Water Entitlements and Trading Project

Phase 2

CHINA | 2007

Overview

This final report of the Water Entitlements and Trading ('WET') Project consists of the following:

- An executive summary.
- Part 1 provides an introduction to the project and provides a summary of the major findings. It includes the background to the project, its organisational structure, purpose and objectives. It also summarises the activities undertaken during the course of the project and the key findings for each component.
- Part 2 includes high-level policy recommendations on a number of key WET issues. These reports are intended as the basis for future guidelines on these areas. Reports are provided on:
  - water resources allocation planning;
  - environmental flow definition and management;
  - allocation and management of water rights in irrigation districts; and
  - water abstraction permit specification and registration.
- Part 3 is a detailed report on the pilot study on water resources allocation planning and environmental flows undertaken in the Jiao River, in Zhejiang province.
- Part 4 is a detailed report on the pilot study on allocation and management of water rights within large irrigation districts, undertaken in Hangjin Irrigation District in Inner Mongolia.
- Part 5 includes reports on several areas of technical and policy research and accompanying recommendations. This part covers:
  - water resources management modelling;
  - water accounting; and
  - urban water management as part of a WET system.
- Part 6 is a report prepared by the Australian Bureau of Agricultural and Resources Economics on the potential benefits from trading of water in the Yellow River. This work did not form part of the WET project, but has been included here because of its relevance and to aid dissemination of the results.
- Part 7 is a detailed report on environmental flows assessment undertaken in the Jiao River as part of the pilot study.

Executive Summary

The report makes recommendations on the key policy and technical requirements necessary to implement a water entitlements and trading system in China. The report builds on the water rights framework developed during phase 1 of this project. That framework promotes a system for allocating water that is consistent and transparent, and which recognises:

- long-term and annual rights to take water at the regional, abstractor and farmer levels; and
- ecological requirements for water.

Water Resources Allocation Plans and Environmental Flows

Water resources allocation plans (WRAPs) underpin the entire WET system. They are the mechanism for allocating water amongst regions and for setting a cap on abstractions. They are also the tool for providing for environmental flows. WRAPs should be a regulatory instrument, providing clear direction for resource managers in how to allocate and manage the resource. This report includes detailed analysis and recommendations on the requirements for making and implementing WRAPs.

Flow regimes are critical for ecological health. The requirement for environmental flows should be considered during the water allocation process and flows should be set based on the best available science, recognising the importance of maintaining natural variability – in terms of duration, timing, frequency and size of flows – to that extent possible. Environmental flows are much more than just a fixed percentage of the mean flow. This report outlines a methodology for identifying ecological assets and determining (and providing) the flows that are important to their health.

A pilot study in the Jiao River in Zhejiang Province was used to demonstrate the application of a water resources allocation planning approach, coupled with an environmental flows assessment. A detailed ecological assessment was completed, which formed the basis for identifying important ecological assets and their flow requirements (in terms of the size frequency, duration and timing of different flows necessary to maintain the assets).

A water resources management model for part of the river was developed. This model was used to assess the ecological impacts of a proposed dam on the Zhu Creek. Different scenarios were developed to show how different abstraction caps and operational rules could deliver different results in terms of supply reliability and achieving the identified environmental flow requirements. The results show there is significant potential for improving both supply reliability and environmental outcomes through modified operational arrangements.

Allocation and Management of Water Rights within Irrigation Districts

This report includes draft guidelines for the allocation and management of water within irrigation districts. These guidelines detail a process for allocating water to water user associations (WUAs). This process includes both the allocation of long-term rights as well as the annual allocation process. The guidelines also make recommendations in respect of the process for establishing and managing WUAs, in a way consistent with the requirements of a WET system.

A pilot study in Hangjin irrigation district in Inner Mongolia Autonomous Region was used to demonstrate the allocation of water rights within an irrigation district. The water available to the district was allocated amongst WUAs in the district, and an annual planning system was developed. The pilot demonstrated the feasibility and practicality of allocating entitlements in this way. The system is simpler and more transparent than current arrangements. At the same time, the new system is designed to reflect historic allocation practices. WUAs are likely to have a greater role in the future under this type of management arrangement. It will be important that they are representative of, and accountable to, their members.

Other Aspects of a WET System

In addition to these key components, work was completed in respect of the following:

- Water abstraction permit management: the requirements for permit specification and registration have been identified.
- Public water supply management: this study involved an assessment of the current approaches in China to allocating water for public water supply, and the role of abstraction permits in this process.
- Water resources management modelling: an assessment of suitable models to support a WET system in China has been completed.
- Water accounting: the report includes an overview of the Australian approach to water accounting. It considers the current situation in respect of water information management in China and identifies improvements that could be made.

Water Trading

There is limited discussion in this report specifically on the issue of water trading. However, the fundamentals outlined in this report – in respect of allocation and security of rights, transparency, and ecological sustainability – are all prerequisites to the development of a water trading system. It is critical that these elements are well established before trading occurs. Once these aspects of a water rights system have been implemented, it will be relatively straight-forward to implement water trading if that is desired.

Contents

PART 1: INTRODUCTION AND SUMMARY OF FINDINGS

Chapter 1: Background to the WET Project

This is the final report for the Water Entitlements and Trading ('WET') project, phase 2. Phase 1 of the WET project was completed in late 2006. The project is a joint initiative of the Australian Department of Environment, Water, Heritage and the Arts ('DEWHA') and the Chinese Ministry of Water Resources ('MWR'), with funding provided by the Australian Agency for International Development ('AusAID'). The project has been undertaken in accordance with a Memorandum of Understanding between DEWHA and MWR about cooperation on technical matters. The Queensland Department of Natural Resources and Water, although not a formal partner, has also provided significant assistance to the project.

The goal of the project is to assist MWR in the development of a WET system suitable for implementation in China. The key activities under the project involved reviewing current arrangements, and making policy recommendations, on seven components identified as critical to the establishment of a WET system.

For each of the components, the project undertook research work and made policy recommendations with a central government focus. This work was coupled with research in two pilot sites. One is the Jiao River in Zhejiang province. The other is the Hangjin irrigation district in Inner Mongolia autonomous region. The pilot sites were used to inform the national-level recommendations, to test the practicality of the WET system being proposed, and to demonstrate its application.

In addition to the policy and pilot work, the project undertook a number of capacity building activities to strengthen the human resources available to implement WET in China.

Chapter 2: Organisational Structure of the Project

The project work was undertaken by a working group of Australian and Chinese water specialists, supported by a number of short-term advisors. Oversight of and broad direction to the project was provided by a steering committee composed of DEWHA and MWR staff.

Technical review of the key outputs and technical advice to the working group was provided by an Australian reference panels. Technical advice was also provided by a domestic advisory committee, chaired by Mr Gao Erkun, the Director-General of Water Resources Management in MWR, and composed of Chinese water experts from within and outside of MWR. A domestic supervisory group also provided technical support to the project.

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Chapter 3: Purpose of a WET system

This project aims to assist MWR with the development of a WET system for China. China's eleventh five-year plan requires the improvement of the water resources compensation system and the establishment of a water rights allocation and transfer system.

The WET system is designed to provide a mechanism for sharing water resources between different users – including the environment – in a way that:

- better defines rights to water and provide greater certainty and security to right holders;

- ensures rights to water are granted within the environmentally sustainable limits of the watercourse or aquifer;
- allows for the allocation and transfer of water rights in a way that is transparent, involves stakeholders, and encourages the efficient use of water; and
- allows for a shift towards market mechanisms as the basis for allocating water.

Chapter 4: Broad objectives of the WET Project

This project builds on the work completed during phase 1 of the WET project, which involved a comprehensive review of existing arrangements and recent developments in China in respect of water entitlements and trading.

Phase 2 of the project was designed to provide policy and technical recommendations to address those issues identified as critical to allow for the successful implementation of a WET system in China. These include:

i. **Definition, security and certainty of rights:** Water rights are not always well defined. The duration of rights can be uncertain. There are limited rules and broad discretions for determining annual availability of water under different water rights.

ii. **Connections within the water allocation and management system:** There are inconsistencies between basin and regional water resources allocation plans as well as between long-term and annual plans. Water permits are considered on a case-by-case basis because allocation plans do not provide a basis for permit decisions.

iii. **Recognition of environmental water needs:** The in-stream environmental water requirements are not well understood. Water is generally not allocated to the environment in any meaningful way.

iv. **Rights of farmers:** Within irrigation districts, generally no rights have been granted at the farmer-level. Who has the right to water under an irrigation district water permit is unclear.

v. **System capabilities:** Many of the systems necessary to support water rights management do not exist: hydrologic modelling is not available to support permit and trading decisions and systems for the registration of rights are not of a high standard.

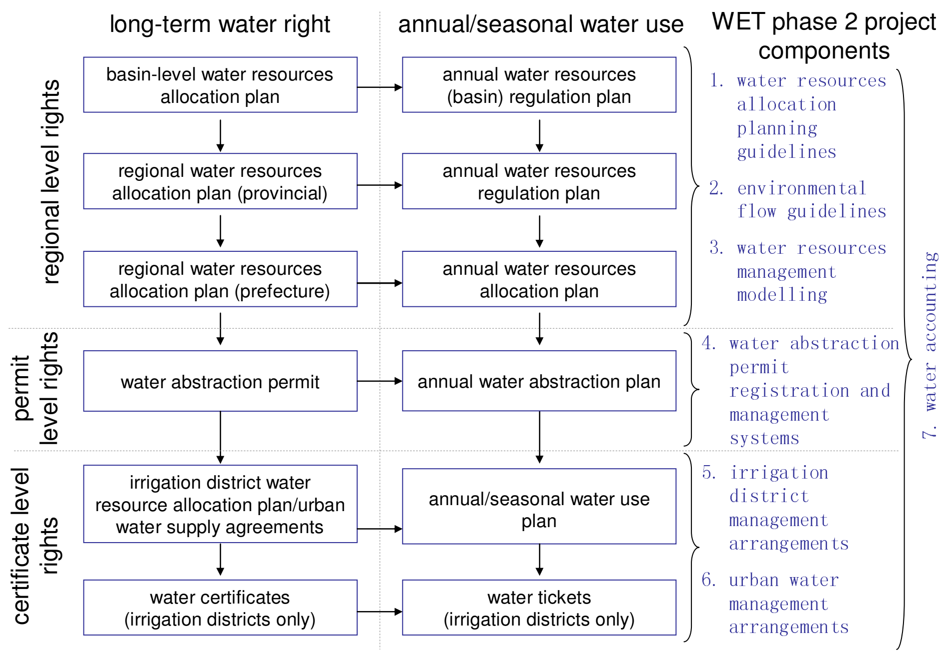
This project aimed to address these and other issues through the systematic development and implementation of a WET framework. The framework being promoted by the project is underpinned by the allocation process outlined in Figure 1.

The framework recognises water rights at three levels:

- **Regional water rights**: the share granted to a province, prefecture or county of a common watercourse or aquifer and the right to allocate that water amongst sub-regions or individuals within the region.
- **Water abstraction rights**: the right of an individual or an entity to take water under a water abstraction permit.
- **User-level rights**: the right of farmers (or others) to a share of water available under a water abstraction permit (e.g. within an irrigation district, or urban water supplied by a water supply company).

The work undertaken in this project was designed to provide the policy and technical tools necessary to implement this framework.

Figure 1: Relationship between the WET phase 2 project components and the overall WET framework



Chapter 5: WET Project Activities

For the purposes of this project, several key requirements for implementing the WET framework were identified. Independent (but connected) policy work was undertaken on each of those components.

The project work was undertaken at two levels:

- **Central level**: For each component, national level reviews have been undertaken of the current situation and recommendations have been made in respect of the requirements for the implementation of the WET framework. These policy recommendations are designed to ultimately assist MWR to prepare national guidelines for these issues.
- **Pilot site work**: to inform the policy and system assessments, to test their practicability, and to demonstrate how the policies and systems would be applied in practice.

The seven components that made up this project – and how they relate to the overall WET framework – are listed in Figure 1. The components are as follows:

i. **Water resources allocation planning:** Water resources allocation planning underpins the entire WET system. It is the process through which regional rights to water are allocated under the WET framework. This component involved the development of recommendations for a water resources allocation planning system, which are intended to provide a basis for the development of guidelines. Water resources allocation planning is also the mechanism for defining and providing for environmental flows.

ii. **Environmental flow definition and management**: This component is central to the WET system, as it is based on the principle that water is first divided amongst environmental and consumptive purposes, before the water available for consumptive use is then shared amongst different users. The project has developed a decision-support tool to assist water resources managers in identifying key river assets, determining the flow requirements for those assets (i.e. what flows need to be provided for a healthy ecosystem), and modifying or implementing regulatory arrangements to provide for those flows.

iii. **Water resources management modelling:** This component is designed to highlight the benefits of water resources management modelling as a tool to support a WET system. Firstly, a review of existing water management models was completed to identify the model(s) most suited to support WET in China. Secondly, a demonstration water management model was built for the Jiao River basin, to demonstrate the use of a model in supporting a WET system.

iv. **Water abstraction permit management:** This component looked at the second level of rights: rights to abstract water. The project made policy recommendations in respect of both the management of abstraction permits as well as the systems used to record details of permits.

v. **Irrigation district management arrangements:** This component considered the arrangements for specifying rights to the available water to groups and individuals within an irrigation district. It thus focuses on rights at the third level, below the abstraction level. The project has made recommendations on a preferred method for allocating rights at this level, and on the requirements to implement such a system, including monitoring requirements and the role of Water User Associations. This methodology was demonstrated in a detailed pilot study in Hangjin Irrigation District.

vi. **Urban water supply arrangements:** Again, this component is focussed at rights to water supplied under a water abstraction permit (but in an urban, rather than agricultural, context). This component makes recommendations about arrangements relating to interactions between water abstraction permitting systems and water savings initiatives. The water supply arrangements in Beijing were used as a case-study to support this work.

vii. **Water accounting:** There are significant information needs that must be met to support a WET system. This component was designed to identify the future requirements for water accounting – that is, a system for measuring, recording and reporting information relevant to a water management. This component is overarching, in that it applies to all levels of rights under the WET framework.

5.1 Pilot Study on WRAP and Environmental Flows

This pilot study was undertaken in the Jiao River, in the southern part of Zhejiang Province. The study involved a review of the different arrangements relevant to WET: water allocation and planning, abstraction permit management, and water information management. Recommendations for future management were made based on the information collected.

A detailed allocation planning and environmental flows assessment was then completed for sections of the Jiao River. This work focussed on the Zhu Creek and a proposed new dam that will be constructed on the creek in the near future. The work looked at the likely impacts of the new reservoir on environmentally-important flows, and how different management arrangements could be used to mitigate those impacts.

The pilot work involved:

- building a water resources management model for part of the basin;
- undertaking detailed environmental assessments, through literature reviews, interviewing locals, and site investigations;
- determining key environmental flow requirements, based on the assessment; and
- developing alternative management and operational rules, to achieve improved environmental flows, as well as different supply arrangements to improve reliability.

5.2 Pilot Study on Irrigation District Management and WET

This pilot study was undertaken in Hangjin Irrigation District, in the Yellow River in Inner Mongolia. The study looked at ways to allocate water rights within the district, to the village level and below. The key work undertaken included development of:

- an allocation model, for allocating water to the village level;
- a model and system for implementing an annual water use plan;
- a system for granting and managing water certificates and tickets;
- a water monitoring system to support the allocation system; and
- a conceptual framework for a water bank, to facilitate water trading.

In addition, a detailed survey of water users and Water User Associations was done to determine understanding of the allocation system and determine future roles for and capacities within WUAs.

5.3 Capacity Building Activities

The following activities were completed as part of the project:

- a two-day workshop on the WET framework and water rights development, undertaken in Wuwei city, Gansu, for approximately 50 local water management staff;
- a one-day workshop on environmental flows, held in MWR for approximately 80 central and local water management staff;
- dissemination workshops in Hangzhou and Taizhou in Zhejiang, and in Hohhot and Hangjin in Inner Mongolia;
- the placement of Mr Zhang Hongxing and Mr Liu Yongpan from MWR within the Queensland Department of Natural Resources and Water for 3-month training programs;
- seminars on various WET-related topics, presented at the Chinese Academy of Science, Renmin University, and the Development Research Centre of MWR; and
- a 10-day study tour to Queensland and New South Wales for a group of eight Chinese water officials, led by the Deputy Director-General Mr Chen Xiaojun.

The group took part in workshops conducted by the Queensland Department of Natural Resources and Water, the Queensland Water Commission, SunWater and Griffith University. The study tour focussed on environmental flows management and drought management. The working group has also assisted with arrangements for a second MWR study to be undertaken in early 2008.

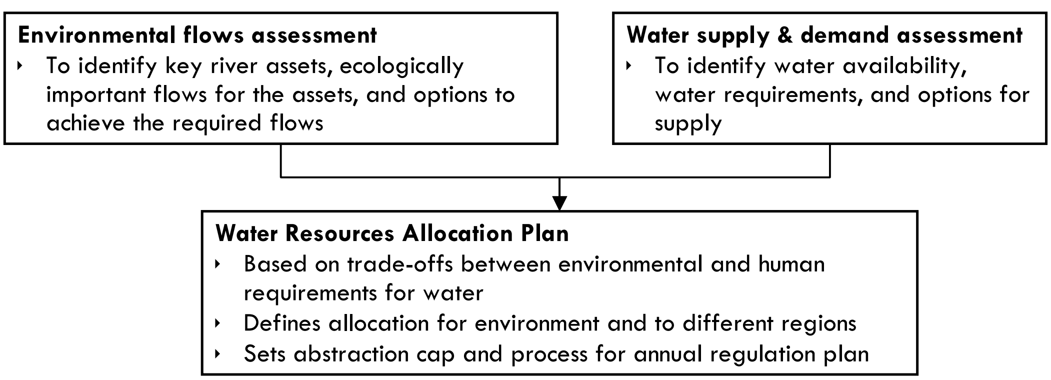
Chapter 6: Summary of Findings

6.1 Water Resources Allocation Planning

Water resources allocation plans (WRAPs) underpin the entire WET system. They provide the mechanism for identifying and defining the total water available for use within a basin or region and for ensuring that water abstractions are capped within sustainable levels. WRAPs also are the basis for defining the water set-aside for in-stream ecological requirements. This report includes detailed guidelines on the nature, content, and procedures required of WRAPs.

- **WRAPs as a regulatory instrument:** WRAPs should go beyond the traditional "planning" approach in China of setting aspirational goals, and instead set enforceable limits on the volumes of water that can be abstracted. They should provide a legal basis for decision making, by setting clear caps on abstraction (and the granting of abstraction permits) and a defined process for making annual regulation plans.
- **First allocation is the split between the environment and human use:** In allocating water, the first step should be defining the water to be left for environmental requirements and that available for abstraction for out-of-stream water use. The second step should be to share the consumptive volume amongst different regions. This allocation process is shown in Figure 2.

Figure 2: Water resources allocation planning process



WRAPs and Environmental Flows

WRAPs are critical for delivering the environmental flows as they determine both the total volume of water that can be abstracted and the timing of when it can be taken. The process of developing a WRAP should involve an assessment of the environmentally important flows. Chapter 1 in Part 2 of the report describes this process in detail. Ultimately, a WRAP will provide for environmental flows by capping the total volume of abstraction permits that can be granted, setting the rules for preparing the annual regulation plan (i.e. determining how much can be taken in any given year), and setting specific release rules for reservoirs, to release flows for the environment.

Use of Water Resources Management Model and Scenario Development

The development of a WRAP should be supported by a hydrologic management model. The model can be used to test different abstraction cap limits, as well as different environmental, operational and sharing rules. This can then show the likely impacts of different WRAP options for the environment and the reliability of supply, and thus form the basis for decision making. By applying this approach, together with a whole-of-basin management model, the WRAP can protect both the reliability of supply and environmental flows from being eroded by incremental decision-making.

Key Procedural and Content Issues

- **Stakeholders should be involved in the development of WRAPs:** Those parties with an interest in the allocation process should be involved in the development of the WRAP. This process should both raise understanding amongst stakeholders of the WRAP and allow consideration of the issues of key concern to the stakeholders.
- **Content and key procedural issues should be clarified:** The content of WRAPs should be defined. The trigger for making a WRAP, as well and the approval process, the duration, and the amendment process should all be specified in guidelines.
- **Monitoring and reporting requirements to be included in WRAP:** The WRAP should define the locations and indicators (e.g. different parameters) to be monitored as well as the responsible agency. The WRAP should also specify the reporting obligations of those parties involved in implementation or monitoring of the WRAP.
- **Water quality issues should be dealt with separately:** While WRAPs should be made taking account of water quality issues, they should not define allocations based on quality. WRAPs should recognise the role of water function zone plans, but should not duplicate the issues addressed by those plans: to do so could cause conflicts between plans and problems implementing the WRAP.
- **Allocation principles to be defined:** the principles for allocating water should be set prior to making the WRAP. The allocation process should recognise appropriate priorities amongst different users, historic water usage and the principles of sustainable development.
- **Consistency issues:** WRAPs should be consistent – in respect of area, time and quantity – with other WRAPs covering the same geographic area. They should also have clear and consistent processes for linking to the permitting process and the annual regulation plan.
- **Issues to be addressed by WRAP:** the WRAP should account for both surface and groundwater. It should also recognise where water is either transferred out of, or in to, the basin as part of an inter-basin transfer project. Additionally, the plan should identify any surplus (‘unallocated’) water and the process for its allocation.

6.2 River Health and Environmental Flows Management

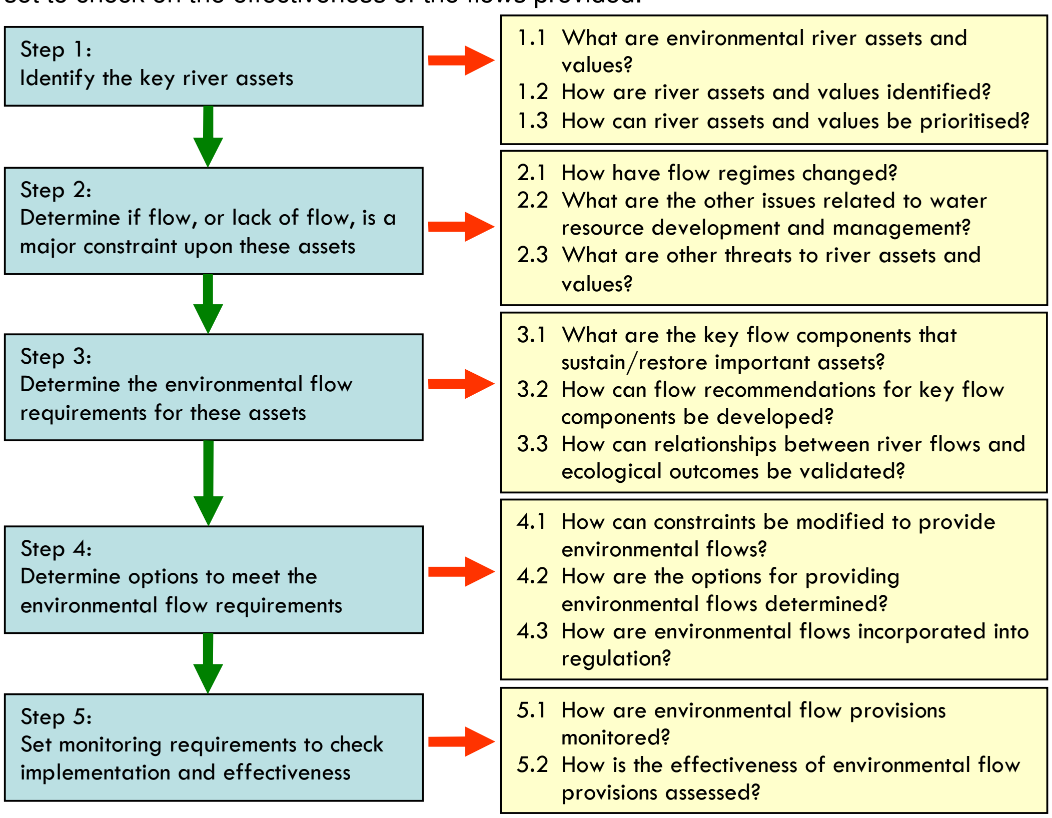
Freshwater ecosystems are regarded as the most threatened on the planet. There are also strong links between the health of rivers, human health and the well-being of society. When healthy ecosystems become degraded, the capacity of the environment to sustain economic activity and human health is diminished. Flow regimes are important to riverine health and freshwater biodiversity because:

- Flow is a major determinant of the physical habitat in streams and rivers.
- River species have evolved life cycles in response to natural flow patterns.
- Flows maintain natural patterns of longitudinal and lateral connection.
- Changes to flow regimes facilitate the invasion of unwanted species.

To protect freshwater biodiversity and maintain the essential goods and services provided by rivers, it is important to mimic components of natural flow variability. The magnitude, frequency, timing, duration, rate of change and predictability of flow events (e.g. floods and droughts) and their sequencing are all relevant for ensuring flows meet the requirements of the ecosystem. Water resources management should account for these requirements. Environmental flows are more than just a simple percentage of the mean annual flow in the river.

Methodology for defining and providing environmental flow

Providing for environmental flows requires identifying the key river assets (e.g. important species). The key flow requirements for the assets should then be determined, followed by options for achieving the required flows. Finally, monitoring requirements should be set to check on the effectiveness of the flows provided.



Determining key flow requirements

Once the key ecological assets have been identified, the flows of importance to those assets should be determined. This process should consider flow requirements for assets at different locations (e.g. upper catchment, trunk stream, river mouth etc).

A conceptual model of the hydrological and ecological system should be developed showing, for each asset, the connections between:

- Different parts of the flow regime (low flows, pulses, floods etc);
- Different ecological and geomorphological processes (flows that create habitat, trigger spawning, allow fish passage, clear channels etc); and
- Different ecological assets.

In the absence of specific information, general principles can be applied for identifying links between different flows and processes. This allows an understanding of the importance of parts of the flow regime for the assets, as well as the possible implications from changes to the flow regime.

Determining a reference condition

Hydrological analysis of the flow regime for the selected river (and/or similar rivers) can identify the natural variability of the different parts of the flow regime. This can provide a "reference condition": if water resources development means that flows will fall outside of this range, there is a high risk of impacts to river health.

In some instances there may be a linear relationship between flows and important ecological processes; in other cases there may be a threshold beyond which the process (and asset) fails completely. This will influence the nature of the impact of changes to the flow regime and should be considered in deciding on an acceptable level of development. Where possible, a precautionary approach should be adopted.

Hydraulic modelling at the river reach scale can also be used to quantify the volumes of water required to achieve certain flow outcomes and/or to verify the hydrological analysis.

Ultimately, this process should identify (1) hydrological indicators for the key elements of the flow regime, (2) the preferred flows for those indices; and (3) the risks associated with failing to maintain flows at that level. How this information is incorporated into the regulatory framework is discussed in the previous section.

Key considerations in allocating water for the environment

- The natural flow pattern should be mimicked to the best extent possible.
- With the same volume of water, better environmental results can be achieved if it is provided in the most ecologically-appropriate manner, based on the best available science.
- Providing for environmental flows is still of value even where there are other major factors – such as pollution – that are affecting river health.
- The cost of rehabilitating degraded rivers is much higher than the cost of taking preventative measures.

6.3 Management and Registration of Water Abstraction Permits

Water abstraction permits are a critical element of the WET system, as they provide the mechanism for controlling the actual take of water from the system. Generally speaking, the existing Water Abstraction Permit Regulation provides a comprehensive basis for regulating the abstraction of water. However, there are several key issues that should be addressed to ensure the abstraction permit system adequately supports the broader WET system.

- **Permits do not link to the WRAP or the annual regulation plan. Strong linkages to these plans should be established:** Abstraction permits must be considered in the context of the relevant water resource allocation plan and other management rules which affect the permit. These plans together affect the reliability of water supply under the permit. Without protection of reliability – which can only be provided by the broader management arrangements – the security (and value) of abstraction permits can be severely undermined;
- **Permits combine multiple different approvals. Future unbundling of permits should be considered to allow for separate management of these issues:** In the long-term, consideration should be given to separating into different regulatory instruments the components of water abstraction permits that relate to water abstraction, the construction of works, water use, water supply and environmental management (e.g. discharge);
- **There is no recognition of the difference between the purpose for which water is used and the reliability of supply:** Distinctions should be made between the *purpose* of a permit (i.e. what it is allowed to be used for) and the *reliability* that water should be available under the permit, as protected by the different management rules;
- **There is an inconsistent approach to dealing with return flows:** The management of return flows should be improved, both in respect of how abstraction permits and the planning process consider this water;
- **Not all water abstractors are captured by the permit system:** A risk assessment should be used to determine which water abstractors, that currently do not hold permits, should be brought within the permit system;
- **Registration systems should recognise the requirements of WET system :** Registration systems should be developed recognising:
  a. The importance of quality assurance and security;
  b. Requirements in terms of content and structure, including allowing for compartmentalising different elements of the permit (to assist future unbundling);
  c. Requirements to support water accounting; and
  d. Requirements of the system if and when trading of permits becomes a regular occurrence.

6.4 Irrigation District Management

Based on investigations in the Hangjin irrigation district, a guideline on water management in irrigation districts has been prepared addressing the following issues.

Institutional and Personnel Management

WUAs should be established in accordance with the prescribed process. Representatives should be elected by farmers and the executive should be accountable to its members. WUAs should be adequately funded. The process of WUA formation should involve farmers at the outset to raise awareness of both their rights (including voting and operational decision-making) and duties.

Initial Water Rights Allocation

An initial allocation of rights should be completed, distributing the water available under the district's permit amongst WUAs within the district, while accounting for transmission losses. The allocation process should recognise the current situation, future requirements and be both fair and sustainable.

Annual Water Planning System

An annual water planning process should be established to allocate annually available supplies amongst WUAs, based on the long-term rights of the WUAs. The process should be coupled to the relevant annual regulation plan, which will determine the water available to the district and the annual entitlements of WUAs.

Water Certificate and Ticketing System

Water certificates should be granted to WUAs based on their group water entitlement. WUAs will be responsible for granting tickets to individual farmers supplied under the certificate. Water tickets will be purchased by farmers from WUAs prior to irrigation and will assist both ordering as well as fee collection.

Water Fees and Budget Management

The water service fees collected by management agencies should be based on a two-part tariff, with a fixed element to cover the agency's operation and maintenance costs, and a variable element to reflect actual water deliveries to WUAs. This will retain accountability between the agency and water users, and provide the agency with stable revenues and financial security.

Monitoring and Metering

Monitoring and metering systems need to support the requirements of the allocation and management system. Deciding on an appropriate system should involve consideration of the costs and benefits of alternatives. System changes should be transparent and monitoring information accessible to all parties.

Water Trading

Water trading should be via a water bank, which would purchase any water savings and then sell on the "pooled" savings. Trades should be preceded by a water savings proposal, which should include an independent assessment to ensure the savings are "real" and do not affect other users/uses in the basin. Adjustments to water certificates and (if water is traded out of the district) the permit should be made at completion of the trade.

6.5 Public Water Supply under Abstraction Permits

Incorporating public water supply management within a water rights system presents special problems, because of the essential nature of the supply of water for public (and particularly domestic) use. These problems are particularly evident during times of water shortage. The water entitlements approach of setting limits on the volume of water that can be abstracted is often unrealistic in the public water supply context. However, it is still necessary to ensure that arrangements for defining the entitlement of urban water supply entities are consistent with the broader water rights framework. Thus, public water supply arrangements should recognise both the unique nature of public water supply, as well as the requirements for whole of basin planning and allocation under a WET system.

Public water supply arrangements in Beijing city have been reviewed as part of an assessment of current arrangements and their compatibility with a WET system. The key issues have been identified, together with preliminary recommendations. There is however the need for significant further work in this area to determine mechanisms to better reconcile public water supply management with water rights development.

Key Issues in the Public Water Supply System

Key issues identified within the urban water supply system relevant to WET are:

- Water abstraction permits are not used as a mechanism to regulate the volume of water available. The permit volume granted is determined based on the supply capacity of the works, not the availability of the resource.
- The annual water use plan is not linked to the water abstraction permit and the annual water use plan is used in place of an annual abstraction plan.
- There are overlapping roles and responsibilities within the public water system, particularly between MWR and the Ministry of Construction and inconsistencies between regulations issued by different Ministries. The roles and responsibilities within the Beijing Water Affairs Bureau are ambiguous.

Recommendations for Public Water Supply Management

- Allocation and management of water for public water supply should be recognised as part of the whole-of-basin planning exercise, both in terms of long-term planning and the annual allocation process. The abstraction permits granted to urban water supply entities should be consistent with, and connected to, this process.
- Outdated regulations related to public water supply should be repealed to reduce potential conflicts.
- Information exchange between administrative sectors within the public water supply system should be improved.
- Based on further research, detailed guidelines should be developed for the definition and management of abstraction permits for public water supply, focussing on providing a consistent approach between different systems and regulatory instruments.

6.6 Water Resource Management Modelling

The WET system proposed depends on the use of water resources management (hydrology) models to provide a scientific and quantitative basis for water resources allocation and planning. Seven international and five domestic water resources management models have been reviewed to assess their suitability to meet the requirements of a WET system. Based on the review, a short-list of models suitable for water resources management and water allocation modelling in China has been prepared.

International models

In an overall sense, and from a technical point of view, six out of the seven international models reviewed are potentially suitable for use in water resources management investigations in China. The preferred model would generally depend on the modelling objective and the model functionality required for the specific application. Based on the overall findings of this review it appears that MIKE BASIN and IQQM are the models best suited for detailed water resource management studies in China. For broader water resource assessment and planning studies WEAP may be preferable because it is much simpler and inexpensive to use.

Domestic Models

Based on available information, none of the domestic models reviewed in this report are suitable or can be recommended for water resources management and water allocation planning studies in China. The Xinanjiang model however is suitable for the provision of river and tributary inflows to water balance models used for water resources management purposes (including most of the international models reviewed in this study). It is recommended that this model be used wherever possible, in conjunction with the selected water resources management model(s).

Jiao River Basin IQQM

A preliminary water resources management model, using the Integrated Quality and Quantity Model (IQQM), has been built for the Jiao River basin to support the pilot work undertaken in Taizhou, specifically in respect of water resources allocation planning and defining environmental flows. The IQQM built for Jiao River provides a mechanism for demonstrating the application of a water resources management model in China, in addition to supporting the pilot work in Taizhou. The model has been able to successfully demonstrate the assessment of the consequences of different water management strategies on the reliability of supply to water users and on flows for the environment. If the model is to be used for future allocation and planning activities, it should be calibrated and improved via minimising the assumptions and simplifications that had to be made for the pilot study. Further, it is recommended that the period of simulation be increased up to 50-100 years. This will require the development and calibration of rainfall-runoff models for tributary catchments to extend the time series streamflow inputs to the model.

6.7 Water Accounting

Water accounting is the application of a consistent and structured approach to identifying, measuring, recording and reporting relevant information about water.

Water accounting recognises the importance of information to the way water is managed and used, and that different users have different information requirements. In Australia, water accounting has been designed to:

- ensure the users of information can have confidence in the information they are provided;
- provide accountability for those taking water for consumptive purposes; and
- provide transparency in the volumes of water recovered and managed for environmental purposes (e.g. where government invests in water savings purposes, to enable more water to be returned for the environment).

Water information requirements of a WET system

Implementation of a WET system will create specific requirements for water information. Information will be required to support:

- water resources allocation planning: including hydro-meteorological data, river flow data, dam operations, water demands, assessments of environmental requirements etc;
- implementation of WRAPs: including information to manage water abstractions and to reservoir operations;
- monitoring and reporting: including information to:
  - check compliance with regulatory obligations;
  - assess whether WRAPs and other measures are achieving the desired outcomes; and
  - provide data to support future planning activities.

Developing a structure approach to water information management will ensure that the type and quality of data necessary to support a WET system is available, and that it is collected and managed in the most efficient manner.

Key principles for management of water information

In moving towards a water accounting approach, China should:

- build on existing information management systems;
- identify the different parties that will require water information (including non-government parties, such as water users and researchers);
- identify the specific information requirements of these groups, in terms of data type, quality/accuracy, and frequency of collection;
- determine to what extent standard reports can be developed to meet the information requirements of different parties; and
- dedicate adequate resources to support water information management.

6.8 Jiao River Pilot Study on WRAP and Environmental Flows

This pilot study involved an assessment of current water resources management practices in Taizhou prefecture, as relevant to a WET system. Generally water resources management in the prefecture is at an advanced level. However, several key issues were identified.

In respect of **water resources planning**, planning is demand-based, with no 'cap' to limit water resources abstraction. There is no basin-wide evaluation of cumulative impacts of development and abstractions on the environment or reliability of supply to existing users.

In respect of **environmental flow management**, there is limited understanding about the particular flows required to maintain river health. There is no scientific basis for setting aside water for the environment. The absence of an abstraction cap means that there is nothing to prevent total abstractions from exceeding sustainable levels.

Other key issues – and recommendations for addressing them – include:

- **No connection between water resources allocation planning and water abstraction permit management.** Applications for permits are not assessed against a WRAP. There is no mechanism to ensure permits are granted within sustainable limits or that intended reliabilities are achieved. A cap should be set (via a WRAP) and used as the basis for permitting decisions.
- **Parties involved in water resource allocation, management, supply and delivery can have unclear or conflicting responsibilities.** Service providers' obligations to their users and the rights of users to a particular share of the resource under certain conditions should be better defined.
- **Water supply, delivery and use arrangements associated with water entitlements are bundled in a single authorisation**. This approach can reduce flexibility and transparency and can act as a barrier to good decision making. Future consideration should be given to unbundling these elements.
- **Current arrangements do not encourage efficiency in resource allocation and use, largely because water resources are considered to be abundant.** The costs associated with water supply infrastructure are not properly recognised in pricing regimes in Taizhou. New infrastructure is generally viewed as the solution to water shortage problems. This may be a more expensive alternative than improving efficiency. Options to better recognise the cost of providing water should be considered.

Demonstration of WRAP and environmental flows approach

The second stage of the pilot study involved the application of the environmental flows and water resources allocation planning methodologies to parts of the Jiao River. It was designed to demonstrate how a WET system could address some of the issues identified in respect of planning and environmental flows. This study focussed on the Zhu Creek (a small tributary of the Jiao River) and the trunk stream downstream of the creek. The study considered a new reservoir, proposed for construction on the creek in the near future. It assessed the likely impacts of the reservoir on environmental flows in the basin and put forward different management options for achieving improved environmental flows and/or supply reliabilities. The study also considered options for defining an abstraction cap within the study area.

Assessment of requirements for environmental flows

The first stage of the environmental flows assessment involved identifying key ecological assets via a detailed literature review, interviews with over 30 officials and others connected to the river, and site investigations. The assessment mostly focussed on fish of economic importance. A conceptual model was then developed, identifying the links between the key assets and different parts of the flow regime (low flows, pulses and high flows/floods). This was used as the basis for defining the flow objectives. Hydraulic criteria (i.e. depths of flow) were assigned to the different flow objectives (e.g. maintaining pools) as a means of calculating the actual volumes of water required to achieve the objective. Cross-section surveys of different reaches of the river were used as the basis for these calculations.

The final result of this process was a table that identified, for each of the five reaches of the section of the river studied:

- Clusters of key ecological assets (e.g. species dependent on pools, including carp).
- The important flows for those assets (e.g. base-flows in Zhu Creek for maintaining the deep water holes necessary to support species of large fish).
- The timing, frequency, duration and size required for each flow to achieve the desired result (e.g. continuous base flows from October to March of 0.5 m^3).

The different desired flows were also prioritised and an assessment done of risks associated with not providing the recommended flows.

Demonstration of water resources allocation planning approach

A water resources management model was constructed for the relevant sections of the Jiao River basin. This was used to model different scenarios and show, for each scenario, the reliability of supply for forecast demands (both urban and irrigation) and the impact on the environmentally-important flows identified. Different scenarios modelled included one providing for all the desired environmental flows and a sub-optimal environmental flows scenario. In addition, different supply and operational arrangements were tested. The results demonstrate that:

- The current proposal for operating the Zhuxi reservoir will have major impacts on the provision of environmentally-important flows.
- Environmental flow requirements can be incorporated into the operating arrangements without having major impacts on the reliability of supply, particularly urban supply.
- Different operating arrangements for Changtan reservoir could significantly improve the reliability of urban water supply, at a cost of reduced reliability for irrigators.

6.9 Hangjin Pilot Study on Irrigation District Management

The pilot study used the Hangjin irrigation district, located on the Yellow River in Inner Mongolia, to demonstrate the application of the WET framework within an irrigation district context. The objective of the pilot was to show how water – taken by the irrigation district under its water abstraction permit – could be allocated to both WUAs, and to the farmers within them. The allocation process was designed to be consistent with the overarching allocation process for the Yellow River.

This activity involved the following six parts:

i. **Rights definition and allocation**: The study has demonstrated how all diversions and losses within the irrigation district can be accounted for, and how water user associations (‘WUAs’) can be assigned volumetric quotas – termed Group Water Entitlements (‘GWEs’) - on the basis of irrigated area, crop water quotas and conveyance efficiencies. A hydrological model of the district was built for this purpose. The result is an allocation plan for the district that assigns proportional rights to each WUA. Individual WUAs would then be responsible for sharing that volume amongst their members.

ii. **Water certificates**: The study evaluated the role water certificates could play in formalising the GWEs defined above, and in providing information to WUAs on their ‘quota status’ over the course of a year. The study also examined how certificates could be combined with existing water ticketing arrangements to ensure that water purchased by WUAs, on behalf of farmers, occurs within quota.

iii. **Water use planning and scheduling**: The study has developed a model-based planning system for allocating the rights defined above between and within irrigation periods in a way that is fair and transparent. The spreadsheet-based model allocates water between WUAs based on the long-term allocation plan and annual availability (determined by the Yellow River Conservancy Commission - YRCC). It incorporates annual caps on water diversions to WUAs (the GWE) and scheduling plans for low flow periods. The model is consistent with, and able to adapt to, the Yellow River allocation process.

iv. **Assessment of the role of water user associations**: WUAs are currently involved in the purchase and distribution of water to farmers. Changes to existing rights (to specify group entitlements) and ticketing arrangements will have implications for the role of WUAs, though the allocation system will continue to combine bulk delivery to WUAs with area-based charging for farmers. Discussions with WUAs and farmers, and a formal survey conducted in October 2007, provided information on the performance of existing payment and water accounting procedures. These generally work well, and provide a good basis for quota-based management.

v. **Metering and monitoring**: An assessment of current monitoring and metering arrangements, together with the requirements to support the proposed allocation and management system, was completed. Based on this, a plan for upgrading the existing system has been prepared.

vi. **Water trading**: Current practices of transferring water saved via channel lining are popular, although it has created challenges for the Irrigation District

Management agency as its revenue has been reduced. A conceptual model for water trading, based on the use of a water bank, has been developed. The water bank would act as a mechanism for "pooling" water savings and then selling the saved water to interested parties. The bank would be designed to overcome the high transaction costs associated with trading small volumes of saved water.

Findings and Recommendations

- The use of an allocation plan to allocate water to WUAs is feasible. The annual allocation process can be aligned both with the allocation plan and the YRCC annual allocation process. The result is a process that is easier, more transparent, and fairer.
- The allocation process undertaken has identified "unallocated water", i.e. water in excess of the current water requirements in the district (but within the volume allowed under the district's permit). This means this water can be allocated to the new agricultural land that is being developed in the district. This can now occur in a way that will allow other farmers to have confidence that allocations are fair, and that there will not be an impact on the availability of water to them.
- Transmission losses have now been formally quantified and allocated (up to the purchase-point by WUAs). This will simplify the process for future trading of transmission losses and will also increase the confidence of WUAs that trading is being done in a fair way that will not impact on their water supply.
- Existing contract and ticketing procedures operating between the management bureau and WUAs are well understood and respected. They provide an excellent platform for the introduction of GWEs and ticket-linked water certificates. Procedures for distributing water to farmers within WUAs generally work well, though water accounting and payment methods vary. Those WUAs that have set up systems of continuous water accounting between irrigations, and volumetric delivery to (and billing of) individual production teams, will be better able to meet new quota obligations in a fair and transparent manner.
- Water trading has reduced the revenue available to the Irrigation District Management Agency. The issue of funding will need to be addressed to ensure the long-term sustainability of the trading program and channel infrastructure, and to protect farmers' long-term water rights.
- While existing monitoring arrangements work well, and are respected by WUAs and farmers, any future pressure to reduce GWEs may increase demand for more accurate and timely measurement. A key priority will be to strengthen monitoring of water deliveries at WUA purchase points, as monitoring here affects both WUA payment and compliance with GWEs.

PART 2: NATIONAL LEVEL RECOMMENDATIONS

Chapter 1: Water resource allocation planning – policy review and recommendations

1.1 Background

Water resource allocation can involve allocating water between different water users, over different times, in different regions and for different purposes, as well as any combination of these things. In article 2 of the "Interim Measures of Water Resource Allocation", 'water resources allocation' refers to allocation of available water resources or water quantity which can be allocated level by level to the administrative regions, to define the water resource consumptive or abstraction volume for domestic and productive purposes within the administrative regions.

Successful water resource allocation depends on the formulation and implementation of an annual water resource regulation plan. Article 45 of Water Law 2002 states that the regulation and storage of run-off and the allocation of water shall be in accordance with the river basin plans, including the mid- and long-term water supply and demand plans. The water resources allocation plan shall be formulated on the basis of a river basin as a unit. Article 6 of Regulations on Management of Water Abstraction Permits and Water Resources Fees dictates that the implementation of a water abstraction permit system should comply with comprehensive water resources plans, comprehensive river basin plans, mid- and long-term plans for water supply and demand as well as water function zone plans, as well as abiding by water resources allocation plans established under the Water Law of People's Republic of China. If there is no plan for water allocation, agreements between relevant local governments should apply. Article 15 states that the approved water resources allocation plans or signed agreements are the bases upon which to determine the cap control of the water abstraction in river basins and administrative regions.

A water resource allocation plan is a plan that allocates the different sources of water to each administrative region in a river basin on the basis of water use circumstances, geography, climate, water resource condition, population, land, economic development and structure, water use efficiency and water resources management standards and other factors in each of those administrative areas of the river basin.

1.2 Introduction

1.2.1 Water resource allocation plans as a management instrument

Water resource allocation plans are the basis of water resource management in China. They also provide a mechanism to define the water availability in a particular river basin and to then allocate water amongst the different users (including ecological and environmental needs). Therefore, water resource allocation plans are the mechanisms and tools of water resource management instead of simply being a traditional planning tool.

As a management instrument, a water resource allocation plan needs to solve water resource allocation issues on two levels: the first is in-stream and out-stream water resource allocation, i.e. to balance the water demand in the stream for ecological and environmental purposes (environmental flow) with sustainable water resource usage in a river basin; the second is water resource allocation among regions in a river basin, i.e. to allocate sustainable water resource volumes to each region in a river basin and to define the allowable water resource usage for each region.

At the river basin level, combining with the rules of annual water resource allocation (water resource regulation rules), a water resource allocation plan becomes a basis to formulate an annual water resource regulation plan and therefore determine the actual water abstraction volume within the river basin. At the water abstractor and user level, the water abstraction can be determined by the water resource allocation plan, and the plan will provide the basis for the approval of water abstraction permits in the river basin or the region.

1.2.2 The cycling water resource allocation planning process

Water resources allocation is a political decision-making process supported by scientific knowledge, and including a negotiation and agreement-making process for all the stakeholders (including representatives for the future), with the stakeholders' values being both reflected and balanced in the final result. Water allocation between in-stream and out-stream needs represents the process designed to recognize the value of river assets and balance this value with other needs. Within a river basin, there are all kinds of assets including natural assets (e.g. various species and eco-systems), and social and economic assets (e.g. the development of the economy and the improvement of people's living standards). Also, human beings are one of the river assets, and are in fact the most important one.

The determination of an asset's value is the reflection of human priorities. Prioritization must occur when the water resources in a river cannot meet the demands of all its assets, such as the demand by the natural ecological and environmental assets (including in-stream and out-stream), and the demand for social, economic and domestic uses. Humans need to clearly recognize the importance of each asset and to judge the priority accordingly. So, under the present knowledge on values, humans will identify the importance of the different assets and make trade-offs. Then water allocation is a decision-making process and a process to express values. To realize this process, the water resources allocation planning is a cycle with continuous monitoring and assessing, improving and consulting (Figure 3).

1.3 Procedural issues in water resources allocation planning

1.3.1 Triggering a WRAP

So far, we have discussed a type of water resources plan which contains a water resources allocation plan. Generally, there are two motives in formulating a water resources allocation plan or a water resources plan:

i. According to the national social-economic development plan (generally for 5 years, or 10-15 years in a mid- to long-term plan), the relevant water resources plan needs to be drawn out or modified. Examples of these development plans are the National Water Resources Comprehensive Plan and the Zhejiang Province Water Resources Protection, Development and Utilization Plan, both of which are made in line with Water Law.

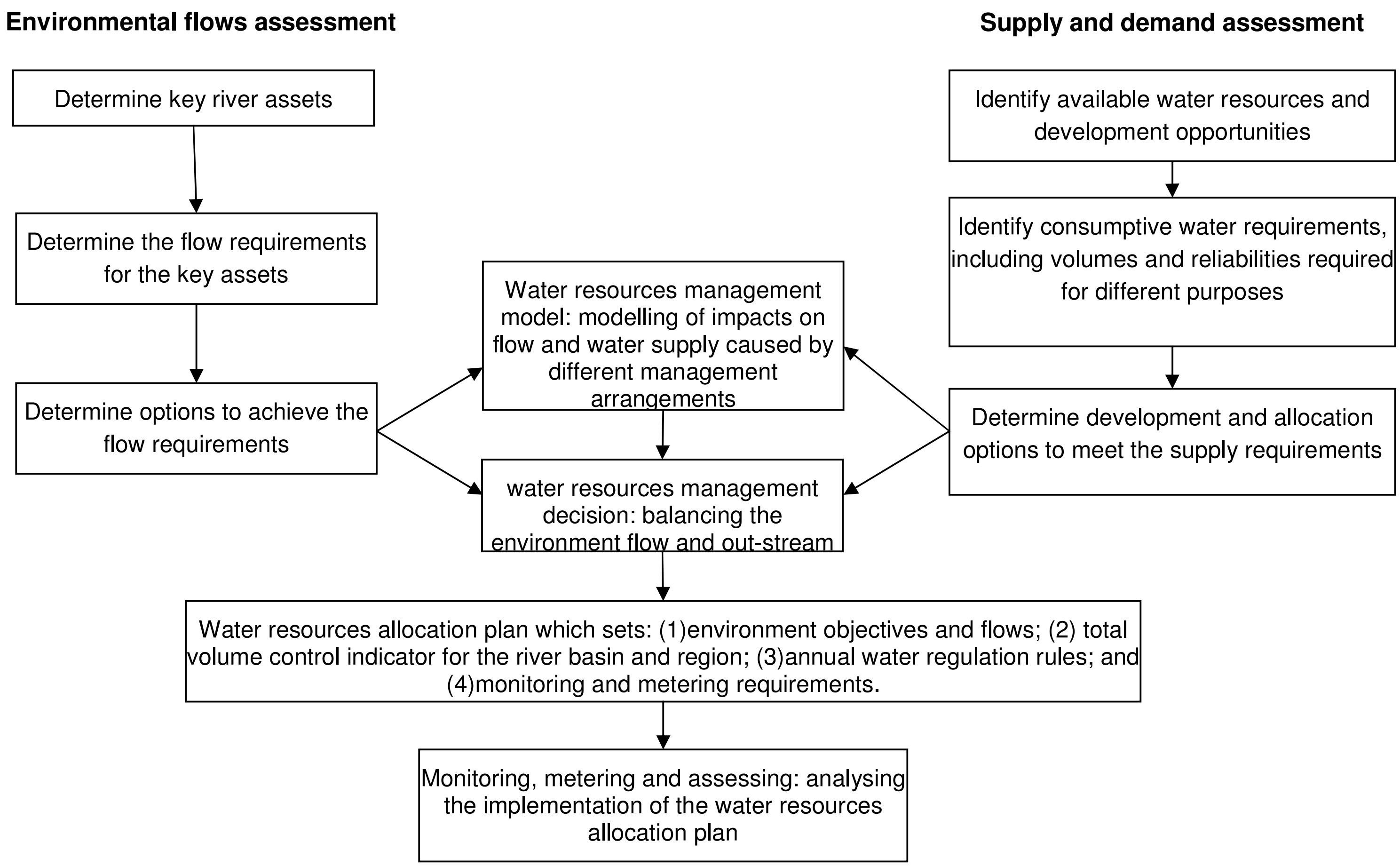
ii. The original plan or WRAP cannot meet the demand of social-economic development and water resources management because of serious water resource problems, and so needs to be re-formulated and modified. Examples of this occurring are: Water Resources Allocation Plan of Downstream of Jinjiang River which was made in 1996 and modified in 2006; the Water Plan of Heihe Main River (including Liyuan river) made in 1992, Water Resources Allocation Plan of Heihe River made in 1997; Near-term Harness Plan in Heihe River Basin made in 2001, the Sustainable Using Plan of Water Resources of Capital in the Early Stage of 21 Century (2001-2005), the Water Resources Allocation Plan Among 3 Counties made in 1963, the Preliminary Water Plan of Shiyang River Basin made in 1990 and the Water Resources Allocation Plan of Shiyang River Basin made in 2005. All of these plans were revised or formulated under such circumstances.

Laws and regulations in China have not clearly specified the trigger mechanism for water resources allocation planning. The main reasons for the modification of comprehensive plans of major river basins in China are the following: (1) it is almost 20 years since the formulation of the comprehensive plans of the seven large river basins, in all of which the basic information is now out of date, and the term of these plans has been reached; (2) the earlier plans focused on key water development projects, instead of ecological construction, environmental protection or water resources management; (3) due to a lack of knowledge in sustainable water resources use and protection of the environment, the plan contained little information about allocation, saving, protection and management of water resources; (4) with the formulation of the state main function zoning, the river basin comprehensive plans need to come into compliance; (5) the river basin comprehensive plans lag behind the special plans, which results in ineffective management of water resources development and utilization, and causes over-exploitation of water resources and unorganised hydropower development.

So, two issues in the trigger mechanism must be clarified:

i. The formulation of water resources allocation plans must begin in accordance with the Water Law (2002) in the river basins and regions which lack water resource allocation plans.
ii. The river basins or regions need to modify the water resource allocation plans where any of the following situations occur:
iii. the current water resource allocation plan cannot be implemented;
iv. the current water resource allocation plan is unsuitable for the regional social-economic development and environment protection;
v. the current water resource plan does not comply with law, regulations or other plans (such as the allocation plan of the level above); or
vi. the term of the current allocation plan has expired.

Figure 3: The water resources allocation planning process



1.3.2 Content of a WRAP

The lack of specification of the contents of water resource allocation plans has resulted in a variety of water resource allocation plans nation-wide. On the one hand, it is due to differing local conditions; on the other hand, it is the result of a lack of rules and regulations.

In practice, two categories of water plans and water resource allocation plans have evolved in China:

- Simple plans, such as the plan of the Yellow River and downstream of the Jinjiang River; these plans normally only include the content of water resources analysis, water resources allocation principles and the plan itself.
- Detailed plans, which generally combine with other water resource plans, such as water resource development, utilization and protection. Examples of these include the plans of Zhejiang province, the river mouth of the Qiantangjiang River, the Fuhe, Haila'er Rivers and the Shiyang river basin. These plans contain more content, such as the introduction of the river basin, water resource conditions, assessment of water resource development and utilization, social-economic development projection in the river basin, the supply and demand analysis, the principles of water resource allocation, the allocation plan, the layout of engineering and arrangement, water resource protection plan, the safeguard measures for the implementation of the plan and the environmental impact assessment, and so on.

Objectively, from the aspect of standardized management of water resources, there is no unified and standardized water resource allocation plan in China. All the local allocation plans are formulated out of the locality and its demands. However, we need a relative standardized water resource allocation plan with unified content for the uniform national system and the multiple levels of water resource management.

According to Article 10 of the Interim Measures of Water Resource Allocation, a water resource allocation plan shall include information about the following:

i. water resource availability and water quantity which can be allocated in the river basin and the administrative region;

ii. water resource quota and the relevant section of the river, reservoir, lake and the area where groundwater is exploited in the administrative region;

iii. the regulation of the annual water use of each administrative region and the relevant regulating principles at different possibilities or different reliabilities;

iii. reserved water quota and the relevant section of river, reservoir, lake and the area where groundwater is exploited;

iv. the runoff at the boundary cross section, the flow, the water level of the lakes, the water quality of the rivers and the lakes that cover more than one administrative region and the control indicator both of groundwater level and water quality in the groundwater source area that covers more than one administrative region.[1]

According to the reality of water resources management and the requirements of water allocation in China, a water resources allocation plan should include the following:

i. A general introduction to the river basin, including social-economic development in the basin.
ii. Assessment of water resources in the basin.
iii. Water resources development assessment.
iv. The existing problems in development, utilization, protection and management of water resources.
v. The objectives of basin development, including social-economic development and ecological and environmental protection.
vi. Water supply and demand analysis of the river basin.
vii. The principles of water resource allocation.
viii. Water utilization and demand analysis of the river basin, both in-stream and out-of-stream.
ix. Details of the river basin water resource allocation plan.
x. Operational rules of the river basin.
xi. Reserved water resources management.
xii. Safeguard measures for the implementation of water resources allocation plan in the river basin.
xiii. Water engineering arrangements.
xiv. Monitoring and metering arrangements.
xv. Stipulation of the status of river basin water resource allocation plan.

1.3.3 Approval process

The Water Law has clearly stipulated the process of formulation, approval and implementation in Article 45, which states:

"Water resource allocation plans and preliminary plans for water distribution under drought and emergency conditions that cover more than one province, autonomous region or municipality directly under the Central Government shall be worked out by the river basin authorities through consultation with the relevant people's government of the province, autonomous region or municipality directly under the Central Government, and should be implemented upon approval by the State Council or the department authorized by the State Council. Other water resource allocation plans and preliminary plans for water distribution under drought and emergency conditions that cover more than one administrative region should be worked out by the same administrative department for water resources under the people's government at the next higher level through consultation with the relevant local people's governments, and should be implemented

[1] See Interim Measures of Water Resource Allocation.

upon approval by the people's government to which the administrative regions respectively belong."

Additionally, Article 4 of the Interim Measures of Water Resource Allocation (which will come into effect soon) states:

"The allocation plan for inter-provincial water resources should be drawn up by the river basin management authority…set up by the Minister of Water Resources in conjunction with people's government of the provinces and should be submitted to the State Council or the department entrusted by the State Council to give approvals."

"Water resource allocation plans of inter-administrative-regions (below provincial level) should be drawn up by the administrative department for water resources of the same people's government at the next higher level in conjunction with the relevant local people's government, and should be submitted to the people's government at this level for approval."

As to the process of implementation, the Yellow River Operational Regulation, Article 7 states:

"The water resource allocation plan of the Yellow River shall be worked out by the Yellow River Commission in consultation with the people's governments of eleven provinces and regions, shall be examined by both the administrative departments of development and reform and administrative departments of water resources, and shall be approved by State Council. "The Notice of Transmission by the Office of State Council about water availability report of Yellow River by the National Planning Commission and Ministry of Water Resources and Power" (State Council Document [61]) issued by State Council Office approved the Yellow River Water Resource Allocation Plan."

"The Overall Plan of Water Resources Protection, Development and Utilization, Zhejiang Province" was approved by the Zhejiang people's government in April 2005 while the "Water Resources Allocation Plan of the Qiantangjiang River Mouth" was approved jointly by the Ministry of Water Resources and Zhejiang people's government. Meanwhile, the water resource allocation plan of the Shiyang River covers two prefectures so it was approved by the people's government of Gansu Province. "The Short-term Management Plan for the Heihe River Basin" covering three provinces and regions was approved by State Council in the form of State Document [2002]86. "The Sustainable Use Plan of Water Resources of Capital in the Early Stage of the 21st Century" concerning Beijing, Heibei and Shanxi was approved by State Council. "The Water Resource Allocation Plan of Downstream of the Jinjiang River" was approved by the Quanzhou people's government.

The actual approval process complies with the provisions of law and regulations; however, there are still different approaches. For example, the national level approval which could be made by the State Council might actually be made by the State Council or the State Council Office while the law also stipulated that approval can be made by the State Council and authorized departments (such as MWR). The flexibility of the approval authorities may result in different legal effectiveness of the water resource allocation plan, which affects the implementation of the plan. The reasons that a particular authority may be the approval authority for a particular water resource allocation plan or planning may be: 1) the importance of the river basins or regions; 2) the complexity of the issues (generally the more complex the issues, the higher the level of the approval authority); 3) the source of implementation funding (generally the approval authority is the government that funds the plan).

Therefore, for each water resource allocation plan, it is strongly suggested that approval and implementation should be strictly in accordance with the law.

1.3.4 Duration of the water resources allocation plan

Currently there is not a clearly specified duration in China's water resource allocation plans. The duration in most of the water resource allocation plans or water resource plans is reflected as the plan year, that is, to stipulate the situation to a particular year, such as 2010, 2015 and 2030.

The duration of a plan is actually connected with the amendment mechanisms for the plan. "The Water Resources Allocation Plan of the Yellow River" in 1987 provided that the planning duration was until the commencement of the South-to-North Water Diversion Project (didn't clearly define the water diversion line). "The Water Resources Allocation Plan in the Down-stream of the Jinjiang River" provided that the water resource allocation plan was not unchangeable and that appropriate adjustments could be made according to the requirements of social and economic development in the Jinjiang River Basin. Article 9 of the "The Regulation of Water Resources Diversion in the Yellow River" provided that if the water resource allocation plan needed adjusting, the adjustment plan shall be proposed by the Water Resources Commission of the Yellow River in consultation with the people's government of the 11 provinces and regions, examined by the National Development and Reform Commission and the Ministry of Water Resources, and approved by the State Council.

In such circumstances, we suggest making a clear stipulation of the duration of the water resource allocation plan within the plan. A clearly-defined duration helps to clarify the legal effectiveness of the water resource allocation plan in a river basin, provides certainty to the right-holders, and helps to implement, amend and adjust the water resource allocation plan.

1.3.5 Monitoring and reporting

The monitoring and reporting system is essential to the implementation of the water resource allocation plan, and is also the key tool in assessing and supervising the implementation of the water resource allocation plan.

Basically, there are no specific requirements regarding monitoring of and reporting about the implementation in the existing plans. In some of the plans, one or several key monitoring locations in a river basin, which are used to define the water allocation regions or areas, become the monitoring and reporting locations. For example the hydrologic monitoring stations near the boundary of each province in the main stream of the Yellow River, the Caiqi Section of the Shiyang River Basin, and the Yingluo Gorge and Zhengyi Gorge of the Hei River Basin.

Article 11 of the "Interim Measures of Water Resource Allocation" provided that the water quantity which is used by a particular administrative region from the river, lake and groundwater sources area that cover more than one administrative region shall be monitored through the statistics of the flow and run-off at the boundary cross-section of the rivers and the water levels of both the lakes and the groundwater. The water quality should be monitored while monitoring the water quantity of surface water and the water level of groundwater. Article 13 provided that to prevent water disputes arising between different provinces, the volume of water abstraction and water utilization which is diverted from the boundary rivers or lakes of the provinces or from the rivers that cover more than one province should be defined by the river basin management authority in conjunction with the relevant administrative departments for water resources under the people's government of the provinces, in accordance with the approved water resource allocation plan and the hydrological plan of the boundary rivers (river section and lake) of the provinces. They should fulfil the regulation plan and implement the measures of metering and monitoring.

The volume of water abstraction and water utilization from the groundwater sources areas that cover more than one province should be defined by the river basin management authority in conjunction with the administrative department for water resources under the people's government of the provinces according to the approved water resource allocation plan and the utilization and development plan of groundwater in the boundary areas of the provinces. They should fulfil the regulation plan and implement the measures of metering and monitoring.

An explicit monitoring and reporting system needs to deal with the following issues in the preparation of the water resource allocation plan and the implementation of the annual water resource regulation plan:

i. stipulate the monitoring and metering locations to implement the standard of the water resources allocation plan;
ii. specify the indicators of the monitoring, such as water quantity, water quality, surface water and ground water, and the monitoring and metering of the water use in different industries;
iii. specify the reporting system and its reporting contents which stipulate the implementation condition of the annual water resource regulation plan;
iv. stipulate the organizations and units that compose and release the report.

1.3.6 Amendment procedure

The Water Law of the People's Republic of China stipulates the amendment procedure for plans. Article 18 states that wherever an approved plan needs to be amended, the amended plan should, in accordance with the procedure for the formulation of plans, be subject to approval by the original authority that gave approval for the plan.

That is to say, if the water resource allocation plan needs to be amended, the amending procedure is the same as the formulation procedure.

1.3.7 Consultation and public participation in the WRAP development

The formulation of the water resource allocation plan should involve wide consultation with the stakeholders in the river basin or region. At the same time, the widespread consultation and public participation help to formulate the water resource allocation plan. Article 9 of the "Interim Measures of Water Resource Allocation" provides that the water resource allocation system should be based on scientific assessment and democratic consultation combined with the administrative decision-making system. The authority which is drawing up the water resource allocation plan should compare the plans, broadly take into consideration the suggestions from consultation, and then define the administrative regional water resource quota and the control indicator of the relevant flow, water level and water quality. It should draw up the water resource allocation plan and submit it to the approval authority for approval.

Wide public participation and consultation in water resource allocation planning helps achieve greater understanding from the river basin on the water demand and ecological protection, better understanding of the water system, and helps to promote better implementation of the plan.

Due to the fact that water resource allocation planning in China is dealt with by making regional and/or sectoral water allocation, the participation and consulting bodies are mainly stakeholders relevant to water resource development, use and protection, including governmental organizations and agencies at various levels, water infrastructure operators and managers, industrial organizations, big water users, environmental protection organizations and minority groups in the basin.

The consultation and public participation in the water resource allocation plan consists of three aspects, that is, technical coordination, administrative coordination and public consultation.

The technical coordination is to consult and discuss the technical issues regarding the water resource allocation plan, including data, formulating measures and tools, the choice and establishment of the model, etc. Generally the technical coordination is aimed at the relevant professional organizations in the river basin or region.

Administrative coordination carries out consultation and coordination to the principles and proposals of the water resource allocation plan based on the technical coordination. Generally the administrative coordination is aimed at the relevant administrative organizations in the river basin or region.

Public consultation is used to elicit opinions and suggestions regarding the water resource allocation plan, from members of the public in the river basin or region.

Currently, there is no prescribed public participation and consultation procedure in the water resource allocation plan in China. It is it shall be specified the following aspects in the formulation of the water resources allocation plan: 1) the consultation and public participation procedure; 2) the consulting and involving organizations; 3) the feedback opinions of the consultation.

1.4 Assessment, development & management of water resources

This section discusses the process of assessing the water resources condition, together with its development and management in the river basin or region, to provide the basis for water resources allocation planning.

Standard water resources assessment measures and tools have been set up in China. In 1999, “The Guideline of Water Resources Assessment” (SL/T238-1999) was promulgated. “The Detailed Technical Rules of the Nation-wide Water Resources Comprehensive Plan” enacted in 2002 also specifically stipulated the assessment of the water resources and its development and utilization.

Therefore, the assessment of the water resources, and its development and utilization in the water resources allocation plan can be carried out according to these well developed methods.

1.4.1 Water resources assessment

Water resources assessment includes both quantity and quality assessments of the water resources. The quantity assessment includes the assessment of the vapour transmission, precipitation, evaporation, surface water resources, ground water resources and total water resources, etc. The quality assessment includes the assessment to the river sediment, natural water chemical characteristics and water pollution condition, etc.

Water resources assessment in the water resource allocation plan mainly focuses on a quantity assessment, including that of the surface water, ground water and total water resources. Water resource quality assessment may also be carried out if the plan involves allocation based on the water quality.

In accordance with “Guidelines for Water Resources Assessment”, the content and the precision of water resources assessment in a river basin or a region shall comply with the requirements of the water resource allocation plan. Water resources assessment should be carried out separately in different regions, and the region should be divided according to the geographic distribution of the river systems. Water resources assessment should also be carried out separately in different administrative regions according to the administrative sub-regions.

The nation-wide and regional water resources assessment should follow the calendar year, while if necessary, the water resources assessment in special-purpose works may adopt the hydrologic year.

Surface water resources assessment

Surface water resources is the renewable water in the surface water bodies such as rivers, lakes and glaciers, is produced by local precipitation, and is indicated by natural river run-off. The quantity assessment of the surface water resources should include single station runoff statistical analysis, annual run-off calculation of the main rivers (generally refers to rivers whose basin area is more than 5000 km^2), surface water quantity calculations in different regions, temporal and spatial distribution analysis of surface water, quantity calculations of water flow into the sea, the water flow abroad and the water flow into the country, and human activities impacts analysis on the river run-off.

Annual run-off calculations of the main rivers should calculate the average figure of the long-term run-off data and the annual run-off in different possibilities separately, according to the long-term run-off data in the control station of the river outlets.

For calculations of the water flow into the sea, the water flow out of the country and the water flow into the country, one must select the hydrologic stations near the estuary of the river or the boundary of the assessment area, convert the run-off data series from metering into the water in the sea section, exit section and enter section year by year, and then analyse the annual variability.

Groundwater resources assessment

The quantity assessment of groundwater should include the calculation of recharge quantity, discharge quantity, available quantity, temporal and spatial distribution analysis, and human activities impacts analysis on the groundwater.

The quantity assessment of the groundwater should be carried out based on regions; the regions would be divided into plain areas and mountainous areas according to different topographic and geomorphologic features.

The quantity assessment of ground water in plain areas should carry out the calculation of recharge quantity, discharge quantity and available quantity separately.

The quantity assessment of ground water in mountainous areas only calculates the discharge quantity. The discharge quantity of groundwater in mountainous areas includes basic river flow, mountain spring flow, mountain lateral outflow, river bed underflow, evaporation quantity of the underflow and actual net consumption quantity of the developed yield of groundwater. The sum of each discharge quantity is the total discharge quantity, that is, the quantity of groundwater resources.

Total water resources assessment

Total water resources assessment should be based on the quantity assessment of surface water and groundwater, and should include analysis in relation to the three kinds of water (precipitation, surface water and groundwater), calculation of the total water resources and the estimation of the total water available.

1.4.2 Assessment of water availability

According to the “Guidelines of Water Resources Assessment”, water resources availability can be analysed and calculated using water availability of surface water and groundwater. “Detailed Technical Rules of the Nation-wide Water Resources Comprehensive Plan” provide the same measure.

The “Interim Measures of Water Resource Allocation” provides that water resources availability includes water resources availability of surface water and the exploitation quota of groundwater. The overlapped water quantity should be deducted from the quota. The availability of surface water is the one-off maximum water resources for out-of-stream use from surface water which can be supplied through economical and rational measures with technological feasibility based on deducting the water resources for in-stream ecology and environment flow. The exploitation quota of groundwater is the maximum water resources explored from the groundwater aquifer without causing deterioration to the ecology and the environment.[2]

However, because of the regional conditions, it may be difficult or unreasonable to allocate water resources according to the total availability in some river basin or region. For example, in the river-net area, it is difficult to monitor and control the regional water consumption, so, it is inconvenient to allocate water availability to determine the regional water consumption; in the area rich in water resources, the water allocated to each administrative region from the total water availability may be much more than the actual

[2] See Interim Measures of Water Resource Allocation.

water consumption which cannot inspire pollution discharging control and water saving in the region; in the river basin where there is high efficiency of water utilization, there is massive difference between the present usage and the water availability, therefore, it is very difficult to allocate total water availability.

The experience of water allocation in some pilot areas shows that to allocate water resources according to the local conditions is much more practical and directed. Taking the local characteristics and the requirements of water allocation and water management into consideration,[3] Interim Measures of Water Allocation stipulates the subject-water available for allocation, which is the base for making the WRAP according to the local conditions. The Interim Measures state that "Water available for allocation is based on the water resources already allocated in the regions where the exploitation rate of development and utilization of water resources is high; in the river basins and administrative regions rich in water resources or in the regions with network of rivers that have complicated flow conditions or other river basins and administrative regions where are not adequate to allocate water resources in the unit of water availability. The allocation of water resources in those river basins and administrative regions mentioned above shall be implemented in the principle of convenient for management and operation, saving and protecting water resources and coordinating water supply and demand, comprehensively considering water for daily lives, production and ecology and environment".[4]

Surface water availability

"The Guideline of Water Resources Assessment" stipulates that the available surface water is the one-off maximum water volume that can be controlled and used out-stream on the precondition of economical and rational using and meeting the demand in-stream and downstream by water storing, water diversion and water pumping (not including recycled water). The available surface water cannot exceed water volume calculated from the domestic runoff, plus runoff from upstream, and less the outflow required by any water allocation agreements with neighbouring areas.

"The Detailed Technical Rules of the National-wide Water Resources Comprehensive Plan" stipulates that available surface water means the one-off maximum water volume that can be supplied by economical, rational, technical measures on the base of overall consideration of water utilization for domestic, production and ecology and environment (not including circulation of discharged water).

When estimating the surface water availability, the in-stream ecological water usage (environmental flow) should be determined and allocated in advance, so the estimation of surface water availability is closely related to environmental flow.

Available groundwater

The Guideline of Water Resources Assessment provides that available groundwater means the maximum water volume based on the reasonable economic and technical conditions, which can be abstracted from the aquifer without causing environment

[3] See the Explanation.
[4] See Interim Measures of Water Resource Allocation.

problems, such as decreasing the water level, deterioration of water quality, seawater intrusion or ground subsidence, and without impacting on the ecology and environment. The available groundwater shall be less than the total recharge of groundwater in the relevant area.

The Detailed Technical Rules of the National-wide Water Resources Comprehensive Plan provides that:

i. Available groundwater means the maximum water volume based on the reasonable economic and technical conditions, which can be abstracted from the aquifer without causing environment deterioration.
ii. The scope of the area which is assessed for groundwater exploitation shall be the area where the groundwater has been exploited or has the prospect of exploitation.
iii. The way to determine the annual average volume of the groundwater exploitation available of the shallow aquifer in the plain area are the followings: the actual investigation method (suitable for areas where there is in a high rate of shallow groundwater exploitation and there is data of actual shallow groundwater exploitation and the evaporation of aquifer is small), exploitation coefficient method (suitable for areas where is in significant research on the hydrology and geology of the aquifer), annual average regulating method and analogy method (for areas where there is limited information available).
iv. The calculation method and techniques requirements of determining available deep sub-artesian water in the plain area should be stipulated separately. The result of assessment of exploitation of deep sub-artesian water is not included in the total water availability.
v. The annual average available groundwater in mountain areas can be estimated using the monitoring information of springs, the actual exploitation of groundwater or by analogical method of hydrology and geology. The groundwater which is assessed as part of surface water resources that has been assessed as the overlapped volume.

Total water availability

According to the Detailed Technical Rules of the National-wide Water Resources Comprehensive Plan, water availability is the maximum water volume which can be used one-time based on the water utilization of domestic, productive and environment demand through the economical, reasonable and technical measures.

Generally, the calculation of water availability can be estimated by the adding surface water availability to shallow groundwater availability and deducting the overlapped part. The overlapped volume is mainly the shallow groundwater that leaks from the canals and the exploitation volume of supplement leaking from the fields. Following is the calculation:

$$Q_{total} = Q_{surface} + Q_{groundwater} - Q_{overlapped}$$

In that formula, $Q_{overlapped} = \rho(Q_{canal} + Q_{field})$

In the formula, Q_{total} is the total water availability; $Q_{surface}$ is the surface water availability; $Q_{groundwater}$ is the shallow groundwater exploitation; $Q_{overlapped}$ is the volume calculated overlapped; Q_{canal} is the supplement volume leaking from canal; Q_{field} is the supplement leaking from irrigated field by surface water; ρ is the coefficient, i.e. the ratio of groundwater availability to groundwater resources.

1.4.3 Assessment of water resources development

Assessment of water resources development generally involves the assessment of socio-economic development and water supply infrastructure, analysis and assessment of water supply, water utilization, water consumption, the water utilization ratio, and water development and utilization.

Investigation and analysis of socio-economic status

The investigation and analysis of the socio-economic status of river basin or region generally includes the following three parts: the analysis and assessment of natural resources in river basin and region; the assessment of river basin and regional economic development; the analysis of river basin and regional social development.

The main natural resources in the river basin and region (except water resources) are the land which is suitable for agriculture and herding, the mineral resources suitable for exploitation, and the grassland and forest region which can be used. The analysis mainly focuses on the distribution, quantity, current state and level of exploitation and utilization and the key problems.

The assessment of river basin and regional economic development includes industry and agriculture and urban and rural area focusing on the distribution and development of sectors, output value and yield of each industry.

The analysis of river basin and regional social development mainly focuses on the change of population distribution, the development of urban and rural areas.

Analysis of existing water supply infrastructure

The analysis of existing water supply infrastructure shall focus on the current status, key functions and the problems.

The water supply infrastructure can be divided into 3 types: surface water source, groundwater source and other water source, reflected by quantity, water supply capability of infrastructures. Water supply capability is the water supply based on the relevant reliability of current conditions, related to inflow, infrastructure conditions, and the characteristics of water demand and operation methods.

The surface water infrastructure can be divided into storage infrastructure, water diversion infrastructure, water pumping infrastructure and water diversion infrastructures across river basins. The infrastructure of groundwater resources means the wells using groundwater, which can be divided into shallow groundwater and deep sub-artesian water. Other water infrastructures include rainwater harvesting infrastructure, sewage treatment and reusing infrastructure and seawater utilization infrastructure.

Analysis and investigation of current water supply

The amount of water supply is the gross total water supplied by different types of water works including water loss in diversion, calculated according to water receiving areas. In the water receiving areas, water supply can be calculated based on three different water sources, that is surface water sources, groundwater sources and other water sources.

The out-stream water supply is according to different sources including local surface water, ground water, passing water, inter-basin water transfer, sea water, and waste water being treated or not.

Water supply from surface water sources is analysed according to different types of water works such as water storage works, water diversion works, water pumping works and water transferring works. Water supply from groundwater sources is the water abstracted from wells, and it shall be calculated separately according to shallow fresh water, deep artesian ground water and brackish water. Water supply from other water sources includes recycled waste water, rainwater collecting projects and sea water desalination.

Analysis and investigation of current water use

Water use is the gross total water use allocated to the water users, including water lost in diversion, and it can be divided into three types according to the characteristics of the users, that is, agricultural water use, industrial water use and domestic water use.

Agricultural water use includes water use of farmland irrigation, forestry, animal husbandry and fishery. Farmland irrigation is the most important agricultural water use, and it is generally calculated separately considering the different irrigation quota of paddy fields, irrigated (dry) lands and the vegetable lands. Water use of forestry, animal husbandry and fishery is calculated separately according to forest and fruit tree irrigation (including fruit tree, nursery garden and economic forest, etc.), grassland irrigation (including artificial grass land and forage base, etc.) and fish ponds water recharge.

Industrial water use is calculated according to the amount of water use (the amount of clean fresh water). Any recycled amount is not included. General industrial water use is calculated based on use by thermal (nuclear) power industries and general industries.

Domestic water use is calculated for both urban and rural domestic water use. Urban domestic water use includes residents' water use, public water use (including water use of service industry, catering industry, freight telecommunications industry and construction industry) and environmental water use (including beautification and water recharge of rivers and lakes). Rural domestic water use includes rural residential and domestic animal water use.

Analysis and investigation of water consumption

"Water consumption" is the water consumed through evaporation, soil absorption, water-consuming products removed from the system, and residential and domestic animals drinking which can not return to the surface water or ground water.

The water consumption of farmland irrigation includes evaporation, evapo-transpiration, channel surface water evaporation and infiltration losses. It generally can be calculated through balance analysis of the water in the irrigation region.

Industrial water consumption includes water loss in diversion and evaporation loss, water consuming products removed from the system, and factory area domestic water use in the production process. Generally, the industrial water consumption is the industrial water abstraction less any discharged waste water.

Domestic water consumption includes water lost in diversion and water consumed by residents and public facilities. The calculation method of urban domestic water consumption is basically the same as industrial water consumption, that is, water abstraction less any discharged waste water. Generally there are no water discharge facilities in rural houses, so the water use quota is quite low and the consumptive rate is comparatively high (water consumption is roughly the same as rural domestic water use); for the rural area which has water discharge facilities, typical investigations shall be carried out to estimate the water consumption.

Analysis of current water use standard and efficiency

The analysis of water use standard and efficiency involves analysing and calculating the comprehensive water use index, agricultural water use index, industrial water use index and domestic water use index of a river basin or region, assess the water use standard, water use efficiency and its changing condition based on the collection of social and economic information and the investigation and analysis of water use.

The comprehensive water use index includes per capita water use and per unit GDP water use.

The agricultural water use index is be calculated separately according to water use for farmland irrigation, forest and fruit tree irrigation, grass land irrigation and fish pond water recharge. The farmland irrigation index can be further divided into paddy fields, irrigated lands and vegetable lands.

Industrial water use index is calculated separately for thermal power plant industries and for general industries. The water use index of thermal (nuclear) power plant industries is expressed by water use for unit generating capacity; the water use index of general industries is expressed by water use for unit industrial outputs or water use for unit industrial value added.

Water reuse rate is the percentage of reused water (including water reuse for more than twice and recycling water use) in the total water use including recycling water use, the equation is:

$$\eta = Q\ \text{water reuse}/Q\ \text{total water use} \times 100\%$$

$$\text{or } \eta = (1 - Q_{\text{water recharge}} / Q_{\text{total water use}}) \times 100\%$$

In the equation, η is the reuse rate of industrial water use; $Q_{\text{water reuse}}$ is the reused water amount; $Q_{\text{total water use}}$ is the total water use amount (the amount of clean fresh water and reused water), Q water recharge is the amount of recharged water (i.e. clean fresh water).

Domestic water use index is split into a urban domestic water use index and a rural domestic water use index. Urban domestic water use index is calculated separately according to urban residents and public facilities, and expressed by daily water use per capita. Rural domestic water use index is calculated according to rural residents and domestic animals. Residents' water use index is expressed by daily water use per capita. Domestic animals water use index is expressed by daily water use per head, with large and small animals calculated separately.

Analysis of the level of water resources development

This is the calculation and analysis of the rate of development of surface water resources and shallow groundwater, and the water resources utilization and consumption rate in the river basins and regions. It should reflect the existing level of water resources development. Basic data such as total surface water resources, total ground water resources in plain area, total water resources, total surface water supply, the developed yield of shallow ground water and water consumption amount shall be used in analysis and assessment.

The rate of surface water resources development is the percentage of water supply from surface water sources in the total surface water resources.

The rate of shallow groundwater development in plain areas is the percentage of developed yield of shallow ground water in the total ground water.

The water consumption rate is the percentage of water consumption of the total water resources.

Investigation and analysis of the in-stream water use

In-stream water use can be divided into industrial water use and environmental water use. The former is water used for hydropower generation, fishery and navigation. The latter refers to water used to flush sands and silt, dilute pollutants, protect wetlands of the rivers and lakes and the minimum runoff and water into the sea which is necessary to maintain the environment.

1.4.4 Assessment of water resources management

This step involves the analysis and assessment of the current water resources management circumstances of the river basin or region, identification of the problems of the existing water resources management system, and proposes policy recommendations for the water resources allocation planning. The assessment of water resources allocation plan generally will analyse the legislation, institution, mechanism and the supporting system of the water resources management.

The legislative analysis of the water resources management assessment needs to analyse the existing law and regulation system related to water in the river basin or region, analyse the consistency of the existing law and regulation, examine the enforcement and implementation condition of the existing law and regulation system, and propose corresponding policy recommendations.

The institutional analysis of water resources management assessment needs to analyse the existing managing organizations related to water in the river basin or region, analyse the function of each organization, examine their intersecting and overlapping condition, analyse their coordination condition, analyse the capacity of their personnel and facilities in implementing their function, and propose corresponding capacity building measures.

The mechanism analysis of water resources management assessment needs to analyse the enforcement and implementation condition of the existing water resources management system, such as water abstraction permit system, water resources fee management system and the public involvement and organization involvement condition in the water resources management.

Analysis of the supporting systems for the water resources management assessment should consider existing monitoring and metering systems and the water information management system. It should consider whether the existing monitoring and metering system meets the requirements of water allocation and the requirements of law and regulation, and it the water information systems has been set up and whether it meets the requirements of water allocation.

1.5 Water demand forecast

1.5.1 Basic requirements

The water demand forecast is to identify the water required in the river basin or region in different years to meet the requirements of social and economic development and ecological protection. According to the requirements of a water resource allocation plan, a water demand forecast needs to forecast all needs for out-of-stream water demands, including water demand for social and economic development and for out-of-stream ecology and environment. Water demand for in-stream ecology and environment is identified separately as the environmental flow requirements.

There are many methods for water demand forecast, including quota forecast, water use index forecast, tendency forecast, mechanism forecast, per capita water use forecast and flexible index forecast. Among all these methods, quota forecast and water use index forecast are the most fundamental methods. "The Detailed Technical Rules of the National-wide Water Resources Comprehensive Plan" stipulates the water demand forecast of all industries explicitly.

Water demand for domestic and industry is generally called social and economic water demand. Domestic water demand is calculated according to the quota. Water demand for industry is the water demand for all kinds of productive activities which have economic outputs, including the primary industries (framing, forestry, animals husbandry and fishery), the secondary industries (industry, construction), and the tertiary industries (service industries). Social and economic water demand forecast includes net water demand forecast and gross water demand forecast. Net water demand forecast is carried out according to net quota of the terminal user, the net irrigation quota is the irrigation quota of the crops in the farmlands and the net water use quota of industries and domestic is the quota of the terminal user. Based on the outcome of net water demand forecast, the gross water demand forecast is according to the estimated water use index.

Water demand for ecology and environment is divided into in-stream water use and out-stream water use. The out-stream ecology and environment water demand forecast is carried out according to quota.

The water users of water demand forecast can be divided into three kinds, that is, domestic water users, industrial water users and ecological and environmental water users. Domestic and industrial water demand is generally called social and economic water demand. Water demand for industry is the water demand for all kinds of productive activities which have economic outputs, including the primary industry (framing, forestry, animals husbandry and fishery), the secondary industry (industry, construction), and the tertiary industry (catering industry and service industry).

The forecast of social and economic developing index is generally based on social and economic developing plan of the governments of different level and developing plan of relevant industries. Middle or long term social and economic developing index can be forecast according to the outcomes of middle or long term plan of relevant departments.

There are many factors which can affect the outcomes of the water demand forecast. Water demand is quite different under different social and economic developing conditions, different industrial structures and water using structures, different water using quota and level of water saving. Those differences can be reflected through different water demand scenarios.

1.5.2 Forecast of social and economic development

The forecast of social and economic developing index includes parameters about population and urbanization ratio, economic developing index, development of agriculture and utilization of farmlands etc.

Population and the level of urbanization

The population index includes total population, urban population and rural population. We can adopt model method or index method to forecast, or take use of the plan outcomes and forecast data.

The urbanization forecast shall be in accordance with the development strategies and plans of central and local governments. The urban population can be forecast based on the rate of urbanization (the percentage of urban population in the entire population).

The water user population forecast is based on the urban population forecast. The population of urban water user is the number of water users supplied by the urban water supply system, an enterprise water supply system and or self-supplied water source. However, the population of rural water user is the water users who use water supplied by the rural water supply system (including self-supporting water abstraction).

The population of urban water users includes the registered population those who have been living there for more than 6 months. If the moving population is in a quite low percentage, the urban population can be regarded as the population of urban water users. However, in rural areas where the population outflow is comparatively large, the impact of the population outflow must be considered.

Index of economic development

The index of economic development is estimated by considering different the sectors. The projection of economic development in the plan year shall be in line with the strategic objectives of the river basin or region for economic development, consistent with the regional economy and the status of water resources. Besides the total economic indices, the development index of main economic sectors shall be projected and the relationship between individual index of sector and total amount index shall be coordinated. The development index of each sector shall focus on the value-added, with the output value as an auxiliary.

Due to special nature of the thermal (nuclear) power sector, it shall be assessed independently and treated separate to the calculation and projection of the index of the value-added and total output value.

The estimation of water demand for building industry depends on the quota calculation of completion area unit.

Index of agriculture development and the land utilization

The index of agriculture development and the land utilization includes both a total amount index and a sub-index. The total amount index includes the total cultivated land area, total cropping area, grain cropping area, cash crop area, total output of main agricultural products, effective irrigated area of farmland, irrigated area of forest and orchard, irrigated area of lawn, fish pond with supplementary water, total amount of the livestock, etc. The sub-item index includes all types of irrigation area and all irrigation area of each crop, etc.

When projecting the farming land, future infrastructure construction, industrialization, and urban development (which occupy the land) shall be considered. Based on the project farm land, according to the crop index, the cropping area could be estimated in different regions. The total amount of crops can be estimated based on the mix of grain crops and cash crops.

The existing irrigation plan of farmland can be the basis of projection of irrigation area. The development index of irrigation area shall take into consideration the local resources conditions such water, land, sunlight, heat and the market demand. The farm irrigation land shall be divided into three types, irrigation land by well, irrigation land by channel and the irrigation land by both well and channel.

According to the development plan of livestock breeding and the demand of livestock, taking into consideration the development of livestock in agricultural areas, to estimate the indicator of irrigated grass area and the amount of livestock. And the development indicator of irrigated forest and orchard shall be projected according to the development plan and the market demand.

1.5.3 Social and economic water demand projection

Domestic water demand projection

The domestic water demand includes urban domestic water demand and rural domestic water demand, which can be projected by average daily water usage per person.

The net quota of daily water usage both in urban and rural areas under different possibilities shall be estimated based on the level of sociol-economic development, average income per capita, water pricing and water saving initiatives, combined with the historic and current water usage, and referring to the existing water using urban domestic standard issued by the Construction Department, as well as the water use quota for similar areas in China and abroad. The net water demand and gross domestic water demand shall be projected according to the result of water supply projection and the water supply network utilization ratio, combined with the projected result of population.

The domestic water demands in urban and rural areas is relatively even across a year, so that the process of water demand in one year can be determined according to the monthly average water demand. Where there is a large variation between months in one year, the monthly domestic water demand could be determined through the typical investigation and analysis of water use.

Agricultural water demand projection

Agricultural water demand includes water for irrigation and water for forestry, live stocking and fishery.

Water demand for irrigation

The water utilization factor for the channel system of irrigation area by well, by channel, and by a combination of the two, shall be determined separately, and used to project the net and gross irrigation water demand. The net irrigation quota for farming land shall be calculated according to the water demand of crops and the leakage of the fields. The gross water demand shall be projected according to the calculated net irrigation quota and the determined channel water utilization factor.

The irrigation quota can be determined comprehensively by choosing irrigation quota of typical crop and combined with the projected result of sown area or cropping pattern.

Where data is sufficient, the irrigation quota can be determined by employing time-series rainfall data. When using the typical year method, the irrigation possibilities of 50%, 75%, 95% shall be drew up respectively. The quotas can be divided into sufficient irrigation quota and non-sufficient irrigation quota. The former one is suitable for the area where is rich in water resources; the latter one is suitable for the area where is short of water resources.

Water demand for forestry, live stocking and fishery

This includes four types: irrigation for forest and orchards, irrigation for grass, irrigation for livestock and fish pond. The irrigation water demand for the above sectors is relatively influenced by rainfall, so the projection result under the possibilities of 50%, 75% and 90% where data is necessary or the water usage is large shall be drawn up. When the total volume is not large or the changes between years are small, the average volume can be used instead.

The net irrigation quota of forest and orchards and grass shall be determined respectively according to local experiments or the typical investigation; the water using factors of channel system shall be determined respectively according to the irrigation sources and methods; combining with the projected index of development areas of forests and orchards and grass to estimate the net water demand and gross water demand for forest and grass. The supplementary volume for fish pond that is calculated in supplementary water quota per mu is for the purpose of maintaining certain water area and certain depth of water. The supplementary water quota per mu shall be determined by leakage of fish pond plus evaporation and the rainfall.

Monthly distribution coefficient for agricultural water demand

The agricultural water demand is seasonal. To reflect the intra-year allocation process of agricultural water demand (and to provide the basis for water resources regulation plan) we need to draw up the monthly distribution coefficient for agricultural water demand for each region. The monthly distribution coefficient can be determined comprehensively according to the cropping structure and irrigation system.

Industrial water demand projection

This part includes the industries of high water utilization, normal industry and thermal (nuclear) power industry. The water demand of industry of high water utilization and normal industry can be projected by water usage per thousand added-values. Thermal(nuclear) power industry includes circulated and directly water utilization types of which the demand projection can be drawn up by water utilization of electricity generation per unit (100 million kwh) and be checked by water utilization of installed capacity per unit (10 thousand kw).

The standard quota for industrial water use set by the relevant department and province is the basis of projection of industrial water use. The long-term quota of water use can be determined by reference to the current industrial water use quota in countries or regions where the economy and standard of water use are relatively advanced, combined with the local conditions.

The monthly distribution of industrial water utilization in a year is generally even. For areas water varies during the year, the water demand of industry shall be determined through typical investigation to analyse the water using processes and then calculate the monthly distribution coefficient.

Water demand projection for construction and tertiary industry

The water demand of the construction sector shall be calculated by the unit of water use of construction area and checked by the water utilization of added value per 10 thousand. The water demand of tertiary industry can be projected by the water utilization of added value per 10 thousand. Based on the plans for these sectors and combined with an analysis of current water use, the net water demand quota and coefficient of water using in each planned year can be projected, as well as the net and gross water demands.

The monthly distribution of water utilization in construction sector and tertiary industry in a year is relatively even. For areas there is a large annual variation in demand, this can be determined through typical investigation to calculate the monthly distribution coefficient.

1.5.4 In-stream and out-of-stream ecological water demand projection

The out-of-stream ecological water utilization includes the ecological and environmental beautification of cities and water using of other ecological construction.

The calculation methods of different types of ecological water demand are different. The ecological water demand (of which the vegetation water demand is largest) such as beautification of cities, forest and lawn protection can be projected by quota. The difference between the evaporation and rainfall is the ecological water demand for any supplemented water resources of lakes, wetland, rivers and lakes in the cities. The groundwater level shall be controlled because of the ecological water demand of vegetation. The other ecological water demand can be calculated according to the actual situation of local regions and each river by relevant methods.

1.5.5 Other in-stream water demand projection

Water utilization of other in-stream productive activities (including navigation, hydrological power, fishery and tourism) do not consume water resources but require certain water levels and flows. In order to balance the water volume at the controlling nodes this type of water utilization shall be estimated according to its specific requirements and characteristics. The monthly water demand level at each controlling node shall also be calculated.

1.6 Application of water resources management model

The water resources management model, which is the technical support to water resources allocation planning and the decision-making supporting tool, could support the scenario analysis and decision making for all management measures. So it is the basis of water resources allocation planning and water resources management practices.

Water resources management models have not yet been widely applied in water resources allocation planning in China. In the formulation of the water resources allocation plan in Shiyang river basin, a groundwater model had been set up to analyse impact of different allocation scenarios on the groundwater downstream. The analysis is the basis for the decision of water demand downstream.

Generally speaking, the selected water resource management model(s) of river basin and region should (ideally) be able to:

i. take into account both surface water and groundwater sources in a basin;
ii. support the definition of water rights;
iii. support the definition of environmental flow requirements; and
iv. be used for the preparation of water resources allocation plans and setting up water transfer rules.

To be able to meet the above functionality requirements, the selected model(s) should ideally have the ability to undertake the following:

i. route flows in the streams and channels;
ii. operate on and off-river reservoirs;
iii. operational management of multiple reservoirs;
iv. interaction of groundwater/surface water processes;
v. simulate losses from the river system (evaporation, seepage, etc);
vi. estimate irrigation demands, crop water demands, orders, diversions;
vii. simulate fixed demands such as town water supply and industrial demands;
viii. simulate hydropower demands;
ix. simulate flows into effluent channels and return flows from effluent channels;
x. take into account minimum flow requirements;
xi. simulate wetland demands and floodplain storage characteristics;
xii. take into account water sharing for both regulated and unregulated river systems;
xiii. resource assessment and water accounting; and
xiv. take into account inter-provincial water sharing agreements;

When comparing and evaluating the different models for their suitability to meet the modelling requirements outlined above, the following technical and non-technical criteria should be considered.

Technical criteria:

i. Model functionality and capability.
ii. Model complexity.
iii. Data requirements.
iv. Processes included/excluded.
v. Ability to model both water quantity and quality.
vi. Ability to model both surface water and groundwater use.
vii. Ability to interface with GIS systems.

Non-technical criteria:

i. User friendliness and ease of use.

ii. Skill level required to set up and run the model.
iii. Ability to support water resources management planning.
iv. Purchase and maintenance costs.
v. Availability of technical support.

Meanwhile, during the process of making the water resources allocation plan, it should be specified that water resources management model is the basis of decision making both of water resources allocation plan and management measures. Therefore, the legal status of water resources management model shall be clarified, so shall the output of model. The model shall be identified as the authoritative tool to identify whether the management decision complies with the goal of environmental flow and the reliability of water resources allocation.

1.7 Water resources allocation

1.7.1 Defining the water resources allocation

This refers to the identification of the aspects of the allocation, as stated in the allocation plan. The elements should be clearly identified to define the allocation being made under the plan.

Water volume: consumption & abstraction

Water volume in water resources allocation means the allocation plan or that according to which standard to allocate water resources. Generally, depending on the characteristic of the water source, water volume may be specified as either water abstraction or consumption.

At present, there are two types of water resources allocation in China: water abstraction volume and water consumption volume (sometimes not in the form of water consumption but actually the water consumption, such as the required discharge controlled by the hydrological stations in Heihe river basin, the water resources flowing into Guanting reservoir for allocation of upstream of Yongdinghe river).

In southern China with plenty of water resources, allocations are set based on water abstraction volume. This occurs for the water resources allocation at the river mouth of Qiantangjiang River and allocation of Jinjiang River, Quanzhou, and in the regions or rivers in the southern China, such as Fuhe river, Jiangxi province, Dongjiang river, and Guangdong province.

In the northern China, where water resources are in short supply, generally, allocations are defined based on water consumption, as is the case in the Shiyang riverbasin, Heihe river basin, Yellow River Basin, upstream of Guanting reservoir, the Tarim river basin, Dalinghe river basin, and the Huolinhe river basin.

From the aspect of water allocation, defining allocations based on either water abstraction or consumption is feasible, and without any problems about reasonability and science. Generally the water abstraction is the object of allocation in the region rich in water resources, such as south of China; while in the region short of water resources the water consumption is the object, such as North China Plain, North West area and Yellow River basin.

A different approach to specification will influence the operation and implementation of water resources allocation plan, especially the monitoring and measuring. The existing water resources management mainly focuses on the management of water abstraction and discharging. Therefore the difference between the choice of water abstraction or water consumption as the way for defining allocations is that the former does not require water discharges to be regulated, while the latter does. When allocations are set as an abstraction volume, monitoring and measuring of the abstraction should be according to the regulations on Management of Water Abstraction Permit and Water Resources Fee. When allocations are defined as by water consumption, monitoring shall be carried out at the boundary cross section to determine the water consumption of each region. Therefore, the implementation of water resources allocation plan based on the water consumption is much more complicated than that based on the water abstraction.

Water source: groundwater and surface water

The WRAP should specify the source of allocations: whether they are from surface water, groundwater or both surface water and groundwater. The way the water source is defined will change with the changing of water conditions and the development and utilization of water resources in the river basin.

The change specification of the water source in Yellow River basin reflects the shift from using inflows to local water consumption (in fact it is both the surface water and groundwater). Meanwhile the history of water allocation in Hexi corridor also reflects the trend from surface water to both surface water and groundwater.

In southern China, the management focuses on surface water the region is rich in surface water resources and the groundwater is used less. Water allocation mostly relates to surface water (referring to some groundwater allocation; however the groundwater exploited is the shallow part, and in fact is recharged from surface water).

Therefore, the choice of water source shall be based on the specific management requirement in the planning. At present, the choice of surface water in south China and the choice of both surface water and groundwater in north are relatively reasonable. However, the attention shall be paid to the individual or united source allocation in certain river basin and region.

The importance in the allocation planning is that whether the allocation of certain water source will impact the development and utilization of other water source. The single management of surface water may intensify the exploitation of groundwater. If it is serious, all of the water source allocation shall be under control, not only the surface water and groundwater, even the overland flow (such as in Queensland, Australia).

Defining the time: past, present and future

Allocations should specify the time period for which the allocation is made. Generally, the shortage of water resources in the river basin or region is the decisive factor of allocation time period.

The time period can be divided into three parts: past, present and future. The different choice of time period determines the basis of water resources allocation.

According to the existing water resources allocation plan, the allocation of Yellow River basin is based on the actual water utilization in 1980 through analysing the development scale of irrigation, the increase of water utilization of industry and cities and the construction possibilities of the large-middle scale water works in relevant provinces. The total water allocation is 40% more than usage in 1980. The water resources allocation plan for the Downstream of Jinjiang River focuses on the flow in dry season at the Jinji water gate downstream of Jinjiang River. The allocation ratio of each county (city, district) is based on the socio-economic development and the projection in 1994 and the water demand and supply in 2000. In addition, the water allocation of Shiyang River is based on the water utilization and social-economic development in 2003. 2020 is the base year for water resources allocation at the mouth of Qiantangjiang River. And the projection of exploitation level of water resources in 2030 and the water utilization are the basis for water allocation of Haila'er river basin.

So, when drawing up the water resources allocation plan, if there is still plenty of water resources and certain kind of potential for exploitation and utilization, the water resources in the future certain year or the enlargement of the current water abstraction and utilization will be the way for defining the allocation, typically the allocation plan based on the annual average water resources in the south and the allocation plan in the Yellow River basin in the north, such as the water allocation of Haila'er river basin.

On the contrary, if the river basin or the region is short of water resources, or water resources is running out or the water for certain sector is occupied (for example the water resources for in-stream ecology and environment), the present water usage or even the past, will be the basis of water allocation.

Water quality

Though water quality should generally not be included in the content of the water resources allocation planning, the water quality is still significant. The quality will be different for different sources; equally, where water is allocated for a purpose, the quality needs to be adequate for that purpose. When the water quality cannot meet the requirement of the specific purpose, water resources shall be allocated according to the quality. In the last period, the water pollution is not as serious as present time or the water quality can meet people's requirement, or people do not care about water quality, the water quality allocation issue has not been included in the scope of water resources allocation planning. When the pollution became so serious that the problem of water quality has been brought into the scope of allocation more and more, which leads into the situation that water resource with certain quality attracts more and more attention during the process of drawing up the allocation plan.

The issue of water quality allocation attracts attention in resources allocation at river mouth of Qiantangjiang river. According to the different requirement of water quality, the water supply and demand were analysed by different water quality individually in the allocation of Qiantangjiang river mouth. Because of the serious shortage of water resources in the north, the issue of water quality allocation has not become the content of allocation in time. But in the region where rich in water resources and in serious situation of pollution, to allocate water quantity and quality at the same time is necessary and the requirement to reasonably allocate water resources.

The design of water resources allocation plan combining water quantity with water quality is very complicated. The principle of 'better water for better purpose' needs to be taken into consideration. The different requirements to water quality and water use for different sectors should be taken into consideration. Especially in the design of allocation plan, this must be more specific and raise higher requirements to monitor, measure and report.

Spatial definition: river basin or point location

It is necessary to define the location or region for different water allocations. “Location” refers to a point of take, while a region means an area. In most cases, water resources allocation planning is for a region. Taking river basin and region for example, the allocation there is to allocate water resources within the river basin and the region; while sometimes water resources allocated is only for a location.

In existing water resources allocation plans, there are two types of water allocation: one based on region reflected in two ways: directly named by the administrative region, such as Shiyang River basin and Yellow River basin; or named by the key controlling points for the upstream, mid-stream and downstream, such as upstream of Heihe river, upstream of Guanting reservoir; the other based on locations, such as the historical allocation in the Hexi Corridor, Jinjiang river, Quanzhou.

The choice of region or location is related to the requirement of the river basin. But no matter which form will be selected, the chosen controlling stations and typical locations are the key points for water resources allocation planning in the river basin. Therefore, the issue of space is a specific issue of choice to be decided based on local conditions.

Table 1: to defining water allocations in the existing WRAPs

River basin or region	Water quantity	Water quality	Water source	Time	Space	Reserved	Time period
Mouth of Qiantangjiang river	Abstraction	Under consideration	Surface water (SW)	2020	Region	No	Whole year
Zhejiang province	Abstraction		SW	2020	Region	No	Whole year
Heihe river	Consumption		SW and groundwater (GW)	Present	Region	No	Whole year
Shiyang river	Consumption		SW and GW	2003	Region	Yes	Whole year
Zhujiang river	Abstraction		SW	Future	Region	No	Whole year
Fuhe river	Abstraction		SW	2030	Region	Yes	Whole year
Yellow river	Consumption		SW and GW	Based on 1980	Region	No	Whole year
Upstream of Guanting reservoir	Consumption		SW and GW	2000	Region	No	Whole year
Hu’nan provionce	Abstraction		SW	2020	Region	No	Dry season
Downstream of Jinjiang river	Abstraction		SW	2000	Point	Yes	Dry season
River basin of Haila’er	Abstraction		SW	2030	Region	Yes	Whole year

1.7.2 Allocation principles

There must be principles for allocating water resources, and these should be specific, executive and be reflected in the allocation plan. The principles should be set before the allocation plan is made.

In some ways, deciding the principles is much more important than the plan itself, because the allocation principles will determine the way the plan will allocate water. Therefore, the principles must undergo adequate discussion and consultation with stakeholders.

The following table lists the principles followed in existing plans.

Table 2: Water resources allocation plan principles

River basin	Province	Allocation year	Principles
River mouth of Qiantangjiang river	Zhejiang	2005	Insist on water saving first, control pollution in the basin, both quality and quantity, under the condition of fully using of local resources, with the shortage abstracted from the river mouth of Qiantangjiang. In the river mouth water resources allocation, first securing the urban water use for Hangzhou City, with higher priority to meet the urban and rural water demand, at the same time to considering water demand for industry, agriculture, ecology and environment, navigation. Share the benefits among up and downstream, left and right banks, and relevant regions, to fully achieve comprehensive benefits from water resources.
Huolin river	Inner Mongolia Jinlin	2006	Government's macro-regulation and consultations principle. Basin uniform distribution. Total control and quota management. Justice, equity and openness. Integrated Plan of status usage and future demand.
Daling river	Inner Mongolia Liaoning	2006	Principle of fairness. Different regions and different crowds enjoyed the equal water rights for survival and development Unified water allocation. Uniform consideration of surface and groundwater, main stream and tributaries, quality and quantity Government's macro-regulation and consultations principle Balanced sharing between the living, production and ecological water. The order of priority is (1) life; (2) minimum ecological environment water need; (3) water demand of the second and third industrial; (4) agricultural irrigation water demand Deciding the requirement on possible provision Integrated Plan of status usage and future demand Total control and quota management Classification recognized
Zhang river	Heibei	2003	Water saving Consider upstream and downstream, the left and right bank

River basin	Province	Allocation year	Principles
			Respecting for the history and facing the reality, appropriate considering the future development, taking into account the engineering status and water usage status
Wei river	Hebei	2003	Sustainable development principles Basic living needs priority and ecological demand priority Respecting the history and focusing on the reality principle Integrated consideration and resources sharing Equality and efficiency
Yellow river		1984	Priority to the people's living water and key State construction and industry projects Sediment movement in the Lower Yellow River Navigation and fishery water demand are not separately allocated Consider upstream and downstream Do not increase the groundwater extraction
Shiyang river	Gansu	1990-2006	National ownership principle Basic water priority and balance between fairness and efficiency Respecting for the history and facing the reality, appropriate considering the future development Democratic consultation and integrated decision-making
Tarim river	Xinjiang	2005	Effectiveness Principle Justice Principle Systemic Principle Coordination Principle Priority Principle
Fu river	Jiangxi	2005	Respect the status quo Justice Principle Justice and Effectiveness
Downstream of Jinjiang river	Fujian	1996	Respect the future, Prior Appropriation and Justice Base on the status and consider the future demand in a proper way
Haila'er river basin	Inner Mongolia	2005	1）guarantee the domestic water requirement, which has with first priority; 2) reasonably allocating ecological and environmental water use. 3) reasonably reserving risk allocation, with 15% reserve for ecology and environment, and 5% for domestic. 4) optimal allocation productive usage; 5) reasonably allocation of different sources.

Article 21 of Water Law states that development and use of water resources, should first meet the requirements of urban and rural domestic water use, with the consideration of agricultural, industrial, ecological and environmental water use and navigation. In the arid and semi-arid zones, development and use of water resources should fully consider the ecological and environmental water requirements. Article 5 of Interim Measures of Water Resources Allocation provides that Water resources allocation shall be implemented in the principle of fairness and justice. Attention shall be paid to the circumstances of water resources within the river basin and the administrative region, the history and the reality of water supply and water utilization, the supply capacity and demand of water resources and the demand for saving-water society construction. The water using relationship between upstream and downstream, between the banks of the river shall be properly treated. The water using of surface water and groundwater and of in-stream and our-stream shall be coordinated. And the water using of daily lives, ecology and environment shall be comprehensively arranged.

Therefore, generally, the following content of the principles should be determined:

As the basis of allocation, first is sustainable development, to fully coordinate the water use between socio-economic development and ecological protection in the river basin or region. Second is the basis for allocation, such as respecting the present situation. Third is the priority of water use purposes and regions, such as priority to domestic, to urban areas. Fourth is the procedure of water allocation, such as democratic consultation and concentrated decision. For each specific river basin or region, the principles of allocation can be determined according to the actual requirements of allocation in the local areas.

1.7.3 Reserved water

Reserved water is one of the issues to be considered in the water allocation of some regions or river basins such as Shiyang River Basin and Jinjiang River Basin. Similar reserved water allocation exists in Queensland, Australia. Water which is not allocated is regarded as reserved or unallocated water: the detailed management system of reserved water is also prescribed in the water resources allocation plan.

In order to satisfy the water demand of future development and important developing strategy, reserved water should be considered in the water resources allocation plan. However, taking the different water resources conditions in different river basins and administrative regions into account, it is not realistic to reserve water in all river basins and regions. Therefore, Article 8 of “Interim Measures of Water Resource Allocation” prescribed that: in order to meet the water resources demand for future development and the national strategy of key development in the future, the authority for drawing up the water resources allocation plan may, according to the water resources conditions within the river basin or the administrative region, reserve some quota of water resources, through consultation with the relevant administrative department. The rights to manage the reserved water resources shall be defined by the approval authority for water resources allocation plan. The reserved water resources, before being allocated, can be allocated reasonably to the annual water resources regulation plan.

Generally, there are two situations resulted in the reserved water, one is water resources is surplus, the other is there are risks in water allocation which need to adjust through reserved water. For the first situation, we generally regard all the water resources which are not allocated as reserved water, and the reserved water is managed by government. For the second situation, we generally think there are probably some unpredicted risks in the existing water resources allocation plan, for example the ecological and environmental water demands is not met, or the regional or river basin water resources allocation plan is not rational. Actually, the key issue is not whether the reserved water is rational or not, but the management of reserved water.

Reserved water actually is the water which is not allocated, the management of reserved water is actually another water resources allocation process, and the political and technical issues thereof are probably the same as that in formulation of water resources allocation plan.

Therefore, in order to reduce the cost of management, we shall set up clear and defined managing system of reserved water in the formulation of water resources allocation planning. However, this part of content is not included in China's current water resources allocation plan which refers to reserved water.

The management of reserved water in water resources allocation plan shall clearly define the following aspects:

i. the amount and usage of reserved water;
ii. the managing authority of reserved water; and
iii. the principle and procedure of using reserved water.

1.7.4 Environmental flow

In-stream ecological and environmental water use is included in the framework of China's water resources allocation plan with more and more attentions are paid to ecological and environmental issues. However, there are still some questions in the identification of in-stream ecological and environmental water use.

In the design of specific water resources works such as the discharge flow of a reservoir, many design agencies take the flow of most dry month in a P=90% base year as the designing basis of a reservoir's minimum discharge volume, such as the design of Zhuxi Reservoir in Jiaojiang River Basin. In the river basins and regions where a water resources allocation plan has been formulated, in-stream ecological and environmental water use or ecological and environmental water use in the downstream of the river are considered in the water resources allocation plan of Qiantangjiang River Basin, Hunan Province, Haila'er River Basin, Yellow River Basin, Shiyang River Basin and Heihe River Basin.

As to the technical guideline, "The Supplement Detailed Rules and Regulation of General National Water Resources Allocation Plan" stipulates the category and estimation of in-stream ecological and environmental water demand. The in-stream ecological and environmental water demand mainly includes:

i. environmental flow of maintaining the basic function of river (includes preventing dry-up of the river flow, maintaining the water demand for river self-purification, flushing sands and survive of aquatic species);
ii. environmental flow of lakes and wetlands (includes water demand for lakes and wetland); and
iii. environmental flow of river mouth (includes water demand for flushing sedimentation and protecting harbour, diluting salt water and preventing tide, and protecting species in the river month).

In China, in water resources allocation planning, the environmental flow definition and management should be according to the following process.

1.7.5 Inter-basin water transfer definition

There should be clearly defined regulations on the water quantity which is diverted into or out of the river basin or region in the water resources allocation plan.

For the time being, a lot of inter-basin water diversion projects are being constructed, such as the east line and middle line of the South-to-North Water Diversion Project, or have been constructed, such as the project of diverting Yellow River water to Qingdao and the project of diverting water from Liu river to supply the Jinchang City. However, because the formulation of water resources allocation plan in China is lagging behind the construction of water diversion projects, there are not many regulations on the water allocation of inter-basin water diversion in the current water resources allocation plans.

Water allocation in the water receiving area in the current water resources allocation plan, such as Shiyang river basin, stipulates that water diverted from other river basins (rivers basins other than Shiyang River Basin) shall belong to whoever invests in the water diversion projects. For the water diversion projects invested by the state, the allocation of the diverted water shall belong to the state and be used for regional development objectives with first priority.

For the area from which water is diverted out, for example, Shandong Province, Hebei Province and Tianjin Municipality in the downstream of Yellow River (where the water has been diverted from the Yellow River basin), the water allocations are defined in the water resources allocation plan of the Yellow River Basin. Water diverted to east of Zhejiang Province is also reflected in the water resources allocation plan of Qiantangjiang River Mouth.

Therefore, normally, in the water resources allocation plan for the area from which water is diverted, the water diverted out is part of the total water availability of the river basin or region, but it isn't allocated within the river basin or region. But to the diverted-in river basin or regions, the diverted allocation is varied. Article 15 of the "Interim Measures of Water Resource Allocation" stipulates that "The water resources diverted into the diversion project which has been implemented or been approved shall be allocated according to the plan or the relevant agreement."

1.7.6 Consistency Requirements

The requirements for consistency arise due to the multiple levels of water resources allocation plan and the variable nature of hydrology. The consistency issues for a water resources allocation plan include spatial consistency and water quantity consistency.

Spatial consistency

Due to the characteristics of China's administrative management system, water allocation is a multiple-level allocating procedure. So there is an issue of spatial consistency, that is, whether the water to be allocated in different plans is coupled or consistent.

According to the definitions of "The Water Law of People's Republic of China", a reasonable water resources allocation procedure should first formulate major river basin water resources allocation plan which allocates water to provinces (autonomous regions, municipalities), second formulate provincial water resources allocation plan which allocates water to prefectures (cities), and third formulate prefecture level water resources allocation plan which allocates water to counties (cities). This is a water resource allocation procedure which the area covered by the plan changes from large to small.

However, for the time being, spatially, water resources allocation in China does not follow the above procedure. Theoretically, water resources allocation plans under the provincial level shall not be formulated before the central level or large river basin water resources allocation plan has been completed. Actually, there is a consistency issue in all water resources allocation plans that are being (or have been) made, because the major river basin water resources allocation plans have not been formulated. For example, “Shiyang River Basin Water resources allocation plan” of Gansu Province in 2006 is not consistent with the water resources allocation plan of Jinchang City issued in 2000.

All water resources allocation plans have legal force after approval. However, under the hierarchy of administrative power, the power of higher level government is greater than the lower level of government, so the legal rights of the higher level plan are superior to the lower level plan. Under such circumstances, an appropriate amendment mechanism for the lower level plan should be set up. If the lower level plan is formulated before the higher level plan, it will probably cause inconsistency, and should be amended. Otherwise, the implementation of a series of inconsistent water resources allocation plans would result in chaos in the water resources management.

The amendment of the subordinate plan water resources allocation plan can refer to the requirements of “The Water Law of People’s Republic of China”. The amendment process is also discussed earlier in this report.

The technical requirement for the amendment of subordinate plan is that the water quantity to be allocated in a given year must be coupled or consistent spatially.

Water quantity consistency

The consistency requirement of water quantity is also related to the multiple levels of water resources allocation planning in China. Because there are many water resources allocation plans at different levels, there are different ways of defining allocations in different water resource allocation plans. However, in technical terms, regardless of the way the allocation is defined, the water quantity must be consistent in different levels. For example, if the higher level water resources allocation plan stipulates the volume of water abstraction, while the lower level of water resources allocation plan stipulates the volume of water consumption, technically the water quantity should be coupled. Similarly, if the higher level and lower level water resources allocation plans are in different time, the water quantity in the same base year shall be coupled.

In general, the temporal aspects of the definition of water allocations are relatively consistent. For a large river basin or region and any sub-basins or sub-regions, a same year will be chosen for planning.

However, the spatial aspects of water quantity are more complex. For the water resources allocation plans where all the plans are allocating either water abstraction or water consumption, it is relatively simple. However, where plans covering the same area adopt a different approach, it is complex because water consumption needs to be estimated according to water abstraction and water discharge. Although there are few river basins where this has been done, if this does occur, we can analyse and deal with it according to the hydrological transforming relation.

Connection with water abstraction permit

Article 15 of “Regulations on Management of Water Abstraction Permit and Water Resources Fee” stipulates that: the approved water resources allocation plans or signed agreements are the basis to determine the cap of the water abstraction in river basins and administrative regions. Where no allocation plans or agreements are made on rivers or lakes across boundaries of provinces, autonomous regions or municipalities directly under the Central Government, the river basin authorities shall, based on the water resources conditions in the river basin, develop the caps of water abstraction of the concerned provinces, autonomous regions or municipalities directly under the Central Government, in accordance with comprehensive water resources plans, comprehensive river basin plans and medium and long-term plans for water supply and demand and in combination with current water abstraction and supply-demand conditions of provinces, autonomous regions or municipalities directly under the Central Government, and shall consult the relevant administrative departments for water resources under the people's governments of provinces, autonomous regions or municipalities directly under the Central Government, and shall submit to the administrative departments for water resources under the State Council for approval. The administrative departments for water resources under people's governments of provinces, autonomous regions or municipalities directly under the Central Government shall set total control indicators of water abstraction of cities (prefectures), counties (cities), in accordance with the total control of the concerned provinces, autonomous regions or municipalities directly under the Central Government, and in conjunction with their respective local water abstraction and supply-demand situations, and shall be submitted to the river basin authorities for record.

The connection with allocation planning to water abstraction permit indicates that in water resources allocation plan we shall set up and propose the total controlling index of water abstraction permit for a river basin or region, so as to provide a basis for the approval of water abstraction permits.

Because the implementation of water abstraction permit system takes water abstraction as a starting point, while the specification of an allocation by a water resources allocation plan might be either water abstraction or water consumption, so we should treat them differently.

Where allocations are defined as a water abstraction amount, the identification of the cap of water abstraction permit is very simple. That is, the water resources allocation plan of the river basin or region simply becomes the total controlling index of water abstraction permit.

Where allocations are defined as a consumption amount, the identification of the total controlling index of water abstraction permit is more complex. There are two options:

- One is to identify and examine water consumption in the management of water abstraction permit, that is, we still takes water consumption as the allocation method in the water resources allocation plan and don't propose a cap of water abstraction permit as such. However, in the approval of the water abstraction permit, we analyse water consumption according to the water resources justification report for the construction project so that providing a basis for the approval of water abstraction permit. The characteristic of this arrangement is that water allocation is relatively simple, but the technical difficulty for assessing abstraction permits is increased.
- The other arrangement is to identify water consumption in water resources allocation plan, that is, we propose the cap of water abstraction permit of a river basin or region explicitly in the water resources allocation plan, which could be used directly in the approval of water abstraction permit. Generally we can estimate the cap of water abstraction permit of a river basin or region according

to the water use of different sectors in a river basin or region. However, because the water use is quite random for the future (no one know if it will be an industrial or agricultural user), there may be great risks in this kind of estimation, although the approval of water abstraction permit is quite simple.

Connection with annual water resources regulation plan

At the river basin or region level, Article 46 of “The Water Law of People’s Republic of China” stipulates that the administrative departments for water resources under the local people’s governments at or above the county level or the river basin authorities shall, on the basis of the approved water resources allocation plans and the predicted annual volume of in-coming water, work out annual water resources allocation plans and distribution plans for unified distribution of the volume of water.

The runoff is the basis for preparing water resources allocation plan. The water volume in the water resources allocation plan is an annual average water volume. Because the runoff between years is different, the water volume to be allocated in different years will vary. Therefore, the river basin management agencies and the water administrative authorities of each province, prefecture and county shall prepare the annual water resources regulation plan and operational plan of the river basin or region according to the approved water resources allocation plan of the river basin or region and the predicted runoff for the year.

Water resources regulation plan is to allocate the water resources in different time periods and different administrative regions scientifically, according to the approved water resources allocation plan prepared based on the predicted runoff. The water administrative authorities and river basin management agencies at or above county level shall implement the water regulation according to the annual water resources regulation plan.

Because water resources allocation plan is targeted to annual average water volume, and the annual water resources regulation plan refers to the water volume of a particular year. In fact, we can not make water resources regulation plan for each year in detail within the WRAP. Therefore, approach is to set up a calculating principle that can be followed to convert the principles in the water resources allocation plan into an annual water resources regulation plan; for example this could be via the same-rate of increase or decrease. Therefore, actually it is the water resources allocation plan, the predicted runoff of a year and the water resources operation principle that determine the actual water use or abstraction volume of a particular year.

There are water operation regulations in some of river basin’s water resources allocation plan in China, such as the Yellow River and the Shiyang River. “The Water Operation Regulations of Yellow River” in 2006 stipulates that annual water resources allocation plan shall be prepared according to approved water resources allocation plan and predicted annual runoff, the water storage in the reservoirs, following the principle of increasing in the wet years and decreasing in the dry years with the same ratio, multiple years regulating reservoirs storing water in wet years and discharging water in dry years, and based on the proposal of annual water using plan and reservoir’s water operational plan which is reported under overall balance.

According to the water allocation principle regulated in the “Interim Measures on the Water Operation Management of the Main-stream of Hei River”, the annual water operation of Hei River adopts an amending month by month principle, an annual total control principle and parallel lines principle.

- *The annual total control principle.* According the approved water discharge index and water diversion index of the Zhengyi Valley Section, annual total control is carried out to the water discharge of the Zhengyi Valley Section and the water use of the Dingxinpian and DongfengChang Area.
- *Amending month by month principle.* We shall amend the water operation plan in the remaining period month by month and get close to annual water resources allocation plan step by step according to the runoff of Yingluo Valley in the time period which has already happened and the water discharge condition of Zhengyi Valley Section in the operation year.
- *The calculating rules of water quantity.* Accumulated calculating method is used in the water operation of Hei River Basin. Operational deviation is allowed in water quantity calculation, and the rule of "refund for any overpayment or a supplemental payment for any deficiency" is applied to the water operation between years, that is, for the water discharge index of Zhengyi Valley which is identified in the plan, operational deviation which is not more than 2% is allowed in the operation of real time less discharged water. If particular water condition happens, which causes serious impact on accomplishing water operation objective, the operational deviation can appropriately enlarge, which still can not more than 5%. Operational deviation caused by more discharged water is not regulated; the operational deviation is refunded for any overpayment or paid for any deficiency in the next operational year.

We should pay attention to the following issues in the preparation of water resources operation rules:

i. Technical consistency: it is necessary to guarantee the technical consistency of the water resources allocation plan and annual water operation plan, which should reflect the same hydrological regime.
ii. Fairness: the water operation rules shall be as objective as possible, reflect the natural regime and the rules which have already been established, and reduce the intervention of management authorities.
iii. Enforceability: the issue of enforcement shall be considered when making the water operation rules, and be sure that the rules are enforceable and practicable.

Chapter 2: Environmental (ecological) flow guidelines

2.1 Introduction

2.1.1 River health and biodiversity

Rivers, lakes and wetlands contain only a fraction of the world's water and cover less than 1% of the Earth's surface, yet they support about 40% of the planet's fish diversity and a quarter of the known vertebrate species[5]. However, extinction rates of freshwater animals are the highest of any other ecosystem, and freshwater ecosystems are already regarded as the most threatened on the planet[6]. More than 20% of all freshwater species of fish are either threatened or endangered[1]. Further marked declines in freshwater biodiversity are predicted as a consequence of declining river health in the face of an expanding human population and climate change.

Rivers are often described as the 'ecological arteries' or the 'life-blood' of the landscape – and it is clear that in many ways there are strong links between the health of rivers and the well-being of society[7]. The term 'river health' is used in this chapter in much the same way as when the health of humans is discussed. There are many obvious direct links between human health and the health of rivers[8].

- The term 'healthy' is used in this chapter to describe systems in good ecological condition, as measured in terms of:
- organisation (e.g. biodiversity, food web complexity);
- vigour (rates of aquatic production and nutrient cycling); and
- resilience (ability to recover from disturbance) [9].

Clean fresh drinking water is an example of an 'ecosystem service' that is provided by healthy rivers (for free). Healthy rivers and their associated wetlands also perform many other essential ecosystem services, such as:

- sustaining subsistence and commercial fisheries;
- providing safe environments for recreation; and
- trapping and transforming contaminants.

The provision of these and other essential services has an estimated global economic value of several trillion US dollars each year[10]. More importantly, when healthy ecosystems become degraded by human activity, they can no longer provide the same level of service and the capacity of the environment to sustain economic activity (and human health) is diminished.

River health is a relative term. It can mean different things to different people depending on their particular societal values or beliefs. It is important to recognise that societal

[5] Dudgeon et al. 2006
[6] Malmqvist and Rundle 2002; Postel and Richter 2003
[7] Bunn, 2003.
[8] Gleick, 2004; Postel, 2001.
[9] Bunn, 2003.
[10] Postel & Carpenter, 1997.

values change over time. This is particularly relevant as scientific understanding of river systems increases and there is a greater public appreciation of the benefits of the natural, healthy river environment.

2.1.2 The influence of flow regimes on river health

The alteration of flow regimes is arguably the most serious and continuing threat to the health of rivers and their associated floodplain wetlands[11.] "Flow regime" refers to the overall pattern of flow, including seasonality, predictability and the frequency, timing and duration of specific flow events. There is growing awareness that flow regimes are key drivers of the ecology of rivers and their associated floodplain wetlands.

Flow regimes are important because:

- flow is a major determinant of the physical habitat in streams and rivers;
- river species have evolved life history cycles in response to the natural flow patterns;
- flows maintain natural patterns of longitudinal (i.e. upstream–downstream) and lateral (e.g. river-floodplain) connection; and
- changes to flow regimes facilitate the spread of unwanted pest species[7].

Although flow is an important determinant of the health of rivers, it cannot be considered in isolation from other stresses (e.g. pollution, in-stream and riparian habitat degradation and invasive species). Other influences on the condition of rivers also need to be considered, such as water quality and physical habitat integrity.

2.1.3 The concept of environmental (ecological) flows

Environmental (ecological) flows are the flows of water that are needed to maintain river health and ensure that the benefits derived from rivers and streams can be sustained.

Research on environmental flows in China has been underway since the 1970s. This research initially focused on issues related to sedimentation of river channels, sea-water intrusion in tidal reaches and dilution of water pollution problems[12]. These early technical approaches focussed on the concept of minimum flow requirements, based primarily on a range of hydrological and hydraulic methods. However, there is increasing awareness of holistic approaches to the assessment of environmental flow that achieve a broader range of water quality and ecological outcomes.

Internationally, there is now general agreement among scientists and water managers that river health requires mimicking components of natural flow variability. This means considering all of the variables for key flow components (e.g., floods and droughts) including their:

- magnitude;
- frequency;
- timing;

[11] Bunn and Arthington, 2002.
[12] Jiang et al., 2006.

- duration;
- rate of change; and
- predictability.

It is therefore not surprising that arbitrary "minimum" flows are unlikely to be adequate to protect many important environmental, economic, social and cultural benefits associated with rivers.

An understanding of the different requirements for each of these variables is important to be able to provide the flows necessary to protect freshwater biodiversity and maintain the essential goods and services provided by rivers[13]. The major goal of ecologically sustainable water management is to meet direct human needs and at the same time provide flows to sustain ecosystem health and biodiversity in rivers and their associated wetland and coastal systems[14].

2.1.4 Some basic principles

There are several key principles that link hydrology to aquatic biodiversity and river ecosystem health. These principles are depicted in Figure 4 and discussed in detail below.

Principle 1: Flow is a major determinant of the physical habitat in rivers, which has a major influence on the composition of aquatic animal and plant communities[15]

- The shape and size of river channels, the distribution of riffle and pool habitats, and the stability of the substrate are all largely determined by the interaction between the flow regime and local geology and landform.
- In turn, this interaction between flows and physical habitat is a major determinant of the distribution, abundance and diversity of river organisms.
- Close associations with physical habitat can be found in many stream organisms ranging from algae and aquatic plants to invertebrates and fish.
- The structure and dynamics of riparian plant communities are also strongly driven by the flow regime[16].

Principle 2: Aquatic species have evolved life history strategies in response to their natural flow regimes[17]

- River flows and wetland water regimes have a major influence on recruitment and growth of aquatic plants.
- Critical life history events in many species of fish are linked to the flow regime. This includes the timing of key life history events, spawning behaviour, larval survival, growth patterns and recruitment.

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[13] Arthington et al., 2006.
[14] Bernhardt et al., 2006.
[15] Bunn and Arthington, 2002.
[16] Nilsson and Svedmark, 2002.
[17] Bunn and Arthington, 2002.

- Many of these life events are synchronised with temperature and day-length. This means that changes in flow regime that are not in natural harmony with these seasonal cycles can have a negative impact on aquatic biota.

Principle 3: The maintenance of natural patterns of longitudinal (i.e. upstream – downstream) and lateral (river – floodplain) connectivity is essential to the viability of populations of many riverine species[18]

- Many aquatic animals need to move freely through the stream network.
- Migratory macroinvertebrates (such as shrimps and crabs) and diadromous fishes (which migrate long distances within the main channels and larger tributaries of rivers) are particularly sensitive to barriers to longitudinal passage. Obstruction of their migratory pathways often interferes with the completion of their life cycles.
- Dams are also barriers to the movement of waterborne vascular plant propagules. Regulated riparian zones harbour fewer vascular plant species than free-flowing ones[19].
- The lateral expansion of floodplain habitats during flooding creates important spawning, nursery and foraging areas for many fish species and a variety of other vertebrates.
- Lateral connections between rivers and floodplains during flood events also provide an important opportunity for the exchange of energy and nutrients, increase soil fertility, and increase floodplain productivity[20].
- Flow regulation by dams and other structural modifications (such as channelisation and levee banks) can reduce lateral connectivity between rivers and floodplains.

Principle 4: The invasion and success of exotic species in rivers and riparian zones is facilitated by the alteration of flow regimes[21]

- Many species have been introduced into regions or countries beyond their native range either deliberately or accidentally. Some of these species have become pests.
- Stabilisation of flow patterns can reduce the growth and survival of native aquatic plants and encourage invasive weeds such as water hyacinth (*Eichhornia crassipes*). Water hyacinth can form dense surface growths covering large areas of open water which interfere with flow and river navigation, disrupt recreation, impede access of livestock to water and negatively impact upon water quality.
- Pest fish and invertebrate species tend to have greatest success in waters where there are more constant flow regimes than previously existed due to damming or other flow modifications. These invaders can displace species of conservation or fisheries importance and lead to changes in water quality.

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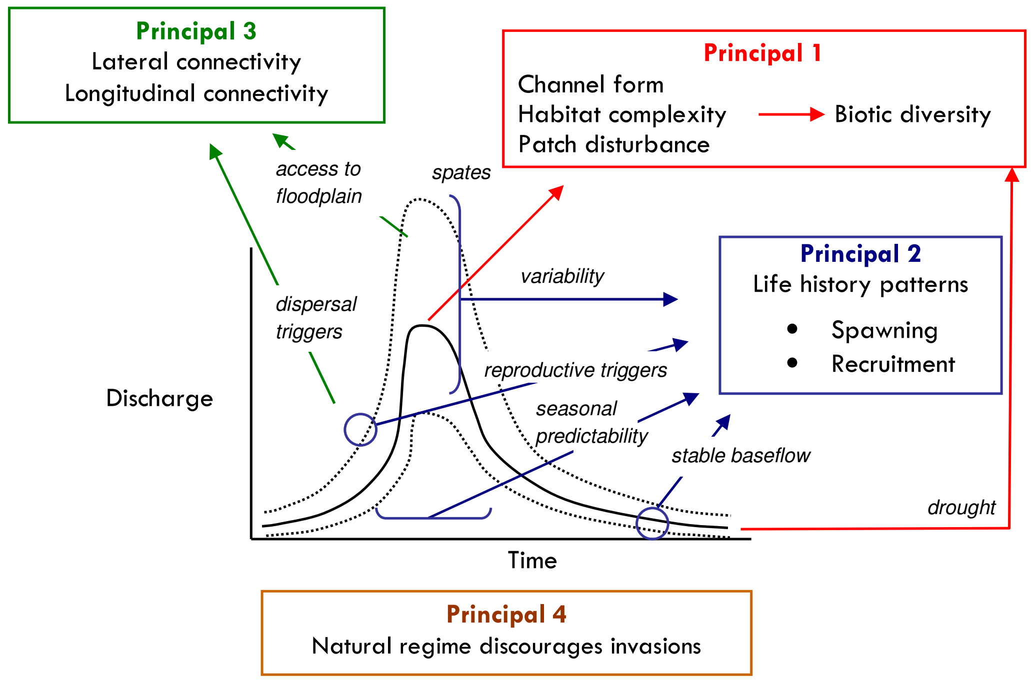
[18] Bunn and Arthington, 2002.
[19] Nilsson and Svedmark, 2002.
[20] Nilsson and Svedmark, 2002; Pinay *et al.*, 2002.
[21] Bunn and Arthington, 2002; Nilsson and Svedmark, 2002.

- Conversion of rivers to permanent standing water bodies (e.g. reservoirs) can lead to the proliferation of pest species.

Figure 4: Aquatic biodiversity and natural flow regimes



The natural flow regime of a river influences aquatic biodiversity and river ecosystem health via several, inter-related mechanisms operating over different spatial and temporal scales.

Source: Bunn & Arthington 2002

2.1.5 About these guidelines

The aim of this document is to provide a framework for water resource managers to:

i. identify environmental flow needs to sustain important river ecosystem benefits; and

ii. incorporate environmental flows into the regulatory regime.

The determination of environmental flows should be considered as an integral part of the water resource allocation planning process, which is discussed in Chapter 1. The principal responsibility for allocating water to the environment lies with the relevant water resource departments. However, specific ecological assessments may require experts sourced from the relevant government agencies, universities, research institutes and river basin authorities.

These guidelines are designed as a decision tool with five principal steps:

- Step 1: Identifying key river assets (ecosystem goods and services)
- Step 2: Determining key threats to river assets
- Step 3: Defining the flow requirements of river assets
- Step 4: Delivering environmental flows through modifications to river infrastructure and management arrangements

- Step 5: Monitoring and assessing the effectiveness of environmental flow provisions

Each step begins by asking a fundamental question. The text and examples in the following sections guide the user to collect the information necessary to develop an appropriate answer to these questions (Figure 5). In some situations it may be necessary to return to earlier steps within the guidelines. Each section concludes with a statement describing the desired outcome(s) and recommends the next step.

While the recommended approach is considered to be generic for most settings, the guidelines may need to be refined to address issues that are specific to a particular region. The guidelines have been written in a sequential fashion; however some stages of the data collection and analysis may be more logically undertaken in parallel.

It is important to use the best available technical information in following these guidelines. It is recognised that there is an incomplete understanding of many river systems and that existing knowledge will be often far from perfect. However, this should not prevent the provision of environmental flows.

Initial recommendations may be based largely on professional judgement and experience from other systems, including those from other parts of the world. However, as new information is collected during monitoring, environmental provisions can be further refined and improved.

Where possible, a precautionary approach is recommended in the face of uncertainty. This provides greater flexibility for refinement of water plans should the balance between consumptive, out of stream water uses and environmental uses need to be revisited in the future. This should be seen as an iterative process, and monitoring of the success of environmental flow strategies should inform periodic reviews of plans, to ensure that the key objectives are being met.

2.2 Step 1 – Identifying key river ecosystem assets

The first step in these guidelines describes the process for identifying and prioritising river ecosystem assets (‘river assets’). For the purposes of these guidelines ‘river assets’ refers to those benefits derived from “leaving water in the river” as distinct from abstraction for out-of-stream urban, industrial or agricultural use.

River assets will differ for different rivers. Which assets are important will also vary depending on societal values and the choice of the river assets to be protected will depend upon what is considered important for that particular river basin or catchment and requires consultation with the relevant stakeholders.

The choice of assets will guide subsequent steps in these guidelines and provide the rationale for the provision of environmental flows.

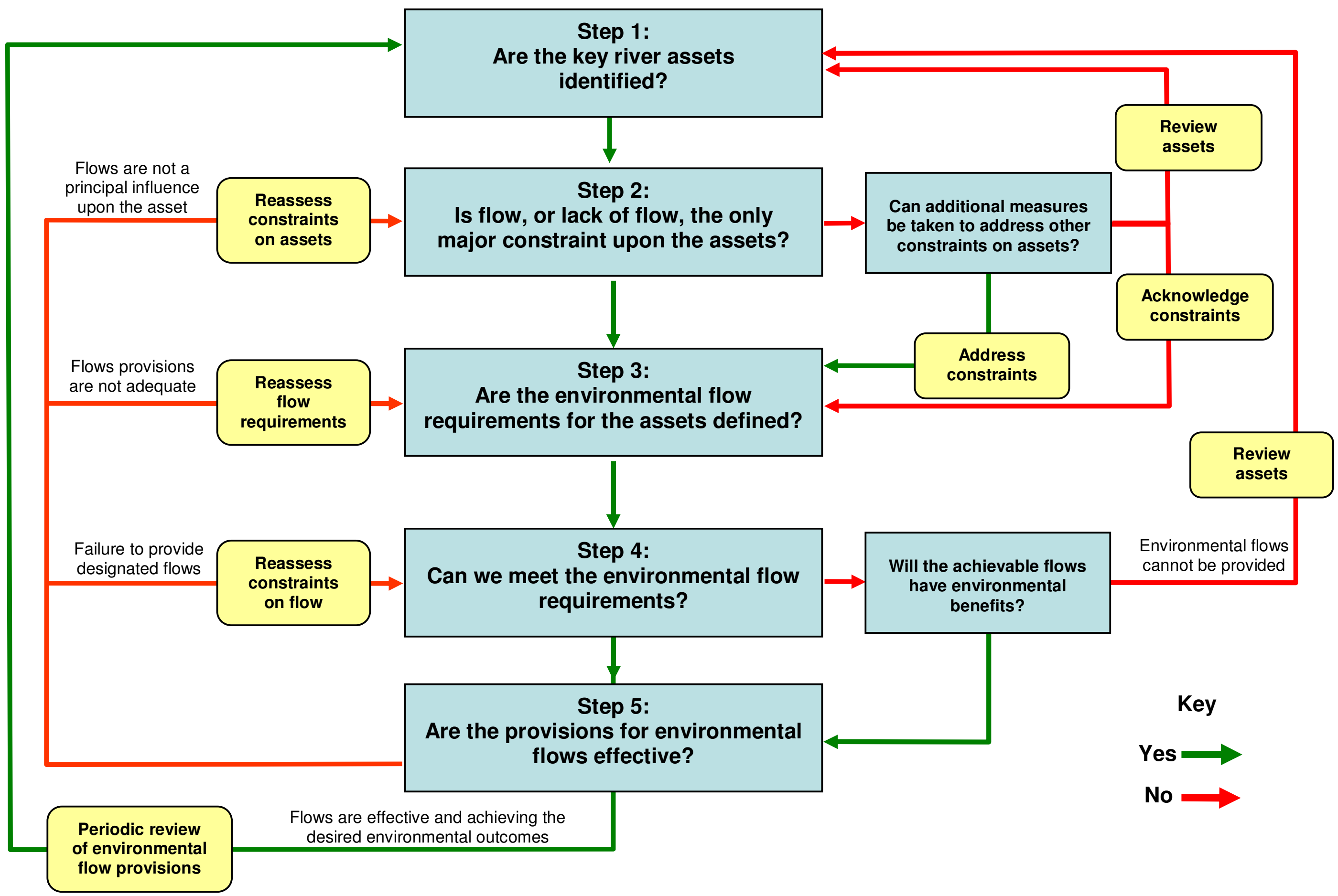
The objectives of this section are to:

Provide guidance on the identification of key river assets.

Suggest ways in which assets can be identified.

Provide criteria for prioritisation of assets.

Figure 5: Environmental flow guidelines structure showing the five fundamental questions and arrows that return the user to earlier steps in the guidelines or take the user to the next step



2.2.1 What are river assets?

A river asset is any attribute of the natural ecosystem of value to society. The value could be ecological, social and/or economic. An asset may have multiple values. The term asset is used broadly in these guidelines and encompasses “goods”, “values” and “services”.

River assets include species, biological communities, habitats and ecosystems of conservation importance (collectively referred to as “conservation assets”).

River assets include social and economic benefits derived by the natural river environment – that is, the river goods (or produce) and services (processes of value to society that are naturally generated by the river system) derived from leaving the water in the river. River assets include both in-stream and off-stream surface water ecosystems where these are affected by natural flows, such as wetlands, floodplains, riparian zones and groundwater dependent ecosystems. River assets also include assets within estuarine and coastal waters that are influenced by river flows.

Rivers provide a great range of goods and services to society. Some of these benefits are well recognised (for example supporting fisheries and the dilution of pollutants). Other ecosystem processes occurring in river systems are less obvious but nevertheless provide essential services of benefit to human societies. Table 3 describes some river goods and services that may be considered in an inventory of key river assets for the region of interest.

2.2.2 How can river assets be identified?

Key river assets may be identified from a review of existing information and the collection of new data. In collecting information, it is important to also consider the key threatening processes that are likely to influence assets, as this information will be required for Step 2 of these guidelines.

Considerations when collecting data include the following:

- Assets, and the key processes that threaten them, will differ depending upon the characteristics of the area or region of interest (i.e. its size, topography, geology, principal land-uses and climate). Therefore information should be collected on the characteristic(s) of the catchment, for use in later assessments.
- Assets and key threatening processes may not be distributed uniformly, either spatially or temporally. Therefore, information collected will need to be explicit about actual distribution.
- Data collection should aim to identify both existing and future issues. For example, information should be collected on planned developments.
- The quality of the data collected should be considered, particularly in terms of how well it can be relied upon.
- Where information specific to the river of interest is not available, information about a similar river or region (in terms of its ecology and hydrology) may be used.

Table 3: Examples of ecosystem goods and services from rivers

Production of aquatic resources or produce	Commercial and subsistence wild fisheries, including estuarine and coastal habitats e.g. fish, turtles, frogs, shellfish, shrimps, crabs, aquatic plants and other fauna; Sites for aquaculture operations (such as floodplain ponds, wetlands, channel backwaters and estuaries); A source of clean water and wild fish fry and crab seed for aquaculture stocking. Materials for building or construction, e.g. timber, sand and reeds; energy materials; products used in traditional medicines; and derivatives for the production of synthetic pharmaceutical drugs.
Human wellbeing - spiritual, cultural and recreational needs.	Rivers may be sites of important cultural events (e.g. dragon boat racing or floating lantern festivals) and may be highly valued as sites for recreational (fishing, camping and swimming) and aesthetic enjoyment.
Transport and dilution of pollutants	Flows are often an important mechanism for flushing out pollutants and re-oxygenating river water.
Water purification	Trapping and transformation of contaminants particularly in wetlands, floodplains and riparian zones; e.g. denitrification (the processes by which microbes convert nitrate into nitrogen gas) reduces nitrogen pollution in water and improves water quality.
Maintenance of river channel form and erosion control	River flows are important for transporting sediments and maintaining river channels for navigation. Sediment deposition can stabilise river banks and replenish beaches and deltas.
Floodplain wetting and soil enrichment	Materials deposited on floodplains and wetlands during flooding can enrich soils providing an important source of essential plant nutrients that are beneficial for agricultural production. Wetlands and floodplain flooding may also be important sites of groundwater replenishment.
Flood control	Rivers are used to convey floodwaters and wetlands can serve to mitigate downstream flooding.
Conservation	Rivers may be sites of high biodiversity and conservation interest, sustaining rare, endangered or threatened species and/or communities of animals (e.g. fish, birds, insects, amphibians, reptiles and mammals) and plants (including in-stream, riparian, wetland and floodplain habitats).
Migratory routes	Rivers provide migratory pathways for some species to move between coastal, estuarine and freshwater habitats. Many important fisheries species are migratory and their life cycles take place in both freshwater and seawater. Species migrate between these habitats to reach spawning, nursery and feeding grounds. Off-channel habitats such as wetlands and floodplains may be utilised by these species for spawning and nursery habitats and fish of all sizes may also use these habitats for feeding.

Capturing existing data and knowledge on river assets

Information on river assets and their flow requirements may be found in a variety of existing written documents. A list of example written data sources useful in the identification of key river assets is provided below. Other documents specific to the river basin or catchment of interest should also be sourced wherever possible.

- **Ecological surveys/inventories/monitoring programmes:** Surveys or inventories of rivers and associated wetland and floodplain habitats undertaken may be useful in identifying species of economic and conservation importance.
- **Fisheries statistic year books:** May provide information on commercial inland, estuarine and marine fisheries catch data. Statistical year books may be useful in

identifying river species of economic importance and (based on historical records) trends in catch rates.

- **Species and/or habitat databases and directories:** Existing databases and directories may list assets of conservation importance in the region of interest (examples are given in Appendix A). For example, species regarded as endangered and protected may be included in lists of National Key Protected Wild Animals (1998) and National Key Protected Wild Plants (1999). Species of conservation importance may also be recognised under international agreements such as the Chinese-Australia Migratory Bird Agreement (CAMBA) and the Agreement on Migratory Birds and Habitats Conservation between China and Japan (CJMBA). Habitats and ecosystems of special conservation interest include those recognised under international agreements (e.g. the Ramsar convention on wetlands) and/or as nature reserves. An extensive system of nature reserves has been developed throughout China which includes terrestrial, in-land freshwater bodies and marine nature reserves. In addition to threatened and protected species recognised at the national and international level, provinces, autonomous regions and municipalities may also provide special local protection to animals and plants. Information on these species and/or habitats may be identified through contact with the relevant local government agencies (for example the environmental protection and forestry bureaus).
- **Other information sources:** Other sources of information may include maps and other spatial data sets (e.g. vegetation maps), reports, published journal articles, river management plans and online web resources (e.g. www.fishbase.org - the global information system on fish). Consultation with stakeholders and experts can be used to identify further sources of documented information.

Consultation with land and river users can also allow the incorporation of broader knowledge about river assets – information which may not be captured in written documentation.

The use of workshops and/or interviews may be particularly important in regions where documented information on river systems, specific species and/or river habitat assets is poor or lacking completely. Those undertaking interviews should be familiar with the focus river catchment or basin.

Workshops and/or interviews could include interested stakeholders (e.g. local government authorities, hydropower companies, other industries, farmers and other land users, commercial and recreational fishermen, environment groups) and experts sourced from local universities, research institutes, government agencies, and river basin agencies. Experts could be drawn from biophysical fields (e.g. hydrologists, geomorphologists, water quality experts, botanists, zoologists, microbiologists, marine biologists) and socio-economic fields (e.g., public health, livestock health, anthropology, sociology, water use and resource economics).

Interviews to identify assets and associated issues should target communities likely to be affected by any new development (such as those communities downstream of a proposed reservoir).

A field assessment may also be useful in identifying river ecosystem assets, as well as issues or threatening processes likely to influence assets. A field visit should involve expert representatives across both biophysical and socio-economic research fields and should consider local knowledge gained from workshops or interviews.

A field assessment may be particularly valuable where new developments are planned (for example, the construction of a new reservoir). Assessments should identify river assets, as well as issues (such as threatening processes – refer to step 2) that are likely to result from new developments.

2.2.3 How can river assets be prioritised?

Where multiple river assets are identified, prioritisation may be necessary. Prioritisation may be based on external drivers, for example assets that are considered in the national and international interest due to:

- uniqueness (threatened, rare species or endemic species present);
- national or international recognition (for example, Ramsar or CAMBA listing); or
- legislative obligations

Prioritisation may also be based on local or internal drivers, such as:

- community/stakeholder support;
- the impact of the asset on other river values (for example, impacts on tourism, fishing and recreation); or
- the condition of the asset (i.e. can the health of the asset be improved or would efforts be better directed at protecting other assets?).

The criteria used for identifying priority assets will be region specific and will need to be undertaken in consultation with stakeholders and experts. This prioritisation process could also be performed within the workshop forum. In some cases, high priority assets may have already been identified within the water plans for the region.

2.2.4 Taking the next step

The subsequent steps within the guidelines should focus on the ecological assets of highest priority. However, where possible, the requirements of other assets should be considered.

At the end of this step, a list of priority river assets (goods and services) should be completed, that will form the basis for the environmental flow provisions (See example table in Appendix B).

It may be necessary to return to this step later and reassess the priority assets where the objectives are not feasible due to other pressures (refer to Step 2) or where the required flows cannot be achieved (refer to Step 4). During this reassessment it may be useful to consider what environmental gains can be achieved given the identified threats and available water.

Step 1 outcomes:

Key river assets identified.

Key river assets prioritised.

2.3 Step 2 – Identifying key threats to river assets

Many rivers face multiple threats. In much of the world, human development has resulted in many floodplains being permanently separated from their rivers. Most of the world's larger river systems have been moderately or heavily fragmented by reservoirs and flow regulation. Pollution, escalating nitrogen loads, habitat loss and degradation, introductions of pest species, climate change and the over-exploitation of aquatic resources all pose serious threats to river systems.

The provision of environmental flows may mitigate some influences from the construction of reservoirs and flow regulation. Other issues (such as pollution) may also be addressed in part by river flows. Additional measures, however, may need to be taken to address other threats before the desired environmental (ecological) outcomes are achieved – that is, improved flows on their own may not be enough to achieve a healthy river system.

It is important to identify other influences upon the health of river assets, some of which may ultimately determine the environmental (ecological) outcomes. Recognition of these threats enables water resource managers to:

- make an informed decision on whether to proceed with providing environmental flow recommendations; and
- identify where additional measures are needed to achieve the desired river health outcomes.

It is important to note however, that the presence of an additional threat does not mean that environmental flows should not be implemented until other pressures have been addressed – significant progress may still be made towards the objective of protecting or restoring key environmental assets.

The objectives of this section are to:

Enable the user to recognise threats to river assets.

Enable the user to make an informed decision on the suitable next step.

2.3.1 Direct changes to flow regimes

Alteration to natural flow regimes refers to reducing or increasing flows, altering seasonality of flows, changing the frequency, duration, magnitude, timing, predictability and variability of flow events, altering surface and subsurface water levels and changing the rate of rise or fall of water levels. Many human activities alter surface water and groundwater flow regimes. The primary goal of environmental flow allocations is to mitigate the impacts associated with these changes.

Examples of human activities that influence flow regimes include:

- the construction of reservoirs and weirs (for water supply, hydropower and flood control);
- the construction of other river infrastructure, such as roads and levee banks;
- water abstractions, diversions and transfers;
- catchment modifications that alter rainfall run-off, such as the presence of impervious surfaces; and
- channel modifications, such as dredging and channel lining.

Specific examples of the impacts of changes to flow regimes in Chinese rivers – in terms of the ecological, physical and chemical responses – are given in Appendix C.

2.3.2 Water infrastructure issues

Water resource development typically has impacts in addition to changing the flow regime. River infrastructure and management may also fragment river systems, degrade water quality and alter physical habitat. Short descriptions of some key issues are given in the following sections.

Barriers and fragmentation

The survival of many river species depends upon their ability to move freely through the river system [Basic Principal (iii)]. Many river systems, however, have become fragmented through the construction of barriers that:

- inhibit the passage of river biota; and
- impede critical river services such as the transport of sediments and pollutants downstream.

The most obvious barriers to movement are large structures such as reservoirs. However, smaller structures (such as sluices, weirs, road crossings, causeways, culverts and levee banks) are also significant barriers to the movement of river biota. A succession of small structures can have a significant impact upon river ecosystems.

Access to off-stream wetlands and floodplains is disrupted by barriers such as levee banks that are designed to control flooding and confine the river within its channel.

Significant mortality to river biota can also occur whilst passing through hydraulic turbines and over spillways.

Temperature and water quality

The viability of many river species depends upon both the quantity of water and its quality. Issues of water quantity and quality are strongly interrelated. There is a number of ways in which river regulation can affect water quality:

- *Cold deoxygenated water releases from reservoirs:* Water quality problems can arise downstream of reservoirs when water is released from deep stratified water layers in reservoirs (For an explanation of stratification see Box 1). The release of this cold, oxygen-deficient water can compromise its benefits to downstream biota. For example, some warm water fish rely on both temperature and flow cues for reproduction. Cold water releases can significantly delay or even prevent fish spawning. Fish with specific temperature requirements may be completely eliminated and very low oxygen waters can lead to fish kills.
- *High pressure reservoir releases:* Water released under high pressure can be supersaturated with gases. If these gases are absorbed by river species, they can cause significant damage or even death to the species.
- *Long water residence times:* Reductions in flow extend the time taken for a body of water (such as a natural pond, or one created by a weir) to be completely replaced (or flushed through) – "water residence times". Longer water residence times may lead to the accumulation and concentration of contaminates and a deterioration in water quality. Stratification and deoxygenation in slow moving and stationary waters may further reduce water quality. Incidents of blue green

algal blooms may increase because they are a function of longer water residence times, stratification and high nutrient loads. In turn, algal blooms can lead to toxin and odour problems impacting upon drinking water and other amenity water uses.

Box 1: Reservoir stratification

Stratification is where a layer of warm-water lies over cooler, bottom waters. This often occurs in deep reservoirs and other water impoundments. Oxygen concentrations in these cooler waters can become depleted compared with surface waters. In low oxygen waters chemicals such as phosphorus, aluminium, magnesium and ammonia (which are normally bound to river sediments under oxygenated conditions) may be released into the water.

Sediment and habitat

Flow is an important determinate of physical habitat. Physical habitat, in turn, influences the distribution, abundance and diversity of river biota [Basic Principal (i)].

River regulation can alter sediment transport processes and channel form. Reservoirs trap all but the finest suspended sediments. Consequently, water flowing from a reservoir carries a reduced sediment load. During flow releases from a reservoir, channels may become eroded. As a consequence, river bed materials below the dam become coarser and there may be accelerated rates of channel bank erosion. Further downstream sedimentation and channel elevation commonly occur because the high flows and floods, which are needed to maintain channels and mobilise sediments, no longer take place.

2.3.3 Additional threats to river assets and values

Not all processes that threaten the health of river assets are directly related to water resource development and management. Examples of pressures resulting from other anthropogenic activities include:

- pollution;
- invasive (pest species);
- habitat loss and/or degradation;
- the over-exploitation of river biota; and
- climate change.

Impacts can come from both present activities and past human activities. For example, past mining activities may still result in contamination even where the mining activities themselves have ceased.

Pollution

There are many point and diffuse sources of pollution (both toxic and non-toxic) that may impact on the quality of river water.

Pollution issues may in part be addressed by river flows. Increasing flows may flush out accumulated pollutants and reoxygenate river waters. Environmental flows may (and often are) used to dilute wastewater and improve water quality.

It is important, however, to recognise the limitations of river flows in addressing poor water quality. This is particularly relevant in China given the shortage of water in many regions and the increasing rates of growth and development. Ideally, wastewater and other pollutants should be treated before they enter the river system. This would reduce the need for "flushing" flows to dilute pollutants and increase the water available for other uses.

Three key water pollution issues are:

- *Excess nitrogen and phosphorus*: Excess nutrients (in the form of nitrogen and phosphorus) degrade water quality, reducing amenity values and impacting upon the health of river assets. Some changes resulting from excess nutrients may have consequences for human and livestock health (for example poisoning from excess nitrates). Excess nutrients can also cause an increase in plant growth, in particular the growth of toxic blue-green algae.
- *Organic waste*: Large amounts of organic waste (such as from sewage effluent) result in a high biological oxygen demand. This is because the micro-organisms that decompose organic materials use up more oxygen than is naturally replaced (by aeration and plant production). Deoxygenation can have a rapid and sometimes devastating effect on aquatic biota leading, for example, to large fish kills and poor water taste and odour problems.
- *Toxic substances:* Discharge of toxic substances such as heavy metals, pesticides and herbicides into rivers may also have rapid and adverse effects on river health. Some substances such as heavy metals can accumulate within river biota, particularly within the tissues of predatory species, to concentrations that are detrimental to human health.

Invasive species

Many plants and animals have expanded beyond their native ranges or have been introduced from other parts of the world. They may be introduced into a new area accidentally or intentionally (for example as agricultural species). Some of these species become pests, adversely affecting the habitats they invade by, for example:

- predating on, or compete with, native species;
- altering ecosystem processes such as nutrient cycling and energy transfers; and
- impeding water ways (as in the case of many invasive aquatic weeds).

Physical habitat degradation and loss

Physical habitat degradation and loss may occur as a result of a number of human activities. In some circumstances, no flow regime will achieve the physical or chemical conditions necessary to support or restore key river assets. In such circumstances additional measures will need to be taken to restore physical habitats.

River assets may have specific river habitat requirements and an understanding of these requirements will need to be developed with relevant experts.

The following are examples of human activities resulting in the degradation and loss of habitat:

- *Channel dredging:* Dredging activities may occur to maintain or deepen navigation channels, extract gravels and sands and, reclaim lands prone to flooding or waterlogged soils. In-stream activities such as dredging and mining can substantially alter the availability and quality of habitat for river biota.

Dredging and mining activities may also result in the release of contaminants into rivers and streams.

- *Stream channelisation*: Channelisation is the widening, straightening or lining of a channel to improve the conveyance of water and stabilise channel banks. Channelisation is generally used to manage flows and reduce flooding. However, it often results in the simplification of channel forms which can lead to loss of in-stream habitats essential for in-stream biota and a reduction in complexity of habitat (which is an important influence on river biodiversity).
- *Wetland and floodplain loss*: Direct loss of wetland and floodplain habitats occurs through land drainage and reclamation for development.
- *Riparian vegetation removal*: Riparian vegetation is the vegetation adjacent to a stream or river channel. It is one of the most important factors affecting the health of small streams and rivers. Loss of riparian vegetation through the clearance of riparian zones for human uses (such as farming and urban development) or grazing by livestock may severely degrade river systems.

Over-exploitation of river resources

Over-fishing presents a key threat to the sustainable use of river fishery resources. Where harvesting occurs at an unsustainable rate, that is, a rate at which the species is unable to maintain its population, fisheries stocks become depleted. Without intervention, species become extinct. Over-exploitation can be exacerbated by river regulation. Reservoirs and other barriers can impede migratory routes, which may result in the detainment of fish. These locations can then become targets for intensive local fisheries.

Climate change

There is now strong evidence and international consensus that the global climate is changing. Temperature changes and variation in weather patterns threaten river systems. Glaciers are shrinking in size resulting in decreasing water volumes to many major rivers in Asia. Changes in precipitation will alter river and stream flows. Increases in temperature will increase evaporative losses of water and are likely to offset localised increases in precipitation. Temperature changes may also alter geographic distributions of many species resulting in the extinction of species unable to migrate to more suitable habitats.

2.3.4 Taking the next step

Once the pressures on key river assets have been identified, it will be necessary to evaluate these pressures to determine whether they represent a serious and continuing threat to the health of the river asset. Where additional threats are identified it will be necessary to decide whether:

- it is feasible to address the threats – in which case, they should be addressed, and the process of identifying environmental flow requirements should continue (proceed to Step 3);
- if the additional threats cannot be addressed, and consequently the environmental goals set in step one are not realistically achievable – it will be necessary to review the selected assets and identify more appropriate ones (return to Step 1); or

- if the threats cannot be addressed, but the ecological goals can still (to some degree) be achieved by implementing environmental flows – continue on to the next step but acknowledge that ecological outcomes may be constrained by the additional threats (proceed to Step 3).

In some cases it may be possible to completely remove the threat (for example removal of a direct toxicant discharge). However, this may not be an option in many situations. Measures may therefore need to be taken to reduce the impact of the threat through improved practices (for example, the adequate treatment of wastewater or better farming practices).

Step 2 outcomes:
Identification of key threats to river assets
Assessment of whether desired environmental outcomes can still be achieved
Informed decision regarding next step

2.4 Step 3 – Defining environmental flow requirements

The science underpinning environmental flow management has advanced considerably since the first attempts to quantify minimum "in-stream flows" to sustain fish populations were made in the United States in the late 1940s. Since then, more than 200 methods have been developed

Much of the environmental flows research in China to date has been based on a 'minimum-flow' approach, using a range of hydrological, hydraulic and habitat simulation methods. These methods have been adequate to address issues related to sedimentation of river channels, sea-water intrusion in tidal reaches and dilution of water pollution problems.[22]

However, there is now general agreement among scientists and water managers that a more holistic approach to the assessment of environmental flow is needed. This is especially the case if the goal is to achieve a broad range of water quality and ecological outcomes.

Those implementing environmental flows have a range of environmental flow assessment methods available to choose from that fall into four basic categories. These are described in Table 4.

The method chosen will depend upon:

- the nature of the asset and its importance to society;
- information available on the asset and its flow requirements;
- technical ability and financial constraints; and
- the scale of assessment.

[22] Jiang et al., 2006.

Table 4: Summary of four basic categories of environmental flow methods

Method category	Description	Information required	Advantages	Disadvantages	Example methods
Hydrological methods	Simple rules, based on flow duration or mean discharge.	Historical or simulated flow data.	Rapid and low cost	Assumes links between flow and environmental outcomes Not site specific	Tennant or Montana method
Hydraulic rating methods	Model hydraulics as a function of flow and assume links between hydraulics, habitat availability and key river biota.	Historical or simulated flow data and information on river cross sections in critical habitats	Relatively rapid Low cost and site specific	Assumes links between flow and environmental outcomes	Wetted perimeter method
Habitat simulation methods	Relate hydrological and hydraulic conditions directly with biological responses. Optimum stream flows for a number of individual species can be determined and the results used for recommending environmental flows.	Historical or simulated flow data , information on river cross sections in critical habitats and biological response data	Ecological links included Site specific	Extensive data collection and high cost Can be a lengthy process	PHABSIM (Physical HABitat SIMulation model) The Instream Flow Incremental Methodology (IFIM)
Holistic methods	Frameworks for organising and using flow related information and knowledge. They are not limited to a single method. Holistic methods focus explicitly on a wide range of environmental outcomes.	Information required varies depending upon the method selected Methodologies often require both flow data and hydraulic	Focuses on a wide range of environmental outcomes	Extensive scientific expertise required High cost and can be a lengthy process	Building Block method DRIFT Expert Panel Benchmarking Methodology Ecological Limits Of Hydrologic Alteration (ELOHA)

Source: adapted from Tharme 2003 and Dyson et al. 2003

The method described in this step is a generic, holistic approach. It describes a detailed process which draws on various methodologies. Not all aspects need necessarily be applied in all circumstances. A simpler process could be followed where that was deemed appropriate. The methods and tools chosen and, the rationale for the approach taken are at the discretion of the user.

This section describes the steps needed to:

Identify the key flows (in terms of timing, size and duration) of importance to the key river assets

Develop environmental flow recommendations

Validate relationships between river flows and ecological outcomes

2.4.1 What are the key flow components that sustain/restore important assets and values?

Different parts of the flow regime are likely to have different environmental and ecological functions. The first stage in this section is to identify those environmental flow components of most significance to the assets to be protected.

The selection of key environmental flow components and their hydrological descriptors should be underpinned by a conceptual understanding of the relationship between:

- a particular river asset;
- river flows; and
- other biological, physical and chemical components of the environment.

This conceptual understanding is developed in consultation with the relevant experts and local knowledge sources.

A description (or conceptual model) of this understanding can easily be represented in a diagrammatic form (for two examples, see Figure 6). Conceptual diagrams are recognised as useful tools because they effectively communicate this conceptual understanding to water managers and other members of the community. The processes of developing conceptual diagrams for each priority asset also helps to clarify and synthesise thinking, identify gaps or deficiencies in understanding and inform monitoring programs.

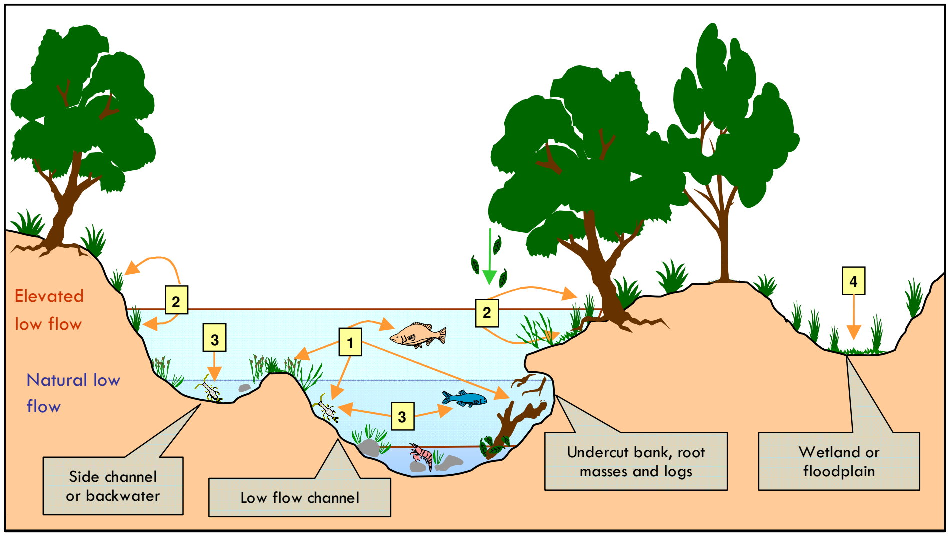
A conceptual diagram should:

- show how a healthy river (or wetland) ecosystem functions and how flow may influence key assets;
- show how the system is expected to respond to flow change (or other disturbances); and
- indicate critical biotic components/processes in the system to target for future monitoring.

The development of a conceptual diagram is a dynamic process and can be refined and improved as new information becomes available. This conceptual understanding needs to be developed for each river asset. Many assets have similar flow requirements. Grouping assets on this basis can simplify the process of developing conceptual models and subsequent steps defining environmental flow requirements.

Figure 6: Examples of conceptual diagrams

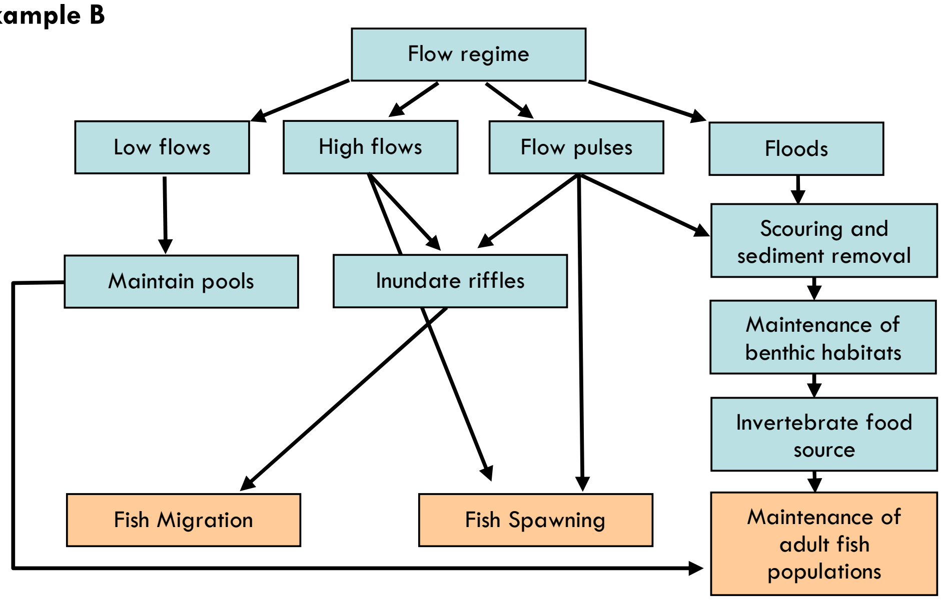
Example A



Conceptual diagram of flow-induced habitat changes in a lowland river. 1: Elevated low flow increases habitat availability. 2: Elevated low flows lead to increased growth of aquatic vegetation and changes in species composition. 3: Changes in channel depth, velocity, substrates, water quality and low flow areas alter habitat availability and quality for invertebrates, fish, frogs, etc. 4: Pools and wetlands provide habitat during drought.

Source: SEQWQMS, 1999.

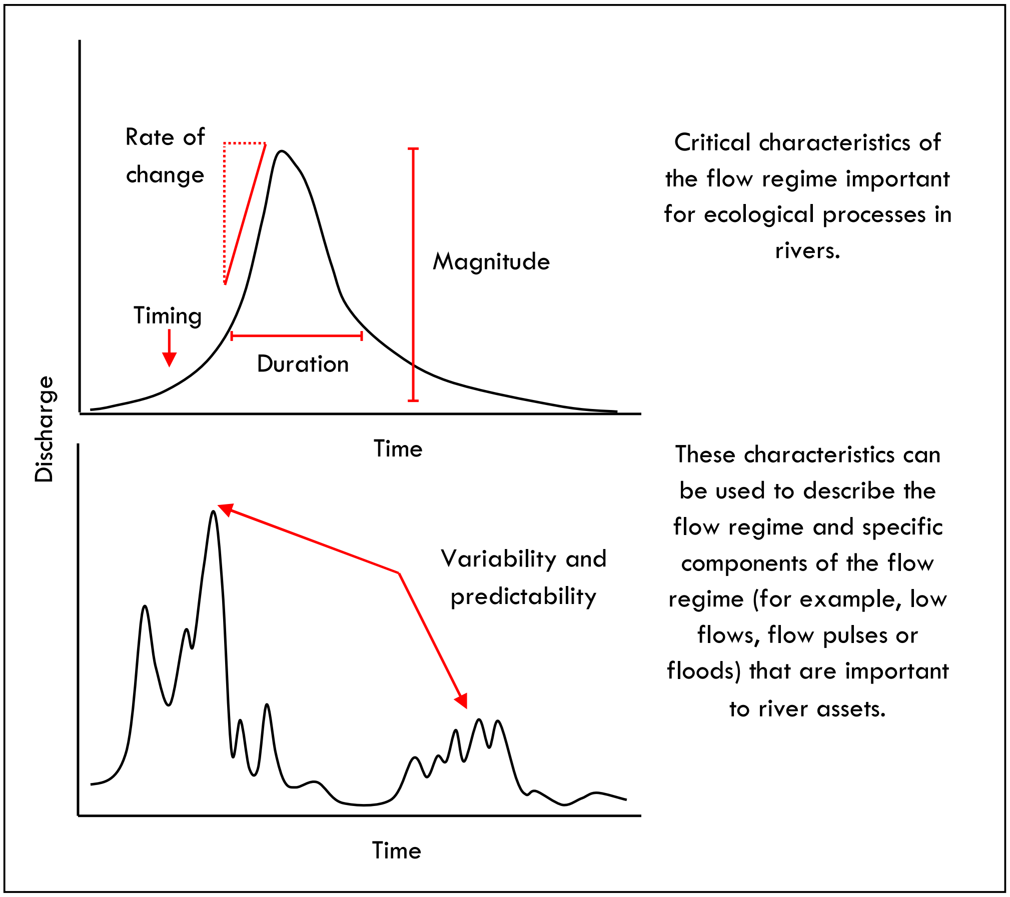
Example B



Conceptual flow diagram of the influence of flow on fish. Low flows maintain critical deep pool habitats for large bodied species during the dry season. High flows during the wet season maintain fish passage over riffles. High flow pulses trigger fish spawning and migration. Pulses and floods maintain river habitats and, scour and remove sediments for benthic invertebrates food sources.

The influence of flow on river assets can be considered in terms of key characteristics of the flow regime (Figure 7) that are important for ecological processes in rivers. These are the magnitude, duration, timing, predictability, variability and rate of change in hydrological conditions[23]. These characteristics can be used to describe the flow regime and specific parts or components of the flow regime (for example, low flows, flow pulses or floods) that are important to river asset.

Figure 7: Characteristics of the flow regime



Several generic components of the flow regime have been identified[24] that are likely to be ecologically important. These are:

- *monthly low flows* – the mean or median values of low flows during each calendar month;
- *extreme low flows* – the mean or median of extremely low flow events for each year or season;
- *high flow pulses* – small or short duration peak flow events (these are flows that exceed the base or low flow);
- *small floods* – floods with an annual recurrence interval of 2-10 years; and

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[23] Poff et al. 1997

[24] Richter and Thomas 2007

- *large floods* – floods with an annual recurrence interval greater than 10 years.

Details of the ecological significance of each of these flow components for different environmental assets are provided in Appendix D.

These general descriptions, together with published information and expert opinion, can be used to identify which elements of the flow regime may have an important influence on river ecosystem assets and critical characteristics such as the timing or duration of these components. In the absence of specific information, it is advisable to consider flow components such as those identified above[25].

> **Key message**
>
> It is important to document the decisions made, data sources used and the rationale behind decisions regarding the important flow components and their characteristics.

So far, the approach described above for identifying key flow components has been a qualitative descriptive process. However, for some key assets (clean water or river channel maintenance) a number of quantitative models are available (for example sediment transport models). Where quantitative models are available and relevant to the identified assets, these can be used to identify flow requirements. Where these models are not appropriate, a more detailed process must be followed to determine the required flows.

2.4.2 Developing environmental flow recommendations for key components

This section describes the steps for developing flow recommendations for the flow components identified in the previous section. It is necessary to quantitatively define the flow requirements for the environment so that they can be incorporated into water resources allocation plans and translated into operational rules (for example as release rules from reservoirs).

This section involves the following steps:

i. Identifying hydrological descriptors of key flow components
ii. Establishing a reference condition
iii. Defining an acceptable range or threshold
iv. Assessing changes to key flow components (and associated risks)

Identifying hydrological descriptors of key flow components

For the key flow components identified in section 2.4.1 it is necessary to select statistical descriptors that can be used for hydrological analyses. There are many different flow statistics that can be used to describe a flow regime and its various components. Conventional parameters, such as mean or median annual flow, may be important in understanding water availability for human supply but may not necessarily be the appropriate variables to relate to environmental outcomes. What is necessary is to select

[25] Richter and Thomas 2007.

a descriptor that accurately describes the part of the flow regime of interest. It could be to describe any of the following (or a combination of them):

- total volumes of water over a period of time (e.g. total flow during the dry season);
- the frequency with which a certain event occurs (e.g. the number of days when a flow threshold is exceeded); or
- the size of a certain event (e.g. the size of the average 1 in 5 year flood).

Appropriate statistics (e.g. for the flow components listed earlier) can be easily generated from daily flow data sets (actual hydrological records or simulated flow data) using readily available software programs (e.g. River Analysis Package – RAP – or Indicators of Hydrological Alteration – IHA).

Establishing a reference condition

Having identified the list of flow variables (descriptors) for the key flow components, it is necessary to understand the range of variability under natural flow conditions. This can be determined by analysing the data for each variable from a range of rivers from the same class or regional setting (see Box 2) and developing frequency distributions for each flow variable (Figure 8).

Box 2 Develop a regional reference condition

The magnitude, frequency, timing, duration, rate of change and predictability of important flow events (e.g., floods and droughts) will vary significantly between geographic regions. These variations will depend on many factors including climate, catchment area, vegetation, topography and geology.

It is important to understand the natural range of flow parameters for the region of interest, to ensure that environmental flow recommendations adequately describe the natural flow variability for the river being assessed.

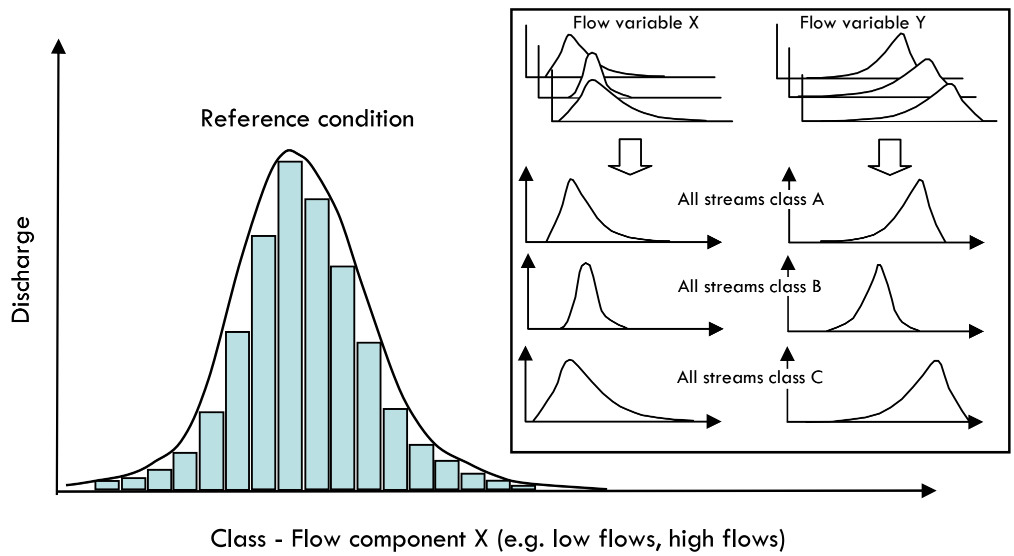
One approach is to develop a hydrological classification. This classification can be derived by analysing long-term flow data of natural flow patterns from a number of rivers in different regions. If flow records cannot be obtained for largely unmodified flow conditions, simulated flow data (preferably daily flows) can be used.

It may also be possible to develop a regionalisation based on catchment characteristics that ultimately drive flow patterns (e.g. climate, topography, catchment size, geology etc)

The resulting classification can be used to assign rivers into distinct classes – each would be characterised by different flow patterns and, in turn, would be expected to have different environmental flow requirements.

Regional reference conditions can then be developed for the variables which describe the key flow components for each river class. These regional reference conditions provide a robust measure against which future conditions can be assessed for rivers within this class.

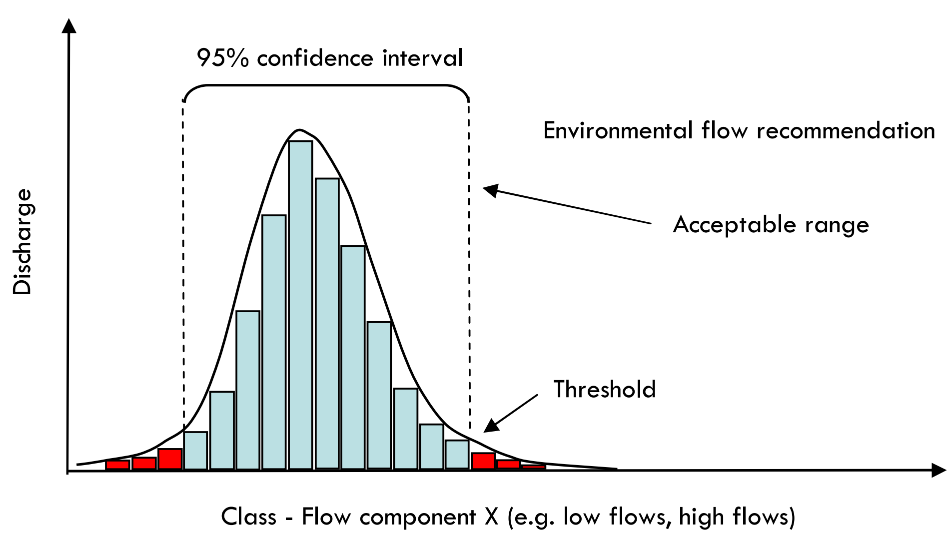
Figure 8: Frequency distributions for each flow variable in each class



Frequency distributions are developed for each flow variable in each class and combined to represent the natural range of spatial and temporal variation in each flow variable across all streams in the class

In this way, each of the important flow parameters can be described in terms of their natural mean or median value and the expected range or confidence interval (see Figure 9). These statistical descriptions provide the reference condition against which future condition can be assessed.

Figure 9: Defining an acceptable range or threshold



An acceptable range or threshold is to set a statistical limit or range based on the reference condition. This could be defined as the 95% confidence interval for the statistical distribution of each flow descriptor. However, if the asset is of high value, a narrower confidence interval could be chosen.

Ideally a regional reference condition should be developed using flow data from many rivers. However where this is not possible and data is only available for the particular stream or river of interest, then long-term hydrological record from a single river can be used to establish the degree of temporal variability.

In determining reference conditions, it may be necessary to consider different parts of the river separately. For this purpose, the river may be divided into management reaches. These are river sections with similar biophysical attributes that can be considered homogeneous for management purposes. This recognises the different nature of different parts of the river, the different assets in those parts, and their different flow requirements.

There are many different methods for determining management reaches and reaches may be defined on the basis of:

- bioregion (climate, land use, geomorphology, geology);
- river network (i.e. presence of river confluence);
- presence of river infrastructure; and
- freshwater or tidal.

The most appropriate method for defining management reaches will depend upon the key assets under consideration and the characteristics of the catchment. Subsequent environmental flow recommendations should then be then provided for each reach. Such an approach would take into account the likely spatial and temporal variability in river flows.

Defining an acceptable flow range or threshold

A straightforward approach to defining an acceptable range or threshold is to set a statistical limit based on the reference condition. For example, this could be the 95% confidence interval for the statistical distribution of each flow descriptor (Figure 9). However, if the asset is of high value, a narrower confidence interval could be chosen as a precautionary approach.

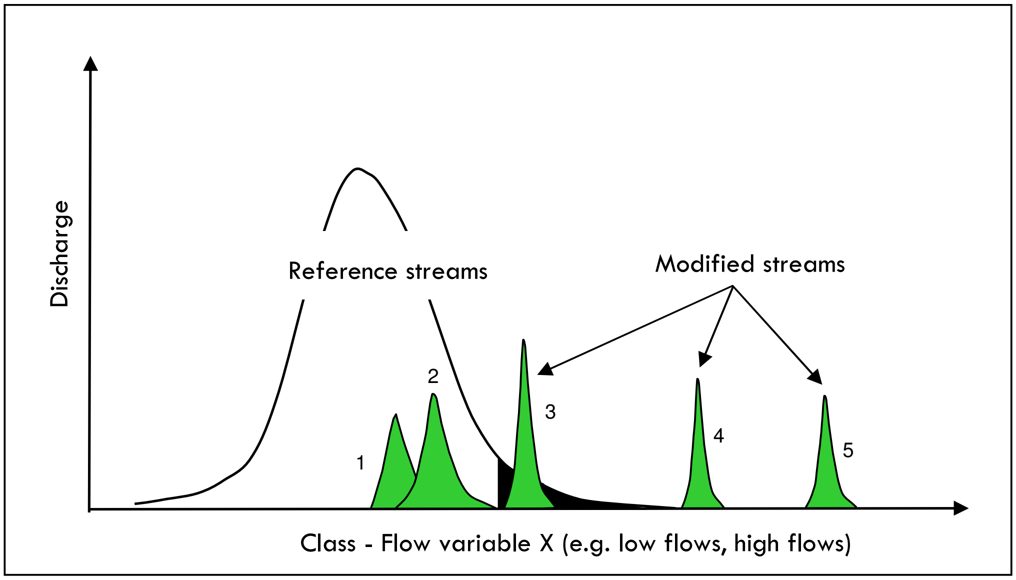
Other approaches to defining ranges or thresholds include undertaking reach scale assessments using hydraulic and or habitat simulation methods.

Having identified the acceptable range or threshold it is possible to derive environmental flow recommendations for each flow parameter – these would lie within the acceptable range (for example the mean or median of the statistical distribution), or could be a threshold limit which should not be exceeded. These ranges or thresholds can also be used to compare different future water use scenarios and determine the risk to river assets associated with each scenario.

Assessing changes to key flow components

Having (i) identified the list of important flow variables, (ii) established their natural variability under reference condition and (iii) established an acceptable flow range or threshold, it is now possible to determine how much these variables are expected to deviate from the natural or reference condition under different management scenarios (see Figure 10). Assuming that aquatic ecosystem health and biodiversity are likely to be strongly influenced by the natural flow regime, it is reasonable to expect significant impacts if important flow variables no longer fall within the range (or appropriate confidence interval) of the reference condition.

Figure 10: Comparison of frequency distributions from flow-modified streams with the reference condition frequency distribution for the stream class



In the example given in Figure 10, the modified streams (i.e. development scenarios) 1 and 2 fall within the expected distribution for this flow variable (in this particular class of stream). This could be expected to have a low risk of a negative effect on environmental assets that are influenced by this flow variable. In contrast, scenarios 4 and 5 fall well outside of the expected range for streams in this class. Under these modified flow conditions, it could be expected that there would be a significant risk of impact.

By analysing each of the flow variables for each of the proposed water development scenarios, it is possible to predict the likely risk to each of the identified river assets.

2.4.3 Validating relationships between flow and ecological outcomes

The methodology described so far has involved principally a hydrological process, guided by known or likely relationships between the flow parameters and important river ecosystem assets.

It is possible, and indeed desirable, to validate these hydrological assessments with data on ecological responses.

Developing a flow response curve

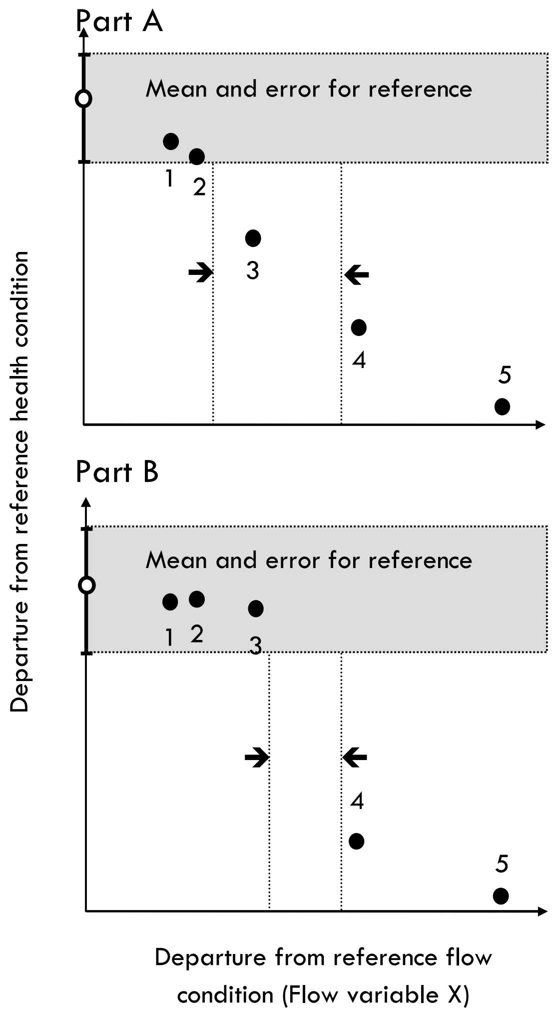
Based on our understanding of river ecology, we expect that changes in some attributes of the flow regime will result in corresponding changes in river ecosystem health. The nature of this relationship can take many possible forms. For example, an incremental change in a flow parameter might result in a linear or curvilinear ecological response (e.g. Figure 11, Part A).

An example of such a relationship might be the amount of fish production in estuaries as a function of the annual summer discharge[26] (see Figure 12). It can then be expected

[26] Loneragan and Bunn 1999.

that a decreased summer flow in this system would result in a decline in fish catches, with resulting implications for recreational and commercial fishing returns. Information like this can be easily obtained by analysing the long-term relationships between fishery data and patterns of river discharge into estuaries.

Figure 11: Departure from reference condition



The ecological health of a river may decline in response to flow alteration in (a) a curvilinear fashion or (b) an abrupt threshold change.

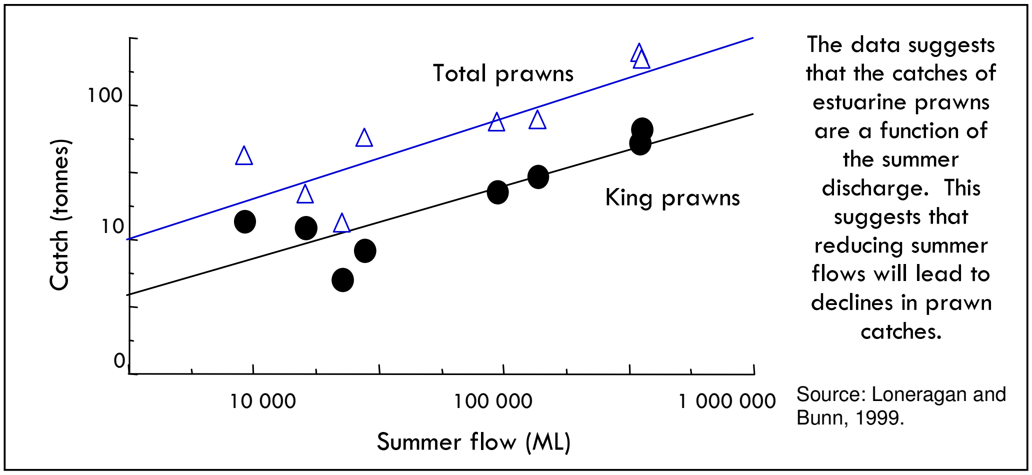
Source: Arthington et al. 2006

The numbers refer to the numbered scenarios in Figure 7, where examples 4 and 5 clearly fall outside of the expected range of flows for that particular flow class.

However, many ecologists believe that ecological responses to some flow changes are likely to be step functions (Figure 11, Part B) rather than incremental changes (Figure 11, Part A). This implies that the ecological attribute might remain apparently unchanged in the face of flow regime change up until a threshold or ‘tipping point’ at which stage the system shifts dramatically to an alternative ecological state (and often one that is less desirable).

The implication is that as the flow regime changes, the risk that the system will switch (or tip) to an alternative (and undesirable) state increases. This also means that, as the system approaches a threshold, a small change to flows can result in a large (and adverse) ecological impact.

Figure 12: The known relationship between annual prawn (shrimp) catches and summer river discharge



Source: Loneragan and Bunn, 1999.

Collection of data on the relationships between flow and ecosystem health (or measures of a particular environmental asset) allow better understanding and predictions of the likely changes in river health in response to flow alteration.

Information of this kind can be obtained by sampling river assets across a gradient of flow changes to determine the nature of this flow-response relationship.

Thresholds of acceptable change in ecosystem health

In some circumstances (e.g. Figure 11, Part A, and Figure 12), an incremental change in ecological condition may be expected in response to changes in flow regime. How large a change in ecological condition is acceptable may simply be a value judgement. In the case of the relationship between flow and fisheries (Figure 12), how much of a reduction in fish catches is acceptable? This decision could be based in purely economic terms.

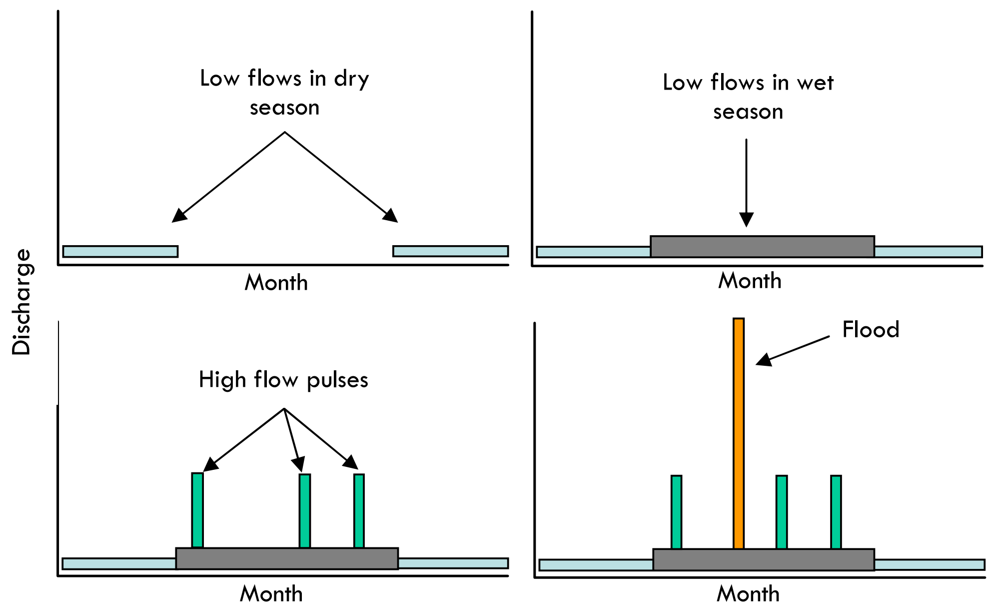
In the case of non-linear responses (e.g. Figure 11, Part B), it is often very difficult to predict the 'point of no return' – that is, the threshold before which the system moves from a desirable state to an undesirable state. However, it is relatively easy to find examples of the 'negative' benchmarks. There are often many examples of rivers where the flow regime has been markedly modified and where there is agreement that the state of the river is unacceptable in terms of biodiversity or ecosystem health. It is possible to determine the degree of flow modification associated with these undesirable conditions and to set these as unacceptable levels (see Figure 11). At the very least, managers should ensure that the flow regime is not modified to this extent because the risk of unacceptable changes in ecosystem health is very high. The important concept to note is that the risk of unacceptable (and perhaps unrecoverable) change will increase with flow alteration.

Monitoring and assessment of river systems that have already been modified can provide important insights as to the nature of the relationship between flow and ecological responses.

2.4.4 Reconstructing the flow regime

Having defined, for each asset, the key flow components and derived environmental flow recommendations for each flow descriptor separately, the final step is to collate this information into a single set of recommendations for each river management reach – that is, to reconstruct the environmental flow regime (Figure 13). During this processes it is possible that conflicting requirements between river assets may be identified. Under these circumstances it may be necessary to review asset priorities and determine which takes precedence.

Figure 13: An example of reconstructing the flow regime



The flow regime is reconstructed incorporating recommendations for each flow component. Where possible, the flows provided should include a natural rate of rise and fall.

2.4.5 Taking the next step

At this stage, environmental flow recommendations should have been developed for each key river ecosystem asset within the different river management reaches and the risks associated with not providing the recommended flows assessed.

Step 3 outcomes:

Identification of key flow components and their characteristics

Determination of the flow requirements of key assets

An assessment of the risks from changes to key flow components

The next step is to determine if and how the desired flows can be incorporated into the water resources regulatory system to ensure that they are provided. This will involve considering different management scenarios and how they would impact on the supply of water for human uses, as well as the consequences for environmentally important flows.

2.5 Step 4 – Delivering environmental flows through modifications to river infrastructure and management

The previous step described a general process for defining environmental flow requirements and assessing the impact on key river ecosystem assets of alterations to the flow regime. In practice, it will often be unfeasible – due to human water demands – to provide all of the desired environmental flows. This step outlines a process for identifying the changes can be made to current (or proposed) arrangements to achieve the desired environmental flows. It also considers ways to develop alternative scenarios for achieving – to various degrees – the desired flows.

Alternative scenarios may be developed to meet environmental flow recommendations (in full or part) through operational and/or structural modifications to river infrastructure and management.

The first part of this section explores opportunities for the modification of constraints to:

- provide the environmental flows; and
- mitigate impacts from water resource development and management such as loss of connectivity and water quality degradation.

The second part of this section discusses mechanisms for implementing environmental flows.

The objectives of this section are to enable the user to:

Identify opportunities for operational and structural modification to provide environmental flows

Develop scenarios to meet environmental flow recommendations

Identify mechanisms for implementing environmental flows

2.5.1 Modifying constraints to provide environmental flows

There are two key aspects of water resource development that affect flows and hence two key areas for potential modification to provide for improved environmental flows:

i. Water abstractions: flows can be modified by changing the total volume of water taken from the system and the time when the water is taken. Typically this would be implemented via the water abstraction permit system.

ii. Water infrastructure: flows can be modified by:

    - regulating where water infrastructure is constructed;
    - operational changes (e.g. by changing the rules about what water must be released and at what times); and
    - structural changes to infrastructure.

It is also relevant to note that:

- regulating the gross take of water (i.e. the total average annual volume taken) and, hence protecting the average annual volume left for the environment can be done via the combination of:
    - the water resource plan (which determines the total volume of water available for allocation);
    - the water abstraction permit system (which determines the entitlement of individual abstractors); and

- the annual regulation plan (which determines the amount of water that can be abstracted in any given year); and

- changes to the operation of water infrastructure (and, if possible, changes to the time when water can be taken under abstraction permits) are necessary to change the "shape" of the flow curve – i.e. the size, duration and timing of different flows throughout the year.

In determining what environmental flows will be provided consideration should be given to:

- how the water left for the environment, given existing or future levels of water abstractions, can be managed to achieve the best environmental outcome; and
- if a different level of abstractions was made (whether more abstractions, due to growth, or less due to increased efficiency), the best environmental result that can be gained from the available water.

It is important to note that it is possible to obtain improved environmental flows without reducing the total volume of water available for out-of-stream use.

Review of existing and future water entitlements

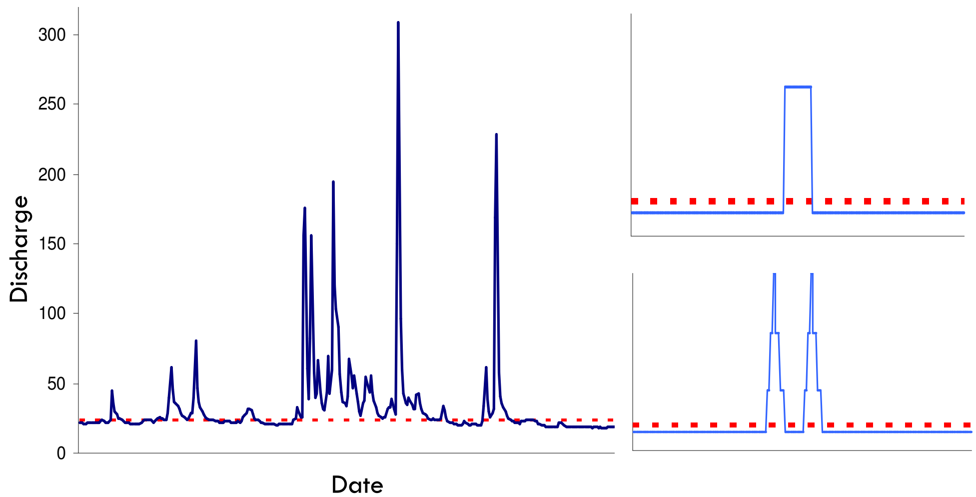
A key constraint on the delivery of environmental flows is the availability of water. Where water is allocated for consumptive purposes, there may simply be insufficient water available to provide an environmental flow. It may be necessary to reduce existing and future water entitlements by increasing water use efficiency, reducing loss of water during conveyance and changing use practices. Where this is necessary, such a review should be undertaken within the water planning process.

Alterations to dam operations and structures

Modifying dam operations:

- Significant opportunities to provide environmental flows may occur through modifications to reservoir operations both individually and through the coordination of multiple structures. Assessment of reservoir operations will have to be performed on a case by case basis as each situation will differ depending upon factors including the reservoir type, use, location and age.
- Ecological outcomes may be achieved by varying the pattern of water supply without necessarily changing the volumes of water allocated to the environment. In some cases it may even be possible to reduce the water allocated to the environment. Environmental flows are often supplied as a minimum flow at a constant or uniform rate through reservoir releases. However, the same volume of water may be supplied in a more variable manner that more closely mimics the river's natural flows. Supplies from reservoir could be varied to achieve particular flow components, timings of flows or rates of rise and fall (Figure 14).
- Flow components can be provided to achieve a particular ecological outcome; e.g. a high in-channel flow could be provided to flush out pollutants and improve water quality (mimicking high flows or flushes); or a high flow at a particular time of year to trigger migration and spawning of an economically important fish species.

Figure 14: Mimicking natural flow regimes



The same volume of water allocated for the environment may be supplied in a manner that mimics the natural flow regime. Releases from reservoirs can be varied to achieve particular flow components (for example low flows, high flows or flow pulses), timing of flow components and, rates of rise and fall.

Multiple storages

Many river systems have multiple regulatory and storage structures. Coordinating operations amongst multiple reservoirs may provide opportunities to achieve ecological outcomes. Improved coordination of multiple storages (optimisation) may enable more flexible operation and reveal opportunities to provide environmental flows through the more efficient use of resources.

Where multiple dams supply users in the same location but are situated on different tributaries, dam use could be balanced to achieve outcomes on rivers with higher priorities at the expense of lower priority tributaries. Alternately, where multiple dams are situated along a single river stretch, water use could be balanced such that the reservoirs lower on the river act to re-regulate river flows to mimic a more natural flow pattern.

Structural modifications to storages

Regulatory and storage structures may need to be modified to provide environmental flows. Modifications could be physical, operational or both.

Water may be released through a variety of mechanisms (such as outlet pipes, spill-ways, sluice gates, turbines, diversion tunnels and fish passage structures). Outlets need to have sufficient capacity to release higher water volumes to provide for high in-channel flows and floods when appropriate. Installing variable off-takes allows environmental flow releases from surface waters and mitigates water quality problems associated with the release of bottom waters. The capacity to vary releases will also provide considerable flexibility and allow for future changes in water management.

The potential benefits of making physical modifications to existing structures will depend upon the type of storage, its location and its state of repair[27]. Structural modifications are most easily incorporated into the design of new works because there is often limited capacity to alter existing structures and retrofitting is expensive.

Changes to the operation of reservoirs are firstly limited by the physical constraints mentioned above. Where these are not an issue, it may be possible to make changes to require water to be released to meet environmental needs. These rules will need to recognise the impacts of such releases on the availability of water for other users. In addition, operational rules will still need to give priority – for example – to flood management.

Other strategies for mitigating the impacts from river regulation include:

- the use of reservoirs downstream of hydropower dams to dampen the effects of erratic hydropower releases;
- the incorporation of pumped storage facilities into the design of hydropower stations – these recycle the water needed for hydropower generation, thereby allowing much of the natural flows to pass downstream; and
- the use of off-channel reservoirs to limit impacts to river ecosystems.

Modifying associated impacts from river regulation

Temperature and water quality

There are two main strategies for the management of cold water releases from dams.

- Firstly, thermal stratification may be broken down artificially within the dam through processes such as aeration and mechanical mixing (for example, surface pumps and draft tube mixers). Mechanical mixers are often located near the outlet, mixing water locally rather than across the entire reservoir. Other mixing strategies include the use of submerged weirs or curtains that provide a barrier to water passage within the dam.
- Secondly, water may be selectively withdrawn from particular water depths[28]. This could include the use of variable off-take or outlet points to achieve water quality of the desired characteristics. Outlets may also be used singularly or in combination[29].

Depending upon the particular water quality concerns, it may not be necessary to use these strategies throughout an entire year. For example, mitigation of cold water releases may only be necessary during spring and summer when the weather is warmer.

Barriers and fragmentation

There are a number of ways by which the impacts from barriers (such as reservoirs and smaller infrastructures) can be mitigated.

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[27] IUCN.

[28] Sherman, 2000.

[29] Other examples of selective withdrawal include trunnions which are used in smaller dams with low discharge requirements: Sherman, 2000

Before construction, consideration should be given to the location of reservoir to minimise their disruption to river ecosystem assets. This might include placing reservoirs on tributaries (or even off the channel completely), rather than on the main river stem. Reservoirs may also need to be positioned at a suitable distance from estuarine bays to minimise impacts on migratory species.

River infrastructures may be designed to allow migrating river biota to bypass barriers. Infrastructure design should considering the use of bypass mechanisms such as artificial channels, fish ladders and elevators. A variety of bypass structures are utilised across reservoirs worldwide.

However in the design of such structures it is important to note that:

- the abilities of migrating species to use these structures differ – as such, consultation with fish ecologists is essential before undertaking the design and construction of bypass structures; and
- additional issues may arise where fish using passages are exposed to increased predation and fishing intensity on the structure itself.

Bypass structures do not necessarily have to be highly engineered or expensive – natural rock substrates may be used to create passages for fish migration. A further option may be the removal of barriers to migrations that are no longer in use (abandoned structures, roads, culverts) or, perhaps, no longer economically viable.

Impacts from fish passing through hydropower turbines may be mitigated through modifications to their design and operation. Strategies include installing intake screens and diverting fish away from turbines. There are also a number of approaches available to minimise the damage caused to fish that pass through turbines (for example, altering the angle of turbine blades and blade revolution speeds).

Where floodplains are extensively developed for human habitation or industry, there may be limited opportunities to flood lateral floodplains and wetland habitats. If feasible, however, a number of options exist to reconnect the river and its floodplains and wetlands (at least some extent). Examples include:

- the relocation of flood levees further back from the river, providing access to a limited corridor of floodplain neighbouring the river;
- permitting the seasonal inundation of wetlands and floodplains (depending upon the level of floodplain and wetland development); and
- flood routing to discrete targets or locations – limiting the flooding extent but still providing some of the ecological and environmental benefits gained from floodplain and wetland inundation identified in Section 2.2.2.

Sediment and habitat

There are relatively few opportunities to mitigate the effects of river regulation and storages on river sediment transport and channel forming processes. While challenging, mechanisms include allowing the passage of flows with high sediments loads through the dam or even adding sediment below the dam. Such methods should be used very cautiously as they can have negative effects on downstream river ecosystems. More recently, approaches suggest maintaining some semblance of a river's geomorphology through the provision of channel maintaining flows.

2.5.2 Determining the options and considering tradeoffs

This section considers ways to develop and consider different options (scenarios) for allocation of water and what the impacts on environmental flows would be.

The “scenarios” referred to here are different management options: i.e. different levels of water abstractions, with different infrastructure and different operating rules for infrastructure. The management arrangements ultimately implemented will determine the volume (and reliability) of water available for consumption, as well as the flows that occur in the river (and hence the flows available for environmental purposes).

The process of developing scenarios is at the core of the water resource allocation planning process. The starting point in developing scenarios should be to consider the proposed allocations for agriculture, industry or domestic use. From this starting point, further scenarios may be identified for providing environmental flows through modifications to structural and operational constraints or by altering total supply for consumption. Opportunities for doing were discussed earlier in this step. Ultimately, the water available for the environment will be determined (for the most part) by supply requirements for human needs. In many cases, scenario development will focus on how – assuming fixed supply requirements – the remaining water can be best managed to achieve environmental outcomes.

A water resource management (hydrological) model can be used to predict the modified flow regime under each scenario and to generate modified daily flow data sets for analysis. The predicted flow regimes for each scenario can then be analysed in the way described in Step 3, to determine which scenarios will take the different aspects of the flow regime beyond the limits of the reference condition. Potential changes to flow regimes from climate change could also be modelled in this way.

Creating viable scenarios and determining the preferred option for delivering environmental flows is necessarily a part of the larger water planning process. This process will need to consider socio-economic needs as well as those of the environment. Generally, this process involves the following aspects:

- Identifying the effects of different scenarios – both positive and negative – on different water users, populations/communities and industrial sectors. It will be necessary to consider the effects over time and in different locations.
- Assessing the risks to the environment from different scenarios (as a result of their impacts on the flow regime).
- Identifying trade-offs and negotiating the preferred option.

The process of assessing the consequences of different scenarios and determining a preferred option can involve extensive (and sometimes protracted) consultation with stakeholders and experts. It is important to recognise that while providing the optimal environmental flows may not be possible, ecological gains may still be made in moving towards the desired thresholds or ranges for the various flow components.

An important part of this process is prioritising environmental flow provisions and determining the flow components that will provide the greatest benefits to key river ecosystem assets. Where trade-offs are required, these should be made with an understanding of the likely implications for the environment of altering the flow regime, and based on the priority given to the different river assets. Under some circumstances it may be necessary to revisit the priority of different river assets (return to Step 1). The priority of the assets can be reconsidered in terms of the possible scenarios identified: will the achievable flows have any environmental benefits or, would the water resources be better used elsewhere?

2.5.3 Implementing environmental flows

Having selected a preferred scenario, the next stage is implementing environmental flows. This is principally achieved through the water resources allocation plan. The development and content of a WRAP is described in a separate chapter. However, the key regulatory aspects required are listed below.

Setting a limit

Probably the most critical step to protect river assets is to set limits on abstractions. This can be achieved via a cap. This sets a limit on the amount of water that can be taken out of the river (and hence on the total volume of water abstraction permits that can be granted).

Protecting certain flow events

Abstraction limits may be placed upon certain flow events (for example a flow pulse during fish spawning season). That is, as well as limiting (via a cap) the total, long-term volume of water abstracted, it may be necessary to set restrictions on the water taken at particular times. This can be achieved via the annual regulation plan, coupled with conditions on water abstraction permits.

Reservoir release rules

Reservoirs can be managed to provide improved environmental flows. Where reservoirs prevent the desired flow regime from being achieved, it will be necessary to include operational rules (such as release requirements) to ensure that flows downstream of the reservoir occur in the way required. This may involve – for example – a requirement of reservoir operators to make releases to achieve certain base-flows, or releasing pulses of water to achieve higher flows at environmentally-relevant times.

One way to include these types of requirements is to include what are referred to as “transparent” and “translucent” reservoir release rules.

Transparent rules require that all reservoir inflows occurring at certain times are passed immediately downstream, as if the reservoir wasn’t there. Transparent rules maintain the natural flow pattern and variability.

Translucent rules require that a proportion of all reservoir inflows occurring at certain times are passed immediately downstream. Translucent rules ensure that some semblance of the natural flow pattern and variability is maintained although volumes are less.

In addition to maintaining some consistency with the natural flow pattern, transparent and translucent rules have a number of other advantages. They are:

- clear and straightforward to implement for reservoir operators; and
- do not require the storage of a contingency bank or volume of water.

However, translucent flow releases may not meet all the desired environmental outcomes (for example where a certain threshold volume is required).

Environmental flow reserve

There are two ways in which water for the environment can be defined:

i. water available for abstraction can be specified (via a cap). The "environmental flows" volume is, by default, the remaining volume of water left in the river; or
ii. a specific volume of water can be allocated to the environment, with an entitlement granted in the same or similar way as entitlements are granted to human users of water.

In this second case, the environmental flows entitlement is then actively managed, in accordance with guiding principles, to achieve the best environmental results. For example, water can be released to meet specific environmental flow requirements at a specified time (for example dilute pollutants or flush out algae blooms). In this case, it is necessary to identity the appropriate entity to hold the entitlement (on behalf of the environment) and to make decisions as to when the water should be released.

This approach of granting an environmental flow "entitlement" is more likely to be appropriate in catchments that are highly developed, and where there is a greater risk that environmental flows can be overlooked in meeting consumptive demands.

2.5.4 Taking the next step

Ultimately, environmental flows will need to be incorporated within the regulatory framework. This should occur through the water resource allocation plan. The process for doing this is discussed in detail in the previous chapter, on water resource allocation planning.

Step 4 outcomes:
Identification of the opportunities to modify structural and operational constraints
The development of scenarios for the provision of environmental flows

At this point, the environmental flows that will be made available should have been defined and the mechanism for providing them set in the necessary regulatory instruments. The next, and final, step is to develop an appropriate monitoring system to ensure that the environmental flows are actually provided and that they are achieving the desired ecological outcomes.

2.6 Step 5 – Monitoring and assessing the effectiveness of environmental flow provisions

Establishing and implementing an appropriate monitoring program is a critical final step in providing for environmental flows. Monitoring (and reporting the results of the monitoring) has two key purposes:

i. compliance monitoring, to ensure that reservoir operators, resource managers and others comply the environmental flow provisions; and

ii. monitoring the effectiveness of the environmental flow provisions – that is, determining whether the flows that are being provided are achieving the desired environmental (ecological) outcomes.

Monitoring programs also provide an opportunity to collect further data to be fed back into the process for determining flow requirements. From monitoring information, environmental flow provisions can be further refined and improved.

The objectives of this section are to:

Provide the user with guidance on designing and implementing a monitoring program.

2.6.1 Compliance monitoring

Monitoring should be undertaken to ensure compliance with environmental flow provisions – that is, are the designated environmental flows actually being delivered? Compliance may be monitored through river flow gauging, infrastructure operational records and records of abstraction permits and water use data.

This information should be publicly reported on a periodic basis to ensure transparency in terms of whether relevant parties, including government agencies, comply with their obligations. Under some circumstances, it may be found that the specified operational rules can't be met in practice, e.g. because of physical constraints. In this event, it may be necessary to adjust the operational rules or, under some circumstances, reassess the key ecological outcomes in terms of their feasibility (i.e. return to Steps 3 and 4).

2.6.2 Monitoring the effectiveness of environmental flow provisions

As well as ensuring that the prescribed rules (i.e. the cap, release rules etc) are complied with, it is important to ensure that the rules are actually achieving the desired environmental outcomes. To do this it will be necessary to:

- design a monitoring regime: in terms of what indictors to monitor, what locations to monitor, and how often the data should be collected;
- implement the monitoring system; and
- analyse the results and – where appropriate – act on the findings of this analysis.

Choosing indicators of success

There is a range of indicators that will need to be monitored to assess whether the environmental flow provisions are effective. These can include:

- flow statistics – to see whether the different types of flows (which the management rules are designed to achieve) are being provided;
- hydraulic indicators – to see whether the flows provided achieve the hydraulic results desired (e.g. whether a certain flow level does in fact fill water holes, etc);
- water quality indicators – to identify changes in water quality; and
- biological indicators – to identify trends in the populations of key species.

The conceptual understanding (developed during Step 3 of these guidelines) of how the river functions, how key river assets are influenced by river flows and how these may respond to human disturbance, underpins the design of monitoring programs. It guides the identification of appropriate indicators (measures of health) for monitoring and defines the expected response to the flow provisions (direction of change and/or range of possible values).

Monitoring programs are most likely to be undertaken if they are modest in size. Hence, indicators should be chosen that provide the greatest information (and the least redundancy), whilst being relatively cost effective and easy to implement. Importantly, the indicators chosen should have relevance to the specific assets and their flow requirements identified in the preceding steps of these guidelines.

Factors to consider when selecting indicators to monitor include the following:

- The frequency of monitoring required. For some indicators, it will be relevant to monitor changes over a period of days or weeks, for others only long-term (e.g. annual) changes may be of relevance. Consequently, specific time periods may be stipulated for monitoring. Highly temporally variable indicators may not be appropriate for long term monitoring but may be useful for more intensive short term monitoring.
- Appropriate locations for monitoring:
    - Natural changes in indicator values may occur along the length of a river. Spatial variation in indicator values needs to be evaluated. Additionally, it may be necessary to select different indicators for different locations.
    - Small scale variation in indicators may also occur within monitoring locations as a result of a specific habitat or condition. Where this is the case it may be necessary to define the specific habitats or conditions to be sampled.

In terms of biological indicators, desirable qualities for the indicators include the following:

- A clear response to change in flow within a timeframe useful for monitoring.
- Relative insensitivity to the influences of non-flow related factors. Influences from other factors should be quantifiable so that the influences of flow can easily be discerned.
- Easy to interpret. Measurement of the indicator should produce results that experts and water resource managers are able to interpret.
- Cost-effective and relatively easy to measure.

Often a single indicator will not capture all the aspects of the status of a particular environmental asset. A balance will need to be achieved between the number of indicators, the intensity of indicator monitoring, the availability of resources (financial, staff) and the likelihood of detecting a response to the environmental flow provisions.

Designing programs to monitor success

To assess the effectiveness of environmental flow provisions a baseline is often used against which monitoring results are compared. Commonly used baseline comparisons include:

- comparing indicator values before and after environmental flow provisions commence;
- comparing indicator values at sites where environmental flows are being implemented with control sites with regulation and/or abstraction and no provision of environmental flows; or

- a comparison with reference sites where the human disturbance is minimal or absent – reference sites represent the desired future condition.

Monitoring programs may include a combination of the above comparisons. Control sites could include river tributaries with regulation and abstraction that are not receiving environmental flow provisions. Reference sites may include tributaries or main river channels that are not subject to significant regulation and/or water abstractions. For both control and reference conditions, the character of the river or stream will need to be as similar as possible to the specific river for which environmental flows are being provided. This ensures that the changes or responses observed during monitoring are a result of environmental flows and not due to other differences between the sites.

Often, however, such approaches are not feasible because:

- data for a particular monitoring indicator may not be available prior to the implementation of environmental flows (no 'before' data);
- appropriate control and/or reference sites may not exist, particularly for larger rivers; or
- more complex monitoring designs that include control and/or reference sites may not be economically or logistically feasible. This may be particularly pertinent where a large 'regional' scale monitoring program is being implemented.

Therefore, while control/reference monitoring designs provide the greatest scientific rigour and confidence, in practice monitoring may be restricted to the river(s) of interest (i.e. rivers receiving environmental flows) after environmental flows have commenced. This latter approach focuses on ecological outcomes predicted by flow-ecology relationships and identified through the development of a conceptual model. Without spatial or temporal controls, however, the ability to determine whether environmental outcomes are due to external influences (not related to environmental flows) is difficult.

Finally, to ensure consistency across the monitoring program during its implementation it is essential that clear guidance be given on how data are collected, stored and analysed.

Identifying where flow provisions are not effective

Once a monitoring program has been implemented and the data collected and analysed it is possible to assess the effectiveness of the flow provisions. This entails returning to the key assets and reviewing the monitoring data in terms of the flows provided and the predicted environmental (ecological) outcomes. The following question is asked at this stage:

> *Are the values for indicators falling within the acceptable or desirable range(s) or moving in the expected direction of change?*

If the answer is 'yes' to the above question then monitoring and assessing should continue. However, even in these circumstances, the environmental flow targets should be reviewed periodically, based on new information collected during monitoring, to refine and improve flow provisions (return to Step 3). Information collected may also be used to identify new ecological assets and reassign priorities (return to Step 1). Periodic reviews will also allow for changes or shifts in human values to be incorporated into water plans.

Where the objectives are not being achieved (i.e. where the answer to the above question is ‘no’ for some or all indicators) it may be necessary to revisit earlier stages in these guidelines.

Circumstances under which flows are delivered but not effective include:

- flows are not the main/principal influence upon the asset (return to Step 2); and
- the flow provisions are not adequate and the requirements of the asset need to be reassessed (return to Step 3).

Under these latter circumstances it will be necessary to revisit earlier steps in the guidelines. It may be necessary to undertake a review of both steps where a likely cause for failure to achieve environmental (ecological) outcomes can not be identified clearly. Consideration should also be given to whether the failure to detect the desired ecological responses is due to a time lag, with the indicator response to the environmental flow taking longer than expected.

Step 5 outcomes:

Identification of monitoring indicators and determining monitoring design

Undertake monitoring

Glossary of Key Terms used in Chapter 2

Aquatic biodiversity	The variety of organisms, communities and, freshwater, estuarine and marine ecosystems in which they occur.
Duration	The length of time associated with specific flow conditions
Ecosystem services	Processes of value to society that are naturally generated by the river system
Environmental (ecological) flows	The flows of water that are needed to maintain river ecosystem health and ensure that the benefits derived from rivers and streams can be sustained.
Floodplain	An area on one or both sides of the stream channel that is inundated by floodwaters at some interval, from frequent to rare (for example the North China Plain)
Flow component	A specific part of the flow regime (for example, low flows, flow pulses or floods) which may be described in terms of its magnitude, frequency, timing and predictability, duration and rates of change
Flow regime	The overall pattern of river flow, including the magnitude, frequency, timing and predictability, duration and rates of rise and fall of specific flow events or components
Frequency	The number of times a certain flow event occurs within a given time interval
Lateral connectivity	The degree of water connection (both surface water and groundwater) between the main river channel and lateral river habitats such as wetlands and floodplains
Longitudinal connectivity	The degree of water connection (both surface water and groundwater) between upstream and downstream sections of a river system.
Magnitude	The amount of water moving past a location at a certain time.
Predictability	The regularity and certainty with which a particular flow event or component occurs. For example, floods may occur on a regular predictable seasonal basis or on an irregular or unpredictable basis.
Rate of rise and fall	The rate of change in flow conditions
Reach	A short, relatively homogeneous length or section of stream or river
Riffle	A relatively shallow reach of stream in which the water flows rapidly
Riparian vegetation	The vegetation adjacent to a stream or river channel. Riparian vegetation can have multiple influences upon river systems including; regulating energy transfers, intercepting nutrients and sediments (including airborne particles), influencing in-stream light and temperature regimes; providing habitat and maintaining biodiversity; influencing in-stream flow regimes; and reducing erosion and stabilising river banks through provision of root cohesion.
River ecosystem asset	An item of value to society where those values could be ecological, economic or social.
River ecosystem goods	Products that are provided by the river ecosystem such as clean drinking water, fish, and shellfishes.
River ecosystem health	The ecological condition of a river. The term 'healthy' is used in these guidelines to describe river systems in good ecological condition and is measured in terms of their organisation (e.g. biodiversity, food web complexity), vigour (rates of aquatic production and nutrient cycling) and resilience (ability to recover from disturbance)[30].

[30] Bunn, 2003.

River infrastructure	The physical structures built on or near a river system such as reservoir structures, hydropower facilities, flood protection embankments, weirs, river channel lining structures etc.
Scenario	Potential river management arrangements.(i.e. different levels of water abstractions, with different infrastructure constructed and different operating rules for infrastructure).
Stakeholder	A person or organisation that has a share (for example an abstraction permit) or interest in the river system. Stakeholders may include government agencies and administrative organizations, electricity companies and other industries, fishing department, farmers, other river and land users and, environmental groups.
Sustainable	Capable of being continued and maintained in the long term at the same level. The major goal of ecologically sustainable water management is to meet direct human needs whilst providing ecological flows to sustain river ecosystem health and biodiversity in rivers and their associated wetland and coastal systems
Threat	A human activity or disturbance that may adversely affect the river ecosystem, such as surface water abstraction, groundwater abstraction, waste water discharge, in-channel habitat modification and floodplain development.
Timing	The time when a specific flow component or event takes place during the year
Tributary	A stream or river joining a larger stream or river

Appendix A: List of National and International Agreements and Databases

Name	Details	Further information
International agreements		
Ramsar convention on wetlands	The Convention on Wetlands is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resource. There are 30 Ramsar wetlands in China (December 2007)	http://www.ramsar.org
UNESCO world heritage convention	Convention concerning the protection of the world cultural and natural heritage. Includes sites of natural heritage encompassing river systems.	http://whc.unesco.org
China Australia migratory bird agreement (CAMBA)	An agreement between the government of Australia and the government of the People's Republic of China for the protection of migratory birds and their environment. 81 bird species are currently included in this agreement.	http://www.jl2sy.cn/xssq/hbsn/green/law/zohouniao.htm
Agreement on Migratory Birds and Habitats Conservation between China and Japan (CJMBA)	An agreement between the government of Japan and the government of the People's Republic of China for the protection of migratory birds and their environment. 152 bird species are included in this agreement.	http://www.jl2sy.cn/xssq/hbsn/green/law/zrhouniao.htm
National databases		
Chinese directories of National Key Protected Wild Animals (1998)	Database of species listed under the Wild Animals Protection Law, IUCN, CITES appendices, China Red Data Book of Endangered Animals	http://www.zd.brim.ac.cn/division/endan1e.html
National Key Protected Wild Plants (1999)	Plant species listed under China's Law of Wild Plant Protection	http://www.cae.org.cn/huanjingwang/yesheng_zwbh.asp
Chinese species information system (CSIS)	Provides comprehensive information on Chinese fauna and their conservation status Provides maps of national nature reserves	http://www.chinabiodiversity.com
Vegetation species resources information system	Databases on vegetation species, rare and endangered species and economically valuable species	http://pe.ibcas.ac.cn/

Name	Details	Further information
Database of nature reserves	National Environmental Protection Agency database of nature reserves (information on both national and provincial nature reserves is provided)	http://www.sepa.gov.cn/apps/nature/reserves.php3?offset=30
Database of wetlands	Database provided by wetlands china. Lists Ramsar wetlands	http://www.wetlands.cn/data/im/index.html
International databases		
Fishbase	Global information system on fish	http://www.fishbase.org/home.htm
IUCN Red List of threatened species	International database of threatened flora and fauna	http://www.iucnredlist.org

Appendix B: Template Example

Asset	Objective or function	Key flow components	Key flow component characteristics (for example timing, duration, frequency)	Hydraulic criteria	Justification
Fish (e.g. grass, silver and bighead carp)	Flows to provide habitat during the high flow period, to induce spawning of grass, silver and bighead carp and to maintain transport of semi-buoyant eggs within the water column	High flow	Timing = April to September Duration = continuous	Average velocity >0.15-0.25 ms-1, Increase the depth and area of backwater habitats for juvenile fish	Exceeds minimum velocity and depth criteria for asset
Fish (e.g. species requiring deep pools such as eels and carp)	Maintain sufficient water depth in pools for large-bodied fish	Low flow	Timing = October - March	Depth > 0.2 m Velocity < 0.1 ms-1	Meets depth criteria for asset
Channel form	Mobilise bed sediments	Flood	Frequency = once every two years	Critical shear stress	mobilise sediment particles < 47mm

Appendix C: Ecological, Chemical and Physical Responses to Flow Change – Examples from China

Direct impact		Indirect impact				Example rivers	Sources
Flow change		Fish	Riparian wetlands	Water quality and temperature	Sediments and physical habitat		
Lower flow	Longer no flow period, Longer low flow period, lower river discharge into the sea	Lotic fishes and migratory fishes decrease or disappear. .	Wetlands shrink and desertification takes place. Degradation of delta wetlands		Change in stream physical conditions, refinement of sediments. Increased sediment deposition in the main river course, erosion and shrinkage of the river channel.	Qiantangjiang Hanjiang Huaihe Middle and downstream of the Yellow River Hutuo river	Li F.,2001 NIGAS,1981 Liu et.al, 1992, Yu et.al., 1981 Chen et.al.,1990 Zhu,1992 Su,1987 Zhang Z.J,2003 Shi C., 2000
			Floodplain wetlands decrease in area, Diversity of wetland animals declines Downstream wetland areas decline		Severe deposition in river main channel, narrowing of river width, change in riverbed morphology, Increased flooding	Low reaches in the Changjiang the Yellow River	Zhai J.,2003 Li F.,2001 Wang L.,2006
			Decline in groundwater level			Naoli River Tarim River	Xu.Y.et.al.. 2001 Feng Q.et.al.. 1998 Wang L.,2006

Direct impact		Indirect impact				Example rivers	Sources
Flow change		Fish	Riparian wetlands	Water quality and temperature	Sediments and physical habitat		
		Decline in quantity of fishes	Variation in downstream water level, increase in mineralization	Total ion concentration increases		Lower reaches in the Yellow River Kaidu River	Chen J. 2000 Wan X. 2006 Jiao Y. ,1998
		Influence living habits of marine migrating fishes	Erosion of delta		Recession and erosion of deltas	The Yellow River	Jiao Y.,1998 Li F. ,2001
		Influence animal growth		Change in estuarial concentration		The Yellow river	Li F. ,2001
		Shorter spawning period with a suitable temperature. Less eggs in high quality	Habitats shrinking of aquatic animals	Salinity variation	Lower estuary temperature and higher salinity	The Yellow River	Jiao Y.,1998 Jiang C.,2003
	Water break Longer low flow process		Obviously decrease on vegetation and animal diversity in basin Decreased plantation coverage Drought of Konqi River and Tarim Delta Degradation of lower grasslands Land desertification and salinization	Higher peak salinity, Higher salinity of shallow groundwater in lower reaches	Narrowing of river width, change in riverbed shape	Tarim River Upper Alager Stn and lower Kala Stn in Tarim Basin	XGRI. 1995 Zhou X. 1990 Wu S.Y. 1992 Xu.Y.et.al.. 2001 Feng Q.et.al.. 1998

Direct impact		Indirect impact				Example rivers	Sources
Flow change		Fish	Riparian wetlands	Water quality and temperature	Sediments and physical habitat		
	Flow change in time	Behaviour of migrating fishes influenced				The Changjiang	Yang J.,2007 Zheng S.,2004 Jiang C.,2003
	Lower velocity	In the estuary, freshwater fishes decreased and marine fishes increased. In reservoirs and upper, much many drifting eggs sank and were lost.		Phytoplankton increase including Margalef diversity index, species richness, generic richness, taxonomic composition, and the percentage of diatoms.		Qiantangjiang XiangxiRiver Hanjiang Lvhe river Yuxi River and Danjiang in Guangdong	Wu N.,2007 Chen et.al.1990 Zhu,1992 Su,1987 Lin Q.Q.,2003 Yu Z.,1981 Qi J.,2005
					Declining erosion ability to bank slope	Changjiang	Zhu Y.,2005
		Population variation in lentic fishes and lotic fishes		Algae increase		Danjiang	Kuang Q.,2000 Zhu Y. ,2005
		Influence fish spawning			Sediment deposition	Changjiang	Zhu Y. ,2005,
	Lower peak flow			Sediment content increasing	Bed-forming role of flood weakens, the plane and the cross section scales of river decrease, erosion areas reducing	Downstream of Yellow River	Su Y.,2007
					Less discharge flow into sea, Downstream areas shrink	Changjiang	Qi J. ,2005
					Change the erosion condition	Lancang river	Chen R.,2007 Qi J.,2005
		Increasing				Bei River in	Cai X.,2007

Direct impact		Indirect impact				Example rivers	Sources
Flow change		Fish	Riparian wetlands	Water quality and temperature	Sediments and physical habitat		
		biomass of plankton				Guangdong	Qi J.,2005
		Decreasing resources of fishes producing drifting eggs, spawning ground loss				Hanjiang	Li X.,2006
Flow regime	High level flow emission	Fishes death due to strong aeration of released water	Downstream wetland vegetation grow in an usual conditions	Increasing dissolved oxygen		Middle reaches of the Changjiang	Li Q.,2005 Yu G.,2006 Zheng S.,2004
		Fish species unable to spawn			Geological change in the downstream riverbed.	Middle reaches of the Changjiang	Zhu Y.,2005
	Unstable flow variation	The growth of herbivorous fish is slower because of delayed growth of aquatic plants influencing by lower temperature. Fishes can't spawn or unsuccessful incubation in the changed river bed.	Wetlands erosion, landscape fragmentation, endangered water birds decrease	Lower average temperature with a higher minimal and a lower peak. Downstream temperature decreased in the Xinanjiang and Danjiang and increased in Liujiaxia reservoir and Fengman reservoir	As the water and sediment variation, scouring and sedimentation change in the river course	Hanjiang, The Yellow River Danjiang Lanchang river, Changjiang Naoli river	Liu et.al, 1992 Deng et.al.,1981 Dept. of Ichthyology, 1976 Cai W., 2001 Zheng S.,2004 Wan X.,2006 Liu H.,2006
	Frequent variation in the daily flow	Lower water temperature influences			Stronger erosion in the downstream river valley	Upper Changjiang	Zhang Z.Y.,2001 Qi J.,2005

Direct impact		Indirect impact				Example rivers	Sources
Flow change		Fish	Riparian wetlands	Water quality and temperature	Sediments and physical habitat		
		spawning and growth of fishes					
		Influence living of fishes in the shallow places				Jinshajiang	Zhao H.,2002 Qi J.,2005
		Population of river dolphin greatly reduced.				Changjiang	Hua.Y., 1992
Seasonal variation	Disappearance of seasonal floods	Decrease of estuarine planktons and benthic organisms	Wetlands disappeared			Lower reaches of the Changjiang	Jiang C.,2003 Zhao H.,2002
	flooding strength decreasing		Scarcity of water supply to wetlands			Wuyue River	Wang L.,2006

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Appendix D: Flow Components and their Roles

(Adapted From Richter and Thomas 2007)

Environmental flow component	Hydrological parameters	Example ecosystem influences
Monthly low flows	Mean or median values of low flows during each calendar month	Provide adequate habitat for aquatic organisms Maintain suitable water temperatures, dissolved oxygen and water chemistry Maintain soil water tables in floodplains, soil moisture for plants Provide drinking water for terrestrial animals Keep fish and amphibian eggs suspended Enable fish to move to feeding and spawning areas Support hyporheic organisms living in saturated sediments
Extreme low flows	Frequency of extreme low flows in each water year or season Mean or median value of extreme low flow events Duration Magnitude Timing	Enable recruitment of certain floodplain plant species Purge invasive, introduced species from aquatic and riparian communities Concentrate pray into limited areas to benefit predators
High flow pulses	Frequency of high flow pulses in each water year or season Mean or median value of high flow pulse events Duration Peak flow (maximum flow during event) Timing Rise and fall rates	Shape physical character of river channel Determine size of stream bed substrates Prevent terrestrial vegetation from encroaching into channel Restore good water quality conditions after prolonged periods of low flows by flushing away waste products and pollutants Aerate fish eggs in spawning gravels and prevent silt Maintain suitable salinity conditions in estuaries

Small and large floods	Mean or median value of small flood events Duration Peak flow (maximum flow during event) Timing Rise and fall rates	The following may apply to both small and large floods: Shape physical habitats of floodplains Drive the lateral movement of river channels and the formation of new habitats (for example secondary channels and oxbow lakes) Flush organic material into channel Rejuvenate floodplain soils through the deposition of nutrients during flooding Provide migration and spawning cues for fish Trigger new phase in life cycle (for example some insects) Enable fish to spawn in floodplain, provide a nursery area for juvenile fish Provide new feeding opportunities for fish, water fowl and other biota Recharge groundwater Provide recruitment opportunities for floodplain vegetation through prolonged access for seedlings to soil moisture Maintain diversity in floodplain forest types Control the distribution and abundance of plants on floodplains Disperse propagules (for example seeds and fruits)

Chapter 3: Guidelines for irrigation district management in China

3.1 Terms of guidelines

1 Foreword

1.0.1 The overall aim of this document is to provide guidance for the sustainable management and development of irrigation districts (IDs) in China. In particular, guidance is intended to support implementation of a water-saving society and new countryside building, and promote efficient use of water within agriculture.

1.0.2 The guideline is directly applicable to surface water gravity IDs. It can also act as a reference document for groundwater irrigation and mixed (surface and groundwater) systems.

1.0.3 The scope of irrigation management discussed in the guideline includes:

a. Institutions and personnel management
b. Irrigation and water resources management
c. Project and equipment management

1.0.4 Irrigation management should meet the following requirements:

a. Irrigation management agencies should have a certain income in order to maintain their survival and healthy development.
b. Irrigation districts should establish an efficient water allocation, water supply and water management system step by step based on the principle of water entitlements.
c. Irrigation districts should have a series of sound management systems for agency, water resource and project management.
d. It is necessary to focus on the relationship and coordination between the systems.
e. Attention should be paid to hydrological uncertainty and water resources risk management, and emergency management plans for irrigation management in drought periods should be prepared.
f. Irrigation management should benefit local people, and help promote local democracy and farmer participation.
g. Irrigation management should be consistent with rural administrative management and new countryside building.

1.0.5 Irrigation management should be consistent with this guideline, but also be consistent with existing national standards.

2 Institutions and personnel management

2.1 General provisions

2.1.1 Irrigation district management institutions should include, at a minimum:

a. An Irrigation Management Bureau
b. Several Irrigation Management Sections under the Bureau

c. A Water Monitoring Agency

d. Water User Associations (WUAs) and farmers.

2.1.2 Irrigation district management institutions and personnel management should meet the following requirements:

a. Irrigation district management institutions at all levels should operate independently and communicate smoothly.

b. The revenue of ID management institutions should be increased and stabilized in order to fully meet staff salaries and ensure the sustainable development of institutions.

c. Strengthen the capacity building and personnel training, to ensure the efficient management of IDs.

d. Personnel recruitment and management should be transparent and fair.

2.2 Irrigation district management institutions

2.2.1 Irrigation district management institutions should include, at a minimum: an Irrigation Management Bureau, several Irrigation Management Sections under the Bureau and a Water Monitoring Agency. The Irrigation Management Bureau and Sections are responsible for irrigation and water supply management.

2.2.2 Irrigation district management institutions should meet the following requirements:

a. The institutions should have a certain income in order to maintain their survival and sustainable development.

b. The institutions should have modern management tools and effective commitment to the management of the ID step by step.

c. The institutions should have high-quality personnel. Appointments should transparent and competitive.

2.2.3 It is necessary to specify the role of irrigation management institutions. Irrigation management institutions should be a non-profit organizations focusing on water resources management.

2.2.4 There should be a strict cap on new appointments. Any new post should be approved under the "tidy, efficient" principle beneath the cap.

2.2.5 All staff in an ID should be re-employed every three years. Irrigation district management institutions should sign an employment contract with the employee if both agree with it. The contract should define the tasks of an employee. It is necessary to introduce an incentive mechanism to enhance the working enthusiasm of all the workers. Employee competency and ability to meet the objectives set out in the contract, appraised every year, should determine re-employment.

2.3 Water Monitoring Agency

2.3.1 The Water Monitoring Agency should be responsible for monitoring and information management with regard to water supply and use.

2.3.2 The Water Monitoring Agency should meet the following requirements:

a. It should have advanced and reliable monitoring equipment to ensure accurate real-time hydrological data collection and information management.

b. It should have professional technical personnel.

2.3.3 The tasks of a Water Monitoring Agency include:

a. Operation and use of automated water monitoring systems
b. Monitoring of real-time hydrological data and support for water supply, water fee collection and water entitlement transfer. Ensure the implementation of the water use plan and improve the quality of irrigation management.
c. Management and operation of software and hardware equipment of water monitoring system

2.3.4 The technical personnel in an ID Water Monitoring Agency should meet the following requirements, besides having some professional knowledge:

a. Staff should be familiar with the name, purpose and usage of water monitoring equipment, information transmission equipment and data processing equipment.
b. Staff should have basic abilities in computer operation and database use, and should be able to find relevant information in the database according to decision-making needs.
c. Staff should be aware of an ID's area, canal construction and monitoring network.
d. Staff should be aware of the standard charge for irrigation water.

2.3.5 Training for technical personnel in an ID's Water Monitoring Agency should be implemented.

2.4 Water User Associations

2.4.1 Water management within the command areas of an ID's branch canals should be implemented through WUAs together with the Irrigation Management Bureau. This is commonly done beneath 4th level canals.

2.4.2 WUAs should adopt independent accounting and self-management in order to service farmers, reduce irrigation costs and improve the efficiency of water use.

2.4.3 WUAs should comply with relevant state laws and regulations, and accept supervision from the government and public.

2.4.4 WUAs should be supervised by a the Irrigation Management Bureau in accordance with the law to take water, the planned water, water conservation and optimize the allocation of water resources and promote sustainable development of the ID.

2.4.5 The establishment of WUAs and selection of WUA representatives should meet the following requirements:

a. WUAs are established and registered in accordance with specified procedures, and involving a WUA Preparatory Committee consisting of local village leaders, staff from the Irrigation Management Bureau and farmers.
b. The general procedures for the establishment of WUAs should include: establishment of a Preparatory Committee; investigation of WUA's irrigation area; charter preparation and water users' representative elections; nomination of Executive Committee recommended candidates; training;

holding the meeting of all the water users' representatives; the establishment of the Association; asset evaluation; registration; and inspection.

c. Election procedures should be democratic. Water users' representatives should be democratically elected by farmers, and the Executive Committee and Chairman of the Association should be democratically elected by those representatives. All elections should be conducted through closed ballots. Farmers have the right to recall the Executive Committee and the Chairman of the Association.

d. The Irrigation District Management Bureau should issue letters of appointment to the members of the Executive Committee. The Chairman of the WUA acts as its legal representative, and is responsible to both water user representatives and the Irrigation District Management Bureau. At the same time, the Irrigation District Management Bureau should issue certificates and membership cards to water user representatives and farmers with details of their rights and responsibilities.

e. WUAs must adhere to the principles of democratic management and democratic decision-making, and meet at least twice a year on behalf of water user representatives. In addition, WUAs may need to hold additional meetings to discuss other important matters.

f. In conjunction with the relevant irrigation district management institutions, WUAs should prepare an Operation and Management Manual, and develop a series of regulations on irrigation management (including water distribution procedures and priorities among production teams and farmers), engineering and maintenance procedures, financial management and the roles and responsibilities of members of the Executive Committee.

2.4.6 The services and functions of a WUA should meet the following requirements:

a. The services provided by a WUA extend to irrigation and other water uses authorised by villagers within the channel-defined boundary of the WUA.

b. The main functions of a WUA are water fee collection and water distribution, canal and gate operation and maintenance, the promotion of agricultural production and increasing farmers' incomes.

c. A WUA has water use and management rights on the canals and hydro-buildings within the command area of the association.

d. A WUA is responsible for promoting water-saving irrigation technologies and cropping patterns.

2.4.7 WUAs should be adequately funded to ensure sustainability. The Irrigation District Management Bureau should return a certain percentage of all charges to WUAs to cover their operation costs and staff wages. Funding should be supervised by water user representatives.

2.4.8 There should be sound financial management regulations in WUAs for account management. A WUA should maintain clear accounts for inspection by WUA representatives and members, and should report regularly to representatives and members. It should also be subject to financial supervision and inspection by relevant departments.

2.4.9 It is necessary to have staff training through WUAs in order to enhance their knowledge and capacity of water resources management.

2.4.10 If there are irrigation disputes between WUAs, the Irrigation District Management Bureau should be responsible for dispute resolution.

2.5 Farmers

2.5.1 Farmers should be aware of the management system in an irrigation district, and be familiar with their rights and obligations with respect to irrigation water allocation and management, and their membership of a WUA.

2.5.2 Farmers should actively cooperate with the WUAs for irrigation, and participate in elections and meetings of WUAs.

3 Irrigation and water resources management

3.1 General provisions

3.1.1 Irrigation and water resources management within an ID should be based on: an initial allocation of water rights; a water planning system; a water certification and water ticketing system; water fee budget management; and water rights trading management.

3.1.2 Irrigation and water resources management should pay attention to links and coordination between each of the items listed above.

3.1.3 Irrigation and water resources management should be based on a clear demarcation of responsibilities for each of the items listed above.

3.1.4 The management systems and regulations below should be confirmed and supported through law.

3.2 Initial water rights allocation

3.2.1 The aim of the initial water rights allocation process is to distribute the water held through the permit of an ID to users within the ID, so that users have volumetrically-defined usufruct and trading rights of a fixed duration according to the ID's stipulation.

3.2.2 Initial water rights shall be allocated to the level of WUAs through Group Water Entitlements (GWEs), and a GWE Allocation Plan shall be prepared defining the long term volumetric rights of each WUA.

3.2.3 The initial GWE (Water Rights) Allocation Plan shall have legal effect and government authority.

3.2.4 Initial water rights shall be allocated through democratic negotiation and consultation in accordance with government guidance, and the interests of users shall be fully safeguarded.

3.2.5 The steps of initial water rights allocation include:

a. Negotiation of allocation principles
b. Survey of ID population and irrigated area.
c. Survey of current water use and prediction of future water use
d. Preparation of the initial Water Rights Allocation Plan

e. Plan negotiation and revision.

f. Report to the upper level and auditing

g. Issue of Water Rights Allocation Plan

3.2.6 Allocation principles shall at least include:

a. Fairness

b. Sustainability

c. Respecting the current situation

d. Priority of basic living water and eco-water demand

3.2.7 Irrigation district management institutions shall fully investigate the ID's population, irrigated area and current water use to predict future water demand, and to provide a basis for the initial allocation of water rights.

3.2.8 Irrigation district management institutions shall allocate long term water rights rationally according to the allocation principles, current water use and future water demand.

3.2.9 An ID shall allocate eco-environmental water and leave some unallocated water for future use at the same time.

3.2.10 The Water Rights Allocation Plan shall take conveyance losses into account and determine the body that bears the losses.

3.2.11 The upper limit of water rights allocation is the ID's water permit.

3.2.12 During the allocation process the ID's management institutions shall fully consider users' opinions and resolve conflicts according to "Negotiation - Feedback" procedures.

3.2.13 After plan compilation ID management institutions shall report results to the upper department for auditing. Following approval the plan should be publicised.

3.2.14 The initial Water Rights Allocation Plan should specify the duration of rights and revision principles.

3.3 *Water planning system*

3.3.1 Based on the Water Rights Allocation Plan described above, ID management institutions should prepare a Water Use and Scheduling Plan for each irrigation period.

3.3.2 Generally, the preparation of a Water Use and Scheduling Plan should be led by the Irrigation Management Bureau working together with Section Offices and WUAs.

3.3.3 The Water Use and Scheduling Plan should consider the following:

a. The water abstraction permit of the ID.

b. The GWEs defined in the Water Rights Allocation Plan.

c. The annual/monthly Regulation Plan issued by the higher level river basin management authority.

d. The water demands of farmers, articulated through WUAs.

3.3.4 Hence the Water Use and Scheduling Plan should be consistent with, and reconcile, the ID abstraction permit, the Water Rights Allocation Plan, the Annual Regulation Plan and WUA needs. The Annual Regulation Plan issued by the upper river basin management department and the ID permit determine the amount of water allocated to the ID; the Allocation Plan and WUA demands determine how this water is allocated within the ID. The detailed process is as follow:

a. Based on Water Abstraction Permit of the ID and the water demands of WUAs, ID management institutions develop an Annual Water Use Plan with the total water need declare at the beginning of the year, and submits it to the upper river basin management authority for approval

b. According to the Annual Regulation Plan, the relevant river basin management authority checks and revises the Water Use Plan as necessary, and then approves an annual water allowance for the ID within its permitted cap.

c. Based on the annual water allowance and the Water Rights Allocation Plan, the, Water Use Plan then determines annual allocations to each WUA and provides the basis for an Irrigation Scheduling Plan for meeting allocations. .

3.3.5 At the beginning of each irrigation period, and based on the water needs of WUAs in this period, their water entitlements and water use in previous periods, the Water Use Plan determines allocations to each WUA and an irrigation schedule for all WUAs in the ID.

3.3.6 The Water Use Plan for each irrigation period may need to be adjusted to reflect the monthly water use plans issued by the relevant river basin management authority. If the authority reduces the water supply to the ID during an irrigation period that has already commenced, the Water Use Plan for the irrigation period should be changed according to an emergency management programme.

3.3.7 The compilation of a Water Use and Scheduling Plan should include the following steps:

a. WUAs declare their water demands for each irrigation period;

b. The Irrigation District Management Bureau checks to see if the total WUA demand exceeds available water supply at this stage;

c. Establish a regulation for irrigation scheduling and orders. Some WUAs can be irrigated at the same time (continuous), and some should be irrigated taking turns (sequential). It is decided by the WUAs' locations and canals structure. The irrigation orders should be fair and acceptable.

d. Establishment of continuous and sequential systems.

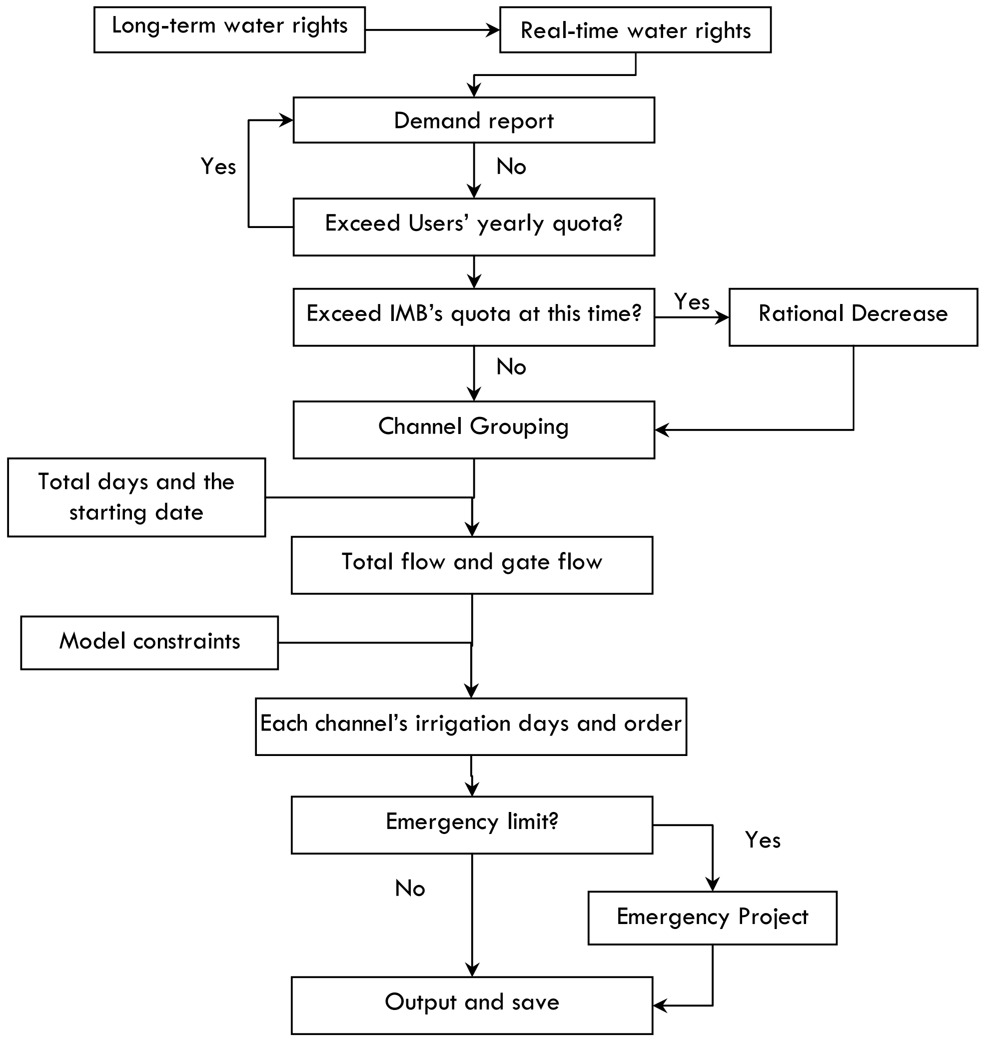
e. A Water Use and Scheduling Plan is prepared;

f. The plan is audited and issued;

g. An Emergency Plan comes into effect if water supply is less than anticipated, and a revised Water Use and Scheduling Plan is prepared.

3.3.8 The procedure for developing the Water Use and Scheduling Plan is illustrated in Figure 15.

Figure 15: Procedure for developing the Water Use and Scheduling Plan



3.3.9 Before each irrigation period the Irrigation District Management Bureau shall clarify and confirm each WUA's water demand and the total demand according to the "User claim and rational decrease" principle.

3.3.10 The ID shall build a sequential and continuous irrigation system to ensure more convenient operation of channel gates and reduce transportation losses, based on each WUA's geographic location and channel characteristics.

3.3.11 The Water Use and Scheduling Plan shall determine each WUA's starting and finishing date of water supply and flow needs.

3.3.12 The Water Use and Scheduling Plan shall be able to adjust to daily changes in water diversion to the ID and meet risk management requirements.

3.3.13 If diversions to the ID are reduced during drought, basic domestic water use and cropland needs should be first guaranteed, and farmers who received low priority under the old plan and who have less arable land shall be irrigated first.

3.3.14 The ID is advised to compile the Water Use and Scheduling Plan by computer to save time and increase efficiency.

3.3.15 The preparation of, feedback on and adjustment to the Water Use and Scheduling Plan shall be convenient and quick, and the Irrigation District Management Bureau shall audit and revise the plan in a timely manner.

3.3.16 The Water Use and Scheduling Plan shall be compiled in an open and transparent way to guarantee users' right to know.

3.4 *Water certification*

3.4.1 The ID shall implement the water certification and water tickets system based on the water rights system.

3.4.2 Water certification is a certification of limited property. Its owner possesses the rights of usufruct and disposal of corresponding water amount. Water certification shall record the property of long-term water rights. In addition, it can record the annual purchasable water limits, the water tickets buying during each stage and the information of water tickets trading and water rights trading.

3.4.3 After the initial water rights allocation the Irrigation District Management Buerau will grant the allocated water rights to WUAs in the form of water certificates. Water certificates should be kept by the leader or representative of a WUA and used under the WUA's stipulation.

3.4.4 At the beginning of each year, the Irrigation District Management Bureau shall calculate the corresponding annual purchasable water limits of each certificate holder and record it on the certificate. This will be adjusted before each irrigation according to water availability. In addition, the Irrigation District Management Bureau shall also calculate the phased purchasable water limit based on actual water tickets purchased in previous periods. A WUA can buy water tickets under this limit.

3.4.5 The Irrigation District Management Bureau shall set a fixed time period for renewal of water certificates according to the time limit specified during the initial allocation of water rights, and will check information on water use and water trading regularly.

3.4.6 A WUA can sell any water saved under its GWE at a negotiated price to other WUAs, or sell back to the ID Management Bureau at a higher price to encourage conservation efforts. For long term trading within the ID, the Bureau will renew both buyers' and sellers' certificates and take back old ones following an auditing process. The Bureau shall recalculate the new purchasable limits according to new long term water rights after trading.

3.5 *Water tickets*

3.5.1 Water Tickets combine rights with a specific volume and price. A water ticket has a fixed denomination of water amount. WUAs shall declare the water demand and drift Water Use Plan to the Irrigation District Management Bureau before they know the water available limit for the follow period. The Irrigation District Management Bureau then sells tickets according to water availability and the purchase limits of each WUA, and supplies enough water for each ticket. Tickets can be traded freely according to the specified rules.

3.5.2 Before each irrigation, a WUA shall declare its water demand and proposed ticket purchase amount to the Irrigation District Management Bureau. The Bureau will then grant tickets to each WUA and collect the corresponding water fee based on each WUA's purchasable limit and water demand auditing. Meanwhile, the Irrigation District Management Bureau will compile the Water Use and Scheduling Plan and forward it to each ID Section and water delivery (gate) manager.

3.5.3 The water delivery (gate) manager will inform the WUA of its forthcoming water allocation, collect the water fee and supply water to the WUA. During this process, the representative of the WUA and staff from the Section Office and Hydrological Station will supervise delivery together and sign separately to ensure agreement on procedure and outcome. .

3.5.4 If actual water supply is less than the purchased water tickets due to an emergency water restriction, WUAs can sell their extra tickets (or the supply shortage) to the Irrigation District Management Bureau at a price not lower than the original price, or reserve them for irrigation in the next period.

3.5.5 During a given time specified by the Irrigation District Management Bureau before each irrigation period, WUAs can sell saved tickets freely within the section and registered in the Bureau, or the Bureau can buy saved tickets and sell to other user WUAs in other sections. Alternatively, the Bureau and/or a Water Bank (see below) can 'pool' saved tickets for trading to users outside the ID. The Bureau shall set up a bulletin board of water trading information to provide information on water demand and water supply in order to raise trading efficiency and improve allocation within the ID.

3.5.6 If a water certificate is damaged, a WUA can apply for a new one from the Bureau. If lost, however, there will be no compensation.

3.6 *Water fee budget management*

3.6.1 ID management institutions are non-profit institutions but can collect funds to cover maintenance and operation costs.

3.6.2 The main income of ID management institutions is water fees and the administrative expenses of water rights trading. The main expenditures are submitting the water fees, staff salaries, the operation funds of the departments and WUAs and maintenance of irrigation infrastructure.

3.6.3 ID management insinuations shall establish separate systems of water fee income and expenditure for specific applications. Financial auditing and monitoring shall be strengthened. Some bad phenomena such as "collection together with other items" shall be forbidden. Expenditure shall be strictly controlled. The efficiency of fund use shall be raised and users' burden shall be reduced.

3.6.4 ID management insinuations are encouraged to implement a tiered system for the collection of water fees such that the Bureau collects fees from WUAs, and WUAs collect fees from farmers. The collection shall be fair, transparent and reasonable.

3.6.5 ID management institutions are encouraged to implement a "two-part" water tariff, consisting of a flat fee based on cultivated land area, and a progressive fee based on volumetric use. The establishment and modification of a water price system shall widely solicit users' opinions and be implemented only after auditing and approval by the local competent department in charge of pricing.

3.6.6 ID management institutions can charge, at cost, for the issue and replacement of water certificates but cannot levy administrative fees for water tickets.

3.6.7 For long-term water rights trading managed by the Bureau, the Bureau could collect an adequate administrative fee to cover expenses. The establishment of collection standards shall widely solicit users' opinions and shall be implemented after the auditing and approval of local competent department in charge of price.

3.6.8 At the beginning of each irrigation period, WUAs shall collect water fees from users according to approval amount of the water demand and WUA's regulation, then buy water tickets from the Bureau or the section and pay by ticket denomination. Payment should precede supply.

3.6.9 During irrigation, the representatives and the staff of the ID section and hydrological station should measure actual flow and sign together as basis for accounting the water amount and water fee. The expenditure of ID funds shall be economical, normal, reasonable and transparent.

3.6.10 The salaries of ID staff shall be granted under the guidance of local government and maintained at a proper rate of salary increase.

3.6.11 ID management institutions can only levy charges to cover their operational and maintenance expenses, separately accounted for. The scale of charges levied should account for users' opinions and shall be implemented only after auditing and approval of a local competent department in charge of pricing. Procedures for adjusting charges should be specified.

3.6.12 Conditionally, ID management institutions should save some income as a future ID development fund to support modernization and upgrading of software and hardware, to promote the sustainable development of the ID and to enhance its economic strength.

3.6.13 ID management institutions shall implement a transparent financial system, publicize the irrigation water amount, water price and water fee of each WUA after each irrigation period, and publicize the financial income and expenditure of the Bureau, the sections and each WUA in each period in a timely manner to ensure transparency and accountability.

3.6.14 WUAs should establish agreed (by members) systems for water fee collection and fund expenditure, including procedures for distributing income from water trading.

3.6.15 Staff who break financial rules will face appropriate punishment, including legal sanction if laws are broken.

3.7 Water monitoring and metering

3.7.1 Water monitoring and metering procedures in an ID should include the following steps:

a. Lay out the monitoring sites according to the actual situation of the ID.

b. Set up the sections for water level measurement and recording.

c. Measure the water abstraction of the canals at all channel levels, as well as the relationship between water flow and water level in the main canals. Draw the relation curves of water level and flow for the sluices at main and branch canals.

d. Measure the loss of canals at all levels, as well as the effective water utilization rate of the canals

e. Measure the volume of return flows from the ID. It is a basis for water balance analysis of the ID.

f. Collect and analyze the monitoring data and provide a basis for water supply, fee collection, irrigation management and planning.

3.7.2 The ID should adopt water monitoring and metering systems that are practical, reliable, cost-effective and fit for purpose. Decision criteria include:

a. Specific information and decision-making needs of irrigation stakeholders.

b. Extent to which existing systems meet those needs.

c. Based on the above, a full evaluation of the advantages and disadvantages of alternatives, including training, operational and upkeep requirements.

3.7.3 The ID should establish an advanced and automated water monitoring system step by step. If an automated water monitoring system is selected, it should include:

a. Systems of data acquisition and transmission

b. A database and data platform for water resources management

c. An information and business management system based on monitoring information

3.7.4 The monitoring system should be easy to maintain and use.

3.7.5 Lay out the monitoring sites in the canals above the fourth level to measure the water use volume of WUAs and provide a basis for levying water fees.

3.7.6 There should be public notification and supervision regulations in any automated water monitoring system. Water monitoring information should be transparent and open, especially for water use data of WUAs.

3.7.7 There should be sound regulations on equipment use and maintenance.

3.8 *Water trading management*

3.8.1 When pre-conditions are in place, water trading within and from an ID can be managed through a water bank.

3.8.2 The process of trading water through a water bank can involve:

a. A WUA (or farmers within a WUA) saving water and applying to transfer some of its GWE (as allocated under the Water Rights Allocation Plan) to the bank. This part of the process simply involves reallocating the total volume available under the abstraction; it does not affect the permit at all.

b. The bank transfers banked entitlements from the permit holder (for the ID) to the purchaser (e.g. an industry outside the ID). This will require an amendment to the ID's water abstraction permit, and the granting of a new permit to the purchasing industry.

3.8.3 The first step to banking water should be the development of a 'water savings proposal'. This could be done by either the Bureau or WUAs.

3.8.4 There should be rules and standards for water savings proposals. Proposals should meet the following requirements:

a. A water saving proposal should set out the detail of the proposed measures and calculations of the volume, location and reliability of water that would be saved.

b. The proposal would need to show that savings are 'real'. Real savings are reductions in non-beneficial evapo-transpiration and losses to non-recoverable water bodies (sinks) such as saline aquifers. Proposals would therefore need to demonstrate that savings would be consistent with a net reduction in ID diversions, and would not adversely affect the water rights of other users and uses (within the ID, and within the river basin) that might depend on irrigation return flows.

c. The proposal would need to demonstrate that water savings can be sustained in the long term. A water savings proposal would therefore need to set out the means by which the water savings will be sustained in the long term, including the maintenance required for any proposed works.

3.8.5 Water saving proposals should be scrutinised by independent, accredited authorities to ensure the measures contained in the proposal are: technically sound; will reliably provide the claimed savings; address potential impacts on 'third parties' (e.g. groundwater users, environmental assets); and are consistent with the law.

3.8.6 The entitlement holder would be required to submit a 'completion certificate' from an independent authority certifying that the water savings had been achieved in accordance with the approved water savings proposal. Banking would not be allowed without this certification.

3.8.7 The development of a water bank should not undermine the financial stability the Bureau requires to plan its water supply services into the mid term.

3.8.8 The water bank should pay the entitlement holder for the banked entitlement immediately, at the standard price set by the bank and change the register of water entitlements.

3.8.9 The total of the banked entitlements should be registered on a publicly accessible database, enabling interested parties to see how much water is available for purchase. To facilitate trades, banked entitlements should not be able to be withdrawn from the bank.

3.8.10 The bank should be responsible for matching buyers with available entitlements. It would need to keep a register of interested buyers (which would be particularly important should banked entitlements not meet demands).

3.8.11 Rules would need to be established about the bank's role in selecting those parties allowed to purchase the banked entitlements. These rules would need to ensure fairness and transparency, and minimize corruption opportunities.

3.8.12 The price the bank pays to water entitlement holders should recover the cost of water saving, the encouragement for water saving and the water fees.

4 Hydraulic infrastructure and equipment management

4.1 General provisions

4.1.1 Engineering equipment within an ID includes: hydraulic engineering equipment and metering and monitoring equipment.

4.1.2 Equipment management should separate management and maintenance functions. ID agencies should establish a scientific and rational mechanism for engineering equipment management with clear functions and responsibilities.

4.1.3 The ID Management Bureau has the responsibility of the hydraulic engineering infrastructures management within the ID, and the supervision of the equipments maintenance and safely operation.

4.1.4 There should be a separate, specialized corporation taking charge of infrastructure and equipment maintenance. Maintenance of infrastructure and equipment can be maintenance can be conducted in a commercial way.

4.1.5 The ID Management Bureau should cover the operation and maintenance costs of equipment.

4.2 Irrigation infrastructure management

4.2.1 A statement or regulation should be issued concerning the management scope of hydraulic engineering infrastructure according to the relevant national hydraulic infrastructure management and protection regulations and the local situation. The management and maintenance of infrastructure shall be strictly within this scope.

4.2.2 Local hydraulic construction projects shall be approved after the auditing of competent organization according to the capital construction procedures.

4.2.3 Channel and other hydraulic works above the 4th level shall be protected and maintained by ID Management Bureau. Other engineering works under 4th level shall be protected and maintained by WUAs. The ID Management Bureau should return a certain proportion of the water fee to WUAs to pay for WUA salaries and the subsidies for WUA office and administration costs.

4.2.4 It is forbidden to build dams for backwater on channels at the 1st, 2nd, 3rd level. It is forbidden to shoot weapons or explode items adjacent to hydraulic works. People who damage infrastructure and cause losses shall accept financial and administrative punishment, or legal sanction.

4.2.5 Natural vegetation adjacent to 1st and 2nd level channels shall be protected by the ID Management Bureau and anybody or any corporation shall not fell at will. The ID Mangement Bureau shall plant trees within protection zones and maintain and use existing vegetation. .

4.2.6 It is forbidden to build any construction around both sides of the 1st channel. Crop planting within the protection zones of 2nd and 3rd channels shall be gradually reduced and converted to forest. Autumn irrigation is forbidden.

4.2.7 The ID Management Bureau shall establish reward and punishment regulations for managing hydraulic works according to local conditions.

4.3 *Monitoring equipment management*

4.3.1 There should be a series of regulations for monitoring equipment management, such as technical standards, system targets etc.

4.3.2 All automatic monitoring devices, information transmission equipment, data processing and display equipment should be managed by the Water Monitoring Agency under the ID Management Bureau, and maintained by professional companies.

4.3.3 Equipment maintenance should meet the following requirements:

a. Equipment cleaning should be carried out in a clean and dust-free environment.
b. The structure and operation of equipment should be familiar to those charged with maintaining it before it is disassembled and cleaned.
c. Attention should be paid to rust, electric shock and leakage in equipment storage and transport.

4.3.4 According to international and domestic information system safety design principles, formulate a unified security strategy to improve safety management and ensure system security.

4.3.5 Prevent monitoring equipment being deliberately damaged and stolen

5 Appendix A

List of irrigation district management regulations:

A.0.1 Regulations of staff management

A.0.2 Regulations of water monitoring management

A.0.3 The statutes of WUA

A.0.4 Regulations of WUA election

A.0.5 Water entitlement allocation programme

A.0.6 Regulations of water use planning

A.0.7 Regulations of water ticket use

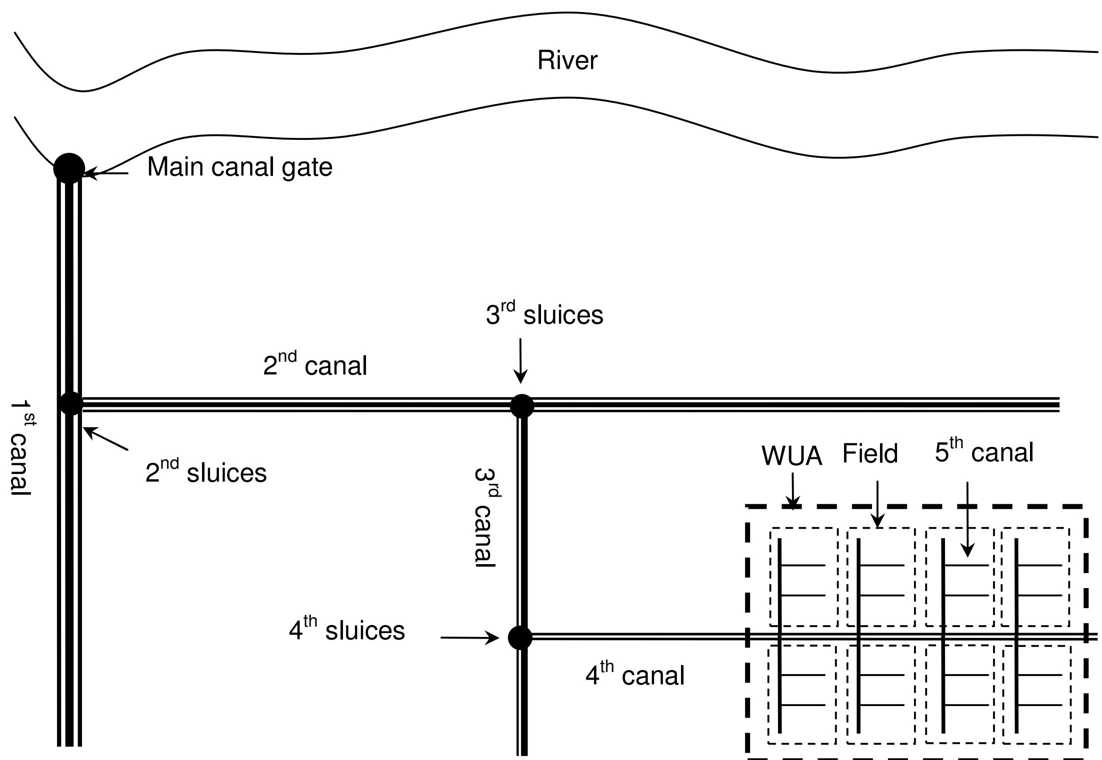
A.0.8 Regulations of water fee collection

A.0.9 Regulations of water trading and water banking

A.0.10 Regulations of project and equipment maintenance.

6 Appendix B

Illustration of irrigation district layout



1st canal – Main canal

2nd canal – Sub-main canal

3rd canal – Branch canal

3.2 Explanations of terms

1 Foreword

1.0.1 Agriculture irrigation districts are vital for national food security. Irrigation district management reform also underpins the building of a water-saving society and a new socialist countryside. It is the main force in China's agricultural production and rural economic development, and plays an important role in the national economy and social development. Its positive role is not only reflected in irrigation water supply and agricultural production, but also in the protection of the ecological environment, improving people's production and living conditions.

1.0.2 Based on investigations and studies in Hangjin Gravity Irrigation District, located on the southern bank of the Yellow River in Inner Mongolia, these guidelines summarise management experience and issues, and provide recommendations on the sustainable management of IDs in China more generally. .

1.0.3 Irrigation management agencies refer to the human beings; irrigation and water resources management is the major work of irrigation management; hydraulic engineering projects and equipment is the hardware supporting irrigation management. These three parts cover the main aspects of irrigation district management.

1.0.4 A water rights system provides the foundation for advanced irrigation district management. The system includes initial water rights allocation, water use planning, issue of water certificates, payment through water tickets and water trading. The water rights system must be fair, and ensuring that water rights have legal standing helps achieve this objective. The water rights system should also be transparent. If the definition and allocation of rights is clear, households will have confidence in the system and will abide by it.

At the same time, a transparent water rights system will inspire and encourage irrigation management agencies, making their duties and tasks clear and improving the service they provide. A water rights system can also increase the efficiency of water use, raise awareness of water scarcity and encourage the conservation efforts of farmers. Stable rights of land and water have the same effect. In addition, the establishment of a water rights system will strongly push the development of water measurement and monitoring systems, thus supporting irrigation management and development more generally.

Because of the different annual available water and limitations of long-term hydrological forecasting, there are issues of uncertainty and risk in ID management. It is therefore necessary to consider hydrological uncertainties in irrigation water rights management and planning, and prepare contingency plans for drought. .

As some IDs have been operating for many years, it is important to consider their history and current situation when planning reforms so that existing technologies and best practices can be built on and developed further in ways that are acceptable to both farmers and agencies. .

2 Institutions and personnel management

2.1 General provisions

2.1.1 If the area of an ID is large (e.g. over 300,000 mu), it should be managed in separate sections. These should be defined by the ID Management Bureau. Besides management sections, the Bureau includes offices, a financial office, water police and police station, etc. The Water Monitoring Agency is under the Bureau.

2.1.2 Cooperation between WUAs, the Irrigation District Management Bureau and the Water Monitoring Agency is an important part of ID management. The shortage and low quality of human resources is currently an important problem facing irrigation district management. So it is necessary to train and improve the treatment of staff and invest in capacity building.

2.2 Irrigation district management institutions

2.2.1 Irrigation districts provide both public and private goods. For this reason, they cannot operate as financially autonomous, private institutions. They should be viewed as public institutions.

2.2.2 The main problems currently faced by ID management institutions are lack of funds, poor management and a low skills base. To solve these problems, the guidelines provide recommendations on sustainable development for irrigation district management agencies.

2.2.3 Reference to "The Post Standards for Water Conservation Department" by the Ministry of Water Resources and Ministry of Finance, 2004, 7.

2.2.4 The introduction of competition and incentive mechanisms.

2.3 *Water Monitoring Agency*

2.3.1 A Water Monitoring Agency forms an essential part of ID management, especially in the management of water rights. It directly related to the implementation of water rights.

2.3.2 Water monitoring equipment in an advanced ID should be based on measurement automation and networking. An advanced monitoring system is a sign of an ID's modernization. However, this does not mean that advanced equipment alone will realize the goal of efficient operation and sustainable development of an ID. The measurement and monitoring system should also be developed with the actual situation of the ID in mind, paying close attention to the needs and priorities of users.

2.3.3 Water monitoring and measuring is an indispensable part of irrigation management. It should provide basic data and a scientific basis for water use planning, reasonable irrigation, water conservation, water utilization rate improvement, and economic development of the ID.

2.3.4 Following the establishment of an automated monitoring system, the workload of monitoring staff should decrease. They would not need to operate water monitoring equipment by hand, or make manual calculations. So if staff have the ability to use computers and a basic knowledge of irrigation water conservancy, they should be able to operate new systems.

2.4 *Water User Associations*

2.4.1 Local water management through WUAs has been widely promoted in China at branch canal level and below as a means of encouraging popular, farmer participation in ID operation. Self-management by farmers in IDs can reduces intermediate management work, and avoid many unreasonable charges, and can also lower the cost of agricultural production.

2.4.2 Water User Associations should be fully democratic, allowing farmers a 'say' in how water and irrigation infrastructure is managed within a WUA command area. They can raise the enthusiasm of farmers and, at the same time, reduce the workload in irrigation management and engineering maintenance of the ID Management Bureau. At the same time, because farmers are familiar with local conditions, a WUA can manage more effectively and harmoniously.

2.4.3 A WUA is a socio-economic group organized by farmers through democratic means and takes charge of agricultural irrigation management. It is a non-profit water use organisation. The WUA can manage irrigation water within its boundaries independently with appropriate rules and regulations, and enjoy civil rights and civil liabilities lawfully.

2.4.4 The establishment of WUAs will help support the reform of irrigation water use system and the establishment of water pricing system. Farmers irrigate in accordance with a proposed water use plan. The ID Management Bureau collects water fees according to irrigation water volume. It will effectively reduce the waste of water and promote greater rural water conservation.

2.4.5 Mass and autonomy are the main advantages of WUAs. Democracy is the protection for WUAs' mass characteristics. Therefore, the establishment and election of WUAs should be fully democratic, with procedures in place for ballot-based, well publicized elections at a time and place that is convenient for farmers. A WUA consists of a President (or Chairman), an Executive Committee, representatives of farmers and farmers themselves. Currently, farmers' understanding of WUAs, and of their rights and responsibilities within them, is often poor. So the WUA should hold well publicized meetings at least twice a year for its members, issue letters of appointment to the members of the Executive Committee, and provide representative and membership cards to farmer representatives and farmers, respectively. Cards should summarise the rights and duties of members. In addition, careful attention should be paid to the process of WUA formation so that farmers are made fully aware of a WUA's purpose and mandate, and their rights and duties as members, during a WUA Promotion and Consultation Phase that precedes formal establishment. This should include farmer meetings, and the preparation and distribution of leaflets and other appropriate material.

2.4.6 Since WUAs are local, participatory bodies, they can manage the irrigation water, maintain infrastructure, collect water fees and save water in a cost-effective and efficient manner.

2.4.7 The workload of the Executive Committee and Association President can be burdensome. To provide a reasonable work incentive, they should receive a basic salary specifically tied to their work as WUA representatives, paid for from a proportion of water fees returned by the ID Management Bureau. Careful attention should be paid to the payment mechanism so that WUA representatives have an incentive to both raise fee collection rates and promote water saving. Information on salaries and payment procedures should be made available to all WUA members.

2.4.8 The finance of WUAs should be separated from the village to avoid interference and interception by village executives.

2.4.9 For the modern management systems and advanced monitoring equipment, it is necessary to train the staff of WUAs and ensure the WUAs correspond with advanced irrigation district management. Each WUA should receive training on operation and maintenance of irrigation infrastructure and equipment, documented in a manual that is left with the WUA. In addition, the WUA Chairman and/or members of the Executive Committee should receive training in WUA financial management, and WUA water accounting procedures needed for effective understanding and operation of new, rights-based certificate and ticketing systems.

2.4.10 Irrigation district management agencies are responsible for solving dissension between associations.

2.5 Farmers

2.5.1 Farmers are the direct users of water resources, and are the customers for irrigation services. Farmers should be made aware of ID management systems and be familiar with their rights and obligations through WUAs so that they can support ID management and protect their water rights. Farmers should also be made aware of new rights-based water certificate and ticketing arrangements. This can be achieved through the WUA Promotion and Consultation Phase mentioned previously.

3 Irrigation and water resources management

3.1 General provisions

3.1.1 The initial water rights allocation provides a total cap limit for water use planning; water use planning allocates water under the cap for water tickets; water tickets provide an efficient method of quota-based water fee collection; and water monitoring and metering provide the data for delivery of water, water fee collection and water trading. Therefore, the initial allocation of water rights, water use planning, the water ticketing system, water fee collection and management, water monitoring and metering and water trading comprise the core of an ID's water management system. At the same time, the management measures mentioned above link together. It is important to pay full attention to their integration and coordination.

3.1.2 The legal authority of ID management systems is directly related to their implementation.

3.2 Initial water rights allocation

3.2.1 The initial allocation of water rights is important to control the total volume of irrigation water use and to safeguard water use rights, and helps promote water efficiency and conservation. Water rights allocation is the core of an ID's water rights management system and forms the basis for water trading. However, there are typically large numbers of farmers in an ID and large differences in per capita land endowments. So the most feasible and practical way of allocating, managing and monitoring rights is through groups of farmers in WUAs. The GWEs held by WUAs provide the foundation for ID water rights management and water conservation.

3.2.2 Developing a water right allocation programme should fall under the guidance of government, but should fully considering the views and needs of WUAs. The principle of "minority is subordinate to the majority" can be used to solve any disagreement during programme development. The allocation should consider the current water use of households.

3.2.3 Eco-environmental water refers to the water taken out of channels for use in wetlands and trees. Generally there are some trees planted besides the canals for canal protection. Because of leakage and groundwater flow, there are often wetlands at the end of IDs which may support valuable flora and fauna. The need to protect such assets should be factored into the design of any channel lining and rights reform programme. It should also be noted that groundwater recharge from irrigation returns may support domestic, agricultural and environmental uses within and outside the ID. Again, these uses/users need to be considered in programme design.

3.3 *Water planning system*

3.3.1 Water use planning can balance water supply and demand, guide water rationing and help manage real-time water rights. It is therefore necessary to develop a water use plan for ID management. According to the principle of "User claim and rational decrease", prior to each irrigation period WUAs shall submit a water plan (the WUA's water demand) to the ID Management Bureau. Once all WUA demands have been collated, and assuming total ID demand does not exceed total ID supply, the Bureau can prepare a Water Use and Scheduling Plan which meets WUA demands. However, if supply is insufficient the Bureau should allocate proportional shares of available water to each WUA according to the "rational decrease" principle and formula. Hence WUAs can freely decide their demands for each period, but summed demands cannot exceed their long-term water rights, and actual delivery has to reflect water availability in any given period.

3.4 *Water certification*

3.4.1 Water certificates and water tickets are the vouchers for water rights implementation water trading.

3.4.2 The property rights embodied in a water certificate are defined according to capped volume, time duration, and implementation and operation rules.

3.4.3 The function and uses of water certificates are summarized in Table 5.

Table 5: Function and uses of water certificates

Function	Use
Voucher for long term rights	HIMB records each WUA's long-term water rights (GWEs) in a water certificate.
Calculation of purchase limits	At the beginning of the year, HIMB calculates the water purchase limit (annual entitlement) of each WUA and records this information on the certificate. After purchasing tickets in each irrigation period, the purchase amount will be recorded on the certificate to calculate the remaining purchase limit for the following periods. WUAs can purchase tickets beneath the limit.
Record of water trading	HIMB section offices record all information on water transactions.
Reference for water rights reallocation	HIMB will accumulate data on actual water use across seasons and between years, helping to guide any future adjustment.

3.5 *Water tickets*

3.5.1 The function and uses of water tickets are summarized in Table 6.

3.6 *Water fee budget management*

3.6.1 The ID Management Bureau collects water fees from WUAs; WUAs collect water fees from farmers. These are normally area-based.

3.6.2 The revenue from water trading should accrue to WUAs, and be used in accordance with related provisions for sustainable development of WUAs.

3.6.3 Widely solicit users' opinions: questionnaires and conferences.

Table 6: Function and uses of water tickets

Function	Use
Support for permit control and quota management	WUAs buy tickets under their caps; HIMB sells tickets according to water availability and water rights limits.
Pre-payment for water	Water is only supplied by HIMB once WUAs have purchased tickets.
Water trading and monitoring	WUAs can buy and sell 'saved' tickets; HIMB monitors ticket turnover and adjusts caps as necessary.
Payment voucher – rights and duties	Tickets provide information on GWEs, actual delivery and payment – a summary of entitlement and payment obligation.

3.7 Water monitoring and metering

3.7.1 This term is applicable to surface water gravity IDs. The automated monitoring system should be used to complete the work described in this term.

3.7.2 Currently, monitoring equipment in most Chinese IDs is rudimentary. For example:

a. Water levels and flows are measured by hand. And water use is also calculated manually using paper forms. Water monitoring and measurement takes a long time, and is not very accurate.

b. For large IDs, water measurement places a very heavy workload on staff. They may need to spend many days in the field at monitoring sites.

c. During irrigation, many sites need to be monitored to check diversions to WUAs. But because of the large irrigated areas, there is a serious shortage of flow measurement staff and their workload is heavier.

An automatic monitoring system can increase the accuracy of water management, shorten sluice operation times, reduce staffs workload and release staff time for channel and field-level water management activities.

This system can measure water more accurately. The water demand and supply situation can be displayed directly on computer. It is easy for management and supervision with this system, so that the water supply cost reduces, the credibility of water supply management increases and social and economic benefits are realized.

3.7.3 This term is suitable for the IDs that establish WUAs below 4th level canals. Measuring WUAs' water use information is a major task of the monitoring system, so the system needs to have monitoring sites at WUA delivery points.

3.7.4 The main canals are directly managed by the ID Management Bureau, and real-time information on important sections/gates should be displayed in the ID Management Bureau distribution center. Information from 4th level canals where WUAs take delivery of and purchase water should be monitored in real-time as this affects farmer costs and supports quota-based management.

3.7.5 This term is suitable for IDs that establish WUAs under 4th level canals. The flow in the 4th canals is smaller and related to water fees of WUAs, so the measurement here should be of higher accuracy.

3.7.6 Automated monitoring and data transmission systems can sometimes make monitoring less transparent to users, and data less easily accessible. It is important that systems are transparent, and that information is made available to all interested stakeholders, especially WUAs and farmers, in a form that is accessible and easily understood.

3.8 *Water trading management*

3.8.1 Efficiency improvements undertaken by individual farmers and WUAs – and even main channel lining works carried out by an ID Management Bureau – may not save sufficient water to meet the needs of new users. Hence, only pooled savings from efficiency measures throughout an entire ID may generate enough water for trade. In these circumstances, there is a need for a mechanism that can coordinate water saving measures and accumulate savings throughout an ID, and transfer the collated savings to other parties.

3.8.2 Water trading should occur under the water permit of the ID.

3.8.3 A bank could transfer and sell water out of the ID to (for example) municipal and industrial users. However, if the water saved and sold was already being recycled and used by others (e.g. by 'downstream' groundwater users dependent on irrigation returns), then water is simply being re-distributed, and savings are not 'real'. Only those conservation measures that lead to reductions in non-beneficial evapo-transpiration (ET), and/or reduce non-recoverable losses, generate real savings. Note: non-beneficial ET in this context is water evaporated or transpired (e.g. from water surfaces, riparian vegetation, uncovered soil) that does not contribute to crop growth. Non-recoverable losses occur when water is lost to further use – e.g. flows to saline water bodies, deep aquifers that are not economically exploitable, or flows to the sea.

3.8.4 This requirement would not preclude a water savings proposal from being prepared and submitted after works had been completed, but in these cases entitlement holders would run the risk that the proposal would not be approved or would be approved conditionally (for example, subject to further work or testing).

3.8.5 After banking water, the WUAs should also continuously pay the water fee for banked water to the ID Management Bureau.

3.8.6 Rules would need to be established about the bank's role in selecting those parties allowed to purchase banked entitlements. These rules will need to ensure fairness and transparency, and to minimize corruption opportunities. The development of such rules would need to take into account regional plans and policies in respect of development. However, they could be as simple as requiring the bank to facilitate the transfer of available entitlements to the first willing buyer.

3.8.7 Because the water rights holders should still pay water fees to the ID Management Bureau after water banking, so the price the bank pays to holders should include the water fee.

3.8.8 The beneficiaries of water banking should pay for the associated costs. These costs would be covered by the difference in the price the bank receives for the transferred permit and the price it pays to the entitlement holders at the time of banking. The price setting process therefore needs to consider the bank's budget requirements.

4 *Hydraulic infrastructure and equipment management*

4.1 *General provisions*

4.1.1 Irrigation district hydraulic engineering projects and equipment management includes the management and maintenance of hydraulic engineering projects and monitoring equipment to ensure its longevity.

4.1.2 Hydraulic engineering projects and equipment maintenance should be separated from management. It can reduce the workload and costs of hydraulic engineering projects and equipment management.

4.1.3 Although the WUA is responsible for irrigation infrastructure and equipment within its command area, the ID Management Bureau takes overall responsibility for the ID and equipment within it. Hence, the hydraulic engineering projects and equipments managed by WUAs should be subject to supervision and inspection by the Bureau.

4.1.4 Commercialized operation refers to the management and maintenance approach of market-oriented companies. Companies manage and maintain hydraulic engineering projects and monitoring equipments, and are paid by the ID Management Bureau. At the same time, a company may also undertake maintenance in other IDs.

4.2 *Irrigation infrastructure management*

4.2.1 The management zone: a distance extending from the canals' edges.

4.2.2 Capital construction procedures refer to "Irrigation and drainage engineering design norms".

4.2.3 This term applies to IDs that establish WUAs under 4th level canals.

4.2.4 Vegetation should be planted on both sides of main and branch canals to prevent sandstorms. It is necessary to protect and manage such vegetation.

4.2.5 For the winter coming, it is strictly forbidden to irrigate near the main canal in the autumn (4th) irrigation period, in order to avoid the water penetration and Frost Heave which could cause the channels destruction.

4.3 *Monitoring equipment management*

4.3.1 Automated monitoring systems are expensive. They need management regulations and maintenance systems for protection.

4.3.2 The monitoring system directly refers to the water use and water fee of WUAs. So it should be managed all by the ID Management Bureau and would not be managed by WUAs.

4.3.3 Advanced computer systems and networks should pay full attention to information security and virus protection. Therefore, automated monitoring systems in an ID should pay close attention to information security.

4.3.4 As some monitoring equipment will be placed in the field far away from management agencies for operations, it is necessary to prevent damage and theft.

Chapter 4: Water abstraction permit specification and registration

4.1 Introduction

This chapter describes the key requirements for the specification and registration of water abstraction permits, to meet the needs of a WET system. It considers issues associated with the way entitlements to take water are defined, how return flows are considered (both in the permit and planning context), and requirements for registration systems used to record and manage abstraction permits.

4.2 Water abstraction permit specification

Specification of a water permit means describing the details of the right to take water. This involves specifying more than just the volume that can be taken annually and the location from which it can be taken. It includes specifying management rules to ensure that the reliability with which water can actually be obtained under a water entitlement does not change. Specification of the management rules is necessary because the volume of a water permit is meaningless unless the reliability with which it can be taken is also specified (and protected).

For example, consider an entitlement to take 1,000 million m^3 per year. There will be some drought years when restrictions are applied so that the volume that can be taken is less than 1,000 million m^3 year. Allowing for restrictions, the long term average may be 900 million m^3 year. However, if additional water entitlements were issued, restrictions would need to be applied more frequently and the long term average may be only 800 million m^3 per year. Although the volume of the water permit would not have changed, the amount of water that could be taken would have fallen because of decisions that were taken about other water permits.

Therefore, a framework for clearly specified water permits should be seen as comprising two elements:

- *The water entitlement:* These are details that are specific to the water permit such as the volume that can be taken and the location from which the water can be taken.
- *The management rules*: These are the rules about the management of the system that ensure that the reliability of supply under all water permits is maintained at specified levels. The rules will include explicit limits on the total amount of water entitlement that can be granted. They will also include water sharing rules that specify restrictions to apply for individual years – these will be described as percentages of the water entitlement volume for specified levels in water reservoirs.

In China, strong connections do not exist between the water plans for a catchment and the abstraction permits to take water in the catchment. A key objective of water resources allocation planning is to improve existing water management rules to ensure that the intended water supply reliabilities for water permit holders are protected.

4.3 Allocating and re-allocating water

4.3.1 Allocating additional water to water abstraction permits

Water resources allocation planning processes should involve setting an explicit limit on the total volume – the cap – that can be allocated from a catchment.

The justification report attached to a water abstraction permit application should consider the water resources allocation plan for the catchment (if one has been established). If it is not possible to grant a water abstraction permit without exceeding the cap specified in the plan, then the application should be refused.

4.3.2 Reallocating water amongst water abstraction permits

When water abstraction permits have been issued in a catchment to the full extent of the cap, there will need to be some means of reallocation so that water can be made available for highest priority water uses. There are essentially two reallocation methods.

- *Reallocation by government.* This may involve government requiring an existing water permit holder to use water more efficiently, and then reallocating the water saved to a new water user. The government can remove financial impacts on the existing user by requiring the new water user to pay the cost of the water efficiency measures.
- *Reallocation using market forces.* When water permits can be traded, permit holders voluntarily innovate to achieve efficiencies to make water available to the market. The price of water entitlements rises or falls to balance supply and demand. This method can be more effective in terms of time, user satisfaction and financial impacts.

It is especially important to have clearly specified water permits under a market-based approach. If water permits are not recognised as secure rights, people will not pay money to buy them and there will be fewer incentives for permit holders make water available by increasing efficiency.

Regardless of how reallocation occurs, clear entitlement specification is important to ensure that all parties have clear understandings about *what* is being reallocated. That is, the water users and resource managers all need to know:

- what the new user's rights to access water will be;
- what conditions will be attached to those rights; and
- what the original users' rights to access water will be after the reallocation.

4.4 Unbundling water abstraction permits

4.4.1 What is meant by 'bundled' water abstraction permits

The application for a water abstraction permit requires an applicant to provide details about a range of matters. These details become conditions of the water abstraction permit issued on completion of the process. As a result, the permit mixes together several matters which can be separated into three groups.

- The 'water entitlement' component of the water permit includes matters that define the share of the water resource that the holder of the water permit is authorised to take.

- The ‘works approval’ component includes matters that define the works that are used to take water under the water permit, including metering and monitoring requirements.
- The third group covers other matters and primarily includes details about environmental management through the regulation of the discharge of effluents by the enterprise.

Additionally, in some instances where trading of water rights has occurred, water permits can be coupled with supply conditions, including the price that will be paid for the water.

4.4.2 Why unbundling permits is important

There are different issues involved in making decisions about the three components.

- For the water entitlement component, the issues concern maintaining river flows or aquifer levels in order to sustain ecological processes and water supplies for users.
- The works approval component is concerned with local impacts on the riverine environment, as well as consistency between the water entitlement component and the works used to take water under the entitlement.
- The issues for the third component are primarily about the total load of discharged pollutants and the capacity of the receiving environment.

Unbundling – that is, separating out these different aspects of a water permit into distinct regulatory instruments (including different assessment and approval processes and (finally) different approval documents) – can lead to improved water resource management for a number of reasons.

Most importantly, it can lead to better decision making, because it allows for clearer responsibilities for the resource manager and more specific criteria for assessing applications. This allows the water resource manager to focus on the particular issue of relevance.

Thus, in assessing an application for a “water entitlement” (i.e. for the volume of water the person wishes to take, as distinct from the other aspects of the water permit) the decision maker need only consider the availability of water, and whether taking the water from that location will impact on supply of water to other users or the environment.

This approach avoids the need for the resource manager to consider whether the proposed use of the water might be unsuitable (e.g. the land is inappropriate for agriculture or for the type of industry proposed).

Similarly, in considering the impact of the works themselves the decision maker need only focus on specific criteria relevant to that issue.

In turn, this approach reduces the use of the water allocation process as a *de facto* land management tool. Rather than using water abstraction permitting as a means of controlling – for example – the types of industries that can develop in a certain location. This approach is likely to lead to improved decision making – both in terms of water resource management and land use management.

In addition, the unbundling of water permits is important to allow for reallocation and trading systems. When water is reallocated, only the entitlement to take water is transferred. As reallocated water will be used in a different location, the works approval for the original entitlement holder's land is irrelevant to the new holder but will need to be retained by the original entitlement holder.

If the different elements of a water permit have already been unbundled, the process of transferring the water entitlement is both clearer and simpler. This will reduce the administrative time and cost involved in a transfer and will make it clear what exactly is being transferred

Unbundling would also allow for separate transfer systems (including market based systems) for pollution discharge rights (e.g. a "cap and trade" system in rights to discharge pollutants to a river).

Unbundling water abstraction permits involves major adjustments to regulatory systems and should, therefore, be seen as a long-term goal. In the interim opportunities should be taken as new registration systems are developed to structure them in a way that reflects the different components of permits.

The following sections discuss the 'water entitlement' and the 'works approval' components, which are key to the water entitlement specification framework and management system. The discussion provides a guide to the changes that will need to be made to water permits to implement the WET system.

4.4.3 The water entitlement component

Core attributes

The core attributes of the water entitlement component should link closely to the water resources allocation plan and the modelling of basin hydrology that underpins the plan. These attributes are exclusively about water quantity issues and not water quality issues or the way the enterprise that uses the water is run.

These core attributes are as follows:

- *Water resources allocation plan identifier:* The water entitlement should clearly specify the water resources allocation plan under which the entitlement is managed. There are two key reasons for this:
  - The water resources allocation plan will detail a range of matters about water entitlements managed under the plan, which effectively form part of the specification of the water entitlement.
  - Where a regional cap has been set by a water resources allocation plan, it will be necessary to know which water abstraction permits are included within the cap.
- *Volumetric Limit:* This is the maximum volume that that can be abstracted in a given period (usually twelve months). If there is a need to also limit the rate of extraction over a shorter period, an additional volumetric limit (such as a daily limit) can be specified.
- *Entitlement priority/reliability category*: Different categories will correspond to different sets of water sharing rules in a water resources allocation plan. These water sharing rules will determine the reliability with which water is available under the water entitlement. While different users are expected to have access to different reliabilities of supply in China, water permits do not currently

recognise explicit entitlement categories because water plans do not contain water sharing rules that help define the water entitlements.

- *Location:* This is the permitted location of the abstraction. It should be specific enough to ensure that the actual site of the pump (or other works) cannot be moved far enough to cause unplanned impacts.
- *Conditions:* These are conditions relating to the abstraction itself. For example, a condition on a water permit for a hydro-electricity plant would be that a specified high proportion of the water abstracted be returned to the watercourse.

Distinguishing between reliability and purpose

Often water permits specify the purpose for which the water may be used (i.e. agriculture, industry, etc). Although the purpose has nothing to do with hydrology, it has been included as a condition of water abstraction permits (in many parts of the world) for two key reasons:

i. as the basis for determining priority of access to water in the case of shortages (such as to give priority to domestic water supplies); and
ii. to protect the shift of water from one sector (typically agriculture) to other sectors.

While this approach has generally been appropriate, more efficient use of water can be achieved – while still ensuring the necessary reliability of supply – by separating the issue of purpose and reliability.

In China, agricultural water supplies are typically designed to be available at 75% reliability while permits for other supplies should have 95-97% reliability. While domestic water supply inevitably requires highly reliable water supplies, the issue is not always so straightforward with other water users. Given the opportunity (and provided the cost is appropriately reflected) industrial users of water may choose to water access rights with a lower reliability.

Similarly, some agricultural users, especially those growing permanent crops (such as grapes of fruit trees) may benefit significantly from higher reliability of supplies.

To allow for this approach, water permits should recognise both:

- purpose – which could, if necessary be used as a means for protecting or promoting certain industries; and
- priority – which determines the priority of permit in terms of water sharing arrangements (and hence its reliability).

In the first instance, it is likely that permits with the same purpose would be given the same priority/reliability. However, over time, this approach would allow for different priorities and reliabilities to be established for water taken used for the same purpose.

This approach may also reduce the risk a problem that can arise from water being reallocated from one sector to another. Where priority is based purely on purpose, then the reallocation of water from agriculture to industry will also amount to a change in priority.

Where a permit only states a maximum volume that can be taken, this change in priority (and reliability) will amount to an increase in the average annual volume of water that will be taken under the permit – because there is the same maximum allowed, but it will be taken more often with the higher reliability. This in turn is likely to affect other users, the environment, or both. Distinguishing between purpose and priority means that these potential problems are more readily apparent and will make resource managers better placed to deal with the problems before they arise.

On-supply responsibilities for some permit holders

Water entitlements are often not used in their final form by the permit holders. In many instances, the entitlement holder provides a water service to end users.

For example, the householders in an urban community do not hold water abstraction permits. Rather, a water supply company holds the permit and uses the water taken to provide a water supply service to the urban community.

Where water services are provided by an entitlement holder, there should be some control of the supply with defined rights and responsibilities. This is important to ensure that all users' rights to access water are secure. Such controls can be provided in rules that water service providers must comply with, agreements between service providers and end users, or a combination of both mechanisms.

Specifying return flows as a permit condition

Return flows

'Return flow' describes water that returns to a river or groundwater aquifer having previously been taken from the river or aquifer. Return flows can be both intentional and unintentional discharges back to the source.

- Examples of intentional return flows include discharges from hydroelectric power stations, factories (waste water) and irrigation channel systems that are designed to overflow back to the river.
- Unintentional return flows can result from things like leaky channels and pipes, as well as runoff and deep percolation from irrigated farmland.

The return flow is then available to be retaken by downstream water users or, in some cases, may contribute environmental flow benefits to downstream areas. Often, however, the return flow will be of diminished quality as a result of its use or the way in which it returns to the water source.

Situations where return flows are relied upon by downstream users are considered to involve 'double accounting' because the same volume of water (i.e. the return flow water) is both included in the first abstractor's entitlement and then relied on to satisfy a second entitlement downstream.

Issues associated with return flows, water planning and abstraction permits

How return flows are dealt with will have impacts on users' opportunities to become more efficient and on the security of other entitlements. There are two key issues to be considered in dealing with return flows:

i. whether or not water planning processes should assume that the water will be returned (and hence whether it will be available to contribute to environmental flows or for reallocation downstream); and
ii. whether or not the return of certain flows should be a condition of taking water under a water permit.

In addressing this issue, water managers should focus on the following principles:

i. Planning and permitting approaches should be consistent. Water resource planning should only assume that water will be returned to the system where there is a condition on the abstraction permit that requires the water to be returned (and vice-versa). If no legal requirement to return the water exists, there is a risk that the water user becomes more efficient, and does not return the water, thereby threatening the plan outcomes (in terms of supply to other users and for the environment).

ii. Conditions relating to return flow should be designed to encourage water use efficiency and to minimise the return of polluted water. Where possible, return flows should not be set as conditions of water permits, and should not be assumed during the water planning process. In particular, this should apply in the case of water that is returned unintentionally or in a highly polluted state.

iii. High-volume return flows that are returned to the river in an unpolluted state and can be accurately measured (e.g. from hydroelectric power stations) should be regulated by being specified as a condition of the entitlement, and should be considered in the water planning process.

Water quality issues

In China, water permits for industrial enterprises often specify both a return flow volume and quality. These volume requirements are more likely to be related to the maximum pollutant load than to required return flows for resource allocation purposes. They should, therefore, not be considered to be part of the water entitlement component of the water permit.

Water permits should clearly distinguish between return flows required for water entitlement purposes and specifications for effluent flows. Effluent flow requirements, and other water quality issues, should be treated as part of third component of water permit matters and separate to the water entitlement component.

4.4.4 The works approval component

The works approval component comprises the details in the water permit that are about the abstraction works. It does not include any details in the water permit about the enterprise using the water.

The works approval would specify any requirements about meter installation. The conditions would be consistent with policies about responsibilities for ownership, installation, maintenance and reading of meters.

The works approval can include constraints on the size of the works to ensure consistency with the water entitlement component of the water permit. For example, the works approval for a groundwater abstraction might limit the depth of a tube well that can be used to extract water to ensure water is taken from the particular source aquifer specified in the water entitlement. Similarly, a works approval for a river pump may limit the size of the pump so that it is no larger than would be appropriate for the water entitlement. This type of constraint would only be necessary where there is no capacity to ensure compliance through the use of water meters.

The installation of abstraction works can involve the clearing of vegetation and the works can change the flow of water causing erosion difficulties. The works approval component should set any conditions needed to minimise these impacts.

4.5 Exclusions from the system

4.5.1 Current exclusions

Some water abstractors are not required to hold a water abstraction permit. Exclusions of certain abstractions should only occur on the basis that the associated risk to the environment and other users have been assessed to be low.

Many countries have decided to exclude stock and rural domestic use from their entitlement systems. In those cases, it has been assessed that the potential for any significant change in the volume used for stock and domestic purposes is small and does not pose a significant risk to the reliability of supply to water entitlement holders or to the environment. At the same time, it has been assessed that the cost of monitoring and regulation would be high.

Although excluded from the entitlement system, the amount of water taken by these users needs to be assessed for water planning and evaluation purposes.

In China, rural residents taking a small quantity of water for domestic use or for poultry and livestock are excluded from the water permit system. However, there are additional exclusions from the need to hold a water permit and these exclusions are significantly influenced by historic factors rather than a risk assessment. Collectives are excluded from the water permitting system. In addition, although other agricultural users are required to hold a water permit, many do not. This is especially the case for agricultural users of groundwater.

Table 7 shows how the proportion of agricultural use that occurs under water abstraction permits in China is much lower than for the industrial and domestic sectors.

Table 7: Comparison of permitted and actual water consumption by sector

		Industrial	Domestic	Agricultural	**Total**
National (2005)	Gross annual water consumption (billion m^3)	128.52	67.51	358	**563.3**
	Permitted water consumption (billion m^3)	108.753	52.739	235.602	**397.094**
	Proportion of water taken under permits (%)	84.62	78.12	65.81	**70.49**
Zhejiang (2005)	Gross annual water consumption (billion m^3)	6.273	3.096	11.458	**20.826**
	Permitted water consumption (billion m^3)	5.504	3.841	6.185	**15.529**
	Proportion of water taken under permits (%)	87.74	100	53.98	**74.57**

Note: The agricultural water consumption covers irrigation, forestry, livestock husbandry, and fisheries, as well as for the 'environment' (i.e. beautification).

4.5.2 Including users in the permit system

As agriculture is the major use of water in China, agricultural users need to be brought fully into the water permitting system.

Water user communities, particularly agricultural users, can be expected to resist being included in the water permitting system for the first time because of:

i. concerns that a water permit may reduce their access to water;
ii. a desire to avoid charges that apply for water taken under a permit; and
iii. views that contributions made to the construction of irrigation systems should warrant exclusion from the need to pay the associated charges.

The following strategies are proposed to address these issues and concerns:

- *Education*: a range of core messages need to be explained:
    - Water permits create rights, which will become increasingly valuable over time.
    - Water permits are protected from the erosion of reliability by the WET framework including a cap on the allocation of water. Abstractions without permits are not protected.
    - Even though establishing water permits will involve some costs, ultimately the change will be in the financial interests of end users.
    - Management costs continue to accrue. Contributions to infrastructure construction do not justify exemptions from management charges indefinitely.
    - The rights of all water users depend on all agricultural users being part of the water permitting system. It is unfair for some to put the security of others at risk.
- *Transition Pricing:* water charges for existing water users moving into the water permit system could be introduced progressively (e.g. over a five-year period) if the water user applies for a water abstraction permit during a grace period (e.g. one year). A longer transition period could be offered to those who contributed to scheme construction.
- *Administrative:* development of a stream-lined approach for identifying those agricultural users without abstraction permits and for granting permits to them, including clear criteria for deciding:
    - who the permit should be grated to; and
    - the volume that should be granted.

4.6 Registration systems

4.6.1 The concept of a register

As a water resource becomes more heavily committed, the water permits in that system will become more valuable. As the entitlements become more valuable, the security of the entitlement system will become more important.

In addition to the clear specification of the entitlement, a key aspect of security is the water permit register. The register is the record of the details of all of the water permits that have been issued and the person who holds the permit.

Registers should be structured and accessible.

- ‘Structured’ means that the details are organised in a way that enables the data to be sorted and analysed. For example, a structured register could be searched to find the total of the volumetric limits for water permits of a certain type in a certain area.
- ‘Accessible’ means that the public have the right to search the register and have practical access to the information it contains.

There are a number of key advantages to having registration systems that record water permits in a structured and accessible form, including:

- providing stakeholders with confidence in the system – stakeholders will be able to see any changes that occur and the managing authority can be held accountable for the changes;
- protecting stakeholders against fraud by having a defined holding point for permit details (for example, if a prospective buyer of an enterprise noticed a difference between the details on a water permit for the enterprise and the details on the water permit register, then that would be a matter to be resolved before proceeding further);
- making water accounting easier by enabling reports to be generated about particular aspects of water permits, and changes to permits, quickly and simply.

4.6.2 Electronic and paper-based registers

Information about water abstraction permits in China is primarily maintained in paper archives. One implication of this is that it makes sharing information amongst the management organisations at different levels of government difficult, particularly if information is needed quickly. This is a key reason for China investigating electronic information management systems.

It should be noted, however, that while modern electronic database systems are excellent tools for housing reliable registers, they can also house unreliable registers. At the same time, paper based registers can be reliable even if they are not as accessible or flexible as electronic registers. Therefore, it should not be assumed that by simply assembling entitlement data on en electronic system, a reliable and effective register will be achieved.

4.6.3 Change issues

If a register is well structured and accessible, stakeholders will be able to see the changes that occur. However, stakeholders should also be able to see the reasons why changes are made. This adds to confidence that the water management system as a whole is being managed in accordance with the rules. Currently, however, China’s water laws do not explicitly define the ways that permits can be changed or the procedures for making changes.

In China, the justification report is the key document on which a water permit decision is based. A comprehensive and robust register should record the justification report and any other significant documents, or at least references to such documents.

Electronic databases have provided opportunity for great improvements in this area. Documents can be scanned and then attached to the water entitlement in the register. A person searching the register can then not only see changes to a permit, but can also see the reasons for the changes.

4.6.4 Structure issues

In developing a structured electronic register of water entitlements there should be a clear understanding about its boundaries. In addition to the details of the water permit itself and the person who holds the permit, the regulating authority will need to collect and record a range of other data for management, reporting and compliance purposes. This could include metered use data, the details of the works actually constructed, and perhaps the types of crops grown under an irrigation entitlement.

These information elements should not form part of the register because they are not part of the permit itself or instruments on which a change to the register was based.

If it is necessary that a single database house both the register and the other information, then a virtual separation should exist. Delegations (in terms of who can access and change particular information) and processes surrounding the two parts of the database should be managed separately.

The bundling issues discussed in previous sections should be considered when new registration systems are under development in China. The water permit register should incorporate a water entitlement component, a works approval component, and another component encompassing other matters such as effluent management. While it is desirable that separate instruments are issued to regulate the separate matters, it is likely that water permits will continue in essentially their current form into the immediate future. However, when new registration systems are designed the water entitlement component should be structurally separated from other components. This will encourage clear thinking about bundling issues and will make it easier to remove some of the data sets at a later date if it is eventually decided to regulate the non-entitlement issues separately.

4.6.5 Timing issues in register development

There is a risk that if development of registers proceeds in advance of the development of the water entitlement framework, less than optimal register structures may result and adjustment may be needed soon after the register is built.

For example, through water resources allocation planning it may be decided that new attributes are needed for the water entitlements in a catchment. It may be decided that in addition to the annual volumetric limit, water entitlements should also have a volumetric limit of the amount of water that can be taken in the first quarter of the year. As a result, the ‘first quarter volumetric limit’ would become an attribute of the specification on approval of the water resources allocation plan. The register should record the new attribute in a structured way that facilitates audit and reporting, rather than as a ‘free field’ condition of the water entitlement.

Over time, the specification of water permits and associated water register structures can be expected to evolve. As a result, the register will never have or retain an optimal structure. Nevertheless, the biggest changes can be expected to be associated with the initial water resources allocation planning cycle. Register design and construction should be concurrent with planning processes to the extent practicable.

PART 3: TAIZHOU PILOT STUDY REPORT WRAP & E-FLOWS IN THE JIAO RIVER

Chapter 1: Summary of the pilot work undertaken in Taizhou

This chapter describes a pilot study undertaken in Taizhou as part of Phase 2 of the WET Project. Various members of the project team undertook numerous visits to Taizhou to meet local officials, to gather relevant information and conduct site assessments. Officials from the Zhejiang Water Resources Department and the Taizhou and county-level Water Resources Bureaus provided significant support throughout this process.

The first stage of the pilot work involved collecting background information, including details about:

- the geography, natural environment and socio-economic conditions;
- water resource availability;
- current levels of water use and development
- the operating arrangements for existing reservoirs; and
- existing water resources management systems, including permitting arrangements, etc.

This information is summarised in Chapter 2. It was used to analyse the existing water resources management arrangements in Taizhou and led to the identification of key issues that would need to be addressed to support the implementation of a water rights system. These issues are discussed in detail in Chapter 3.

Concurrently, an IQQM water resources management model was built for part of the Jiao River basin. The construction of the IQQM for the Jiao River basin is discussed briefly in Chapter 5 and again in detail in the context of the review of potential water resources management models for China in Part 5 of this report.

This model was used both to demonstrate the functionality and benefits of such a model and to support the detailed environmental flows assessment and water resources allocation planning work undertaken for the Jiao River basin.

This detailed work is discussed in detail in Chapters 4 and 5. In summary, the process involved:

- identifying the important environmental assets for the basin;
- identifying the parts of the flow regime of importance for the environmental assets and determining objectives for these flows;
- using hydrologic and hydraulic models to quantify the magnitude, duration, frequency and timing of flows required to meet the environmental flow objectives;
- formulating a range of scenarios involving different approaches to water resources allocation, management of infrastructure and environmental flow management. This included some scenarios with operational rules that would ensure that the environmental flow objectives were achieved;

- the evaluation of the scenarios, using the results of the IQQM, to identify their respective advantages and disadvantages in terms of impacts on environmentally-relevant flows and on the volume and reliability of water available for consumptive purposes; and
- describing how a preferred scenario could be incorporated into a water resources allocation plan for the Jiao River basin.

Chapter 2: Background information on the Taizhou pilot site

2.1 Introduction to Taizhou

Taizhou prefecture is located in the mid-coastal region of Zhejiang province. Zhejiang is located in the southern part of the Yangtze River Delta on China's southeast coast. It lies directly to the south of Shanghai.

Taizhou's total land area is 9,411 kilometres^2 and its population is almost 5.5 million. The prefecture comprises two cities (Linhai and Wenling), three districts (Jiaojiang, Huangyan and Luqiao) and four counties (Yuhuan, Tiantai, Xianju and Sanmen). Six of these nine counties[31] border the East China Sea. Maps of the region are provided at Appendix 1.

2.2 Natural environment in Taizhou

Zhejiang has a wide variety, and extensive coverage, of vegetation. Forestry covers 59.4 percent of the province's total area with rich resources of economic forests and bamboo grove. More than fifty species found in the province are listed in the Directory of Rare Plants under State Protection.

Zhejiang also has about 1,900 species of wild animals, over 120 of which are under state protection. These species make up one-third of those in the Directory of Wild Animals under State Protection. The province is also abundant in fishery resources.

Taizhou's landform is high in the west and low in the east. On the east coast are the Wenhuang, Jiaobei and Datian plains. Sanmen bay is located in the north, Taizhou bay in the middle, Aiwan bay in the southeast and Leqing bay in the south west. Taizhou prefecture includes 687 islands near the east coast. The mainland coastline is 745 kilometres long, while the total coastline (including islands) is 1,660 kilometres.

The main types of landform are hills and mountains, which cover 73% of Taizhou's land. The plains cover 22.4% and the inland water area accounts for 4.6%.

The Jiao River basin lies within the evergreen broad-leaved forest vegetation region of China. The natural vegetation in the basin consists of subtropical evergreen broad-leaved forests and needle leaved evergreen forests. Typical central subtropical evergreen broad-leaved forests are distributed in areas at altitudes from 650m to 1250m. Mason Pine forests are distributed in hilly regions below 800m. Chinese fir forests grow at altitudes below 1200m. Higher altitude mountain regions are occupied by secondary

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* The information in this report is taken from the *Comprehensive Plan for Water Resources in the Taizhou Prefecture* and discussions with local officials, unless footnoted otherwise.

[31] NB: cities and districts are both classified as county-level governments.

shrubs and herbs. Lowland floodplain areas have been extensively cultivated for rice, wheat and other crops such as fruit and vegetables.

The Taizhou Gulf, Yueqing Gulf and Sanmen Gulf are the three most important wetlands in the Taizhou region. They are composed largely of tidal estuaries and inter-tidal mudflats with small islands. Nature reserves and ecological function reserves with biodiversity significance occupy only 0.64% of the total area of Taizhou[32]. Taizhou has one county level nature reserve (Kuocang Mountain) and no ecological function reserves.

Taizhou has 21 rivers (including tributaries) each covering a basin area of over 100 kilometres^2. The most significant is the Jiao River ("Jiaojiang"). The Jiao River basin is the third largest in Zhejiang province. With a total length of 208.2 kilometres and catchment area of 6,750 kilometres^2, it covers 70 per cent of Taizhou's land area[33].

- The section from the headwaters of Jiao River to Sanjiang Village (in Linhai) is called the Yong'an Creek ("Yong'anxi").
- The mid-stream section, from Sanjiang Village to Sanjiangkou, is called the Ling River ("Lingjiang").
- The lower reaches, from Sanjiangkou to Niutoujing, is referred to as the Jiao River ("Jiaojiang").
- The estuarine section of the Jiao River runs from Niutoujing to Songpuzha, where it reaches Taizhou Bay and the East China Sea.
- The major tributaries in the Jiao River system are the Shifeng Creek (with a length of 122.1 kilometres and basin area of 1,609 kilometres^2) and the Yongning River (with a length of 77.2 kilometres and basin area of 890 kilometres^2).

2.3 Taizhou's climate

Taizhou's climate is subtropical and monsoonal. The division of seasons is clear. The average temperature is between 16.6℃ and 17.3℃, increasing from north to south. The extreme temperatures range between lows of –5.4℃ to –9.9℃ and highs of 33.8℃ to 41.7℃.

Taizhou receives regular and relatively high wet season rainfall due to monsoonal and typhoon influences. Average annual precipitation across Taizhou is 1,632 mm and average annual runoff ranges between 600mm and 1,200mm.

Floods are common in the wet season. However, a distinct dry season exists over winter. Periods of drought (or of water shortages) are of relatively short duration.

2.4 Socio-economic conditions and projections

Taizhou is highly industrialised. While the population is split almost equally between urban and rural areas, only about 20 per cent of the total population is engaged in agriculture. Continued growth in the urban population and industry is anticipated.

[32] Website of the Taizhou Environmental Protection Bureau, 2007.
[33] Zhuxi Reservoir design documentation

Despite these trends, the agricultural sector remains the biggest consumer of water in Taizhou. The majority of the agricultural use occurs during the wet season (April – September). In 2002, 60 per cent of the region's supplies were used for agriculture, 14.9 per cent for domestic use, 21.1 per cent for industry and four per cent for ecological environment (i.e. for watering parks and gardens, and beautification projects, etc). The most recent data, however, indicates that primary industries accounted for only 47.1 per cent of all water use in Taizhou in 2005[34]. This includes irrigation, aquaculture, forestry and animal husbandry.

Taizhou officials advise that agricultural water needs are reducing due to a combination of a general shift away from the sector (with land either left stagnant or lost to industrial and urban expansion), changing cropping practices (e.g. farmers are generally replacing rice with grapes and watermelons) and the adoption of rural water use efficiency practices. These trends are expected to continue into the foreseeable future.

Contrary to these trends, however, the comprehensive water resources plan for Taizhou is based on agricultural water use increasing by about seven per cent by 2010 then returning to existing levels by 2020. Only in the following ten years are agricultural demands predicted to drop below current levels.

Taizhou's population concentration is highest in the south-east, where the bulk of developed industry is located. In these areas, the average per capita availability of water resources is 873 m^3, whereas the average across the prefecture is about 1650 m^3 and the provincial average is 2123 m^3. Of the available water resources, 38.4 per cent has been developed (i.e. 38.4 per cent of the mean annual flow is taken for out-of-stream consumptive purposes).

In contrast, the north of Taizhou has more water resources, but lower levels of development. For example, Xianju county has the highest average per capita volume of water resources at 5,191 m^3, of which 6.9 per cent has been developed.

Total water demand in the south of Taizhou (which is largely supplied by the Changtan Reservoir) is expected to increase from 76.5 million m^3 in 2010 to 117.7 million m^3 in 2020. Most of the additional demand will come from growth in urban and industrial consumption.

The increase in urban consumption will result from population growth as well as predicted increases in average domestic use from improved living standards. Household consumption in these regions is expected to increase from the current average of about 119 L/p/d to 135 L/p/d in 2010 and then to 155 L/p/d by 2020. In the north-eastern part of Taizhou, similar trends are likely to occur (but potentially to a lesser degree). Annual population growth throughout Taizhou is 0.722 per cent.

2.5 Water resources development

On average, about 9.08 billion m^3 of water resources is available annually. In 2005, about 1.54 billion m^3 was used throughout Taizhou[35].

[34] *Taizhou Water Resources Bulletin 2006*

[35] *Taizhou Water Resources Bulletin 2006*

Currently, there are four major storages in Taizhou:

i. The Changtan Reservoir in Huangyan District is the biggest storage in Taizhou. It was built in the late 1950s and early 1960s on Yongning River. It has a capacity of 732 million m^3 and is used predominantly for urban supply to the Jiaojiang township (the largest population centre in Taizhou). It also supplies water for the irrigation of about 66,667 ha (one million mu) of cultivated land. Dam releases are first directed through a hydropower station.

iii. The Niutoushan Reservoir in Linhai city was built in 1989 and is mainly used to supply two irrigation districts. About two-thirds of its 302 million m^3 capacity is used to irrigate almost 2100 ha (about 313,000 mu).

iv. The Lishimen Reservoir is on the upper reaches of the Shifeng Creek (which joins the Yong'an Creek). It has a capacity of 199 million m^3 and is used for urban water supply (to the township of Tiantai), irrigation supply and hydropower generation.

v. The Xia'an Reservoir is on the western boundary of Taizhou prefecture. It has a capacity of 135 million m^3.

There is also a large number of smaller storages throughout the prefecture, generally maintained by villages.

Groundwater resources are limited, generally very shallow and over-exploited. The extent of artesian groundwater development has caused serious land subsidence. Consequently, most artesian bores are being closed progressively (with only some to be retained for contingencies). Areas of restriction or prohibition have been established in the most overdeveloped subartesian groundwater areas. Groundwater resources are essentially reserved for low impact use such as stock and domestic.

2.6 Existing planning arrangements and systems

2.6.1 Water supply planning

A comprehensive water resources plan for Taizhou prefecture was finalised in 2004. This was prepared in accordance with central level and provincial requirements and in the context of water shortages that occurred throughout Taizhou in 2003. The prefecture is experiencing water shortages in certain areas again this year. The water shortages in the southern and eastern parts of Taizhou, in particular, are considered to be due to a lack of supply infrastructure and poor water quality.

In general terms, the planning undertaken to date has been based on expectations that total water supply requirements for Taizhou will increase significantly through to at least 2020. The major source of demand increases will be from the domestic and industrial sectors in the southern and eastern areas of the prefecture.

The supply planning approach taken in the Taizhou comprehensive plan involves a three-tier water balance exercise.

- First, projected population growth, economic development, urbanisation and living standards are compared with existing water supply infrastructure.
- If a supply shortfall is identified against projected demands, then the water balance is recalculated assuming strengthened water efficiency measures and some industrial restructuring.

- If still required, a third calculation will involve adjustments to economic layout and industrial structures, and the transfer of water between basins.

This approach has led to two key outcomes for Taizhou.

i. A pipeline currently is being constructed to deliver water from the Changtan Reservoir to Yuhuan. It is due to be completed in 2009 and will relieve the water storage and distribution problems on the island, which required water shipments via tankers from Wenzhou prefecture in 2003 and again this year.

ii. Two major new dams have been proposed in the south-west of Taizhou to accommodate projected increases in water demand: the Zhuxi and Shisandu Reservoirs. These projects have been proposed in accordance with "The master plan for water resource protection and development and utilization in Zhejiang Province". The two new storages, when combined with the Changtan Reservoir, are expected to provide sufficient supplies (totalling 145 million m^3) for development in the south of Taizhou beyond 2020.

A few other new storages are also proposed to be constructed in Taizhou by 2020. The most significant proposals are discussed in the following paragraphs.

Zhuxi Reservoir[36]

Zhuxi Reservoir is due to be operational by 2011. It will be located on the Zhu Creek ("Zhuxi") in Xianju county. The construction of two or three new weirs on the tributary downstream of the dam is also proposed.

The catchment area is 172.3 kilometres^2 and the mean annual flow is 190 million m^3. The area to be inundated will be about 174 ha (2613 mu) and about 6,600 people will be relocated to enable the dam's construction.

The dam wall for Zhuxi Reservoir will be about 70 metres high. The storage capacity will be about 125 million m^3 and the effective storage volume will be 98.67 million m^3. The beneficial capacity (excluding the dead storage) is 93.53 million m^3. The dam will also have a flood mitigation function with a defence capability of 28.31 million m^3.

The dam will increase the total annual volume of water supply by about 122 million m^3, which will be used to:

- increase urban water supply in the basin to 8.76 million m^3;
- increase water supply for the irrigation of about 2,460 ha (37,000 mu) in the basin to 15.58 million m^3 (in 2010);
- provide 4.41 million m^3 for parks, gardens and beautification projects; and
- transfer 93.68 million m^3 to Changtan Reservoir for on-supply to other users and counties (via a pipeline with a capacity of eleven m^3 per second).

The dam will also be used for opportunistic hydropower generation (that is, usually only when releases are made for other purposes). Two 2500 kW units are to be constructed, to provide an expected generating capacity of 15.81 million kWh.

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[36] *Comprehensive Water Resources Plan for Taizhou Prefecture* and Zhuxi Reservoir design documentation

While the dam proposal and feasibility report have been completed, the project is still at the preliminary approval stage. Approval of the whole project is ultimately required from the National Development and Reform Commission, at the central level. The nature of the final project approval will determine the actual volume that can be supplied from the reservoir.

The total investment for this project is expected to be about 950 million RMB. The institutional arrangements for the dam's ownership are yet to be determined, including the nature of any agreements governing the supply of water from Zhuxi Reservoir to Changtan Reservoir.

Shisandu Reservoir

The second major reservoir is proposed to be constructed in the Shisandu basin by 2020, subject to future assessments of Taizhou's water demand. This reservoir is projected to yield about 145 million m^3 per annum.

The Shisandu basin is towards the western border of Taizhou and, thus, more remote from the main areas of future demand. This site is considered to be a contingency option and would only be progressed if the projected demand increases actually eventuate to the extent suggested.

The project would involve a pipeline to one of the new weirs just below the Zhuxi Reservoir via another new dam, the Wanchang Reservoir, on Shibadu Creek. This is designed to enable the on-supply of water to the high-demand areas in the southern and eastern parts of Taizhou.

Huanglong Reservoir

The Huanglong Reservoir in Tiantai county (north-west Taizhou) is nearing completion. Unlike the proposed Zhuxi and Shisandu Reservoirs, it is designed to replace an existing dam as the primary source of supply for Tiantai township.

Currently, the township is supplied via 36 kilometres of channels and tunnels from the Lishimen Reservoir. Lishimen's main functions, however, are irrigation supply and hydropower generation. Removing its urban supply component will increase the reliability of supply for these users. It will continue to act as a back-up supply for Tiantai in case of emergencies.

Fangxi Reservoir

The Fangxi Reservoir is planned to be constructed on a tributary that flows northwards into the Yong'an Creek just west of Sanjiang Village. This will be the major source of supply for Linhai township, providing about 58.4 million m^3 per annum.

2.6.2 Water resource planning

There is a general expectation that urban and industrial users will receive an annual reliability of 95 or 97 per cent, while agricultural users will have 75 per cent reliability. Designs for future water supply projects typically aim to achieve these reliabilities.

Beyond the comprehensive plan for water resources in Taizhou, no more specific resource planning or allocation arrangements have been implemented. The comprehensive plan does, however, include triggers for contingency supply arrangements. These are in general terms and provide for four drought classes (see Table 8).

Table 8: General drought contingency arrangements in Taizhou

Class	Drought period	General contingency arrangements
1st: Common	40 to 50 days	N/A
2nd: Big	50 to 70 days	All polluting industrial water use is forbidden
3rd: Serious	70 to 90 days	All industrial water use forbidden (except important and low consumption users)
4th: Extreme	over 90 days	All industrial use forbidden (except very important industries)

In addition, the comprehensive plan and Zhuxi design documentation outline more specific arrangements for managing the major reservoirs (Changtan, Zhuxi and Shisandu) during future water shortages. The specific arrangements vary depending on the status of the future infrastructure projects. They dictate the cessation of supply to different sectors when certain water levels are reached, as well as operation arrangements for the pipelines between the storages according to the water levels in the supplying dams.

Both the general and specific drought response arrangements are based on the following prioritisation of users:

i. urban and rural domestic water users;
ii. priority industrial and agricultural water users;
iii. low consumption and non-polluting industrial water users; then
iv. polluting industrial water users (other than priority industries).

It would appear that considerable discretion exists for how available water is shared amongst users when in short supply. Should such circumstances arise, specific arrangements are developed between the county and prefecture governments.

While the fundamental principle appears to be guaranteeing urban and rural domestic supply, in practice these users still experience restrictions and these can be severe and abruptly imposed.

- For example, in 2003, Wenling residents' supply was limited to two hours each morning and evening.
- Similarly, supply to workers (and their families) housed by the Taizhou power station company was limited to two hours per day for three months with no phase-in period. At the same time, however, the water needs for agricultural users and the power station itself, which are both supplied from the same dam, were guaranteed.

As such, it is not clear how design reliabilities and prioritisation principles correlate to actual supply reliabilities.

While prioritisation of various users is apparent (even if the mechanisms to achieve this hierarchy are not), it is not clear what (if any) provision has been made for natural ecosystem requirements in the assessment of storage yields and reliabilities. Currently, it appears that consideration is given to releasing water from storages, or allowing flows to reach the end of river systems, on an ad hoc basis only. Further, any such decisions appear to be made in order to dilute downstream pollutants and for off-stream consumption associated with beautification, restoration, dust suppression or other landscape amelioration activities.

2.6.3 Modelling

The Xin'anjiang hydrology model has been used in Taizhou. While the areal extent of this modelling is not clear, it has seemingly been used to analyse specific projects rather than for assessing basin-wide hydrological conditions. There is no water resource management model in place for Taizhou.

Justification reports prepared for abstraction permit applications need to be supported by assessments of inflows, return flows and water levels in the river and channel networks. However, there is no modelling undertaken to support the evaluation of potential third party impacts from the proposed abstractions.

2.6.4 Permitting

Water permits in Taizhou

Throughout Zhejiang, permits are not required for volumes of water abstraction up to:

i. 2,000 m^3 per year for stock and rural domestic use;

ii. 5,000 m^3 per year for irrigation; and

iii. 3,000 m^3 per year where the water is taken manually or by animal power (unless it is for commercial purposes).

In Taizhou, a water quota for agriculture was set in 1988. It was intended that this quota be reviewed regularly, but no such review has ever occurred. Permits are not always issued for rural domestic supply, especially where reservoirs and ponds are collectively owned.

Table 9 summarises the status of water abstraction permits in Taizhou at the end of 2006.

Table 9: Status of water abstraction permits in Taizhou in 2006

	Industry	Domestic	Agriculture	Water supply	Total	Hydro
Total no. of permits	617	210	2,103	60	**2,990**	210
Total volume (billion m^3)	0.055	0.007	0.218	0.152	**0.431**	4.54
No. of reviewed permits	578	198	0	56	**832**	139
Total volume (billion m^3)	0.046	0.006	0.032	0.046	**0.13**	2.868
No. of expired permits	26	6	0	0	**32**	0
Reduced volume (billion m^3)	0.016	0.0001	0	0	**0.002**	0
No. of changed permits	28	0	0	0	**28**	1
Increased volume (billion m^3)	0	0	0	0	**0**	0
Reduced volume (billion m^3)	0.001	0	0	0	**0.001**	0.025
No. of metered permits	423	176	0	67	**666**	0
Percentage of total permits	68.6	83.8	0	116.7	**22.3**	0

The process for granting water permits

The Regulations on Management of Water Permit and Water Resources Fee have been implemented in Taizhou and applications for water abstraction permits are considered in accordance with these regulations.

Applications are considered by either the provincial, prefecture or county water resources authorities, depending on the circumstances of the proposal (i.e. the responsible level of government is defined by a combination of purpose, volume and source of the proposed abstraction).

The processes involved in seeking a new water abstraction permit are essentially the same at each level of government and involve two key stages. The first involves expert consideration of a 'justification report', which must demonstrate the availability of the water and consider potential third party impacts. The second stage is the consideration of the permit application and is contingent on the justification report being accepted. This stage allows for the hearing of any objections from the public.

Once an application is approved, the proponent can construct works (this includes installing meters, the types of which are stipulated according to the abstraction volume). After a period of trial operation, the government inspects the constructed works for compliance with the preliminary approval before issuing a water abstraction licence.

Annual abstraction plans for the permits are set each year by the Water Resources Bureaus based on current water availability and rainfall forecasts.

2.6.5 Registration systems

Both the Zhejiang Water Resources Department and the prefecture Water Resources Bureau are developing information systems to record details about water abstractions.

The provincial database will include details about applications, permits (including the justification report), annual allocations, metering details and, in future, real-time monitoring data. When operational and populated, this database is expected to contain about 20,000 permits. Most of these will be managed at the county level, while the provincial government will deal with about 20 records per year (including renewals) and the Taizhou Government only two or three per year.

The database will be complemented by a publicly-accessible website detailing information such as summary data, forms and area quotas.

Taizhou's information system has been under development since 2005. It will record details about permit applications, approvals, transactions, and monitoring. While independent of the provincial system, some information will be replicated in both databases. Further, permits issued at the provincial level for abstractions that occur in Taizhou will be included in the database being developed by the prefecture. The Taizhou Water Resources Bureau will also be responsible for the management and monitoring of these permits.

2.6.6 Monitoring and compliance

The provincial government requires real-time monitoring of water use by enterprises that abstract more than 500,000 m^3 per year.

At the end of every year, enterprises must submit a water use summary. This information will be considered by the Water Resources Bureaus when setting the following year's Annual Abstraction Plan.

The Taizhou Water Resources Bureau has some inspectors who undertake checks on abstraction volumes, metering devices, return flow quality and water resources fee payments. While this includes checking that the point of return flow is consistent with the requirements under the abstraction permit, the Water Resources Bureau currently has no capacity to test the discharge quality, other than by a 'visual test'. The Environmental Protection Bureau can conduct tests and take necessary action over suspected water quality issues.

An enterprise that is discovered to be abstracting water without a permit will be asked by the Water Resources Bureau to go through the application process. If an enterprise is taking more water than is allowed under its abstraction permit, the Bureau will either allow the take where there is sufficient water, but charge for the additional volume) or strictly limit the take in dry times. In making such decisions, the significance of the enterprise to the local economy will be taken into account.

If an enterprise consistently takes more water than is allowed under its permit, the reasons for this will be considered. If the excess take is due to slight changes in water use practices, then the annual abstraction plan will allow the take (i.e. these plans can authorise abstraction volumes greater than provided for under the permit). Ultimately, however, this may lead to the Water Resources Bureau or the user proposing the consideration of a replacement abstraction permit. Conversely, any increased take due to a fundamental change in an enterprise's activities and use of water will need to be dealt with under a new permit.

Reporting is generally in accordance with a format prescribed at the central level and focussed mainly on the availability of water resources. Current reports produced in Taizhou address precipitation, surface water, groundwater, abstractions and water use.

2.6.7 Water Information

Dam levels are regularly measured using a range of methods and real-time data is available where automatic gauges exist. While there are only two flow gauging stations in Taizhou, there are numerous water level monitoring stations and the spatial coverage of rainfall gauges is comprehensive with 64 gauges mapped in the prefecture. A detailed overview of the water information situation in Taizhou is presented in Part 5.

Chapter 3: Key water resources management issues identified in Taizhou

3.1 Summary

Taizhou's water resource management arrangements are generally quite sophisticated and well developed. Many of the tools that are necessary for the implementation of a WET framework are in place. These include the water abstraction permit system and the information management systems being developed to record details about permits and use. As noted previously, a comprehensive plan has also been developed for Taizhou, which addresses water demands and supplies over the coming decades.

Over the coming years, economic development and an increase in the standard of living are likely to combine to increase demand for water supplies. At the same time, Taizhou will need to ensure that its development is consistent with building a water saving society.

A range of specific regulatory and institutional issues have been identified that may limit achieving this goal. In particular, these issues related to water planning and environmental flow management.

The **water planning** issues include:

- a focus on meeting demands – there is no supply 'cap' to limit water resources allocation and new infrastructure is considered ahead of alternative ways to meet demand increases;
- an absence of any basin-wide evaluation of the cumulative impacts of development and abstractions on existing users and the environment;
- limited mechanisms to protect various users' intended supply reliabilities; and
- a lack of water sharing rules to define how the water that is actually available for consumption in a particular year should be distributed.

The **environmental flow management** issues include:

- a lack of detailed understanding about the needs for particular flow volumes and patterns to achieve ecological outcomes;
- an absence of any formalised provision of environmental flows;
- the absence of a cap on the total volume of water that can be taken from the system, which means that there is nothing to prevent total abstractions from exceeding sustainable levels; and
- infrastructure not being designed or operated to deliver ecological outcomes.

Underlying all of the identified issues is an engrained assumption that water in Taizhou is (and perhaps always will be) abundant. This is understandable because Taizhou's relatively high and regular rainfall has meant that the region has generally had more than enough water available to meet its users' needs. However, continuing to rely on this assumption about the availability of the resource could have significant environmental, economic and social consequences in the future.

The regulatory and institutional issues identified as obstacles to perfecting water resources management in Taizhou are discussed further in the following sections.

3.2 Water planning issues

3.2.1 Demand-driven approach to water planning, with minimal consideration of supply limitations

Water planning in Taizhou is heavily demand-driven. That is, planning arrangements are focussed on ensuring that the infrastructure is in place to provide adequate supplies to meet existing and future demands. Consequently, improving the allocation of existing supplies is not a high priority. This also leads to an approach to allocating water that is inconsistent with efforts to build a water saving society.

Sustainable limit not defined: there is no cap on water resource allocation

There is no clearly defined cap controlling the number of permits that can be granted or the total volume of water that can be abstracted from individual regions or the basin as a whole.

New infrastructure is considered ahead of alternative arrangements

Where it is thought that future demands are unlikely to be able to be met by existing supplies, new infrastructure is proposed to increase the total volume of water abstracted. The comprehensive plan for water resources for Taizhou states that the current approach is to identify supply according to demand (with a shift towards a supply-driven approach to be considered at some stage in the long-term).

A demand driven approach leads to a focus on engineering solutions before (or instead of) any consideration of other mechanisms to meet growth in demand (e.g. efficiency measures, reallocation of surplus water between sectors, water trading). Often, such mechanisms have considerable benefits over the construction of new, large-scale infrastructure.

Infrastructure projects generally involve significant financial costs, can have adverse social and environmental consequences and require long lead times for development. There are also limits to the degree of development landscapes and ecosystems can tolerate. Eventually these limits will be reached (or exceeded), at which point it is often much more difficult and expensive to reduce water use to sustainable limits.

3.2.2 Relying on assumptions about agricultural water use has implications for planning

There is limited data on actual agricultural usage due to the lack of coverage of water abstraction permits and meters. As such, planning work relies on assumptions about use.

The comprehensive plan for Taizhou assumes that agricultural water needs will increase by about seven per cent between 2002 and 2010, then decrease by about 17 per cent over the following 20 years. The projected decline is expected due to increased water use efficiency and a reduction in cropped area. How these assumptions about the sector's needs are determined and then taken into account in planning and allocation decisions, however, is not transparently documented.

Further, without any regulatory tools such as the use of abstraction permits, it will be difficult to ensure that demands are maintained at predicted levels or to know when to review plans to take account of shifting demand patterns. This has risks for the integrity of water resources allocation plans and the security of other users' entitlements.

While it is unrealistic for such regulatory mechanisms to be applied at the individual farmer level, specifying entitlements at the irrigation district level would provide a greater degree of certainty both to individual farmers as well as to other water users.

3.2.3 Assessments of projects only consider local implications, not the cumulative effects on water availability and users basin-wide

There is no basin-wide hydrological modelling or evaluation of the cumulative impacts of infrastructure development and abstractions in Taizhou. This has risks for the sustainability of water resources management decisions because:

- reservoir yields and reliabilities may be less than estimated, and downstream impacts may be greater than estimated, due to the cumulative effect of developments;
- there is no basis for evaluating the nature of flows required to achieve ecological outcomes; and
- resource allocation planning, and decisions about new infrastructure and abstractions, occur on ad-hoc bases with no whole-of-basin consideration.

3.2.4 Intended supply reliabilities are not safeguarded

The construction of water infrastructure in Taizhou is designed around providing agricultural users with 75 per cent supply reliability and urban and industrial users with about 95 to 97 per cent reliability.

However, there is a lack of regulation and management rules to help guarantee these levels. In particular, the lack of a cap on water abstractions and the tendency to develop new infrastructure to meet demand growth can put these reliabilities at risk.

While applicants for new abstraction permits must undertake a hydrological assessment to demonstrate the availability of the water and that its abstraction will not impact on other users, the lack of a catchment-wide assessment makes it difficult to consider the cumulative impacts of projects. Ultimately, this can reduce the reliability of supply for existing users.

3.2.5 No water sharing arrangements to define how the water available in a given year should be distributed

Water sharing rules have not been defined at either the regional or permit level (i.e. rules that determine how the water that is actually available for consumption in a particular year is distributed amongst different regions and users within each region). Currently, it is only when reservoirs reach specified low levels that any action is taken to share the water that is actually available – at this point, the contingency arrangements outlined in the comprehensive plan come into operation.

In the absence of water sharing arrangements, entitlement holders are allowed to take as much water as they want (up to their entitlement limit) on a first-come first-served basis. As dam levels approach contingency cut-off points, this can encourage individuals to use their water as fast as possible, to avoid missing out, and thus speed the region towards a contingency situation.

3.2.6 There is no phased implementation of contingency arrangements

Contingency measures are only applied when water supplies are at a critical level. There are no efforts to reduce consumption (e.g. low-level restrictions) by any sector until then. This means that when restrictions are eventually imposed, they can be severe and abruptly implemented. For example, in Wenling in 2003, residents' supplies were limited to two hours each morning and evening.

A phased approach to the implementation of contingency measures (in conjunction with clear water sharing arrangements) could defer the point at which such action is required and/or reduce the length of time they apply.

3.3 Environmental flow management

The assumption that there is an abundant supply of water means that little consideration has been given to environmental flow requirements. Over the long-term, this is likely to pose risks to ecological health in the basin.

Limited understanding of ecological needs for water

There is virtually no recognition of ecological needs for water in the basin. The concept of providing water for the environment is limited to ensuring there are sufficient flows to flush pollutants and to supply beautification projects. There appears to be no limited understanding of the connections between river flow and riverine ecosystem health.

Management of resource availability

Taizhou's water planning and permitting arrangements do not cap the total volume of water that can be taken from the system. As such, there is no mechanism to prevent total abstractions from exceeding the resource availability and, hence, becoming unsustainable and impacting on the natural environment.

Infrastructure design and operation

In designing infrastructure and determining operational rules, consideration is not given to environmental requirements, for example in terms of what water can (or should) be released, how, and when, to meet environmental needs.

The impact of existing constraints need consideration

Extensive floodplain development will make it difficult to recreate previously occurring flood events because this would have major social and economic implications. There has also been considerable lining of river channels and other modification works, which inherently change habitats and riverine conditions. It will be necessary to evaluate whether these modifications are to such a degree that providing any sort of flow regime would deliver any ecological outcomes.

3.4 Other identified issues

In addition to the planning and environmental flow related issues, a number of other issues were identified.

3.4.1 Water abstraction permit issues

Water supply, delivery and use arrangements associated with water entitlements are mixed

Details about water abstraction, construction of works, and use (including return flows) are contained within a single authorisation. There are different issues involved in making decisions about the three components.

- For the water entitlement component, the issues concern maintaining river flows or aquifer levels in order to sustain ecological processes and water supplies for users.
- The works approval component is concerned with local impacts on the riverine environment, as well as consistency between the water entitlement component and the works used to take water under the entitlement.

- The issues for the third component are primarily about the total load of discharged pollutants and the capacity of the receiving environment.

Bundling theses issues into a single document can also result in bundling of the decision making process itself, which can result in decision makers considering irrelevant issues in the decision making process.

Unbundling – that is, separating out these different aspects of a water permit into distinct regulatory instruments (including different assessment and approval processes and (finally) different approval documents) – can lead to improved water resource management for a number of reasons.

Most importantly, it can lead to better decision making, because it allows for clearer responsibilities for the resource manager and more specific criteria for assessing applications. This allows the water resource manager to focus on the particular issue of relevance. Thus, in assessing an application for a “water entitlement” (i.e. for the volume of water the person wishes to take, as distinct from the other aspects of the water permit) the decision maker need only consider the availability of water, and whether taking the water from that location will impact on supply of water to other users or the environment.

Further, the bundling of entitlements can reduce flexibility in management as well as reduce transparency in the decision making process.

No connection between water resources allocation planning and water abstraction permit management

There is no connection between water resources allocation planning and water abstraction permit management. Applications for abstraction permits are not assessed against a basin or regional water allocation plan; thus there is no mechanism for ensuring that permits are granted within defined limits for the basin or region, or that intended reliabilities are achieved.

Similarly, on an annual basis, there is no mechanism for ensuring that the water taken under abstraction permits is consistent with planned approach to sharing the available water.

Both of these issues reduce certainty and security for water users.

3.4.2 Institutional arrangements

In Taizhou, there are instances where different parties involved in water resource allocation, management, supply and delivery have unclear or conflicting responsibilities. These distinct roles should be clearly defined and appropriately constrained. In particular, there is a lack of formal documentation about:

- service providers’ obligations to their users; and
- rights of users to a particular share of the resource under certain conditions.

The following two examples help demonstrate the risks associated with unclear institutional arrangements.

Example 1: The Taizhou power station

The company that operates the Taizhou power station is also responsible for managing the Xikou Reservoir. As well as the power station, this storage supplies irrigation districts and the township the power station company maintains for its workers and their families.

As storage operator, the power station company is thus responsible for supplying its own needs, its workers' residences and the irrigators' needs. This amounts to a clear conflict of interest in the power station company's roles.

Such a conflict could encourage the company to pursue its own interests at the expense of others. Alternatively, the company could be in a position where its compliance with reservoir operating rules would not deliver the best outcomes for the company.

Example 2: Management of the Lishimen Reservoir

A single bureau is responsible for the management of both the Lishimen Reservoir and an adjacent hydropower station. The reservoir is principally designed to provide water for irrigation districts and the Tiantai township[37]. Water for hydropower generation is of a lower priority.

The bureau has a significant annual operating loss, largely because irrigators are not required to pay fees for their water use. The Tiantai county government provides a notional contribution to the company on behalf of the irrigation districts, but the vast bulk of the dam company's revenue is derived from hydropower generation.

Consequently, there is a conflict between the different purposes for which the reservoir is operated – that is, making money from hydropower versus supplying urban and agricultural users.

3.4.3 Efficiency drivers

Tools to encourage efficiency in resource allocation and use

Water resource management in Taizhou is not focussed on increasing water allocation and use efficiency, largely because water resources are considered to be abundant.

The formalisation of efficiency drivers would help to ensure water resources are allocated towards high-value uses and in an environmentally sustainable manner. Such tools need to be considered on a case-by-case basis for appropriateness and include:

- voluntary trading of water entitlements (either temporarily or permanently);
- incentives to adopt more efficient water use practices;
- infrastructure improvements and loss reduction measures (e.g. channel lining); and
- cross-sectoral agreements about operating arrangements (e.g. farmers could agree to irrigate at times that would maximise revenue from hydropower stations, such as evenings, in exchange for some benefit for the inconvenience).

[37] A new reservoir to supply Tiantai township is nearing completion. This will become the primary source of urban supply, while Lishimen Reservoir will be treated as a back-up supply.

The effectiveness of efficiency drivers such as these often depends on strong supporting systems (e.g. a cap on total abstractions, together with permitting and registration tools) and the availability of related information.

Lack of recognition of supply costs is a disincentive to efficiency

The costs associated with water supply infrastructure are not properly recognised in pricing regimes in Taizhou. Cost accounting is inadequate and there are no clear cost recovery arrangements or transparently applied subsidies.

Ultimately, this acts as a disincentive to increased efficiency. By not including accurate information about costs and cost recovery, assessments of various water management strategies and supply options can produce misleading results. Not properly accounting for costs in pricing also means that at a local level there is no financial incentive to encourage more efficient water use practices.

Taizhou's agricultural sector, in particular, is not required to pay water resources fees for a range of other policy reasons (including encouraging farmers to remain on the land). While these reasons may justify not charging users, the costs of the services should at least be calculated and reflected somewhere. For example, irrigators do not pay for supplies from the Lishimen Reservoir but the county government pays the storage operator 500,000 RMB per year on their behalf. However, this figure seems to be arbitrarily obtained and is only a fraction of the total infrastructure operating costs.

3.5 Addressing the key issues through the pilot work

As discussed, the key areas of Taizhou's water resources management arrangements that could be strengthened to support the implementation of a water rights system relate to water planning and environmental flow management. The detailed pilot work undertaken in Taizhou therefore focussed on these areas.

The pilot work concentrated on the Zhu Creek and downstream from it to the mouth of the Jiao River (i.e. including parts of the trunk stream). In particular the work assessed the proposed new reservoir for Zhu Creek, together with other associated infrastructure, including a pipeline connecting it to Changtan reservoir. This was intended to demonstrate how the new reservoir could be managed within a WET system – in a way that recognised environmental water requirements, as well capping abstractions and protecting the reliability of supply of water abstractors.

The work aimed to prepare, for the focus reaches:

- a preliminary list of environmental assets and their flow requirements;
- a set of environmental flow recommendations designed to protect and maintain these identified assets;
- options to cap abstractions and alter water supply infrastructure operational arrangements to achieve these environmental outcomes;
- options to alter water supply infrastructure operational arrangements to improve and/or protect the reliability of water supplies;
- options for water sharing arrangements between different users in Taizhou; and
- an indication of the cumulative risks of incremental development in the Jiao River basin.

The objectives of this work were:

- To assist the local water resource managers address the environmental flows and water planning issues that had been identified in Taizhou, by providing some practical tools and preliminary planning options.
- To demonstrate the applicability and benefits of the environmental flow guidelines and the water resources allocation planning guidelines, prepared as part of the WET Project and described in detail elsewhere in this report.
- To feed information about the application of these national-level guidelines in a local Chinese context into their development.

Some of the other issues that were identified in Taizhou were dealt with indirectly through the pilot work on environmental flows and water resources allocation planning. For example:

- preparing options for a total cap on abstractions leads to a requirement that all major abstractions from the system, including for agriculture, are permitted;
- defining supply caps and reliabilities from individual reservoirs requires that abstraction permits are clearly specified, particularly in terms of the location of the abstraction and source of supply; and
- preparing some options to balance environmental flow recommendations with supply requirements leads to the consideration of adopting efficiency measures for some users to manage overall demands.

Issues such as these are discussed in the following chapters on the detailed pilot work.

Chapter 4: Environmental flows assessment and recommendations for the Jiao River

4.1 Summary of methodology

This chapter summarises the environmental flows assessment for the Jiao River basin in Taizhou. A full report documenting this work in detail is available in the supplementary material on Phase 2 of the WET Project.

The environmental flows recommendations presented in this chapter should be regarded as preliminary. This is primarily because all of the issues could not be fully considered in the limited timeframe over which the work was undertaken.

The critical steps undertaken were the following:

i. The entire stream length of interest was divided into manageable reaches, based on hydrological, geomorphological and ecological factors.
ii. For each defined reach, environmental assets were identified based on:
    - existing reports, published and unpublished literature;
    - field investigations; and
    - discussions with experts (ecologists, geomorphologists, etc) and interviews with water managers, fisheries officers and river users (e.g. fishermen).
iii. A conceptual model linking the identified assets to key aspects of the flow regime was developed to define environmental flow objectives for each river reach.

iv. Hydraulic and hydrologic models were used to determine the magnitude, duration, frequency and timing of flows required to meet these objectives.

- It should be noted that reaches 5 and 6 were not hydraulically modelled due to practical limitations. As such, flow recommendations were made using an alternative, risk assessment methodology.
- Hydrological analysis was undertaken initially to develop an overall understanding of the hydrological characteristics of the streams. It was also used to characterise the hydrology of particular hydraulically defined events of interest and after the flow recommendations had been made to check for compliance.

v. For each reach, specific flow rules were developed for inclusion in a water resources management model (in this case, IQQM). These rules are designed to provide the minimum flow regime required to sustain the ecological integrity of the river in the long-term at a low level of risk (i.e. it is not an "ideal" environmental flow regime, which would in fact be the natural regime).

vi. Additional, sub-optimal flow rules were also developed, which would provide more-limited environmental flows (and hence would come at a higher ecological risk) but which would allow for more water for consumptive purposes.

vii. The results of modelled future development scenarios incorporating the recommended environmental flows were considered. This stage of the methodology interacts with the work on water resources allocation planning and is described in more detail in the following chapter. Notably, this is an iterative process whereby alternative options were suggested when security of supply objectives dictated that the environmental flow objectives could not be met. From an ecological perspective, assessment of the alternative options should be based on the priority given to individual objectives outlined in the initial recommendations.

This methodology is regarded as appropriate for the Jiao River basin, despite the preliminary nature of the recommendations. Future, more detailed, consideration of any aspect of the work described throughout this chapter can be used to refine the environmental flow recommendations.

4.2 Defining relevant river reaches and flow components

The environmental flows assessment and the implementation of the agreed flow regime require simplification of the river system into a manageable number of reasonably homogeneous reaches. The Jiao River basin study area was therefore divided into six distinct river/estuary reaches:

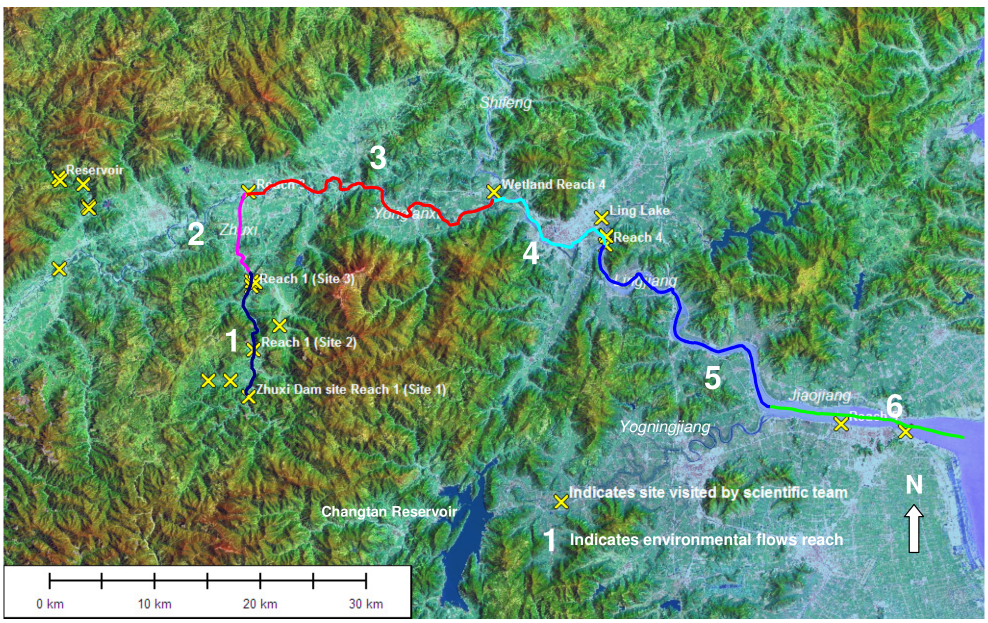
- Reach 1: Zhu Creek between the reservoir site and the first major downstream tributary entering Zhu Creek.
- Reach 2: Zhu Creek between the first major tributary below the reservoir site and the downstream confluence with Yong'an Creek.
- Reach 3: Yong'an Creek between the Zhu Creek confluence and Shifeng Creek junction. This is the approximate upper limit of tidal influence.

- Reach 4: The freshwater estuarine section of Ling River (downstream of Shifeng Creek junction), which is under tidal influence but above the upper limit of saltwater intrusion from the sea.
- Reach 5: The estuarine section of Ling River (to the Yongning River junction) that is influenced by both tidal and salinity fluctuations.
- Reach 6: The estuarine section of Jiao River (downstream of the Yongning River junction to Taizhou Bay) that is influenced by both tidal and salinity fluctuations.

A map, comprising elevation data and a georeferenced satellite image and which shows the defined river reaches and assessment sites, is at Figure 16.

Again for the purposes of simplifying the process, it was necessary to divide the flow regime into different components. The specific flow components considered relevant in the Jiao River basin, together with their hydrological descriptors and the times of year associated with the flow components are listed in Table 10.

Figure 16: Composite map of assessment area, showing defined reaches



4.3 Identification of key river basin assets for each reach

Key assets in the Jiao River basin were identified for the defined river reaches (and information about those assets was collected) from a range of sources including:

- existing ecological data in reports, albums, websites and statistical yearbooks;
- consultation with experts from Taizhou Ocean and Fishery Bureau, Taizhou Statistical Bureau and Zhejiang Institute of Freshwater Fisheries, as well as from the local Water Resources Bureaus;
- interviews with key stakeholders and sources of local knowledge, including fishermen; and
- site assessments and surveys by various scientists.

Table 10: Description of flow components referred to in this report

Flow component	Hydrological description	Relevant season
Low Flow	Provides a continuous flow through the channel during the low flow (dry) season, keeping in-stream habitats wet and pools full.	October – March
Low Flow Pulse	Flow events that are frequent, low in magnitude and short in duration and that exceed the baseflow (Low Flow) for one to several days as a result of localised rainfall during the dry season.	October – March
High Baseflow	Persistent increase in baseflow that occurs with the onset of the wet season.	April – September
High Flow Pulse	Increases in flow that exceed the baseflow (High Baseflow) as a result of sustained or heavy rainfall events in the wet season.	April – September
Bankfull Flow	Completely fill the channel, some localized inundation, but no general spill onto the floodplain.	More common in wet season (April - September), esp. associated with typhoons (August – September)
Overbank Flow	Higher and less frequent than bankfull flows, and spill out of the channel onto the floodplain.	More common in wet season (April - September), esp. associated with major typhoons (August – September)

In general, fish and fisheries emerged as the most highly valued asset throughout the study area, particularly those species of economic importance. Fish populations therefore form a core component of the environmental flows assessment. However, in recognition of the strong interdependencies between fish and other components of the riverine ecosystem – such as plants (aquatic and riparian), geomorphology and water quality – these other factors were also considered for each reach. For example, flows to maintain fish must consider not just the direct effects on fish but also on flows to maintain habitat, food resources and water quality.

4.3.1 Fisheries assets

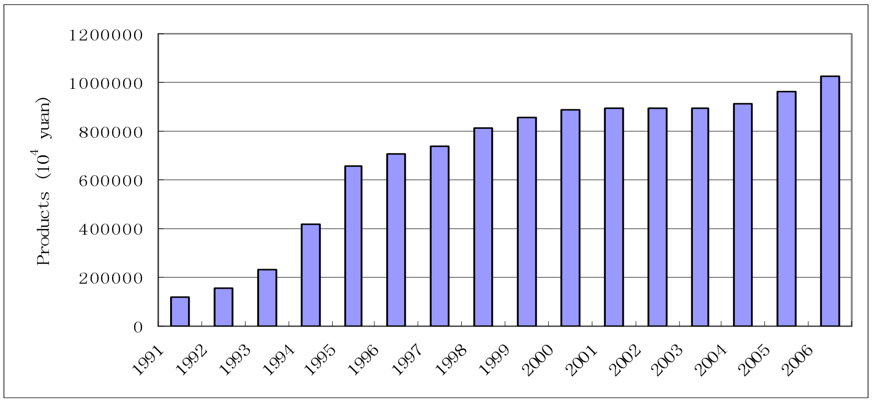
Importance of fisheries in Taizhou

Fishery production is increasing in Taizhou. In 2006 it reached 10.2 billion RMB (Figure 17) and constituted 52% of the total agriculture, forestry, husbandry and fishery production. Total fisheries yield has remained quite stable since 1999 at approximately 1.4 million tonnes with marine fisheries yield accounting for around 96% of the total.

Freshwater fisheries yield reached a peak of 48,000 tonnes in 2003. Wild harvesting as a proportion of the total fisheries yield is currently approximately 70% (one million tonnes) and has shown a steady decline since the 1980s. The proportion of wild harvesting in the freshwater fisheries' production decreased from 100% before 1955 to 30% in the 1960s. Currently, wild harvesting comprises around 15% of the total freshwater fisheries yield.

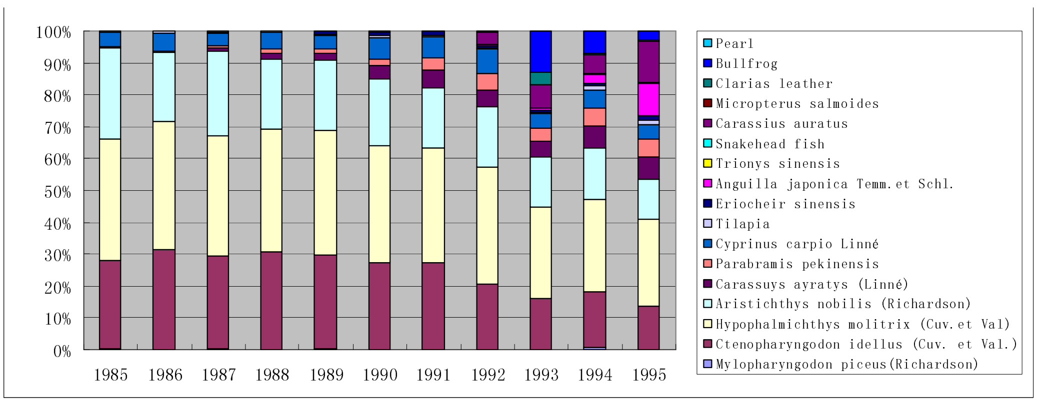
From 1985 to 1995, the contribution of the three most important economic species – Grass Carp, Silver Carp and Bighead Carp – towards total freshwater aquaculture production decreased (Figure 18). Of the increased production from other species, a number are new to the region.

Figure 17: Fisheries production of Taizhou, 1991-2006



Source: Taizhou Statistical Yearbook, 2006

Figure 18: Proportion of main freshwater aquaculture species, 1985-1995



Source: Taizhou Statistical Yearbook, 2006.

According to the Taizhou Aquatic Wildlife Protection and Management Album[38], 42 species of aquatic wildlife are likely to be found in and around Taizhou. Nineteen of these species are listed in the IUCN Red List or CITES Appendices, while twenty-three species are under national protection.

Information gathered from existing sources

The main sources of existing ecological information that was collected are summarised in Appendix 2. The most detailed assessment of fish and fisheries in the Jiao River basin comes from a 1971 survey of aquatic resources in Linjiang, by the Zhejiang Fishery Bureau and Zhejiang Institute of Freshwater Fisheries. This information is supplemented by a report prepared by the Taizhou Fisheries History Committee in 1998. The findings from these reports and other information sources are outlined in the WET Project Phase 2 Supplementary Materials.

In summary, about 100 species of fish have been reported in the Jiao River basin. Of these, just over half (59) were entirely freshwater, nearly a third were from the lower (saline) estuary (24), and 14 were diadromous (meaning they migrate between fresh and

[38] Taizhou Ocean and Fishery Bureau, December, 2006.

saltwater). This last group contains many of the species that are of conservation and/or economic importance.

The species that were considered in detail in developing the environmental flow recommendations are outlined in Appendix 3. The inclusion of species in the detailed analysis was based on two factors:

i. conservation and economic significance; and
ii. the availability of information on biology, habitat requirements, etc.

As a first step the international online "Fishbase" database (www.fishbase.org) was used to establish the availability of information about the listed species, together with more general online literature searches. Fishbase was also useful to identify species from local names (the site provides common species names in numerous languages, including Chinese). Scientific literature searches also provided useful background information. Additional information is assumed to be available from internal Chinese reports and from Chinese research and fisheries agencies, but only some of this material was accessible within the available timeframe.

Stakeholder interviews

In recognition of the extensive knowledge regularly held by people with a connection to their local river systems, a series of structured interviews were conducted at various locations throughout Taizhou. The interviews were focussed on collecting information related to fisheries assets[39], particularly local knowledge about:

- important fish (and other aquatic species) in each of the defined river reaches;
- trends in the number and size of different fish over time;
- fish diets and habitats;
- fish breeding patterns and times;
- fish migration patterns; and
- any relationships between the above details and changes in river flows, including during periods of drought and after typhoons.

About 30 interviews in total were conducted with:

- commercial fishermen (both freshwater and ocean);
- recreational fishermen;
- freshwater fish farmers;
- tidal flats farmers;
- wholesale and retail market stall holders; and
- local elders.

In summary, the interviews conducted around Zhu Creek provided the following information:

- The water quality is good in Zhu Creek.
- Most fish caught are wild.

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[39] A copy of the questionnaire used to guide the interviews is provided in the WET Project Phase 2 Supplementary Materials.

- The species of fish present has not changed much over time, but both the population and size decreased noticeably over the past 10 – 15 years.
- The main spawning season is from mid April to the end of May.
- More fish are caught during and immediately after typhoon or flood events.
- Some fishermen are concerned that the construction of the Zhuxi Reservoir will reduce fish populations.

The interviews conducted around Yong'an Creek and Ling River provided the following information:

- The extraction of sand and gravel from the rivers has reduced fish habitats and water quality, which has in turn impacted upon the population and yield of fish.
- Human activities have altered the shape of the river channels (for example, part of the river bed has been raised or moved aside).
- Fish with a lower spawning ability decreased more in population, such as mandarin fish, salmon, eel and turtles.

From the interviews conducted around the Jiao River estuary, the following information was obtained:

- The number of different fish species has decreased over time.
- Previously significant species that can no longer be found include yellow croaker, anchovies and big-head croaker.
- Fish numbers are closely related to water quality.
- Fish catches have a close relationship with typhoons – immediately following a typhoon, catches decrease sharply, and then rise above the average level, for several weeks.
- The main aquatic species in the tidal flats are Samoan crab (which breeds during April) and blue-spotted mudskipper (which breeds from June to August).
- The main birds living in the tidal flats are aigrette and grey marabou.
- The main vegetation in the tidal flats is lobelia herb.

Fisheries asset list

The key fisheries species identified were subsequently grouped into categories of species with similar flow requirements. This was to simplify the process of identifying environmental flow objectives for the basin. This process is discussed in subsequent sections. However, first it was necessary to also identify key vegetation and geomorphologic assets, and then to determine the relationships between these assets and flow.

4.3.2 Vegetation assets

Background searches did not identify any specific information on riverine plant species or communities in the Jiao River basin. Further, no species related to riverine systems were identified from lists of protected species (at both the national and regional level).

While there are no formal nature reserves or protected areas encompassing riverine habitats, an area of floodplain wetland was identified near Linhai city, immediately downstream of the confluence of Yong'an Creek and Shifeng Creek (see Figure 16). This is characterised by mixed woodland (including Populus sp.) with some open marshland. Useful background information on the ecology of riverine vegetation and its relationship to river flows was obtained from a number of international publications[40].

A number of invasive aquatic plant species are recorded as widespread in southern and eastern China and are likely to occur in the prefecture. These include Alternanthera philoxeroides (Alligator weed) and Eichhornia crassipes (Water hyacinth)[41]. Cabomba caroliniana (Fanwort) was also recently recorded in Zhejiang province[42]. Alterations to river flow regimes are considered to be important in facilitating the establishment and proliferation of invasive aquatic species[43].

As specific vegetation-related environmental assets were not identified for the Jiao River basin, the environmental flow objectives focus on the flows necessary to maintain existing riparian and wetland plant communities and provide opportunities for recruitment through the maintenance of habitats. Periodic scouring of vegetation also provides opportunities for recruitment of riparian species on areas of open ground and transfers organic material to the stream. Flows were also considered to prevent encroachment of terrestrial species into the river channels.

4.3.3 Geomorphology

Field assessments to determine the geomorphology of the rivers and streams

Limited existing information was identified that provided details about the geomorphology of the watercourses in the Jiao River basin. As such, the identification of geomorphological processes that support the local ecosystem (and the identified fisheries and vegetation assets, in particular) involved on-site assessments at various locations.

The bed material particle size was sampled at four sites in reaches 1 and 3. The results of these samples are depicted at Figure 19. It was not possible to sample the bed material at other reaches. Zhu Creek is a cobble-coarse gravel bed river, with sand-sized material present within in the substrate. The creek bed is actively mined for sand and gravel in many places. In the lower reaches, downstream of Linhai city, the bed particle size changes to sand, and the estuarine section has a mud bed[44].

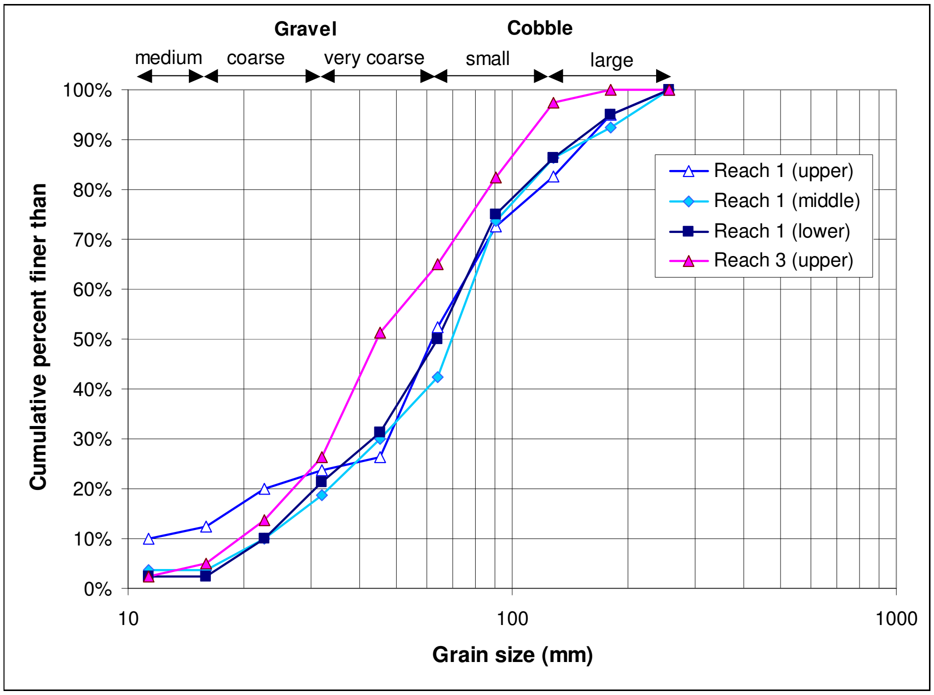
The morphology of the river varies throughout the study area. In overall size, it increases from the dam site towards the sea. Long pools of variable depth, separated by fast flowing runs and glides, can be found all along the system. There are occasional bedrock outcrops, especially noticeable in constricted sections. Large woody debris is not a feature of this river system.

The river appears to have a high sediment supply, which leads to a wandering gravel bed form. The bedload is shaped by high flows into large bars. Mounded gravel and cobbles form the banks in places, although most areas also have a fine grained (loamy sand and silt) floodplain present. The width of the floodplain varies enormously. In some places, the river is tightly constrained between valley walls, while in others it opens onto a

[40] including Naiman and Decamps (1997) and Nilsson and Svedmark (2002).
[41] Xie et al., 2001.
[42] Zhang et al. 2003.
[43] Bunn and Arthington, 2002.
[44] Guan et al., 2005.

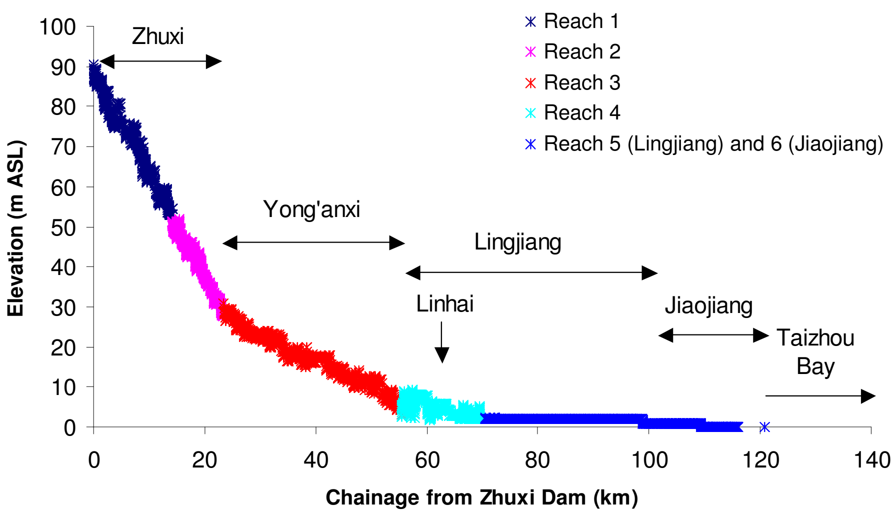
floodplain that is kilometres wide. Much of the river is lined with artificial levees, offering protection for the floodplain land.

Figure 19: Particle size of bed surface materials in Zhu Creek (Reach 1) and Yong'an Creek (Reach 3)



The channel gradient, which was determined from an analysis of on-line elevation data, varies from 0.24% for Zhu Creek to virtually flat for the lower reach (Figure 20). There is a clear change in gradient just downstream of Linhai city, where the river is close to sea level. This is the natural limit of the upstream migration of the salt wedge from the estuary.

Figure 20: River profile for the defined reaches



The relatively high channel gradient of Zhu Creek and Yong'anxi, combined with ample supply of coarse bed material, meandering course and bedrock outcrops, generates a wide variety of hydraulic habitat. As well as fast flowing sections, there are deep pools, eddies and backwaters present.

Geomorphology of the Jiao River estuary

In contrast to the inland system, extensive information was identified from existing reports about the geomorphology of the Jiao River estuary[45]. The water quality, sediment dynamics and hydrodynamics of the estuary are well understood.

According to the literature[46], the estuary is about 35 kilometres long, although local knowledge suggests that saline water can reach almost as far as Linhai city.

The estuarine waters are extremely turbid with suspended sediment concentration values at times exceeding 40 kilograms per cubic metre during spring tides in calm weather. In order to maintain a constant bed elevation, the estuary is dredged at a rate of about 0.05–0.3 metres per year[47]. Of the sediment deposited on the bed of the estuary, only 5% is due to locally derived fluvial material. The sediment infilling the estuary originates from the Yangtze River, the mouth of which is located 200 kilometres further north[48].

During a low river discharge, the total suspended mass has been predicted to decrease, resulting in increased sedimentation[49]. Saline water moves further upstream and the suspended sediment concentration is reduced. During high river discharge, the sediment is gradually carried out of the estuary.

Flow-related geomorphic issues

There are two key geomorphic issues in the Jiao River basin:

i. maintaining ecological processes in the fluvial reaches; and
ii. maintaining channel form throughout the basin.

Both issues relate to the maintenance of sediment transport processes. One component of these processes is frequent flushing of fine deposits from the bed.

The sediment load of the channels in the Jiao River basin is sourced from inflowing tributaries, the channel bed itself and the channel banks. Zhuxi Reservoir will trap the entire local bedload. Downstream of the reservoir, the river channel will incise into the dominantly gravel and cobble-sized bed material to bedrock or until the remaining bed material is coarse enough to resist mobilisation (to create an armoured bed). These consequences were observed downstream of an existing reservoir on a northern tributary of Yong'an Creek. About one kilometre from the reservoir, the bed material contained some finer material and within five kilometres the bed material contained gravel and cobbles. Thus, in this case the incision recovered over a reasonably short distance downstream of the reservoir, indicating ample local sediment supply.

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[45] See Guan et al. 1998 and 2005, Dong et al., 1997, Zhu, 1986, Bi and Sun, 1984, Fu and Bi, 1989 (cited in Guan et al. 2005), Hung et al., 2007 and Liu et al., 2007.

[46] Guan et al, 2005.

[47] Guan et al., 1998.

[48] Hung et al., 2007 and Liu et al., 2007.

[49] The 3-D hydrodynamic model of Guan et al. (2005)

Zhu Creek and the downstream areas are particularly prone to this form of channel adjustment because of the high sediment transport capacity, the current intensity of gravel extraction and the extensive confinement of the river within rock levees (limiting the supply of sediment from the banks). There is little that can be done to prevent this scour process, short of ongoing augmentation of the sediment supply,[50] which is a difficult and expensive process. Alternative ways to maintain sediment supply could include stopping gravel extraction activities and allowing bank erosion to proceed.

The flow and sediment processes in the Jiao River estuary are largely controlled by marine rather than fluvial inputs. The estuary will require regular dredging regardless of any periodic scouring that might be provided by high river flows. During large floods, freshwater will extend further into Taizhou Bay, and sediment will be transported offshore. This may create ecological responses in the estuary and offshore (although conflicting anecdotal evidence was provided by local fishermen). During low flow periods, the rate of fine sediment deposition on the bed of the estuary tends to increase. At these times, salt water will migrate further upstream.

Thus, the issues for environmental flows in the estuary are mainly to do with maintaining the mean position of the salt wedge, by maintaining river flows. Inland migration of the salt wedge due to reduced flows will not change the overall character of the estuary, but it may slightly increase the size of the tidal prism. The ecological consequences of this cannot be determined, as it is not known if there are any habitats or biota in the upper part of Reach 5 that are particularly sensitive to salinity change.

4.4 Defining the environmental flow requirements for the identified assets

4.4.1 Broad environmental objectives

Based on the identified environmental assets, environmental flow recommendations were developed to achieve the following broad objectives:

i. Maintain fish diversity and abundance.
ii. Maintain subsistence and commercial fisheries.
iii. Maintain water quality at a level capable of supporting objectives i and ii together with existing uses of the river.
iv. Maintain riparian vegetation in its current form in riparian and low-lying floodplain habitats.
v. Maintain geomorphic processes that are required to support objectives i - iv.

As previously discussed, the primary objective selected was to protect fish and fisheries. The other broad objectives were designed to help achieve this goal. Having identified these broad objectives, it was necessary to develop more specific objectives, which could be translated into flow requirements. This required:

i. establishing the links between the key environmental assets and different flow components; and (having identified which flows are important)

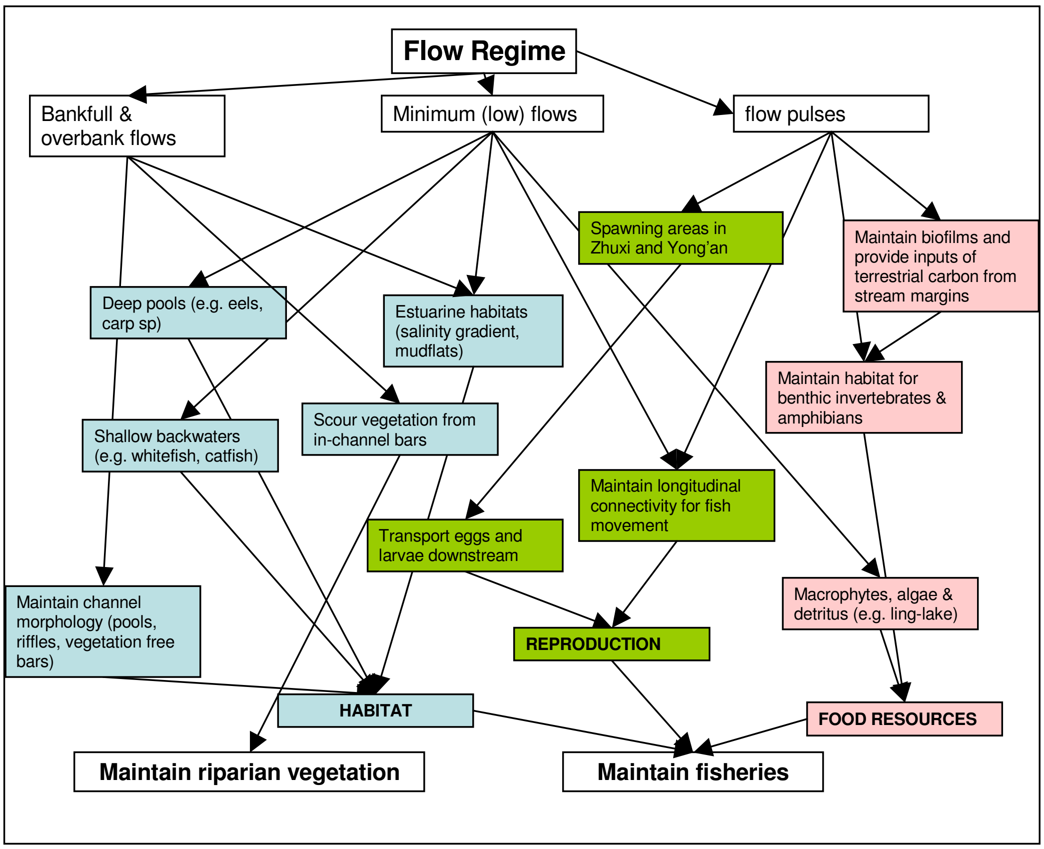
[50] Bunte, 2004.

ii. quantifying the actual flows required to achieve the outcomes sought for the different environmental assets.

4.4.2 Linking the identified environmental assets to flow components

Specific environmental flow objectives pertaining to geomorphology, vegetation, and fish were determined independently from one another for each reach. Associations were then made between each flow objective and the components of the flow regime on which the objective depends. These associations are broadly represented as a conceptual model of flow-ecology-geomorphology relationships in Figure 21.

Figure 21: Example conceptual model of the links between individual objectives and specific flow components



This conceptual model illustrates the role of multiple specific flow components in achieving the overall flow objectives. The linkages were developed based on general scientific understanding of the interrelationships that exist in river systems of this kind between the ecology, flows and geomorphology.

It should be noted that while individual flow components may relate to several objectives, typically there is one objective that acts as the key constraint. During the balance of the environmental flows assessment, these were treated as the "controlling objectives".

In addition to the component of the flow regime that is important for the specific environmental objectives, the timing of the flows is also important.

4.4.3 Hydraulic criteria to define recommended environmental flow release rules

In order that environmental flow recommendations can be made operational, each component making up the regime has to be specified as a flow volume, with associated frequency, timing and duration. Hydraulic criteria (i.e. depths and velocities of flows) were assigned to the different flow objectives as a means of calculating the actual volumes of water required to achieve each objective.

It is possible to state that certain ecological processes are associated with certain flow components (e.g. low flows, high flow pulses, bankfull flows, etc). However, it is rarely possible to make a confident direct link from an ecological process to a specific flow magnitude.

Instead, the ecological processes of interest are more readily defined as a depth of water in the channel (e.g. a minimum depth over riffles to sustain macro-invertebrates), an elevation in the channel (e.g. corresponding to the location of a particular flow dependent vegetation community, or the top of the banks), maximum or minimum velocities (e.g. limits of swimming capability of a fish species), or shear stresses (e.g. sufficient to mobilize bed material, or scour vegetation from the bed). The magnitude of flow components can subsequently be derived from this kind of hydraulic information. Knowledge of the channel morphology and roughness allows the hydraulic characteristics to be described for any given flow (and vice-versa).

The relevant flow components, timing and hydraulic criteria for each environmental flow objective were then incorporated into a table with the groups of environmental assets and their related flow objectives (Table 11, Table 12 and Table 13).

4.5 The recommended environmental flows regime

The final step in developing environmental flow recommendations was to convert the hydraulic criteria for each objective into flow volumes for each reach. A hydraulic model provides the numerical link between hydraulics and flow. Basic hydraulic models were therefore developed for reaches 1-4 of the Jiao River basin study area.

These hydraulic calculations were based on cross-section surveys conducted for these reaches of the river. Given that it was not possible to conduct such surveys for reaches 5 and 6, an alternative methodology was used to specify the recommended environmental flows. This alternative risk assessment approach is discussed in further detail in section 4.5.5.

Notably, each table specifies the recommended environmental flow releases both as peak (Q_{PEAK}) and daily (Q_{DAILY}) flows. This is because flow event magnitudes determined by hydraulic methods represent instantaneous peak discharges (which may not need to be achieved for an entire day), whereas mean daily discharge is the common unit used by river managers, scientists and stakeholders. It is also the base unit used in hydrologic models such as IQQM. For events that require the threshold to be achieved for one day or longer (such as pulses and baseflows), the peak and daily discharges are the same.

Mathematical relationships were thus developed as part of the pilot work to enable the peak flow recommendations to be incorporated into the daily time-step model for the Jiao River basin. The processes involved in developing these relationships is discussed in detail in the full environmental flows assessment report (Part 7: Supplementary Report).

The various environmental flow requirements included significant redundancy – that is, in some circumstances the one flow can meet multiple environmental flow requirements. Consequently, the final environmental flow recommendations condense the multiple objectives listed in Tables 4, 5 and 6 into a much simpler collection of required flows.

Table 11: Fish-related environmental flow objectives with flow components and hydraulic criteria

Species group	Environmental flow objective	Reach	Flow component	Hydraulic criteria	Timing
Pool Guild (e.g. Eels, Spinibarbus, Carp species)	Maintain sufficient water depth in pools for large bodied fish	1, 2, 3, 4, 5, 6	Low flow	Depth > 1.5 m in pools in reaches 1 – 3 Depth > 3 m in reaches 4 & 5	Oct-Mar
Pool Guild (e.g. whitefish, catfish) and riffle species	Maintain sufficient depth in riffles and in depositional habitats out of the flow	1, 2, 3, 4, 5, 6	Low flow	Depth > 0.2 m	Oct-Mar
Whitefish, catfish	Localised movement of resident fish	1,2,3	Low Flow Pulse	Depth > 0.2 m over riffles	Oct-Mar
Spinibarbus, Misgurnus mizolepis	Maintenance of benthic habitats and hyporheic flushing	1,2,3	Low flow Pulse	Sufficient to flush fine sediments from gravel	Oct-Mar
Grass, silver, bighead carp	Flows to provide habitat during the high flow period, to induce spawning of grass, silver and bighead carp and to maintain transport of semi-buoyant eggs within the water column	1,2	High flow	Mean velocity> 0.15-0.25 m/s	Apr-Sep
Anadromous and Potamodromous guilds. (e.g. carp, Coilia ectenes, Macrura reevsii)	Stimulate spawning migration and maintain longitudinal connectivity (estuary to headwaters)	1,2,3	High flow pulse	Inundate barriers Increase depth > 0.25 m over riffles	April
Species that spawn on floodplains (no local information supplied)	Provide access to floodplain habitats	2, 3, 4, 5, 6	Overbank flow	Sufficient depth to inundate low lying areas of the floodplain such as wetlands	Anytime
Freshwater estuarine guild (e.g. Lateolabrax japonicus)	Flow to prevent increases in the upstream intrusion of saline water during low flows	4, 5, 6	Low flow & High flow	Non-hydraulic criteria	All year
Estuarine Guild (e.g. Mugil spp.; Acanthopagrus schlegelii; purple spotted mudskipper	Flow to maintain salinity and sediment dynamics at the mouth of the estuary. Physical habitat is mudflats and river-channel	5, 6	Low Flow	Complex hydro and sediment dynamics Estuarine hydrodynamic modelling	Summer
Estuarine Guild (e.g. Mugil spp.; Acanthopagrus schlegelii; purple spotted mudskipper	Flow to maintain salinity and sediment dynamics at the mouth of the estuary. Physical habitat is mudflats and river-channel	5, 6	High Flow	Complex hydro and sediment dynamics Estuarine hydrodynamic modelling	Summer

Table 12: Vegetation-related environmental flow objectives with flow components and hydraulic criteria

Environmental flow objective	Reach	Flow component	Hydraulic criteria	Timing
Scour vegetation from gravel bars and transfer organic material to the stream	1, 2, 3	High flow pulse	Sufficient to scour vegetation	High flow season (Apr-Sep)
Maintain vegetation neighbouring the river channels (riparian vegetation)	1, 2, 3, 4, 5	Overbank flow	Morphologically defined levels	Anytime
Prevent encroachment from terrestrial species into river channels (e.g. *Salix* sp.)	1, 2, 3	Bankfull	Critical shear stress	Anytime
Maintain floodplain wetland communities (perennial and annual species)	1, 2, 3, 4, 5	Overbank flow	Morphologically defined levels	High flow season (Apr-Sep)

Table 13: Geomorphology-related environmental flow objectives with flow components and hydraulic criteria

Environmental flow objective	Reach	Flow component	Hydraulic criteria	Timing
Maintain channel form	1, 2, 3, 4	Bankfull	Morphologically defined levels	Anytime
Flush fine sediment from surface of bed	1, 2, 3, 4	Low flow pulse & High flow pulse	Critical shear stress to mobilise silts	Low flow & High flow
Mobilise coarse bed sediments	1, 2, 3, 4	High flow pulse/Bankfull	Critical shear stress to mobilise >50% of bed material	Anytime
Maintain channel form and key habitats	1, 2, 3, 4	High flow pulse/Bankfull	Morphologically defined levels	Anytime

4.5.1 Reach 1 recommendations

A summary of the environmental flow recommendations for reach 1 are provided at Table 14. The justification for the recommended flows is provided in the subsequent paragraphs.

Table 14: Summary of flow requirements for Reach 1

Flow component	Timing	Months	Q_{PEAK} m³/s	Q_{DAILY} m³/s	Frequency (per year)	Duration	Rise/fall target(max) m³/s‡
Low flow	Low flow season	Oct-Mar	0.5	0.5	continuous or less than if natural		
High flow	High flow season	April-Sep	1.3	1.3	continuous or less than if natural		
Low flow pulse	Low flow season	Oct-Dec; Jan-Mar	20	20	2	1 day in Oct-Dec and 1 day in Jan-Mar	+13(+20)/ -10(-14)
High flow pulse	Spawning period	April	20	20	1	2 consecutive days	+13(+20)/ -10(-14)
High flow pulse	High flow season	May-Sep	20	20	4	2 consecutive days	+13(+20)/ -10(-14)
Bankfull†	high flow season	Anytime	524	177	0.52	1 day peak; Achieve Q_{PEAK} and Q_{DAILY} on day of peak	+150(+190)/ -134(-165)
Overbank	High flow season	Anytime	571	191	0.52	1 day peak; Achieve Q_{PEAK} and Q_{DAILY} on day of peak	+158(+200)/ -141(-182)

† If Overbank delivered then Bankfull component can be omitted.

‡ Rate is maximum change in discharge that is allowed from one day to the next. Target is recommended rate change, but maximum can be used (at higher environmental risk). If allowable rate change exceeds the required event magnitude then discharge can be raised to the event magnitude over one day.

Low Flow

A dry season baseflow of 0.5 cubic metres per second is recommended to maintain both:

i. adequate minimum water depths in riffle habitats; and
ii. sufficient wetted area and depths in pools and shallow runs.

Water depth in pools should be adequately maintained by the presence of riffles acting as a downstream control on depths. Lower flows are acceptable whenever they would occur naturally (i.e. when inflows to the reservoir fall below 0.5 m^3 per second).

Low Flow Pulse

Periodic flow pulses of 20 m^3 per second have been recommended to flush fine sediments and algae from cobbles and to maintain water quality by ‘turning over’ pools and re-oxygenating the hyporheic zone. These pulses also provide opportunities for fish to move between pools that might otherwise be isolated by shallow water over riffles during low flows and move terrestrial organic material thereby providing a potentially important source of carbon for aquatic food webs. The flushing of fine sediments (which would only partially be achieved) and the scouring of vegetation from bars are the controlling objectives for this flow. Two events, each lasting a minimum of one day, are recommended to reflect the natural frequency of these events.

High Flow

A wet season (Apr-Sep) baseflow of 1.3 m^3 per second is recommended to:

i. maintain sufficient water depths for fish movement into and out of spawning areas;
ii. ensure that average flow velocities in the channel exceed 0.25 metres per second, which is necessary to maintain the buoyant and drifting eggs of grass carp, silver carp and black carp in the water column[51]; and
iii. ensure sufficient backwater habitats exist for juvenile and young fish.

High Flow Pulse

Periodic flow pulses of 20 m^3 per second have also been recommended during high flow periods. These pulses serve the same objectives as the low flow pulses, but at different times of the year. An event has been specifically recommended during April to coincide with the onset of spawning by several carp species – both to potentially stimulate spawning and to provide opportunities for upstream migration. An additional four events are necessary in the period May-September to scour detritus and algae from the streambed and vegetation from bars. Releases can coincide with natural increases in discharge downstream to reduce the volume of water released from the dam. Each high flow pulse should be of two days minimum duration.

Bankfull Flow

Zhu Creek is a typical gravel bed river in which many of the natural channel features (pools, riffles, bars) are maintained by bankfull flows mobilising bed material and scouring encroaching terrestrial vegetation. These geomorphic features create unique habitats that must be maintained to meet the fish and vegetation objectives. The peak discharge required to reach the top of the bank at the surveyed cross-section was estimated to be 524 m^3 per second, but this need only be reached instantaneously. The associated mean daily flow for input to the IQQM model is 177 m^3 per second. These flows should on average occur once every two years.

Overbank Flow

Overbank flows have been recommended to maintain the natural disturbance regime in riparian areas, where periodic floods can play a key role in vegetation structure (including wetland communities). Flows necessary to inundate riparian areas in close proximity to the channel were estimated at 571 m^3 per second (instantaneous). Overbank flows are less likely to be important for fish in Reach 1 due to the absence of extensive floodplain areas, so should occur on average once every two years.

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[51] Tang, 1989; Zhong, 1996.

4.5.2 Reach 2 recommendations

A summary of the environmental flow recommendations for reach 2 is provided at Table 15. Many of the recommendations for reach 2 are based on the same reasons for those in reach 1, but with different recommended volumes. Accordingly, the discussion of the reach 2 recommendations below only addresses the differences in reasoning for the specific flow components.

Table 15: Summary of flow requirements for Reach 2

Flow component	Timing	Months	Q_{PEAK} m³/s	Q_{DAILY} m³/s	Frequency (per year)	Duration	Rise/fall target(max) m³/s‡
Low flow	Low flow season	Oct-Jan	1.3	1.3	continuous or less than if natural		
Low flow	Low flow season	Feb-Mar	3.4	3.4	continuous or less than if natural		
High flow	High flow season	April-Sep	4.0	4.0	continuous or less than if natural		
Low flow pulse	Low flow season	Oct-Dec; Jan-Mar	53	53	2	2 consecutive days in Oct-Dec & 2 days in Jan-Mar	+29(+52)/ -23(-37)
High flow pulse	Spawning period	April	53	53	1	2 consecutive days	+29(+52)/ -23(-37)/
High flow pulse	High flow season	May-Sep	53	53	4	2 consecutive days	+29(+52)/ -23(-37)/
Bankfull†	Anytime	Anytime	1,011	397	0.58	1 day peak; Achieve Q_{PEAK} & Q_{DAILY} on day of peak	+294(+437)/ -285(-382)
Overbank	High flow season	April-Sep	1,102	428	0.58	1 day peak; Achieve Q_{PEAK} & Q_{DAILY} on day of peak	+323(+440)/ -340(-387)

† If Overbank delivered then Bankfull component can be omitted.

‡ Rate is maximum change in discharge that is allowed from one day to the next. Target is recommended rate change, but maximum can be used (at higher environmental risk). If allowable rate change exceeds the required event magnitude then discharge can be raised to the event magnitude over one day.

Low Flow

Due to marked seasonal variation in natural low flows over the dry season, separate low flow components have been specified for October-January (1.3 m^3 per second) and February-March (3.4 m^3 per second). The higher flow for February-March ensures that the recommended regime remains within the historical range.

Low flow Pulse

Two periodic flow pulses of 53 m^3 per second, each lasting for two consecutive days, are recommended for reach 2.

Overbank flows

Overbank flows may play a role in allowing fish to access floodplain habitats in the lower reaches of Zhu Creek where a more extensive floodplain occurs. As such, overbank flows should on average occur a little more than once every two years in reach 2.

4.5.3 Reach 3 recommendations

A summary of the environmental flow recommendations for reach 3 is provided at Table 16. Again, as many of the recommendations for reach 3 are based on the same reasons for those in reach 1, the discussion below only address any differences in reasoning for the specific flow components.

Table 16: Summary of flow requirements for Reach 3

Flow component	Timing	Months	Q_{PEAK} m^3s^{-1}	Q_{DAILY} m^3s^{-1}	Frequency (per year)	Duration	Rise/fall target(max) $m^3/s^‡$
Low flow	Low flow season	Oct-Jan	6.8	6.8	continuous or less than if natural		
Low flow	Low flow season	Feb-Mar	17.3	17.3	continuous or less than if natural		
High flow	High flow season	April-Sep	22.2	22.2	continuous or less than if natural		
Low flow pulse	Low flow season	Oct-Mar	96	96	4	4 consecutive days	+38(+78)/ -25(-45)
High flow pulse	High flow season	April-Sep	146	146	6	7 consecutive days	+61(+120)/ -47(-80)
Bankfull	Anytime	Anytime	1,289	948	1.3	1 day peak; achieve Q_{PEAK} and Q_{DAILY} on day of peak	+453(+809)/ -499(-801)

‡ Rate is maximum change in discharge that is allowed from one day to the next. Target is recommended rate change, but maximum can be used (at higher environmental risk). If allowable rate change exceeds the required event magnitude then discharge can be raised to the event magnitude over one day.

It should be noted that in this section of Yong'an Creek flows will reflect overall levels of water extraction from the entire upstream catchment, not just diversions from Zhu Creek.

Low Flow

Due to marked seasonal variation in natural low flows over the dry season, separate low flows have been specified for October-January (6.8 m^3 per second) and February-March (17.3 m^3 per second).

While the objectives for the low flows in reach 3 are the same as for reach 1, riffle and pool habitats were not observed in the field (as this reach was in flood at the time of inspection). However, exposed bed material was visible on the satellite image and the reach is sufficiently high gradient to have pool/riffle morphology.

Low flow Pulse

The low flow pulse component was assumed to correspond to inundation of the lower bench (Bench 1) identified in the cross section conducted in reach 3 (Figure 22).

The low flow pulses should occur approximately four times each year during October-March (natural frequency) and each event should last four consecutive days (natural median duration).

High Flow Pulse

The low flow pulse component was assumed to correspond to inundation of the middle bench (Bench 2) identified in the cross-section for this reach (Figure 22). High flow pulses should occur six times every year (natural frequency) during April-September, with each event lasting seven consecutive days (natural median duration).

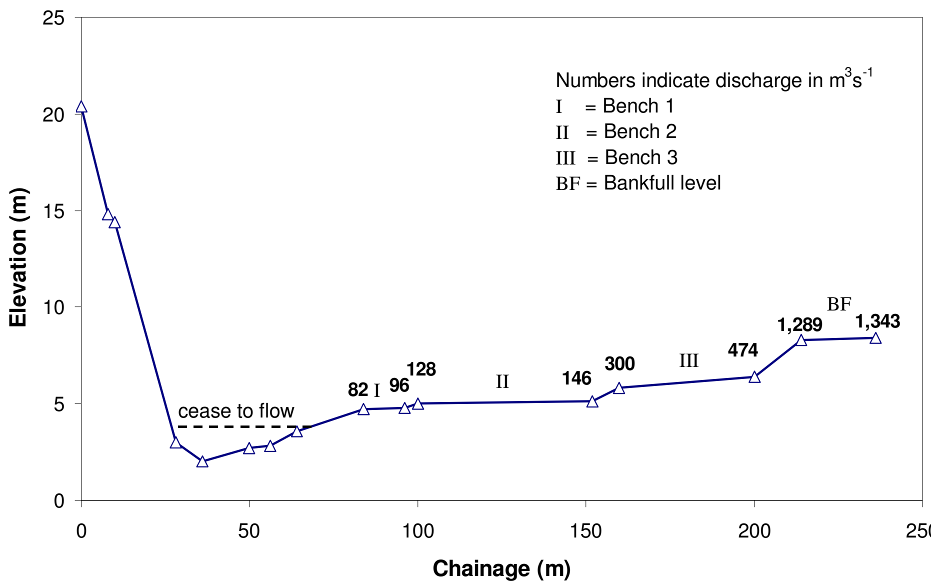
Bankfull Flow

Like Zhu Creek, Yong'an Creek is a typical gravel bed river in which many of the natural channel features (pools, riffles, bars) are maintained by bankfull flows mobilising bed material and scouring encroaching terrestrial vegetation. Such flows should occur on average 1.3 times per year (or four events every three years) based on the natural frequency of occurrence.

Overbank flows

Overbank flows were not recommended for this reach due to the presence of extensive levee banks that limit the potential benefits of overbank flows.

Figure 22: Cross-section in reach 3, showing discharge corresponding to morphologically defined levels



4.5.4 Reach 4 recommendations

A summary of the recommended environmental flows for reach 4 is provided at Table 17. It should be noted that in this section of the Ling River, flows will reflect overall levels of water extraction from the entire upstream catchment, not just diversions from Zhu Creek.

Low Flow

Due to marked seasonal variation in natural low flows over the dry season, separate low flow components have been specified for October-January (16 m^3 per second) and February-March (31.8 m^3 per second). It is expected that this will maintain the flow of low salinity water on the ebb tide in the upper part of the reach, helping to maintain the position of the fresh/brackish/saline interface (otherwise this flow component does not have a strong ecological role).

High Flow

A wet season (April-September) baseflow of 46 m^3 per second is recommended again to maintain the flow of low salinity water on the ebb tide in the upper part of the reach (helping to maintain the position of the fresh/brackish/saline interface).

Bankfull Flow

The upper limit of Reach 4 defines the approximate upstream extent of significant tidal influence in Ling River, while the downstream limit (just below Linhai city) defines the upstream extent of saline water intrusion. As a result of the tidal influence, hydraulic conditions within the river are controlled more by tidal processes than inflows from upper reaches. The exception is under high flow conditions. As water levels are controlled by river discharge only during high flow events, recommendations for bankfull flows have been made primarily to maintain periodic inundation of – and access to – an important riparian wetland area.

Table 17: Summary of flow requirements for Reach 4

Flow component	Timing	Months	Q_{PEAK} m^3s^{-1}	Q_{DAILY} m^3s^{-1}	Frequency (per year)	Duration	Rise/fall target(max) m^3/s‡	Comment
Low flow	Low flow season	Oct-Jan	16.0	16.0	continuous or less than if natural			Will maintain low salinity flow on the ebb tide in the upper part of the reach
Low flow	Low flow season	Feb-Mar	31.8	31.8	continuous or less than if natural			
High flow	High flow season	April-Sep	46.0	46.0	continuous or less than if natural			
Bankfull†	Anytime	anytime	3,110	2,488	0.59	1 day	+3,674(+5,171)/ -2,963(-4,481)	Event to reach 7.0 m at wetland
Bankfull†	Anytime	anytime	3,545	2,836	0.48	1 day	+3,674(+5,171)/ -2,963(-4,481)	Event to reach 7.5 m at wetland
Bankfull†	Anytime	anytime	3,980	3,184	0.45	1 day	+3,674(+5,171)/ -2,963(-4,481)	Event to reach 8.0 m at wetland

† Due to uncertainty in the stage required to inundate the wetland in this reach, three scenarios spanning 7.0 - 8.0 m have been identified. Only one of these events needs to be implemented. The higher level is preferred to ensure full inundation of the wetland, provided this can be achieved with minimal additional impacts on security of supply over the lower scenarios. Duration is one day at peak, and to achieve Q_{PEAK} and Q_{DAILY} on day of peak.

‡ Rate is maximum change in discharge that is allowed from one day to the next. Target is recommended rate change, but maximum can be used (at higher environmental risk). If allowable rate change exceeds the required event magnitude then discharge can be raised to the event magnitude over one day.

The estimated flows required to achieve bankfull and inundate the fringing wetland areas range between 3,110 m^3 and 3,980 m^3 per second (instantaneous). This uncertainty is due to the lack of a detailed survey of the bank height adjacent to the wetland to accurately determine the sill level. Monitoring of the flows required to inundate the wetland could quickly address this uncertainty. The frequency of these events ranges between 0.45 and 0.59 times per year (i.e. about once every two years).

Pulses

A convincing ecological basis for pulses could not be established in this reach and pulses have therefore not been recommended. Pulses will not influence water level, but may have a minor and temporary influence on downstream salinity gradient.

Overbank flows

Overbank flows were not recommended for this reach as the bankfull component achieves inundation of the important environmental asset (the wetland). A separate overbank flow component was not specified due to the widespread floodplain levees in this reach.

4.5.5 Reaches 5 and 6 recommendations

While the Jiao River estuary is dominated by marine influences, freshwater flows are also ecologically important. During high river flow events the saline estuarine water is pushed out to sea, which causes a major disruption to the normal ebb and flow cycle. The biota have evolved to either take advantage of this sudden change in the hydraulics and salinity regime, or to minimise negative impacts. A significant reduction in the frequency of major runoff events, or in the volume of water passing to the estuary during major rainfall events, could have significant ecological consequences.

Due to lack of resources, it was not possible to derive specific flow rules for Reach 5 and Reach 6 using the methodology used in the other reaches. The hydrodynamics of the estuary are complex and derivation of flows based on an understanding of the hydrodynamics would require a separate investigation. As previously noted, the hydraulics of the Jiao River estuary have been very well studied and there is an existing hydrodynamic model, so the tools to conduct such an estuarine environmental flows investigation are available.

For Reaches 5 and 6, a risk assessment was undertaken to explore the potential impacts associated with the following key hydrological change indices:

- reduction in low baseflow (October-March);
- reduction in high baseflow (April-September); and
- reduction in the frequency of bankfull floods.

The potential environmental changes likely to be associated with these hydrological changes include:

- upstream migration of salt wedge;
- increased sediment influx from the Yangtze River;
- increased salinity within near-shore environments;
- reduced depths in the river channel due to sedimentation; and
- altered biogeochemical cycling.

For each of the hydrological change indices, a list was made of the environmental assets that were potentially at risk of impairment from such a change (Table 18). The assets were rated according to three conservation status classes, with the consequence of change increasing for higher conservation levels (Table 19). The degree of change was ranked into four classes on the basis of the likelihood of impairment due to hydrological change (Table 19). The product of consequence and likelihood gives risk of impairment, which was grouped into five classes, ranging from insignificant to very high (Table 20).

Table 18: Environmental assets (and environmental flow objectives) potentially at risk of impairment from hydrological changes in reaches 5 and 6

Environmental asset / environmental flow objective	Asset code
Upstream migration of anadromous fish	A
Marine derived freshwater opportunists	B
Estuarine resident fish	C
Species inhabiting tidal mudflats	D
Freshwater dependent vegetation	E

Table 19: Environmental asset classes rated for consequence to ecosystem if a change occurs and rated likelihood of impairment due to four degrees of hydrological change

Asset	Consequence score
Species of commercial or national conservation significance	3
Species of recreational or regional conservation significance	2
Native species with no particular commercial, recreational or conservation status	1
Degree of change	**Likelihood score**
No significant change in quality or extent of habitat / process	0
Minor change in quality or extent of habitat / process	1
Major change in quality or extent of habitat / process	2
Loss of habitat or process	3

Table 20: Risk matrix, showing classes of risk of impairment for product of consequence and likelihood scores

		Likelihood			
		0	**1**	**2**	**3**
Consequence	**1**	risk level 1: very low	risk level 2: Low	risk level 3: moderate	risk level 3: moderate
	2	risk level 1: very low	risk level 3: moderate	risk level 4: high	risk level 4: high
	3	risk level 1: very low	risk level 3: moderate	risk level 4: high	risk level 5: very high

Consequence and likelihood scores were assigned to each environmental asset, and risk scores were calculated for each asset for three future planning and development scenarios for Reach 5 (Table 21) and Reach 6 (Table 22). These scenarios were developed as part of the water resources allocation planning component of the pilot work and are discussed in further detail below. In summary, they are:

- Scenario 2: 2020 conditions; based on the current, proposed reservoir developments, operations and water transfer rules (from both Zhuxi and Shisandu Reservoirs).
- Scenario 3: Same as Scenario 2, but with environmental flow rules as recommended from the environmental flows assessment (note: the environmental flow rules specified were only to achieve the required flows in reaches 1 and 2. It was not possible to set rules to achieve all of the flows required in the lower reaches, because the IQQM was only considering management arrangements in Zhu Creek and Zhu Creek has a limited influence on the trunk stream).
- Scenario 6: Same as Scenario 2, but with an additional reservoir supplying local demands equivalent to Zhuxi Reservoir in the Yong'an Creek catchment upstream of Zhu Creek.

Table 21: Risk to environmental assets in Reach 5 in response to hydrological changes associated with future planning scenarios

	Asset code	Consequence	Scenario 2 Likelihood	Scenario 2 Risk level	Scenario 3 Likelihood	Scenario 3 Risk level	Scenario 6 Likelihood	Scenario 6 Risk level
Reduction in low flow baseflow			8-10%		5-7%		9-11%	
	A	3	1	3	1	3	1	3
	B	2	0	0	0	0	0	0
	C	3	0	0	0	0	0	0
	D	3	0	0	0	0	0	0
	E	1	0	0	0	0	0	0
Reduction in high flow baseflow			4-9%		3-7%		4-10%	
	A	3	1	3	1	3	1	3
	B	2	0	0	0	0	0	0
	C	3	1	3	1	3	1	3
	D	3	0	0	0	0	0	0
	E	1	0	0	0	0	0	0
Reduction in flood magnitude & frequency			14%		7%		14%	
	A	3	1	3	0	0	1	3
	B	2	0	0	0	0	0	0
	C	3	0	0	0	0	0	0
	D	3	0	0	0	0	0	0
	E	1	1	1	0	0	1	1

Table 22: Risk of impairment to environmental assets in Reach 6 in response to hydrological changes associated with future planning scenarios

	Asset code	Consequence	Scenario 2 Likelihood	Scenario 2 Risk level	Scenario 3 Likelihood	Scenario 3 Risk level	Scenario 6 Likelihood	Scenario 6 Risk level
Reduction in low flow baseflow			13-17%		11-14%		13-17%	
	A	3	1	3	1	3	1	3
	B	2	0	0	0	0	0	0
	C	3	0	0	0	0	0	0
	D	3	0	0	0	0	0	0
	E	1	0	0	0	0	0	0
Reduction in high flow baseflow			6-8%		5-6%		6-8%	
	A	3	1	3	1	3	1	3
	B	2	0	0	0	0	0	0
	C	3	1	3	1	3	1	3
	D	3	0	0	0	0	0	0
	E	1	0	0	0	0	0	0
Reduction in flood magnitude & frequency			16%		17%		16%	
	A	3	1	3	1	3	1	3
	B	2	0	0	0	0	0	0
	C	3	0	0	0	0	0	0
	D	3	0	0	0	0	0	0
	E	1	1	1	1	1	1	1

Analysis of Ecological Risks in Reaches 5 and 6

The three scenarios examined appear to pose a fairly minimal threat to the environmental assets in reaches 5 and 6. The greatest, yet still only *moderate*, threat is posed to the upstream movement of migratory fish and to estuarine resident fish species under all scenarios. The main threat to the latter group is likely to be a change in the distribution and availability of suitable spawning habitats, which are often located in areas with salinity levels below that of seawater. Reductions in high flow baseflows during the spawning period may cause changes in salinities in the middle and upper estuary that could isolate appropriate spawning sites from areas with appropriate water chemistry.

Floods also play a major role in periodically flushing estuaries and redistributing salinity gradients, and in inundating low lying wetland areas dependent on freshwater. Hence these also were identified as an important component of the flow regime to consider. It is worth noting that in Reach 5, scenarios that included environmental flow rules ameliorated the risks associated with a reduction in flood frequency for migratory fish and freshwater dependent vegetation.

Overall, it would appear that construction of dams on Zhu Creek and Yong'an Creek would cause small but incremental changes in the baseflow volume and flood magnitude and frequency in reaches 5 and 6. This incremental change highlights the importance of assessing the impacts of water resource development at the basin scale, as further development in other sub-catchments will almost certainly increase the risk posed to environmental assets over the levels reported here.

These risk levels from future planning scenarios were then assessed using hydrological indices.

Impacts on low and high baseflows

Low and high baseflows were analysed using a single hydrological index. These recommended minimum environmental flows correspond to the flows exceeded 75% of the time ("the 75^{th} percentile flow").

Therefore, for each of the four main defined flow periods in a year, the flow thresholds corresponding to the 75^{th} percentile flow were determined for the current flow regime. The percentages of time that these thresholds were exceeded in the future planning scenarios were then calculated

The baseflow analysis revealed that the high flow periods (April-July and August-September) suffered greater reductions in baseflows than did the low flow periods (October-January and February-March). This is probably explained by the water resources development tending to capture water in the high flow periods. In addition, reach 6 was consistently more affected than reach 5 in the high flow periods, while in the low flows period there was no difference between the sites.

Impacts on bankfull floods

One way of assessing the impact of water resources development on flood frequency is to plot and compare the partial duration flood frequency curves for the various scenarios. These curves suggest that modelled development scenarios lead to only a modest decline in flood frequency for any given discharge, and the scenarios all have a similar level of impact.

4.6 Non-flow Related Issues

A number of non-flow related issues impact the Jiao River basin and represent threats to the success of any implemented environmental flow regime in achieving the objective of a healthy river. It is suggested that these issues be further investigated and appropriately managed.

4.6.1 Sand and gravel extraction

Sand and gravel extraction is widespread in the river system. The process appears to be one of removing the desired sand and gravel-sized fractions and leaving the coarser cobbles behind. Apart from the disruption caused by the process of extraction, the practice can have longer-term repercussions. The types of changes that can occur are:

- loss of bed volume;
- change in the particle size of the bed material;
- disruption of armoured surface layers;
- alteration of natural bedforms that may be important habitats in their own right, or they may be important because they generate desirable hydraulic habitats under certain flow conditions; and
- potential for extraction exceeding the rate of supply, leading to downstream or upstream progression of bed incision. Incision can be followed by a phase of widening.

4.6.2 Estuary channel dredging

The Jiao River estuary requires constant dredging in order to overcome the naturally high rate of sediment deposition (with the vast majority of the sediment coming from the sea, not the Jiao River itself). However, dredging at a rate exceeding the deposition rate will deepen the estuary and this could have the effect of increasing the tidal range. The impacts of this have not been considered in any detail, but it will almost certainly have some impact.

4.6.3 Pollution

There are numerous point and non-point sources of pollution in the catchment (agricultural, urban and industrial). If pollution exceeds the limits of the biota, then the environmental flows will be obsolete.

Cold-water pollution is caused by cold water being released below reservoirs that have deep releases. This generally causes severe ecological disruption for a distance downstream, but it can be easily overcome by designing the reservoir with a multi-level off take.

4.6.4 Over-fishing

As previously noted, fishery production is increasing in Taizhou. It is beyond the scope of this report to comment in detail on the sustainability of fishing practices in the Jiao River basin, although it is clear that ongoing monitoring of fisheries is warranted. Fisheries sustainability is exceptionally difficult to measure, but should take into account yields, efforts and the species that make up the catch. Declines in resource availability are often masked by increased catch effort or a shift toward more abundant species.

Aquaculture also warrants some mention. Major aquaculture species in the Taizhou region include several native carp species. While these species can readily be spawned and reared in captivity, scientific research suggests that natural recruitment of wild populations and the environmental conditions that maintain these populations are still of importance to aquaculture.

Chapter 5: Application of a water resources allocation planning methodology in the Jiao River basin

5.1 Introduction

This chapter describes the process that was used to develop and evaluate various operational and water supply scenarios for the Jiao River, as the basis for developing a water resources allocation plan that can incorporate environmental flows, define abstraction caps and protect the reliability of supply for water users.

The pilot work focussed on the proposed Zhuxi Reservoir. The study considered the impact of different management arrangements on (and what different options for a water resources allocation plan would mean for):

i. reliability of local supply on Zhu Creek;
ii. reliability of supply from Changtan Reservoir; and
iii. impacts on flows, from Zhuxi Reservoir downstream to the river mouth.

In summary, the water resources allocation planning methodology adopted in this study involved the following steps:

i. identification of water resources availability and supply requirements;
ii. identification of environmental flow requirements (as described in the previous chapter);
iii. development of a water resources management model (IQQM), capable of modelling the impacts of different operational and supply arrangements on river flow and supply reliability (the model development is described in detail in Part 5);
iv. modelling of the current management and supply arrangements;
v. development of different management scenarios, including scenarios that incorporate environmental flow requirements;
vi. analysis of the modelled results for each scenario, in terms of impact on environmentally-relevant flows and reliability of supply (for fixed demand); and
vii. identification of the way that a preferred management scenario could be converted into a water resources allocation plan.

A final recommendation is not made on a particular planning scenario. Ultimately a decision on what are acceptable outcomes – in terms of water availability and environmental flows (and risks) – is a matter for the local government to decide. The pilot work in Taizhou is intended to demonstrate the process of water resources allocation planning, and the likely consequence of adopting alternative management arrangements.

5.2 Identifying water resources availability and supply requirements

Assessing water supply and demand within a river basin requires the identification of:

- water resources availability, including existing supply infrastructure operating arrangements and limitations;
- potential water resources development opportunities; and
- the consumptive requirements for water from the basin for different users, both in terms of total volumes and the level of supply reliability required.

As discussed previously, an evaluation of current and future water supplies and demands was undertaken in Taizhou as part of the comprehensive plan for Taizhou. These issues were not further considered during the pilot work. Rather, the pilot work focussed on options to deliver the demands – for the year 2020 – as identified in the comprehensive plan, while also providing the recommended environmental flows.

5.3 Water resources allocation plan scenarios

Different scenarios were developed to allow assessment of the impacts of different management arrangements on the provision of water for environmental purposes and human uses. This included alternatives in respect of:

i. the construction of infrastructure (e.g. what reservoirs where constructed and where);
ii. release rules for reservoirs (e.g. the circumstances under which releases must be made for environmental purposes);
iii. the inter-operation of reservoirs (e.g. the rules for deciding when water is transferred from one reservoir to another); and
iv. water sharing rules (e.g. at what water level is supply to different categories of water user stopped).

In broad terms, the pilot work focussed on how environmental flows could be provided while optimising supply reliabilities. Initially, scenarios were developed to compare the current situation with:

i. the proposed 2020 arrangements; and
ii. the proposed 2020 arrangements, adjusted to incorporate the environmental flow rules (note that throughout this chapter, “the environmental flow rules” refers to the recommended flows for the Zhu Creek/Jiao River, as described in the previous chapter).

Further scenarios were then developed to assess other issues including the effects of different operational arrangements for the proposed infrastructure, alternative development proposals and various combinations of these scenarios. The process of considering different scenarios was iterative, allowing for the consideration of the advantages and disadvantages of each scenario with a view to providing viable options for a water resources allocation plan.

Ultimately, eleven different scenarios were modelled. These are summarised in Table 23 and examined in further detail below.

Table 23: Modelled scenarios

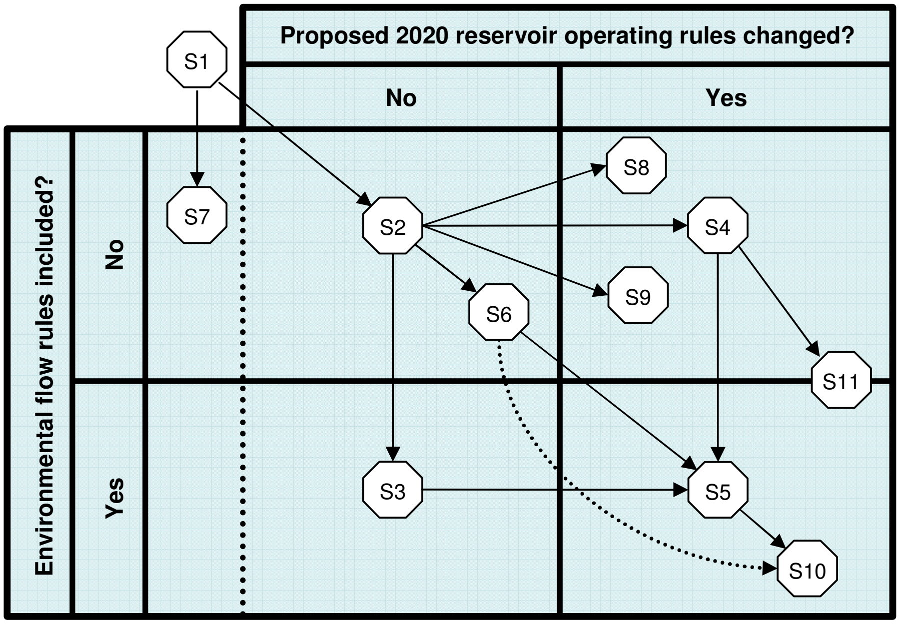
Scenario	Description
S1	Existing (2004) conditions
S2	Planned 2020 arrangements (demand based on Taizhou Comprehensive Plan; assumes construction of Zhuxi and Shisandu Reservoirs)
S3	Same as S2, but with environmental flow rules as recommended from the environmental flows assessment
S4	Same as S2, but with modified Changtan Reservoir operation rules (altered sharing rule for urban and irrigation supply)
S5	Same as S4, but with environmental flow rules as recommended from the environmental flows assessment
S6	Same as S2, but with additional reservoir with local demands equivalent to Zhuxi Reservoir in the Yong'an Creek catchment upstream of Zhu Creek
S7	2010 demands with no Zhuxi Reservoir and no environmental flow rules
S8	Same as S2, but with no water transfers from Shisandu Reservoir
S9	Same as S2, but with lower release threshold for Zhuxi water transfers to Changtan Reservoir
S10	Same as S5, but with additional reservoir with local demands equivalent to Zhuxi Reservoir in the Yong'an Creek catchment upstream of Zhu Creek
S11	Same as S4, but with modified (sub-optimal) environmental flow rules

Some notes on these scenarios follow:

- Except for Scenarios 1 and 7, each of the scenarios is based on the assumed demands for the year 2020 that are outlined in the Taizhou comprehensive plan.
- The environmental flow rules referred to in the scenarios reflect the recommendations made in the previous chapter (except for scenario 11, which has modified (sub-optimal) environmental flow rules).
- The modifications to the operating arrangements for different infrastructure (Scenarios 4, 5 and 9-11) were considered as possible ways of improving supply reliabilities for various users.
- Scenarios 6 and 10, which contemplate an additional reservoir being constructed in the Yong'an Creek catchment upstream of Zhu Creek, were included to demonstrate the cumulative impacts of continuous development.
- Scenario 7 assesses capacity to meet demands for the year 2010 from existing infrastructure (i.e. without Zhuxi Reservoir).
- Scenario 8 assesses whether the expected demands for the year 2020 could be met without transferring water from Shisandu Reservoir to Zhuxi.
- Scenario 11 was designed to consider the implications of a 'trade-off' of some environmental outcomes in favour of improved supply reliabilities.

The way the different scenarios relate to each other is depicted in Figure 23. This diagram can be helpful to understand which scenarios should be compared when analysing the various sets of model results.

Figure 23: Diagrammatic representation of modelled scenarios

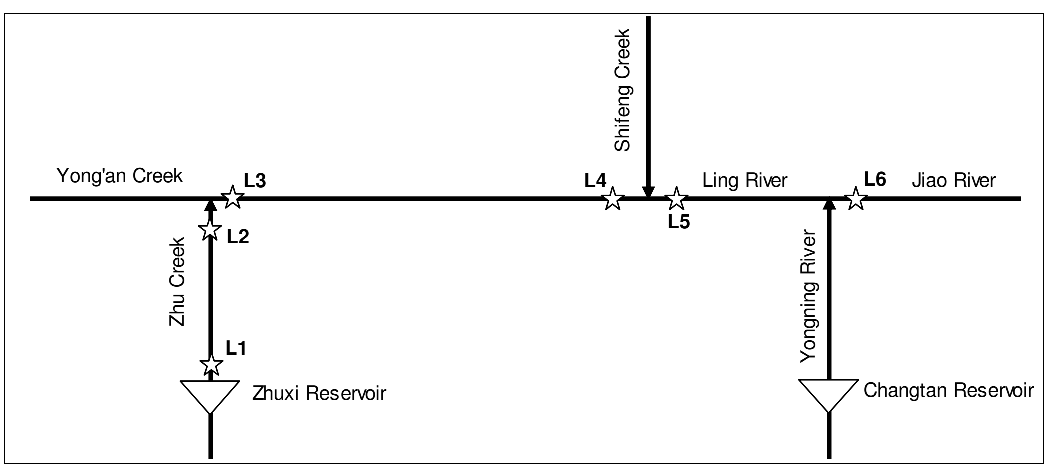


5.4 Water resource management model

The IQQM was used to model each of the scenarios. The model produces a huge range of statistical outputs. However, the study focussed on the following for each scenario:

- daily and annual reliabilities (for fixed supply volumes) for urban/industrial users and for irrigation, from both Zhuxi and Changtan Reservoirs;
- average annual supply for urban/industrial users and irrigation, both as a volume and a proportion of the sectors' demand, from both Zhuxi and Changtan Reservoirs;
- average annual transfer of water from Zhuxi to Changtan Reservoir, both as a volume and a proportion of the maximum possible through the pipeline;
- flow data for the reaches, which was used to assess compliance with desired environmental flows. (The six flow reporting nodes are shown in Figure 24).

Figure 24: Schematic of IQQM model flow reporting nodes



5.4.1 Model parameters for Zhuxi Reservoir

The *basic parameters* for Zhuxi Reservoir are as follows:

- The full storage volume is 118.38 million m^3.
- The inactive storage volume is 5.14 million m^3.

The *operation rules* of Zhuxi Reservoir are defined by the following factors:

- Zhuxi Reservoir has multiple objectives, including water supply, flood control, irrigation and power generation.
- The reservoir must firstly meet water use needs of Zhu Creek and then, if possible, transfer water to Changtan Reservoir.
- However, water supply operation is subject to flood control operation.
- Defined reservoir water levels at which different uses become inactive:
  - for irrigation: 122 metres – storage volume of 34.82 million m^3;
  - for power generation: 120 metres – volume of 30.64 million m^3; and
  - for urban water supply: 100 metres – volume of 5.14 million m^3.

Minimum environmental demand is 0.14 m^3 per second to be released from Zhuxi Reservoir.

The *pipeline from Zhuxi Reservoir to Changtan Reservoir* will deliver:

- 270,000 m^3 per day in 2011; and
- 680,000 m^3 per day in 2020 – this includes the diversion of 410,000 m^3 per day from Shisandu Reservoir.

5.4.2 Model parameters for Changtan Reservoir

The *basic parameters* for Changtan Reservoir are as follows.

- The full storage volume is 357 million m^3.
- The inactive storage volume is one million m^3.

Notably, the model assumes a change to the infrastructure design for Changtan Reservoir. The low level outlet capacity for Changtan Reservoir as per the design report is too small to supply the 2020 demands. To remove this constraint to supplying the required demands, the model assumes increases to the capacity for the lower storage volumes. The discharge characteristics adopted in the model and the original design values are compared in Table 24. There were no changes to these characteristics above 134,000 ML (the characteristics are provided up to a stored volume of 732,000 ML).

Table 24: Changes to the Changtan Reservoir low level outlet discharge characteristics

Stored volume (ML)	Outlet capacity in design report (ML/day)	Modelled outlet capacity (ML/day)
1,000	0	
72,000	1,296	1,500
95,000	1,296	3,700
104,000	1,296	3,700
114,000	2,419	3,750
124,000	2,419	3,800
134,000	4,579	4,579

5.4.3 Levels of demand

Table 25 shows the assumed levels of demand assumed in the IQQM.

Table 25: Levels of Demand

Region	Year	Irrigation Demand (ML/year)	Urban Demand (ML/Year)	Total Demand (ML/Year)
Lower Zhu Creek	2004	16,080	3,650	19,730
	2020	16,080	13,505	29,585
Lower Yong'an Creek	2004	22,250	8,560	30,810
	2020	30,900	18,010	48,910
Lower Shifeng Creek	2004	16,740	5,420	22,160
	2020	21,760	8,770	30,530
Yongning River	2004	330,000	84550	414,550
	2020	257,000	529,250	787,150

5.5 Evaluation of the model results for the scenarios

A detailed analysis of each of the scenarios is provided below. Table 26 provides a summary of the results, which are generated from a 26 year simulation period.

5.5.1 Scenario 2 – Current proposed arrangements for year 2020

Scenario 2 models the expected flows and reliabilities, based on the currently planned supply and operational arrangements for 2020.

Implications for reliability of supply

Local water supply from Zhu Creek for urban/industrial is provided at a daily reliability over 97%. Annual reliability for irrigation from Zhu Creek is 100%.

From Changtan reservoir, urban industrial users are suppled at an annual reliability of 96% and a daily reliability of 82%. Irrigation supplied from Changtan Reservoir is at an annual reliability of 69%.

Notably, based on the model results, reliability of supply for all purposes from Changtan Reservoir is likely to be below an acceptable level for the currently proposed arrangements.

Implications for environmental flows

Table 27 provides an overview on the impact of the proposed 2020 development on most of the environmentally important flows within reaches 1, 2 and 3.

As would be expected, the greatest impacts are in reach one, immediately downstream of Zhuxi Reservoir. Baseflows at the required level are almost non-existent (see Figure 25), and the number of environmentally-important pulses (both low and high) is reduced to 5% or less of their natural number.

The impacts on flows further downstream are less (due to inflows from other parts of the catchment). However, there are still major impacts on baseflows and the number of pulses.

Bankfull and flooding events are generally not affected, due to the size of these events.

The environmental implications of these changes are discussed in detail in the previous chapter (which describes the ecological significance of these aspects of the flow regime).

Table 26: Performance criteria – supply reliabilities

			Scenario								
			S2	S3	S4	S5	S6	S7	S8	S9	S10
Changtan	Urban/Industrial	Average annual supply (ML)	506,468	493,072	520,919	513,409	506,468	274,851	458,605	515,192	513,409
		Average annual supply (% of demand)	96%	93%	98%	97%	96%	98%	87%	97%	97%
		Daily reliability (% of days full daily demand met)	82%	74%	96%	93%	82%	92%	63%	85%	93%
	Irrigation	Average annual supply (ML)	173,845	160,901	167,654	151,089	173,845	177,006	135,368	175,672	151,089
		Average annual supply (% of demand)	69%	64%	67%	60%	69%	61%	54%	70%	60%
		Annual reliability (% of years full annual demand met)	0%	0%	0%	0%	0%	0%	0%	0%	0%
Zhuxi	Urban/Industrial	Average annual supply (ML)	13,446	13,514	13,446	13,514	13,446	8,757	13,446	13,451	13,514
		Average annual supply (% of demand)	100%	100%	100%	100%	100%	100%	100%	100%	100%
		Daily reliability (% of days full daily demand met)	97%	100%	97%	100%	97%	100%	97%	97%	100%
	Irrigation	Average annual supply (ML)	11,247	10,645	11,247	10,645	11,247	11,255	11,247	10,662	10,645
		Average annual supply (% of demand)	100%	95%	100%	95%	100%	100%	100%	95%	95%
		Annual reliability (% of years full annual demand met)	100%	67%	100%	67%	100%	100%	100%	63%	67%

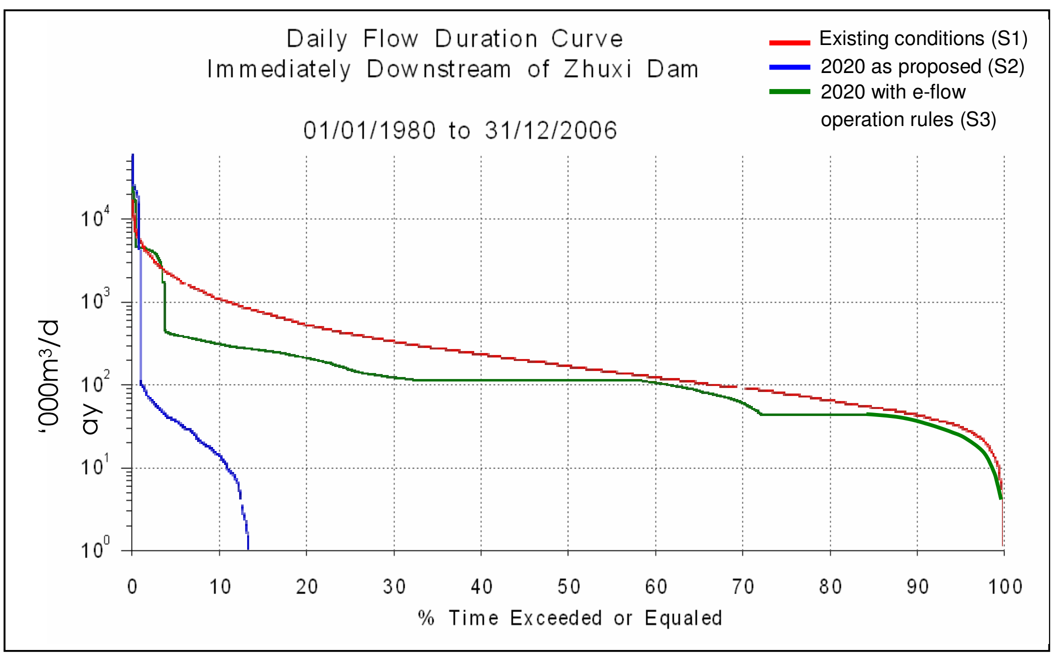
Table 27: Impact of development on the flow regime in first three reaches

Reach 1: Zhu Creek just downstream of Zhuxi Reservoir	**Existing (S1)**	**2020 (S2)**
Low flow season (Oct-Mar): % time flow >= 43.2 ML/day	78.4%	0.3%
High flow season (Apr-Sep): % time flow >= 112.3 ML/day	74%	1.6%
Low flow pulse (Oct-Mar): No. of days > 1,728 ML	100	6
High flow pulse (April): No. of 2 consecutive days > 1,728 ML	13	0
High flow pulse (May-June): No. of 2 consecutive days > 1,728 ML	108	2

Reach 2: Downstream end of Zhu Creek	**Existing (S1)**	**2020 (S2)**
Low flow season (Oct-Jan): % time flow >= 112.3 ML/day	74.5%	42%
High flow season (Apr-Sep): % time flow >= 345.6 ML/day	71.7%	48.5%
Low flow pulse (Oct-Mar): No. of 2 consecutive days > 4,579 ML	19	8
High flow pulse (April): No. of 2 consecutive days > 4,579 ML	15	6

Reach 3: Yong'an Creek upstream of Shifeng Creek	**Existing (S1)**	**2020 (S2)**
Low flow season (Oct-Jan): % time flow >= 587.5 ML/day	76%	58.5%
High flow season (Apr-Sep): % time flow >= 1918.1 ML/day	72%	59.9%
Low flow pulse (Oct-Mar): No. of 4 consecutive days > 6,393.6 ML	68	50
High flow pulse (Apr-Sep): No. of 5 consecutive days > 10,627 ML	33	31

Figure 25: Benefits of providing environmental flows



The consequences, for Zhu Creek and to a lesser extent Yong'an Creek, are likely to include:

- loss of habitat (especially the loss of deep pools);
- loss of pulses to trigger spawning events;
- loss of migratory paths;
- loss of flows to maintain riparian vegetation;
- loss of flows to maintain geomorphic processes, important for maintaining both water quality and channel form.

Together, these changes are likely to have a major impact on fish and fisheries within Zhu Creek and downstream of it.

From reach 3 (Yong'an Creek) downstream to the river mouth, the greatest threat from alteration to the flow regime is likely to come from the cumulative impacts of development. The likely implications for the estuarine parts of the Jiao River are discussed in detail in the risk assessment in the previous chapter.

5.5.2 Evaluation of the effects of the environmental flow rules

Three of the modelled scenarios (S3, S5 and S10) test the impact of the introduction of environmental flow rules, in accordance with the recommendations made from the environmental assessment discussed earlier.

The environmental flow rules specified were only to achieve the recommended flows in reaches 1 and 2. It was not possible to set rules to achieve all of the flows required in the lower reaches, because the pilot study (and the IQQM) was focussed on management arrangements in Zhu Creek, which has a limited influence on flows in the trunk stream. However, the release of additional water into Zhu Creek will still see some improvement in flows in the trunk stream.

The benefits of providing these flows are apparent from Figure 25. The environmental flows rules would ensure that stream flows at this location closely mimic the natural baseflows.

The environmental flow rules mean that the recommended flows will be achieved in reaches 1 and 2. Consequently, there should be a high level of confidence that incorporating these environmental flow rules within a water resources allocation plan would protect the ecological health of Zhu Creek.

As noted, the environmental flow rules will not guarantee that the recommended flows are achieved in reach 3 and further downstream. Protecting these reaches would require a whole-of-basin water resources allocation plan (and testing compliance would require a whole-of-basin model).

There are, though, benefits for the trunk stream. These benefits are less further downstream from Zhu Creek, due to the overriding impact of other factors. The benefits to the trunk stream of providing for environmental flows (from Zhuxi Reservoir) can be seen by analysing the mean annual flows at the reporting nodes under each of the scenarios (see Table 28).

Table 28: Mean annual flows at reporting nodes

Flow reporting location		Scenario									
			S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
L1		Volume (ML)	176,648	73,380	118,724	73,447	118,724	73,380	176,648	74,191	57,870	118,724
		Proportion of existing	100.0%	41.5%	67.2%	41.6%	67.2%	41.5%	100.0%	42.0%	32.8%	67.2%
L2		Volume (ML)	440,187	320,485	366,621	320,552	366,620	320,485	437,634	321,296	305,806	366,621
		Proportion of existing	100.0%	72.8%	83.3%	72.8%	83.3%	72.8%	99.4%	73.0%	69.5%	83.3%
L3		Volume (ML)	1,930,895	1,530,037	1,576,172	1,530,104	1,576,172	1,514,151	1,928,341	1,680,596	1,515,358	1,560,287
		Proportion of existing	100.0%	79.2%	81.6%	79.2%	81.6%	78.4%	99.9%	87.0%	78.5%	80.8%
L4		Volume (ML)	2,279,866	1,862,364	1,908,480	1,862,431	1,908,480	1,846,473	2,268,952	2,012,902	1,847,686	1,892,594
		Proportion of existing	100.0%	81.7%	83.7%	81.7%	83.7%	81.0%	99.5%	88.3%	81.0%	83.0%
L5		Volume (ML)	3,779,532	3,362,031	3,408,146	3,362,098	3,408,146	3,346,140	3,768,618	3,512,568	3,347,352	3,392,260
		Proportion of existing	100.0%	89.0%	90.2%	89.0%	90.2%	88.5%	99.7%	92.9%	88.6%	89.8%
L6		Volume (ML)	5,006,355	4,497,658	4,524,884	4,488,956	4,513,634	4,481,767	4,876,989	4,584,517	4,487,916	4,497,748
		Proportion of existing	100.0%	89.8%	90.4%	89.7%	90.2%	89.5%	97.4%	91.6%	89.6%	89.8%

Providing environmental flows would, however, impact on the reliability of water supply (see Table 26):

- It would reduce the daily reliability of supply for urban/industrial users from Zhuxi Reservoir from 100% to 97%. This is still within the target range of urban water reliability under the Taizhou comprehensive plan.
- It would reduce the average annual supply (as a % of demand) for irrigation from Zhuxi Reservoir from 100% to 95%. This translates into a reduction in the annual reliability of these supplies (i.e. the proportion of years in which irrigators would receive their full demands) from 100% to 67%.
- It would reduce the reliability of urban/industrial supplies from Changtan Reservoir:
    - The average annual supply reduces by between 1% and 3% of the sector's demands (depending on other factors considered in the scenarios).
    - The daily reliability reduces considerably (from 82% to 74%) unless the Changtan Reservoir operation rules are also changed, in which case the reduction is relatively minor (from 96% to 93%) (This change to the operation rules is discussed later in this chapter).
- The annual average supply for irrigation from Changtan Reservoir would be between 5% and 7% lower (to between 60% and 67%).

The impact of the provision of environmental flows on supply from Changtan Reservoir can also be understood by considering the volume of water piped from Zhuxi Reservoir to Changtan Reservoir.

Under the planned pipeline operational rules, water is only transferred to Changtan Reservoir depending on the water level in Zhuxi Reservoir (relative to Changtan Reservoir). The provision of environmental flows reduces the times when the prerequisites for transfer are met. As shown in Table 29, this reduces the annual volume transferred by about 40%.

Table 29: Water transfer from Zhuxi to Changtan

	Average annual transfer	
Scenario	**Volume (ML)**	**% of maximum**
S2	106,493	80.4
S3	61,356	46.3
S4	106,424	80.3
S5	61,355	46.3
S6	106,493	80.4
S7	-	-
S8	105,676	79.8
S9	121,887	92.0
S10	6,1355	46.3
S11	73,451	55.4

NB: Maximum supply rate is 132,495 ML per annum

The provision of these flows, should they be adopted and included in a water resources allocation plan, would require amending the operational rules for Zhuxi Reservoir.

5.5.3 Evaluation of the effects of changing the Changtan Reservoir operation rules

The modified Changtan Reservoir operation rules (applied in S4, S5 and S10) involve lowering the threshold at which water for urban supplies must be restricted. Under the currently planned rules, urban water supply is restricted and irrigation water supply is reduced to zero when the water level falls to 21.05m (72 million m^3). The modified arrangements involve lowering this restriction threshold to 15.05m (12 million m^3) for urban supplies, but not changing the threshold for irrigation supplies. This allows urban/industrial users to be supplied from what would otherwise be “dead” storage.

These scenarios were considered to attempt to improve reliability of urban/industrial supplies from Changtan Reservoir. As per Table 26, under the 2020 base case (S2), average annual supplies would be about 96% of demand, but the daily reliability would only be about 82% (i.e. on 18 days out of every hundred during the model period, urban/industrial supplies would be restricted).

The changed operating arrangements would significantly improve the reliability of supply to urban/industrial users. Under each of these modified scenarios, the daily reliability would rise to 93%-96%, depending on other variables (such as the inclusion of environmental flow rules).

Making this change would reduce average annual supply to irrigation by between 2%-7% (of demand). There are no consequences for users supplied directly from Zhuxi Reservoir.

5.5.4 Evaluation of the effects of changing the Zhuxi-Changtan pipeline operation rules

Under planned operating rules for Zhuxi Reservoir, no water is transferred to Changtan Reservoir when the Zhuxi Reservoir level falls below 130 metres (56.1 million m^3). The modified arrangements in Scenario 9 involve lowering this threshold to 120 metres (30.64 million m^3).

This scenario (S9) was considered in an attempt to improve the reliabilities of supply for users from Changtan Reservoir.

Table 26 shows that these modified arrangements would have minor benefits for users supplied from Changtan Reservoir, increasing the reliability of achieving average annual demand by approximately 1%.

These changes would not impact on urban/industrial users supplied from Zhuxi Reservoir. However, the average annual irrigation supplies would reduce in volume and annual reliability. The relative values of these benefits and costs on the different users would need to be evaluated to determine whether altering the pipeline operating rules in this way is appropriate.

5.5.5 Evaluation of cumulative effects of development

Two scenarios were modelled to demonstrate the cumulative effects of development on flows downstream. These scenarios both contemplate an additional (hypothetical) reservoir being constructed in the Yong’an catchment upstream of the point where Zhu Creek meets Yong’an Creek. The modelling assumes identical levels of local demand as from Zhuxi Reservoir but, significantly, does not involve the transfer of water out of the catchment (i.e. it is assumed this reservoir only supplies relatively small local demands).

Scenario 6 is based on the proposed 2020 arrangements. As such, the results for this scenario should be compared to those for the current planned development (S2).

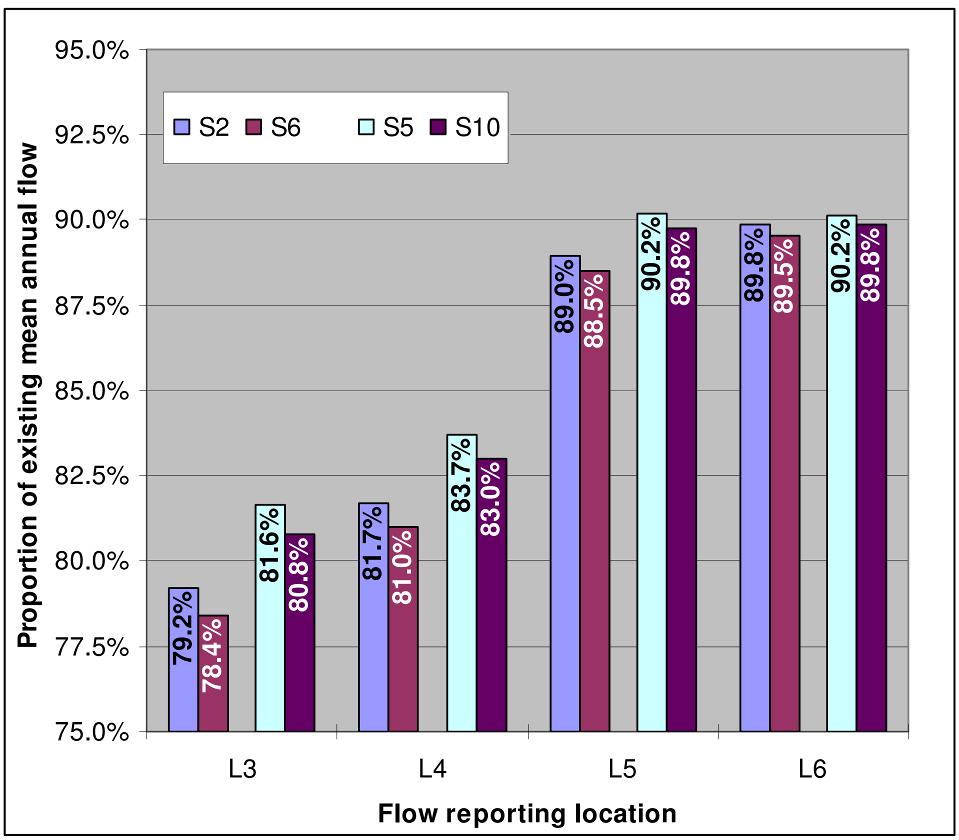
Scenario 10 is based on the 2020 arrangements with modified Changtan Reservoir operating rules and the provision of environmental flows. The model results for this scenario should be compared to the results from Scenario 5. This second scenario is the most extreme variation from the arrangements proposed in the Taizhou comprehensive plan that was considered and modelled as part of the pilot work.

As the new hypothetical reservoir is not connected to the Zhu Creek and Yongning systems, there are no implications for supply from Zhuxi or Changtan Reservoirs, nor for flows (and thus the achievement of environmental outcomes) within Zhu Creek.

As such, the comparison of modelling results only needs to focus on flows in Yong'an Creek, Ling River and Jiao River (i.e. at flow reporting locations 3-6).

Figure 26 shows the impact of the additional reservoir on mean annual flows. While the impact is relatively small, it would be greater if the additional reservoir was used to supplement supplies in other parts of Taizhou as well as serving local demands.

Figure 26: Changes to mean annual flows at key reporting locations



The key question is at which point these cumulative effects have an unacceptable impact on the environment, which needs to be considered in the context of the specific environmental flow objectives for the river. The environmental assessment undertaken does not allow for a definitive recommendation on the threshold at which these impacts will mean an unacceptable level of ecological risk. Most important to recognise though is that:

i. there is a point at which development *will* impact on the environment; and
ii. even where that threshold is unknown, resource managers should be aware of the risk, should monitor trends within the relevant indicators for the flow, and if possible set flow objectives which must be achieved (even where there may not be clear evidence supporting exactly where that level should be set).

5.5.6 Evaluation of the effects of not proceeding with planned developments

Two additional scenarios were modelled to consider the implications of not building some of the infrastructure planned for in the Taizhou comprehensive plan.

The first (S7) assumed Zhuxi Reservoir was not in fact built by 2010. The model results indicate that the predicted 2010 demands could generally be met by existing infrastructure, subject to the irrigation demands from Changtan Reservoir being reduced to the 2020 demand levels.

All users on Zhu Creek would receive 100% of their demands in 2010, despite there being no reservoir to supplement their supplies. Urban/industrial users from Changtan Reservoir would have a greater daily reliability and average annual supply (relative to demand) than they would in 2020 under the currently planned levels of development.

However, on average, irrigators supplied from Changtan Reservoir would only receive 61% of their demands. This is largely due to the predicted irrigation demand pattern over the coming decades. Agricultural water use is predicted to increase by about seven per cent by 2010 then return to existing levels by 2020. Only in the subsequent ten years are agricultural demands predicted to drop below current levels.

Should some additional efforts be introduced to limit the increase in use by the agricultural sector and maintain demands at existing levels, irrigators supplied from Changtan Reservoir would receive an average annual supply of over 70% of this level. This situation would be comparable to the level of reliability these users would have in 2020 under the currently planned scenario.

These results indicate that the construction of Zhuxi Reservoir could be delayed until a later stage. This could allow for the deferral of:

i. capital investment; and
ii. the final design of the reservoir, which in turn could allow for its further optimisation (based on the most up-to-date demand information and technology) for environmental and supply security outcomes.

Scenario 8 modelled the construction and operation of all planned development by 2020 except for the pipeline to transfer water from Shisandu Reservoir to Zhuxi Reservoir. That is, Shisandu Reservoir would supply local demands only.

Under this scenario, users of water from Zhuxi Reservoir would receive the same reliability of supply as they would if the pipeline from Shisandu Reservoir was included. The average annual volume of water supplied from Changtan Reservoir would, however, be significantly lower, which would substantially reduce the reliability of supplies received by both urban/industrial and agricultural users.

Determining whether infrastructure operating rules under this scenario could be modified to improve supply reliabilities would require further modelling work. However, it is likely, however, that any such modifications would have consequences for other users, such as those supplied from Zhuxi Reservoir.

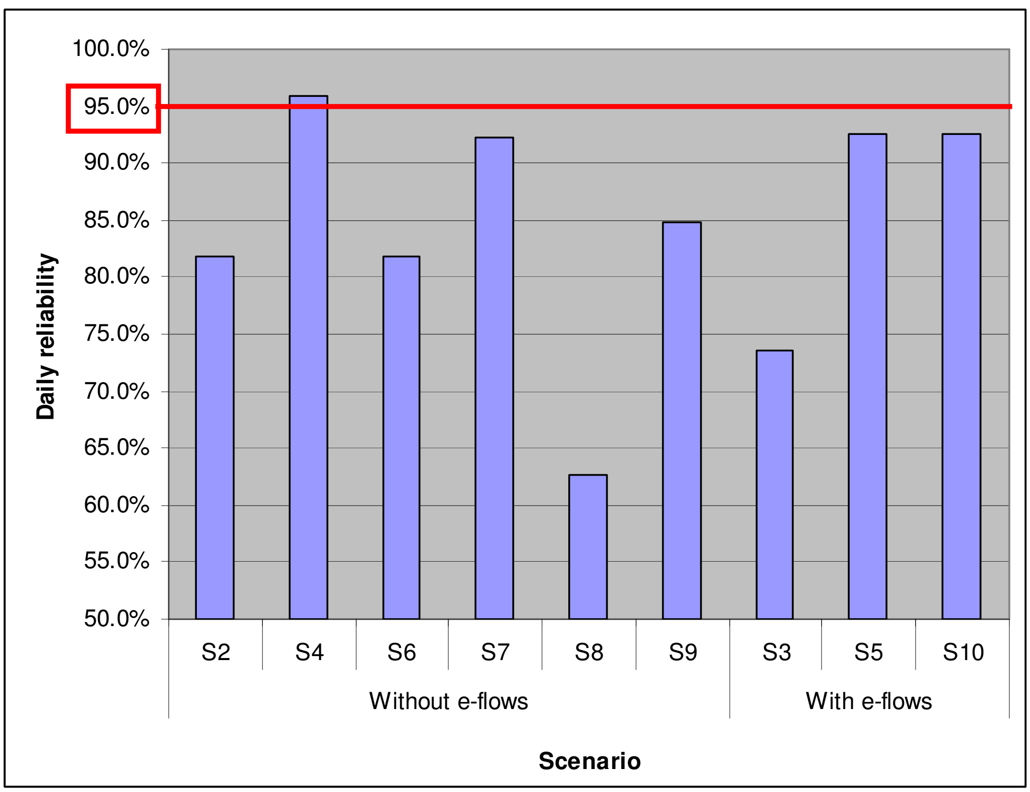
Consequently, transferring water via a pipeline from Shisandu Reservoir to Zhuxi Reservoir appears necessary to ensure the predicted 2020 demands for water from Changtan Reservoir can be met.

5.5.7 Evaluation of the effects of sub-optimal environmental flows

The last scenario (S11) that was developed was designed to demonstrate a 'trade-off' of some of the environmental outcomes in favour of improved supply reliabilities.

As shown above, the provision of the recommended environmental flows would impact on the reliability of supply for various users, and in particular urban/industrial users supplied from Changtan Reservoir. These users would normally expect to receive a daily reliability of at least 95%. This level is not achieved under any of the scenarios where all the recommended environmental flows are provided (Figure 27).

Figure 27: Daily reliabilities under modelled scenarios for urban/industrial users supplied from Changtan Reservoir (with comparison to the target of 95%)



This final scenario was developed to try to raise the reliability of urban/industrial supplies from Changtan Reservoir, while still providing some of the critical environmental flows. This required revisiting the environmental flows assessment and recommendations to come up with alternative, ‘sub-optimal’ environmental flow rules. The process undertaken in developing these alternatives is described below, followed by an evaluation of the model results for the final scenario.

Developing alternative environmental flows recommendations

Reducing the level of environmental flows requires prioritisation of the identified assets and objectives to determine which of the recommended flows can be reduced or ignored.

It must be recognised that the sub-optimal environmental flow option represents a departure from the *recommended* flow regime, so it carries a higher risk that the identified assets will not be protected. Accepting a higher risk is a management decision, not a scientific one.

The advantages and disadvantages of reducing a specific flow component depend on:

i. the potential to improve security of supply; versus
ii. the risk to the environment from that reduction.

The potential to improve supply security was determined by calculating the volumes of water required to supply the various flow components, and then determining the relative impact on total system savings by halving the flow component volume. The relative impact depends on the magnitude/frequency/duration characteristics of the component. For example, High Flows are of a relatively low magnitude, but long duration, so they account for a large percentage of the total flows.

To rank the potential to reduce the various aspects of flow components, a simple risk assessment was undertaken based on the following rules:

- “Relative potential” to modify is higher where the risk to the environment is lower and the potential for improving supply security is higher.
- Reduction in event magnitude resulted in a high risk to the environment (as the necessary hydraulic threshold required to achieve/initiate the ecological/ geomorphological process might not be met).
- A high risk to the environment resulted in no potential to modify the component.
- A nil potential to improve security of supply resulted in no potential to modify the component.
- Reduction in Pulse frequency was favoured over reduction in duration (as duration may be important to allow the ecological process to be completed).
- Pulse durations of one day cannot be reduced.
- Bankfull event duration can only be reduced for Reach 3, and Overbank duration cannot be reduced. (Bankfull and Overbank are less frequent than Pulses, so reducing their frequency was considered more detrimental than reducing frequency of Pulses, which would still occur at least once per year).
- The procedure for ranking options to modify the hydrological aspect of flow components did not allow sequential ranking within a component (i.e. if reduction in frequency of a component ranked highly, the duration of that component could not be ranked immediately after it). This was intended to reduce the likelihood that the final alternative environmental flow regime would involve a reduction of both duration and frequency to any one component.

Table 30 shows how each aspect of the various flow components was considered in terms of supply benefits and environmental risks and then ranked in terms of its potential to be modified in the environmental flows recommendations.

Table 30: Relative potential to modify flow components

Flow components (and hydrological facets)	Relative security of supply improvement	Relative risk to environment	Relative potential to modify	Ranked potential to modify
Low Flow magnitude	Moderate	High	Nil	-
High Flow magnitude	Moderate-High	Moderate	Moderate	4
Low Flow Pulse magnitude	Low	High	Nil	-
Low Flow Pulse duration	Low	Moderate	Low	7
Low Flow Pulse frequency	Low	Low	Low	6
High Flow Pulse magnitude	Moderate	High	Nil	-
High Flow Pulse duration	Moderate	Moderate	Moderate	5
High Flow Pulse frequency	Moderate	Low	High	1
Bankfull magnitude	Moderate-High	High	Nil	-
Bankfull duration	Nil†	Moderate	Nil†	5†
Bankfull frequency	Moderate-High	Moderate	Mod.-High	2
Overbank magnitude	High	High	Nil	-
Overbank duration	Nil	Moderate	Nil	-
Overbank frequency	High	Moderate	Mod.-High	3

† Reach 3 is an exception, with moderate potential to improve security of supply. Implement with High Flow Pulse duration reduction.

The final rank of potential to modify enabled the generation of alternative environmental flow scenarios. As additional changes are progressively included (in the ranked order), the potential to improve security of supply increases but so too does risk to the environment. These consequences are not numerically related and must be evaluated qualitatively.

Scenario 11 incorporated environmental flows, with changes made to the seven components listed in Table 30 as suitable for modification. This meant for scenario 11 for each of the seven components (as compared with the other environmental flows options):

- The value of the hydrological aspect of each flow component was halved (except for High Flow magnitude).
- Halving the High Flow magnitude was deemed to carry excessive risk to the environment, so was instead reduced by 25%.
- The High Flow Pulse associated with spawning was regarded as high risk to the environment if reduced in any way, so was not modified.
- The Overbank component was removed completely. Overbank would achieve little more than Bankfull because most of the potential floodplain asset is protected by levees. Overbank is of value only if some areas of floodplain are re-connected.

The effects of the sub-optimal environmental flows option

The supply reliabilities for users from Changtan and Zhuxi Reservoirs under the recommended and sub-optimal environmental flows options are compared in Table 31. Both of the scenarios analysed involve the changed operational arrangements for Changtan Reservoir to maximise the supply reliabilities for urban/industrial users.

Table 31: Supply reliabilities under the recommended and alternative environmental flows options

			Scenario S5	Scenario S11
Changtan	Urban/Industrial	Average annual supply (ML)	513,409	515,045
Changtan	Urban/Industrial	Average annual supply (% of demand)	97%	97%
Changtan	Urban/Industrial	Daily reliability (% of days full daily demand met)	93%	93%
Changtan	Irrigation	Average annual supply (ML)	151,089	162,024
Changtan	Irrigation	Average annual supply (% of demand)	60%	65%
Changtan	Irrigation	Annual reliability (% of years full annual demand met)	0%	0%
Zhuxi	Urban/Industrial	Average annual supply (ML)	13,514	13,513
Zhuxi	Urban/Industrial	Average annual supply (% of demand)	100%	100%
Zhuxi	Urban/Industrial	Daily reliability (% of days full daily demand met)	100%	100%
Zhuxi	Irrigation	Average annual supply (ML)	10,645	11,258
Zhuxi	Irrigation	Average annual supply (% of demand)	95%	100%
Zhuxi	Irrigation	Annual reliability (% of years full annual demand met)	67%	100%

The reduced level of environmental flows has the following impacts:

- Average annual reliability for urban/industrial users supplied from Changtan Reservoir does not change materially.
- There is a significant increase in the average annual supply for irrigation users from Changtan Reservoir.
- Urban/industrial users supplied from Zhuxi Reservoir continue to receive 100% of their demands.
- The reliability of supply for irrigation users from Zhuxi Reservoir increases substantially. Under the alternative environmental flows option, these users would be the biggest beneficiaries, receiving their full demands every year.

Under the alternative environmental flows scenario, more water would be transferred from Zhuxi Reservoir to Changtan Reservoir each year – 73,451 ML (or 55.4% of the maximum possible) compared to the 61,355 ML (46.3%) under the recommended environmental flows scenario (refer to Table 29). This is the cause of the increased reliability for irrigators supplied from Changtan Reservoir. However, it is not enough to noticeably improve urban/industrial supply reliability as increased transfers will not occur during the dry periods, which is the time when there will be greatest shortages. However, changing the operational and water sharing rules (e.g. when water is transferred, and also when irrigation water is supplied) could further increase urban water supply reliability from Changtan (but at a cost to irrigators). Notably, under this scenario supply reliability for irrigators from Zhuxi Reservoir would be significantly higher (100%) than would normally be expected for agricultural users.

5.5.8 Summary of the key findings from the scenario analysis

These key messages can be summarised as follows:

- Generally, the 2010 demands could be met from within existing supplies (i.e. without the development of Zhuxi Reservoir), subject to the irrigation demands from Changtan Reservoir being reduced to the 2020 demand levels. This would require more aggressive efficiency measures (such as those described in section 3.4.3 above) being promoted within the agricultural industry. Zhuxi Reservoir will however be required by 2020.
- The transfer of water from Shisandu Reservoir to Zhuxi Reservoir is not necessary to meet the 2020 demands on Zhu Creek. However, it is necessary to ensure supplies can meet the 2020 demands from Changtan Reservoir.
- The current, proposed arrangements will not achieve acceptable levels of supply reliability for users supplied from Changtan Reservoir.
- Lowering the restriction threshold for urban/industrial water supplies from Changtan Reservoir would significantly improve the urban/industrial supply reliability (both daily and annual) with only a small reduction in annual reliability for irrigators.
- The planned 2020 developments and infrastructure operating rules would have a major impact on environmentally-important flows on Zhu Creek, as well as impacts to lesser degrees further down the system to the Jiao River estuary.
- Adopting the recommended environmental flow rules would have a significant positive impact with no consequence for urban/industrial supplies from Zhuxi Reservoir, but various reductions in the reliability of irrigation supplies from Zhuxi Reservoir and all supplies from Changtan Reservoir.
  - These rules would significantly reduce the annual volume of water transferred from Zhuxi Reservoir to Changtan Reservoir.
  - The adoption of the environmental flow recommendations would require the operational rules for Zhuxi Reservoir to be redesigned.
- Alternative, sub-optimal environmental flow rules would improve the reliability of supplies for irrigation users within the Jiao River basin, but not provide much benefit for urban/industrial users. These rules would increase the risk of not achieving environmental outcomes.
- Several of the scenarios assessed provide for better results – both in terms of supply reliability AND environmental flows – that the arrangements that are currently planned for 2020 (i.e. S2).

It should be noted that the number of scenarios that could be considered is infinite. Additional scenarios would normally be developed if the results from the above scenarios do not demonstrate an acceptable balance between the supply and environmental objectives for the basin, or where the potential for improved results from changing operational arrangements is identified.

5.6 Converting a preferred scenario into a water resources allocation plan

5.6.1 Introduction

The scenario modelling allows resource managers to determine the likely outcomes (flows and reliabilities) from different management arrangements (abstraction caps and operational/release rules).

Having decided on an acceptable scenario – in terms of the management arrangements (e.g. the total water available for abstraction) and the predicted consequences of those arrangements (e.g. in terms of the reliability of supply of that volume) – the management arrangements should be converted into a regulation, in the form of a water resources allocation plan.

The resource manager (and others) can then have a level of confidence that – provided those management rules are complied with – they will achieve the outcomes predicted by the model (i.e. the reliability of supply and the flows that will be achieved). That should in turn provide confidence to water users in respect of the water they will receive from year to year, as well as confidence that the ecological health of the basin will be protected.

This section describes the process required to convert the work described above into a water resources allocation plan ('WRAP'). It should be noted that the pilot work alone does not provide an adequate basis for preparing a complete WRAP. The reasons for this are:

- The WRAP should cover the entire Jiao Basin. The environmental and water supply/demand assessments undertaken, as well as the water resources management model, were only done for parts of the basin.
- The scenarios developed represent only a start at the process of identifying a preferred water management scenario. Further scenarios should be developed. However these can only be done once decisions are made on what are acceptable outcomes: in terms of the environment and the volumes and reliabilities of water supplied.

As previously noted, it was not the intention of (nor possible for) this study to complete these parts of the planning process.

5.6.2 Content of the WRAP

A water resources allocation plan is a regulatory tool that should set:

- the outcomes sought for the basin;
- the sustainable levels of water abstraction, and identify the regions or groups entitled to abstract that water (i.e. the cap);
- the required reliability for the volumes to be supplied;
- the desired environmental flows; and
- the operational and sharing rules to achieve the above requirements.

As an example, this section describes the process for determining how these elements would be defined for a WRAP that was prepared to implement Scenario 11.

This should not be interpreted as a recommendation that Scenario 11 be used as the basis of a water resources allocation plan for the Jiao River basin. However, Scenario 11 shows one option for balancing environmental and water supply, and for implementing the operational alternatives discussed above.

In summary, Scenario 11 is the current proposed 2020 arrangements (i.e. with construction of Zhuxi and Shisandu Reservoirs), with the following modifications:

- the "sub-optimal" environmental flow rules have been included; and
- the supply rules from Changtan Reservoir have been adjusted as discussed above.

Outcomes for the WRAP

The WRAP should state the broad outcomes sought for the plan. For Scenario 11, these would primarily be:

- To provide certainty to water users by protecting their reliability of supply, by ensuring;
  - urban and industrial users have a reliability of supply greater than X%; and
  - agricultural users have a reliability of supply greater than Y%.
- To maintain the environmental flows necessary to sustain fish and fisheries within the basin, by ensuring:
  - habitats, water quality, riparian vegetation and natural geomorphic processes are protected; and
  - flows mimic the natural flow pattern to that extent possible, particularly in respect of low flows and pulses.

Setting water abstraction caps

The WRAP would set caps on total annual abstractions should be set for each reservoir and the reaches downstream (e.g. a single cap would be set for Zhuxi Reservoir and Zhu Creek). The cap would also specify the sectors that the volume would be available to.

- The total cap on abstractions from Changtan Reservoir would be 664,498 ML, comprising:
  - 513,409 ML for urban/industrial users; and
  - 151,089 ML for irrigation users.
- The total cap on abstractions from Zhuxi Reservoir would be 24,159 ML, comprising:
  - 13,514 ML for urban/industrial users; and
  - 10,645 ML for irrigation users.

These caps would apply when considering applications for new water abstraction permits – the permit would not be granted if it would cause the cap to be exceeded. The accuracy and effectiveness of the abstraction caps relies upon all downstream users holding water abstraction permits. These permits would need to identify the relevant reservoir as the supply source.

By defining the total amount of water that is authorised to be taken under water abstraction permits in this way, water managers can be confident that users will receive the expected supply reliabilities. In this example, it is assumed that the modelled supply reliabilities for each sector supplied from each reservoir are considered acceptable.

Setting water sharing rules

There will be periods of water shortage when users will not receive 100% of their entitlements under their permits. To manage these situations fairly, water sharing rules need to be defined in the WRAP. These are the rules that determine the proportion of the available water that different groups of users will receive during shortages. (These rules would only apply during "normal" periods of shortage; separate rules would be applied during times of critical shortage).

The water sharing rules for the current example would principally involve the rules that determine the point at which different groups will not be supplied. The details of this will be set by the operational arrangements (e.g. release rules) for the Zhuxi and Changtan Reservoirs.

Setting reservoir release rules

Reservoir release rules need to be clearly defined in a WRAP to ensure that the infrastructure operator has clear guidance on what is required in operating the reservoir to ensure the plan's supply and environmental outcomes are achieved. The WRAP should provide practical day-to-day rules for operation (or for incorporation into the operational/release rules).

Operational rules to be set in the WRAP for Zhuxi Reservoir would include:

i. No water is to be transferred to Changtan Reservoir when the Zhuxi Reservoir level falls below 130 metres (56.1 million m^3).
ii. Water supply for irrigation demand would cease when the dam water level falls below 122m (34,820ML).
iii. Hydropower station would cease operations when the dam water level falls below 120m (30,640ML).
iv. Water supply for urban demand would continue until the dam water level reaches the inactive water level of 100m (5,140ML).

Similarly, the modified operating arrangements for Changtan Reservoir under Scenario 11 would provide the following release rules:

i. When the water level falls to 15.05 m (12 million m^3), urban/industrial supplies are to be restricted by releasing water at a rate of 3 m^3 per second (259,000 m^3 per day).
ii. When the water level is between 21.05 m (72 million m^3) and 23.05 m (104 million m^3), the maximum irrigation release is restricted to 12 m^3 per second (1 million m^3 per day).
iii. When the water level falls to 21.05 m (72 million m^3), irrigation water supply is reduced to zero.

iv. The hydropower station is to cease operations when the water level falls below 23.05 m (104 million m^3). Between 23.05 m and 24.05 m, the maximum release for hydropower is restricted to $25m^3$ per second (2.16 million m^3 per day). Between 24.05 m and 26.05 m the maximum release is restricted to 50 m^3 per second (4.3 million m^3 per day).

The WRAP would also need to include specific environmental release rules. These would require that the reservoir operator release particular volumes of water for the environment at particular times. For example, these would include (noting that these are the "sub-optimal" environmental flows rules) a requirement that the reservoir operator achieved the flows list in Table 32 for reach 1:

Table 32: Flows required for reach 1 under scenario 11

Component	Timing	Magnitude (m^3s^{-1})	Frequency (per year)	Duration (days at peak)
Low Flow	Oct-Mar	0.5	Continuous	
High Flow	Apr-Sep	1.0	Continuous	
Low Flow Pulse	Oct-Dec; Jan-Mar	20	1 each period	1 day / period
High Flow Pulse	Apr	20	2	2
High Flow Pulse	May-Sep	20	2	1
Bankfull Flow	Anytime	177	0.26	1

For the low and high flows, the rules would also require that if the "natural flow" was less than the prescribed flow, only the natural level of flows would be required (e.g. if the inflows to the reservoir were only 0.3 m^3s^{-1} then the operator would only be required to release 0.3 m^3s^{-1} rather than the 0.5 m^3s^{-1} set out above.)

The key requirements that the operator would have would be:

- to continuously release the low and high flows stated;
- to monitor whether the require pulses had been achieved (in terms of magnitude, frequency and duration) and – if they have not been naturally achieved – make necessary releases to meet these flows within the required timeframes.

As mentioned earlier, it is likely that the bankfull flows would occur naturally during flood events without the reservoir operator being required to make any special releases.

Monitoring requirements

The water resources allocation plan will also need to include a range of monitoring requirements to monitor:

i. compliance with the plan's rules;

ii. whether the rules are actually achieving the objectives of the plan (e.g. in terms of maintaining ecosystem health); and

iii. to provide information to help future planning activities.

These monitoring arrangements would relate to all aspects of the plan, including:

- river flows (volume, frequency, duration and timing);
- volumes of water abstracted by (or supplied to) different user groups;
- water quality;
- water releases from reservoirs; and
- environmental indicators, including for:

- health and distribution of animal, plant and micro-organism species and communities; and
- condition of riverine and estuarine habitats (including lake ecosystems, stream-bed habitats, upper and in-channel riparian zones, floodplains and wetlands).

5.6.3 Implementation and enforcement

Finally, it should be noted that achieving the outcomes desired from the plan will require its implementation and enforcement. This will require:

- ensuring that water is only abstracted by parties that hold a water abstraction permit. (e.g. those entities that do not hold water abstraction permits should be granted them);
- the total volume of all abstraction permits is within the abstraction cap set by the WRAP. Further, where the WRAP sets specific volumes for different regions or sectors, the total abstraction permits for those regions or sectors should not exceed those limits;
- the process of assessing applications for new abstraction permits should require that the new permits only be granted if the total volume remains within the cap (regional or sectoral);
- amending release rules for reservoirs where required by the WRAP, to ensure that releases of required environmental flows are made in the appropriate circumstances; and
- requiring that an annual regulation plan be prepared based on the rules of the WRAP. This will ensure that rules for sharing water between sectors are complied with, and the different reliabilities required for the sectors are protected.

In addition to these requirements, it will be important that there is regular reporting (e.g. annual) by the local water departments as well as operators of reservoirs, to ensure that all parties have complied with their obligations.

Assuming that the WRAP is made and implemented as discussed above, this should achieve (subject to error within the model) the performance for water supply described in Table 33. It will also mean that the environmentally-important flows described for the "sub-optimal" flows scenario would be achieved for reaches 1 and 2, and that flows in the lower reaches would be improved. While this would not be the optimal environmental outcome, it is likely this would result in a significant improvement in the long-term health of the river system (particularly compared with the planned scenario 2).

As a final point, it is worth noting that many of the aspects described above for inclusion in a WRAP are consistent with either current or proposed practice in water management. However, a key requirement for implementing a WET system is to take these practices and document them and ensure that they are a requirement, rather than just a goal or a guide.

Table 33: Supply performance results – Scenario 11

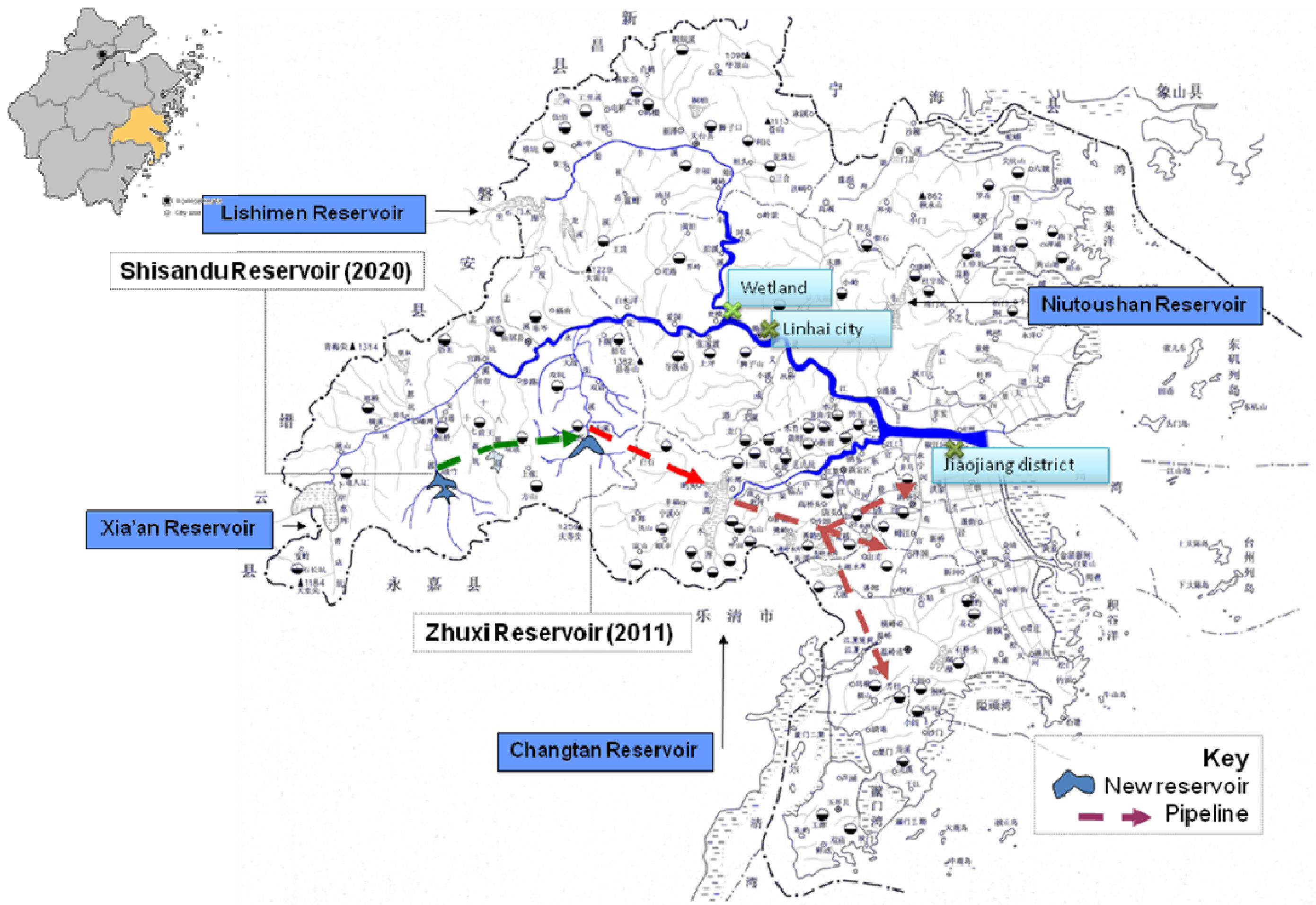
Changtan	Urban/Industrial	Average annual supply (ML)	515,045
		Average annual supply (% of demand)	97%
		Daily reliability (% of days full daily demand met)	93%
	Irrigation	Average annual supply (ML)	162,024
		Average annual supply (% of demand)	65%
		Annual reliability (% of years full annual demand met)	0%
Zhuxi	Urban/Industrial	Average annual supply (ML)	13,513
		Average annual supply (% of demand)	100%
		Daily reliability (% of days full daily demand met)	100%
	Irrigation	Average annual supply (ML)	11,258
		Average annual supply (% of demand)	100%
		Annual reliability (% of years full annual demand met)	100%

Appendix 1: Maps of Taizhou

Zhejiang Province

Source: http://www.muztagh.com/images/map/map-of-zhejiang-large.jpg

Taizhou prefecture



Appendix 2: Information Sources for Asset Identification

		Information source				Information description		
Asset	Type	Title	Date	Author/institute/publisher	Interviewee	Description	Dates	Time interval
Freshwater fish	Report	Linjiang Aquatic Organism Investigation Report	1971	Zhejiang Institute of Freshwater Fisheries	Chen Jianming researcher Zhejiang Institute of Freshwater Fisheries	List of 73 species of fish found in freshwater or with some reliance on freshwater	1971	Once
Aquatic wildlife	Album	Taizhou Aquatic Wildlife Protection and Management Album	2006	Taizhou Ocean and Fishery Bureau	Luo Huaming researcher, Taizhou Ocean and Fishery Bureau	Species of aquatic wildlife with some reliance on freshwater , estuarine habitats or inshore		
Freshwater resources	Report	Taizhou Fisheries History	1998	Taizhou Fisheries History Committee, Zhonghua Book Company	Chen Jianming researcher Zhejiang Institute of Freshwater Fisheries	Freshwater resources of economic value: 59 freshwater fish, 24 estuarine fish, 14 species with some reliance on freshwater during their life cycle, 3 crustacean species, 3 shellfish, 2 reptiles		
Freshwater aquaculture	Year book	Taizhou Statistical Yearbook	2006	Statistical publishing company	Hu Rongjin, Taizhou Statistical Bureau	Yield of six main freshwater aquaculture species (Ctenopharyngodon idellus, Hypophalmichthys molitrix, Aristichthys nobilis, Carassuys ayratys, Parabranis pekinensis, Cyprinus carpio)	1985-1995	Annual
						Freshwater fisheries yield (as aquaculture and fishing) in Taizhou.	1990-2006	Annual
fishery production	Year book	Taizhou Statistical Yearbook	2006	Statistical publishing company	Hu Rongjin,Taizhou Statistical Bureau	The proportion of fishery production in total agriculture, forestry, husbandry and fishery production is about 52%	1949-2006	Annual
Estuary resources	Report	Investigation Report of Integrated Island Resources in Taizhou of Zhejiang province	1993	Taizhou Fishery Bureau	Luo Huaming researcher, Taizhou Ocean and Fishery Bureau	8 species of migratory fishes, 7 species of migratory crustaceans, 212 species of economic fishes, 79 species of economically important crustaceans	1993	Once
intertidal organism	Report	Taizhou Fisheries History	1998	Taizhou Fisheries History Committee, Zhonghua Book Company	Luo Huaming researcher, Taizhou Ocean and Fishery Bureau	4 kinds of intertidal organism，114 species of molluscs, 64 species of crustaceans, 54 species of fish, 100 species of Algae		

Offshore fishing ground	Report	Taizhou Fisheries History	1998	Taizhou Fisheries History Committee, Zhonghua Book Company	Luo Huaming researcher, Taizhou Ocean and Fishery Bureau	22 species of fish and shrimps		
Important wetlands		Taizhou Forestry Bureau website	2007	http://www.tzly.gov.cn		three most important wetlands		
Important vegetation		Taizhou Forestry Bureau website	2007	http://www.tzly.gov.cn		2 species of national 1 grade, 9 species of national 2 grade, 7 species of National 3 grade, 4 species of provincial grade, 3 species of rare and precious species from other place, 3 species of local protection or endangered species.		
Forest Parks and Nature Reserves		Taizhou Environmental Protection Bureau website	2007	http://www.tzepb.gov.cn		One National Forest Park, One Geo-Park, five Provincial Forest Park, one County Nature reserve		

Appendix 3: Species Considered During Environmental Assessment

Family	Scientific name	Common name	Adult habitat	Spawning habitat	Larval habitat	Feeding	Migratory pattern	Spawning period
Engraulidae	*Coilia mystus*	Osbeck's grenadier anchovy	coastal waters; easturies; mid river reaches				Amphidromous	May
Engraulidae	*Coilia ectenes*	Tapertail anchovy	coastal waters; easturies; mid river reaches	among reeds, mid river reaches	eggs drift to eastuary	omnivorous (planktivore)	anadromous	May-August; 3 times
Clupeidae	*Macrura reevsii*	Hilsa Herring	coastal waters; easturies	freshwater, among reeds	tide pools; estuaries	Zooplankton	Anadromous	May-July
Plecoglossidae	*Plecoglossus altivellis*	Sweet fish, Ayu	coastal waters, estuaries	freshwater, lower reaches, silt free gravel beds	drift to sea	omnivorous (benthivore)	Anadromous	March (spring)
Sparidae	*Acanthopagrus schlegelii*	Black Porgy	coastal waters, estuaries	upper estuary, seagrass beds?	seagrass beds?	zooplankton, benthos	Anadromous	spring-summer
Bagridae	*Anguilla japonica*	Freshwater eel	deep pools in rivers	Ocean	ocean-estuary	fish & invertebrates	Catadromous	autumn
Bagridae	*Anguilla marmoratus*	Giant mottled or marbled eel	deep pools in rivers	Ocean	ocean-estuary	fish & invertebrates	Catadromous	spring?
Serranidae	*Lateolabrax japonicus*	Japanese sea bass	inshore reefs	estuaries			Catadromous	
Mugilidae	*Liza so-iuy*	Far Eastern Mullet	lowland river	estuaries			Catadromous	
Periophthalmidae	*Boleophthalmus pectinirostris*	Blue spotted mud skipper	intertidal mudflats	mudflats	mudflats	omnivorous	Non-migratory	autumn?
Sciaenidae	*Larimichthys croceus*	Large yellow croaker	coastal waters, estuaries			fish, zooplankton	Oceanodromous	October-January

Family	Scientific name	Common name	Adult habitat	Spawning habitat	Larval habitat	Feeding	Migratory pattern	Spawning period
Cyprinidae	*Aristichthys nobilis*	Bighead carp	riverine	flowing waters; upper reaches;	riverine	zooplankton; benthic and planktonic	Potamodromous	summer?
Cyprinidae	*Ctenopharyngodon idellus*	Grass carp	riverine	flowing waters; upper reaches;	lowland rivers	vascular plants; algae	Potamodromous	
Cyprinidae	*Hypophalmichthys molitrix*	Silver Carp	riverine	flowing waters; upper reaches;		phytoplankton; detritus	Potamodromous	spring (April-May)
Cyprinidae	*Mylopharyngodon piceus*	Black carp	rivers; lakes; reservoirs	flowing waters; upper reaches;	lowland rivers	zooplankton; benthic and planktonic	Potamodromous	April-May

PART 4: INNER MONGOLIA PILOT WORK REPORT

Chapter 1: Summary and outline

This Pilot Report discusses the results of work carried in Hangjin Irrigation District (HID), Inner Mongolia, applying the WET Framework to rights issues in irrigation management. Topics covered include water allocation and planning, water certificate and ticketing systems, the role of Water User Associations (WUAs) in rights reform, water monitoring and water trading.

This chapter of the Pilot Report provides a summary of work completed in HID.

Introduction

Chapter 2 provides a brief summary of the terms of reference that have guided work in HID and how work has been organised.

Situation analysis

Chapter 3 provides an overview of the current situation in HID, including water allocation and management, and summarises key problems faced by different stakeholders within the district, and by government agencies above it.

First, following a brief introduction to the area and the irrigation system, institutions with a direct or indirect interest in irrigation management in Hangjin are identified, and their *roles and responsibilities* are discussed. The *management priorities* of different stakeholders are also explored, and it is noted that priorities may differ. For example, farmers are mainly concerned about water availability, access, reliability and 'fairness', and in ensuring that irrigation services continue to be provided at reasonable cost. In contrast, the concerns of the irrigation agency (Hangjin Irrigation Management Bureau - HIMB) relate primarily to financing, and their ability to perform maintenance and water allocation and planning functions with dwindling revenues. Higher level agencies have a wider mandate. Increasingly, they have to mediate between the claims of competing uses/users, with 'water for agriculture' one of a number of such claims.

The chapter then continues with a discussion of how water is allocated to the ID, and how water is allocated within the ID. In terms of *allocation to the district*, diversions from the Yellow River are ultimately determined by the Yellow River Conservancy Commission (YRCC) which:

i. sets minimum flow requirements for the river at provincial boundaries; and
ii. allocates relative shares to individual provinces according to prevailing supply and demand conditions.

Working within these restrictions, HIMB and its parent Water Affairs Bureau (WAB) prepare *Annual Water Use Allocation Plans* to distribute water to main and lateral canals, based on consultations with WUA representatives, and WUA consultations with farmers. The outcome is a 'bottom-up' water requirement articulated by farmers constrained, during the course of an irrigation season, by 'top down' supply restrictions imposed by the

YRCC. Following the establishment of WUAs, farmers now pay for irrigation water using Water Tickets, purchased by WUAs on behalf of their membership.

Finally, having presented the basics of water allocation and distribution, a novel *water transfer project* initiated by the Water Resources Department (WRD) in Erdos is discussed. Under this project, water saved through channel lining in the ID is transferred to downstream industries, with the costs of lining met directly by industrial beneficiaries. Although the project is a new one, its impacts on different stakeholders – intended and unintended – are already being felt. In particular, while the project has been welcomed by farmers (who now pay less for leakage) and industry (provided with a source of low cost supply), HIMB has seen its revenues fall (farmers no longer pay for channel losses) and impacts on other uses/users (through changes to return flows) remain unclear. The chapter concludes with a summary of the key problems currently confronting the ID.

Applying the WET framework – key issues

Chapter 4 begins by exploring some of the *arguments in favour of unambiguous, formalised rights* in the context of IDs such as Hangjin. These include water security for farmers (assuming rights can be enforced), greater transparency in allocation, potential gains in water use efficiency and farm productivity, and livelihood diversification.

In this context, the chapter concludes by discussing the *relationship between rights reform and different demand management policies*. A key message is that growing pressure to release water from agriculture to higher value uses will increase demands to formalise rights. In particular, there will be pressure from farmers within the ID – and from non-agricultural interests outside – to better define, record and protect rights as water scarcity increases.

Detailed application of the WET framework

Chapter 5 discusses how the WET framework has been applied to rights definition, allocation and planning issues in HID, the role of WUAs in administering rights and, potentially, the role of a water bank in facilitating water trading.

The chapter begins by looking at water rights *allocation principles* adopted in other countries, and then principles applied in China (Section 5.1). China clearly has to follow its own, principled reform path, but the experiences of other countries can provide useful insights, if not blueprints.

Following this, the chapter then recommends some key principles that should be observed in rights reform in HID. These include respect for current arrangements, equity of rights (between and within WUAs), overall government control/regulation, and the need to account for externalities – impacts on 'third parties' such as the environment and (potentially) downstream groundwater users that might be affected by the redistribution of water.

Drawing on these principles, the chapter then looks at how *principles can be applied in practice.* In particular, the findings of modelling work designed to accurately determine the flows required through main and branch canals to satisfy WUA water needs in different areas of the ID are presented (Section 5.2). Based on these findings, it is proposed that WUAs are assigned *Group Water Entitlements* (GWEs) based on irrigated areas, crop water needs and conveyance efficiencies through the channel system. These would cap water diversions at WUA purchase points on branch canals, and formalise each WUA's long-term water rights within the ID's permitted allowance. In contrast to the current 'open-ended' arrangements for purchasing water, these would introduce a transparent, quota-based approach to irrigation planning and future demand management (including potential for trading), with all transmission losses through main and branch channels accounted for.

Drawing on the above, Section 5.3 then describes how a system of *water certificates* can be used to record and monitor the rights of WUAs, providing information on long-term rights (defined by GWEs), annual water entitlements (defined by available supply in any given year and irrigation period) and the water purchased in each irrigation period. In addition, it is proposed that certificates should provide information on any water transactions that have occurred between WUAs, and between WUAs and HIMB. Rights allocation and water accounting would follow a number of steps:

- After an initial water rights allocation process, HIMB would grant long-term rights (as GWEs) in the form of a water certificate lodged with the WUA Chairman – the legal representative of the WUA.
- Before each irrigation, HIMB sections would calculate the annual water entitlements of each WUA based on predicted supply (determined by the YRCC), and estimate the corresponding water purchase limit for that period, recorded on each water certificate.
- After purchasing water tickets in any given irrigation period, the purchase amount would be recorded on the certificate to calculate the remaining purchase allowance, or entitlement, for the next period.
- Any water trading would be recorded by the relevant HIMB section office on the water certificates of both buyer and seller. Trading with other sections would also be checked and registered with HIMB. Certificates would also show actual water deliveries after trading.

Implementing such a system with the existing paper-based accounting procedures used by HIMB would be both complex and time consuming. Section 5.4 therefore discusses a model-based *irrigation planning and scheduling* system developed by the project that can be used by HIMB managers to combine the (quota-based) water use plans of WUAs with ID supply forecasts, to produce an irrigation schedule that balances demand and supply, guides water allocation between WUAs and helps manage real-time water rights in a quick and transparent manner. The model also includes a contingency programme for adapting to the monthly, weekly or real-time operations imposed by the YRCC under its *Annual Water Regulation Plan.* The Plan may affect, at short notice, diversions to HID during irrigation periods. A key element of the proposed contingency programme is the prioritisation of irrigation supply to smaller farms in the upstream area of the ID when water is particularly scarce.

It is important to note that the revised allocation process summarised above would continue to combine bulk volumetric charging to WUAs with area-based charging for farmers. In particular, WUAs would retain responsibility for distributing water to individual farmers based on pre-payment for a bundled water service. Key questions therefore concern the ability of WUAs to manage rights effectively on behalf of their members, with fair distribution of water to all farmers – whatever their socio-economic status - beneath capped limits.

Against this background, Section 5.5 examines the *role WUA managers and farmers play in managing water* within WUA command areas. The section begins by looking at the rationale for WUA formation in relation to some of the typical problems facing IDs in China. A common assumption is that, since farmers have a direct interest in enhancing and sustaining the quality, cost-effectiveness and local equity of irrigation, they should be empowered, through WUAs, to take on some of the functions previously carried out by government, or village leaderships. Domestic and international experience is mixed, however, so the section goes on to discuss some important conditions that need to be met if WUAs are to manage water rights effectively on behalf of farm households, drawing on evidence collected from a detailed field survey of WUA managers and farmers.

A key message is that existing contracting and ticketing procedures operating between HIMB and WUAs generally work well, and provide a sound basis for the introduction of GWEs and ticket-linked water certificates. However, those WUAs that have set up systems of continuous water accounting, and volumetric delivery to (and billing of) individual production teams, will be better able to meet future quota restrictions in a fair and transparent manner.

Section 5.6 then explores the feasibility of *water trading* within HID, and between HID and downstream users on the Yellow River. The arguments for trading are appealing. In contrast to water allocation by administrative decision, market allocation guarantees compensation to users, with decisions based on individual (or group) assessment of the value of water in alternative uses. However, permanent trading of agricultural rights to other downstream users – beyond current trade in channel savings – would need to meet stiff pre-conditions. The main conclusion is that trade in GWEs held by WUAs via a *water bank* would help in meeting these. In the short to medium term, however, temporary trade in GWEs between WUAs, facilitated by HIMB, is more realistic. Section 5.3 provides some examples of how seasonal trades, using certificate-based accounting procedures, might work.

The final section of Chapter 5 (Section 5.7) examines the monitoring and information systems that are needed to support rights-based reforms. The section begins by noting that although existing monitoring arrangements work reasonably well, they are labour intensive and (by modern standards) crude. Any future pressure to reduce GWEs may therefore increase demand (from all stakeholders) for more accurate and timely measurement. A key priority will be to strengthen monitoring of water deliveries at WUA purchase points, as monitoring here affects both WUA payment and compliance with quotas.

The final chapter of the report – Chapter 6 – provides a summary of key conclusions and recommendations for HID. These are discussed in more detail, and with reference to irrigation reform in China more generally, in the *Guidelines* section of the WET final report.

Chapter 2: Introduction

The Terms of Reference (ToR) that have guided pilot work in HID were drafted in early 2007 presented in the WET project's Inception Report of 16 May 2007. Terms of reference were then discussed by Chinese and international experts at a Chinese Reference Panel Meeting held at the Ministry of Water Resources on 24 May 2007.

Based on feedback from the meeting, final ToR were approved by Chinese and Australian Team Leaders in June 2007.

Terms of Reference IM Pilot: Summary of Objectives

Rights definition and allocation: set out the principles and that should underpin rights allocation in HID, and demonstrate how volumetrically-defined rights could be allocated to WUAs and farmers.

Water certificates and water ticketing: provide recommendations on water certificate and ticketing systems that would formalise the group water rights of WUAs and allow them to purchase water beneath capped limits. In addition, develop guidelines for the issue, modification and transfer of certificates and/or tickets.

Water use planning and irrigation scheduling: develop a model-based water use planning system for allocating rights between and within irrigation periods that is fair and transparent, and accounts for all water losses.

Role of Water User Associations: evaluate the role WUAs currently play in the purchase and distribution of water to farmers, and the implications of changing existing arrangements to accommodate quota-based water certificates and tickets.

Water trading: explore the feasibility of further water trading (beyond the current trade in channel savings) at different scales, both temporary and permanent.

Metering and monitoring: develop a plan for upgrading existing metering and monitoring arrangements to meet the planning and allocation needs emerging from above.

Interim findings and conclusions from the pilot were presented in the project's Mid-term Report, dated 31 August 2007. Findings were discussed with HIMB and IM-WRD, and subsequently presented at project seminar at the Ministry of Water Resources on 26 November 2007.

Pilot work in HID has been carried out by a core team of four domestic consultants and one international staff member. In addition, the Centre for Chinese Agricultural Policy (CCAP) was employed to carry out a survey of WUA managers and farmers in October 2007, and an international advisor was contracted to explore the feasibility of trading water through a water bank.[52]

[52] The core team comprises Wang Zhongjing, Zheng Hang and Liang You (Tsinghua University), and Roger Calow (international consultant). The team from CCAP was led by Wang Jinxia. Randall Cox (international consultant) provided recommendations on water trading.

Chapter 3: Situation Analysis

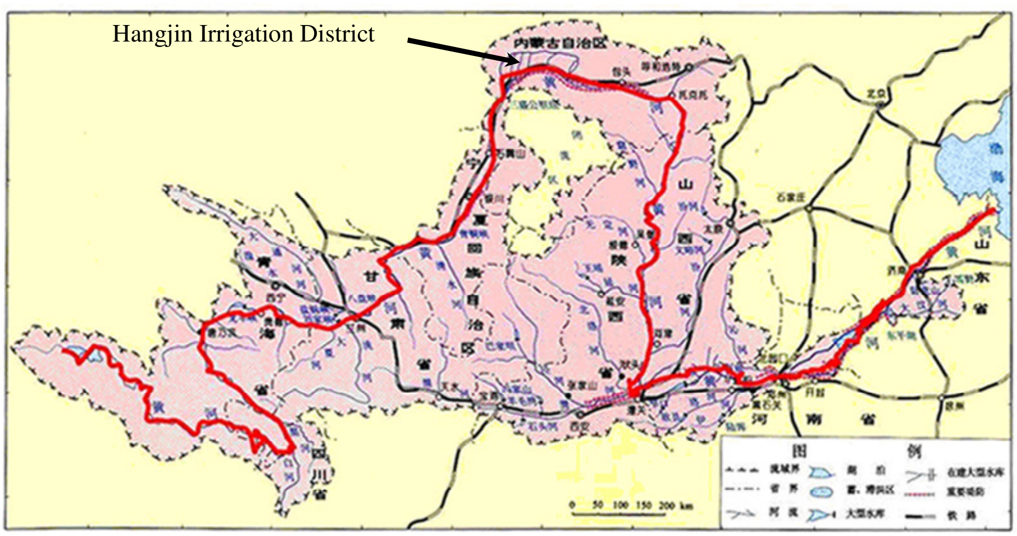
3.1 Context

Hangjin County is located to the northwest of Erdos City in Inner Mongolia. Along its northern margin the Yellow River winds down with a length of roughly 253 km, making Hangjin the longest flowing section of Yellow River of all counties nationwide (see Figure 28).

Hangjin County includes nearly 0.6 million mu (40,000 ha) of designated farmland along the Yellow River, and is one of three major irrigation zones of Inner Mongolia. It is also one of China's main grain producing areas. Hangjin Gravity Irrigation District (HID) in Hangjin County – the focus of the current study – is the only ID in Erdos with the right to take water from the Yellow River.

HID is located on the south bank of the Yellow River and covers an area of approximately 345,000 mu (23,000 ha). Of this, roughly 320,000 mu (21,000 ha) is gravity fed and 25,000 mu (1700 ha) is pumped (at the head of the system). An ongoing land improvement programme, and a plan to expand the command area served by the main channel, will see the irrigated area expand to some 600,000 mu (40,000 ha) over the next five years.[53]

Figure 28: Location of HID in the Yellow River Basin



Note: Yellow River shown in red.

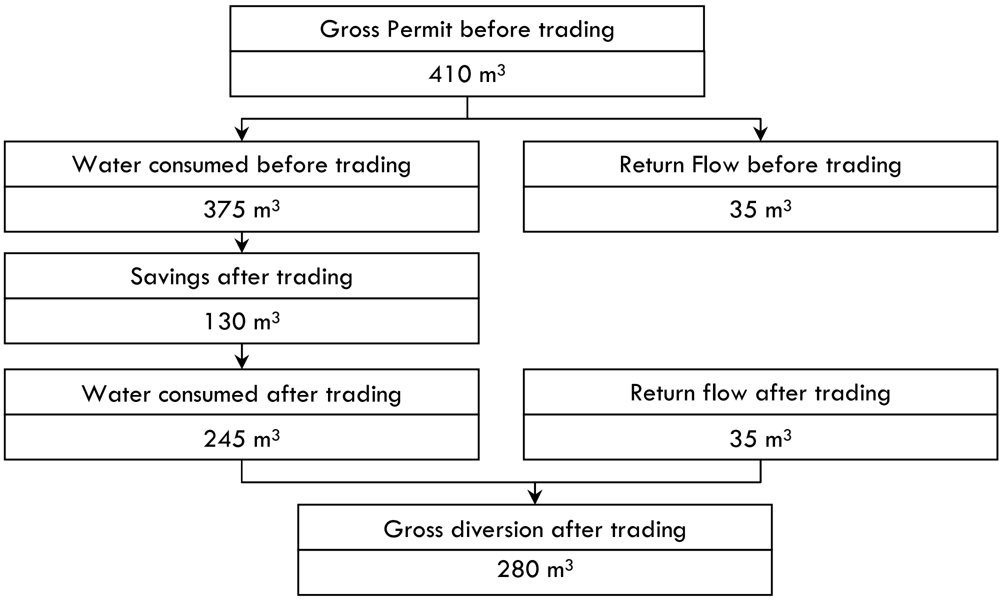
3.2 Overview of the irrigation system

The normal net diversion to HID is 375 million m^3. This comprises a gross diversion of 410 million m^3 (the permitted volume) and a mandated return flow of 35 million m^3 per year. Return flows are fed back to the river through four main drainage channels. Savings

[53] Major flooding in 2003 severed the ID in two; roughly 200,000 mu (13,000 ha) of land below Jianshe section now relies on water pumped directly from the Yellow River under a temporary permit, rather than flows from the main ID channel. Note: 1 mu = 0.067 hectares (ha).

of 130 million m^3 per year from channel lining, traded out of the ID (see Section 3.5 below), will leave an ongoing diversion of 280 million m^3 per year. However, the permit will not change until savings have been verified. Figure 29 below highlights the relationship between the permitted diversion, consumption and return flows in the ID.

Figure 29: Diversion, consumption and return flows for HID



Note: figures above in million m^3

There are five levels, or orders, of channel (see Figure 37). The main intake sluice for HID diverting water from the Yellow River is controlled by the Yellow River Irrigation Management Bureau (YRIMB), under the Inner Mongolia Water Resources Department (IM-WRD – see Table 34). From here, water flows into the main (first order) channel in accordance with the Yellow River *Annual Allocation Plan* and *Annual Regulation Plan* formulated by the Yellow River Conservancy Commission (YRCC), and administered by IM-WRD (see Section 3.4 below).

Table 34: Yellow River water allocations (10^8 m^3)

Prov/region	QH	SC	GS	NX	IM	SAA	SA	HN	SD	HB	Total
Allocation	14.1	0.4	30.4	40	58.6	38	43.1	55.4	70	20	370

Source: Yellow River Annual Allocation Plan for Non-flood Season, July 2006 – June 2007.

NB: QH Qinhai, SC Sichuan, GS Gansu, NX Ningxia, IM Inner Mongolia, SAA ShaanXi, SA Shanxi, HN Henan, SD Shandong, HB Hebei.

Flows from first to third channels are controlled by stations under HIMB. Flows from third to fourth channels are also controlled by HIMB following channel lining and the installation of new sluices between levels three and four (fourth level sluices, or gates). The fourth and fifth level canals are managed by WUAs.

WUAs manage and monitor flows below fourth level sluices on a rotational basis, as the irrigation system cannot deliver water to all WUAs at the same time. Prior to the lining of level three channels and the construction of new sluices, farmers bought water at the third gates.

The gravity flow section of HID is divided into three sections (Mugan, Balahai and Jianshe) for the purposes of management by the irrigation agency - HIMB. Water allocation occurs through sales of water tickets to WUAs operating on branch canals. Ticket sales to WUAs in each section are managed by separate Section Offices under HIMB. The monitoring of flows through sluices is undertaken by a separate Hydrographic Office under HIMB.

Household land holdings vary considerably in size. In Balahai – the largest section of the ID – farms sizes can exceed 100 mu, with a survey average of 113 mu. In Mugan – the smallest section - land holdings are much smaller, with a survey average of 56 mu. Across all three sections, sunflower is the major irrigated crop accounting for over 70% of the irrigated area, although area-based returns to maize (the second most widespread crop) are greater. Household incomes are still heavily dependent on irrigated agriculture, although the contribution of non-farm income is increasing.[54]

Hetao Irrigation District on the north bank of the Yellow River, opposite Hangjin ID, is much bigger, covering an area of 8 million mu (536,000 ha). This is the third largest irrigation zone in China. Here, land holdings are much larger. Water rights reform and management in Hangjin ID is intended to provide lessons for Hetao and other IDs.

3.3 Institutional hierarchy and objectives

Lines of authority between the different institutional stakeholders with an interest in irrigation management in Hangjin are shown in Figure 30. Hangjin Irrigation Management Bureau – the irrigation agency for HID – is highlighted in yellow, together with its (subordinate) Section Offices and Hydrology Station, and its 'parent' body – Hangjin Water Affairs Bureau (WAB).

In Hangjin, the Management Bureau reports directly to the County WAB because this is the smallest administrative unit that encompasses the entire command area. Larger irrigation districts may report directly to a city-level WAB, while the smallest ones may report to a township-level WAB. Water Affairs Bureaus at different administrative levels are charged with carrying out plans and policies initiated from levels above them – from Water Resource Departments and, ultimately, the Ministry of Water Resources in Beijing. Only vertical lines between water agencies are shown in Figure 30. In practice, however, horizontal ties to local government may also be significant, with the heads of WABs appointed by, and reporting to, leaders of their own jurisdictions.

The only hydraulically defined bodies charged with implementing policies across provincial boundaries are (National) River Basin Commissions. The YRCC therefore approves and enforces provincial water withdrawal plans from the Yellow River (but not its tributaries) across eight provinces[55] and two autonomous regions – Inner Mongolia and Ningxia. The *Annual Water Use Plan* developed by HIMB is also approved by the Water Dispatching Centre of the YRCC following scrutiny by county, prefecture and provincial authorities (see Table 35 and Section 3.4).

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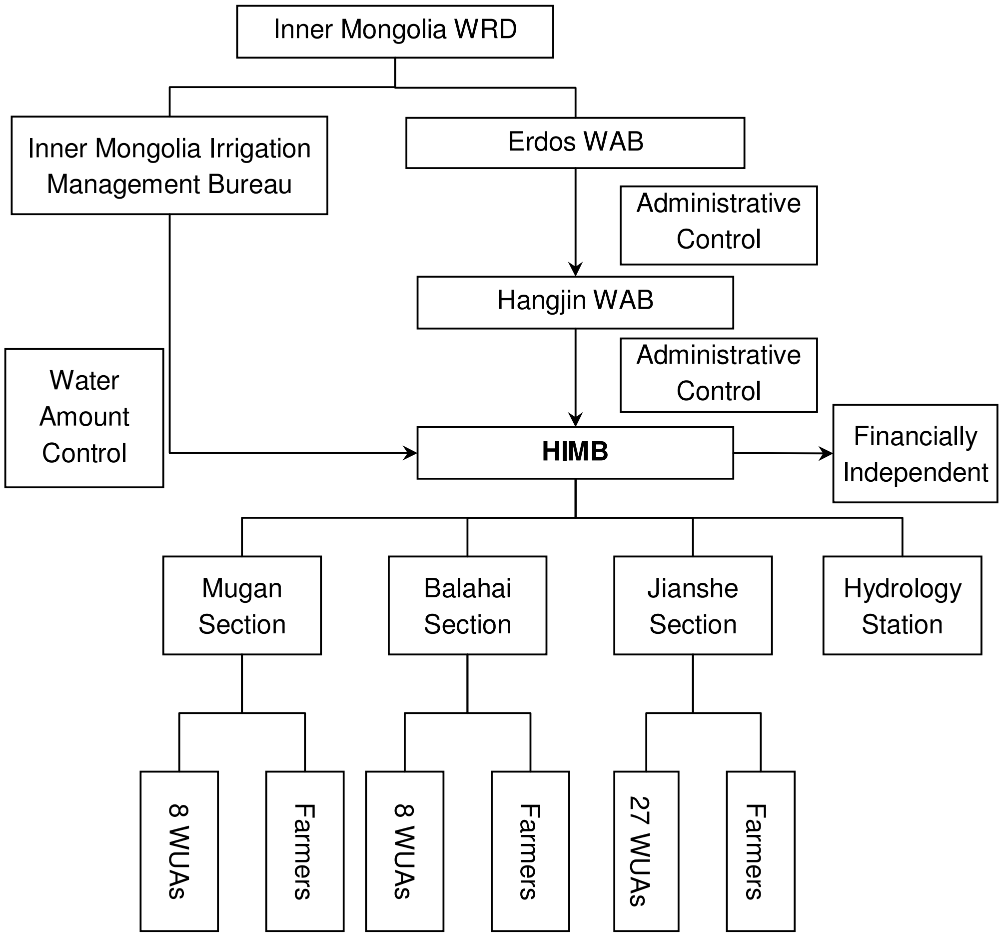
[54] CCAP Survey results, October 2007, discussed further in Section 5.5. Note: although returns on maize exceed those for sunflower, sunflower is more salt-tolerant and only requires 2-3 irrigations per year. In 2007, roughly 56% of household income was derived from cropping, 25% from livestock and 18% from non-agricultural activities. The average, total (net) income recorded in the survey was RMB 86,000.

[55] Qinhai, Sichuan, Gansu, Shanxi, Henan, Shandong and Hebei

Table 35: Institutional functions and interests – water allocation and management

Scale/boundary	Institutions	Functions/tasks	Rights/ irrigation reform perspective	Remarks
Basin	Yellow River Conservancy Commission (YRCC)	Sets minimum flow requirements for Yellow River at provincial boundaries	Maintenance of trans-boundary flows	
Provincial	Inner Mongolia WRD Inner Mongolia Yellow River Irrigation Management Bureau (IM-YRIMB)	Holds permits for major irrigation schemes and manages gates on river Has to maintain minimum flow at border with Shanxi	Maintenance of trans-boundary flows Balancing the interests of different uses/users – agriculture, municipal, industrial, environmental	Controls gate to Hangjin irrigation district. In 2005, low gate (gravity) flow supplemented by pumping 80km downstream
Prefecture	Erdos WRD Office of water rights & transfer	Office manages the reallocation of 'saved' water liberated through canal lining to industrial bidders	Managing the current (and future) water transfer process; increasing the value of water while protecting the interests of farmers	
County	Hangjin WAB Hangjin Irrigation District Management Bureau (HIMB)(south bank) Under HIMB there are 3 management sections and a Hydrographic Office	Compiles requests submitted by WUAs for annual water supply; submit claim to Erdos WRD Section offices responsible for managing ticket sales to WUAs in 3 sections of irrigation district & controlling level 2-4 gates. Hydrographic office responsible for monitoring allocations to WUAs	A system that provides stable revenues sufficient to cover bureau costs (including repair of new channels) and retain key staff An allocation system that is simple to administer and understood by farmers and agency staff	HIMB financially autonomous since 1983. Currently facing a financial squeeze Monitoring is independent of fee collection
Irrigated areas defined by rotational gate releases	Water User Associations (WUAs).	Reported by HIMB and WUA as irrigation management (incl. monitoring), salinity control and fertilizer application/advice Also responsible for maintenance of level 4-5 channels	Simple system for administering and monitoring rights; cost recovery (% retention of ticket sales) sufficient to retain professional staff; effective process for collective decision making	43 WUAs established at levels 2&3; now being subdivided to create 84 WUAs with fourth channel command areas
Farm/land holdings	Households		Timely, reliable and adequate deliveries at reasonable cost; farmland improvement; WUAs that articulate farmer interests	Elect salaried positions of WUAs and nominate monitoring personnel

Figure 30: Organisational hierarchy for irrigation management



As noted above, the ID itself is divided into three sections, with sales of water tickets managed by each Section Office. The monitoring of flows through gates (levels one, two, three and four) is undertaken by a separate Hydrographic Office, or Station, with a staff of 18. Figure 31 illustrates the management structure of HIMB.

Hangjin County WAB, in common with other county-level WABs in China, funds its operations and investments from a mix of fees for water deliveries, water extraction and well drilling permits, and through transfers from the administrative hierarchy above. However, HIMB is a financially autonomous agency, dependent entirely on raising revenue through sales of water tickets and mandated water charges. It currently employs around 160 staff, and revenue is insufficient to pay regular wages[56]. Financial problems are recent, and relate to channel lining/water transfer out of the district and broader issues of revenue retention. In particular:

[56] The Bureau was separated from the Prefecture as a self-funded entity in 1982. As of 8 June 2007, staff had only received two months wages for the year (Visit Report, June 2007).

- Revenue from water sales has declined by around one million RMB per year following channel lining and the trade of water out of the district, and is expected to decline further once the transfer programme is complete. This is because farmers are now paying for lined channel deliveries at fourth level gates, rather than unlined deliveries (and losses) at third level gates.
- The Bureau only retains a proportion (3.5%) of ticket revenue based on volumetric sales to WUAs (farmers pay 0.054 RMB per m^3). The volumetrically-defined revenue it returns to IM-WRD, however, is based on the district's gross diversion permit (410 million m^3 per year) - including return flows – rather than ticket sales.

Figure 31: The structure of Hangjin Irrigation Management Bureau

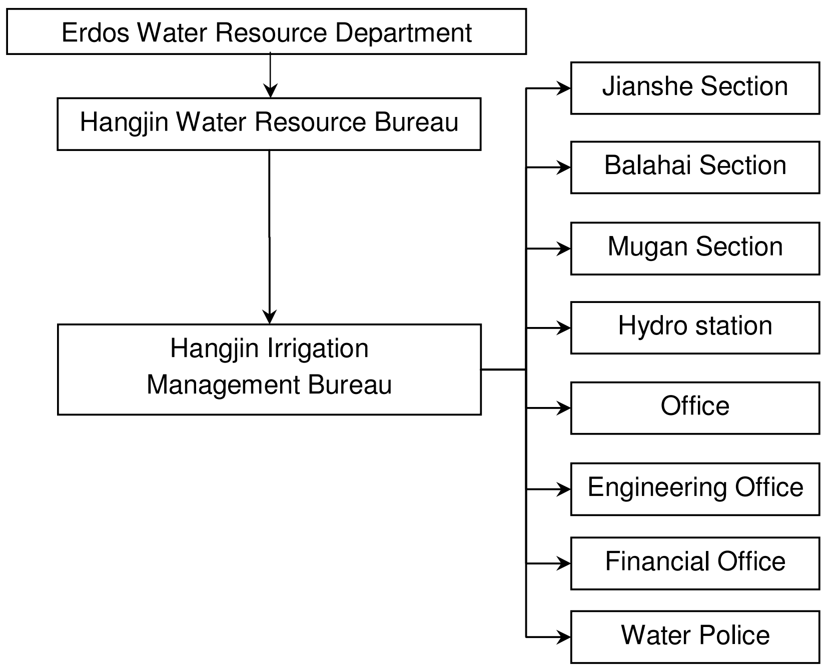


Table 35 provides some further detail on the tasks and responsibilities of the different stakeholders identified above. Also highlighted are key priorities in relation to water rights and irrigation reform more generally.

Focussing specifically on priorities, it is worth noting that these may differ between levels. As discussed further in Section 3, higher level government agencies have to mediate between the claims of competing uses and users. As a result, there is growing emphasis on the efficiency (and value) of water use within and across sectors, and on the ability of irrigated agriculture to release water to higher value urban and industrial users. Hence the interest – and investment in – water trading (see Section 3.5). In contrast, the concerns of HIMB relate primarily to financing, and their capacity to implement reforms to existing rights within the irrigation district.

Farmers, conversely, are mainly concerned about water availability, access and reliability, and in ensuring that services continue to be provided by HIMB at reasonable cost. In Hangjin, as in many other IDs in China, WUAs have been promoted by government to ensure that these concerns are addressed. In particular, WUAs established on branch canals, conceived as farmer-run, participatory bodies, now assume responsibility for farmer-level water distribution and the management of irrigation infrastructure within their command areas, issues discussed further in Sections 3.4.2 and 5.5.

3.4 Procedures for allocating and managing water

In this section we address two questions. Firstly, how water is allocated to HID. Secondly, how water is allocated within HID to WUAs and farm households.

3.4.1 Allocation to the district

Hangjin Irrigation District draws all of its water from the Yellow River. Its water use is therefore controlled, ultimately, by the YRCC, which sets minimum flow requirements for the Yellow River at provincial/regional boundaries (based on the *Yellow River Annual Allocation Plan*), and allocates relative shares to individual provinces and regions according to supply and demand conditions.

In a normal year, Inner Mongolia therefore receives 5.86 billion m^3 out of a total flow of 37 billion m^3. In a drought year, however, shares across provinces are reduced. Hence for the period July 2006 – June 2007, with an estimated 84% of normal flow in the Yellow River, all provincial shares were reduced by 16%, leaving Inner Mongolia with 49.14 billion m^3. Ongoing shares within any given year are detailed in an *Annual Regulation Plan* based on the *Annual Allocation Plan* noted above, incorporating an annual water forecast and annual reservoir storage and reservoir 'balancing'. In addition, the *Regulation Plan* provides for monthly 'scheduling' by the Commission, based on monthly water use and reservoir operation plans prepared by individual provinces and, if necessary, 10 day or real-time 'operation'. Articles 13, 14, 15 and 16 of the *Yellow River Regulations* (2006) describe procedures in further detail – see box below.

Yellow River Regulations (2006) – articles dealing with scheduling

Article 13: The *Annual Water Regulation Plan* should be formulated according to the approved *Yellow River Annual Water Allocation Plan*, the annual water forecast and stored water in reservoirs, using the same percentage reduction when dry and regulating reservoir balances.

Article 14: The Yellow River Conservancy Commission shall issue monthly water operation programmes and scheduling plans according to the *Annual Regulation Plan*, based on recommendations arising from monthly water use plans declared by provinces and a reservoir operation plan. During periods of water use tension, it may issue water operation programmes every 10 days according to need.

Article 15: The Yellow River Conservancy Commission can adjust monthly or ten day water operation programmes and issue real-time operation orders according to real-time water levels, rainfall, drought conditions, soil moisture status, reservoir storage and water uses.

Article 16: It must comply with the approved *Annual Regulation Plan*, monthly or ten days water operation programs, and real-time scheduling orders to implement the *Yellow River Water Operation Regulation*.

A key question is how these variable allocations to Inner Mongolia translate into irrigation diversions in Hangjin. Table 36 illustrates how HID - like other IDs in Inner Mongolia – operates within a volumetric permit, or cap, held by the Inner Mongolia Yellow River Irrigation Management Bureau (IM-YRIMB), under the (Inner Mongolia) WRD (Table 35). The maximum (sometimes termed 'normal') gross diversion to the district – the permit – is 410 million m^3 per year, including a mandatory return flow of 35 million m^3 per year.

Table 36: Water abstraction permits, Yellow River, Inner Mongolia: $10^4 m^3$ (2005)

Permit no.	Abstraction license ref. no.	Diversion point	Permit holder	Gross permit	Changes (2003 - 2005)
1	14002	South bank gate	IM - YRIMB (for HID)	41,000	0
2	14003	North bank (Shenwu) gate	IM - YRIMB (for Hetao ID)	45,000	-13,340
3	14004	North bank (main) gate	IM - YRIMB (for Hetao ID)	432,000	-8000
4-9	14005-14010	Baogang pump station	Baotou City	57,930	-2970
10-16	14011-14018	Madihao pump station	Tuoketuo County	18,835	-1175
17	14014	Xiaoshawan pump station	Zhenger County	4700	0
Total				*599,465*	*-25,485*

However, actual diversion in any one year under the cap may vary, and is the outcome of an iterative process that sees bottom-up demand (from farmers and the HIMD) revised through a process of top-down adjustment and approval. Specifically, it is determined by:

- The *Annual Water Use Allocation Plan* prepared by Hangjin WAB and its subordinate irrigation agency, HIMB (see Section 3.4.2 below). This is demand-driven, in that it reflects the water requirements articulated by farmers through WUAs. It is prepared in March-April, prior to release of the YRCC's *Annual Regulation Plan*.
- Secondly, on approval and adjustment by higher level authorities. So, the *Annual Water Use Allocation Plan* prepared by HIMB and Hangjin WAB is submitted upwards to IM-YRIMB, to the IM-WRD and, finally, to the Yellow River Water Despatching Centre under the YRCC, with adjustments made that reflect the *Annual Regulation Plan*. Once approved, HIMB has to revise its *Water Use Allocation Plan* accordingly[57]. Further adjustments may also be required during the year to accommodate the monthly or real-time scheduling described above.

In addition, the water transfer project begun in 2004 (see Section 3.5) also affects diversions to HID. Although the permit will remain unchanged until the project has received completion approval from YRCC, estimated savings of 130 million m^3 per year

[57] Hence for the period July 2006 – June 2007, with an estimated 84% of normal flow in the Yellow River, all provincial/regional shares *and ID shares* were reduced by 16%.

have been 'taken off' the allowable diversion, leaving the ID with a current gross diversion of 280 million m^3 per year (see Figure 29)[58].

3.4.2 Allocation and management within the district

Hangjin Irrigation Management Bureau has formulated a series of rules and regulations for managing irrigation water within the district in accordance with national policies (e.g. on popular participation through WUAs), and under the guidance of the county and prefecture/provincial WABs/WRDs. These are discussed below, together with the direct experience of HIMB staff and WUA members documented during project visits.

The irrigation management 'system' in Hangjin is represented in Figure 32 below. This highlights the *range of existing procedures* for system maintenance (engineering), water monitoring and measurement, the establishment and functioning of WUAs, water ticket sales and fee collection, and irrigation scheduling. Procedures are recorded in a guidance document entitled "*HIMB Irrigation Water Use Management*, 2003", henceforth termed HIMB's *Management Guidelines.*

Looking firstly at the **water planning procedure in overview**, Article 2 of the Management Guidelines stipulates that:

> **Article 2:** Water is allocated according to a Water (Use) Plan, prepared jointly by HIMB, HIMB's three Section Offices and WUAs.
>
> HIMB prepares a *Channel Scheduling Plan* of water flow at sluices leading off the main (first level) canal. This is then passed down to Section Offices and WUAs. Based on this (volumetric) schedule, Section Offices and WUAs then develop scheduling plans below this level. Specifically, WUAs develop water use plans for their command areas below fourth level sluices based on water demands from farmers, and these are then discussed and agreed with Section Offices. Section Offices develop Water Allocation Plans for their own sections (for flows from second level sluices) according to both (bottom-up) WUA demands and HIMB's (top-down) Channel Scheduling Plan.
>
> Following an iterative process of scrutiny and adjustment, Hangjin WAB compiles an overall Irrigation Water Scheduling Plan for the ID, and submits it to higher level authorities for approval.

The process described in Article 2 is illustrated in Figure 33.

Discussions with HIMB staff and a field survey of farmers and representatives from WUAs have confirmed these broad arrangements. In particular:

- From January to March, WUAs clean channels, repair gates in their command areas and check the area of land each farmer wants to irrigate. Irrigated area was reported as roughly the same from year to year.
- In March, WUAs confirm land areas to be irrigated for the purpose of developing the scheduling plan referred to in Article 2. However, it is clear that bottom-up

[58] Mandatory return flows remain the same, so the allowable net diversion is now 245 mcm/year. However, *actual* diversions to the district are likely to fall below this limit following the adjustment and approval process described.

(farmer) demand does not *fully* determine allocations to WUAs as 'adjustments' are made through the year to accommodate supply constraints imposed by the YRCC. Since water allocation to WUAs is based on turns (there is not enough water from second level channels for all WUAs to irrigate at once below this level), some WUAs spread risk by alternating turns. Similarly, farmers within WUAs drawing water off a shared channel may also take turns between years to irrigate first.

- There are four irrigations per year, though some crops (e.g. sunflowers) may only require 2-3 irrigations, depending on rainfall. Irrigations occur in late April, at the beginning of July, at the end of July and late September/early October. Survey results, discussed in more detail in Section 5.5, indicate that water deliveries over the last 10 years have generally been adequate and reliable.

Looking now at the actual **water allocation process**, Articles 8 and 9 of the Management Guidelines, as well as WUA regulations (see below), provide details on Water Fees and the purchase of Water Tickets, respectively.

> **Article 8:** Water allocation is based on the payment of water fees, paid prior to each irrigation. Payments are made on a '*one contract, one ticket, one table and one notice*' basis.
>
> '*One contract*' refers to the purchase of a water ticket by a WUA from the relevant Section Office under HIMB; '*one ticket*' refers to the pre-purchased water ticket specifying the quantity of water demanded by each WUA prior to each irrigation period; '*one table*' refers to the water fee calculation table that is used to calculate the water fee payable by the WUA on a particular day, and the quantity of water that will therefore be released through the gate; and '*one notice*' refers to the notice that is publicly displayed afterwards showing the water volume received and the fee paid by each WUA, and acceptance by WUAs of monitoring and supervision arrangements for delivery. In addition, each WUA is obliged to openly record the irrigated area and fee payment of each water user.

Article 9 provides further detail on how the process for purchasing water tickets relates to the overall water planning procedure described under Article 2:

> **Article 9:** WUAs must purchase the tickets provided by HIMB and declare their Water Scheduling Plans to the relevant Bureau Section. Specifically:
>
> (a) WUAs must purchase water tickets for each irrigation period in spring, mid-July and before 20 August;
>
> (b) The Bureau will issue tickets according to payment, but also according to the upstream water situation (this indicates that delivery is not entirely 'on demand'; a shortfall in delivery in one irrigation round can be 'made good' in the following round, for example);
>
> (c) Section Offices, under the direction of the Bureau, will provide prior notice to WUAs of the timing and volume of water deliveries; and
>
> (d) Following each irrigation period, the Bureau will note any excess or deficit in delivery, and adjust the next delivery accordingly.

Figure 32: Irrigation management regulations in HID

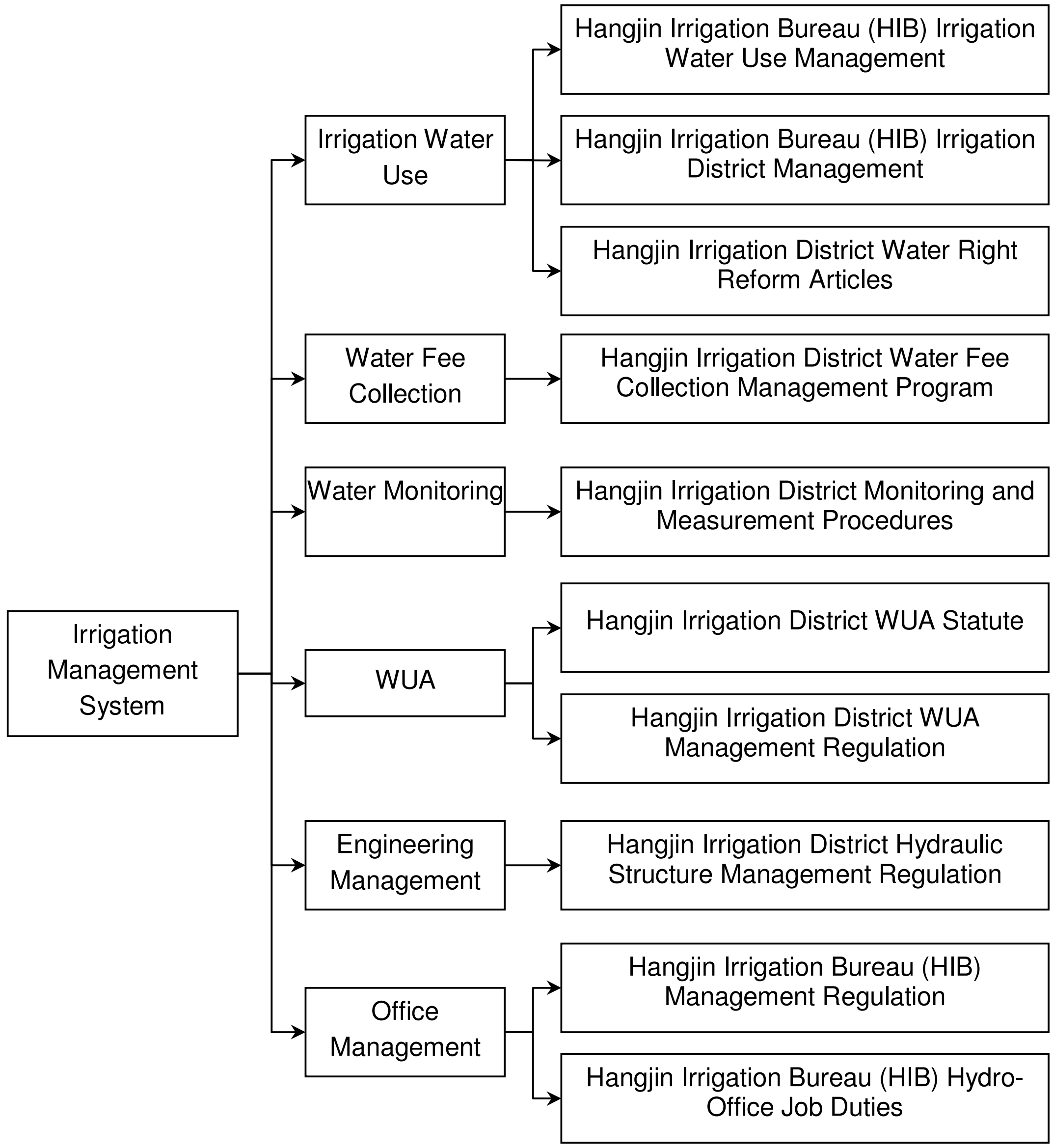
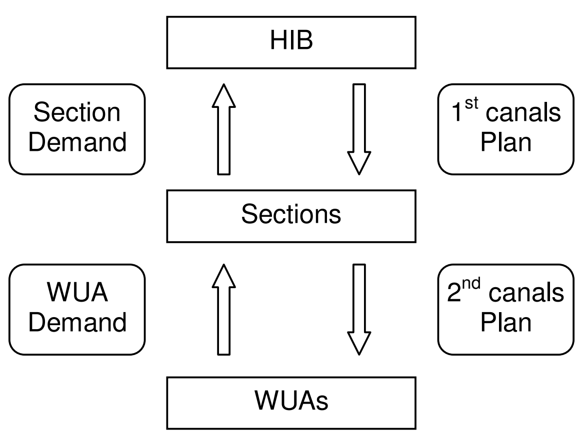


Figure 33: Water planning procedure, HID



The water allocation and management responsibilities of WUAs

The document '*Interim Management Measures for Water Users' Associations on the South Bank of the Yellow River*' outlines the rights, responsibilities and duties of WUAs in HID. The document is split into six chapters, covering: (1) General Provisions; (2) Formation and Election Procedures; (3) Business Scope and Functions; (4) Irrigation Management; (5) Maintenance of Infrastructure; and (6) Fee Collection and Financial Management.

The broad objectives of a WUA described are to promote agricultural production, increase the income of farmers, maintain infrastructure and increase water use efficiency. In terms of water allocation and management responsibilities, and the WUA's democratic mandate, the document states that:

WUAs are responsible for collecting area-based fees from WUA members (farmers in the defined command area), and for purchasing water tickets;

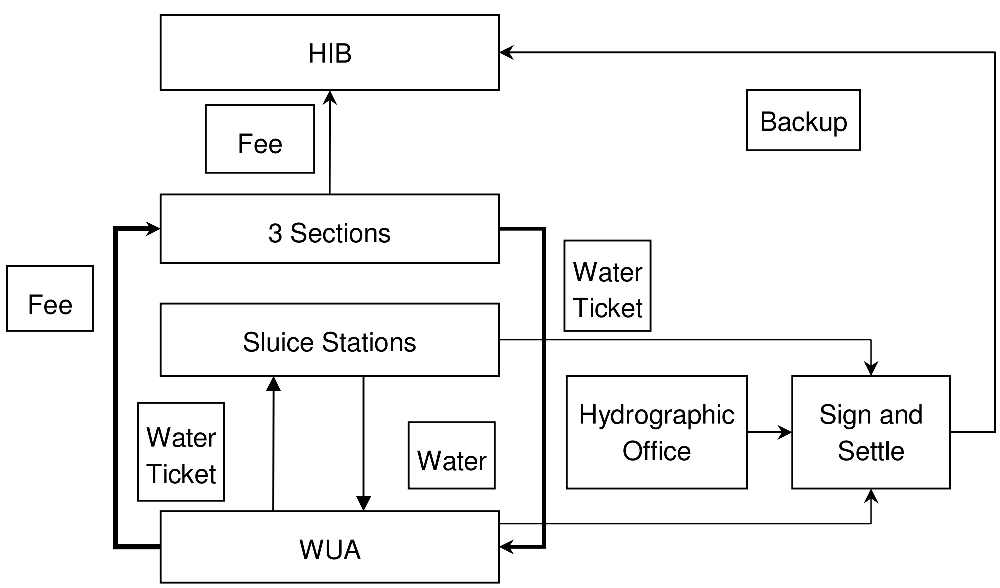
WUAs are also responsible for the operation and maintenance of channel infrastructure within the WUA command; the costs of any repair should be borne by the water user(s) that benefits, estimated through area or volume.

WUAs should sign a water using agreement with HIMB Section Offices prior to each irrigation period (the 'contract' discussed elsewhere in this section), with WUA managers supervising and signing-off deliveries to the WUA;

WUA representatives – including members of the Executive Committee and the Chairman and Vice Chairman, should be democratically elected by farmers. The President (Chairman) of the WUA acts as its legal representative.

The relationships between WUAs and the HIMB (including Section Offices and the Hydrographic Office) are represented in Figure 34.

Figure 34: Purchase and issue of water tickets

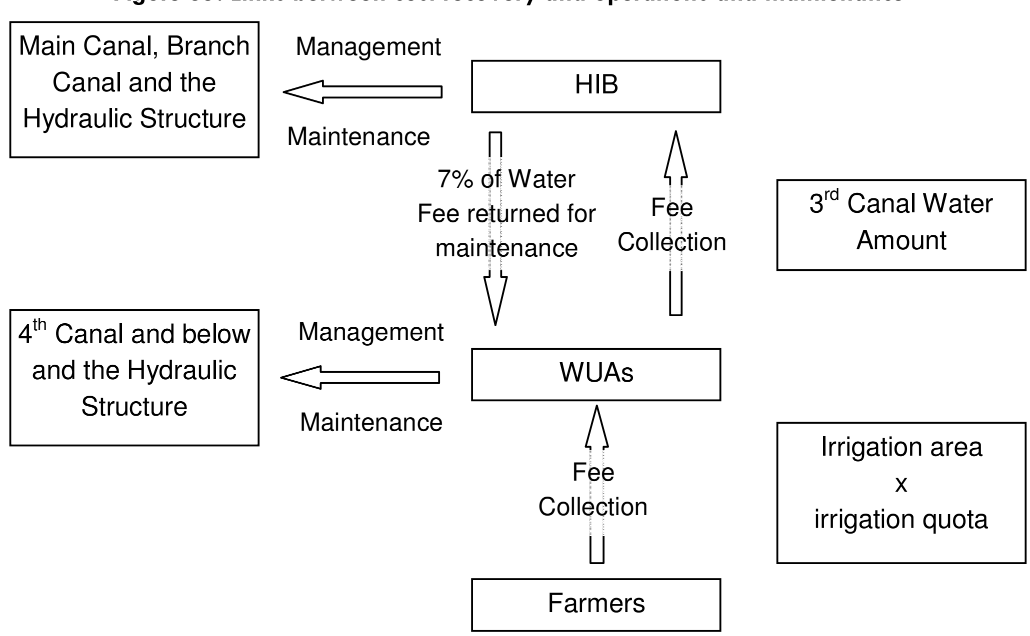


The experience of HIMB staff and WUAs suggests that the 'one ticket, one contract, one table, one notice' procedure works well in practice and is understood by farmers, WUAs and the HIMB. Key points, discussed further in Section 5.5, include the following:

- Farmers pay for water on the basis of *land area irrigated*, with 15 RMB per mu reported for the first irrigation on 28 April 2007. Area based fees levied on each farmer are collected by WUA managers and converted to a volumetric equivalent by HIMB Section Offices for ticket-based delivery to WUAs. The current 'sale' price of water is 0.054 RMB per m^3, with prices set outside the district.
- There is no price differentiation on the basis of the type of crop grown, even though sunflowers (for example) use significantly less water than corn. Since farmers pay for water before irrigation by area, *there is little incentive to economise on use when irrigation begins*, though some WUAs adjust area-based fees according to monitored delivery to individual production teams on tertiary channels.
- *Section Offices under the HIMB display details of water tickets issued and payments outstanding*. It appears that trusted WUAs, for example, are allowed to purchase tickets even if full payment cannot be made, on the basis that outstanding charges from defaulting farmers will be collected by the WUA and passed onto the station in due course.
- Advantages of the monitoring arrangements reported are the *separation of ticket payment from measurement, and oversight of gate releases by WUA members*. Specifically, WUAs pay at the Section Offices, then take their tickets to a gate keeper who makes the release while volumes are measured by staff of the Bureau's Hydrographic Office.

The next issue concerns the **link between water allocation, revenue flows and operation and maintenance**. Specifics are dealt with in two documents – 'Hangjin Gravity Irrigation Water Fee Collection and Management' and 'Hangjin Gravity Irrigation Hydraulic Structure Management' – and illustrated in Figure 35.

Figure 35: Links between cost recovery and operations and maintenance



As noted in Section 3.5, the establishment of WUAs (and the introduction of water tickets) and the transfer of water out of the district have changed the links above. Drawing on discussions with HIMB staff and WUA members, the following points are worth highlighting:

- WUAs are now responsible for maintaining and operating channels and sluices in fourth and fifth order channels, and also oversee deliveries by HIMB Section Offices to fourth order channels (see box above).
- HIMB are responsible for maintaining the higher level channels and sluices from third and fourth order channels. Although cost recovery rates from WUAs are high, however, HIMB report that revenue has declined because less water needs to be delivered to the fourth level sluices following channel lining.

Turning now to water **monitoring arrangements**, the document 'Hangjin District Irrigation Water Monitoring and Measurement Procedures'[59] provides guidance on methods and procedures. Specifically:

Hangjin Irrigation Water Monitoring and Measurement Procedures (2005)

Methods: flows are measured using a velocity-area calculation. That is, using the measured cross-sectional area of the channel and flow meters to estimate a flow rate through a section.

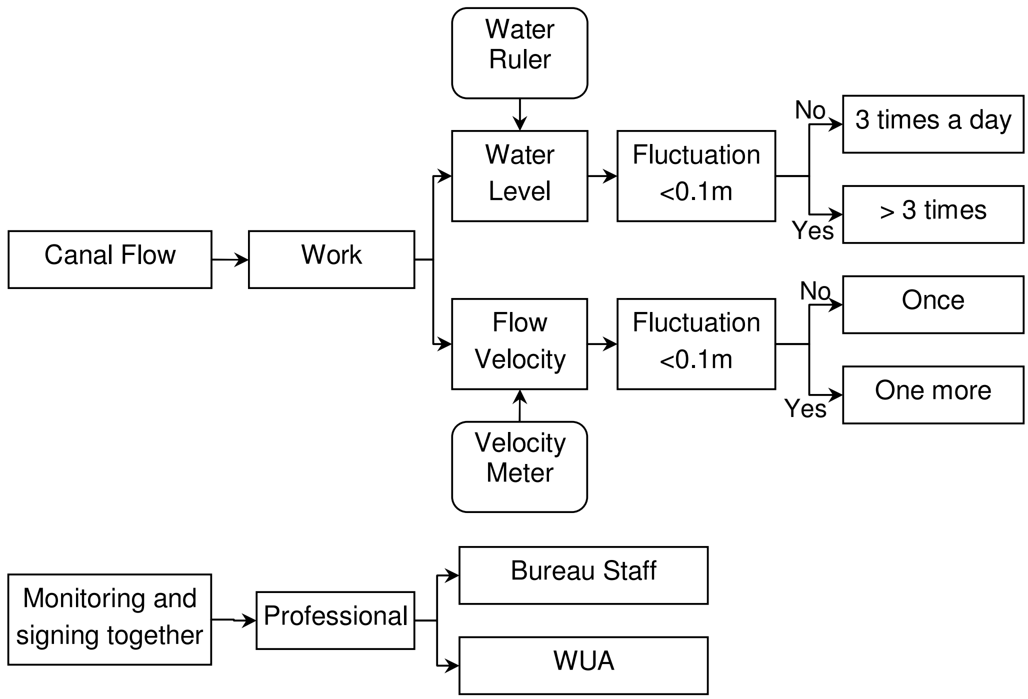
Observation: if the water level changes during the period of measurement in a slow way (a fluctuation of less than 0.1 m over a day), the level should be checked three times a day at 08:00, 14:00 and 20:00. If the water level change is more significant (over 0.1 m in a branch channel, or over 0.2 m in the main channel), observations should be increased.

Recording period: this should be the interval between the start and end of discharge. During the discharge period, flow should be measured at the beginning, mid-point and end of discharge. If the discharge fluctuates by more than 0.1~1.4 m (related to channel size), one more measurement should be taken.

Monitoring and supervision procedures are illustrated in Figure 36, and discussed further in Section 5.7.

[59] Hangjin Gravity Irrigation Hydraulic Structure Management Regulations, 2005.

Figure 36: Water monitoring and measurement in Hangjin



3.5 Water conservation and transfer

In order to address water shortages experienced by downstream industrial users, the Water Resources Department in Erdos has initiated a novel water transfer project. Beginning in 2004, the Office of Water Rights and Transfer under the WRD has overseen a programme in which water saved through channel lining in HID is transferred to downstream industries, with the costs of lining met directly by the industrial beneficiaries.

According to the "Inner Mongolia Autonomous Region Water Rights Transfer Planning Report", in the three year period from 2005 to 2007, 13 enterprises will have invested a total of 600 million RMB in channel lining, including 133 km of main (first order) canal, 229 km of second and third order branch canals, 202 km of fourth order canals and 411 km of field ditches. According to the plan, the implementation of the project will save as much as 138 million m^3 of water. Under the plan, industrial users funding the capital costs of canal lining are also obliged to meet the ongoing operations and maintenance costs (O&M) of channel repair over a 25 year term. However, funding for this will not be released until the project has been completed and approved.

By 30 September 2006, a total of six projects had been completed, each funded by a separate industrial enterprise. This has included the lining of 126 km of main canal, 13 km of branch main channel, 76 km of the second order canal, 69 km of third canal, 63 km of fourth canal and 24 km of fifth canal, with a combined investment of 405 million RMB. The outcome is a transfer of 78 million m^3 of water to downstream users.

To support the water transfer project, Hangjin County has also invested heavily in land improvement. Across the southern Yellow River Gravity Irrigation area improvements will be made to roughly 400,000 mu (26,667 ha) of farm land, with 100,000 mu (6,667 ha) completed by the end of 2007. Improvement focuses on land levelling in strips of 600-

800 m length and 50-100 m width, with benefits in terms of reduced (field) water use and increased mechanisation. In addition, shelter belts are being planted along main canals to reduce evaporative losses from high winds. These combined measures are expected to generate further water savings of 20-50 million m^3 per year[60] for release to industry.

However, it is clear that flood irrigation will remain the norm, and while transfers of saved water may increase the allocative efficiency of water use between uses, they do not create incentives for more efficient use of water within the district by farmers (productive efficiency, or 'crop per drop').

Although the water transfer programme is a new one, its effects on different stakeholders – both positive and negative - are already becoming apparent. In particular:

- *Impact on industry.* Although details on the marginal cost of new supplies from alternative sources is not available, the willingness of industrial enterprises to invest in channel lining indicates that this is a least cost supply option for them, at least in the short to medium term.
- *Impact on farmers.* The extension of the channel lining programme to lower order channels under the management of WUAs will increasingly benefit farmers through reduced water charges (they will pay for less). Initial discussions with WUAs suggest savings of around 20-30 RMB per farm household per year. Farmers have also benefited from the lining of higher order channels as the point of purchase has changed: farmers (through WUAs) now pay for lined channel deliveries at fourth level sluices, rather than unlined deliveries (and channel losses) at third level sluices.
- *Impact on the service provider.* The HIMB, on the other hand, has seen its financial position undermined by the channel lining programme[61]. This is because it relies on the purchase of water tickets, rather than core funding from government, to fund its activities. In the longer term, questions remain about the ability of HIMB to fund ongoing O&M for the channels and measuring equipment for which it remains responsible.
- *Impact on other uses/users.* One outcome of the savings-transfer programme is the drying up of lakes and wetlands towards the tail of the irrigation district. Impacts on groundwater levels within the district are not being monitored. More diffuse impacts on groundwater flows beyond the basin are uncertain, and questions remain over the extent to which conservation gains represent 'real' savings.

3.6 Summary of current problems

Drawing on the Situation Analysis above, we can summarise the problems that HID *currently* faces as follows:

- **Loss of revenue for the irrigation agency.** The water transfer project has, indirectly, affected the financial position of the HIMB. In the medium to longer-

[60] Pamphlet published by HIMB, entitled 'An introduction to the water resources of Hangjin County along the Yellow River.

[61] Discussions with HIMB suggest revenue has fallen by around RMB1 million/year.

term, this may compromise the ability of HIMB to maintain new channels and monitoring equipment, and retain key staff.

- **Management capacity of the service provider.** In light of the above, the ability of HIMB to sustain management functions – including the development of water use and scheduling plans, water ticketing and monitoring – is open to question. With resources stretched, revisions to the existing system of water allocation, recording and scheduling may be difficult to implement.
- **Third party impacts of water transfer.** The outcome of the water transfer programme on different water users requires further evaluation. For example, the impact of channel lining on flows through branch and lower order channels and ditches is uncertain, and monitoring arrangements at these levels are inadequate. Moreover, reductions in groundwater recharge are already affecting adjoining wetlands, and may have unforeseen impacts on the shore ecology of the Yellow River and 'downstream' groundwater users. One benefit may be the restoration of farmland previously affected by salinity (from high groundwater levels), though any expansion in irrigable area may increase demand for irrigation water.
- **Monitoring arrangements.** Following on from the point above, water measurement in Hangjin is still based on equipment and methods used in the 1950s, with recording all carried out by hand. This creates a heavy workload for the staff of HIMB's Hydrographic Office. A modern, automated system is needed to accurately monitor and allocate flows.
- **Irrigation efficiency.** While current transfers of saved water may increase the allocative efficiency of water use between uses, they do not create incentives for more efficient use of water *within* the district by farmers (productive efficiency, or 'crop per drop'). Land improvement will help in this respect, but evaporative losses from flood irrigation will continue to be significant.

Chapter 4: Applying the WET framework – key issues

4.1 The importance of rights definition, allocation and management

The WET framework sets out the general procedures and rationale for rights definition, allocation and management, though not in the specific context of an irrigation district. In this sub-section, therefore, we briefly explore some of the arguments in favour of unambiguous, recorded and enforced rights for *irrigation schemes such as Hangjin*.

Arguments in favour of assigning and enforcing legal rights can be summarised as follows:

- *Security:* if the rights of users are recorded and protected by law, equity issues associated with unfair water distribution can be addressed more easily. In large irrigation schemes, for example, secure claims to water would help prevent head – tail problems, where those at the head of a system take too much water, while those at the end are left with little or none at all.
- *Transparency:* the transparent allocation of clearly defined rights provides users with greater confidence that rules are being followed by others, and provides

service providers, such as HIMB, with greater clarity (and accountability to users) about their obligations and duties.

- *Water efficiency and farm productivity:* farmers are more likely to invest in improved land and water management if they have secure title to water (and land). While land in China is not privately owned, leases are long and land distribution is generally equitable.
- *Livelihood diversification:* farmers are also better able to exploit employment opportunities in the wider rural and/or urban economies if rights are secure, and enforcement improves reliability. Livelihood diversification is particularly important for poorer farmers because it helps spread risk and reduce vulnerability.
- *Building blocks for other reforms:* clearly specified rights provide the foundation for other reforms – both regulatory and market based. In addition, the establishment of formal water rights can give rise to strong pressure for improving the data and monitoring systems needed for management. Table 37 explores some of the links between water rights and the implementation of demand management policies.

It is also important to understand how the priorities of different stakeholders may differ (Table 37 and below). As noted previously, an agency such as HIMB is primarily concerned with cost recovery, *not* demand management. HIMB is also likely to favour systems with low transactions costs: that is, systems that are easy to implement, and easily understood by both their own staff and by WUAs and farmers. Conversely, higher level government agencies have to mediate between the claims of *competing* uses (agricultural, municipal, industrial and environmental). They therefore have a greater interest in agricultural water efficiency, and the potential for transferring water from irrigated agriculture (the major water user and consumer) to higher value users. These different priorities reflect the actual interests of different stakeholders. And the case of Hangjin ID also indicates that water right system construction and reform must be comprehensive, coordinated and implemented fully. That is to say, the water rights system and reform should be strong enough to satisfy all stakeholder needs.

In Hangjin, preliminary discussions with officials, WUA representatives and farmers have focused on existing water rights and allocation. The current system has no legal force, but nonetheless serves to allocate a permitted system allowance (monitored and enforced) to WUAs and individual farmers in a way that *appears* to work reasonably well. In particular:

- The allocation system is understood by both users and the irrigation agency (HIMB), with regular contact and information flow between the two.
- Water is distributed in an equitable manner. No serious problems are reported with farmers at the head of the system, for example, taking too much while those at the tail have less than they need. Moreover, the rotation of water allocations between WUAs helps ensure that the risk of low or no flow is spread.
- Monitoring of flows is rudimentary, but transparent. For example, flows through fourth level sluices are supervised by both WUA representatives and agency staff, and flows to individual farmers are monitored and recorded by the WUA.
- Cost recovery is improving, not least because farmers now have to pay for their irrigation service in advance. There appears to be no low level equilibrium in

which poor service leads to low levels of cost recovery and a further decline in service. In spite of this, however, water transfers and external control of prices have undermined the financial position of HIMB.

- The establishment of WUAs along lateral canals is intended to take the management of local irrigation deliveries away from the village collective, by-passing the traditional village-township-county route of fee payment to the irrigation district, and saving farmers money. Allowing farmers a say in decision-making through the WUA is also intended to improve local management of water, fee collection and maintenance.
- Reallocation of saved water from channel lining within the district is providing downstream industrial users with high value water. This works in the absence of formal, tradable rights because the trade is in savings, not productive (claimed) water.

In this context, key questions for rights reform in Hangjin relate to the broad costs and benefits of *changing* current arrangements. Specifically, can existing arrangements support moves towards water conservation and reallocation, while meeting the needs of farmers and the HIMB? If not, what are the arguments in favour of reform, and what specific changes are proposed?

4.2 The objectives of rights reform

In Hangjin, rights arrangements have been developed to allocate a permitted supply to the ID based on laws and regulations. They were not designed to accommodate *changing demand pressures from other sectors*. In any system where demand exceeds supply, or where water conservation and reallocation become key objectives, there is likely to be pressure to formalise rights. In particular, there will be pressure from farmers within the district – and from non agricultural users outside – to define, record and protect rights as scarcity increases.

Currently the rationale for rights reform in Hangjin (and other irrigation districts) extends well beyond support for trading. Water trading is one of a number of demand management tools; others include regulatory control, pricing and technical intervention. Each depends – directly or indirectly – on the presence of clear rules governing ‘who gets what’ as demand management measures are introduced.

Table 37 sets out a range of demand management options and criteria that could be used to evaluate them. Criteria are not fixed, and different stakeholders may prioritise them differently. In addition, the tools listed are not mutually exclusive. They can be introduced in combination, as part of a package of demand management measures. Below, we summarise their rationale, outline rights requirements, and identify gaps that exist in Hangjin between ‘*where we are now*’ and ‘*where we would need to be*’ for effective implementation.

Table 37: Demand management options and performance criteria

Options	Productive efficiency (kg/m3)	Allocative efficiency (RMB/m3)	Equity (distribution outcomes)	Transactions costs (ease of implement.)	Predictability of outcomes (certainty)
	Performance/Decision Criteria				
Trading					
‣ local, informal, temp.	Yes	Yes, between farms	Good	Low	Temporary – e.g. hours
‣ local, formal, temp.	Yes	Yes, between farms	Good	Higher	Temporary – e.g. hours, days
‣ intersectoral, formal, temp.	Yes	Yes, between sectors	Good – with strong regulation	High – *regulated* market	Temporary - e.g. during drought
‣ intersectoral, formal, perm.	Yes	Yes, between sectors	Good – with strong regulation	High – *regulated* market	Permanent – outcomes variable
Rights dimension/notes	Rights do not have to be legally defined, recorded and enforced for informal trading to occur, or for reallocation of 'un-used' water from channel savings. In Hangjin, the latter is occurring. Uncertain if temporary (e.g. hourly) farmer to farmer trades are currently occurring along channels. Formal trading (local and inter-sectoral) of agricultural water requires transferable rights, with legal backing, recording/monitoring, enforcement and arbitration within a capped limit. Requires strong institutions, infrastructure capable of measuring and controlling delivery to rights holders and internalisation of 3rd party effects. In Hangjin existing rights separate from land, but other pre-conditions not in place. **Key message:** permanent trading of agricultural rights to other downstream users – beyond current trade in channel savings - has to address stiff pre-conditions and would be politically contentious, especially for agricultural – urban/industrial transfers. A long term option.				
Pricing					
‣ area based	Marginal	No	Good	Low	Good
‣ crop based	Marginal	No	Good	Medium	Seasonal
‣ input/output based	Variable (indirect tax)	No	Variable	High	Seasonal
‣ volumetric	Yes	Unlikely	Variable	High	Variable
Rights dimension/notes	Area based fees (e.g. in Hangjin) have a small volumetric element, but no positive marginal cost to users. Volumetric pricing can be used to limit demand if prices high enough (e.g. >10% farm income), but transactions costs high and politically stressful. Hence prices set by higher level authorities under political control. Formalisation of rights is not a precondition for pricing, but there is a positive link between the two. Users' willingness to pay likely to be higher for well-defined, recorded and monitored rights, especially if bundled with improved service (O&M, reliability/timeliness of				

	deliveries etc). **Key message:** the immediate challenge in Hangjin – and probably in other irrigation districts – is to cover the costs of a slimmed-down service provider, ensure sustainable O&M and strengthen link between user payment and agency performance. Pricing reform – for cost recovery or demand management - might create bottom-up pressure to formalise rights and upgrade monitoring so payments perceived as fair.				
Administrative					
‣ system permits	Yes, if D>S	Yes	Variable	Low	Good
‣ group certificates	Yes	No	Variable	Medium	Good
‣ individual tickets	Yes	No	Good	High	Good
Rights dimension/notes	In Hangjin, irrigation district already works within variable cap specifying total withdrawal and returns. Currently, water availability and access does not appear to be a limiting factor in production. Any proposal to lower the cap, however, might increase pressure to formalise rights and upgrade monitoring at WUA level (supply capped, rather than current negotiation) and below (individual households). The capacity of WUAs to monitor and manage revised arrangements uncertain. **Key message:** rationing through system permit and lower level caps, by itself, may not feasible. Could be implemented as part of a package of measures aimed at raising water productivity and farm incomes (the carrot), while capping water use (the stick) – see below.				
Technical					
‣ engineering measures	Yes – if directed at lowering ET	No	Good	Low, though focus on ET increases complexity	Good
‣ agronomic measures	Yes – if directed at lowering ET	No	Good	Low, though focus on ET increases complexity	Good
‣ scheduling	Yes – if directed at lowering ET	No	Good	Low, though focus on ET increases complexity	Good
Rights dimension/notes	Best implemented as part of a 'contract' between farmers and government agencies. In return for land improvement, for example, farmers/WUAs would agree to a cut in permitted allocations. This would need to be implemented (and be seen to be implemented) in a fair and transparent manner. Hence the need for clearly defined and agreed allocation rules (and flexible caps) as savings are translated into permanent reductions in volumetric rights. **Key message:** politically much less stressful than other options, hence popularity with government. Can form part of a compensation package for farmers asked to reduce water use (as occurs in e.g. Hai He).				

Note: "ET" is evapotranspiration

4.2.1 Trading

Rationale: in contrast to water by allocation by administrative decision (see below), market allocation guarantees compensation to users, with decisions based on individual (or group) assessment of the value of water in alternative uses.

Requirements (rights): trades of 'productive' water (as opposed to saved water) are *possible* when individuals or groups have a secure, volumetrically-defined claim to water that is transferable and separate from land ownership. Market transactions are *efficient* if the full benefits and costs of a transfer, including impacts on third parties, are factored into the decision-making process.

Gaps: in Hangjin, farmers enjoy a *de facto* claim to water based on long term land tenure and payment for a bundled 'water service' (water plus delivery). However, rights are not, as yet, volumetrically capped, recorded, codified or transferable. The efficiency criterion could only be met if third party effects (externalities) were evaluated by a regulatory/supervisory body before trade was sanctioned.

Potential: permanent trading of agricultural rights to other downstream users – beyond current trade in channel savings – would need to meet stiff pre-conditions. It might also be politically contentious, at least for agricultural – municipal/industrial transfers. Trade in group entitlements held by WUAs and mediated via a water bank (see Section 5.6) would help address institutional needs, but would require collective decision making by WUAs to sell water prior to delivery, without full information on (future) agricultural returns.

4.2.2 Pricing

Rationale: cost recovery and demand management are two distinct objectives requiring different types of intervention. Cost recovery (typically annual O&M costs, and possibly a proportion of capital costs) is often achieved through area-based pricing, though other methods are possible. Demand management requires volumetric pricing, either directly (e.g. metered diversion) or via a proxy (e.g. crop-based), though prices are rarely set high enough to balance demand and supply.

Requirements: for direct volumetric pricing to influence demand, farmers need to be able to control how much water they use, with delivery and monitoring standards acceptable to both the irrigation agency (e.g. HIMB) and the user. Farmers are likely to be more price-responsive where in-field water management losses (as opposed to conveyance and distribution losses) are significant. In Hangjin, therefore, channel lining would potentially support moves towards pricing for demand management.

Gaps: in Hangjin the formalisation of rights would not be a precondition for pricing, but there would be a positive link between the two. For example, users' willingness to pay would likely to be higher for well-defined, recorded and monitored rights, especially if bundled with improved service (O&M, reliability/timeliness of deliveries etc).

Potential: the immediate challenge in Hangjin – and probably other irrigation districts – is to cover the costs of a slimmed-down service provider, ensure sustainable O&M and strengthen the link between user payment and agency performance. Pricing reform – for cost recovery or demand management - might create bottom-up pressure to formalise rights and upgrade monitoring so that payments are perceived as fair.

4.2.3 Administrative rationing

Rationale: internationally, market instruments (pricing, trade) are generally not used to balance demand and supply within irrigation districts, or between sectors[62]. Where irrigation demand has been constrained (a rarity), volumetric permits have been used to cap both irrigation system/district and the users within them. To ensure basin-level efficiency, permits based on consumptive water use have also been piloted in China[63].

Requirements: In Hangjin, the irrigation district already operates within a variable cap specifying total withdrawal and returns (see Section 3). Any proposal to lower the cap, however, might create pressure to formalise rights and upgrade monitoring at WUA level and below. The capacity of WUAs to monitor and manage revised arrangements is uncertain.

Gaps: in Hangjin, water allocations to WUAs and farmers are not volumetrically capped, and water availability and access do not appear to be limiting factors in agricultural production.

Potential: rationing through system permit and lower level WUA caps may not, in isolation, be feasible as farmers would not be compensated for the loss of historic rights. However, controls could be implemented as part of a package of measures aimed at raising water productivity and farm incomes (via land levelling, upgrading irrigation technologies etc – the compensation), while capping water use.

Chapter 5: Detailed application of the WET framework

In this chapter we discuss the application of the WET Framework to rights reform in HID. In particular, we examine:

- Allocation principles, and broad lessons for rights reform in IDs in China (Section 5.1);
- How water rights can be defined and allocated in HID, drawing on the results of an allocation model (Section 5.2);
- The use of water certificates and tickets to formalise and allocate rights and pay for water services (Section 5.3);
- Water planning and irrigation scheduling, and the role modelling can play in helping to allocate water in the context of changing supply and demand conditions (Section 5.4);
- The role of WUAs in irrigation management, and the factors that influence their ability to manage water rights effectively on behalf of farm households (Section 5.5);
- The feasibility of water trading organised through a water bank (Section 5.6); and

[62] FAO 2004. Water charging in irrigated agriculture: an analysis of international experience. FAO Water Reports No. 28. Rome, 2004.

[63] A proposal to adopt farmer/WUA permits based on consumptive water use, with users receiving progressively capped and monitored ET quotas, was presented to China's State Council in 2006, based on experience gained piloting ET quotas on several World Bank projects (personal communication, World Bank Beijing Office).

- Monitoring and information systems that would help support the reforms above (Section 5.7).

The broad objective is to present an approach, and a set of tools, for water management in HID that can:

- Define, allocate, monitor and record proportional, area-based water rights to all WUAs in a way that is consistent with the diversion targets of the YRCC, and accounts for all losses within the ID;
- Support long term water saving through quota-based allocations to WUAs and water ticketing, and provide greater water security for farmers; and
- Provide a basis for future water trading, either within the ID (between WUAs), or between the ID and downstream users.

5.1 Allocation principles

5.1.1 International experience

Different countries have different systems for water rights allocation. Generally speaking, the main principles are: Riparian Ownership; Prior Appropriation; and Public Rights.

Riparian Ownership is derived from English Common Law and the Napoleonic Code of 1804. Riparian rights stipulate that water rights belong to the adjoining land owners; in other words, water rights are tied to land rights, and can only be transferred with land. In the districts with the implementation of Riparian Ownership, either upstream or downstream, the water rights along the bank are equal. As long as the use of water by one owner will not affect the continued flow downstream, then the water amount he can use are without restrictions, and it will not set up the priority by the use order.

The Prior Appropriation Doctrine derives from the water use practice of the western United States in the 19th century, and assigns rights of use rather than title. The main guiding principles are: ‘first in time, first in right’ – established users have priority over newcomers; beneficial use – the water should be used for productive activities; and, related to this, a ‘use it or lose it’ – those not using water productively will lose their rights.

In countries and regions implementing civil law systems, rights are usually defined through legislation and the allocation of Public Water Rights. Such rights are generally based on three principles: the separation of ownership and the usufruct; development and utilization of water resources that is subordinate to wider economic planning and development goals; and the allocation of water rights through administrative measures.

In Chile, some regions use the principle of equality of water rights. The equality principle confers equal rights on all users. When water is short, users’ water consumption is reduced by the same proportion.

To summarise, international experience highlights how principles have evolved according to local context. Hence in regions of relative water abundance such as Europe and eastern America, Riparian principles have dominated. In regions of relative scarcity, conversely, such as the western states of America, the Prior Appropriation Doctrine has dominated, supplemented with Riparian rights. In Japan, both ‘Upstream Priority’ and ‘First in time first in right’ are implemented together.

5.1.2 Allocation principles in China

In China, allocation principles have also evolved according to political and economic priorities. International comparisons provide some lessons, but do not provide China with any blueprints.

Wang[64], discussing usufruct water allocation principles, suggests the following. Firstly, that basic domestic needs should be satisfied, with everyone enjoying equal water rights for living. Secondly, and once this need has been met, other priorities can be considered, including water for agriculture and water for industry. Thirdly, the need for flexibility to accommodate changes over time.

A review of the literature indicates how domestic and international commentators have put forward many principles for usufruct distribution. For the current study, we have collected, analysed and sorted over 40 criteria which can be classified into thee major categories and over 20 basic principles. These are summarised in Table 38.

A review of water rights principles in practice for China, conducted for Phase 1 of the WET Project, revealed different applications in different areas. These are summarised in Table 39.

Table 38: Water usufruct allocation principles

Category	Principles in Detail
Guiding Ideology	The sustainability principles; Rational and efficient use; Security; Food security protection; Comprehensive benefits.
Specific Allocation	Basic living water protection principles; The ecological environment water protection principles; Prior Appropriation Doctrine; Riparian Ownership; Equality Priority; Efficiency Priority; Water Source Priority; Conditional Priority.
Supplemented	Feasibility; Flexibility; Political and Public Acceptance principle (Public Trust and Democratic Consultation, public trusteeship, public participation, the government ultimate decision-making principles); Allow some leeway principle. The consensus of responsibilities, rights and the benefits; the relative and absolute of groundwater ownership; finite time limit principle.

5.1.3 Allocation principles for Hangjin irrigation district

Drawing on the discussion of allocation principles above, and on the analysis of current allocation procedures described in Section 3.4, we now outline some principles of our own for rights allocation in HID.

Allocation based on current conditions but looking towards the future

Any volumetric cap on the water rights of WUAs needs to fully consider existing patterns of water use within and between WUAs, and the experience of farmers, WUA representatives and HIMB staff in administering present systems. We propose that rights allocation follows existing practice by linking land and water rights. In other words, rights assigned are directly linked to the irrigated area of the WUA.

One objective of defining and enforcing group entitlements or rights for WUAs is to end the requirements approach to water use planning that currently prevails. In future water

[64] Wang S 2001. Water right and water market---the economic methods for optimal allocation of water resources. *Hydroelectric Energy*, 2001, 19(3).

savings, rather than additional supply, should be used to maintain or increase farm production and farmer income.

Table 39: Water rights principles in practice in China

River Basin	Province	Allocation Year	Principle
Huoying River	Inner Mongolia Jinlin	2006	Government's macro-regulation and consultations principle Basin uniform distribution Total control and quota management Justice, equity and openness Integrated Plan of status usage and future demand
Daling River	Inner Mongolia Liaoning	2006	Principle of fairness. Different regions and different crowds enjoyed the equal water rights for survival and development Unified water allocation. Uniform consideration of Surface water and groundwater, main stream and tributaries, quality and quantity Government's macro-regulation and consultations principle Over thinking of the living, production and ecological water balanced principle. The order of priority is (1) life; (2) minimum ecological environment water need; (3) water demand of the second and third industrial; (4) agricultural irrigation water demand. Deciding the requirement on possible provision Integrated Plan of status usage and future demand total control and quota management classification recognized
Zhang River	Hebei	2003	Water saving Over consideration of Upstream and downstream, the left bank and right bank Respecting for the history and facing the reality, appropriate considering the future development, taking into account the engineering status and water usage status
Wei River	Hebei	2003	sustainable development principles basic living needs priority and ecological demand priority respecting the history and focusing on the reality principle Integrated consideration and resources sharing Equality and efficiency
Yellow River		1984	priority to the people's living water and key state construction of industry Sand washing water guarantee in the Lower Yellow River Shipping and fishing water are not separately allocated Over consideration of Upstream and downstream Do not increase the groundwater extraction in principle
Hei River	Gansu	1992	Total amount control Parallel lines principle monthly rolling modify principle integrated link of the investment, the project, and the effectiveness

River Basin	Province	Allocation Year	Principle
Shiyang River	Gansu	1990-2006	national ownership principle basic water priority and balance between fairness and efficiency Respecting for the history and facing the reality, appropriate considering the future development Democratic consultation and integrated decision-making
Tarim River	Xinjiang	2005	Effectiveness Principle Justice Principle Systemic Principle Coordination Principle Priority Principle
Fu River	Jiangxi	2005	Respect the status Justice Principle Justice and Effectiveness
Jin River	Fujian	1996	Respect the future, Prior Appropriation and Justice Base on the status and consider the future demand in a proper way

Maintaining a balance between fairness and efficiency

Different regions and different groups of people should enjoy equal rights to water for survival and development. So the allocation of rights should guarantee fairness between different management sections, different WUAs and different water users, and in particular, afford protection to those farmers with small land holdings.

In addition, water rights allocation and management should provide incentives for more efficient water distribution and use of water.

Observing the principles of macro-control and democratic consultation

Water rights should be allocated and authorised under systems of public administration, accompanied by democratic consultation. Democratic and scientific decision-making is based on a bottom-up and top-down process with consultation and feedback fully incorporated. This will fully develop democracy, lead to rational recommendations and safeguard the interests of all parties.

Quota management within the limits set by the ID permit

Volumetric rights assigned to WUAs should fall within the permit limits set by higher authorities. Specifically, within the diversion targets approved by the YRCC and discussed in Section 3.4 If there is remaining water under the cap, this should be reserved for development. If the cap is exceeded, water use should be reduced through fair, proportionate reductions among WUAs (termed ‘rational decrease’ in this report).

Recognition of environmental and other ‘downstream’ water uses

In defining and allocating rights, consideration should also be given to ‘third party’ impacts on (linked) environmental services and other downstream users, such as groundwater users dependent on return flows from the ID.

5.2 Defining and allocating rights in Hangjin

Drawing on the principles outlined above, we now look at their application in practice. In particular, we look at the preliminary findings of modelling work designed to accurately determine the flows required through main and branch canals to satisfy WUA water needs in different areas of the ID. Based on these findings, it is proposed that WUAs are assigned long-term GWEs in the form of water certificates that cap water diversions and therefore limit the volumetric water tickets that can be purchased by each WUA.

5.2.1 Modelling objectives and methods

The objectives of modelling work were as follows:

- Firstly, to estimate the conveyance efficiencies of irrigation channels, and then estimate water use within WUA command areas based on cropping patterns, the irrigation requirements of different crops and areas irrigated.
- Secondly, to develop a Simulation Model of irrigation water allocation that incorporates the data above to estimate flows required at the heads of the main channels, sub-main channels, branch channels and lateral canals to meet WUA water needs.
- Thirdly, to estimate the GWEs of different WUAs over the course of an irrigation season, based on the data and modelling results above.

The water allocation model is summarised in Table 40. The table provides a list of the 43 WUAs so far established in Hangjin, sorted by ID section and the villages each WUA intersects. It also provides data on the irrigated area in the command area of each WUA, average crop water requirements and channel efficiencies to generate data on water withdrawals, consumption and losses.

The steps followed to estimate water diversions needed at different levels to satisfy WUA requirements are as follows:

Firstly, an *average, annual crop water requirement, or index*, was used to estimate in-field demand for irrigation water. The figure used in Table 41 (370 m^3 per mu/year) is derived from the crop water requirement data supplied by HIMB. HIMB figures give an average crop use of 311 m^3 per mu/year. Given the prevalence of flood irrigation in the ID, however, a more conservative figure of 370 m^3 per mu/year is used.

Secondly, the volume of water needed at the delivery point of each WUA (at the fourth level sluices) was determined by estimating the conveyance efficiencies of fourth and fifth level channels below this point.

An average conveyance efficiency of 0.80 (80%) was assumed for this purpose, allowing for greater losses than assumed in the Yellow River Water Trading Plan (see Table 42 below: the Plan assumes a conveyance efficiency of 0.85 based on complete channel lining. Since lining at levels four and five is incomplete, we use the more conservative figure of 0.80). The average conveyance efficiency figure of 0.80 is then used to calculate the annual *unit area water requirements of a WUA* (370 m^3 per mu at 0.80 = 463 m^3 per mu at the fourth sluice gate, or point of purchase). The *annual total water requirements of each WUA* can then be estimated by multiplying this figure by the total area of each WUA. Data on irrigated areas was again provided by HIMB.

Table 40: Water allocation model, Hangjin Irrigation District

WUA	Section	1st Canal	2nd Canal	3rd Canal	Village	Area (mu)	Conveyance efficiency	Unit WUA Requirement (m^3/mu)	Diversion (10^4m^3)	Consumption (10^4m^3)	Losses (10^4m^3)	Permit (10^4m^3)	Current ABS (10^4m^3)
							River Sluice to 4th sluice	4th sluice	River Sluice	4th sluice	River Sluice to 4th sluice	River Gate	River Gate
							Average conveyance efficiency from 4th sluice to field 0.80						
							Average crop water requirement 370m³/mu						
一	Mugan								**1798.88**	**1553.61**	**245.27**		
1		南岸干渠	一支渠	工委渠	东红柳	2373.6	0.890	463	123.40	109.78	13.62		
2		南岸干渠	一支渠	补格退渠	东红柳	7740.0	0.890	463	402.38	357.98	44.41		
3		南岸干渠	一支渠		东红柳	10836.0	0.853	463	587.58	501.17	86.42		
4		牧业分干			五大队	4214.0	0.853	463	228.51	194.90	33.61		
5		牧业分干			五大队	2580.0	0.853	463	139.90	119.33	20.58		
6		牧业分干		沙壕渠	五大队	2752.0	0.853	463	149.23	127.28	21.95		
7		牧业分干		木瑞渠	五大队	2442.4	0.853	463	132.44	112.96	19.48		
8		牧业分干		牧干渠渠梢	五大队	653.6	0.853	463	35.44	30.23	5.21		
二	Balahai								**2709.64**	**2213.08**	**496.56**		
1		南岸干渠	一支渠	四连	东红柳	7052.0	0.860	463	379.04	326.16	52.89		
2		南岸干渠	二支渠		东红柳	14551.2	0.823	463	818.21	672.99	145.22		
3		南岸干渠	二支渠		东红柳	5504.0	0.823	463	309.49	254.56	54.93		
4		南岸干渠	林场渠		林场	6192.0	0.824	463	347.44	286.38	61.06		
5		南岸干渠	林场渠	林场斗渠	林场	4816.0	0.824	463	270.23	222.74	47.49		
6		南岸干渠	林场渠	一大队斗渠	巴音温都子	2580.0	0.824	463	144.77	119.33	25.44		
7		南岸干渠	马头湾支渠		巴音温都子	3612.0	0.775	463	215.42	167.06	48.36		
8		南岸干渠	红泥圪台南一支			3543.2	0.728	463	225.03	163.87	61.15		
三	Jianshe								**18544.64**	**11025.63**	**7519.01**		
1			乌兰宿亥支渠		黄介壕	2683.2	0.672	463	184.69	124.10	60.59		
2			黄介壕支渠		黄介壕	2408.0	0.672	463	165.75	111.37	54.38		

3			黄介壕支渠		黄介壕	1892.0	0.672	463	130.23	87.51	42.72		
4			黄介壕支渠		黄介壕	2408.0	0.672	463	165.75	111.37	54.38		
5				六八渠	麻迷图	10320.0	0.656	463	727.69	477.30	250.39		
6		建设分干	光兴一社		光兴村	2356.4	0.641	463	170.03	108.98	61.05		
7		建设分干	光兴二社		光兴村	2029.6	0.640	463	146.69	93.87	52.82		
8		建设分干	光兴三社		光兴村	2562.8	0.644	463	184.16	118.53	65.63		
9		建设分干	农场渠		农场村	13760.0	0.635	463	1001.83	636.40	365.43		
10		建设分干	白音南支		白音村	3784.0	0.619	463	282.80	175.01	107.79		
11		建设分干	白音北支		白音村	4300.0	0.618	463	321.55	198.88	122.67		
12		建设分干	中和渠		五苗村	36980.0	0.606	463	2821.57	1710.33	1111.25		
13			建设渠	一直斗	光茂村	3078.8	0.613	463	232.45	142.39	90.06		
14		建设分干	中和渠		三苗村	4798.8	0.592	463	375.12	221.94	153.18		
15		建设分干	光茂渠		光茂村	5951.2	0.613	463	449.32	275.24	174.08		
16		南岸干渠	民爱南一支渠		改改召	20605.6	0.597	463	1596.64	953.01	643.63		
17		南岸干渠	民爱南二支渠		光永村	19659.6	0.602	463	1510.76	909.26	601.50		
18		南岸干渠	民爱南二支渠		光永村	19470.4	0.602	463	1496.22	900.51	595.71		
19		建设分干	光前南支渠		光前村	14052.4	0.592	463	1098.48	649.92	448.56		
20		建设分干	光前北支渠		光前村	6123.2	0.598	463	473.88	283.20	190.68		
21		南岸干渠	红旗支渠		红旗村	8651.6	0.542	463	737.92	400.14	337.79		
22			建设渠	乃玛代斗渠	乃玛代村	4919.2	0.538	463	422.85	227.51	195.34		
23			永胜支渠		苏卜盖	4351.6	0.520	463	386.83	201.26	185.56		
24			杨树直拨渠		苏卜盖	3784.0	0.520	463	336.37	175.01	161.36		
25			苏卜盖支渠		苏卜盖	10320.0	0.520	463	917.37	477.30	440.07		
26				碱贵直斗	一大队	23529.6	0.574	463	1897.21	1088.24	808.97		
27		南岸干渠	红五渠		乃玛代村	3612.0	0.538	463	310.48	167.06	143.43		
	Total					**319834.0**			**22527.38**	**14324.57**	**8202.81**	**24500.00**	**23240.00**

Notes: Figures highlighted in blue are totals. The current gross diversion limit at the river sluice is 280 million m^3 per year, including 35 million m^3 of return water; the return water is not included in the table. The difference between the allowable net diversion of 245 million m^3 per year and the modelling recommendation of 225 million m^3 per year could be used to irrigate additional land made irrigable under the land improvement programme. Data highlighted in purple for GuangXin WUA is used in Section 5.3 to illustrate water certificate and accounting procedures.

Table 41: Typical crops and crop water requirements in HID

Crops	Crop area (%)	Average field requirement (m³/mu)	WUA requirement (m³/mu at 4th sluice)
Wheal	2	340	465
Corn	21	240	330
Corn (Silage)	5	160	220
Pasture	10	230	310
Liquorice	10	80	110
Sunflower	18	160	220
Oil sunflower (Hot water)	20	240	325
Oil sunflower	12	140	190
Pythium	2	70	95
Average summer irrigation	15	100	136
Average autumn irrigation	100	105	140
Total	**115**	**311**	**421**

Source: HIMB. Note: figures quoted are average (annual) figures.

Table 42: Channel efficiencies in HID

Irrigation District	Conveyance efficiency		Conveyance efficiency		Averaged efficiencies	
	From the River Gate to 3rd canals		*In the field(4th and 5th canals)*		*Total*	
	Currently	After lining	Currently	After lining	Currently	After lining
Gravity	0.348	0.636	0.7	0.85	0.24	0.54
Pumped	0.500	0.690	0.72	0.90	0.36	0.62

Source: Yellow River Water Trading Plan, Inner Mongolia (2003), Erdos WRD.

Thirdly, *main channel efficiencies were estimated*, based on channel level (first, second and third level) and length, to give an average conveyance efficiency from the river sluice to each fourth level sluice, and therefore each WUA. Unlike the average fourth and fifth channel figure applied for all WUAs above, these figures are specific to each fourth level sluice and WUA. These data then allow estimates to be made of diversions required from the main ID gate into first, second and third level channels allowing for losses through the upper level network. Water losses up to fourth level sluices are also given in Table 40.

A representation of the irrigation canals is show in Figure 37 highlighting annual *unit area water requirements*.

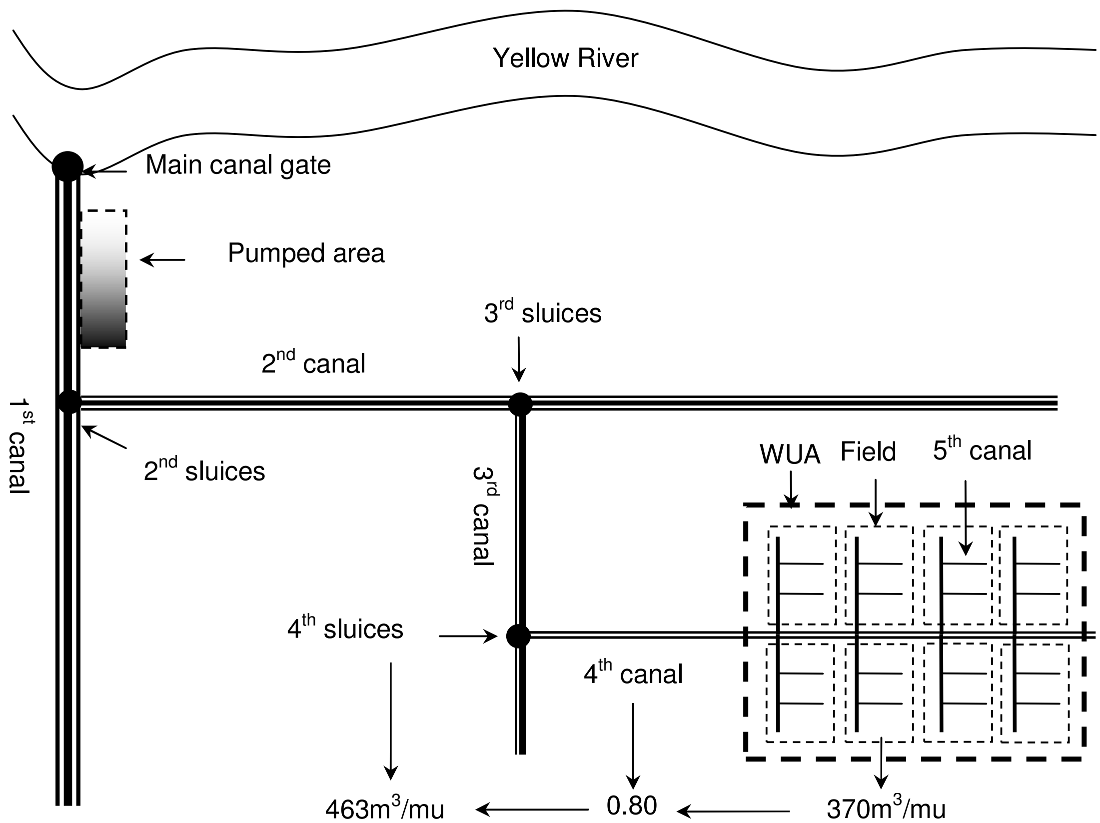
5.2.2 Key findings

Using the methods and data outlined above, it is possible calculate some total figures. These are also presented in Table 40.

- The combined irrigated area of all 43 WUAs in the gravity flow section of HID is estimated at 319,834 mu (21,322 ha).
- The total volume of water that needs to be delivered to fourth level sluices (and therefore WUAs), after subtracting losses in the canals above, is estimated at 143.246 million m^3/year.
- The total volume of water that needs to be diverted from the Yellow River to meet WUA requirements and cover conveyance losses is 225.274 million m^3/year.

- Total losses in the channels above fourth level sluices are estimated at 82.028 million m^3/year. Since losses in each channel have now been estimated, future conservation efforts – including trading in transmission savings – can be better targeted and quantified.

Figure 37: Irrigation canal layout and water use



The current river diversion allowed for HID, following the water transfer project, is 280 million m^3/year (see Section 3.2). This includes a mandated return flow of 35 million m^3, giving a 'net' diversion for the ID of 245 million m^3/year. This is approximately 20 million m^3 more than the net ID requirement of 225 million m^3/year estimated from the modelling, providing an opportunity to allocate the surplus to new agricultural land in a way that is transparent and fair. However, this will depend on whether the ID receives its full, permitted entitlement. In 2006-07, the ID received a net diversion of 206 million m^3 under the YRCC's *Annual Regulation Plan*[65].

5.2.3 Recommendations

Drawing on these data, we propose that modelling results are used to define the long term water rights of each WUA in HID in the form of GWEs, issued as water certificates. In contrast to the current farmer-driven approach to estimating water needs in the ID, therefore, modelling provides a scientifically-sound basis for capping rights within the

[65] The 2006-07 Plan reduced the allowable net diversion by 16%.

overall allowance of the ID, and for accounting for all transmission losses through main and branch channels to WUAs. More specifically, we propose that:

- The GWEs defined above form the basis for rights reform in the ID, including water use planning and scheduling, risk management and contingency planning.
- Group Water Entitlements should be given legal basis by government so that rights can be legally asserted and defended, and provide greater water security to WUAs (and farmers).
- Entitlement-based allocation planning underpins future water conservation efforts and the development of a modern, socialist countryside.

5.3 Water certification and ticketing system

The existing water ticketing system provides a clear, rules-based procedure for allocating water to WUAs, and to the farmers within them. However, the system is 'open-ended' in that the area-based demands of farmers are not capped in any way at the level of the WUA; farmers get what they pay for, as long as the combined demands of all WUAs can be met within the ID permit, or with available supply.

To implement a water rights system in which rights are volumetrically defined and limited, much can be learned from the experience of projects in Shiyanghe and Heihe Basins. Here, water certificates are combined with water tickets so that water sales are volumetrically capped. In the following sub-sections, we describe a proposal for a similar system in Hangjin in terms of functions, targets and operation rules.

5.3.1 The functions and uses of water certificates

A system of water certificates can be used to formalise the rights of WUAs, providing information on long-term rights (defined by GWEs), annual water entitlements (defined by available supply in any given year) and the water purchased in each irrigation period. In addition, the system can provide information on any water transactions that have occurred between WUAs, and between WUAs and HIMB.

To establish and operate such a system, the following steps are proposed:

- After an initial water rights allocation process, HIMB will grant rights to each WUA in the form of a water certificate. This will show the WUA's *long term water right* (the GWE).
- At the beginning of each year, HIMB will calculate the proportional water share that each WUA is entitled to (an *annual entitlement*) based on expected water availability in that year.
- Before each irrigation HIMB will adjust, as necessary, each WUA's annual entitlement in light of predicted supply to give a corresponding water purchase limit for all remaining irrigation periods. The purchase limit will be recorded on each water certificate.
- After purchasing water tickets in any given irrigation period, the purchase amount will be recorded on the certificate to calculate the remaining purchase allowance, or entitlement, for the next period. In other words, a process of continuous water accounting is adopted between irrigation periods.
- Any water trading will be recorded by the relevant section office on the water certificates of both buyer and seller. Trading with other sections will also be

checked and registered with HIMB. Certificates will also show actual water deliveries after trading.

After a reasonable period of operation (say 5-10 years), HIMB can review certificates in light of actual water use and trading experience, and revise as necessary. Following any long term trade of water rights, HIMB can take back old certificates and issue new ones after thorough auditing and recording.

Table 43 provides a summary of certificate functions and uses.

Table 43: Function and uses of water certificates

Function	Use
Voucher for long term rights	HIMB records each WUA's long-term water rights (GWEs) in a water certificate.
Calculation of purchase limits	At the beginning of the year, HIMB calculates the water purchase limit (annual entitlement) of each WUA and records this information on the certificate. After purchasing tickets in each irrigation period, the purchase amount will be recorded on the certificate to calculate the remaining purchase limit for the following periods. WUAs can purchase tickets beneath the limit.
Record of water trading	HIMB section offices record all information on water transactions.
Reference for water rights reallocation	HIMB will accumulate data on actual water use across seasons and between years, helping to guide any future adjustment.

5.3.2 The function and use of water tickets

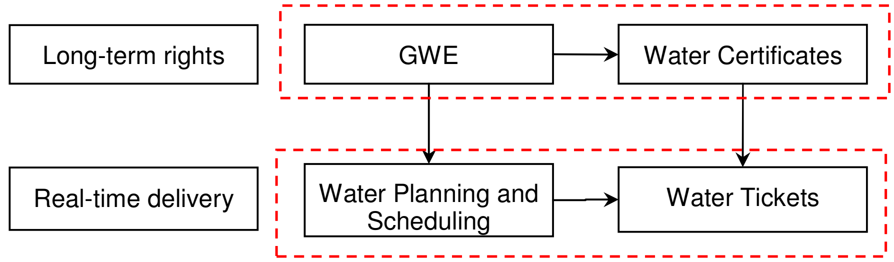
Water tickets provide the basis for water purchase, water delivery and water trading within prescribed limits. The ticketing system can ensure that both WUAs and HIMB offices have clear information on prices, deliveries and volumetric rights, allowing WUAs to trade savings freely. WUAs would buy water tickets according to their water certificates before each irrigation based on existing pre-payment procedures. WUAs can then purchase extra water from those WUAs that have decided not to use their allowance. Trading would occur freely within ID sections in any given irrigation period.

Table 44 provides a summary of the functions and uses of water tickets. Figure 38 illustrates the relationship between long-term rights, defined in water certificates, and real-time deliveries organised through water tickets.

Table 44: Function and uses of water tickets

Function	Use
Support for permit control and quota management	WUAs buy tickets under their caps; HIMB sells tickets according to water availability and water rights limits.
Pre-payment for water	Water is only supplied by HIMB once WUAs have purchased tickets.
Water trading and monitoring	WUAs can buy and sell 'saved' tickets; HIMB monitors ticket turnover and adjusts caps as necessary.
Payment voucher – rights and duties	Tickets provide information on GWEs, actual delivery and payment – a summary of entitlement and payment obligation.

Figure 38: Relationship between water certificates and water tickets



5.3.3 Operational rules

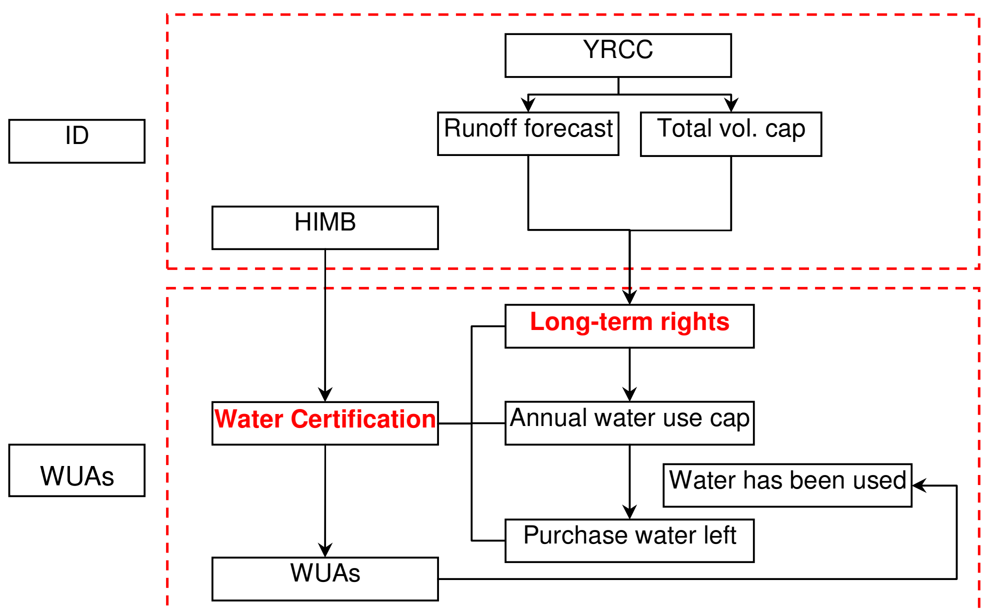
The operational relationships between long-term rights (WUA-GWEs), annually defined rights (WUA annual entitlements), water ticketing and irrigation scheduling are discussed in more detail below.

Water rights and water certificates

The allocation process, illustrated in Figure 39, begins with HIMB issuing certificates and calculating annual entitlements:

- After the initial water rights allocation, HIMB issues certificates to each WUA summarising their long term water rights (GWEs). Certificates are lodged with the WUA chairman – the WUA's legal representative;
- Before the first spring irrigation, HIMB estimates the proportional water shares that each WUA is entitled to (annual entitlements), based on the long term GWEs of each WUA and estimated water availability in the year ahead (based on the YRCC's *Annual Allocation Plan* and *Annual Regulation Plan*).

Figure 39: Water certificates and annual entitlements

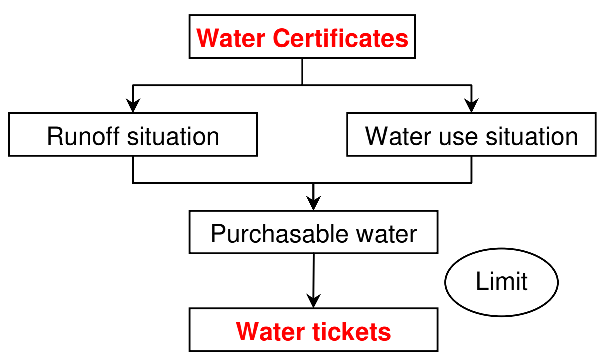


Water certificates and water tickets

Water use planning can then begin, based on water availability, the submission of WUA needs (plans) for each period and purchase of water tickets (Figure 40):

- Prior to each irrigation period, each WUA's annual entitlements are adjusted as necessary to reflect expected supply for remaining irrigation periods, with each WUA receiving a proportional share under the 'rational decrease' formula (see Section 5.4). This gives each WUA a water purchase limit for all remaining irrigation periods once previous purchases have been subtracted.
- WUAs then submit their draft water plans for the forthcoming period to HIMB Section Offices. If all needs can be met for this period, and WUA demands fall within the purchase limits defined above, WUAs can purchase tickets up to the planned volume. If water supply to the ID at that time is insufficient, however (e.g. because of supply restrictions imposed under YRCC's *Annual Regulation Plan*), WUA demands will be revised downwards through the 'rational decrease' formula until demand and supply within the ID balances. Conversely, if water supply exceeds expectations, WUAs would be allowed to purchase 'extra' tickets (to use or sell), above their draft volume. In both cases, WUAs would be required to re-submit an adjusted (downward or upward) water plan for final approval, indicating any planned trades.
- The volumetric tickets purchased by a WUA for any given irrigation period therefore reflect its (adjusted) annual entitlement for all remaining periods, the volume of water purchased in previous periods, the plan it submits to HIMB *based on the above* and, lastly, actual water availability for the forthcoming period.

Figure 40: Water certificates, annual entitlements and tickets



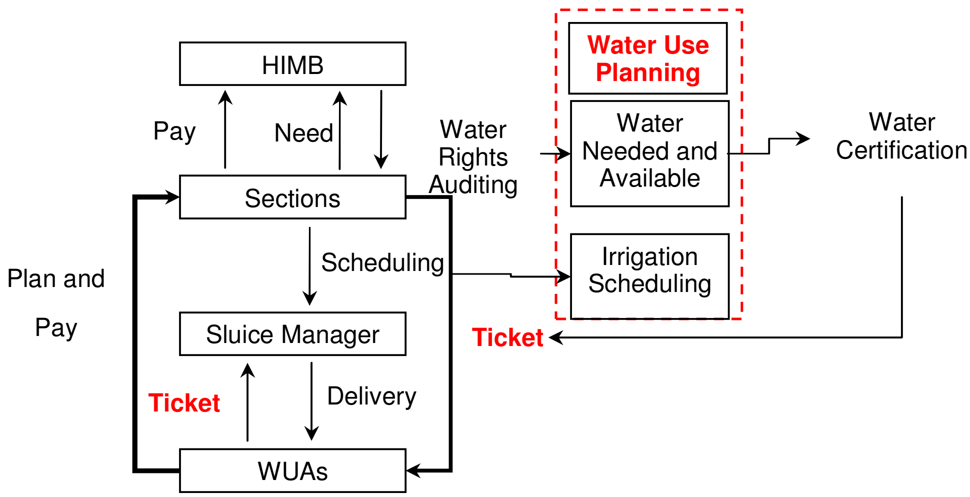
Water tickets and water planning

Once HIMB has calculated the amount of water remaining for each WUA in any given period and checked the draft water use plans submitted by WUAs (and, if necessary, asked for revisions), WUAs can purchase what they need within the limits set by the annual entitlement (Figure 41), previous use and actual water availability for that period. Specifically:

- HIMB would collate the plans of all WUAs and, once adjusted and finalised as necessary, would prepare an irrigation schedule for the whole ID. This would need to reflect any trading planned between WUAs prior to finalisation.

- WUAs would then be able to purchase tickets (to use or sell-on) up to the volumes agreed with HIMB. Section Offices, under the direction of the Bureau, would provide prior notice to WUAs of the timing and volume of water deliveries. Deliveries would be supervised and signed-off by both the WUA chairman and the HIMB section office as they are now.
- If a WUA received less water than it had planned and paid for (e.g. if an emergency restriction occurred after a WUA had submitted its revised plan *and* bought tickets), the WUA could 'sell-back' the volumetric difference to HIMB at a premium[66] (e.g. 120% of the purchase price), or carry-over this undelivered volume to the next irrigation period (Figure 42).
- As noted previously, a WUA could purchase tickets above its draft plan limit (to use or sell) if water availability in the ID exceeded expectations. In this case, the WUA could submit a revised plan for more water, but the WUA would not be able to sell any unused tickets back to HIMB at a guaranteed premium.

Figure 41: Water use planning – normal situation



5.3.4 Water certificate, ticket and accounting illustrations

In this sub-section, we illustrate the kind of information that could be included on a water certificate, water accounting procedures for calculating WUA entitlements in different irrigation periods, and accounting procedures for ticket-based trading.

Table 45 illustrates what a water certificate might look like, using GuangXing WUA in Jianshe section as an example. The GWE for this WUA has been estimated at 108 $10^4 m^3$ (see highlighted row in Table 40). The certificate would normally show a single, annual entitlement for the coming year. In this case, however, three entitlements are specified to illustrate how the entitlement might differ in normal, wet and dry years. In a dry year, for example, the entitlement is likely to be lower because of supply restrictions imposed by the YRCC.

[66] The premium would, in effect, penalise HIMB for not meeting its agreed delivery obligations.

Figure 42: Water use planning – emergency situation

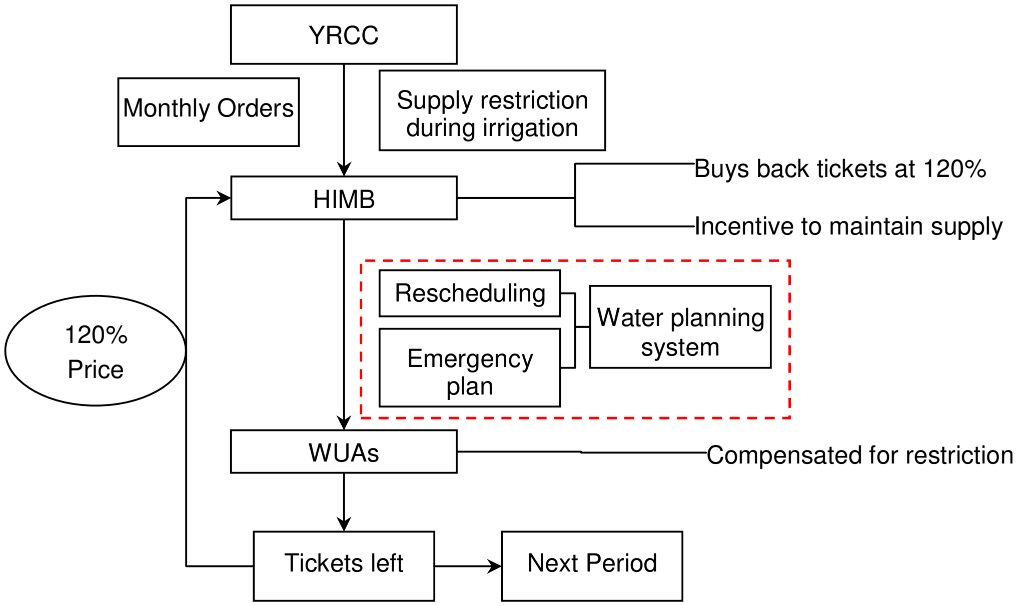


Table 45: Water certificate illustration, GuangXing WUA

Reference number: 3-6		Name of WUA: GuangXingYiShe
Village: GuangXing		Chairman:
Population:		
Quota (m^3)	463	
Irrigated area (mu)	2356	
Water price (Yuan/m^3)	0.054	
GWE (10^4m^3)	108	
Annual entitlement (10^4m^3) - examples	Wet year	120
	Normal year	108
	Dry year	80
Gate: 1st sluice in Jianshe section		

In practice, the annual entitlement is likely to vary over the course of a year, as well as between years. As noted previously, this is because adjustments may need to be made to reflect changing water diversions to the ID. Adjustments could be recorded on separate sheets attached to the front page in Table 45

Baseline scenario

At the beginning of the year the annual entitlement of the GuangXing WUA is calculated as 108 10^4m^3, based on the water availability estimate issued by the YRCC, shared among all WUAs. In this scenario, we assume that no further adjustments are made to the annual entitlement during the year through YRCC's Annual Regulation Plan.

Based on this information, the WUA submits its water use plan to the HIMB section office before the first spring irrigation, and this is approved (along with all other WUA plans) with no further revisions. HIMB can then prepare and finalise a water scheduling plan based on the final plans of all WUAs and actual water availability. GuangXing WUA then buys and uses the planned amount of 21 10^4m^3, leaving a total 87 10^4m^3 available for the following irrigation periods (assuming there are no supply restrictions). The water accounting process is illustrated in Table 46.

Table 46: Water accounting, GuangXing WUA: baseline scenario

GuangXing WUA	Irrigation period				
	1st	2nd	3rd	4th	Total
Annual entitlement (10^4m^3)	108	108	108	108	
Water demanded (planed) (10^4m^3)	21	21	21	45	108
Water purchased (10^4Yuan)	21*Y0.054	21*Y0.054	21*Y0.054	45*Y0.054	108
Water delivered (10^4m^3)	21	21	21	45	108
Entitlement: current period (10^4m^3)	108	108-21=87	108-21-21=66	108-21-21-21=45	
Ticket value left (10^4Yuan)	0	0	0	0	0
Ticket value sold (10^4Yuan)	0	0	0	0	0
Volumetric sales (10^4Yuan)	0	0	0	0	0
Remaining entitlement: next period (10^4m^3)	108-21=87	87-21=66	66-21=45	45-45=0	
Signatures: WUA Chairman: HIMB Section:					

Prior to the second and third irrigation periods the same procedure is followed, with GuangXing's 'carry-over' entitlement monitored and recorded at each stage. For the final (fourth) irrigation, the WUA has left itself with generous 45 10^4m^3, as most farmers in the village are growing sunflowers that require a major autumn irrigation. The WUA purchases and uses the final part of its volumetric entitlement.

Drought scenario 1: emergency plan, no trade

In this scenario, the entitlement of the WUA is again calculated as 108 10^4m^3 at the beginning of the year. However, the annual entitlement is adjusted during the year as ID supply changes, and therefore accounting procedures (Table 47) differ.

As before, the WUA plans, pays for and uses 21 10^4m^3 for the first and second irrigations, leaving a total 66 10^4m^3 available for the following two periods (assuming no supply restrictions). Before the third period, however, the YRCC revises its estimate of annual water availability for the ID downwards, leaving the WUA with a revised annual entitlement of 80 10^4m^3. Since the WUA has already used 42 10^4m^3, a total of 38 10^4m^3 remain for the third and fourth irrigations (assuming no further supply restrictions).

For the third irrigation, the WUA plans and pays for another 21 10^4m^3. However, a restriction imposed by the YRCC at short notice forces HIMB to cut back supply to the WUA to 16 10^4m^3 under its emergency plan. This leaves a total of 22 10^4m^3 (38 minus 16 10^4m^3) available for the final irrigation (assuming no further quota restrictions), including 5 10^4m^3 that has already been paid for, and carried over from, the third period.

For the fourth irrigation, a further reduction in the WUA's annual entitlement to 70 10^4m^3 restricts its final allowance to 12 10^4m^3 (70 10^4m^3 minus the 58 10^4m^3 already delivered). Of this, 5 10^4m^3 has already been paid for and carried over from the third period, so the WUA need only purchase tickets to the value of 7 10^4m^3*RMB 0.054. If this water cannot be delivered by HIMB, there would be no carry-over to the following year. Instead, the WUA would be entitled to 'cash-back' on its unused tickets.

Table 47: Water accounting, GuangXing WUA: drought scenario 1

GuangXing WUA	**Irrigation period**				
	1st	**2nd**	**3rd**	**4th**	**Total**
Annual entitlement (10^4m^3)	108	108	80	70	
Water demanded (planned) (10^4m^3)	21	21	21	12	75
Water purchased (10^4Yuan)	21*0.054	21*0.054	21*0.054	7*0.054	70
Water delivered (10^4m^3)	21	21	16	12	70
Entitlement: current period (10^4m^3)	108	108-21=87	80-21-21=38	70-21-21-16=12	
Ticket value left (10^4Yuan)	0	0	(21-16=5) *0.054	0	0
Ticket value sold (10^4Yuan)	0	0	0	0	0
Volumetric sales (10^4Yuan)	0	0	0	0	0
Remaining entitlement: next period (10^4m^3)	108-21=87	87-21=66	38-21+5=22	0	
Signatures: **WUA Chairman:** **HIMB Section:**					

Drought scenario 2: emergency plan, water trading

An alternative scenario, illustrated in Table 48, would involve the WUA selling back its 5 10^4m^3 of planned, paid for but undelivered water to HIMB at a premium, leaving the WUA with 7 10^4m^3 for the final irrigation. Alternatively, the WUA might be able to sell this water to another WUA, with the transaction brokered by HIMB.

The same trading outcome could also be achieved if the WUA had undertaken water saving measures to reduce its water demand from 21 to 16 10^4m^3, generating 5 10^4m^3 of tradable water for sale to other WUAs or HIMB.

High rainfall scenario: extra ticket purchase, trade

Finally, Table 49 illustrates a water accounting scenario in which estimates of annual water availability are revised *upwards* by the YRCC because of high rainfall and flood conditions prior to the second irrigation.

The result in this case is that forecasted supply (the annual entitlement) increases from 108 to 130 10^4m^3, exceeding the initial expectations of both HIMB and the WUA (which has already submitted a draft plan). The remaining entitlement of the WUA, calculated at the beginning of the second irrigation period, then becomes 109 10^4m^3 (130 minus 21 10^4m^3). The WUA then buys and uses a further 21 10^4m^3, according to its original plan. In addition, however, the WUA purchases an additional 10 10^4m^3 for sale to other WUAs (outlined in a final, revised plan), bringing its total purchase up to 31 10^4m^3 * Y0.054.

In these circumstances, the WUA bears the risk of buying tickets it does not need for its own use; it cannot sell them back to HIMB, or carry the undelivered volume to the next irrigation period.

Table 48: Water accounting, GuangXin WUA: drought scenario 2

GuangXing WUA	Irrigation period				
	1st	2nd	3rd	4th	Total
Annual entitlement (10^4m^3)	108	108	80	70	
Water demanded (planned) (10^4m^3)	21	21	21	7	70
Water purchased (10^4Yuan)	21*0.054	21*0.054	21*0.054	7*0.054	70
Water delivered (10^4m^3)	21	21	16	7	65
Entitlement: current period (10^4m^3)	108	108-21=87	80-21-21=38	70-21-21-16=12	
Ticket value left (10^4Yuan)	0	0	(21-16=5) *0.054	0	0
Ticket value sold (10^4Yuan)	0	0	5*(0.054*120%)	0	5
Volumetric sales (10^4Yuan)	0	0	5	0	5
Remaining entitlement: next period (10^4m^3)	108-21=87	87-21=66	38-16-5=17	0	
Signatures: **WUA Chairman:** **HIMB Section:**					

Table 49: Water accounting, GuangXing WUA: high rainfall scenario

GuangXing WUA	Irrigation period				
	1st	2nd	3rd	4th	Total
Annual entitlement (10^4m^3)	108	130	140	130	
Water demanded (planned)(10^4m^3)	21	21	21	45	108
Water purchased (10^4Yuan)	21*0.054	31*0.054	21*0.054	45*0.054	130
Water delivered (10^4m^3)	21	21	21	45	120
Entitlement: current period (10^4m^3)	108	130-21=109	140-21-31=88	130-21-31-21=57	
Ticket value left (10^4Yuan)	0	10*0.054	0	0	0
Ticket value sold (10^4Yuan)	0	10*(0.054*X%)	0	0	0
Volumetric sales (10^4Yuan)	0	10	0	0	10
Remaining entitlement: next period (10^4m^3)	108-21=87	109-31=78	88-21=67	0	
Signatures: **WUA Chairman:** **HIMB Section:**					

5.3.5 Changes to service contracts

As noted in Section 3.4.2, WUAs enter into seasonal contracts with HIMB section offices for the payment, delivery and monitoring of water delivered to fourth channel gates. For the new functions described above, we propose an additional 'one certification' clause (underlined below), modifying HIMB's Management Guidelines as follows:

Article 8: Water allocation is based on the payment of water fees, paid prior to each irrigation. Payments are made on a 'one certificate, one contract, one ticket, one table and one notice' basis.

'One certificate' is the water certificate for recording a WUAs long-term water rights; 'one contract' refers to the purchase of a water ticket by a WUA from the relevant Station under HIMB; 'one ticket' refers to the pre-purchased water ticket specifying the quantity of water demanded by each WUA prior to each irrigation period; 'one table' refers to the water fee calculation table that is used to calculate the water fee payable by the WUA on a particular day, and the quantity of water that will therefore be released through the gate; and 'one notice' refers to the notice that is publicly displayed afterwards showing the water volume received and the fee paid by each WUA, and acceptance by WUAs of monitoring and supervision arrangements for delivery. In addition, each WUA is obliged to openly record the irrigated area and fee payment of each water user.

5.3.6 Water ticket design

Figure 43 illustrates the current water tickets used in HID. These are effectively receipts for delivery and payment. We propose that tickets are revised to look more like money (Figure 44), and therefore a right to purchase a specific volume of water.

Figure 43: Current water ticket

Figure 44: Modified water ticket proposed for HID

5.4 Water planning and irrigation scheduling

The study has developed a model-based planning system for allocating the rights described above between and within irrigation periods. The objective is to replace the current manual planning system in Hangjin with a computer-based model that can balance demand and supply, guide water allocation between WUAs and help manage real-time water rights in a quick and transparent manner.

The section begins with a discussion of the planning principles that underpin the model, and the need to ensure adaptability to changing socio-economic conditions. The model is then described in detail, and its data requirements, assumptions and outputs are discussed.

5.4.1 Planning principles and context

The water planning system takes the GWEs defined previously as a starting point, and then translates them into a real-time water schedule for WUAs. In so doing, the following points are observed:

- According to “user claim and rational decrease” principle, each WUA articulates its water demand to HIMB prior to each irrigation period (the ‘claim’). If the total demand of all WUAs can be supplied for any given period, then HIMB can authorise full delivery. If demand cannot be satisfied, however, HIMB will allocate proportional shares of demand to each WUA to balance demand and supply (the ‘rational decrease’) – see below.
- Each WUA is therefore free to decide how much water it wants for each period, but the annual sum of its demands cannot exceed the long-term rights assigned to it, and its seasonal purchase must reflect actual water availability in the ID at that time. This is because allocation in any given period has to account for the effects of monthly scheduling and real-time operations under the YRCC’s *Annual Regulation Plan* (see Section 3.4). These may affect, at short notice, diversions to HID, particularly during the dry season.
- The irrigation schedule for each irrigation period is determined by the location and flow properties of each channel. The planning system ensures that each section receives a continuous flow during each irrigation period.

It is also worth noting that planning may need to accommodate changes happening within the ID that might affect demand-supply conditions. For example:

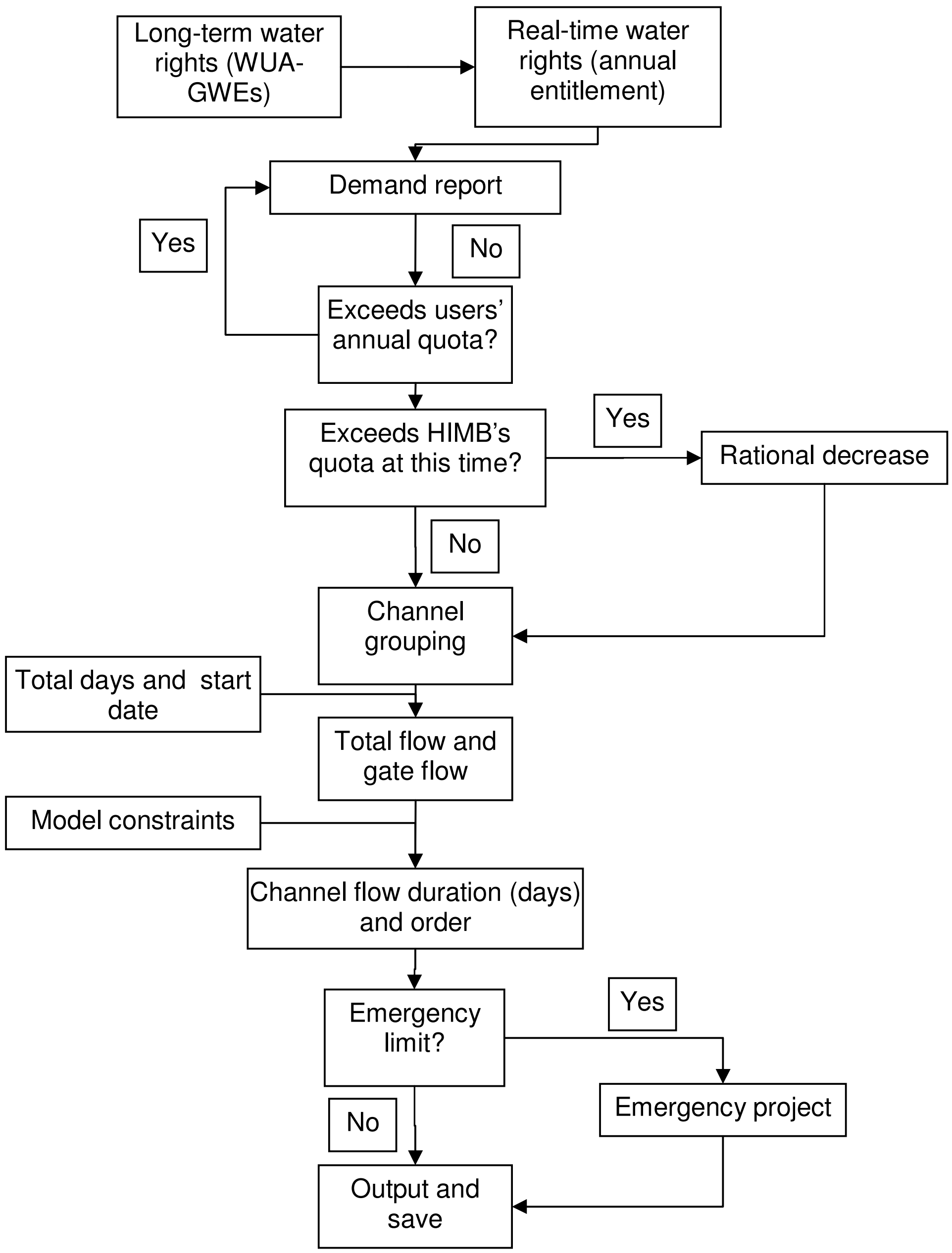
- Land improvement and/or technical change in existing irrigated areas that generates water savings.
- Land improvement that leads to an expansion in the irrigated area and increases water demand.
- Water transfer out of the district.

In these circumstances, the volumetrically-defined rights of WUAs might need to be adjusted. For example, caps could be lowered to either reflect savings that have already been made, or to help stimulate more water-efficient practices and cropping patterns where needed, possibly in tandem with technical assistance (see Section 4.2 for further discussion).

5.4.2 Modelling

The water planning model for the ID is illustrated in Figure 45. The flow chart shows how, before each irrigation period, WUAs report their desired water demands to HIMB. The HIMB can then compare demands with availability (total demand vs ID supply; WUA demand vs WUA annual entitlement), and allocate proportional shares as necessary (see box below).

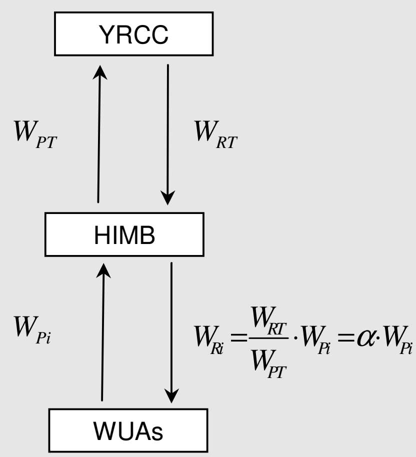
Figure 45: Water planning model



The "user claim - rational decrease" formula

If the total demand of all WUAs can be supplied in any one period, then HIMB can authorise full delivery according to the irrigation schedule produced by the planning model. If demand cannot be satisfied, the model will allocate proportional shares of demand to each WUA to balance overall demand and supply (the 'rational decrease') within the ID. The model does this by calculating the percentage reduction in supply (restricted supply/unrestricted supply for the ID), and applying the reduction to each WUA. If the restrictions imposed mean that the original irrigation schedule cannot be implemented, a new schedule is computed.

The formula used is as follows:



Where:

W_{RT} ---Restricted water volume for the ID

W_{PT} ---Planed water volume for the ID

W_{Ri} ---Restricted water volume for a WUA

W_{Pi} ---Planned water volume for a WUA

Following this, HIMB will decide on a start day and the duration of flow. HIMB can then distribute water according to the planned rotation within each section, and determine the time that each control gate needs to stay open. Programme 'outputs' can then be saved to disk.

Model details are summarised below:

Model object

- Branch channel gates

Model input

- WUA water demand
- Irrigation start date
- Irrigation duration (days)

Model variables

- Flow through branch channel gates
- Opening duration (days) of branch channel gates
- Opening date of branch channel gates

Model constraints

- The three ID sections are irrigated continuously and the duration of each irrigation is the same for each section.
- The total flow of water for each section remains constant during each period.
- The height of branch gates remains constant during each irrigation.
- Gate flow is equal to the total volume required at the lower gate plus conveyance losses
- Lower gates are adjusted first; the main gate is not adjusted during the irrigation period.
- Actual flows must not exceed design flows through channels and gates.
- Calculation of volumetric deliveries is based on flow duration and the channel properties of branch channels.
- Requests:
  a. Flows through branch channels are less than maximum design flows
  b. Branch channel flow remains unchanged.

Model outputs

- The flow, start date and opening duration of each gate in each irrigation period
- The flow through Nanan Gate, main channels and branch channels.

Model algorithm

- WUAs report their water demands to HIMB; HIMB checks availability against demand and rations if necessary;
- HIMB decides when irrigation will begin and how long it will last for;
- The opening and closure dates of all gates are determined, and water is allocated on a continuous basis to each of the three sections (but with rotation within). Allocation must satisfy the model constraints summarised above.
- An emergency module for allocating water under severe restrictions can be activated if needed (see below); and
- Results (model outputs) are saved to file.

Emergency programme

Although water availability within the ID is generally adequate (see Section 5.5), this may not always be the case. For example, growing urban and industrial demands may create further pressure for water transfer from agriculture, and global warming may increase the frequency of droughts. Contingency plans are therefore needed and have been incorporated in the water planning model in the form of an emergency module, based on the ‘rational decrease’ principle outlined above. The emergency module is designed to ensure that all WUAs receive some water, and that irrigation for smaller farms (concentrated in Mugan section) is prioritised.

The emergency module begins when the YRCC lowers the main gate of the ID (Nanan Gate). First, the module calculates the water reduction rate following closure (restricted supply/original supply). It then calculates the degree to which each WUA's demands have already been met (water supplied/water demanded) – a 'satisfaction' rate. If the satisfaction rate exceeds the water reduction rate, then no more water will be supplied to the WUA. If not, the WUA will continue to receive supplies according to the original schedule, but the volume will be reduced to the reduction rate. If a WUA has not irrigated when the restriction is imposed, irrigation for that WUA can be brought forward (at a reduced volume) to ensure that all WUAs receive some water:

$$\alpha_T = \frac{W_{RT}}{W_{PT}}; \beta_T = \frac{W_{ST}}{W_{PT}}$$

$$\alpha_i = \frac{W_{Ri}}{W_{Pi}}; \beta_i = \frac{W_{Si}}{W_{Pi}}$$

Where:

W_{ST} ---Water supplied to the ID

W_{Si} ---Water supplied to a WUA

If $\beta_i \leq \alpha_T$ then supply to WUA stopped

If $\beta_i \succ \alpha_T$ then continue with reduced supply to WUA

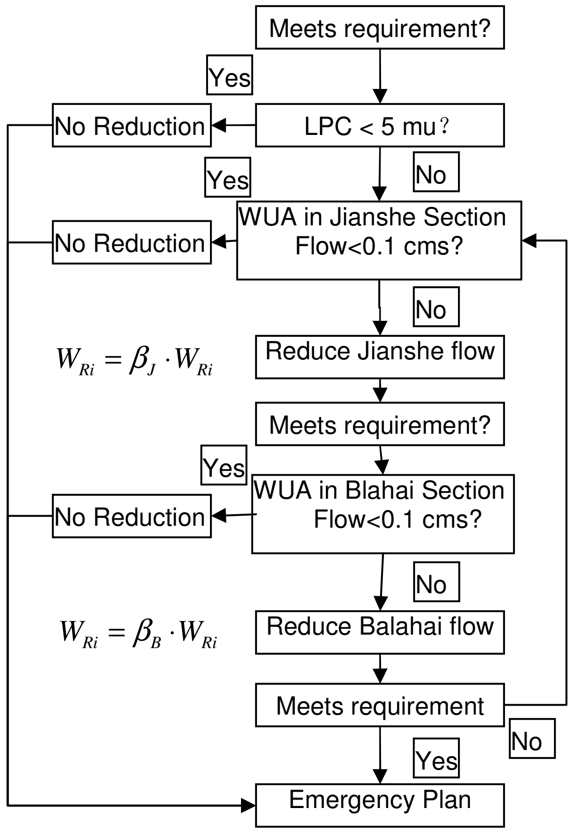
The emergency programme also ensures that water supply for small farms is prioritised. The model currently does this by prioritising water supply in Mugan section, where average per capita land holdings are less that 5 mu, over supply to Jianshe and Balahai. During a severe drought, therefore, water supply to Mugan would be maintained (at a reduced level) by firstly diverting water from Jianshe (the largest of the three sections; the largest farms) and, if necessary, by diverting water from Jianshe *and* Balahai. The model could be developed further to prioritise individual WUAs with small (average) land holdings.

Prioritisation and decision-making criteria are illustrated in Figure 46.

5.4.3 Model interface and outputs

Figure 47 shows the entry interface of the Water Planning System – a diagram of the ID. Figure 48 illustrates the main interface, with links to all system inputs and outputs. The model has been designed to make data entry and outputs easy to use and understand. Table 50 shows the input interface for entering data on water demand before each irrigation. This can be completed by HIMB section offices on behalf of WUAs, and provides WUA-specific information on irrigated areas and water entitlements.

Figure 46: Prioritisation criteria under the emergency programme



Note: LPC is land area per capita; β_J is flow reduction rate to Jianshe; β_B is flow reduction rate to Balhai

Figure 47: Entry interface, water planning model

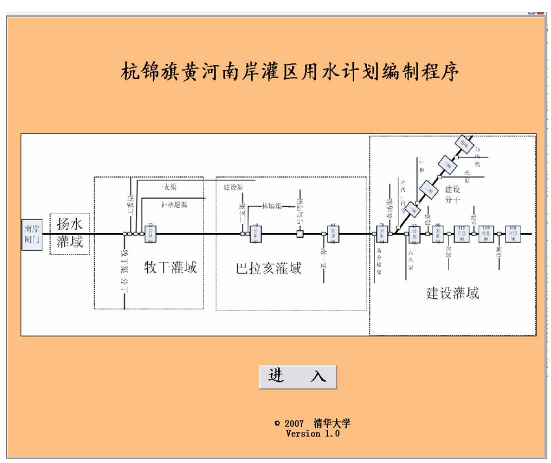


Figure 48: Main interface, water planning model

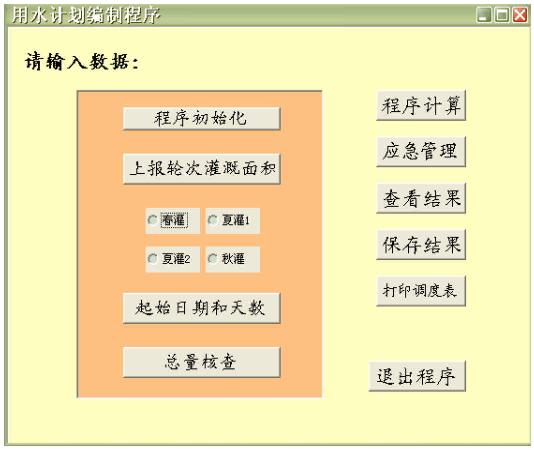


Table 51, Table 52 and Table 53 illustrate some model outputs that can be used by managers in HIMB to assist allocation planning and management. Table 51 shows a planning table for the whole ID. It includes flows at the gates from first and second level canals, and would help HIMB staff calculate the period of irrigation time according to the water demand of each section. The assumed flow from the second level canal gates is a total flow of several gates of each section. This table can be used to help control irrigation durations and gate flow at the first level canal in the irrigation period.

Table 52 shows a planning table covering each section of the ID. The table includes flows at the gates from the second canal. Each gate provides water to several WUAs. The table can help HIMB staff calculate irrigation durations according to flows at each gate. Based on the irrigation order of WUAs, it can guide staff in adjusting gates from the second level canal in terms of opening size and time. It is intended to cover the period 26th April to 15th May – the first irrigation in HID.

Table 53 provides data on the flows required at each gate to meet the allocation plan. After calculating transmission losses level by level, actual flows to each gate can be calculated. HIMB staff can check channel operation with reference to this table to ensure the water allocation plan is met.

5.4.4 Summary

The water planning system described above can be used to balance supply and demand and allocate proportionate shares of available supply to individual WUAs within their GWEs and annual water entitlements. It is also easy and quick to use, generating an allocation plan in only a few minutes. Perhaps its greatest advantage, however, is that it gives WUAs greater autonomy in determining their annual and seasonal plans, and builds on the existing water ticket system. In future, it could also be used as a basis for water trading.

Table 50: Input interface for WUA data

NO.	Section	Canals				Village	Irrigation Area (mu)	Irrigation Quota (m^3/mu)
		Main Canal	2nd Canal	3rd Canal	4th Canal			
一	牧干							465
1		南岸干渠		一支渠	工委渠	东红柳	2373.6	191.3
2		南岸干渠		一支渠	补格退渠	东红柳	7740.0	191.3
3		南岸干渠		一支渠		东红柳	10836.0	191.3
4			牧业分干			五大队	4214.0	191.3
5			牧业分干		北一支	五大队	2580.0	191.3
6			牧业分干		沙壕渠	五大队	2752.0	191.3
7			牧业分干		木瑞渠	五大队	2442.4	191.3
8			牧业分干		牧干渠渠梢	五大队	653.6	191.3
二	巴拉亥							191.3
1		南岸干渠		一支渠	四连	东红柳	7052.0	191.3
2		南岸干渠		二支渠		东红柳	14551.2	191.3
3		南岸干渠		二支渠		东红柳	5504.0	191.3
4		南岸干渠		林场渠	林场斗渠	林场	6192.0	191.3
5		南岸干渠		林场渠	林场场部斗渠	林场	4816.0	191.3
6		南岸干渠		林场渠	一大队斗渠	林场	2580.0	191.3
7		南岸干渠		马头湾支渠		巴音温都子嘎查	3612.0	191.3
8		南岸干渠		红泥圪台南一支		巴音温都子嘎查	3543.2	191.3
三	建设							191.3
1		南岸干渠		乌兰宿亥支渠		黄介壕	2683.2	191.3
2		南岸干渠		黄介壕支渠		黄介壕	2408.0	191.3
3		南岸干渠		黄介壕支渠		黄介壕	1892.0	191.3
4		南岸干渠		黄介壕支渠		黄介壕	2408.0	191.3
5		南岸干渠			六八渠	麻迷图	10320.0	191.3
6		南岸干渠		农场渠		农场村	13760.0	191.3
7			建设分干	光兴一社		光兴村	2356.4	191.3
8			建设分干	光兴二社		光兴村	2029.6	191.3
9			建设分干	光兴三社		光兴村	2562.8	191.3
10			建设分干	白音南支		白音村	3784.0	191.3
11			建设分干	白音北支		白音村	4300.0	191.3
12			建设分干	中和渠		五苗村	36980.0	191.3
13			建设分干	中和渠		三苗村	4798.8	191.3
14			建设分干		一直斗	光茂村	3078.8	191.3
15			建设分干	光前南支渠		光前村	14052.4	191.3
16			建设分干	光前北支渠		光前村	6123.2	191.3
17			建设分干		乃玛代斗渠	乃玛代村	4919.2	191.3
18		南岸干渠		光茂渠		光茂村	5951.2	191.3
19		南岸干渠		民爱南一支渠		改改召	20605.6	191.3
20		南岸干渠		民爱南二支渠		光永村	19659.6	191.3
21		南岸干渠		民爱南二支渠		光永村	19470.4	191.3
22		南岸干渠		红旗支渠		红旗村	8651.6	191.3
23		南岸干渠		红五渠		乃玛代村	3612.0	191.3
24		南岸干渠		永胜支渠		苏卜盖	4351.6	191.3
25		南岸干渠		杨树直拨渠		苏卜盖	3784.0	191.3
26		南岸干渠		苏卜盖支渠		苏卜盖	10320.0	191.3
27		南岸干渠			碱贵直斗	一大队	23529.6	191.3

Table 51: Water allocation plan (summary) for Hangjin Irrigation District

Hangjin ID Year Period							
Project	**Unit**	**Pump Area**	**Mugan**	**BaLahai**	**JianShe**	**Total**	**Notes**
Irrigation Area	10^4mu	0.5	3.4	4.8	23.8	32.483	
Irrigation Quota	m^3/mu						
Irrigation Times							
Irrigation Area*Times	10^4m^3						
Net Water Use							Net Water Use in 3rd canals
Efficiency in 3rd canal	10^4m^3	0.5	0.947	0.981	0.996		
Gross Water Use	m^3/s						In 3rd canals
Day-average Flow	day m^3/s	1	3	5.5	16	25.5	支渠口流量总和
Irrigation Dates	day						
Loss in 1st and 2nd	m^3/s	2	0.3	0.8	7.5	10.6	
Flow in 1st and 2nd	m^3/s	3	3.3	6.3	23.5	36.05	
Flow at Sluice	m^3/s	Nanan Sluice 36.0	22km Sluice 30.0	64km 24.0	83km 8		
Gross Water Use	10^4mu					0	In 1st and 2nd canals
Proportion	m^3/mu					100	

Table 52: Example irrigation schedule, Hangjin Irrigation District

Mugan Section

Sluice	Water	Flow m^3/s	Dates	Begin	End	September											October																			
						20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
工委渠	46.5712	0.6	9.09	07-9-20	07-9-29																															
补格退渠	151.8628	1.9	9.09	07-9-20	07-9-29																															
一支渠	210.6633	2.5	9.65	07-9-29	07-10-8																															
牧干渠	245.7738	2.5	11.26	07-10-8	07-10-20																															
Total Flow		7.6				2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

BaLahai Section

Sluice	Water	Flow m^3/s	Dates	Begin	End	September											October																			
						20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
建设渠	137.7162	1.1	15.17	07-9-20	07-10-5																															
二支渠	391.8122	3.1	14.83	07-10-5	07-10-20																															
林场渠	264.9062	2.0	15.17	07-9-20	07-10-5																															
马头湾渠	69.3918	0.5	14.83	07-10-5	07-10-20																															
南一支	69.2485	0.5	15.17	07-9-20	07-10-5																															
Total Flow		7.2				3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6

JianShe Section

Sluice	Water	Flow m^3/s	Dates	Begin	End	September											October																			
						20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
黄介壕	182.0146	0.7	30.00	07-9-20	07-10-20																															
六八渠	201.0403	1.8	12.62	07-9-20	07-10-2																															
农场渠	276.7916	1.8	17.38	07-10-2	07-10-20																															
一闸	288.8136	3.0	11.21	07-9-20	07-10-1																															
二闸	874.2731	3.4	30.00	07-9-20	07-10-20																															
三闸	389.7496	2.4	18.79	07-10-1	07-10-20																															
四闸	94.4822	0.6	18.79	07-10-1	07-10-20																															
96闸	1287.9573	5.0	30.00	07-9-20	07-10-20																															
112闸	236.7210	4.0	6.80	07-9-20	07-9-26																															
119闸	355.5737	4.0	10.22	07-9-26	07-10-7																															
138闸	451.9290	4.0	12.98	07-10-7	07-10-20																															
Total Flow		30.8				18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

Table 53: Example water flow table, Hangjin Irrigation District

Section	Canals	Sluices	Flow m³/s																														
			September											October																			
			20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
全灌域	干渠口	南岸闸	36.7	36.7	36.7	36.7	36.7	36.7	36.7	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	38.3	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5	38.5
牧干	支渠	工委渠	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		补格退渠	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		一支渠	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		牧干渠支渠总和	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	分干渠	牧干渠口	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
	干渠	22Km闸	33.5	33.5	33.5	33.5	33.5	33.5	33.5	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	34.9	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1
巴拉亥	支渠	建设渠	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		二支渠	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
		林场渠	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		马头湾渠	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
		六四十公里南一支	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	干渠	40Km闸	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	28.8	28.8	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9	29.9
	干渠	64Km闸	22.6	22.6	22.6	22.6	22.6	22.6	22.6	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.3	22.3	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2
建设	支渠	黄介壕	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
		六八渠	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		农场渠	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
		一闸(光兴、白音)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		二闸(中和)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
		三闸(光前)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
		四闸(乃玛代)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
		96Km闸(民爱)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
		112Km闸(红旗)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		119Km闸(永胜)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		138Km闸(碱柜)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
	分干上	建设一闸	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
		建设二闸	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
		建设三闸	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
		建设四闸	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	分干口	建设渠口	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
	干渠	78Km闸	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3
		83Km闸	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2
		96Km闸	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
		112Km闸	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
		119Km闸	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
		138Km闸	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0

5.5 The role of water user associations in rights reform

5.5.1 Experience and lesson-learning

Irrigation reform in China is designed to address a number of entrenched problems. These include a deterioration in the state of irrigation infrastructure, declines in irrigated area, inefficient water use and falls in agricultural productivity. A key element of reform is the promotion of WUAs, conceived as farmer run, participatory institutions that take the place of village leader-run water control organisations or government agencies, and take over management of water allocation and infrastructure management at a local level.[67] WUAs are registered as legal entities under Chinese Company Law.

The specific logic of such reforms runs as follows:[68]

- Government bureaucracies lack the incentives, knowledge and flexibility to manage water at a local (lateral canal) level. In contrast, farmers have a direct interest in enhancing and sustaining the quality, cost-effectiveness and local equity of irrigation, assuming they are provided with the authority and incentives to act collectively.
- Management 'transfer' to WUAs will save money for the government as it divests itself of the responsibility to finance the costs of O&M within areas turned over to WUAs, and of the costs associated with monitoring and enforcing the distribution of water in those areas.
- In by-passing the traditional village-township-county route of fee payment to the irrigation district, costs to farmers will be reduced and accountability between the service provider and WUAs will be increased.

Following this line of reasoning, we can consider management transfer to be successful if it saves the government (and farmers) money, improves the cost-effectiveness of O&M, maintains or increases the productivity of irrigated agriculture and farm incomes, and supports the equitable distribution of water amongst farmers. Despite the widespread adoption of transfer programmes, however, little objective information is available about experience and outcomes in China.[69]

In HID, irrigation reforms have followed a similar logic. Since 2000, a total of 43 WUAs have been established on lateral canals in the gravity flow sections, with a further 40 planned for completion by the end of 2007. In addition, a series of complementary reforms have been introduced to raise cost recovery levels and improve the flow of information between WUAs and HIMD. In particular, HIMB works with WUAs on the

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[67] Wang, Xu, Huang and Rozelle 2006. Incentives to managers or participation of farmers in China's irrigation systems: which matters most for water savings, farmer income and poverty? *Agricultural Economics* 34 (2006) 1 – 16.

[68] Based on Zhong-cheng Lin 2002. Participatory Irrigation Management by Farmers: Local Incentives for Self-Financing Irrigation and Drainage Districts in China. Environment and Social Development Unit, World Bank Office Beijing. Also drawing on wider international studies such as Vermillion D 1997. Impacts of Irrigation Management Transfer: A Review of the Evidence. International Irrigation Management Institute (IWMI), Research Report No. 11.

[69] Formal WUAs were first established in China in 1993 under the World Bank supported Yangtze Basin Water Resources Project in Hubei and Hunan provinces. However, objective appraisals of their performance in different areas since then are lacking.

development of Annual Water Allocation Plans and scheduling arrangements, and WUAs are obliged to purchase water tickets prior to each irrigation, with procedures documented in a set of guidelines (see Section 3.4.2).

The boundaries of WUAs are defined by areas irrigated by branch and tertiary canals. As a result, WUA and village boundaries do not always match. The command area of Guang Xin WUA, for example, cuts across three villages (see box below).

Case Study 1: Governance in Guang Xing, Baiing and Guang Mao WUAs, Jianshe section

Guang Xin WUA was established in 2003 and was described as a 'typical' WUA. It includes around 50 farm households. The boundary of the WUA is defined by an irrigated area served by a particular branch channel, not by village areas. Hence Guang Xin, with roughly 160 households, intersects three WUAs. The total irrigated area of the three WUAs combined is 11,560mu, of which 2560 mu has recently been improved.

The Vice Chairman of Guang Xin WUA, Mr Li Maochong, is also the Leader of Guang Xin Village. This was described as a normal situation. Elections for leadership positions in the WUA are held every 3 years. In Guang Xin WUA, the Chairman and two Vice Chairmen were elected through a show of hands. They described these as full-time, salaried positions. There are larger WUAs in Hangjin ID with a full-time staff of seven. In addition, non-salaried 'WUA representatives' are selected by farmers, with each tasked with collecting irrigation fees from around 10 households. These are often leaders of individual production teams.

Discussions with WUA managers in Baiying and Guangmao confirmed that all farmers with irrigated land in the ID (based on local residency) have membership rights in WUAs, even if land is sub-leased. There is an active rental market, particularly in Balahai section, with rents of roughly RMB 140 – 190/mu/year. If land is fragmented and a farmer irrigates land in more than one WUA, he/she has membership rights in each, though farmers will often negotiate land swaps to consolidate holdings. In Guang Mao and other WUAs, land improvement by individual farmers has also brought 'new' land into production, increasing farm sizes.

Source: field interviews, June and August 2007

5.5.2 WUAs and the management of water rights

The ability of WUAs in Hangjin (and elsewhere) to achieve the positive outcomes described above depends on a number of factors. Here, we identify four key conditions considered essential to both the ability of WUAs to meet prescribed objectives, *and* their ability to manage water rights effectively on behalf of farm households.

The discussion draws on meetings held with agency managers in Hangjin over a period of six months, and a formal survey of farmers and WUA managers conducted in October

2007 by the Centre for Chinese Agricultural Policy (CCAP).[70] A key focus is on the proposals for rights reform outlined above – in particular allocation planning based on a system of GWEs and annual entitlements - and the ability (and potential willingness) of WUAs and farmers to implement them. Specific lessons and recommendations are then discussed in relation to HID and other IDs in China.

A clearly defined, monitored and enforced water right and water service

The allocation system in HID combines bulk volumetric charging to WUAs established on branch canals, with area-based charging for farmers. This is common to many IDs in China. Under such a system, the ID agency supplies water to WUAs on a *contractual* basis; contracts have no (current) legal authorization, but do specify the rights and obligations of both the agency and WUAs. Such contracts, or agreements, provide a type of group water right, albeit one of limited security.

At the level of the individual farmer, membership of a WUA then confers an *entitlement* to receive water, or rather a bundled water service, subject to payment for that service. This is an indirect right in the sense that the farmer only plays an indirect role in ensuring that the WUA does not lose any rights conferred on it. Leaving this issue aside, the ability of farmers to assert their water rights within WUAs will depend in large part on how well ticketing arrangements work, and the accountability of WUA managers to farmers, an issue explored in more detail below.

How effectively does this local rights framework operate in Hangjin? In particular, does it provide for the reasonably secure, transparent and equitable distribution of water to WUAs, and to farmers within them? The answer to this question is a broad 'yes', with some caveats.

- Firstly, the seasonal water sales contracts that operate between HIMB and WUAs clearly state the rights and responsibilities of both in terms of payment-delivery terms and conditions. These are set out in the HIMB's Irrigation Water Use Management Guidelines (2003), and are also understood by most farmers.
- Secondly, arrangements have been developed by HIMB to share the risk of unreliable/inadequate deliveries to WUAs through seasonal rotations. In addition some – though not all – WUAs have developed their own allocation rules to share risk between production teams. However, most WUA managers and farmers confirmed that water availability and reliability are satisfactory, with no serious rationing problems (see Survey Finding 1 below).
- Thirdly, farmers have a *de facto claim* to irrigation water based on residency and therefore land rights (though not ownership) within the ID, and an entitlement to water on pre-payment of the water fee. This is set out clearly in the WUA regulations (see Section 3.4), though not all farmers (or WUAs) appear to be

[70] Interviews were held with nine WUAs and 36 farmers over a five-day period using separate (semi-structured) questionnaires. The responses of WUA managers and farmers were then compared.

aware of this. Land rights were extended in 1998 to provide security of tenure (and therefore security for water rights) for a further 30 years (1998 - 2028).[71]

- Fourthly, residency within the ID confers membership of a WUA. Water rights are attached to land rights, with the result that farmers with fragmented land holdings across several WUAs have voting rights in each (see Case Study 1). Moreover, such rights are unaffected by the 'ownership' status of the land; farmers that rent land from others have the same water rights as others.
- Finally, the existing system of area-based fee collection, purchase of tickets and allocation of water between production teams, and farmers, is clearly understood and respected. There are variations in procedure, however, and some WUAs clearly invest more time and effort in ensuring that payment is related to actual water use (Survey Finding 1; Case Study 2).

Survey finding 1: Farmers are generally satisfied with existing payment and water distribution arrangements, but there is room for improvement

Water availability, access: no significant upstream-downstream disparities in water access and use were highlighted by the survey, either between sections or within WUA command areas. For example, 97% of farmers interviewed indicated that water was 'not short', although 50% reported delays in irrigation for major crops, particularly during summer and autumn irrigations.

Allocation methods: all WUA managers and the majority of farmers (97%) indicated they were satisfied with existing allocation procedures within WUAs, and considered them to be 'fair'. In contrast, only 50% of farmers regarded previous arrangements under collective (village-based) management as fair. WUAs adopt a variety of methods for allocating water: for summer and autumn irrigations when water is scarcer, five of the nine WUA managers interviewed said that they would adopt random rotations or prioritise dryer land first.

Payment procedures: all WUAs and farmers confirmed that pre-payment for water is based on area-based fees. In five of the nine WUA surveyed, areas are reported and fees submitted prior to each irrigation, with continuous accounting between irrigations based on recorded deliveries to production teams on tertiary channels. Both team leaders and the WUA chairman are issued with receipts for each payment, and each delivery. In this way, credits and debits can be estimated with a final 'balancing' at the end of the year.

In the remaining two WUAs visited, area-based fees are paid for the entire year before the first spring irrigation, with no adjustment for those teams (and farmers) using less water – for example those irrigating twice, rather than three or four times. The managers in these WUAs indicated that that this

[71] Farmland is *de facto* owned by village collectives which extend land lease contracts to individual farm households. Households have most of the property rights: they can use, sub-lease and transfer land, but they cannot sell it.

arrangement was preferred as it was easier to administer and less time consuming (see Case Study 2).

All of the farmers and WUA managers interviewed favour ticketing – however organised – over previous (village-based) arrangements. Different reasons were cited. The main difference, however, is that previously all agricultural fees and taxes were combined and collected at the end of the year, with the result that farmers did not know what their water fees were, or perceive a link between payment and service delivery.

Source: CCAP survey, October 2007

Lessons and recommendations

Existing arrangements for allocating water to WUAs, and for distributing water within them, are understood by the different stakeholders (HIMB staff, WUA managers and farmers), and regarded as fair. In particular, the introduction of water tickets is viewed positively by both WUA managers and farmers, as it has introduced a degree of transparency and accountability into the payment and allocation process that did not exist under previous (village collective) arrangements.

The proposal to introduce a system of capped GWEs and annual entitlements described in Section 5.3 builds on, rather than replaces, existing ticketing arrangements. Hence WUAs would still be responsible for purchasing water tickets on behalf of farmers and for overseeing the orderly distribution of water, but would have to do so within an externally assigned cap. Moreover, deliveries to WUAs would continue to be managed by HIMB's Section Offices, and monitored by both agency staff and WUAs.

Since existing arrangements already work well, and water access and availability are generally satisfactory, no significant implementation problems are envisaged as long as the cap, and procedures for monitoring and recording water use beneath it, are explained fully to WUAs and their membership. In particular:

- The principle of quota-based management should be firmly established before any attempt is made to reduce entitlements over the medium to longer term. In this context, setting the rights of WUAs at levels corresponding to historical, area-based water use, and setting out clear procedures for allocating proportional shares between WUAs in 'normal' and 'emergency' situations, provides a firm foundation for *future* demand management based on equitable shares of the ID permit.
- The certification and accounting procedures described in Section 5.3 should be documented, circulated and explained to WUA (and HIMB) managers, with scope for consultation – and revision – before implementation. WUA managers, in turn, will need to explain procedures to farmers; in particular, how (and why) caps are placed on volumetric ticket sales, and how caps are arrived at within, and between, WUAs.
- New procedures could first be trialed with pilot WUAs and HIMB offices in each irrigation section. The aim would be to build and document experience, and make corrections (to accounting procedures, to certificates, tickets), before scaling-up to the entire ID. The WUAs selected should be those that already adopt continuous water accounting between irrigation periods. The WUA managers identified for implementing the pilot – and possibly an enthusiastic

farmer in each WUA – could then be encouraged (paid?) to explain new arrangements to other WUAs during the scaling-up period.

Over the medium and longer-term, the land improvement programme in Hangjin may require that the ID permit is shared among more farmers, and/or a greater irrigated area. In these circumstances, GWEs may need to be lowered. This may increase pressure from HIMB Section Offices, and WUA managers, for more accurate (directly measured) water deliveries to WUA gates. It may also increase pressure within WUAs for fairer distribution of water to farmers, at least within those WUAs where area-based payments are not adjusted to account for actual delivery. These issues are discussed further below.

Infrastructure that is compatible with water rights, service and local management capacity

Any discussion on water rights reform cannot be isolated from an understanding of the infrastructure that is available to deliver, monitor and record water flows. In Hangjin, and in most other IDs in China, irrigation systems have not been designed to deliver and record flows to individual farmers. In these circumstances, volumetric rights can only be defined, monitored and enforced down to the level of the WUA and, conceivably, to production teams managing tertiary channels.

Key questions in Hangjin, therefore, focus on links between irrigation commands and WUA boundaries, on how well existing monitoring and delivery arrangements work, and whether changes would need to be made to support the allocation and monitoring of entitlements. Drawing on the field visits and survey findings, we can conclude as follows:

- The command areas of WUAs are defined by the irrigated area served by specific branch and tertiary channels, rather than village boundaries. All of the WUA managers interviewed during the field survey had a clear understanding of boundaries and of the channels that fell under their jurisdiction (Case Study 1).
- Arrangements for the delivery, monitoring and recording of water to WUAs appear to work well. While measurement is recognised as rudimentary and time-consuming (especially for HIMB section staff), it is transparent and consistent, with deliveries 'signed-off' by both HIMB staff and WUA representatives under seasonal contracts.
- Most of the WUAs surveyed adopt a process of continuous water accounting between irrigation periods, with individual production teams managing tertiary channels only paying for the water that is actually delivered. So, while all farmers in a WUA (pre) pay the same area-based fee, final payment/mu is determined by monitored delivery to tertiary channels (and therefore teams), at least in those WUAs where water is delivered *sequentially* to each tertiary channel.
- The channel lining programme is popular with both WUA managers and farmers because it makes water allocation within the WUA easier, saves farmers money, reduces labour demands (for both managers and farmers) and may, in the longer term, reduce soil salinity (see box - Survey Finding 2). However, farmers' knowledge of the programme is limited, and responsibilities (and capacity) for the repair and maintenance of new channels unclear. In addition, HIMB has not received any additional funds for the repair and maintenance of the main channels under its authority (see Section 3.5).

Survey finding 2: Farmers are generally satisfied with monitoring arrangements, and the channel lining programme is popular with both WUA managers and farmers

WUA boundaries: all of the WUA managers interviewed were able to provide information on WUA areas, household numbers and the channels under their jurisdiction. WUA membership varied from roughly 150 to 350 households.

Monitoring arrangements and transparency: most farmers interviewed (roughly 90%) said that they were aware of information on water fees, water use and irrigated areas within their WUAs from information posted on boards outside HIMB section offices.

Channel lining: the channel lining programme in Hangjin is popular with both WUA managers and farmers. The main benefits highlighted by farmers included water (and therefore money) saving (89%), the more timely supply of irrigation water (67%), labour saving (59%) and reductions in soil salinity (50%).

Only a few farmers and WUA managers thought that the programme might have negative impacts on soil moisture conditions and groundwater access. Impacts on the shallow aquifers used to supply domestic and livestock water were not considered in programme design, though most villages in the ID are thought to rely on groundwater for domestic supply, and livestock make a significant contribution (roughly 25%) to household income.

Source: CCAP survey, October 2007.

Lessons and recommendations

In Hangjin, and in most IDs in China, the government is promoting WUAs based on hydraulic, rather than administrative, boundaries. This model provides a sound basis for the issue of specific gate-based GWEs. In Hangjin, moreover, the delivery of water to WUAs is governed by service contracts between WUAs and HIMB section offices. These provide a sound basis for clarifying rights and responsibilities around water delivery and payment, and for the monitoring and recording of delivery and payment. They are recommended for other IDs embarking on quota-based rights reform.

Case Study 2: Water delivery and monitoring: the rights of production teams and farmers

Naimadai WUA in Jianshi Section has three branch canals and 38 tertiary canals. These canals serve one village, eight production teams and 353 households, and irrigate an area of over 13,000 mu. Most canals have been lined under the channel lining and transfer programme. In addition to the Chairman, Mr Mei, the WUA has an Executive Committee comprised of leaders of each production team. Mr Mei is also the village leader.

Mr Mei described how arrangements for the delivery, monitoring and payment for water within the WUA are linked with control of gate flows to tertiary channels. “Farmers need to pre-pay the water fee before each irrigation according to their irrigated area. When each irrigation is complete, the average water fee per mu of each tertiary channel is calculated, based on actual (recorded) delivery at the gate".

Mr Mei went on to describe how, under this system of water distribution, the pre-paid (area-based) water fee is adjusted at the level of the production team (tertiary channel) following each irrigation to reflect actual delivery. Farmers within the production team then split the actual cost between them according to (a) whether farmers irrigated or not; and (b) areas irrigated. A system of continuous accounting ensures that production teams can carry 'credits' or 'debits' across irrigation periods, with a final reckoning at the end of the year.

Mr Wang, a local farmer, is happy with the current system, and in particular its transparency and fairness compared with previous arrangements. "Now we, water users, are able to know how much water our production team has used, how much we have paid, and what areas have been irrigated. After each irrigation, the water use information of our production team is published on the board." Mr Wang also noted that since the introduction of the system, farmers had become more aware of how much water individual farmers were using, with farmers "monitoring each other" to prevent waste and reduce group fees.

Source: CCAP Survey, October 2007.

In Hangjin we can also conclude that though monitoring infrastructure is crude, monitoring arrangements are respected and regarded as legitimate by HIMB, WUA managers and farmers. Hence existing systems could effectively support quota-based management and allocation planning of the kind proposed in this report. However, upgrades may be necessary to support any future plan to lower entitlements within the ID. Water availability is not currently a limiting factor in agricultural production, and the GWEs proposed in Section 5.2 only seek to cap water use at historic (average) levels. However, if GWEs were lowered, WUAs and farmers might demand greater measurement accuracy. Nonetheless, it is suggested that any future design retains some of the best elements of the current system. In particular, oversight by both HIMB staff and WUA managers, and freedom of access to information (on payment and delivery) by WUA managers, production team leaders and individual farmers.

The water certificates proposed in this report would define the rights of WUAs, and demonstrate how proportionate shares under the ID permit could be fairly allocated *to this level*. Beneath this level, formal definition and allocation of rights becomes more problematic. However, it is worth noting that *subsidiary certificates* could be issued to production teams in those WUAs where tertiary channels receive separate, *monitored* deliveries. In the majority of irrigation schemes in China, monitoring does not extend to individual farmers.

Channel lining and transfer programmes of the kind piloted in Hangjin may be implemented in other IDs. Our survey suggests these are likely to be well received. Moreover, international experience indicates that channel lining generally enhances water control, making it easier to allocate water between gates and WUAs. However, our survey also highlights the importance of providing information to farmers on the programme, in particular the need to clarify responsibilities for future repair and maintenance *at the outset*. WUAs and farmers are more likely to fulfil these responsibilities if they have been discussed and agreed before work begins. In addition, tasks are more likely to be fulfilled effectively if farmers have the skills, tools and resources to tackle them. Again, issues of capacity should be addressed at the design stage rather than tagged-on to a completed project.

Well-specified management functions, authority and accountability

In Hangjin and other IDs where WUAs have been established, the management functions and authority of WUAs are spelt out in a charter, or set of written rules (see Section 3.4). All include a stipulation that WUAs act as organs of democratic self-management, with chairmen and committee members directly elected by farmer members.

Key questions in Hangjin, and in other IDs, concern the ability of all farmers (richer and poorer; landlords and tenants; 'upstream and 'downstream' land holders) to assert a claim to water proportionate to the area of irrigated land under a system of system of WUA-held GWEs and annual entitlements. This will depend on whether WUAs genuinely represent the interests of all farmers, and whether they have the capacity to resolve competing claims and disputes. It will also depend on farmers' own awareness of their role in the governance of WUAs, and their responsibility to enable it to distribute water equitably.

In Hangjin, we can draw the following conclusions:

- As noted above, the allocation of water to WUAs and the distribution of water within them is governed by service contracts and ticketing procedures that appear to work well. In particular, no significant differences in farmer understanding of and support for existing arrangements were apparent between different sections of the ID, or between farmers within individual WUAs. However, we have also noted that allocation arrangements within WUAs vary, and some are fairer than others (Case Studies 2 and 3).
- Farmers' awareness and understanding of WUAs is limited, or at least restricted to the view that WUAs exist as vehicles for fee collection and water accounting. Although most WUA managers indicated that regular meetings were held with farmers to discuss fee collection and irrigation, fewer than half of the farmers interviewed had taken part in such meetings, and most were unaware of any written rules/guidelines governing WUA responsibilities and functions. In addition, nearly all of the managers and farmers interviewed indicated that the establishment of WUAs had been a government-village committee initiative, with no farmer consultation.
- While all WUA managers and farmers reported that WUA chairmen and members of the executive committee had been selected by farmers, none of the WUAs appear to have held ballots. Management positions in many WUAs have been taken up by those who previously dealt with irrigation issues under the village collective, on the basis that they already know the system well.

Survey finding 3: Accountability exists through fee payment rather than popular participation

The survey of WUA managers and farmers indicated that while water ticketing procedures are well understood, the wider role of WUAs as participatory decision-making bodies is not. In particular:

Establishment of WUAs: all of the WUAs surveyed were established after 2000. Most WUA managers interviewed said that the decision to establish WUAs was taken by the government and village committees; farmers were not consulted. Roughly 30% of the farmers interviewed indicated that they did not know who had been involved in the decision-making process.

WUA regulations: five of the nine WUA managers interviewed confirmed that the WUA had a written constitution setting out its functions, obligations and rules. However, none of the managers could confirm whether their WUAs were officially registered. Most farmers (52%) were unaware of a WUA constitution and most (77%) did not know whether the WUA was registered.

WUA functions and responsibilities: drawing on the above, the survey team concluded that most farmers did not have a good understanding of the purpose and mandate of WUAs. That said, all WUA managers and most farmers reported that WUAs had introduced some new management measures, though with an emphasis on ticketing rather than other activities.

Participation: five of the nine WUA managers reported that regular meetings were held with farmers to discuss issues such as irrigation scheduling, water fee collection and irrigated areas. The remaining two indicated that farmers were not involved in meetings either because it was unnecessary, or the meeting room was too small. Farmers' responses indicate low levels of participation in WUA meetings; fewer than half of those interviewed attended meetings to discuss the issues above, and some farmers were unaware that meetings took place at all.

Selection procedures: all of the WUAs surveyed have a full-time chairman and an executive committee of 4 – 15 members. Four of the nine chairman interviewed are also village leaders. All WUA managers and farmers indicated that chairmen were selected by farmers, though none of the WUAs appeared to have held ballots for the post.

Source: CCAP survey, October 2007.

Case study 3. Water delivery and water rights in Huangjiehao WUA, Jianshi Section

Huangjiehao WUA in Jianshi Section operates one branch canal and six tertiary canals. These serve one village, three production teams, 170 households and 4500 mu. The branch canal and roughly 80% of tertiary channels have been lined. In addition to the WUA Chairman, Mr Guo, the WUA has an Executive Committee of five members. Each manager in the

> WUA manages a tertiary channel. In contrast to most other WUAs, however, these are not production team leaders. Mr Guo is also the village leader.
>
> Mr Guo explained how, in this WUA, farmers pay an upfront fee for irrigation of RMB 30/mu that covers the entire year, irrespective of actual water deliveries to tertiary channels and their production teams. “Farmers need to pre-pay water for the whole year before the first spring irrigation. All farmers’ water fees are the same, no matter how many times they have irrigated, what crops they have planted, or what their soils are like.” Mr Guo explained how this arrangement “saves time and money”. Mr Guo also explained the scheduling plan, stating that “We first irrigate the land near the outlet, then continue irrigating from near to far.”
>
> Source: CCAP Survey, October 2007.

Lessons and recommendations

In Hangjin, pre-payment of water tickets and the monitoring of deliveries through WUAs and (in some cases) production teams helps create accountability between farmers, WUAs and the HIMB. In short, it is the contract and ticketing system, rather than the WUA *per se*, that helps farmers know when irrigation will be available to the users, how much they will get, how long they will it get it for and how much they need to pay.

Whether farmers can *enforce* their entitlements through such arrangements is another issue. Farmers cannot, for example, withhold payment if water is not delivered because they have to pay for water in advance. A tentative conclusion is that enforcement - or rather the ability of farmers to assert area-based claims - is not a significant issue at present because water is not scarce: supply is sufficient to satisfy most farmers, most of the time. In future, however, the situation may change, with pressure to reduce GWEs. And in many other IDs, farmers are already experiencing scarcity. In these circumstances, the ability of farmers to influence allocation decisions *through the WUA* may become more important, particularly in those WUAs where water accounting methods privilege ease of administration over farmer equity, and farmers near WUA off-takes always receive water first (see boxes). Here, the experience of Hangjin highlights some potential problems because farmers’ awareness and understanding of WUAs is limited. In particular, most farmers are not aware of their rights, and perhaps of their ability to remove unresponsive managers.

How can the claims of farmers be strengthened further through a WUA so that ticket-based allocations are fair, and are responsive to changing supply-demand conditions? Key recommendations can be summarised as follows:

- The process of WUA formation should involve farmers from the outset; it should not simply be driven by government and/or ID agencies in a top-down manner. A WUA promotion phase could help here, raising awareness of farmers’ rights (including voting and operational decision-making) and duties before WUAs are formally established.
- All farmers should have access to information, in an appropriate format, on their rights and responsibilities as members of a WUA. For example, farmers could be encouraged to register with the WUA, with membership cards/booklets summarizing rights-duties issued to farmers.

- Elections for WUA positions should be held at a time and place that is convenient for farmers (e.g. at a time when temporary migrants have returned to the ID) using closed ballots. Election procedures, venues, dates and results all need to be well publicised outside WUA offices and on village notice boards.
- Once a WUA has been established, it should be obliged to publish a set of annual water accounts, in conjunction with the relevant HIMB Section Office. Accounts would be available for inspection by farmers and other WUAs. In addition, performance audits could also be conducted by the ID agency and/or relevant government department, at least over a probationary period, focussing on financial accounting and record keeping, fee collection and ticketing procedures, allocation rules for low flow periods and the condition and repair of local infrastructure.

Adequate resources

A common assumption in irrigation turnover programmes is that WUAs are better (than government agencies) at undertaking water allocation, distribution and fee collection – cumbersome tasks that the government is often keen to hand over. However, new obligations may be a serious burden on WUAs if they have been formed without adequate attention to their ongoing support needs. A key question in Hangjin, therefore, is whether pressure to reduce government outlays – a key factor driving management transfer - has extended to an unwillingness to provide sufficient resources for WUAs to retain elected staff and carry out management tasks effectively, particularly in relation to long term water allocation, technical backstopping and maintenance.

Based on survey results and field visits, we can make the following observations:

- The chair and executive committee positions within WUAs are funded from revenue retained from ticket sales. Most farmers are aware of funding arrangements. This provides an incentive to improve collection efficiency[72], but also establishes a link between salary payments and water sales. Similarly, the revenue of HIMB is dependent on ticket sales to WUAs, providing an incentive for billing and fee collection, but a disincentive for water conservation.
- Some of the WUA managers interviewed complained that salaries were insufficient to retain staff or provide work incentives. Others called for training in record keeping and other management tasks (see boxes below).
- The channel lining programme is almost complete. However, questions remain about farmer willingness and ability to carry out maintenance tasks. As noted above, the perception among farmers that the government 'owns' the system (and should be responsible for repairing it), has probably been reinforced by top-down implementation and minimal promotion/information exchange with local people.
- WUAs do not appear to play a significant role in providing technical or agronomic advice to farmers. For example, most farmers did not think that WUAs have introduced 'new management measures' since their formation, beyond their role

[72] The percentage of the billed amount that is collected.

on administering the ticket system. It is not clear whether, or how, farmers can access technical support.

Survey finding 4: WUAs require adequate financing

Financing of WUAs: with the exception of one WUA in Mugan, all WUA chairmen draw their income from water fees collected from farmers. Most – though not all – farmers are aware of this.

Support for management: six of the nine WUA managers interviewed complained about a lack of money to do their jobs effectively. Others expressed a demand for training to increase their management capacity.

Ability and willingness of farmers to pay water fees: some farmers clearly have a problem in meeting up-front cash payments for irrigation before crops are harvested and sold. They may borrow money from other farmers, or the WUA may go into temporary debit with a Section Office. However, most of the farmers interviewed are not poor, with average (net) cropping incomes of over RMB 40,000, and total incomes (including livestock and non-farm) of over RMB 80,000.

Case Study 4. Resourcing issues – GuangXin WUA

According to Li Maochong, WUAs are allowed to retain 3% of ticket revenue collected by the WUA from farmers to pay for salaried staff, and possibly O&M within the WUA boundary. There is therefore a link between revenue collection and salary, though the 3% withheld was reported as insufficient to retain staff when 'more money could be earned elsewhere'. HIMB has suggested that 7% would be a more appropriate share.

Representatives of Guang Xin WUA appeared uncertain over the precise responsibilities of the WUA beyond fee collection, purchase of water tickets and allocation (and recording) of water use. Chairmen were described as the WUA 'gatekeepers', personally responsible for overseeing releases at level 3 sluices (with HIMB staff), and opening sluices and monitoring flows on behalf of the WUA at levels 4 and 5.

One of the major concerns of the Vice Chairman is migration of young people from villages to towns and cities, leaving women and old men to work the fields. The population of Guang Xin village has shrunk from around 700 to 500 over the last few years.

Source: interview, June 2007

Lessons and recommendations

Key questions in any discussion on WUA sustainability concern how WUAs raise revenue to fund management positions, and whether revenue is sufficient to support ongoing management functions. These questions are relevant to the reform of water rights since WUAs (and the HIMB) need to be financially sustainable if they are to manage water allocation, and deliver fair shares to farmers, on an ongoing basis. What are the lessons and recommendations from Hangjin?

Firstly, discussions and survey raise concerns that current levels of funding, based on a percentage share of ticket revenues, are insufficient for both WUAs and the HIMB. Specifically, HIMB has seen its funding base eroded with the transfer of water out of the ID (Section 3.5), and at least some WUAs highlight an inability to retain and incentivise staff. Assuming that the price of water cannot be raised to generate extra funds[73], a solution to this problem may have to wait until the YRCC 'signs-off' the water transfer programme and authorizes release of additional funds to HIMB. WUAs may then be in a better position to re-negotiate their funding formulae.

Secondly, we note that any formula that directly links agency and WUA revenue with ticket sales creates a *potential* conflict of interest. In particular, while it helps increase accountability between the farmers, WUAs and the HIMB (linking payment with service provision), it also creates an incentive to maximize water deliveries, albeit within the caps provided by GWEs. Moreover, it can be argued that volumetric methods are intrinsically unsuited to the recovery of costs. In particular, while the costs of management and operation are relatively stable, revenues from uncertain sales provide organisations with limited financial security.[74] A key recommendation for Hangjin, and other IDs, would therefore be to introduce a two-part tariff, with a fixed element to cover O&M costs, and a variable element to reflect actual water use. Specifically:

- A fixed charge proportionate to, for example, the cultivated area of each WUA or its long term GWE. The charge would paid at the beginning of the year by the WUA to HIMB section offices, and would *not* be linked to actual delivery in any given irrigation period, or year. Such a charge would need to clearly designated for use by the ID agency and accounting procedures would need to be transparent.
- A variable fee, based on the current HIMB practice of billing for actual delivery at WUA off-take gates, and the current WUA practice (in most cases – see above) of adjusting area based fees according to recorded delivery to production teams.

Finally, we note that while WUAs are supposed to provide technical advice to farmers, it is unclear how this is supposed to be delivered or paid for. For example, whether this is a task that WUAs are expected to organise on behalf of their members by contracting-in agricultural extension workers. This question has little immediate bearing on water rights reform, but may become more of an issue over the longer term if GWEs are lowered and farmers need to increase the productivity of water to maintain production and income. In such circumstances, farmers should arguably be offered technical advice to increase 'crop per drop' *in return for* a cut in GWEs.

[73] A proposal by HIMB to (periodically) raise the price to help ration supplies and raise funds was rejected by government. Water pricing is politically contentious, hence prices are set by central government.

[74] FAO 2004. Water charging in irrigated agriculture: an analysis of international experience. FAO Water Reports No. 28, Food and Agriculture Organisation of the United Nations, Rome.

5.6 Water banking

5.6.1 The need for a water bank

The need for incentives to increase efficiency

The growth of heavy industry along the Yellow River in Inner Mongolia has increased the demand for water. However, there is little capacity to issue new water permits for increased abstraction as the Yellow River's water resources are already heavily committed. The major use of water in the area is for agriculture. It is the obvious source for additional water for industry.

These circumstances have lead to a growing demand for the irrigation sector to become more efficient in its water use and transfer the 'saved' water to these emerging industries.

However, there are limited incentives to encourage the adoption of efficiency measures within irrigation areas. Benefits to villages and individual farmers are currently indirect (e.g. they may experience reduced fees) rather than direct (e.g. from receiving payments from the industries in need of water).

Direct incentives can be provided by establishing a way for emerging industries to buy water entitlements that are no longer needed for irrigation due to efficiency improvements.

The need to establish a mechanism to facilitate transfers

Water trading undertaken in Hangjin to date has focussed on savings at the primary and secondary channel level and has been effective in saving water at that level. However, this approach is unsuited to savings made below the WUA level. These savings could be from:

- Channel lining (below the WUA level);
- Changes to crop types; or
- Improved efficiency on-farm (e.g. from improved irrigation techniques (sprinklers, drip-irrigation), land-levelling, etc).

The four key groups involved in the delivery and use of water in irrigation districts in Inner Mongolia are:

- The IM-YRIMB, which holds the water abstraction permits;
- Irrigation district management bureaus, which manage the main channels in irrigation districts;
- WUAs, which manage the delivery of water to individual farms in their areas of responsibility; and
- Farmers.

Each of these groups, other than the IM-YRIMB, is involved in on-ground activities and is therefore capable of undertaking efficiency measures directly. Conversely, the IM-YRIMB is the only one of these groups that holds a formal entitlement to water (i.e. the water abstraction permit) and that, therefore, can make decisions about its long-term water access rights.

As such, there is no direct avenue for the on-ground entities to engage with potential buyers of water entitlements.

An irrigation bureau, WUA or farmer wanting to investigate trading options would currently need to coordinate with the IM-YRIMB and all other higher-order entities. This is an inefficient approach to water rights transfers and may create unnecessary obstacles.

The issue of scale is also important. Efficiency improvements undertaken by individual farmers and WUAs – or even main channel lining works by irrigation district bureaus – may not save sufficient water to meet the needs of new users. It may be that only pooled savings from efficiency measures throughout an entire irrigation district would make enough water available to interest potential purchasers of water rights. As such, there is a need for a mechanism that can coordinate water savings measures throughout irrigation districts and transfer the collated savings to other parties.

The concept of a water bank

A water bank is a way of facilitating the transfer of pooled water savings to emerging industries. Establishing a water bank as a single entity responsible for promoting water savings and facilitating transfers:

- Avoids the need for compulsory reallocations;
- Protects the interests of water users and the irrigation scheme operator; and
- Minimises trading costs.

In summary, a water bank for HID would:

- Be established as an independent entity, with clearly defined functions and operating rules;
- Deal in water entitlements under the district's water abstraction permit;
- Maintain a registry of all such water entitlements;
- Arrange for the purchase of saved water by emerging industries; and
- Maintain a record of willing buyers of water entitlements, where insufficient water had been banked to meet these demands.

5.6.2 Water bank deals in water entitlements

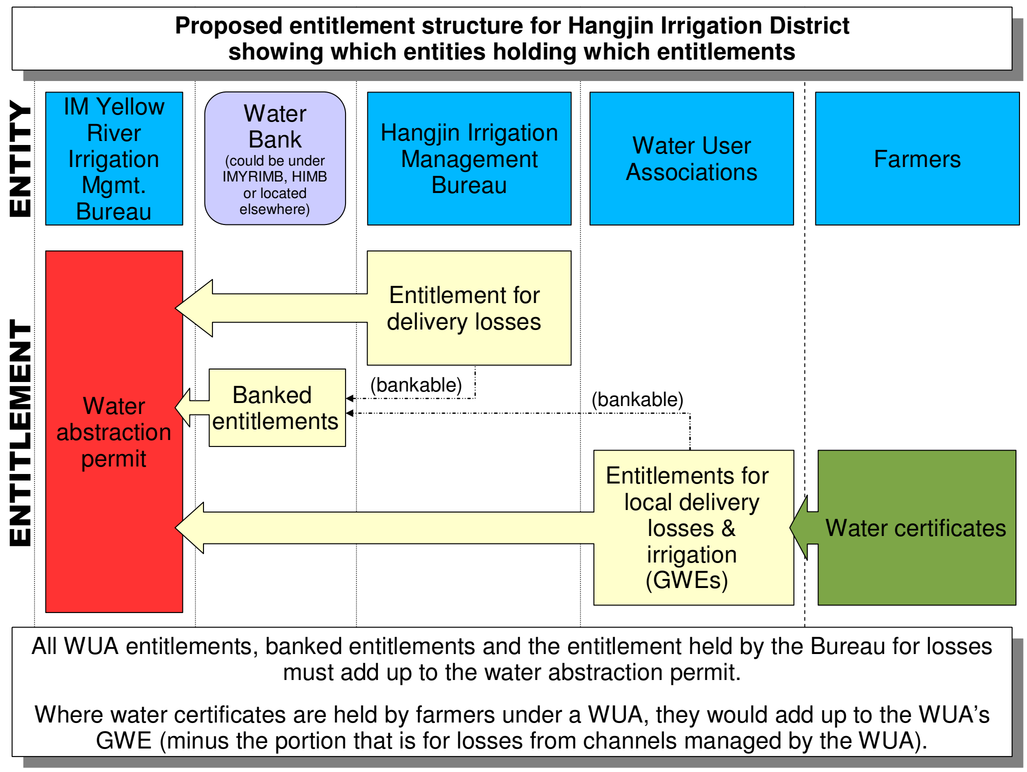
As noted previously, the only water entitlement that currently exists in HID is the single water permit to abstract water for the scheme from the Yellow River.

As discussed previously in this chapter, the following water entitlements will be established under the water abstraction permit:

- An entitlement for each WUA for irrigation water and for evaporation and seepage losses from the channels it operates ("a GWE"); and
- An entitlement for HIMB for the evaporation and seepage losses from the channels it operates.

HIMB's loss entitlement together with the sum of the GWEs held by the WUAs would add up to the water permit volume. Where water certificates are established for individual farmers, they would add up to the entitlement held by their WUA (minus the portion of the entitlement for losses from the channels managed by the WUA).[75] This is depicted for HID in Figure 49.

Figure 49: Proposed entitlement structure for HID



At this stage, it is proposed that the water bank only deal in entitlements held by HIMB and WUAs. It could, however, be expanded to deal in water certificates at a later stage.

If an individual irrigator proposed to implement on-farm water efficiency measures, the WUA could still bank the relative portion of its entitlement. However, the WUA would need measuring and monitoring tools to reduce the water supplied to that individual relative to other farmers in the WUA.

5.6.3 The process of trading water through a water bank

There are essentially two major steps to transferring water rights through a water bank.

The first step involves the 'banking' of the saved water: this is where a WUA (or farmers under a WUA) saves water. The WUA can then apply to transfer some of its GWE (as allocated under the permit) to the bank. This part of the process simply involves reallocating the total volume available under the abstraction; it does not affect the permit at all.

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[75] Note that this example is on the assumption that water certificates would be granted to the farmer level. The previous sections of the report have described a process of granting water certificates only to the WUA level. Allocation of rights below this level would depend on enhanced water metering and monitoring arrangements.

The second step involves the transfer of banked entitlements from the permit holder (for the irrigation district) to the purchaser (e.g. an industry outside the district). This will require an amendment to the irrigation district's water abstraction permit, and the grant of a new permit to the purchasing industry.

5.6.3.1 Step 1: Banking

Preparation of a water savings proposal

The first step to banking water would be to develop a 'water savings proposal'. This could be done by either:

- HIMB - for a proposal relating to efficiency improvements in the channels it operates to deliver water to WUAs; or
- A WUA – for water savings measures including lining channels (those for which the WUA is responsible), changing crop types and introducing new irrigation technologies or practices (such as drip irrigation systems).

Basic information required in a water savings proposal
The water savings proposal would need to set out the detail of the proposed water savings measures and calculations of the volume of water that they would save.

The proposal needs to show the savings are 'real'
Proposals would need to show that the water savings would not just be achieved on a local scale, but would be consistent with a net reduction in abstractions from the Yellow River system. Water that leaked from channels prior to the lining of a channel, moved on somewhere in the water cycle. If it moved back to the Yellow River it would have formed part of the flow that supported water entitlements downstream. Under such circumstances, the granting of new water permits to industry on the basis of the water savings would reduce the reliability of supply to other water users.

Alternatively, if the water that previously leaked from the channels filled pore space underground and moved as groundwater to local wetlands or saline discharges where it evapotranspired, then other water entitlement holders would not be affected. However, the environmental values of the wetland and the impact of the changed flow regime on those values would require consideration. This may be positive or negative depending on whether the wetland is a site of water-logging and salinisation or of ecological value.

Demonstration that the water savings can be sustained in the long term
A water savings proposal would also need to address the means by which the water savings will be sustained in the long term, including the maintenance required for any proposed works.

Similarly, other efficiency measures (such as those involving changed cropping practices) will need to continue in the long term. The mechanisms by which this will be ensured will need to be outlined in the water savings proposal.

Assessing and approving water savings proposals

The proponent of the project would submit the water savings proposal to the YRCC the approving level of government.

The assessment process should follow the well established principles for the approval of water permits in China. That is, water saving proposals should be scrutinised by independent, accredited authorities to ensure the measures contained in the proposal:

- Are technically sound;
- Will reliably provide the claimed savings;
- Address potential environmental impacts, such as the examples noted above; and
- Are consistent with the law.

The YRCC would act on the advice of the accredited independent authorities to approve or reject the proposal.

Having the YRCC as the approvals agency at the water savings proposal stage also minimises the risks that it would reject a subsequent application to amend and transfer water abstraction permits when the banked entitlements are traded away from the irrigation district.

Depositing entitlements in the bank

Only the holder of an entitlement could propose to bank part or all of its entitlement. This is important to ensure that trades only involve willing buyers and sellers.

The entitlement holder would be required to submit a 'completion certificate' from an independent authority certifying that the water savings had been achieved in accordance with the approved water savings proposal. The banking would not be allowed without this certification.

This requirement would not preclude a water savings proposal from being prepared and submitted after works had been completed, but in these cases entitlement holders would run the risk that the proposal would not be approved or would be approved conditionally (for example, subject to further work or testing).

The water bank would pay the entitlement holder for the banked entitlement immediately, at the standard price set by the bank. Issues associated with setting prices are discussed below.

The register of water entitlements would be amended to show:

- The portion of the entitlement that had been banked – this will be held in the name of the water bank; and
- The reduction in the original entitlement, having removed the banked portion.

For example, if one of two WUAs within an irrigation district banked part of its GWE, the register would change as follows:

Holder	Entitlement
WUA 1	50
WUA 2	40
Bureau (losses)	10
Water bank	0
Permit total	**100**

Holder	Entitlement
WUA 1	40
WUA 2	40
Bureau (losses)	10
Water bank	10
Permit total	**100**

The total of the banked entitlements would be registered on a publicly accessible database, enabling interested parties to see how much water is available for purchase. This is the volume available for sale out to parties outside of the district.

To facilitate trades, banked entitlements would not be able to be withdrawn from the bank.

5.6.3.2 Step 2: Permit transfer

The role of the bank in permit transfers

The process to transfer part of the water abstraction permit would commence once the banked entitlements were sufficient to meet demand(s) for water from other entities (i.e. emerging industries).

The bank would be responsible for matching buyers with available entitlements. It would need to keep a register of interested buyers (which would be particularly important should banked entitlements not meet demands).

Rules would need to be established about the bank's role in selecting those parties allowed to purchase the banked entitlements. These rules will need to ensure fairness and transparency, and to minimise corruption opportunities. The development of such rules would need to take into account regional plans and policies in respect of development. However, they could be as simple as requiring the bank to facilitate the transfer of available entitlements to the first willing buyer.

The irrigation district permit will need to be changed

Once a transfer had been agreed between the bank and a buyer, the irrigation district's water abstraction permit would need to be amended to reflect the reduced entitlement and the new permit granted to the purchaser of the water.

For the above example, this would mean the original permit of 100 units would be amended to 90 units and a new permit granted for a further 10 units.

The transfer of the newly created water abstraction permit

On the transfer of the new permit to the purchaser, the register of permits would be amended to show:

- The reduced permit held for the irrigation district; and
- The new permit.

At the same time, the banked entitlements would be cancelled. The register of water rights within the irrigation district would show the banked entitlements as cancelled, as well as the water permit dealings that led to their cancellation.

For the above example, the register would change as follows:

Holder	Entitlement
WUA 1	40
WUA 2	40
Bureau (losses)	10
Water bank	10
Permit total	**100**

Holder	Entitlement
WUA 1	40
WUA 2	40
Bureau (losses)	10
Water bank	0
Permit total	**90**

The subdivision of the original permit and transfer of the new permit would both require the approval of YRCC. This is in accord with the Commission's existing role of considering applications for permits to abstract water from the Yellow River.

5.6.4 Funding the bank and other factors in setting prices

The bank would set prices

The water bank would be the point of contact for potential buyers of the banked entitlements. It would be responsible for setting the standard prices that:

- It will pay WUAs and the Bureau for banked entitlements; and
- Purchasers will be required to pay on the transfer of part of the water permit.

When setting prices, the bank would need to consider the objectives of the water bank system. Prices would need to be set at levels that would balance the:

- Cost to the Bureau, WUAs or farmers of implementing water savings measures (plus incentives for profit); and
- Price industries are prepared to pay for water.

In this context, one option is to set the initial price paid to entitlement holders on the basis of the average cost of likely water savings projects. For example, the standard costs involved in lining a particular length of channel could be used as a benchmark. This could also be averaged with the standard costs involved in the adoption of on-farm efficiency measures for all properties in a WUA's area. Such an approach would require expert input.

Alternatively, the bank could conduct an initial consultation exercise with the entitlement holders to gauge their expectations about what an acceptable price might be (i.e. the price at which they would be encouraged to invest in water savings measures).

There may also need to be separate prices for entitlements banked by the Bureau and WUAs if they face significantly different costs in the adoption of water savings measures.

Regardless, it will be essential to ensure that the price the bank pays for entitlements is less than the price that industry will be prepared to pay to purchase the water. The price set for the purchase of new water permits would need to include both the price paid to the entitlement holder, as well as recovery of its operating costs.

Funding the bank's operational costs

The beneficiaries of the water bank should pay for the associated costs. These costs would be covered by the difference in the price the bank receives for the transferred permit and the price it pays to the entitlement holders at the time of banking. As such, the price setting process will need to consider the bank's budget requirements.

This will include the fees and charges associated with the banked entitlements. The IM-YRIMB is obliged to continue to pay the YRCC for the volume of water specified under the water abstraction permit, including the portions that have been banked. This obligation is only eliminated when the trade of water from the irrigation district permit to the new permit holder occurs. As such, the bank will be responsible for these fees and charges while it holds banked entitlements.

Given that the banking and transfer arrangements that are proposed would be a controlled market, with controlled prices, it will also be necessary to ensure that the bank cannot engage in price gouging from prospective buyers. As such, the bank should be established as a non-profit entity. It would therefore only be able to set its sell prices at a level that would cover its operational costs (and to enable the management of supply and demand issues, which are discussed below).

It is possible that the water bank may not operate successfully as a financially independent entity, particularly if there is variability in the demand for new water permits from emerging industries. It may also have cash-flow issues when first established when it starts paying for banked entitlements, but before selling the new permits. In these situations, the IM-WRD may need to make up any shortfall in the bank's operating costs.

Managing supply and demand through prices

There may be cause for the bank to reconsider the initial prices if there is an imbalance in the supply of, and demand for, banked entitlements.

Ideally, the bank will have in place agreed purchase prices from prospective buyers, prior to the bank purchasing water from entitlement holders within the district. This approach will minimise the risk to the bank of being unable to sell the water rights that it buys.

If there was demand from potential buyers but no (or insufficient) banked entitlements, the bank could consider raising its standard purchase and sales prices.

- This would provide an increased incentive for entitlement holders to undertake water savings work.
- However, associated increases in the price of transferred permits could also reduce the number of willing buyers.
- As such, the bank would need to carefully consider adjusting its pricing to ensure that any changes do not lead to banked entitlements outstripping demand.

If the bank cannot on-sell the banked entitlements to new permit holders because there are no willing buyers, its financial security will be at risk.

- In these situations, the bank may need to consider lowering its selling price to encourage buyers and discourage further banking.
- However, it would need to make sure the price was not lowered so much that the bank was not at least recovering its purchase costs.
- The bank should also ensure it does not continue purchasing water rights from entitlement holders when there is a shortage of buyers.

5.6.5 Other considerations

Establishing rules and standards for water savings proposals

To the extent practicable, rules and standards should be established to simplify the development of water savings proposals. These would:

- Guide the development of water savings proposals by entitlement holders;
- Limit the scope for discretion in decision making about the appropriateness of water savings proposals and their implementation; and
- Provide a level of accountability.

The more detailed the trading rules and standards that are established in the initialisation plan, the more quickly water saving proposals can be developed and approved.

For example, standards for the preparation of water savings plans might include maps of soil types and specify the rates of leakage for different standard channel profiles in the different soil types. Engineering standards for channel lining works and associated maintenance schedules might also be set.

Standards for water savings plans would be produced by the appropriate water management agency within Inner Mongolia. The preparation of these standards would require expert input and would benefit from consideration by some of the independent experts proposed to review water savings proposals.

Impacts of WUA banking on the Bureau

The financial externalities associated with trades under current arrangements are outlined above. In summary, if a WUA trades away some of its GWE, HIMB's revenue will be reduced because it sells less water, but its cost in operating the channels that deliver water to the WUAs will be essentially unchanged.

The development of a water bank should not undermine the financial stability the Bureau requires to plan its water supply services into the mid term. This is in the interest of both the Bureau and its customers.

As such, if a WUA gains some benefit from a reduction in the water it receives (i.e. from a reduction in its GWE), the Bureau should be protected from any unreasonable financial impacts. This would be achieved by each WUA entering into a supply contract with the Bureau. The contract would require the WUA to pay the Bureau a lump sum as a 'partial termination payment' when it received its payment for its banked entitlement.

A fair arrangement for these payments should be developed out of negotiations between the Bureau and WUAs. One option is that the amount be the foregone revenue relevant to the Bureau's fixed costs for a set period (e.g. ten years).

The WUA would take this contractual obligation into account when considering its options for banking and water savings projects.

Trading between WUAs

The water bank could also support dealings between WUAs. For example, if changes in the agricultural sector emerge that drive a shift in WUAs' different water needs, then entitlements could be transferred between WUAs.

The same process for the banking of entitlements as is outlined above would generally apply. However, there would need to be an indication from WUAs that they would be interested in acquiring additional entitlements before this form of water banking could be allowed. This would be necessary because otherwise the permit holder could be in the position of essentially paying for WUA efficiency measures (by paying the WUA for banked water) yet having inactive banked entitlements.

In addition to this distinction from the banking process, there would also be no changes to the water abstraction permit because the transfers would all occur within the single irrigation district.

Expanding the bank's operation to other irrigation districts

A single water bank could operate across multiple irrigation districts. Such an objective would influence where and how the water bank would need to be established. It could still operate as a creature of IM-YRIMB because it is the holder of all the abstraction permits for irrigation districts in Inner Mongolia. Alternatively, it could be independent of any existing agency.

There would not need to be any major changes to the structure of the bank or to the banking and transfer processes. The transfer process may become more complicated if it involves entitlements banked under different permits. However, this could also increase the potential benefits of the water banking system by maximising trading opportunities.

5.7 Water monitoring and information systems

In this sub-section we look at existing arrangements for monitoring, recording and using information on water distribution and use. We then identify and discuss elements of an upgraded monitoring and information system that could better support the allocation and management reforms outlined above.

5.7.1 Current situation

Existing monitoring equipment and methods in HID are crude. Water levels are measured using a gauge, and flows are measured with traditional flow meters. All measurements are done by hand (Figure 50). In a large ID such as Hangjin, this creates a very heavy workload for staff. In particular, the staff of HIMB's Hydrometric Station have to monitor over 20 gates controlling flows to WUAs, and at times of peak irrigation demand, there is a shortage of manpower. The situation is exacerbated by the low and irregular wages staff receive.

Monitoring procedures are described in the document *Hangjin District Irrigation Water Monitoring and Measurement Procedures*, discussed in Section 3.4. Here, we note the requirement that station staff monitor water levels and flows through gates regularly, and that the frequency of measurement increases when water levels and flows fluctuate significantly.

Figure 50: Existing monitoring and recording equipment

5.7.2 Monitoring needs

A key argument is that while existing monitoring arrangements are transparent and trusted by WUAs (see Section 5.5), the demands placed on station staff are unsustainable. Moreover, future pressure to reduce the GWEs (e.g. because the district's water permit has to be shared among more farmers), may increase pressure for more accurate monitoring of allocations.

In this context, how could arrangements be improved? We look first at the performance criteria any upgraded system would have to meet. These are summarised below:

- Automated monitoring and data transmission. Automated systems are more accurate and less-labour intensive than manual ones, eliminating the need for station staff to travel between and monitor individual sites.
- Rapid calculation and easy access to data. Data calculation and analysis should be quick and accurate, and data interrogation should be simple and direct. At present, data enquiries can only be answered by sifting through large numbers of paper records.
- Remote control and monitoring of main sluices. The HIMB should be able to operate sluices on the main and branch canals remotely, avoiding long distance travel for station staff and the need to spend many hours at individual sites.
- Transparency. It is important that an automated system retains the transparency of the existing system. In particular, WUA managers and farmers should have easy access to information on water deliveries to WUAs to build confidence in the quota-based certificate and ticketing arrangements discussed in Section 5.3.
- Affordability. Any upgraded system needs to be affordable in terms of both capital costs, and the ongoing costs of repair and maintenance. Benefits can

help off-set costs, however, and are likely to include time (labour) savings for HIMB, and water security-income gains for farmers (through more timely and reliable water delivery).

- Durability and security. An upgraded system must be able to cope with the sediment-laden inflows of the Yellow River, and not require constant adjustment and maintenance. It should also be equipped with alarms to increase security, and data security and virus protection should be included.
- Ease of use. Finally, the system must be capable of being operated and maintained by station staff.

5.7.3 Monitoring objectives

The overall objective of monitoring is to improve the management and distribution of water in the ID. Specifically, the aim is to support the water rights reforms discussed in the sub-sections above by providing more accurate, timely and comprehensive information on water distribution to all stakeholders. Stakeholders include farmers, WUA managers, HIMB staff and government departments with an interest in ID management.

How can this be achieved? Key tasks can be summarised as follows:

- Establish a system of automated data acquisition and transmission based on the monitoring of gates on main channels and branch channels, down to the level at which WUAs purchase tickets and oversee water deliveries to farmers.
- Establish an information management system that can classify, code, record and store information in such a way that the management needs of all stakeholders are met.

5.7.4 Monitoring framework

The monitoring system proposed for HID combines four key elements:

- Data acquisition and transmission.
- Database platform design (including the operating environment, information exchange and application platform, and a database).
- Operating management systems.
- Norms and security systems.

Figure 51 illustrates how these four components link together to form a complete monitoring framework, or system. They are discussed further below.

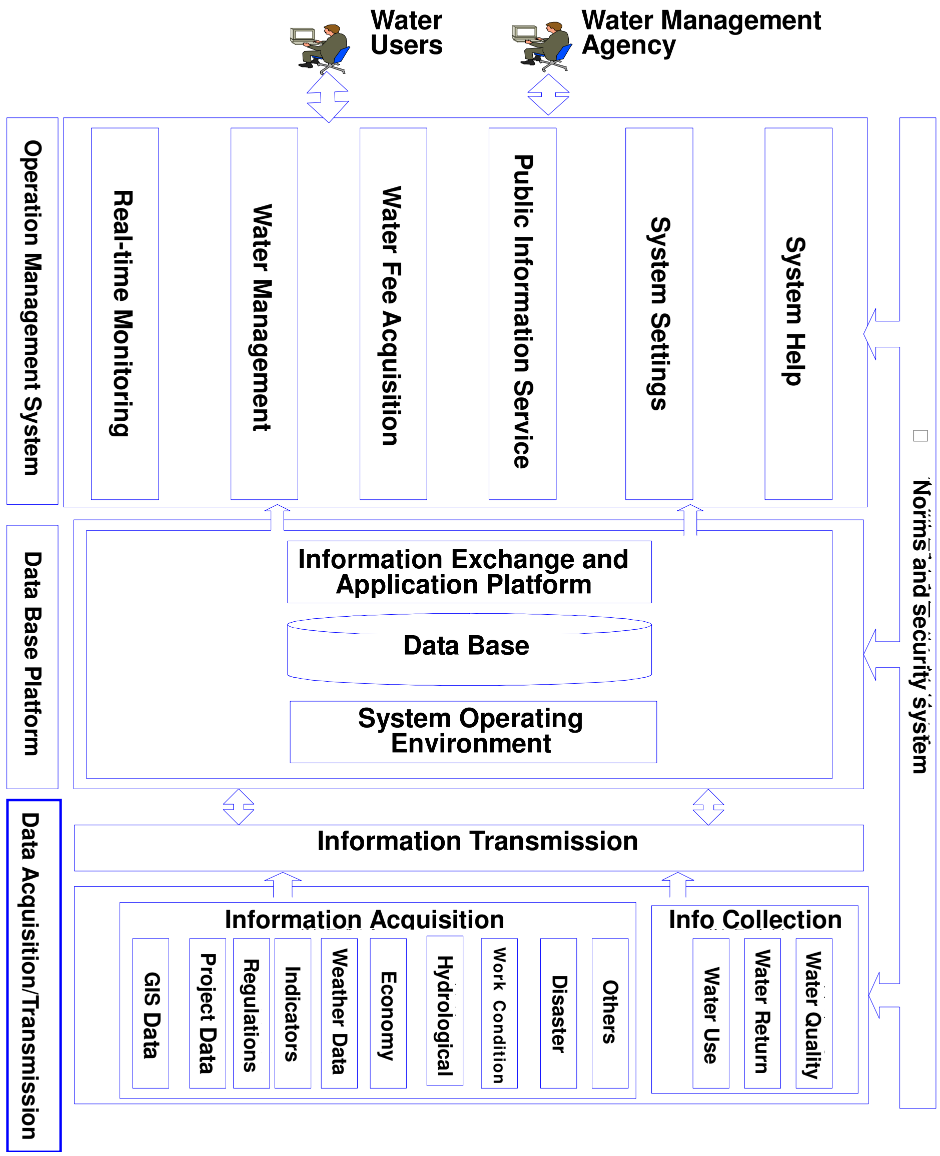
Data acquisition and transmission systems

The data requirements for building the system and adapting it to local circumstances include: geo-spatial references, water infrastructure, management regulations, planning and control indicators, meteorological data, socio-economic data, water diversion and delivery data, and data on return flows. Transmission systems would deliver both real-time and periodic information.

Data base platform

The basic data platform includes a system environment, database and information exchange and an application control platform.

Figure 51: Proposed monitoring framework



The data base platform provides the basis for information exchange and data sharing. Through this platform, water resources management departments at all levels can obtain and share timely water information, enhancing cooperation. ID managers, in particular, will be able to search for and analyse information quickly, speeding-up decision making.

Operation management system

The operation management system is the core of the whole system. It provides comprehensive information and technical support for water resources management and supports efficient water use and distribution. It can also help identify appropriate management actions when environmental factors change. Water supply and demand information, and the status of channel sluices, would be displayed on computer screen.

Norms and security system

Standards and norms are necessary in any monitoring system. Compliance with state and industry standards is to be expected. In addition, ‘internal’ benchmarks will also need to be defined and applied. As the system is modular (composed of separate sub-systems), compatibility is essential for both current operation and any future expansion.

The monitoring system needs to be carefully protected. Security systems need to cover equipment and facilities, data security, firewall and anti-virus software and router configuration requirements.

5.7.5 Data acquisition and transmission

Data acquisition and monitoring frequency

The ID should set the frequency of water measurement and transmission according to management needs. For important sections of the main channels, real-time measurement and transmission of data on water flows and water levels is required. For branch and fourth level channels, measurements can occur hourly or daily. However, at the sluices on fourth level channels where WUAs purchase water from HIMB, real-time monitoring should occur.

Ideally, monitoring equipment should be installed at each gate (monitoring station). However, the system may need to be developed incrementally if funds are limited. The main monitoring priority is to provide accurate and timely information on water deliveries to WUAs, as this provides the basis for assessing compliance with water certificates and payment for water deliveries. Hence, the installation of monitoring stations at HIMB-WUA gates should be a priority.

Data precision

Again, the level of data accuracy required will depend on the type of management decisions the data needs to support. Since flows through fourth level sluices where WUAs purchase water are relatively small and directly affect WUAs’ water fees, measurement at this level needs to be most precise.

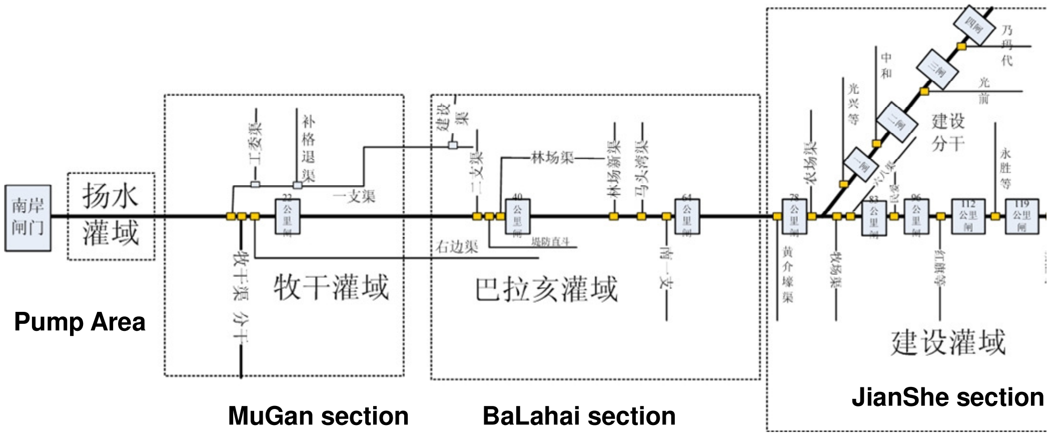
Monitoring equipment

In all cases, it will be necessary to fully evaluate and compare systems available in the market according to different criteria (see criteria listed above). Cost is one factor, but not the only one. The experience of other IDs where modern monitoring systems have been installed should also be sought.

Location of monitoring stations

Figure 52 shows the channel and gate layout of HID. We propose that monitoring stations are installed on all control gates, with real-time monitoring in fourth level channels to support management of WUA-GWEs.

Figure 52: Channel layout and proposed monitoring stations



Information transmission network

Based on management needs and the successful experience of using public communication networks, the proposed network programs for HID are as follows.

HIMB staff can operate the monitoring system through a water resources management *WAN system*. This is convenient and does not require any separate network.

The China water resources management information network already provides a unified transmission platform for flood prevention and drought control, water resources management, water quality monitoring, water and soil conservation, hydropower and electrification. It is one of the most important information technology infrastructures in China. Other users (e.g. government departments) can access the system through the *internet.* Security measures will need to be put in place to protect data exchange between internal and external networks. We propose that farmers and WUA managers continue to access information on water use through the bulletin boards on HIMB station walls.

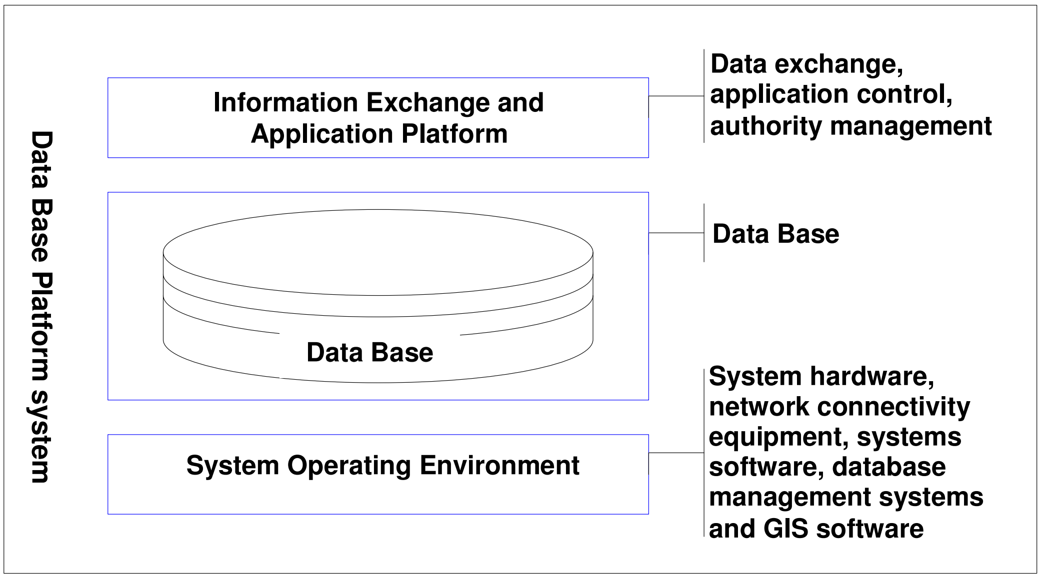
Real-time data transmission can occur through the *public mobile phone network*. This is well developed in China. Both the GPRG and GSM networks of China Telecom, and the CDMA network of China Unicom, are mature and enjoy the benefits of wide coverage, advanced technology, good service, strong stations, stable and reliable communications and low cost. In addition, other real-time data monitoring systems have used the GSM network for some years, with good results.

At present, CDMA is faster than GPRS, but the signal quality of CDMA is lower in rural areas and coverage not as good. In this context, we would therefore recommend using the GPRS network for real-time data transmission. The GPRS network has wide coverage, high reliability and low costs, and can be used in remote areas such as Hangjin with a unified platform for data reception. All water abstraction data can be transmitted through this platform at time intervals determined by the 'volume' of data collected (which will vary over the year). Generally, a single transmission of data through SMS will not exceed 1 KB. The cost of a monitoring terminal is likely to be less than ￥10.

5.7.6 Database platform

The database platform provides an operating environment (hardware and software) for the water monitoring system, while also providing information exchange and application control services. The platform structure is illustrated in Figure 53 below.

Figure 53: Proposed database platform



The operating system provides the basic operating environment for the whole monitoring system, including system hardware, network connectivity equipment, systems software, database management systems and GIS software. The operating system ensures monitoring system stability, reliability, security and maintainability. It is the physical basis for water metering and monitoring systems.

The information exchange and application control platform is the control centre for information storage, maintenance, exchange and application. Its mission is to provide system-level services for the operation of the management system in order to facilitate information exchange and provide unified identity authentication, including access control, security control and an application program interface.

The water database is the core of monitoring system. All data is coded and stored here.

5.7.7 Operation management system

The functions of the operation management system in HID are as follows:

Data acquisition and receipt

Firstly, to receive and validate monitoring data from each station. Secondly, after processing, to record and store information in the database for future reference.

Database maintenance

To display and print data sets; updating of the database; data searches, changes and recording; and automatic archiving, backup and recovery to prevent data loss.

Statistical compilation and analysis

To analyse and summarise real-time, hourly, daily, monthly and annual data recorded by the stations, and also to assist in the calculation of water fees and fee-based enquiries.

Graphics display

Displays may include: monitoring sites (stations and terminals) and network maps; instantaneous and cumulative flow dynamics; real-time dynamic process flow curves; water abstraction curves; comparative 'column curve' of total water use and water fee payment.

Statements

Various tabular statements can be produced. These include: real-time water abstraction tables and tables of total abstraction for a period; tables of daily, monthly and yearly water abstraction; historical flow tables (tables based on historical flows); real-time water fee tables and equipment tables.

Enquiry and search functions

These may include enquiries about: historical water use and real-time traffic data (with corresponding tables); equipment status (with corresponding tables); water fee acquisition status (with corresponding tables), including payment by household.

Alarm functions

To report anything abnormal at the monitoring sites (stations and terminals).

Authority functions

Establish the authority and access conditions for different users.

Data backup functions

To provide automatic data backup functions, with no data loss if communications failure. All data can be retrieved within 30 days of the failure.

Operating log function

Record the operating log automatically.

Online Help

Provides online help functions and a user-friendly search function.

5.7.8 Schedule and system management

Schedule

Installing the monitoring and metering system proposed for HID is a major undertaking. We suggest that work is divided into two phases to 2010:

- 2008-2009 (1st phase): complete design of the monitoring system; complete the database, the infrastructure of information acquisition, transmission, storage and their major application systems; build monitoring sites in the main channel.
- 2009-2010 (2nd phase): build monitoring sites in sub-main and branch channels; complete the water monitoring system as well as the water fee acquisition and management system, and put both into use.

Operations and Management

- Develop management standards, technical standards, regulations and broad terms of reference for HIMB staff.
- Formulate a unified security strategy to improve safety management and ensure system security, based on international and domestic design principles and practice.
- Provide technical training for system operators.
- Estimate the annual budget needed to operate and maintain the system, and include in the annual budget of the ID.

Staff training

HIMB staff will need to be involved in the final design and installation of the monitoring system. They will also need training in system operation once it has been completed. The training approach may include:

- Training courses: technical training on standards, the common platform and system application. Courses would be organized at three levels - decision-making, management and technical training. Courses could be entrusted to a college.
- Training certification: system operators should be certified, so a formal qualification and certification system should be developed.

Chapter 6: Summary and recommendations

The pilot study used the example of HID, located on the Yellow River in Inner Mongolia, to demonstrate the application of the WET framework within an irrigation district context. The objective of the pilot was to show how water – taken by the irrigation district under its water abstraction permit – could be allocated to both WUAs, and to the farmers within them. The allocation process was designed to be consistent with the overarching allocation process for the Yellow River.

This activity involved the following six parts:

i. **Rights definition and allocation**: The study has demonstrated how all diversions and losses within the irrigation district can be accounted for, and how WUAs can be assigned volumetric quotas – in the form of GWEs - on the basis of irrigated area, crop water quotas and conveyance efficiencies. A hydrological model of the district was built for this purpose. The result is an allocation plan for the district that assigns proportional rights to each WUA. Individual WUAs would then be responsible for sharing that volume amongst their members.

ii. **Water certificates**: The study evaluated the role water certificates could play in formalising the GWEs defined above, and in providing information to WUAs on their 'quota status' over the course of a year. The study also examined how certificates could be combined with existing water ticketing arrangements to ensure that water purchased by WUAs, on behalf of farmers, occurs within quota.

iii. **Water use planning and scheduling**: The study has developed a model-based planning system for allocating the rights defined above between and within irrigation periods in a way that is fair and transparent. The spreadsheet-based model allocates water between WUAs based on the YRCC's *Annual Allocation Plan* and *Annual Regulation Plan*. It incorporates annual caps on water diversions to WUAs (the GWE) and scheduling plans for low flow periods. The model is consistent with, and able to adapt to, the Yellow River allocation process.

iv. **Assessment of the role of water user associations**: WUAs are currently involved in the purchase and distribution of water to farmers. Changes to existing rights (to specify group entitlements) and ticketing arrangements will have implications for the role of WUAs, though the allocation system will continue to combine bulk delivery to WUAs with area-based charging for farmers. Discussions with WUAs and farmers, and a formal survey conducted in October 2007, provided information on the performance of existing payment and water accounting procedures. These generally work well, and provide a good basis for quota-based management.

v. **Metering and monitoring**: An assessment of current monitoring and metering arrangements, together with the requirements to support the proposed allocation and management system, was completed. Based on this, a plan for upgrading the existing system has been prepared.

vi. **Water trading**: Current practices of transferring water saved via channel lining are popular, although it has created challenges for the Irrigation District Management agency as its revenue has been reduced. A conceptual model for water trading, based on the use of a water bank, has been developed. The water bank would act as a mechanism for "pooling" water savings and then selling the saved water to interested parties. The bank would be designed to overcome the high transaction costs associated with trading small volumes of saved water.

Findings and Recommendations

- The use of an allocation plan to allocate water to WUAs is feasible. The annual allocation process can be aligned both with the YRCC's *Annuql Allocation Plan* and *Annual Regulation Plan*. The result is a process that is easier, more transparent, and fairer.
- The allocation process undertaken has identified "unallocated water", i.e. water in excess of the current water requirements in the district (but within the volume allowed under the district's permit). This means this water can be allocated to the new agricultural land that is being developed in the district. This can now occur in a way that will allow other farmers to have confidence that allocations are fair, and that there will not be an impact on the availability of water to them.
- Transmission losses have now been formally quantified and allocated (up to the purchase-point by WUAs). This will simplify the process for future trading of transmission losses and will also increase the confidence of WUAs that any trading is being done in a fair way that will not impact on their water supply.
- Existing contract and ticketing procedures operating between HIMB and WUAs are well understood and respected. They provide an excellent platform for the introduction of GWEs and ticket-linked water certificates. Procedures for distributing water to farmers within WUAs generally work well, though water accounting and payment methods vary. Those WUAs that have set up systems of continuous water accounting between irrigations, and volumetric delivery to

(and billing of) individual production teams, will be better able to meet new quota obligations in a fair and transparent manner.

- Water trading has reduced the revenue available to HIMB. The issue of funding will need to be addressed to ensure the long-term sustainability of the trading program and channel infrastructure, and to protect farmers' long-term water rights.
- While existing monitoring arrangements work well, and are respected by WUAs and farmers, any future pressure to reduce GWEs may increase demand for more accurate and timely measurement. A key priority will be to strengthen monitoring of water deliveries at WUA purchase points, as monitoring here affects both WUA payment and compliance with GWEs.

PART 5: SUPPORTING A WET SYSTEM – THROUGH MODELLING, ACCOUNTING & IN AN URBAN CONTEXT

Chapter 1: Water resources management modelling

1.1 Introduction

One of the objectives of the WET Project, Phase 2, is to provide a scientific and quantitative basis for water resources allocation and planning in China via the use of water resources management (hydrology) models. The selected water resources management model(s) should (ideally) be able to:

- take into account both surface water and groundwater sources in a basin;
- support the definition of water rights; and
- be used for the preparation of water resources allocation plans and setting up water transfer rules.

Seven international and five domestic water resources management models have been reviewed and evaluated to assess their suitability to meet the above objective of the WET project. An overview of the functionality required from a model to serve this purpose and an assessment of the ability of available models to meet this need are also provided. Based on the findings of the model review, a short-list of models that can be considered for water resources management and water allocation modelling in China has been prepared.

A preliminary water resources management model, using the Integrated Quality and Quantity Model (IQQM), has been built for the Jiao River basin to support the pilot work undertaken in Taizhou, specifically in respect of water resources allocation planning and defining environmental flows. Initially, it was intended that the development of the Jiao River model would be preceded by the above review of available models to select the preferred model(s) for WET in China. However, due to time constraints, work on the model development had to commence prior to the availability of the findings of the model review. It is noted that regardless of which model(s) is ultimately adopted, the IQQM built for Jiao River provides a mechanism for demonstrating the application of a water resources management model in China, in addition to supporting the pilot work in Taizhou.

This chapter of the report contains four further sections and is structured as follows:

- Section1.2 reviews and evaluates a selection of internationally available water resources models;
- Section1.3 reviews and evaluates domestically available water resources models;
- Section1.4 describes the development and application of the IQQM for the Jiao River basin;

- Section1.5 provides the conclusions and recommendations of the model review; and
- Section1.6 is a list of references used in this chapter.

1.2 International Models

1.2.1 Overview

General

The seven internationally available water resource management models selected for review are listed in Table 54.

Table 54: International models selected for review

Model	Country of Origin
AQUATOR	United Kingdom
IQQM	Australia
MIKE BASIN	Denmark
REALM	Australia
RIVERWARE	United States
SWAT	United States
WEAP	United States

It should be noted that the findings presented in this report are based on a desktop review of publicly available literature on the above models. None of the models have been tested on any Chinese or other river systems as part of this review.

This section of the report provides a summary and comparison of the technical and non-technical aspects of the different models reviewed in this study. A detailed description of each of the models listed in Table 54, including their key features and capabilities, data requirements, reported usage, system requirements, purchase and training costs, availability of technical support, and apparent strengths and limitations for application in water resource management modelling has also been prepared. This can be made available on request.

Functionality

To meet the objectives of the WET Project Phase 2, the desirable functionality of the selected water resources management (hydrology) model include the ability to simulate:

- water resource allocations and abstractions for different types of water users: regulated water users (urban, agricultural, industrial, etc), unregulated water users, environmental flow requirements and transmission losses;
- interconnected reservoir systems and reservoir operating rules;
- conjunctive use of surface and groundwater;
- water quality management;
- return flow management;
- water resources management planning;
- water sharing between different jurisdictions; and
- Water allocation accounting.

To be able to meet the above functionality requirements, the selected model(s) should ideally have the ability to undertake the following:

- route flows in the streams and channels;
- operate on and off-river reservoirs;
- operational management of multiple reservoirs;
- interaction of groundwater/surface water processes;
- simulate losses from the river system (evaporation, seepage, etc);
- estimate irrigation demands, crop water demands, orders, diversions;
- simulate fixed demands such as town water supply and industrial demands;
- simulate hydropower demands;
- simulate flows into effluent channels and return flows from effluent channels;
- take into account minimum flow requirements;
- simulate wetland demands and floodplain storage characteristics;
- take into account water sharing for both regulated and unregulated river systems;
- resource assessment and water accounting; and
- take into account inter-provincial water sharing agreements;

1.2.2 Model Types

The water resource management models can generally be categorised into two types on the basis of the mechanism used for water allocation within the water supply system[76]:

i. models using a heuristic procedure guided by user defined objectives (these models use a rule-based logic approach to simulate the operation of a river system); and
ii. models using a mathematical program, usually a network linear program with user-defined penalties and priorities (these models use an optimisation approach to simulate the operation of a river system).

Of the models reviewed in this study, AQUATOR, IQQM and SWAT fall into the first type. REALM and WEAP fall into the second type. MIKE BASIN and RiverWare claim the ability to simulate the operation of a river system under either mechanism.

1.2.3 Evaluation Criteria

When comparing and evaluating the different models for their suitability to meet the modelling requirements outlined above, the following technical and non-technical criteria were considered.

Technical criteria:

- Model functionality and capability.
- Model complexity.
- Data requirements.
- Processes included/excluded.
- Ability to model both water quantity and quality.

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[76] Kuczera, 1992.

- Ability to model both surface water and groundwater use.
- Ability to interface with GIS systems.

Non-technical criteria:

- User friendliness and ease of use.
- Skill level required to set up and run the model.
- Ability to support water resources management planning.
- Purchase and maintenance costs.
- Availability of technical support.

Note that the technical performances of the various models and their ability to produce accurate results have not been assessed in this review.

1.2.4 Comparison of Models

Table 55 shows a summary and comparison of the technical and non-technical aspects of the different water resource management models reviewed in this section. A report including a detailed analysis of each of the models is available on request.

In addition to the features and capabilities of the various models, the model cost is likely to be an important factor in the selection process. Model costs include the cost of purchase of the software plus the maintenance and update fees involved. Table 55 includes a summary of the expected costs for a single license of each model. It is likely that discounts will be available for multiple license purchases.

Users of all models reviewed in this section are likely to require comprehensive training in the use of these models. Significant costs are likely to be associated with this training. Table 55 also includes a summary of the available information on training and expected training costs.

1.2.5 Summary of Findings

The suitability of seven different water resource management models for use in water resource allocation and planning studies in China has been assessed. Table 55 provides a summary and comparison of the key technical and non-technical aspects of each of the models reviewed. The key strengths and limitations of the different models with respect to their usefulness in water resource management investigations are summarised and compared in Table 56.

In an overall sense, and from a technical point of view, six out of the seven models reviewed are potentially suitable for use in water resources management investigations in China. However, all six models are not suitable to model all river systems. The preferred model would generally depend on the modelling objective (assess broad scale planning issues versus investigate detailed operational strategies) and the model functionality required for the specific application. For example, not all applications will require groundwater modelling, water quality modelling and/or river routing. If some of these processes are not significant for a particular application then there is a wider choice of suitable models for selection.

Table 55: Comparison of reviewed water resource management models

Details	AQUATOR[a]	IQQM	MIKE BASIN[b]	REALM	RiverWare[a,c]	SWAT[d]	WEAP[a]
Country of Origin	UK	Australia	Denmark	Australia	USA	USA	USA
Technical Criteria							
Simulation Type	Rule Based	Rule Based	Rule Based or Optimisation	Optimisation	Rule Based or Optimisation	Rule Based	Optimisation
Functionality & Capability	Adequate (with some customisation)	Adequate	Good	Adequate (for 'Broad Scale' Planning Studies)	Adequate	Inadequate (because of the insufficient flexibility to model water demand & resource management)	Adequate (for 'Broad Scale' Planning Studies)
Conjunctive Use of Surface & Groundwater	Yes	Yes (but limited)	Yes (Comprehensive)	Yes (but limited)	Yes (but limited)	Yes (Comprehensive)	Yes
Water Quality Modelling	No	Yes (but not fully tested)	Yes (but requires purchase of additional WQ module)	Yes (but limited)	Yes (limited)	Yes (Comprehensive)	Yes (but limited)
Detailed Irrigation Demand Modelling	No	Yes	Yes (but requires use of separate Irrigation module)	No	No	Yes	Yes
River Routing	No	Yes	Yes	No	Yes	Yes	No
Simulation Time Step	Daily	Daily	Flexible - daily to monthly	Flexible - daily to monthly	Flexible - Hourly to Monthly	Daily	Flexible - daily to monthly
GIS Interface	No	Yes (but limited)	Yes (Comprehensive)	No	No	Yes (with add-on software)	Yes (but limited)
Data Requirements	Medium-High	High	High (for detailed analysis)	Medium	High	Very High	Medium
Model Complexity	Medium-High	High	High	Medium	High	Very High	Medium
Modelling Flexibility	Good	Good	Good	Fair	Good	Poor	Good
Non-Technical Criteria							
User Friendliness / Ease of Use	Medium (easier with working knowledge of VBA)	Medium	Low-Medium (easier with working knowledge of ArcView)	Low-Medium (easier for less complex river systems)	Low-Medium (easier with working knowledge of in-built programming language)	Low	High

Details	AQUATOR[a]	IQQM	MIKE BASIN[b]	REALM	RiverWare[a,c]	SWAT[d]	WEAP[a]
Skill Level Required to use model	High	Medium-High	High	Medium	High	High	Medium
Operating System	Windows	Windows	Windows	Windows	Windows or UNIX	Windows	Windows
Chinese Menus	No	No	Yes?	No	No	No	Yes
Reported Applications	UK	Australia, Mekong River Commission	Numerous Countries in North & South America, Asia, Europe, Australasia & Africa	Australia	USA	Mainly USA	12 Countries across 5 continents
Model Purchase and Maintenance Costs							
Purchase Cost	Sterling 12,500	AUS$ 2,000-3,000	Euro 7,000	Free	US$ 6,500	Free	Free
Annual Maintenance Cost	Sterling 1,563	Not Known	Euro 700	Free	US$ 2,500	Free	Free
Associated Software Costs			WQ Module – Euro 3,000 (+Euro 300 Annual Maintenance) ArcView GIS– RMB 18,750				
Model Training Costs							
Training Cost	2 days free as part of purchase price	Dependent on the number of trainees, duration, location, etc	2 day basic training – RMB 2,200 per trainee	Dependent on the number of trainees, duration, location, etc	3 day training course – US$1000 per trainee	3 day beginner course – US$500 per person	3 day course – US$1000 per trainee
Technical Support	User support available via email, telephone	Limited free user support	Available via the Shanghai Office – Cost not known	Limited free user support	US$100 per hour	Cost not known	Limited free support

Notes:

a – additional costs to cover transport, accommodation, etc expenses will have to be negotiated, if training is to be held in China

b – Training courses held in Shanghai, additional costs will be incurred if training is to be held elsewhere. Costs for advanced training not known

c – Purchase includes 15 hours user support

d – Training courses held in Texas, USA, additional costs to be incurred if training is to be held elsewhere. Costs for advanced training not known

Table 56: Summary and comparison of model strengths and limitations

	AQUATOR	IQQM	MIKE BASIN	REALM	RiverWare	SWAT	WEAP
Key Strengths	‣ Ability to be used on complex river systems (although this may require extensive user customisation of the model) ‣ Flexibility to customise the model as little or as much as the user wishes to accurately represent the river system operations ‣ Ability to overcome most of the model limitations by extending and customising the model using in-built or third-party programming tools ‣ Ability to model conjunctive	‣ Ability to model complex river systems with complex operating rules ‣ Availability of extensive water accounting, including complex water sharing features ‣ Comprehensive irrigation demand modelling capability ‣ Ability to undertake river routing ‣ Ability to simulate behaviour of large river systems on a daily time step ‣ Comprehensive in-built data interrogation & manipulation tools ‣ Low purchase & maintenance	‣ Ability to model complex river systems ‣ Availability of water accounting, water rights & water quality compliance modelling ‣ Ability to run the model in both rule-based simulation or optimisation modes ‣ Ability to fully integrate the model with GIS ‣ Ability to model conjunctive surface & groundwater use ‣ Ability to undertake comprehensive water quality modelling ‣ Ability to undertake river routing ‣ Ability to run the model on	‣ Input data requirements are modest ‣ Ability to undertake broad scale water resource planning studies relatively easily ‣ Low purchase & maintenance costs	‣ Ability to model complex river systems ‣ Flexibility to configure model on the basis of data availability, desired resolution, time step, etc ‣ Ability to run the model in both rule-based simulation or optimisation modes ‣ Ability to model conjunctive surface & groundwater use ‣ Ability to undertake water accounting & water rights administration tasks ‣ Flexibility to model key hydrologic processes using alternative methods ‣ Ability to	‣ Availability of sophisticated tools to model hydrologic processes, including groundwater ‣ Availability of sophisticated tools to model water quality, irrigation & land use impact on rainfall-runoff behaviour ‣ Ability to model surface & groundwater interaction comprehensively ‣ Availability of the software free of charge	‣ Ability to address broad scale water planning & resources allocation problems & issues relatively easily ‣ Availability of a Chinese version of the model ‣ Ability to investigate conjunctive use of surface & groundwater use ‣ Ability to undertake water accounting & water sharing investigations ‣ Ability to operate model with a modest

	AQUATOR	IQQM	MIKE BASIN	REALM	RiverWare	SWAT	WEAP
	surface & groundwater use • Ability to undertake some economic analyses of water allocations	costs	different time steps • Availability of a local agent & technical support • Ability to undertake some economic analyses • Extensive usage of the model around the world		undertake river routing • The ability to run the model on different time steps		amount of data • Ability to undertake some economic analyses (cost-benefit analyses of water projects) • Availability of the software free of charge
Key Limitations	• Limited in-built options for water resource management operating rules • Applications to complex river systems may require significant customisation (This in turn requires the user to have technical expertise & good programming skills)	• Water quality aspects of the model have not been thoroughly tested • Ability to interface with GIS is limited • Ability to model conjunctive surface & groundwater use is limited • Uncertainty about future development & maintenance of the model • Uncertainty	• Require a high skill level to set up model • Require a good working knowledge of ArcView GIS • Application of the model requires significant data for detailed analysis • Effective application of the model requires add-on software such as ArcView GIS & water quality modules,	• The model is not generally suitable for large river systems where daily time steps are required • It is difficult to incorporate complex river & storage operation rules • Water quality modelling is limited • There is no GIS interface • There is no in-built river	• Require a high skill level to set up model • There are no in-built options (i.e. rainfall-runoff modules) to generate river & tributary inflow time series inputs • Groundwater modelling options are limited. • Water quality modelling options are limited • There do not appear to be any irrigation/crop	• The in-built post-processor is poor & therefore the user needs a separate post-post-processor such as AVSWAT • Modelling of water consumption (demand) use have very little flexibility • Reservoir management modelling options are very limited • The model does not have the	• The model is not generally suitable for large river systems where daily time steps are required • There is no river routing • Water quality modelling is limited

	AQUATOR	IQQM	MIKE BASIN	REALM	RiverWare	SWAT	WEAP
	• There is no in-built water quality modelling component • There is no GIS interface • There is no in-built river routing component • The technical units available for use are limited. • There is no water accounting • High purchase & annual maintenance costs • High training costs • Difficulties in obtaining prompt technical support	about the availability of technical support	also a separate add-on irrigation software if detailed crop water demand estimation is required • The use of the model requires a high skill level & extensive training in the MIKE BASIN model and ArcView GIS • Purchase and maintenance costs of the software are high	routing component • There is no irrigation demand modelling • Ability to model conjunctive surface & groundwater use is limited	water demand modelling modules to estimate irrigation demand within the model • The model has a lot of flexibility, but this also makes it more difficult to use for inexperienced users • Incorporation of user defined operating rules requires the user to learn the in-built programming language • There is no interface with GIS • The model purchase & maintenance costs are high	flexibility to specify environmental flow requirements • The data requirements for the model are very extensive • Calibration of the model is quite difficult • The model is quite complex & therefore requires a very high user skill level • The reported daily simulation results from the model are generally not as good as the monthly results • The model is not-designed for the type of water allocation & resource modelling required for this project	

Models such as AQUATOR, IQQM, MIKE BASIN, and RiverWare are more suited to model resource demands on complex water systems governed by water law and intricate operating rules. For broader water resource-related assessments, models such as WEAP and REALM may be preferable because they are less expensive, easier to apply and require less data.

The purchase and maintenance costs of a model, availability of training and the level of technical support available are also likely to be significant issues to be considered when selecting the preferred model.

It is noted that for large river systems and accurate environmental flow modelling, routing of flows to accurately represent flow travel times and attenuation is important. For such applications, the suitable models are generally limited to IQQM, MIKE BASIN and RiverWare.

It is noted that MIKE BASIN is the only model that satisfies all of the desired functionality requirements and technical evaluation criteria outlined in Section 1.2.3. It is also the only model for which technical support appears to be available within China. However, MIKE BASIN is also the most expensive of all the models reviewed in this study.

Based on the overall findings of this review it appears that MIKE BASIN and IQQM are the models best suited for detailed water resource management studies in China. For broader water resource assessment and planning studies WEAP may be preferable because it is much simpler and inexpensive to use.

1.3 Domestic Models

1.3.1 Overview

Based on available information, a wide range of domestically developed and internationally available models are currently used in China for water resources management studies.

The international models currently used in China include:

- WEAP (Water Evaluation and Planning model - United States);
- SWAT (Soil and Water Assessment Tool - United States);
- IQQM (Integrated Quantity Quality Model - Australia);
- MIKE Suite (including MIKE BASIN - Denmark); and
- WMS (Watershed Modelling Systems - United States).

All the international models listed above, except for WMS, have been reviewed in section 1.2 of this report. WMS was not selected for review because it would not be capable of satisfying the requirements of a WET system.

The domestically developed models currently in use include:

- WRAM (Water Resources Allocation Model);
- WEP (Water and Energy Transfer Process Model);
- Xinanjiang;
- YRBM (Yellow River Basin Model); and
- DTVGM (Distributed Time Variant Gain Model).

Section 1.3.2 provides a brief desktop review of each of the above domestic models based on limited publicly available literature. For this review, the adopted model evaluation criteria are the same as those used for the international models. Further, none of the above models have been tested on any river systems as part of this review.

1.3.2 Model Reviews

WRAM

The WRAM model has been developed by the Chinese Institute of Water Resources and Hydropower (IWHR) over the last 20 years. It is an optimisation type water resources management model and is known to have been used in the Yellow River basin and other basins in northern and western China. Very little information is publicly available about this model. It appears that this model can meet the technical requirements sought for WET modelling. However, it is reported to be quite complex and not user friendly. Further, it is unlikely that technical support will be available for users outside IWHR.

WEP

The WEP model has been developed by Professor Jia at the Chinese Institute of Water Resources and Water Power Research. Over the last few years, the model has been expanded to include snow melt and irrigation modules and also for use in large river basins. This model is known to have been applied in the Heihe River and Yellow River basins. However, based on limited information available, this model does not appear to be capable of satisfying the requirements of a WET system.

Xinanjiang Model

The Xinanjiang model, developed by Professor Zhao of Hohai University in 1973, is a rainfall-runoff model rather than a water resources management model. It is the most widely used rainfall-runoff model in China and has been extensively tested and proven for different types of both small and large catchments around the country. Further, it is understood that regional parameters for this model have been estimated for most major river basins in China. For these reasons, this model is eminently suited for estimating Chinese catchment runoff responses to rainfall and therefore to be used in conjunction with other water resources management models (including most of the international models reviewed in this study). That is, the Xinanjiang model can be used to provide river and tributary inflows to water balance models used for water resources management purposes.

Yellow River Basin Model

The YRBM has been developed for daily and monthly simulation of hydrological processes in the Yellow River Basin. There is very little information available on this model, except to say that it has not been applied to catchments outside the Yellow River Basin.

Distributed Time Variant Gain Model

The DTVGM has been developed by Professor Xia at the Chinese Institute of Geographic Sciences and Natural Resources Research. This model is reported to have been successfully used in the Yellow River and Haihe River basins, but there is very little information available on this model.

1.3.3 Summary of Findings

Based on available information, none of the domestic models reviewed in this report are suitable for water resources management and water allocation planning studies in China.

The Xinanjiang model, however, is suitable for the provision of river and tributary inflows to water balance models used for water resources management purposes (including most of the international models reviewed in this study).

1.4 Development and application of the IQQM for the Jiao River Basin

1.4.1 Overview

A preliminary IQQM of the Jiao River basin has been developed and applied to support the pilot work undertaken in Taizhou, specifically in respect of water resources allocation planning and defining environmental flows. The model has been used to demonstrate the assessment of the consequences of different water management scenarios on the reliability of supply to water users and on flows for the environment.

The IQQM of the Jiao River basin developed in this study is essentially limited to the lower Zhu Creek, lower Yong'an Creek, lower Shifeng Creek, Ling River, Yongning River and Jiao River reaches. Flows from the other reaches of the river system have been included as boundary conditions to the model. It is noted that the model has not been calibrated as part of this study.

This section of the report describes the development and application of the model for existing (2004) catchment conditions, proposed 2020 catchment conditions and a range of different potential future water management scenarios in the Jiao River basin. A detailed analysis of the results produced by the model is included in Part 3 of this report.

1.4.2 Model Configuration

Figure 54 and Figure 55 show the conceptual configurations of the Jiao River IQQM for the existing (2004) and proposed 2020 (with Zhuxi and Shisandu Reservoirs) catchment conditions. Note that some model configuration details, including several existing or proposed small reservoirs that would affect the flow behaviour in the modelled river system (e.g. FangShan, Yuxi, Fangxi and HuAo Reservoirs), have not been included in Figure 54 and Figure 55 to provide clarity in the diagrams.

1.4.3 Model Inputs

The IQQM requires a wide range of input data. The following sub-sections present the various data used as input to the model.

Rainfall

Data from four rainfall stations located in the study area were available for this study. Figure 56 shows the locations of these stations. Table 57 shows the period of the available record at each of the stations.

Figure 54: Jiao River IQQM configuration, existing (2004) catchment conditions

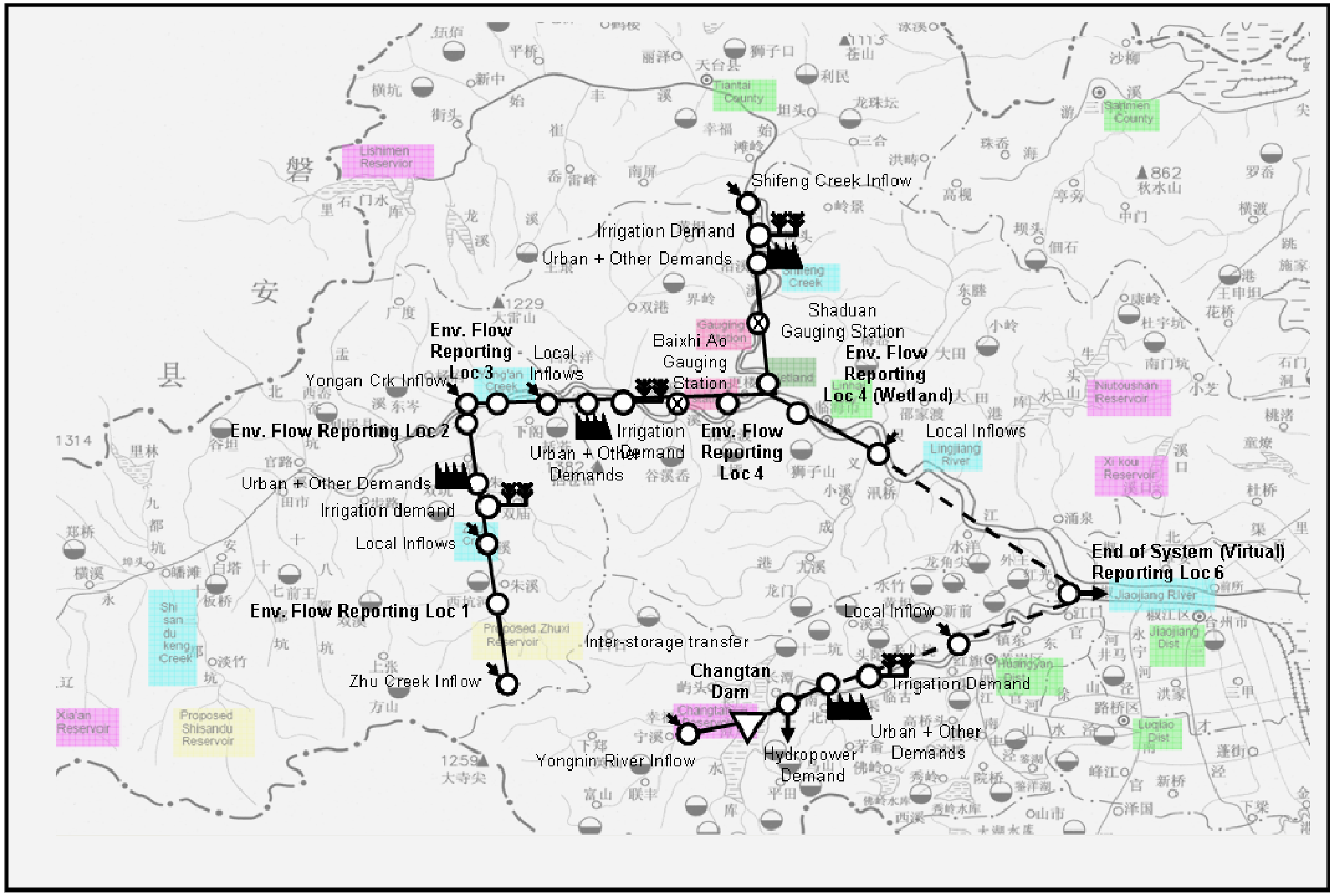


Figure 55: Jiao River IQQM configuration, proposed 2020 catchment conditions

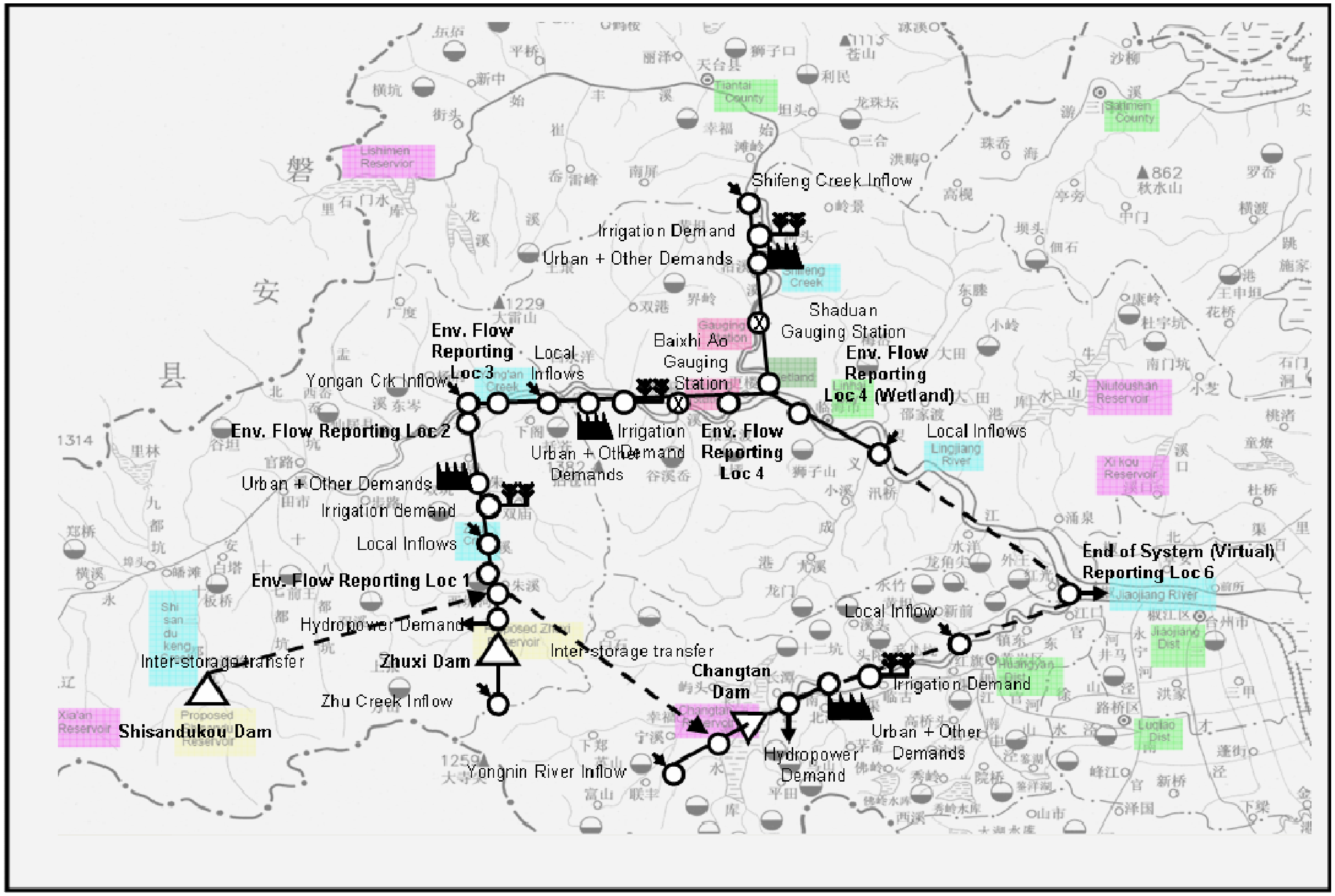


Figure 56: Location of rainfall, streamflow and evaporation stations, Jiao River basin

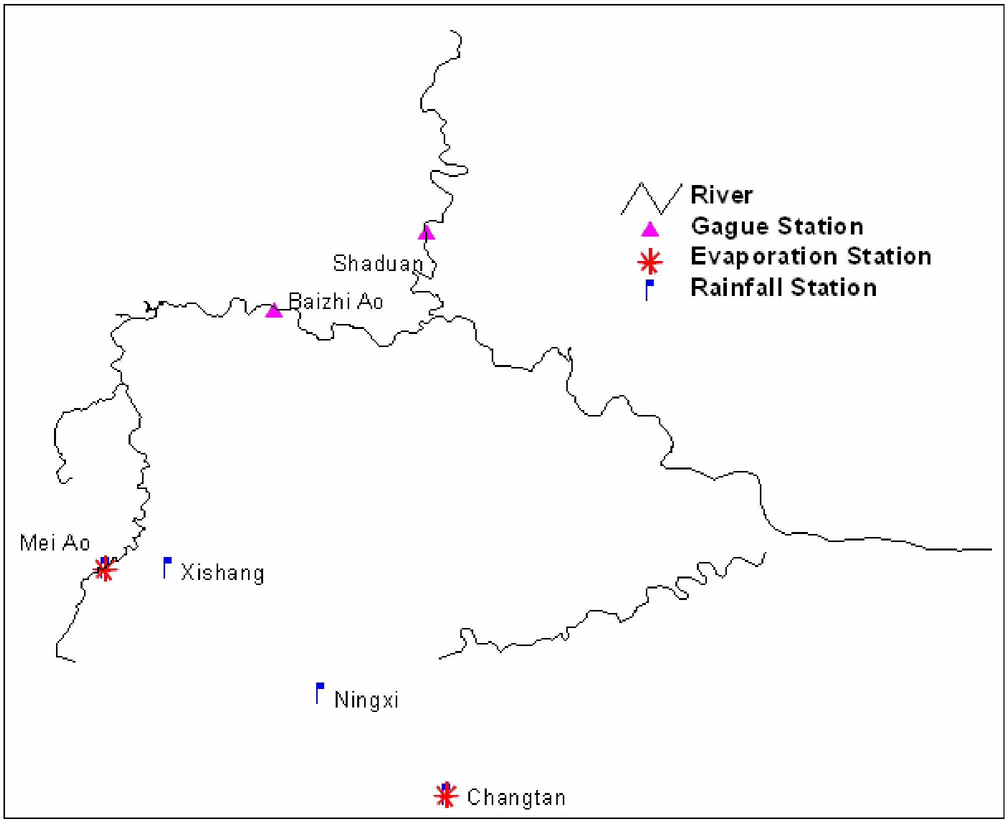


Table 57: Period of available rainfall, streamflow and evaporation data

Data Type	Station Name	Period of Available Data	
		Start	End
Rainfall	Xishang	1957	2006
	MeiAo	1980	2006
	Changtan	1956	2006
	Ningxi	1951	2006
Streamflow	BaizhiAo	1956	2006
	Shaduan	1980	2006
Evaporation	Changtan	1965	2006
	MeiAo	1980	2006

Streamflow

Data from two streamflow gauging stations located in Yong'an and Shifeng Creeks were available for this study. Figure 56 shows the locations of these stations. Table 57 shows the period of the available record at each of the stations.

Evaporation

Data from two evaporation stations located in the study area were available for this study. Figure 56 shows the locations of these stations. Table 57 shows the period of the available record at each of the stations.

Upstream and Residual Catchment Inflows

The IQQM requires time series inputs of river/creek flows at the upstream boundaries of the model and at the residual catchment inflow nodes within each river/creek reach of the model. In this study, these time series inputs were derived by scaling recorded flows at BaizhiAo (Yong'an Creek) and Shaduan (Shifeng Creek) stream gauging stations according to the ratio of catchment areas contributing to the model input location and the representative stream gauging station.

- For Zhu and Yong'an Creek inflows, the scaling was based only on BaizhiAo flows.
- For Shifeng Creek inflows, the scaling was based only on Shaduan flows.
- For Ling and Yongning River inflows, the scaling was based on combined BaizhiAo and Shaduan flows.

Water Demands

Water is abstracted from the various modelled river/creek systems for irrigation, domestic, industrial and other uses. For modelling purposes, all demands other than irrigation demand have been lumped together and modelled as 'urban' demand. Table 58, Table 59, Table 60 and Table 61 show the adopted irrigation and 'urban' demands for Lower Zhu, Lower Yong'an and Lower Shifeng creeks and Yongning River. All demands values show the total volume of water diverted from the creek/river system, including the water that returns to the creek/river system.

Table 58: Lower Zhu Creek water demands, 2004 and 2020 catchment conditions

Year	Irrigation Demand (ML/year)	Urban Demand (ML/year)	Total Demand (ML/year)
2004	16,080	3,650	19,730
2020	16,080	13,505	29,585

Table 59: Lower Yong'an Creek water demands, 2004 and 2020 catchment conditions

Year	Irrigation Demand (ML/year)	Urban Demand (ML/year)	Total Demand (ML/year)
2004	22,250	8,560	30,810
2020	30,900	18,010	48,910

Table 60: Lower Shifeng Creek water demands, 2004 and 2020 catchment conditions

Year	Irrigation Demand (ML/year)	Urban Demand (ML/year)	Total Demand (ML/year)
2004	16,740	5,420	22,160
2020	21,760	8,770	30,530

Table 61: Yongning River water demands, 2004 and 2020 catchment conditions

Year	Irrigation Demand (ML/year)	Urban Demand (ML/year)	Total Demand (ML/year)
2004	330,000	84550	414,550
2020	257,000	529,250	787,150

The same irrigation demand pattern, based on historical data available for the study area, has been adopted for the entire study area. The adopted pattern is shown in Table 62.

Table 62: Adopted irrigation demand pattern, Jiao River basin

Month	% of total
January	0
February	0
March	0
April	4.885
May	7.904
June	9.503
July	21.403
August	19.005
September	26.11
October	8.437
November	0
December	2.753

Proposed Zhuxi Reservoir

Storage Characteristics

The proposed Zhuxi dam has a Full Supply Storage Volume of 98,670ML and an Inactive Storage Volume of 5,140ML. Table 63 shows the Stage-Surface Area-Storage Volume relationship for the proposed dam.

Table 63: Zhuxi Reservoir storage characteristics

Stage (m)	Surface area (Ha)	Stored volume (ML)	Stage (m)	Surface area (Ha)	Stored volume (ML)
83	0	10	130	314	56,100
90	20	720	135	378	73,400
95	35	2,390	140	450	94,120
100	55	5,140	141	460	98,670
105	85	9,210	145	518	118,220
110	125	14,800	150	594	145,920
115	156	21,870	155	664	177,410
120	194	30,640	160	752	212,770
125	260	41,950			

Outlet Characteristics

Table 64 shows the spillway discharge characteristics for the proposed dam. The stored volume-discharge relationship for the proposed lower level outlet of the dam is not available. Hence, it has been assumed that the low level releases from the dam are not restricted by the outlet capacity.

Table 64: Spillway discharge characteristics, Zhuxi Reservoir

Stored volume (ML)	Discharge (ML/Day)
98,670	0
99,232	77,760
118,377	129,600
119,100	155,693
125,000	200,189

Dam Operating Rules

The proposed Zhuxi Reservoir will be a multi-purpose dam with irrigation and 'urban' water supply, flood control and hydro-power generating functions. The dam is to be operated according to the following rules.

- Water supply for irrigation demand would cease when the dam water level falls below 122m (34,820ML).
- Hydropower station would cease operations when the dam water level falls below 120m (30,640ML).
- Water supply for urban demand would continue until the dam water level reaches the inactive water level of 100m (5,140ML).

Flood Control Operations

During the flood season, the Zhuxi Reservoir is proposed to be operated as follows:

- During the period 16th July to 15th October dam water level is to be maintained at 138m.
- During the period 16th April to 15th July the dam water level is to be maintained at 141m.
- During the appropriate periods, flood releases from the dam are to be controlled as follows:
- If the dam water level is between 138m and 141.12m, water is to be released from the dam in a manner ensuring that downstream discharge at the Dazhan Bridge does not exceed 900m^3 per second.
- If the dam water level is between 141.12m and 145.03m, water release is to be increased in a manner ensuring that downstream discharge at the Dazhan Bridge does not exceed 1500m^3 per second.
- If the dam water level is between 145.03m and 145.17m, water release is to be further increased in a manner ensuring that downstream discharge at the Dazhan Bridge does not exceed 1802m^3 per second.
- If the water level rises above 146.29m the release is be increased up to 2317m^3 per second.

Water Transfer to Changtan Reservoir

Water from the Zhuxi Reservoir to the Changtan Reservoir is transferred only if there is sufficient storage in the Zhuxi Reservoir to fully meet its supply obligations along Zhu Creek downstream of the dam, and the storage level in the dam is greater than 56,100ML. Further, water transfers are made only when the following storage volume to average annual flow ratio condition is satisfied. That is, water is transferred only if:

$$\frac{V_{ez}}{W_z} < \frac{V_{ec}}{W_c}$$

Where:

- V_{ez} is the available airspace in the Zhuxi Reservoir.
- W_z is the annual average inflow to Zhuxi Reservoir;
- V_{ec} is the available airspace in the Changtan Reservoir; and
- W_c is the annual average inflow to Changtan Reservoir.

The maximum volume of water that can be transferred from the Zhuxi Reservoir to the Changtan Reservoir (i.e. pipeline capacity) is 363 ML/day. An additional capacity will be available in this pipeline from 2020 to transfer up to 950 ML/day from the proposed

Shisandu Reservoir to the Changtan Reservoir. The long term average transfer rate from the Shisandu Reservoir has been estimated at 410 ML/day.

Environmental Flow Condition

According to the Zhuxi Reservoir design report, the dam has to be operated in such a way as to maintain a minimum environmental flow of 0.14 m^3 per second (12.1 ML/day) at the downstream end of Zhu Creek.

Changtan Dam

Storage Characteristics

The Changtan Reservoir has a Full Supply Storage Volume of 357,000 ML and an Inactive Storage Volume of 1,000 ML. Table 65 shows the Stage-Surface Area-Storage Volume relationship for the proposed dam.

Table 65: Changtan Reservoir storage characteristics

Stage (m)	Surface area (Ha)	Stored volume (ML)	Stage (m)	Surface area (Ha)	Stored volume (ML)
11.05	50	1,000	28.05	2,520	213,000
12.05	150	2,000	29.05	2,655	240,000
13.05	200	3,000	30.05	2,785	267,000
14.05	500	6,500	31.05	2,920	296,000
15.05	600	12,000	32.05	3,050	326,000
16.05	780	18,900	33.05	3,175	357,000
17.05	840	27,000	34.05	3,305	389,500
18.05	940	35,900	35.05	3,430	423,000
19.05	1,200	45,000	36.05	3,550	457,000
20.05	1,400	58,000	37.05	3,670	491,000
21.05	1,600	72,000	38.05	3,780	528,000
22.05	1,800	86,000	39.05	3,885	568,000
23.05	1,900	104,000	40.05	3,995	608,000
24.05	2,000	124,000	41.05	4,100	649,000
25.05	2,105	144,000	42.05	4,200	691,000
26.05	2,240	164,000	43.05	4,310	732,000
27.05	2,480	188,000			

Outlet Characteristics

Table 66 and Table 67 show the adopted low level outlet stored volume-discharge relationship and the spillway discharge characteristics respectively for the Changtan Reservoir. Note that the outlet capacity for stored volumes less than 124,000 ML have been increased (from the values given in the design report) to ensure that the outlet capacity does not restrict the ability of the dam to meet the 2020 demands.

Reservoir Operating Rules

The Changtan Reservoir is a multi-purpose dam with irrigation and 'urban' water supply, flood control and hydro-power generating functions. The reservoir is operated according to the following rules.

- Water supply for irrigation demand would cease when the dam water level falls below 21.05m (72,000ML). Between 21.05m and 23.05m the maximum irrigation release is restricted to 12m^3 per second (1037 ML/day).
- Hydropower station would cease operations when the dam water level falls below 23.05m (104,000ML). Between 23.05m and 24.05m the maximum

hydropower release is restricted to 25m^3 per second (2160 ML/day). Between 24.05m and 26.05m the maximum release is restricted to 50m^3 per second (4320 ML/day).

- Water supply for urban demand would be restricted to 3m^3 per second (259 ML/day) if the dam water level is below 21.05m (72,000ML). An unrestricted supply would be provided if the dam water level is higher than 21.05m (72,000ML).

Table 66: Low level outlet discharge characteristics, Changtan Reservoir

Stored volume (ML)	Outlet capacity (ML/day)	Stored volume (ML)	Outlet capacity (ML/day)
1,000	0	311,000	16,675
72,000	1,500	326,000	17,107
95,000	3,700	341,500	17,625
104,000	3,700	357,000	17,971
114,000	3,750	373,250	18,411
124,000	3,800	389,500	18,835
134,000	4,579	406,250	19,180
144,000	4,579	423,000	19,612
154,000	6,618	440,000	19,872
164,000	7,214	457,000	20,304
176,000	7,931	474,000	20,649
188,000	8,640	491,000	20,995
200,500	9,417	509,500	21,254
213,000	10,281	528,000	21,600
226,500	11,059	568,000	22,204
240,000	12,009	608,000	22,809
253,500	13,046	628,500	23,155
267,000	14,083	649,000	23,414
281,500	15,120	691,000	24,019
296,000	16,070	732,000	24,451

Table 67: Spillway discharge characteristics, Changtan Reservoirs

Stage (m)	Discharge (ML/day)	Stage (m)	Discharge (ML/day)
33.05	0	38.55	103,680
33.55	2,842	39.05	118,108
34.05	8,035	39.55	133,142
34.55	14,774	40.05	148,780
35.05	22,723	40.55	165,024
35.55	31,795	41.05	181,785
36.05	41,731	41.55	199,152
36.55	52,617	42.05	216,950
37.05	64,281	42.55	235,267
37.55	76,723	43.05	254,102
38.05	89,856		

Flood Operations

The Changtan Reservoir is operated in such a way as to maintain maximum monthly stored volumes not exceeding the values shown in Table 68. If the stored volume in any month exceeds the specified target volumes water is released from the dam at a rate of up to 140,314 ML/day.

Table 68: Target monthly maximum stored volumes, Changtan Reservoir

Month	Target stored volume (ML)
January	457,000
February	457,000
March	457,000
April	457,000
May	440,000
June	457,000
July	406,250
August	406,250
September	431,625
October	457,000
November	457,000
December	457,000

Miscellaneous Reservoirs

There are three small reservoirs proposed to be constructed prior to 2020 in the modelled area of the Jiao River basin, but data available for these dams are limited. Table 69 shows the data available for these dams.

Table 69: Details of other proposed reservoirs in the modelled area

Parameter	Yuxi Reservoir	Fangxi Reservoir	HuAo Reservoir
Location	Yong'an Creek upstream of Zhu Creek	Yong'an Creek downstream of Zhu Creek	Ling River Tributary
Catchment area (km^2)	46.32	88.0	17.7
Full supply volume (ML)	22,270	75,500	12,500
Inactive storage capacity (ML)	3,400	7,200	2,200

1.4.4 Model Simulation Runs

Period of Simulation

The adopted period of simulation for this demonstration project was 1980 to 2006 (26 years). This was the period in common for the rainfall and streamflow data available at the key stations in the modelled basin.

Key Assumptions and Simplifications

A number of assumptions and simplifications with respect to model configuration and input data have been made in this study. The key assumptions and simplifications are discussed below:

- There a number of existing large and small dams on Yong'an Creek, Shifeng Creek and Ling River catchments. It is likely that the water demand from these dams would increase between now and 2020. The impact of this demand increase on the modelled system behaviour has been ignored.
- The Fangshan dam (2500ML Full Supply Capacity) located on Zhu Creek upstream of the proposed Zhuxi Reservoir commands about 10.7% of the Zhuxi Reservoir catchment. This reservoir is understood to be used solely for hydropower generation and releases from the dam are understood to enter the Yong'an Creek system rather than returning to Zhu Creek. There is very little information about this reservoir. Therefore, for modelling purposes, it has been

conservatively assumed that Zhu Creek catchment upstream of the Fangshan dam has been diverted to the Yong'an Creek system.

- The proposed Shisandu Reservoir and other associated holding storages would be able to divert up to 950ML/day into Changtan Reservoir depending on their operational rules and storage levels. It was not possible estimate the daily variation in water volumes transferred from the Shisandu Reservoir because those storages are external the current model. In this study, it has been assumed that the water transfer from the Shisandu Reservoir would occur continuously at a uniform rate equivalent to the estimated average daily transfer rate of 410ML/day. Yong'an Creek flows upstream of Zhu Creek have been adjusted appropriately to reflect this diversion.
- It is likely that the proposed Shisandu Reservoir would have to provide regulated water supplies for downstream irrigation and urban demands. These water supplies have not been included in this model.
- For the proposed smaller dams included in the model, the downstream water demands have to been assumed to be a fraction of the Zhuxi Reservoir demand, with the adopted fraction being equal to ratio of catchment areas of the particular dam and Zhuxi Reservoir.
- It has been assumed that the irrigation demand pattern is the same for all irrigation demand users in the model.
- It has been assumed that the urban demands are uniform and constant throughout the year.
- For irrigation demands, the return flow rate for supplies from all creek/river systems, except Yongning River, has been assumed to be 30%. The assumed return flow rate for Yongning River is 3%.
- For urban demands, the return flow rate for supplies from all creek/river systems, except Yongning River, has been assumed to be 50%. The assumed return flow rate for Yongning River is 0%.
- It has been assumed that there are no transmission losses in the modelled river reaches.

Scenarios Analysed

Simulation runs using the Jiao River IQQM have been undertaken for eleven different water management scenarios, including two base case scenarios, over the 26 year period 1980-2006. These simulations runs have been made using the data and assumptions described in the previous sub-sections of this report. The two base case scenarios investigate system performance under:

- current (2004) catchment conditions (Scenario 1); and
- proposed 2020 catchment conditions (Scenario 2).

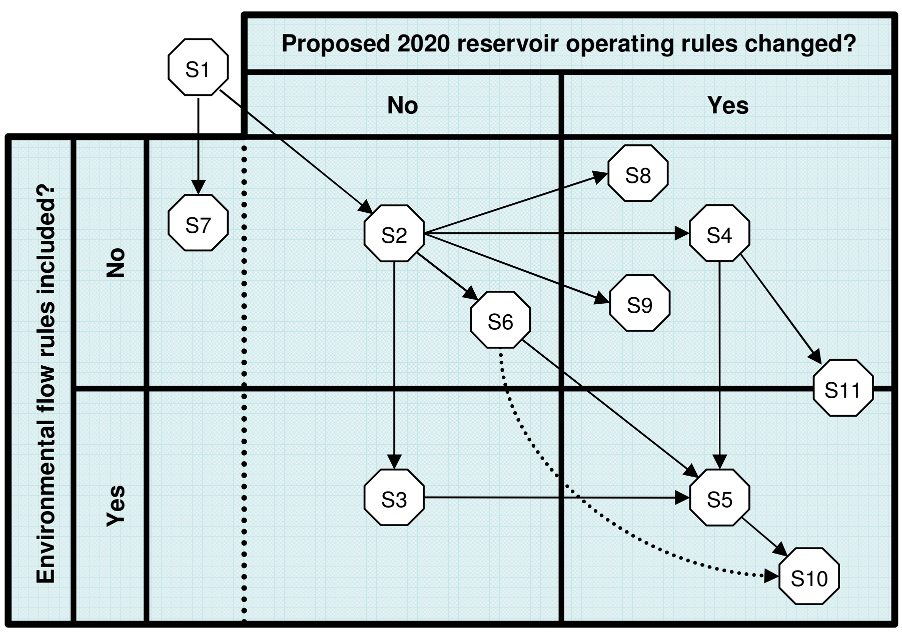
The remaining eight scenarios, except for Scenario 7, investigate the performance of the system under 2020 catchment conditions with and without the imposition of environmental flow requirements; and with different Zhuxi and/or Changtan Reservoir operating rules. Scenario 7 is a special case investigating the system behaviour under 2010 demand conditions if Zhuxi Reservoir has not been constructed by 2010 as proposed.

The reasons for investigating the selected water management scenarios and further details on these scenarios are given in Part 3. Table 70 summarises the eleven different water management scenarios investigated in this study. Figure 57 shows where the different water management scenarios fit with respect to environmental flows and 2020 Zhuxi and Changtan Reservoir operation rules.

Table 70: Summary of water management scenarios investigated

Scenario	Description
S1	Existing (2004) conditions – no Zhuxi Reservoir
S2	2020 conditions – proposed reservoir developments, operations and water transfer rules (from both Zhuxi and Shisandu Reservoirs)
S3	Same as S2, but with environmental flow rules
S4	Same as S2, but with modified Changtan Reservoir operation rules
S5	Same as S4, but with environmental flow rules as recommended
S6	Same as S2, but with additional reservoir with local demands equivalent to Zhuxi Reservoir in the Yong'an Creek catchment upstream of Zhu Creek
S7	2010 demands with no Zhuxi Reservoir and no environmental flow rules
S8	Same as S2, but with no water transfers from Shisandu Reservoir
S9	Same as S2, but with lower release threshold for Zhuxi water transfers to Changtan Reservoir
S10	Same as S5, but with additional reservoir with local demands equivalent to Zhuxi Reservoir in the Yong'an Creek catchment upstream of Zhu Creek
S11	Same as S4, but with alternate (sub-optimal) environmental flow rules

Figure 57: Range of scenarios investigated



Environmental Flow Requirements

Six flow reporting locations have been designated in the IQQM to specify and/or monitor environmental flows. Table 71 lists these locations. Figure 58 is a conceptual diagram showing these locations. The physical locations are shown in Figure 54.

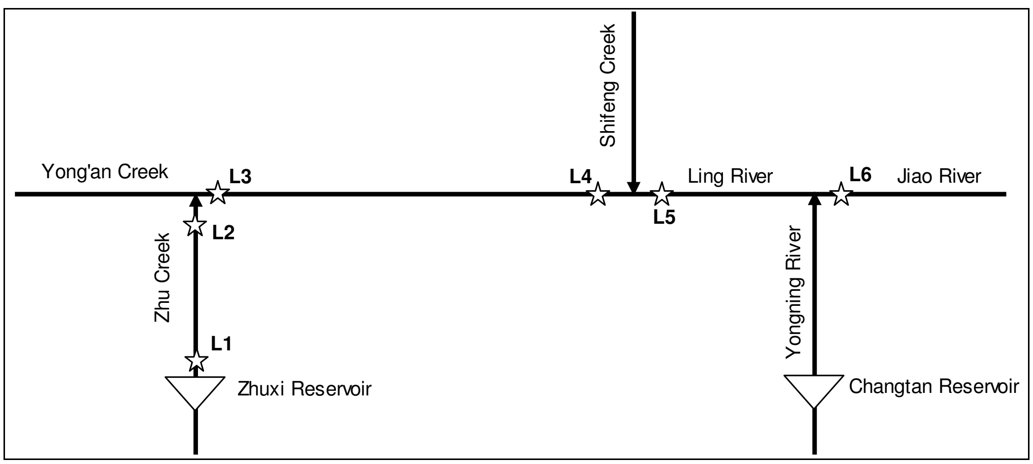
The environmental flow requirements developed for the Jiao River basin (see Part 3) have been imposed on Zhu Creek via the model immediately downstream of the Zhuxi Reservoir (Location 1) and at the downstream end of Zhu Creek (Location 2). The environmental flows requirements imposed for Zhu Creek attempt to mimic natural flow conditions at these locations as much as possible whilst satisfying other water demands from Zhu Creek. The following five types of environmental flow requirements have been specified in the model:

- Low season minimum flows (October to March).
- High season minimum flows (April to September).
- Low season pulse flows (October to March).
- High season pulse flows (April to September).
- Bankfull and overbank flows (Anytime).

Table 71: Environmental flow reporting locations

Location No.	Location Description
L1	Zhu Creek downstream of Zhuxi Reservoir
L2	Downstream end of Zhu Creek
L3	Yong'an Creek downstream of Zhu Creek
L4	Yong'an Creek upstream of Shifeng Creek
L5	Ling River downstream of Shifeng Creek (Wetland location)
L6	Jiao River (Virtual end of system)

Figure 58: Representation of environmental flow reporting locations



A summary of environmental flow requirements specified for Zhu Creek are shown in Table 72. Scenario 11 includes sub-optimal environmental flow rules; some of the flows specified in Table 72 have been altered in terms of size and or frequency. Details of the sub-optimal rules are included in Part 3.

Table 72: The environmental flow requirements specified for Zhu Creek

Flow component	Timing	Months	Flow (ML/day)	Frequency	Duration
Reach 1 (Location 1)					
Low flow	Low flow season	Oct-Mar	43.2	Continuous or less if natural	
High flow	High flow season	Apr-Sep	112.32	Continuous or less if natural	
Low flow pulse	Low flow season	Oct-Mar	1728	2	1 day in Oct-Dec & 1 day in Jan-Mar
High flow pulse	Spawning period	Apr	1728	1	2 consecutive days
High flow pulse	High flow season	May-Sep	1728	4	2 consecutive days *4
Bankfull	High flow season	Anytime	15292.8	0.52	Peak instantaneous (Q PEAK) with rise and fall to achieve (Q DAILY)
Overbank	High flow season	Anytime	16502.4	0.52	Peak instantaneous (Q PEAK) with rise and fall to achieve (Q DAILY)
Reach 2 (Location 2)					
Low flow	Low flow season	Oct-Jan	112.32	Continuous or less if natural	
Low flow	Low flow season	Feb-Mar	293.76	Continuous or less if natural	
High flow	High flow season	Apr-Sep	345.6	Continuous or less if natural	
Low flow pulse	Low flow season	Oct-Dec, Jan-Mar	4579.2	2	1 day in Oct-Dec & 1 day in Jan-Mar
High flow pulse	Spawning period	Apr	4579.2	1	2 consecutive days
High flow pulse	High flow season	May-Sep	4579.2	4	2 consecutive days *4
Bankfull	Anytime	Anytime	34300.8	0.58	Peak instantaneous (Q PEAK) with rise and fall to achieve (Q DAILY)
Overbank	High flow season	Apr-Sep	36979.2	0.58	Peak instantaneous (Q PEAK) with rise and fall to achieve (Q DAILY)

Model Outputs

The IQQM outputs can be used to assess the impact of proposed environmental flow requirements and/or different reservoir management strategies on system performance. The types of outputs produced by the model include:

- reliability of water supply to irrigation and urban users (daily, monthly, annual, etc reliabilities);
- mean and median water supplies for irrigation and urban users (daily, monthly, annual, etc supplies);
- behaviour of storages (variation in inflows, outflows, releases, overflows, stored volumes, etc);
- flows statistics at any location within the modelled river system;
- flow duration curves at key locations; and
- compliance with environmental flow requirements.

The model outputs can be used to compare results of scenarios S3 to S8 with the results for the two base scenarios S1 and S2, and against other scenarios. The difference in results between different scenarios will show the impact of different reservoir management strategies and/or environmental flow requirements on system performance and water supply reliabilities. The IQQM results for the scenarios investigated in this project are analysed and discussed in Part 3 of this report.

1.5 Conclusions and Recommendations

1.5.1 International models

In an overall sense, and from a technical point of view, six out of the seven international models reviewed are potentially suitable for use in water resources management investigations in China. However, all six models are not suitable to model all river systems. The preferred model would generally depend on the modelling objective (assess broad scale planning issues vs. investigate detailed operational strategies) and the model functionality required for the specific application. For example, not all applications will require groundwater modelling, water quality modelling and/or river routing. If some of these processes are not significant for a particular application then there is a wider choice of suitable models for selection.

Models such as AQUATOR, IQQM, MIKE BASIN, and RiverWare are more suited to model resource demands on complex water systems governed by water law and intricate operating rules. For broader water resource-related assessments, models such as WEAP and REALM may be preferable because they are less expensive, easier to apply and require less data.

The purchase and maintenance costs of a model, availability of training and the level of technical support available are also likely to be significant issues to be considered when selecting the preferred model.

It is noted that for large river systems and accurate environmental flow modelling, routing of flows to accurately represent flow travel times and attenuation is important. For such applications, the suitable models are generally limited to IQQM, MIKE BASIN and RiverWare.

It is noted that MIKE BASIN is the only model that satisfies all of the desired functionality requirements and technical evaluation criteria outlined in section 0. It is also the only model for which technical support appears to be available within China. However, MIKE BASIN is also the most expensive of all the models reviewed in this study.

Based on the overall findings of this review it appears that MIKE BASIN and IQQM are the models best suited for detailed water resource management studies in China. For broader water resource assessment and planning studies WEAP may be preferable because it is much simpler and inexpensive to use.

It is noted that none of the models reviewed in this report have been subjected to a comparative technical performance test on a Chinese catchment. Therefore, it is recommended that potentially acceptable models be further evaluated by testing them on a typical Chinese catchment prior to selecting a preferred model(s) to support the implementation of a water rights system in China.

1.5.2 Domestic Models

Based on available information, none of the domestic models reviewed in this report are suitable or can be recommended for water resources management and water allocation planning studies in China.

The Xinanjiang model however is suitable for the provision of river and tributary inflows to water balance models used for water resources management purposes (including most of the international models reviewed in this study). It is recommended that this model be used wherever possible, in conjunction with the selected water resources management model(s), especially for catchments where Xinanjiang models have already been developed as part of other investigations.

1.5.3 Jiao River Basin IQQM

A preliminary IQQM has been developed and applied to the Jiao River basin to support the pilot work undertaken in Taizhou. The model has been able to successfully demonstrate the assessment of the consequences of different water management strategies on the reliability of supply to water users and on flows for the environment.

Although the model has been adequate for the purposes of this pilot study, it is recommended that the model be further developed, improved and calibrated if it is to be used for future formal water resources allocation planning studies in the Jiao River basin. The required improvements to the model include the elimination of the current uncertainties in the input data and minimising the assumptions and simplifications that had to be made for the pilot study.

Further, it is recommended that the period of simulation be increased up to 50-100 years. This will require the development and calibration of rainfall-runoff models for tributary catchments to extend the time series streamflow inputs to the model.

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Chapter 2: Water Accounting in a WET System

Information about water is central to supporting the development and operation of any water management system. Water information is used to formulate policy and to monitor compliance with all aspects of water management. Water information can exist in varying levels of refinement, ranging from raw data through to value added reports or products.

This part explores how water information might be managed in China to support a WET framework. The report structure includes a detailed description of the approach being adopted to develop water accounting in Australia, an assessment of water information requirements in the pilot study area of Taizhou and analysis of water information requirements of a WET framework.

2.1 The Australian context

2.1.1 Introduction

The water industry in Australia is in the third major phase of its history. An initial development phase continued until about the 1970s, a management phase followed and now, in the first decade of the 21st century, an adjustment phase is clearly evident.

During the development phase large storages and water supply assets were constructed by government. A shift to a management phase of water resources was evident in the 1980s and 1990s. A big driver for change was the need for the water utility services to be paid for by the customers. Other drivers included increased environmental awareness, deteriorating water quality and river health and the realization that growth in water extractions reduced the reliability of existing supplies.

Water resource policies shifted from encouraging water use to constraining it. Caps on abstractions were introduced. The intensity of management increased for all water sources through the development of groundwater and stream flow management plans. Water trading emerged as a mechanism to allow further economic development within areas where water abstractions were capped.

An adjustment phase has now begun, driven by widespread opinion that the water resources in parts of southern Australia have been overdeveloped. Water scarcity exacerbated by drought has increased concerns about over-allocation of water resources. This phase is about protecting aquatic ecosystems and providing secure, reliable water supplies.

Water has become much more highly valued economically, environmentally and socially and water trading has increased and is seen as vital for future adjustment. Issues around public and investor confidence in water markets have arisen.

The provision of water information which can be relied upon by a range of users representing many different perspectives has become very important.

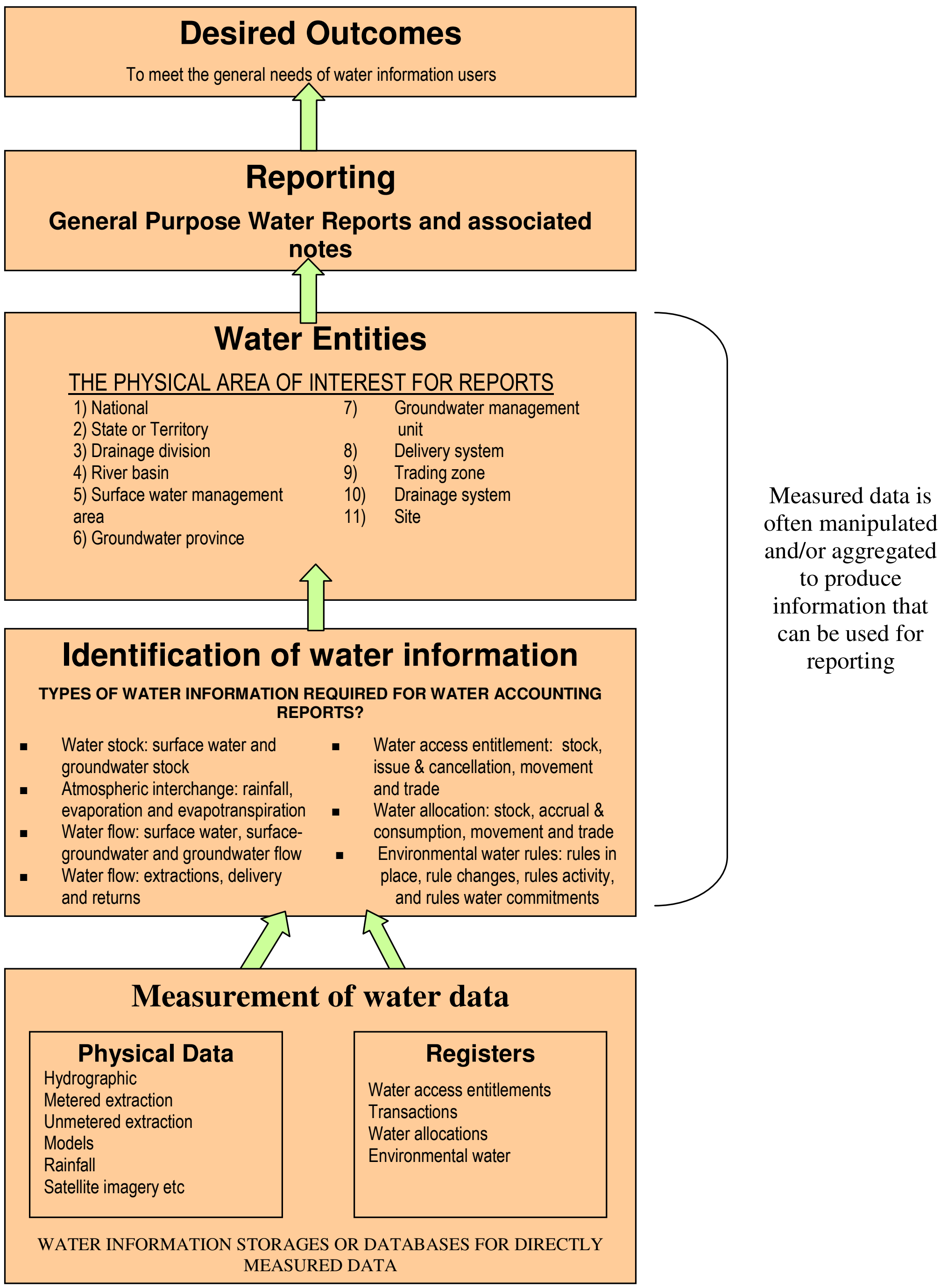
2.1.2 What is water accounting?

Water accounting is an emerging priority amongst Australian water managers. Nonetheless, it has been difficult to reach consensus on a definition of water accounting. The current agreed definition in Australia is that:

Water accounting is the application of a consistent and structured approach to identifying, measuring, recording and reporting relevant information about water.

Key steps used to develop a consistent and structured approach for water accounting development in Australia are shown in Figure 59. The logical approach is to define the requirements of users of water information and to then examine what information (and hence what reports) are required to best meet their needs.

Figure 59: Water accounting logical structure



The application of standards and guidelines at each step of the water information processing is designed to provide the people who ultimately use the information with confidence that reports have been prepared according to a consistent set of principles, and hence they can rely on the information.

One of the objectives of water accounting is to allow for the development and distribution of general purpose water reports – which can meet the needs of various different users. The process outlined in Figure 59 is designed to meet this objective. The benefits of each of the steps are discussed in the following section.

It should be noted that water accounting in Australia is still very much in a development phase. The information below describes a system that is evolving. Many of the concepts discussed have not been fully implemented, and there remains debate about the best way to proceed with a number of the key issues.

Recognition of limitations

One of the concerns of organisations dealing with standardisation (such as water managers at different levels) is that they are being managed or dictated to by external sources. However, water accounting in Australia is proceeding on the following understanding:

- Water accounting does not change who manages water.
- Water accounting will reflect events that occur. Water accounting will not decide what will happen; it will enable reporting of what has happened.
- Water accounting will provide information to assist managers and other information users in decision making.
- Engineering, accounting, statistical and scientific experts will define guidelines and standards associated with identification and measurement of water accounting information.

2.1.3 How can water accounting be of benefit?

The need for water accounting comes from the recognition that:

- information is central to the way water is managed and used;
- there is a range of different users of water-related information; and
- different users have different information requirements.

Water accounting is being developed to ensure that measuring, monitoring and reporting systems evolve in a way that meets these needs. In particular, water accounting is designed to:

- ensure the users of information can have confidence in the information they are provided;
- provide accountability for those taking water for consumptive purposes; and
- provide transparency in the volumes of water recovered and managed for environmental purposes (where the government invests in water savings purposes, to enable more water to be returned for the environment).

These are critical requirements in a water management system where – for example – there is a high level of regulation, where water trading or other significant investment in water projects is occurring, and where money is being spent on improving water for environmental purposes.

Australia's water information and reporting practices have been focused primarily on the needs of management and direct customers, rather than the needs of a full range of users, particularly external users who cannot command the information they need. Development work currently being undertaken in Australia includes a fundamental recognition that the information needs of some of the following user groups will need to be addressed:

- governments and their advisors, including economic, environmental and social policy makers;
- water managers and service providers;
- water users – urban, agricultural, industrial and commercial;
- researchers;
- water industry consultants;
- investors in water dependent enterprises and related parties; and
- other potential users including the public.

Within the discipline of financial accounting, many of the needs of a similar range of user groups are met through the provision of general purpose reports and associated explanatory notes.

General purpose reports are intended to meet the needs of users who are not in a position to demand reports tailored to meet their needs. Water accounting aims to provide standards for preparing general reports that meet the needs discussed above.

Financial accounting can provide general purpose reports that satisfy most of the needs of users as a result of the development of standards and guidelines and (ultimately) the enforcement of these in practice by an independent regulatory body. This provides users of accounting reports with a high degree of confidence in the information that the reports contain.

Establishing a formal process for developing water accounting standards in Australia was seen as a way of ensuring that a similar rigorous and consistent approach to water information management and reporting could be adopted. This is designed to:

i. ensure general purpose water reports are useful for most users of the water information contained in them; and
ii. maximise the benefits from the management of water information and reporting (which does not currently have a consistent management process).

Financial accounting principles are being used to guide the development of water accounting in Australia. This will involve the development of standards and guidelines to underpin a national water accounting system.

As described in the previous section, the system will require standards to be developed to cover each part of water information management from the primary stages of measurement and collation of data to the final stages of general purpose water report production and publishing. Some of these standards may not actually be water accounting standards as such but would be recognised and referenced in water accounting standards – such as standards related to measurement techniques or information technology systems. These types of standards are out of the scope of water accounting but could be integrated into water accounting standards where appropriate to improve information quality and consistency.

2.1.4 Key Steps to applying water accounting principles

The following sections consider some logical steps which could be adopted to integrate water accounting principles into water information management processes.

Identifying the needs of water information users

A priority step in the development of water accounting has been work towards defining user requirements.

The expected outcome of this work will be a formal definition of user requirements. This will inform the development of general purpose reports and the standards that may be applied to these reports. The active engagement of relevant user groups in the development process to discover their requirements for water information enables these requirements to be considered and where appropriate included into the definition.

Improving the quality of water information

Reports which include information about water are regularly produced in many countries. However, the reasons for preparing them can vary. User groups such as industry experts, water users, researchers, policy makers, and investors must be able to understand the water information provided.

Water accounting and associated reporting should be driven by the requirements of the users of water information, not by what is currently available. By identifying report users and their needs, it is likely that reporting will become more targeted and be of a better quality.

The quality of information provided can be improved by:

- adopting standards (e.g. for measuring, metering etc), so that report users will know the way the information was obtained, and hence how accurate it is likely to be; and
- including explanatory notes in reports, to qualify information where necessary. For example, if data was unavailable for a particular river or for a particular year, it might be estimated. The fact that this data was estimated would be included as an explanatory note, so that a user would know that it had a different level of accuracy, compared with the other information in the data set. This approach will improve the confidence of the user in the quality of the information.

Identification of water information

Generally in Australia water information is not consistently recorded or reported between jurisdictions or even between organisations within jurisdictions. Often multiple terms are used to describe the same concept (due to management of water by different jurisdictions). The aggregation and assembly of raw data into more meaningful water information often relies on processes such as modelling or calculations, which is also inconsistent from one location to another in Australia.

These inconsistencies need to be resolved before standard reports can be compiled with confidence. It follows that standard terminology, as well as the processes for using data, need to be developed to ensure consistency between different water management organisations.

The following list of water information categories has been developed. In the future, these categories might form the basis of a table of water accounts, although the categories may be changed as development work continues:

- Water in storage – the volume of water stored in surface water and groundwater.
- Atmospheric interchanges – rainfall, evaporation and evapo-transpiration.
- Water flows – including surface water flows, abstractions, deliveries and returns.
- Water use – application of water to an economic activity.
- Water access entitlements – long term rights to access water, including volume, the number issued and cancelled, and any movement or trade in rights.
- Water allocation – annual allocation of water rights, including volume, accrual (i.e. the volume available at any point in time), and any movement or trade in seasonal rights to water.
- Environmental rules – rules and commitments relating to water for the environment.

These categories could be applied to any number of defined management areas.

The advantage of using an approach such as this is that more rigour is introduced to the management of water information. The development of a standard set of water information categories is what is called a national chart of accounts. Agreement of the information categories to be included in this chart of accounts would then enable a consistent data structure which could be applied to future information system development.

Information system flexibility

One of the key aspects of the design of a financial accounting system is a chart of accounts. A chart of accounts is a series of categories of information that are recorded to enable standard reporting. The relationships between different categories of data can be defined to enable a systematic method of tagging data which allows for future reporting of more than one aspect of the information.

By way of example, consider a water trade, where a water right is traded from one user to another. The simplest method of recording this transaction is to debit the volume of the entitlement from one owner’s account and credit the same volume to a new owner’s account. This approach would only report on the total volume of water traded.

However, additional fields of information could be recorded to allow additional reporting. Additional fields that could be recorded with this transaction could include owner details such as name and location, the respective water trading zones of the two owners involved in the transaction and the source of the water (e.g. groundwater or surface water). Recording these categories of information would allow reports to be prepared on trading of water between particular zones as well as between different water supply sources rather than just recording the total volumes traded.

An information system structured using a chart of accounts and which allows for tagging of transactions can both:

- provide a systematic method for recording and storing information; and

- allow information to be re-arranged into more useful reports with less effort.

The development of a formal chart of water accounts provides an opportunity to develop dedicated water accounting systems to support general purpose reporting. A chart of accounts is essentially the basis for the design of database tables which are required to develop a relational database. Such a database has scope to develop automation capabilities which are likely to make report production much simpler.

Dedicated water accounting information systems may not be developed immediately. However, the development of general purpose reporting standards will define what reports are to be produced. Information systems can then be developed in the future to allow efficient reporting in line with those standards.

2.1.5 Developing Water Accounting in Australia

This section describes some of the key steps taken to date, and currently ongoing, in developing water accounting in Australia.

A national approach

Water resource accounting was formally recognised as a nationally significant water management issue in 2004. This recognition occurred through its inclusion in the "National Water Initiative" (NWI), an agreement between the State and Federal governments, which provides the blueprint for water reform in Australia. The agreement deals with a full range of water management issues.

One of the goals of the NWI is to "ensure that adequate measurement, monitoring and reporting systems are in place…to support public and investor confidence in the amount of water being traded, extracted for consumptive use, and recovered and managed for environmental and other public benefit outcomes".

In 2006, the Federal and State governments undertook a "stock take" of current water information. This involved holding meetings with 38 different organisations from across Australia. Participants included State water departments as well as rural and urban water service organisations. The focus of the meetings was to examine what information was being regularly collected and reported by different organisations.

This stock take concluded water accounting in Australia is in an immature phase and being developed in an ad-hoc fashion.

The water accounting stock take project made recommendations for the development of water accounting in Australia based on analysis of the stock take findings and on the benefits of applying some of the principles of financial accounting.

Principles

Some principles were developed to guide the development stage of water accounting in Australia including:

- Use appropriate starting points wherever practicable – pick up on relevant work undertaken nationally and within jurisdictions, best practice examples within water businesses and specific developments that have been documented, as a cost effective base on which to build.
- Develop a theoretical base to ensure discipline and rigour in a manner which both learns from and informs practice and practicable developments.

- Use targeted pilot projects which test the application of proposed standards.
- Focus on agreed priorities for development of standards, build on current or proposed good practice reporting and support research and development projects that are effective or offer significant potential in developing national standards.
- Involve stakeholder representatives and develop business cases as part of each project or priority action.
- Concentrate on development of a few demonstration water accounting information systems – make real progress on development of information systems with the intent of effective and expandable application of water accounting functionality.

It was recognised that some structure was required to guide water accounting development work in its initial stages. A proposed national water accounting process was developed to provide a method for developing standards for water accounting reports and information systems which can be reviewed and modified as required.

Some of the identified features and requirements of a process where standards are developed and applied include the following:

- An institutional arrangement to oversee the development of water accounting, the establishment and application of a standard development process and the approval of water accounting standards.
- The development of standards to inform the reporting requirements and influence the design and implementation of the water accounting information systems that provide standard reports.
- An assurance process to monitor the integrity of the water accounting information systems and the level of compliance with reporting obligations.
- Recognition that not all standards will be water accounting standards. Some externally developed standards such as those used for measurement techniques or database access or data handling may be referred to in water accounting standards.
- Users of water accounting information being able to influence water accounting and reporting.
- The user information requirements, institutional arrangements, process for development of standards and guidelines and the conceptual framework provide the fundamental intellectual infrastructure for the development of water accounting.
- One of the reasons for improving standards is to provide confidence that the process of preparing water information and reports is correct and that the situation being reported has been appropriately represented

Progress in implementing Water Accounting

In 2007, a Water Accounting Development Committee, made up of prominent water and accounting experts from industry, academia and government agencies was established to oversee water accounting development activities for an initial three year period. A range of development work has commenced.

Theory and practice are being developed in parallel rather than sequentially. One of the important aspects of the development work is that the work is tested through a number of pilot projects throughout Australia, with an emphasis being placed on iteration and learning from experience.

As at August 2007, the status of progress on various water accounting development activities is as follows:

- A preliminary User Information Requirements Interim Report has been prepared and is close to finalisation. The report seeks a range of perspectives on the requirements of general purpose water accounting reports from different stakeholders. Some of the stakeholders that were interviewed included:
- Auditors-General Offices in a range of jurisdictions;
- water brokers;
- mining industry representatives;
- irrigator representatives;
- corporate investors in water related projects;
- environmental groups;
- accounting bodies; and
- water authorities.
- These stakeholders were asked to comment on the requirements for improved reporting of water related issues through a short and structured interview process.
- Options for ongoing institutional arrangements beyond the three year initial development period are being prepared for consideration by the Water Accounting Development Committee. Whilst funding has been made available to support the Water Accounting Development Committee to complete initial development work, it is recognised that a long-term arrangement will need to be established following this three year term. Organisational structure, definition of powers and funding arrangements will all need to be determined.
- Two Australian universities have been contracted to develop a Conceptual Framework for Water Accounting which will inform the development of water accounting standards. The Conceptual Framework is a key feature of financial accounting and it is expected that a similar version for water accounting will be completed in 2008. The Conceptual Framework is to comprise eight Statements of Water Accounting Concepts. The Statements of Water Accounting Concepts to be developed are expected to include aspects such as scope and objectives of water accounting, reporting entities and qualitative characteristics such as reliability of information.
- An initial Standard Development Process has been agreed and is to be modified as necessary based on experience as water accounting standards development proceeds. The process is a series of steps which will provide those developing new standards a consistent method to follow. The process includes a number of steps to ensure that the standard will conform to best practice whilst achieving its intended purpose;
- A first draft Proposed Disclosures for an Initial Standard for Water Market Accounting has been agreed by the Water Accounting Development Committee

as the basis for consultation and further development – the first draft is based on an example for a controlled surface water system and other examples are to be prepared including for a groundwater systems;

- The Water Accounting Development Committee has agreed that general purpose water reports are to form the basis of standardised reporting formats. Whilst report templates have not yet been developed, the general purpose reports proposed for development are likely to resemble some of the general purpose financial reports that exist. Examples of these include:
- A Statement of Water Performance (similar to an income statement) which would show inflows, outflows and net accumulation for any area selected for the report;
- A Statement of Position (similar to a balance sheet) which would show water held in storage, commitments and availability of water;
- A Statement of Physical Water Flows (similar to a Statement of Cash Flows) which would show flows of water for defined areas; and
- A Statement to Change in Available Water (similar to a Change in Equity statement) which would show possible disclosure of entitlements issued or cancelled; changes to shares of a consumptive pool, etc.
- An Initial Common Chart of Water Accounts has been agreed as the basis for consultation. The initial chart of water accounts defines the categories of information that will be required for preparing a range of proposed general purpose water accounting reports and will be used for further development and testing including via pilot projects.

Water accounting pilot projects

Six pilot projects located throughout Australia have been identified to help influence and test both the theoretical underpinnings of water accounting and the initial water accounting standards as they are developed. The pilots will also assist in testing existing water accounting information systems. Three of these pilot projects are listed below with a description of the project specific goals:

Carabooda Groundwater Management Area (Western Australia) – groundwater system

The specific goals of this pilot project are as follows:

- Identify user information requirements, information frequency and from whom it is required. Identify gaps and design strategies for acquisition of minimum information required. Determine the role of modelled data in the water accounting system and negotiate to address gaps.
- Develop a water accounting manual for Western Australia. Answer the question – what is a water accounting "transaction" that needs to be entered into the system? Outline consistent presentation methods.
- Test draft water accounting standards.
- Design pilot systems using current Department of Water tools and identify gaps and short-comings to inform a final design and underlying platforms for future operational water accounting systems in Western Australia. Consider the operation of general and subsidiary ledgers and determine the level of integration required between each transactional system. Design reports such as

periodic statements of entitlement holders, market activity, management reports and consolidated reports at the State level.

- Determine reporting periods and procedures to meet deadlines.
- Determine the need and level of periodic audits of water accounts and supporting water accounting systems, auditor skills required and audit public disclosure requirements. Engage an auditor to participate in the pilot.
- Inform the whole West Australia Department of Water and other stakeholders of the operation and benefits of water accounting.

Pioneer Valley Catchment (Qld) – surface and groundwater systems

The specific goals of this pilot project are to:

- determine the minimum chart of water accounts for Pioneer Valley and Queensland's needs, alongside iterative development of a nationally consistent chart;
- influence and test relevant standards, including general purpose reports and associated disclosures; and
- test current information systems and identify capacity building opportunities.

Goulburn-Broken Catchment (Victoria) – regulated and unregulated surface water systems

The specific goals of this pilot project are to:

- test the initial common chart of water accounts and propose enhancements as required;
- utilise the Victorian water register to test whether double entry accounting can be efficiently applied to water resource and water for the environment accounting;
- develop and record accounting transactions for water resource accounting, using estimates where required;
- establish whether frequent and reliable data can be efficiently gathered for water resource accounting and examine methods for improvement;
- test the initial water accounting standards and ensure that the disclosure requirements are meaningful and can be achieved by Victoria;
- develop a demonstration water accounting system that can deliver the reporting required by initial accounting standards; and
- use the outcomes of the pilot project to provide feedback on the conceptual framework for water accounting and identify gaps and issues with the conceptual framework.

The future of water accounting in Australia

It is quite difficult to envisage to what extent water accounting will have been developed as a discipline and be embedded as a national practice at the end of the three year development period. At this stage, it is hoped that in three years' time:

- sound guidelines for standard development exist;
- appropriate institutional arrangements exist;
- initial standards are being voluntarily applied by several organisations, including those who have been involved with pilot projects; and

- several general purpose standard report types are being regularly produced and used, including by external users.

2.2 Water information management in Taizhou

Development of water accounting principles that might be applied to a WET framework should be based on a detailed consideration of how current water information is managed in China. To understand the current situation in China, a pilot study was undertaken to assess current water information management practices.

The case study area was Taizhou where most of the data on physical processes is controlled by the Taizhou hydrological station. Other water information, including water access entitlements, transactions, water allocations and environmental water, is collected by the Taizhou water resources bureau.

An assessment was completed by examining current practices in the Taizhou pilot catchment and focussed on the aspects of water information management discussed in section 2.1. These include the aspects of water measurement, water information recording, assembling of water data and reporting.

2.2.1 Water measurement

Atmosphere interchange

Rainfall

There are about 300 rainfall monitoring stations in Taizhou. There are 64 perennial monitoring stations, which were established in 1950s and 1960s. At the beginning, there were about 100 perennial monitoring stations. About one third of these were dismantled in the 1990s as they were deemed unnecessary or not cost-effective. Over 200 stations have been added in recent years, which lie around the reservoirs with taking flood prevention and drought fighting into account.

Monitoring stations are generally automatic as shown in Figure 60. The data is sent out at intervals of 5 minutes when it is raining, but suspended when it is not. The data is received by the SMS platform, classified manually, and then input directly into the database.

In addition to the water conservancy sections, the meteorological departments are also monitoring rainfall. However, there are important differences at setting the monitoring stations' location between the water conservancy sections and the meteorological departments. The meteorological departments locate the rainfall monitoring stations primarily according to the administrative divisions. For instance, there are rainfall monitoring stations in the countries and townships.

When setting the hydrological stations, the following factors are considered: the rationality and uniformity of the sites, landform and typhoon. Stations are mostly concentrated in the areas where rainstorms frequently occur and in the mountainous areas.

Evaporation

There are twelve evaporation monitoring stations in Taizhou, each using a model 1601 evaporating monitoring dishes. Data is recorded at each station every day and then input into the database.

Figure 60: A standard rainfall observation site in Taizhou

Surface water

In-stream

Water level monitoring*:* There are 19 water level monitoring stations and three tidewater level stations in Taizhou. The water level and tidewater level information is monitored in real time and automatically recorded, sent out at intervals of six minutes or when the water level changes one centimetre. It is received by SMS platform, transformed into the appropriate series, and then input into the database

Stream flow measurement*:* There are two stream flow monitoring stations, which are located at the two major branches of the upstream of the Jiao River.

- Yong'an Creek: the catchment area is 2400 km^2.
- Shifeng Creek: the catchment area is 1400 km^2.

Each year, speculated stream flow data is generated 70 times in accordance with the water levels. The fundamental principle is that runoff can be determined according to the observed values of flow and water-level under different local flow situations. This is usually expressed in the form of empirical equation, empirical curve and tables. It is determined by various hydraulic factors, such as river width, section area, hydraulic slope, roughness and so on. The relationships between water-level and flow are steady in certain situations (but this is not always the case). Continuous observation of runoff is difficult because it requires complex costly technology, while that of water-level is easily done. So the continuous water-level data is often translated into runoff data according to the relationship between water-level and flow for hydrology calculating, forecasting or analysing.

Reservoirs

Currently, the Reservoir Management Bureau monitors reservoirs located in Taizhou prefecture. The main monitoring indicators are water level and flow out of the reservoir. In addition, evaporation is also monitored in several reservoirs. Water quality monitoring of water-supply reservoirs is mainly completed by Taizhou City Hydrological Stations (under delegation from the Reservoir Management Bureau).

Water level monitoring is automatic. If the water level changes, data is sent every six minutes by SMS to a remote measuring system in the Taizhou Hydrological Bureau. Data is also sent if the accumulated change is more than one centimetre. If the water level remains constant, data is usually sent three times a day (i.e. data is sent to telemetry system through SMS platform at 8:00 a.m., 8:00 p.m. and 12:00 a.m.).

The flow out of reservoirs is calculated by other indexes (such as generators, hydraulic head, power generation efficiency/time) because water levels drop for the power generation function of majority reservoirs located on Taizhou.

Groundwater

The Hydrology station of Taizhou mainly monitors groundwater of the plain, and just monitors the groundwater quality, not the groundwater level. There are five groundwater using wells, which are the source of water samples (the using wells is the test well). The others have been closed. The water sample is obtained three times every year in January, April and July. It is clear to the groundwater quality with the groundwater sample examined, and then results are published in the *Water Resources Bulletin*.

Information on surface subsidence is provided by the Geology and Mining department. Zhejiang province is suffering some of the most serious surface subsidence in China in recent years. In Taizhou prefecture, surface subsidence is serious in the Wenhuang Plain. In an area of 550 km^2, the subsidence is over 50 mm, the sedimentation rate surpasses 30 mm each year and the greatest accumulated subsidence reached 1000 mm to 1300 mm. It is said that exploiting excessively the groundwater is the main reason that caused the surface subsidence in Zhejiang Province.

At present, the government of Zhejiang Province has constituted some orders that forbid industry using groundwater in the province except under special circumstances. A fixed GPS station and a set of layered subsidence automatic monitor systems have been constructed and the economic loss appraisal for the surface subsidence in Hangjiahu plain has been developed.

Water abstraction

Water abstraction measurement

The Zhejiang Water Resources Bureau and Zhejiang Quality and Technology Supervisory Bureau use the following requirements for installation of water abstraction meters:

- Abstraction permits for volumes greater than 500,000 m^3 require an electronic flow meter, ultrasonic flow meter and so on.
- Abstractions between 200,000 m^3 and 500,000 m^3 require an ultrasonic meter and electronic energy meter.
- Abstractions below 200,000 m^3 require a positive displacement meter based on a time of operation.

The instrument of electronic energy meter and time of operation may need parametric correcting, according to the demands of the regulations.

Groundwater is measured by mechanical water meter. Abstraction volumes are generally recorded on a specified paper based record and submitted to the Water Resources Bureau. A web-based submission facility is currently being developed. There is also a quarterly check of meters completed by the BOH (Bureau of Hydrological) prior to final billing.

Water abstraction permit holders pay two types of charges:

- water charge – a charge for water actually removed from the river; and
- water resources management fee – a fee paid to the municipality.

The current billing system is a Microsoft Excel based register of payments received.

Water quality monitoring

There are 80 water quality monitoring stations in Taizhou, which are mainly located in the different water function zones of the main control sections of the primary rivers. Each water function zone establishes a water quality monitoring station. The water function zone was established by the local Water Resources Bureau. The water quality is monitored every season and published in the *Water Quality Bulletin*.

The *Water Resource Bulletin of Taizhou* has been compiled since 1997 and published in the *Taizhou Journal*. There are 18 water quality monitoring stations in the area of reservoirs which are domestic water sources, such as Changtan, Niutoushan, Xi'ou, Xi'ao, Human and so on. They are monitored about one or two times each month. A "water quality briefing" is compiled monthly and sent to the provincial centre and the government of Taizhou.

Water quality standard is essential to water quality monitoring. Main water quality standards are as follows:

- Implementation of the "Surface Water Environment Quality Standard" (GB3838-2002) began from 1 June 2002. This was authorised by the national Environmental Protection Bureau on 26 April 2002, issued federally by the national Environmental Protection Bureau and the national Quality Surveillance Examination Quarantine Bureau and published by the Chinese Environment and Science Publishing Company. It is a national standard. The standard is the same with surface water which may be used, such as river, lake, canal, channel, and reservoir. The limit values are shown in Table 73.
- "Groundwater Quality Standard" (GB/T14848-93) was implemented from 1 October 1994, after authorisation by the national supervision on 30 December 1993. This standard ordains the groundwater quality classification, the groundwater quality monitor and ground water quality protection. This standard is suitable for the common ground water, not for the underground hot water, the mineral water and the salty water.
- "Sewage Synthesis Discharges Standard" (GB8978-1996) was issued and implemented by the national environmental protection bureau on 1 January 1998. This standard ordained the highest permissible discharge densities for 69 kinds of water pollutants and the highest permissible displacement of partial industries. This standard is suitable to the management of the existing unit water pollution discharges, as well as the environmental effect appraisal of the construction projects, the environmental protection and facility design of the

construction projects, the completion approvals and discharge management after production.

- The "Fishery Water Quality Standard" (GB11607-89) relates to water used in fisheries and the "Farmland Irrigation Water Quality Standard" (GB5084-92) relates to water used in farmland irrigation.

Table 73: Water quality evaluation criterion

Item	Classified criterion				
	1	2	3	4	5
PH	6~9				
DO ≥	Saturation rate 90% (or 7.5)	6	5	3	2
Permanganate index ≤	2	4	6	10	15
COD ≤	15	15	20	30	40
BOD5 ≤	3	3	4	6	10
NH3-N ≤	0.15	0.5	1.0	1.5	2.0
TP ≤	0.02 (lake, reservoir 0.01)	0.1 (lake, reservoir 0.025)	0.2 (lake, reservoir 0.05)	0.3 (lake, reservoir 0.1)	0.4 (lake, reservoir 0.2)
Cu ≤	0.01	1.0	1.0	1.0	1.0
Zn ≤	0.05	1.0	1.0	2.0	2.0
F- ≤	1.0	1.0	1.0	1.5	1.5
As ≤	0.05	0.05	0.05	0.1	0.1
Hg ≤	0.00005	0.00005	0.0001	0.001	0.001
Cr ≤	0.001	0.005	0.005	0.005	0.01
Cr6+ ≤	0.01	0.05	0.05	0.05	0.1
Pb ≤	0.01	0.01	0.05	0.05	0.1
Cyanide ≤	0.005	0.05	0.2	0.2	0.2
Volatilize phenol≤	0.002	0.002	0.005	0.01	0.1
oil ≤	0.05	0.05	0.05	0.5	1.0

About water quality evaluation criterion:

- headwaters, national natural protection area;
- centralisation drinking-water resources first level protection area, precious aquatic organism habitat, etc;
- centralisation drinking-water resources second level protection area, fishing watershed and swimming area.

Water use

Agriculture

Agriculture is the biggest water user. Its water volume approximately is half of the total water volume. Because one rain guarantee rate corresponds with the one crop's irrigation water quota, the water department of Zhejiang Province associated with the economical trade committee of Zhejiang Province and the construction hall of Zhejiang Province to publish the "Regarding to how to work well report". It has made the stipulation to the different industries and the type of water used quota. The rain guarantee rate of last year is provided by the hydrology department, the agricultural water used volume is estimated according to the water used quota.

Irrigation guarantee rate and quota are ensured according to irrigation area and the same year precipitation. The irrigation area data comes from water statistical annals by Water Resources Bureau, which means anti-drought ability above 30 days. In normal year, water use volume is calculated by 75% quota. In rainy year, water use volume is calculated by 50% quota. In low flow year, water use volume is calculated by 90% - 95% quota.

Industrial

The industrial used water volume is computed by the new used water volume. It does not include recycled water. The industrial water includes the following: the water brought into the running water pipe network, which was measured according to user water meter. This part of water is accounted by the running water companies; the water source provided for itself, the registration of the water gain permit had explicitly stipulated the water amount; as well as some water used by the towns small business, it had been investigated the inlets of the province and made standard to the part of water in 2006.

Public water

The cities' public water used includes the water volume uses for all kinds of service industry, commodity trade, accommodation, transportation, storage, postal and telecommunications, hygiene education, institutional and so on. This part of water used basically brings into the city reticulated supply network, and prepares to measure by the user water meter.

Domestic

The domestic water refers to the water that the inhabitant uses daily. It is counted separately for inhabitants of the cities and the countryside. The cities' inhabitants' water use is accounted by the running water company with the water meters. Rural domestic water is estimated mainly according to the population.

Out-of stream ecological and environmental water use

The ecological and environmental used water temporarily counts the water volume which is deployed by the artificial measure, not include the water volume satisfied by the rainfall and the runoff. It is counted by the cities' environment used water (contains the water recruited to the river and the lake and the water used for the virescence and clean) and the water recruited to the countryside ecology (refer to the water recruited to the lake, hollowly settles, bog). This volume is almost fixed by public works.

In Taizhou, the surface water source accounts for over 90%. The surface water source is counted separately as the stored water, the drawn water and the diverted water. No matter that it is flow automatically pilot water or draw water, the water from the reservoirs and pond dam all belong to the water supplied by the store water projects; no matter there are gates or not, the water pilots automatically from the rivers all belong to the water supplied by the pilot water projects; the water drew from the rivers by the pumping stations belongs to the water supplied by the draw water projects. The water reservoirs are the primary surface water supply in Taizhou, and the pilot water projects and the draw water project are auxiliary.

Besides the agriculture, the other mostly manufacture water and the domestic water both pass through the city running water pipe network. At present, this department charges the water fee to the water user. The water fee contains the water resources expense and the sewage treatment spends and so on.

2.2.2 Water recording

Precipitation

Rainfall

Data from automatic monitoring stations is received by the SMS platform, classified by manual work, and then input directly into the database.

The information of rainfall data is currently not shared. The long series of data is confidential and stored in the database form. It is just provided the processed data or the typical separate series of data for the requirements of the production institutes. When the unusual weather occurs, the information will be promulgated to the public.

Evaporation

There are twelve evaporation data points in Taizhou, which are manually recorded daily and input into the “southern hydrological data assembly database” (discussed below).

Surface water

In-stream

Water level information recorded by the automatic system should be stored IC card (before) or sent to remote measuring system by the SMS platform, which would be transformed another format and input into the “southern hydrological data assembly database”.

Reservoirs and dams

The recording method is the same as outlined above.

Groundwater

The groundwater quality data is manually input into the “water quality management and evaluation system”.

Water abstraction

Water abstraction recording

The unit or individual abstracting water should report an annual water abstraction plan to the local water administration department and fill in a water abstraction journal by month or season to check their water abstraction plan implementation. At the same time, the local water administration department copies the water amount from the meter to supervise and manage the water abstraction. The data would be input into the form account belong to country and stored in a Microsoft Excel spreadsheet.

Water quality recording

The water quality data is manually input into the “water quality management and evaluation system”, which is monitored by hydrological station.

At the present time, water resources system and environmental protection system have been monitoring water quality separately. The material has not been shared. There is much difference in section locations, and monitoring time and frequency between the two systems. Moreover, the appraisal contents are different.

Water use

As above mentioned, water use in agriculture is measured according to the ration, then, the end would be reported by step-by-step and all levels would Stat. and record according their need; industry water are recorded by municipal administration and water from self-sources Stat. is by water abstraction permit register.

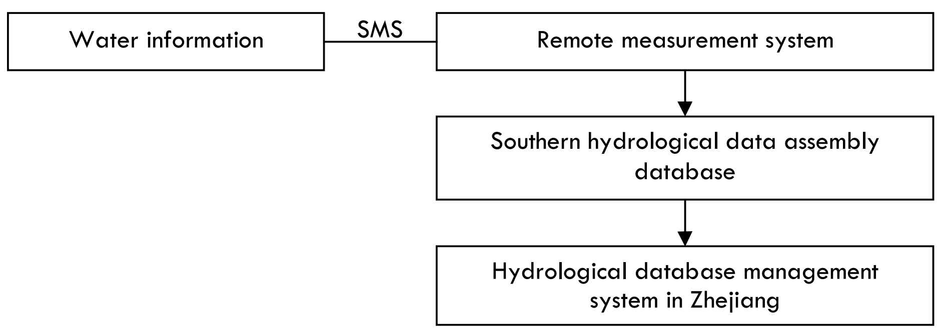
All of the above is recorded by table.

2.2.3 Water assembly

Precipitation and surface water

Some raw data (such as precipitation, surface water, ground water, etc) is input into the material assembly database – the "southern hydrological data assembly database". The database is assembled in real-time. The assembled material is audited every year. The data will be stored in the hydrological database management system in Zhejiang province. The data assembly procedure is outlined in Figure 61.

Figure 61: Data assembly procedure



Southern hydrological data assembly database

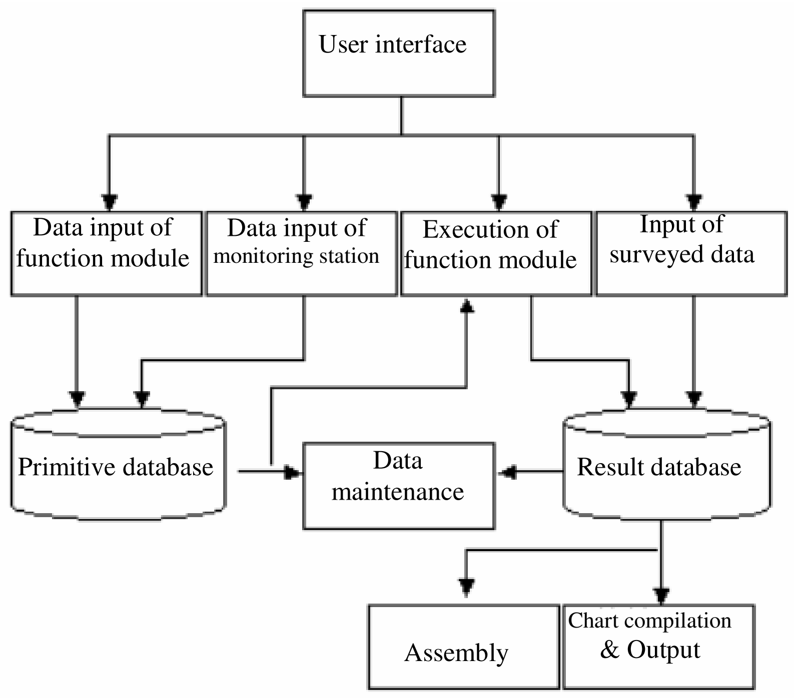
System structure of software

With the database management, GIS etc., the system, a hydrological information collection and compilation system supporting for collecting, censoring, rechecking and compiling with visual and integrated software, is developed to resolve the problem on the hydrological information collection and compilation in the South of China, which offers a standard on the data collection and compilation and all kinds of data editing to communicate and use it conveniently.

The development platform of the system was based on Windows XP, the development platform of GIS, the record of testing data and the function of collection and compilation tables output on Microsoft Visual C++6.0, the function modules development on Microsoft Visual Basic 6.0, the development and modification database on SYBASE SQL Anywhere 5.0 and Access2000, and it was installed with Install Shield Developer 7.0. The key of the system was available to convenience of data query and retrieval, internality of modules function, easiness of the date input and output and system operation.

As Figure 62 shows, GIS, human-computer interaction interface, various kinds of databases and function modules are integrated into this system. And in function modules, data exchange is mainly based on hydrology database and primitive one.

Figure 62: System structure of Southern hydrologic data process software



System function

Functions of GIS platform: Figures, attributes, images and texts data of the five areas are managed by the GIS platform. Using the platform, monitoring stations can be added, deleted, modified, edited, and information inquired, station and attribute of rivers, lakes and reservoirs can be administrated and queried, figures can be protracted, enlarged, reduced, navigated, full picture displayed and so on, area and length of graphs can be measured, DXF file can be input, output, exchanged and saved.

System management function: This function is designed for system manager who can add/delete users and assign users' operation authority by authority database. The manager renews menu and contents related to authority automatically according to user type at the time of user loading to ensure functions for various kinds of users are authorized.

Hydrologic data process functions:

Data process for water-level, runoff, and sediment concentration of rivers/stations

- It realises data processing for water-level, runoff, sediment flux of suspended load, and sediment concentration of water-level/hydrologic station on natural rivers or channels.
- According to the norms, various documents are adapted from the processed data and logged-in hydrologic database.

Tidal level data process

- It realises tidal level/time filtrating, lunar/solar calendar converting, monthly mean value calculating, days of every month (lunar calendar) accumulating, and monthly characteristic values counting.

Data process for suspended load and sediment graduation

- It includes primitive analysing and graduation processing of suspended load, settling time calculating and so on.

Precipitation data process

- Observed precipitation data of all year/flood period are processed. It includes daily precipitation calculating, precipitation excerpting, maximum precipitation counting of various time intervals.
- Kinds of documents are adapted from the processed data and logged-in hydrologic database.

Data process for water temperature/surface evaporation

- Water temperature and surface evaporation of various periods are calculated and counted automatically.
- Daily water temperature/surface evaporation table, surface evaporation assistant project yearly/monthly statistical table are output.

Solid-state storage water-level data process

- Primitive database files read from solid-state storage instrument fetch procedure are evolved and saved as the proper form ones.

Graphics processing

- It realises hydrology element synthesis process line comparing, momentary water-level, runoff and sediment concentration process line collating, large cross section figure protracting, upper/lower reach water-level process line collation drawing, large cross section figure automatic applying distance from starting point and river low elevation coordinate changing, relation between water-level and runoff routing, relation of single-section sand routing, figure enlarging/reducing within arbitrarily range, and curve editing.

Assembly

- Outputting text data in the standard format of input data (plain text) as the PRC "Water year book" typesetting system R1989-2003 required.

The system offers input of explanation and testing information, easy and convenient operation of filling methods, automatic numbering, the Text format date imported in and exported from the system and pasting the date copied from Excel format data and Text format data into the system input interface directly.

The hydrological information collection and compilation forms were exported to carry out the link between GIS and hydrological database in one year and the forms about the water level and hydrologic station of watercourse, the weir and sluice position, the water level (hydrologic) station of tidewater and the collection and compilation report forms of grain grading analysing and calculating, water temperature and evaporation of water surface etc. could be created automatically. The data format is complied with the standard of hydrological annals publication version, meanwhile the text format will be exported with the according standard. And these forms will be saved as image format of JPG or BMP for multimedia display.

<u>Figure analysis and characteristic values count function:</u> The system can carry out hydrology elements synthesis process line comparing, instantaneous water-level, runoff

and sediment concentration process line collating, upper/lower reach water-level process line contrasting, large cross section figures comparing. Using this system, the figures can be enlarged, reduced, refreshed, and closed, the vertical displacement comparison of various curves can be carried out, and top/bottom contrasting analysis as well as rationality examination of various hydrologic elements can be taken conveniently.

Meanwhile, the system provides statistical contrast table of characteristic values of various stations generating from water-level, runoff, sediment flux of suspended load, sediment graduation and precipitation, based on which, the users can analyse hydrologic characteristic values of various stations easily.

Water quality assembly (surface water and ground water): Water quality is measured and then input into the "water quality data management and appraisal system" which was developed based on Visual Basic and begun to use in 2005. The system function includes: recording, storing, appraising, inquiry and Sta., which may manage surface water, reservoir and groundwater by class.

The data was input above system and assembly according to the menu. The order from menu may query, water quality assessment and build the report TXT forms.

Water abstraction: The assembly of the water abstraction permit data is mainly based on the water resource management records of the county Water Resources Bureaus. These are in the form of Microsoft Excel spreadsheets. The basic information is manually input into the Excel sheet, and then gathered to be clear up. The Excel sheet covers the following information: the circumstances of the water abstraction departments, the permit water volume, the annual plan, the practical water abstraction volume, the measurement tool installed and its running state, the water resource fee and so on. The Excel sheets that have been compiled will be sent to the superior, and then approved by the city.

2.2.4 Water reporting

The water resource bulletin

The *Taizhou Water Resources Bulletin* is prepared by the Taizhou Water Conservancy Bureau. The hydrologic station is responsible to carry out the chief compilation. The most recent bulletin from 2006 includes:

- rainfall – summary for each district and special and temporal rainfall distribution for the year;
- water resources quantity – the water resources of the administration districts and the basin districts in Taizhou, the change in the groundwater resources quantity, the total water resources quantity change from the last year;
- water store tendency of the large and middle scale reservoirs – summarises the change of the water stored in 13 large and middle scale reservoirs from the last year;
- consumption of the water supply – the total water supply volume in Taizhou, the water supply composition and the surface water source supply constitution, the change and the constitution of the total water volume, the change and the constitution of the total consumption water volume, the water used situation in various administrative districts and basin districts as well as the effective water use situation;

- water environment condition – the water function region appraisal, the water quality situation in various periods, the water quality condition in primary areas and the water quality of the main reservoir and the eutrophication condition appraisal;
- important water matters – records flood prevention and drought combat work and the hydraulic engineering construction achievement in the last year; and
- water resource management – outlines the progress in the last year on water laws and regulations, the water resource base management, the water conservation plan and the water administration implementation.

The bulletin is available to the public.

The annual report of water resource management

The "Taizhou Water Resource Management Annual Report" is edited by the Taizhou Water Policy Department of the Conservancy Bureau. Its main content includes information on water permits, the water resources charge and the employment of the water staff.

The water resources quality notification

The “Taizhou Water Resources Quality Notification” is the responsibility of the Taizhou Water Conservancy Bureau. The hydrologic station is responsible to carry out the chief compilation. There is a series every season. It is published only for internal use (water resources bureau, the hydrological station). The printing quantity is small. It is mainly notified the water volume condition in a season, including the rainfall, the water-holding capacity of the reservoir and the rivers’ water levels. It also outlines the main drinking water quality in the water source, the water quality of the main rivers and the groundwater quality.

2.2.5 Conclusion

Taizhou water information measurement, recording, assembly and report are advanced according above analysis. In most aspects, automatic monitoring has been adopted.

In one to two years, two systems will be applied.

- One is web database system, which may share data from county to province. The database needs a special manager and access to it by code.
- The other system is the water abstraction management information system. The system can transmit automatically. It can send the information on the water volume to the receiving device automatically, and then be input into the management information system. The system also covers water resource management details, such as water abstraction permits, real-time monitoring, extraction outlets, sewage outlets, water projects and rainfall.

2.3 Water information requirements for a WET system and adopting water accounting

A WET system involves a range of water management activities, which in turn require support from different water-related information sources. Water accounting is designed to provide a more systematic approach to the collection, management and reporting of water information. This can help ensure that the right type of information is available to those parties that require it.

This section examines the information requirements to support a WET framework.

2.3.1 Information requirements under a WET framework

The WET system described as part of this project fundamentally consists of the following:

- the allocation of the right to a share of available water, between different regions or water users (e.g. via a water resources allocation plan). This includes the allocation of water for in-stream environmental purposes;
- implementation: e.g. ensuring that abstraction permits are granted within the caps set by WRAPs; ensuring annual regulation plans are in accordance with the WRAP; releasing water for the environment in accordance with environmental flow rules; ensuring trading of water entitlements are properly accounted for;
- monitoring and reporting on the above steps and the consequences.

The different information requirements for these three elements – planning, implementation and monitoring/reporting – are considered below. This section is not intended as an exhaustive list of the information requirements for a WET system, but rather to demonstrate the different kinds of information required by different parties and the different purposes for which water information is used.

Water resources allocation planning

A water resource allocation plan (WRAP) will include aspects such as aims of water management in the basin, the objectives and outcomes for specific management activities, definition of regional water entitlements, definition of caps on abstractions and description about how to prepare annual resource allocation plans. Water information is critical to allow for informed decisions to be made about how to allocate water under a WRAP.

A water resources management model is normally used in this type of resource planning to test water management rules. The construction of the model is typically reliant on historic data inputs. The information requirements for the model form a sub-set of the information requirements for the water resource allocation planning process.

Similarly, the process of identifying key environmental assets in a river basin and the types of flows required to ensure the health of those assets is also part of making a WRAP.

Information will be required for each of these aspects to make a WRAP. These data requirements are summarised below.

Hydro-meteorological data for a common period (as long as possible):

- Rainfalls (ideally daily)
- Monthly average evaporation
- Water levels and stream flows (ideally daily or hourly) for all gauging stations in the area of interest
- Rating curves (water level vs. discharge relationships) for the gauging stations

River and tributary flow data/estimates:

- Available modelled river and tributary flows estimates (or model + model parameters) for the catchments of interest

River/Tributary flow behaviour:

- Actual or anecdotal data on flow travel times and transmission losses along different reaches of the river/creek system

Data for existing and proposed reservoirs:

- Details of water infrastructure (capacity, elevation/ surface area/ storage volume relationship, outlets etc)
- Reservoir operating rules, targets, priorities, constraints, cut-off levels etc
- Type and upper limits of demands met from the reservoir
- Water sharing rules between different entitlement holders or water users
- Critical water supply arrangements and other emergency provisions affecting reservoir operations or water sharing rules
- Recorded or estimated inflow and outflow time series for existing reservoirs

Demand data:

- Demand locations and annual demands
- For each demand type and location, historic and future projected annual demands and monthly demand patterns

River diversions/effluent channels:

- Any significant river diversions or influent/effluent channels in the modelled river reaches: the flow capacities of these channels and the river flow vs. diversion/effluent channel flow relationships.

In addition to these matters, there are significant data requirements for the environmental flows assessment. Some of these are not directly water-related, such as ecological information (key species, habitats, life-cycles etc).

Others are more water-specific. Where hydraulic modelling is to be used, hydraulic-hydrologic connections (i.e. the volumes required to achieve certain water levels at different locations, e.g. to cover riffles, achieve bank-full flows etc) will be required. These are used to convert hydraulic (environmental flow) requirements into actual flow volumes, which can be specified in a water resources allocation plan. These relationships can be obtained from cross sections of the relevant reach.

Developing environmental flows is also dependent on understanding the natural variability of the river. Ideally this should involve consideration of not only the river in question, but also natural variability in other similar rivers. Consequently, e-flows assessments can require hydrologic information for a number of different rivers.

Implementation of WET

Implementing the requirements of a WRAP will involve:

- A water abstraction permit system, to regulate (and cap) the total abstractions of water;

- An annual regulation plan, to define the water available on an annual basis to regions and permit holders;
- Ensuring daily operation of water infrastructure is in accordance with the requirements of the WRAP, e.g. that water releases for the environment are made in accordance with the WRAP or other requirements.

In respect of the water abstraction permit system, water information will be required:

- To assist with making decisions on whether to grant water permits: this would include information on local water availability and on other water users (to assess potential impacts on those users); and
- To assist in managing permits: this would include information on the use, location of abstraction, volumes of water taken, timing of abstractions. This information would be necessary for planning, billing water users, and monitoring/reporting.

To develop and implement an annual regulation plan, information is required about:

- Predicted water demands (principally from water abstraction permit holders).
- Existing water levels within reservoirs.
- Predicted inflows.

Reservoir operators will require information in respect of:

- Storage levels and daily river flows, to allow the operator to determine what releases to make to comply with their obligations (e.g. environmental flow requirements, flood management etc).
- Daily demands, to ensure releases are made to meet the requirements of water users.

Monitoring and Reporting

Monitoring (and reporting the results) is a critical to a WET system to:

i. Ensure compliance with the requirements of the WRAP;
ii. Check if the requirements of the WRAP are achieving its objectives (e.g. that the environmental flows that are being provided are actually achieving the environmental benefits desired); and
iii. Provide information to support future planning activities, for example better quality information on both availability and demands. This could include information to improve or replace assumptions made in a water resources management model as part of earlier planning activities; and
iv. Build confidence of water entitlement holders and water users in the WET system and encourage future investments in water trading.

Reporting on this kind of information is important to multiple stakeholders. Water resource managers need to know that reservoir operators are fulfilling their obligations. Likewise, water users need confidence that resource managers are complying with the WRAP and other regulatory instruments.

The type of information required to check compliance would include:

- To check compliance with abstraction caps – both the total volumes of abstraction permits granted, together with the actual volume of water abstracted and the locations;
- To check compliance with environmental release rules – the natural river flows at relevant locations throughout the basin, together with the releases made from reservoirs; and
- To check compliance with operation rules – records from reservoirs of inflows, diversions (e.g. to other reservoirs), and releases.

The process of assessing whether a WRAP or other operational rules are being complied with is relatively straightforward. It is more difficult to assess whether implementing those rules is actually achieving the desired results. This is particularly the case because for many of the objectives it may only be possible to tell over the long-term what the consequences of certain management arrangements will be. Consequently, the information requirements to do this can be more difficult to define.

Information may be necessary to show:

- If the combination of abstraction caps and sharing/operational rules are achieving the desired levels of reliability of supply for different users;
- If the volumes of water released for environmental flows are achieving the predicted hydraulic outcomes (i.e. does the volume of water released actually achieve the desired depth of water at the relevant locations?); and
- If the flows provided for the environment are achieving the desired ecological outcomes (e.g. is stream health being maintain or improving as a result of the environmental flows?)

Finally, it is unlikely that all the desired information will initially be available to complete the water resource allocation plan. Inevitably, assumptions must be made as part of the planning process – for example assumptions about the levels or pattern of demand, the ecological state of the river, or the physical resources of the basin. Where possible, future monitoring and reporting should be designed to try and improve the information base available for future planning activities, to remove or reduce the assumptions or estimations that need to be made, and thus improve accuracy.

Summarising water information requirements

There will inevitably be significant overlap in the information required for the different purposes outline above. One of the basic objectives of water accounting is to provide a mechanism for identifying all of the different users and types of information required, and then distil those down to a common set of requirements.

The goal is to meet (to that extent possible) the needs of all the users via a common system for recording, managing and sharing water information.

2.3.2 Summary of information requirements – gap analysis for Taizhou

A comparison between the information requirements under a WET framework and current information collection practices in Taizhou was made to identify areas for future improvement.

The gap analysis, in Table 74, was undertaken using a general listing of water information elements. As has been discussed, the information elements are categories of water information with similar characteristics and were derived in Australia from the fundamental components of any water balance.

The list of information elements provides a check-list of the information that may be required for the different components of the WET system. Because of the overlaps in the water information required for these different parts, a coordinated approach is likely to provide significant efficiencies for water information collection and reporting. An example of this is flood forecasting models which are used to track flood peaks as they travel through a catchment. This information might also be useful for planning environmental flows.

The assessment table is included on the following page. The key results are summarised in the next section along with some principles that could be followed to improve water information management under a WET framework.

2.4 Principles for future development

The development of water accounting is likely to be an evolutionary process rather than a short term project, both in Australia and China. There are likely to be some parallels between these countries and there is significant potential for China to monitor and learn from the Australian experience (and vice-versa).

Water accounting should focus on meeting local needs. In Australia, the pursuit of water management, transmission and usage efficiencies coupled with the need for confidence and transparency in water markets and the ownership of water entitlements, have been key drivers in the development of water accounting. In addition, periodical snapshot assessments of the ecological health of river systems and the effect that water management might be having on river health has also been an important driver in commencing the development of water accounting standards in Australia.

In China, water accounting will need to be developed to meet the country's specific water information needs. Some coordination of the collection and reporting of water information is already undertaken at a central level in China which is an advantage for the development and adoption of standards. .

Practically, there are some key steps that could be undertaken in China to improve the management of water information.

2.4.1 Identification of the users of water information

All parties with water information requirements should be identified. In some cases, these people will be readily identifiable – for example, water resource managers. Current water information systems are likely to already be designed to meet the requirements of these users. However, there are likely to be others who will require water information as well. This might include environmental scientists or others studying the river, or water users (e.g. factory owners, farmers etc), interested in assessing both availability and reliability of water resources, where water is critical to an existing or proposed business.

The needs of this second group – water users – will become increasingly important within a WET system as water is traded or reallocated between different users. Identifying these groups can allow the collection and reporting of water information to be designed to meet the specific needs to these groups, rather than those users simply depending on what information is available by default.

Table 74: Summary of WET Information Requirements

Water Information element	Current information collection (raw data)	Current information synthesis / derivation	Reported - (format)	Current drivers for collection	Future requirements
WATER IN STORAGE (STOCK)					
Volumes in major storages	Levels measured & reported daily on website	Levels converted to volume based on storage characteristics	Yes. Reports published on the Internet & in Water Bulletins	Water resource allocation planning - Knowing available resource	Being done reasonably well in Taizhou. Continue under WET.
Volumes in minor storages (farm dams, natural & artificial ponds)	Not measured	Not currently calculated	No reports	Nil	Unlikely that this detail will be required under WET
Volumes in river channel or artificial channels at particular times	Not measured	Not currently calculated	No reports	Nil	Unlikely that this detail will be required under WET
Volumes in snow pack	Not relevant in Taizhou (possibly measured in other basins where relevant)	Not currently calculated. Snow melt may be included in runoff models	No reports	Water resource allocation planning - Knowing available resource	May assist WRAP & implementation where snow melt is relevant
Volumes of water held in the soil	Not measured consistently on broad scale.	Calculation of rainfall deficit used to assess water requirement on specific land (agricultural) parcels.	Rainfall deficit is reported which links to crop water requirements.	Used to assess crop water requirements (potential demand for resources)	Can be used to improve modelling of agricultural water use under different scenarios
Volumes of water stored in aquifers	Groundwater levels measured by Ministry of National Land Resource – Groundwater Bulletin	Not clear to what extent any models or maps are used to define resources within aquifer systems	The change in groundwater resource over defined periods is reported in the Water Bulletin	Water resource allocation planning - Knowing available resource	Likely to be required under WET as part of WRAP.

INFLOWS & OUTFLOWS (ATMOSPHERIC INTERCHANGE)					
Rainfall	Extensive gauge network. Daily data stored in central database	Volumetric measures derived using Xinanjiang model in Taizhou. Other models exist in other areas for similar purposes.	Yes. Published on the Internet & in Water Bulletins in format aggregated to annual volume.	Water resource allocation planning - How is the resource being supplemented, Flood prediction - Routing of flows	Required for Water resource allocation planning (rainfall/runoff models also recommended)
Evaporation from minor storages (farm dams, natural & artificial ponds)	Not measured directly	Could be estimated based on surface area if known but not clear whether this is done in Taizhou.	No reports	Nil	Some value to water resources models if more detail required to estimate demands
Evaporation from major storages	Gauge network of 12x evaporation pans (measured as a depth). Data is stored in a central database in Taizhou.	The central database has some calculation functions. It is not clear whether there is a documented calculation method for volumetric measure.	No direct reports. Data is used in models.	Water resource allocation planning – to determine how much is the resource being depleted.	Required for Water resource allocation planning & models.
Evaporation from rivers or artificial channels	Not measured directly.	Could be estimated based on surface area if known but not clear whether this is done in Taizhou.	No reports	Nil	Some value to water resources models (defining system losses).
Evapo-transpiration	Not measured.	Algorithms for calculating ET such as SEBAL are used in some parts of China. Not clear whether it is applied in Taizhou.	No reports	Nil	Not typically measured well but is useful to calculate demands in water resource management models (for irrigation).

WATER FLOW (DISTRIBUTION)					
Surface water flows (rivers, flood flows)	Two flow gauges, 19 level gauges	Flood forecasting based on automatic level data & calibrated model.	Flood data is published on the internet. Totalised (annual) flow volume is published in Water Bulletins. Access issues exist because of sensitivities concerning flow data.	Used for understanding hydrology for water resources planning & also used for environmental flows, permitting etc	Water resource allocation planning & determining e-flows requires data (daily). Also required for annual regulation plan.
Rainfall runoff	Real-time monitoring & flood forecasting is common at national level.	Volumetric measures derived using Xinanjiang model for flood forecasting in Taizhou. Same or similar models used widely in China.	Annual totals reported. Database capable of preparing requested statistics	Flood forecasting	Required for water resource management model.
Movements of water between aquifers & surface water (rivers, storages, channels or pipes)	Not measured	Unclear whether any models or assessments exist in Taizhou.	Not reported	Resource planning - sustainability of resource.	Required for water resource management model
Aquifer recharge or injection	Not measured	May be inferred from changes in groundwater level. Not clear whether this is part of current practice.	Indirectly reported as changes in levels	Resource planning - sustainability of resource.	Required for water resource management model
Groundwater movements	Not measured	Usually requires detailed groundwater models. Does not appear to be widely adopted practice.	Not reported	Water resource allocation planning - sustainability of resource.	Required for water resource management model
Volumes of water abstracted from rivers or aquifers	Metering is in place for larger licensed extractions. Urban generally not metered. Agriculture calculated retrospectively	Water abstractions are aggregated	Generally reported as annual demand.	Water resource allocation planning - sustainability of resource.	Required for water resource management model - either individual or aggregated. Locations & time (i.e. demand pattern) required.

Volumes of water delivered to water users (treated or untreated, first use or recycled)	Metering is in place for larger licensed abstraction. Urban generally not metered. Agriculture calculated retrospectively		Reported as annual totals in Water Bulletins.	Water resource allocation planning - sustainability of resource, economic outcomes.	Required for water resource management model - either individual or aggregated by areas.
Returns of water to rivers or aquifers or channels (treated or untreated)	Generally not measured.	Generally assumed but no evidence that estimates are accurate or that permit requirements are being met.	No reports.	Water resource allocation planning - sustainability of resource.	Important for accuracy of management model, especially where return water constitutes a significant % of total.
WATER USE					
Volumes of water used (irrigation, hydroelectricity, domestic, industrial, etc)	Metering of most large users. Permit holders required to submit proposed & actual water usage plans each year.	This information is generally not entered into a database & is not linked to customer payments.	Made publicly available in irrigation district. Annual Bulletin publishes total volumes to each supply area.	Used to track issues with equity, sharing & national interest (e.g. ensuring water available for food production)	Powerful information for reporting & guiding policy/planning matters..
WATER ABSTRACTION PERMITS					
Information about entitlements to water. Covering such things as numbers, size, trading.	Permits are generally recorded on paper based records (database is being built)	Permitting is paper based & generally not readily accessible	Indirectly reported as total system demands.	Transparency & planning.	Useful for assessing & tracking trading, water sharing etc. Potential instrument for guaranteeing e- flows.
WATER ALLOCATIONS (ANNUAL)					
Information about current (seasonal) water allocations. Covering such things as current balances, use of allocations, trading.	No specific data available. Taizhou Water Plan makes provision for forward forecast of annual availability & specifies sharing arrangements. These are built into reservoir operation criteria.	Actual data not used. Demands calculated each year based on previous year's data plus projections of population growth etc	Report total resource availability & total demands - i.e. excess or shortfall each year.	Provision of reliability advice to water users	Required under WET as part of annual regulation plans.

2.4.2 Identification of types of water information required

The types of information required by each of the water information users should be identified. This should establish all details about the types of data that (ideally) would be available, including issues relating to:

- The frequency with which measurements should be taken (instantaneous, daily, monthly etc);
- The timeframe within which the user will require the information (e.g. for real-time operation for flood management, on a monthly basis for adjusting annual regulation plans, etc)
- When summarised data will be adequate, and in what instances detailed raw data is required;
- The quality or accuracy of the data required to meet the purpose.

A starting point for information collection would be to identify the elements to be recorded to make up a "water balance" report. The information in the China (and Taizhou's) Water Bulletins covers many aspects of a water balance at the catchment scale. These reports generally show the total resource available but do not allow managers to examine local scale issues such as water systems efficiencies. This is because water information is not measured and collected at these scales to enable such reports to be produced. This is evident in the gap analysis undertaken for Taizhou.

Water stocks are generally well understood, because water stock relates to water storage and dams are well monitored in Taizhou, primarily for flood mitigation reasons but also for supply.

Water flows from a resource perspective are not necessarily well understood. Although the flow releases from dam are known, the losses, the diversions and extractions are not accounted for with the same degree of accuracy. This type of information will become increasingly important if an abstraction cap is implemented and/or water savings initiatives are undertaken.

2.4.3 Identifying requirements for water reports

Reporting is required both for the compliance/transparency reasons discussed previously, as well as being a way to provide easy access to water information required by multiple users. In moving towards a water accounting system, the types of reports required should be identified – based on the identified users of water information, the information they require, and the information that is actually available.

The current reporting regime in Taizhou provides a good base on which to build. However, the water bulletins take some time to compile which suggests that a coordinated approach to database design and water information categories would be of benefit when seeking to roll out a consistent reporting regime across multiple provinces. Australia is addressing this issue through development of national water accounting standards coupled with a single Australia-wide "chart of water accounts".

There are several specific water reports that are likely to be required to support a WET system:

Environmental flows report

This kind of report could include information on the actions taken together with the impact of environmental flow management activities. Content would vary depending upon the specific river assets, but there would be some standard content that could be adopted. These could include asset health indicators such as daily or monthly flow measurements for key locations or changes in the health of particular assets over time. Importantly, these reports should show releases from reservoirs made of environmental water (and how these releases meet the relevant regulatory requirements).

Water abstraction permit report

Reporting on total abstraction permits granted, together with actual water taken under individual permits would allow users to see that water allocations (both long-term and seasonal) are in accordance with any abstraction cap.

Further, a report produced from a system that has a high level of quality control (e.g. via standards for information measurement) will provide confidence that the information contained in reports is reliable. A number of such reports exist in Australia and could be used as templates.

Finally, it is important to note that these reports will only be able to be (meaningfully) produced once the required information is collected.

2.5 Conclusions

This report has provided a range of perspectives on what water accounting may mean to water managers in China. It has provided some background as to how water accounting is being developed in Australia and has assessed how water information management in China may benefit from some of the principles being adopted In Australia.

There are some aspects of a WET framework that would benefit from improved water information management. It is recommended that water managers:

i. Identify and coordinate information requirements – coordination of water information is likely to be a difficult process. However, identifying the different users and their information requirements is likely to provide efficiency gains.

ii. Build on existing systems and practices – moving to adopt water accounting principles should not involve wholesale changes to current approaches to water information management. It should seek to harmonise existing systems and practices with one another, in away that maximises the benefits from the results.

iii. Develop some standard reports for water balances, permitting and environment water performance and then trial these in a range of applications will allow information gaps to be identified.

iv. Dedicate resources – ensure that appropriate resources are assigned to undertake water accounting development.

Chapter 3: Urban Water Management

3.1 Overview

This section considers the function of water abstraction permits as a mechanism for regulating water supply within public water systems, and how such water use should be managed within a WET system. In particular it looks at the interactions between different institutions involved in public water supply and the interactions between water savings planning, water supply and demand planning, and water resources allocation planning.

Section 2 provides background on the regulatory arrangements of the abstraction permit system, and in particular those regulations of relevance to public water supply. Section 3 provides a description of the legal and regulatory arrangements of public water supply management in Beijing, as an example. Section 4 specifically considers connections between water supply, savings, use and abstraction permits. Section 5 discusses issues and provides recommendation for improved management.

3.2 Regulations for Public Water Supply System and Water Abstraction Permit

3.2.1 Regulations Relating to the WAP

Contents

The state shall apply the systems of water licensing and paid use of water resources according to law. The department of water administration under the State Council shall be responsible for organizing the water license system implementation as well as the nationwide paid use of water resource system. [<Water Law of the People's Republic of China> Article 7]

The entities and individuals that collect water resources directly from rivers, lakes, or underground shall, in accordance with the provisions of the water collection license system and the system of paid use of state water resources, apply to the water administration departments or watershed authorities for a water collection license, pay the water resource fees and thus obtain the right to collect water [<Water Law of the People's Republic of China> Article 48, <Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 2].

Administration

The state shall, with respect to water resources, adopt a system that organizes the administration by basins as well as by administrative areas. The watershed authorities, set up by the department of water administration under the State Council, at the important rivers and lakes (as determined by the state) (hereinafter referred to as the basin authorities) shall, within their respective jurisdictions, exercise the water resource administration and supervision provided for by laws and regulations and authorized by the department of water administration under the State Council. The departments of water administration in the local people's governments at and above the county level shall, according to the prescribed limit of authorities, be in charge of the unified administration and supervision of water resources within their respective administrative areas [<Water Law of the People's Republic of China> Article 12, <Regulations

Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 3].

Basis and Condition

Conform to the comprehensive planning

Actualizing the license for water abstraction must conform to the water resource comprehensive planning, the basin comprehensive planning, the medium and long-term planning for the supply and demand of water and the functional division of water, and be in compliance with the water allocation scheme approved in accordance with the "Water Law of the People's Republic of China". If no water allocation scheme is formulated, the license for water abstraction shall be in compliance with the agreement concluded between the relevant local people's governments [<Water Law of the People's Republic of China> Article 19, <Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 6].

The principle of approving amount of water

To grant a license for water abstraction, the principle of giving overall consideration to surface water and ground water, and the principle of finding more water sources while saving water with priority given to water saving shall be adhered to, and the control of total amount combined with the quota-based management shall apply.

The total amount of water consumed upon approval for water abstraction within a basin shall not exceed the utilizable amount of water resources of the basin concerned.

The total amount of water approved for abstraction within a jurisdiction shall not exceed the water amount allocated by the basin authority or the competent department of water administration at the next higher level for abstraction within the jurisdiction concerned; among which, the total amount of ground water approved for abstraction shall not exceed the exploitable amount of ground water within the jurisdiction concerned, and shall meet the requirements of the planning on the exploitation and utilization of ground water. For making the planning on exploitation and utilization of ground water, opinions shall be solicited from the competent department of state land and resources [<Water Law of the People's Republic of China> Article 46 and 47, <Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 7].

The principle of distributing

The development and utilization of water resources shall first satisfy the needs of the urban and rural inhabitants in their domestic use of water and give overall consideration to the agricultural, industrial and ecological need for water as well as to the needs of navigation. [<Water Law of the People's Republic of China> Article 21, <Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 5]

Water saving

The state shall require strict economy in the use of water, vigorously promote measures for water saving, spread new technology and techniques to conserve water, develop the water-conservation industry and agriculture and service industry, and establish a water-conservation society.

The people's governments at various levels shall take measures to improve the management of water preservation, establish the development and distribution of water-conservation technology, and foster and develop water-preservation industries.

Entities and individuals shall bear an obligation to save water. [<Water Law of the People’s Republic of China> Article 8, <Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 9]

Quality reaching the standard

Water licensing shall reach the standard of water quality management. [<Regulations governing water quality management for water abstraction permit> Article 4 and 5]

The principle of legitimacy

No entity or individual shall, while channelling, storing, or discharging water, infringe upon public interests or the lawful rights and interests of other people. [<Water Law of the People’s Republic of China> Article 28]

Application

Application materials

To apply for water abstraction, the applicant shall submit the following materials :[< Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 11 and 12]

i. the application letter;
ii. relevant statements having an interest relationship with the third party;
iii. relevant archived materials in case of a project for archival filing;
iv. other materials prescribed by the competent department of water administration of the State Council.

Acceptance Department

The competent department of water administration of a local people's government at the county level or above or the basin authority. [<Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 10 and 13]

Examination of and Decisions on the License for Water Abstraction

Approval organ

The water abstraction under other circumstances shall be subject to examination and approval of the competent department of water administration of the local people's government at the county level or above pursuant to the approval power prescribed by the people's government of the province, autonomous region, or municipality directly under the Central Government. [<Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 14]

Procedure

Applicant submit the relevant materials- approval organ check- issue the license certificate for water abstraction [<Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 23]

The time limit for examination and approval

The approval organ shall decide to approve or disapprove an application for water abstraction within 45 working days as of acceptance of the application. If it decides to approve the application, it shall simultaneously issue an approval document for the application for water abstraction. [<Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 19]

Basis for examination and approval of the amount of water for abstraction

The water consumption amount verified according to the quota for the industrial use of water shall be the main basis for examination and approval of the amount of water for abstraction.

The water abstraction approval organ shall, according to the local water abstraction plan of the next year, and the suggestions proposed by the water abstraction entity or individual on the water abstraction plan of the next year, as well as in compliance with the principles of overall coordination, comprehensive balance and reserving space, make the water abstraction plan of the next year to the water abstraction entity or individual.

A water abstraction entity or individual shall, prior to December 31 of each year, submit to the approval organ the water abstraction situation of the present year and the water abstraction plan and suggestions for the next year.[<Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 15, 16, 39, 40, 41 and 42]

The contents of a license certificate for water abstraction

A license certificate for water abstraction shall include the following contents [<Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 24]:

i. name of the entity or individual that draws water;
ii. term of water abstraction;
iii. the amount of water for abstraction and the use of the water to be drawn;
iv. type of the water sources;
v. the location of water abstraction and water withdrawal, the way of water withdrawal, and the amount of water withdrawn.

The valid term of license certificate

The valid term of a license certificate for water abstraction shall generally be 5 years, and shall not exceed 10 years. [<Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 25]

Publicity

The license for water abstraction and the levy and management of water resource fees shall be in compliance with the principles of publicity, fairness, justice, high efficiency and facilitating people.

Where an approval organ holds that the water abstraction involves public interests and a hearing is needed, it shall make an announcement to the general public, and hold a hearing. [<Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 8 and 18]

Modification for water abstraction right

Where an entity or individual entitled to water abstraction according to law conserves water resources by adjusting product and industrial structure, by reforming the process, or by saving water, etc., it/he may, within the valid term of the license for water abstraction and the water abstraction limitations, lawfully assign the conserved water resources on a non-gratuitous basis upon approval of the original approval organ, and go to the original approval organ to go through the modification procedures for water abstraction right. The specific measures shall be formulated by the competent department of water administration of the State Council. [<Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 26 and 27]

Supervision and Administration

Where the water abstraction has been suspended consecutively for 2 years or longer, the original approval organ shall nullify the license certificate for water abstraction.

The competent department of water administration of the local people's government at the county level or above shall, in accordance with the provisions of the competent department of water administration of the State Council, timely submit to the competent department of water administration at the next higher level or the basin authority at the locality of the basin the information on the distribution of license certificates of the last year for water abstraction within the present jurisdiction.

Where the competent department of water administration at the next higher level or the basin authority finds that the total amount of water for abstraction as approved beyond the powers or as ratified by the license certificate for water abstraction exceeds the amount set forth in the water allocation scheme or the agreement, or that the annual actual total amount of water for abstraction exceeds the sent annual water allocation scheme or annual water abstraction plan, it shall timely require the relevant competent department of water administration or basin authority to make a correction.[<Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 44 and 46]

Legal Liabilities

Whoever unlawfully builds water abstraction engineering structures or facilities without obtaining an approval document for the application for water abstraction shall be ordered to stop the illegal act, and to make up the relevant procedures within a time limit; if it/he fails to make up the procedures within the time limit or is still not approved after making up the procedures, it/he shall be ordered to demolish or close down the water abstraction engineering structures or facilities within a time limit; if it/he fails to demolish or close down its/his water abstraction engineering structures or facilities within the time limit, the competent department of water administration of the local people's government at the county level or above or the basin authority shall organize the demolishment or closedown, with the necessary expenses to be borne by the law breaker, who may be fined up to 50,000 Yuan.

Whoever refuses to implement the decision made by the approval organ on restricting the amount of water for abstraction or assigns the water abstraction entitlement without approval shall be ordered to stop the illegal act and to make a correction within a time limit, and be fined 20,000 Yuan up to 100,000 Yuan; if it/he refuses to make a correction within the time limit, or if the circumstance is serious, its/his license certificate for water abstraction shall be revoked. [<Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 48, 49, 51 and 52]

Violation and Punishment

Whosoever commits any of the following acts shall be ordered by the water administration department of the people's government at or above the county level or the watershed authorities, according to their powers, to stop his illegal acts and to take remedial measures within the specific time limit, and be subject to a fine of at least 20,000 Yuan but no more than 100,000 Yuan. Where the circumstances are serious, the offender's water license shall be revoked.1) Collecting water without approval; 2) Failing to collect water according to conditions prescribed by the approved water license. [<Water Law of the People’s Republic of China> Article 69]

Water Resource Fees

Water abstraction entity or individual shall pay water resource fees. Water abstraction entity or individual shall draw water according to the approved annual water abstraction plan. For the water abstraction exceeding the plan or quota, water resource fees shall be charged progressively on the excessive part. [<Water Law of the People’s Republic of China> Article 49 and 55, <Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>> Article 28]

3.2.2 Related to urban water supply system

Contents

The urban water supply contains urban public water supply and self built equipments water supply.

The urban public water supply in these regulations shall be referred to as the acts of supplying water to the residents and units for living, producing and other purposes through the urban public water supply project by the water supply enterprise.

Self built equipments water supply, shall be referred to as the acts of supplying water to itself residents and units for living, producing and other purposes through the self built equipments. [<Urban Water Supply Regulation>Article 2]

Administration

The department of Construction administration under the State Council shall be in charge of the urban water supply of the nation.

The departments of construction administration in the people's government of the province, autonomous region shall, be in charge of the urban water supply within their respective administrative areas

The departments of urban water supply administration in the local people's governments at and above the county level shall, be in charge of the urban water supply within their respective administrative areas.[<Urban Water Supply Regulation>Article 7

The Urban Water Supply Source

The Municipal Water Resource Competent Authority with the presence of other relevant authorities shall make the plan for urban water supply in accordance with the national economy and social development plan. The water supply plan shall be included in the general plan of city development. [<Urban Water Supply Regulation>Article 9, 10, 11, 12, 13 and 14]

Urban Water Supply Project

The design, construction and supervision of the urban water supply project shall be undertaken by the unit which has corresponding qualification document and shall comply with the national technical standard and criterion. The unit which has no qualification document or goes beyond the business scope of the qualification document shall be prohibited from undertaking the design, construction and supervision of the urban water supply project. [<Urban Water Supply Regulation>Article 15, 16, 17 and 18]

Urban Water Supply Management

The urban waterworks supply enterprise and supply water through self built equipments enterprise, must pass the qualification examination and be registered by industrial and commercial administration departments, then can undertake the urban water supply business. The qualification examination method shall be made by the department of construction administration under the State Council.

The urban waterworks supply enterprise and supply water through self built equipments enterprise, shall ensure continuous water supply. Because of constructing the project, repairing the facility and other circumstances being necessary to stop water supply, shall report to the Municipal Water Resource Competent Authority and inform the users before 24 hours. If it is unable to make the aforesaid information in advance due to nature calamity or emergency obstruct, the water supply enterprise shall inform the users at the same time of rush repairs and report to the Competent Authority. [<Urban Water Supply Regulation>Article 19 and 22]

The Water Rate

The water rate of the residential use shall be determined according to the principle of cost plus low-profit and the water rate for other use purposes shall be reasonable charged.

The water rate shall be made by the people's government of the province, autonomous region, or municipality directly under the Central Government. [<Urban Water Supply Regulation>Article 26]

Urban Water Supply Equipment Maintenance

Urban water supply enterprise and self-service water supply enterprise should timely inspect and repair their water supply facilities such as reservoirs, water delivery canals, water intake mouths, pump stations, wells, water transport and distribution pipes, water meters, water purification and distribution plants and public water supply stations, in order to make sure of water supply security. [<Urban Water Supply Regulation>Article 27]

Urban water supply quality

The urban water supply enterprise is in charge of its supplied water quality and the part in which through the second water supply shall be in charged by the second water supply unit.

The urban water supply quality shall accord with the national standards [<Urban water supply quality management regulations> Article 7]

Urban water supply quality monitoring

Urban water supply quality monitoring system is made up of national and local urban supply water quality monitoring networks.

National urban water supply quality monitoring network consists of the construction Ministry urban water supply quality monitoring centre and municipalities, provincial capitals, cities and urban water supply quality monitoring stations (Hereinafter referred to the national station) which have to pass through the accreditation of national quality and technical supervision department. It is in the charge of the main construction sector of State Council department in business. Construction Ministry urban water supply quality monitoring centre is the central station in National urban water supply quality monitoring networks and take charge of the work from the main construction sector of State Council department.

Local urban water supply quality monitoring network (Hereinafter referred to the Local station) consists of the national stations of municipalities, provincial capitals, cities and some other cities' urban water supply quality monitoring stations which have to pass through the accreditation of provincial quality and technical supervision department at least. It is in the charge of the urban water supply sector of local provinces, autonomous regions or municipal government department.

According to the character, the ability of monitoring water quality and the need for water quality monitoring task, the construction administrations of provinces and autonomous regions and municipal People's government should certain the central station of local networks. [<Urban water supply quality management regulations>Article 6]

Violation and Punishment

Whosoever commits any of the following acts shall be ordered by the water supply administration department and be subject to a fine; where the circumstances are serious, report to the people's government above the county level, should be shut down to improve the situation, people who directly in charge or others in charge, a administrative punishment should be executed by the Department he/she stayed or the upper section. [<Urban Water Supply Regulation>Article 33]

i. The water quality and the hydraulic pressure of water supply piping do not reach the national standards.
ii. Stopping water supply without permission or don't carry out stopping water inform.
iii. Didn't carry out her responsibility for timely inspection and repairing on water supply facilities or without repairing on time after accidents.

3.3 Public Water Supply Management – Beijing as an example

3.3.1 Public water supply system in Beijing

There are ten waterworks and one reclaimed-water work in the public water supply system of the urban district in Beijing, which belong to the six branch corporation of the Beijing Waterworks Group Co. Ltd, they are: the Third Waterworks, the Fourth Waterworks, the Eighth Waterworks, the Ninth Waterworks, Tiancushan Water-purification Plant and the Reclaimed-water Factory. Among these factories, the Third, the

Fourth, the Eighth Waterworks use ground water as their source water, while the Ninth Waterworks and the Tiancunshan Water-purification Plant use surface water.

What is more, there are eight waterworks in the suburb, they are: Fengyuan Waterworks, Liangquan Waterworks (two waterworks in Liangxiang and Fangshan are included), Mencheng Waterworks, Tianlongda waterworks, Jinyang Waterworks, Huairou Waterworks, Tanzhou Waterworks. The suburban waterworks are located where there has water.

The sources of surface water are Miyun Reservoir and Huairou Reservoir, while the ground water sources in suburb area mostly on the alluvial fans of Yongdinghe River and Chaobaihe River.

The outline of branch corporations of the Beijing Waterworks Group is as followings:

The Ninth Waterworks

The Ninth Waterworks is the largest waterworks in Beijing whose water source is surface water and it has the designed daily water supply capacity of 1,500,000 m^3 The drinking water production process contains four parts: the source water adoption, transportation, purification and drinking water distribution. The plant was built in 1986 and expanded its production two times during 13years, with a total investment of 6 billion Yuan. The first phase ran in 1988 with the daily water supply capacity of 500,000 m^3. The second phase ran in 1995 with a 500,000 m^3 increase of daily water supply capacity. The third phase ran in 2000 with another 500,000 m^3 increase of daily water supply capacity. The source water for the first two phases is from Huairou Reservoir and the third phase from both Huairou Reservoir and Miyun Reservoir.

The Ninth Waterworks gets Miyun Reservoir as its source water and fetches water from Miyun Reservoir and Huairou Reservoir respectively. It connects one ductile iron pipe of DN2600×33km with three steel pipes of DN2200×42km to transport the raw water to the waterworks for purification and distribution.

After the conventional treatments, such as dosing, coagulation, sedimentation, filtration, and advanced treatment of activated carbon adsorption, the water which meets the state drinking water standard is distributed to the city drinking water distribution network.

The Ninth Waterworks mainly transports drinking water into the Fourth Circle Line and its supply of water accounts for 50~60% of the entire volume of the urban water supply. The highest daily water supply of Beijing in 2007 is 2,425,000 m^3.

Recently, because of the shortage of surface water, the Ninth Waterworks also fetches some ground water. There are two water sources, Huairou emergency source of water, 300,000 m^3/d, partly to the Ninth Waterworks; and Pinggu emergency source of water, with more than 30 wells, 200,000 m^3/d, partly to the Ninth Waterworks.

Furthermore, the Ninth Waterworks will receive the water from Hebei and as well as from the Water Diversion from South to North.

Tiancunshan Water-purification Plant

Tiancunshan Water-purification Plant is a middle-scale water factory with raw water of surface water, and is the first one providing drinking water for urban life by highly treatment, and it was designed the most advanced waterworks with surface water intake. Purifying water technique are using ozone to disinfect and using active carbon to adsorb.

Miyun Reservoir and Guanyunting Reservoir are the raw water source of Tiancunshan Water-purification Plant. The water flows in the Beijing-Miyun diversion canal from Miyun Reservoir and arrive at Tuancheng Lake where water would be piped to the Tiancunshan Water-purification Plant The Guanyunting Reservoir have not been supplying raw water for the plant because of its bad quality since November of 2000, and the Juma river in Zhangfang has being used as supplemental raw water source since August in 2004.

Occupying about 6.5km^2 land and costing about 40.68 million Yuan, Tiancunshan Water-purification Plant begun to been built in 1983, and had been established in June of 1985. It has daily water supply capacity of 170,000 m3

Now, there are 2 department and 1 office and nine production groups in the Tiancunshan Water-purification Plant. Besides, 131 people have registered in the Tiancunshan Water-purification Plant.

The Eighth Waterworks

The Eighth Waterworks is a lager-scale waterworks by emerging the former First water factory, Fifth water factory and Eighth water factory of Beijing Water Corporation in 1989, and it renamed the Eighth Waterworks of the Beijing Water Supply Group since August in 1999.

The Eighth Waterworks has six production sites which covering Shunyi, Pinggu, Chaoyang and Dongcheng districts. There are 87source-wells and 13 pressure-wells equipped with 100 pumps. It has 21 water distribution equipments and water supply pipes of 165 km long. It supply water coving the south and east parts of Beijing urban area, East Fourth Ring to the east, the Tian'an'men to the west, the Fenzhongshi to the south and the Sanyuan Bridge to the north. The area of water supplying also covers the Capital Airport and Wangjing area. The Eighth Waterworks contains 1 office, 2 departments and 12 water production group, and has a daily water supply capacity of 600,000 m^3. There are 267 staffs in the Waterworks.

The Fourth Waterworks

The Fourth Waterworks is constituted of the Fourth water plant, the Seventh water plant, the pressure station, the Fenzhongsi regulating water plant and the Fengtai water plant. The Fourth water plant is the first water plant of the PRC and had been established in 1957, locating at Gaoloucun, Fengtai District. It possesses 22 wells for its water source and provides water of 50,000 m^3 water a day. The Seventh water plant was built at Majiabao, Fengtai District, and it has 5 wells for its water source, with an average water supply capacity of 20,000 m^3. The pressure station, which was constructed in 1978, however, only supply water 4,000 m^3/d for the tall buildings in Qiansanmen. The Fenzhongsi regulating water plant and the Fengtai water plant are both built up in 1998. The former , locating at Fenzhongsi Bridge ,is the first regulating water plant of Beijing ,and it accumulate water at night, just supplying water at water demand summit with an average daily supply of 13,000 m^3. The later, locating in Niwa Road, Fengtai District, has been under the regulation of the Fourth Waterworks since 2006, with an average water supply capacity of 12,000 m^3.

The Third Waterworks

The Third Waterworks uses ground water as its water source, and it can supply 50,000 m^3/d. It was constituted of the Second Water Plant and the Third Water Plant, and the former is called the Northern Station of the Third Waterworks.

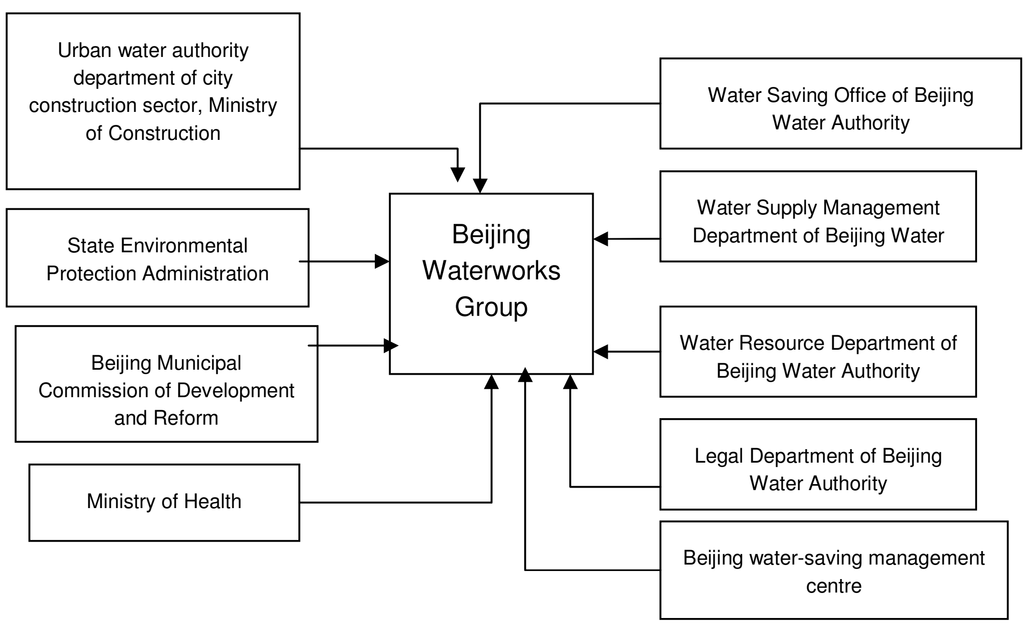
The Third Waterworks possess 151 wells as its water source, which are distributed in Haidian, Dongcheng, Xicheng and Chaoyang districts. There are 8 pipe lines with a total length of 48 km^2 for water supply. Now, there are 3 department and 9 production groups in the Third Waterworks. Besides, 210 people have registered there.

3.3.2 Management of Beijing public water supply

External management system

Beijing Waterworks group co. ltd is the core and executive unit of Beijing urban Water Supply System. This group is a wholly state-owned enterprise, so it has an independent management system as well as supervision from the water administration relative departments, namely external administrative system here. Specific as: The group is under the professional guidance by the Beijing Water Authority. The license for water abstraction and the approval amount of water need to be authorized by the Water Resources Division of Beijing Water Authority. Construction Standards and Water quality specification for the tap water transportation and distribution are supervised by Construction department. The water rate of the urban water supply is determined by Beijing Municipal Commission of Development and Reform and the water saving in the production operation is under the guidance from Water Saving Office.

Figure 63: External management frame of Beijing public water supply system



Administrative sectors that guiding Waterworks are as follows:

Water Resources Department of Beijing Water Authority

This department charges the unified management of water resources monitor and invest and value the water resources, organize to draw up concerned policy and regulations about development and utilization of water resources. This department is also responsible for urban and rural water supply and demand balance, the preparation of the city's water supply and demand in the medium and long term and annual plans, water distribution schedule programs, and supervise the implementation, responsible for the implementation of water and the license system, divide the water into different functional area, study water pollutant carrying capacity, make suggestion on limiting the total amount of sewage, monitor water quality and quantity of rivers, lakes, reservoirs and drinking water, responsible for coordinating basin water resources protection, guide the city's hydrological work. It is in charge of water abstraction permit determination and promulgation of urban public water supply system. However, the permit has no linkage either with public water supplier's annual water intake planning or the non-residential user's water use quota.

Water Supply Management Department of Beijing Water Authority

The Department is in charge of compiling and implementing developmental plan of water supply and annual plan, regulating water supply industry and specific task of franchising, organize to draw up and supervise implementing regulation standard and criterion of technique, management, service and supply of water supply industry. Besides, supplying water quality should be supervised by this department. In a word, this department focus its eye on regulating water supply affairs. The department is industry management unit of public water supply system, but does not take charge of non-residential users' and public water supplier's water intake planning.

Legal Department of Beijing Water Authority

This department mainly deal with some legal affairs, including: drafting local law and regulation, auditing the documents constituted by itself, supervising and studying execution of the relevant laws, codes and regulations, providing litigant agency service for kinds of cases about water problem, mediating the disputes on water use, etc. It is in charge of making, supervising and running management methods for the self-built water supply facility.

Water saving office of Beijing Water Authority

The office take charge of water saving of the whole city; organizing and drafting water saving policy; abstraction up the saving water plan and organizing to put into practice; making relative standards and supervising; collecting, using and managing the water resources fee and the water rate over plan; participating in the design examination and project acceptance.

Beijing Municipal Water Conservation Office

Beijing Municipal Water Conservation management centre takes charge of water saving management of the city; the statistical work on water saving and planning; the extension and propaganda of saving water technology and facilities; monitoring of water quality of self-drilled well; collecting the water resources fee and the water rate over plan and sewage treatment fee; participating in making the regulations and plans of utilization of regeneration water and rain resources to guide these work. It is in charge of making annual water utilization planning for the non-residential users in the public water supply system, supervising and checking the water use and collecting the water rate over plan.

Urban Water Authority Department of City Construction Sector, Ministry of Construction

The main function is to guide the nationwide urban water supply, water saving, urban drainage and sewage treatment work，study out the development strategies of water affair industry, reform measures and development planning, water affair industry regulations, principles and technical and economic policies. By discussing reform, the strengthening of administrative supervision, it can help to improve the franchise system. Strengthening urban drainage facilities by planning, constructing and operating management guidance and supervision, preventing and control regional urban water pollution are as important works as others. What's more, to strengthen the city to save water and to promote water saving management legislation and strengthen urban water supply security system is parts of its works, as well. It is the industry management department for the urban public water supply system in the cities except Beijing and Shanghai. It is in charge of making annual water utilization planning for the non-residential water users in the public water supply system, supervising and checking the water use and collecting the water rate over plan, but is not in charge of water abstraction permit determination and promulgation

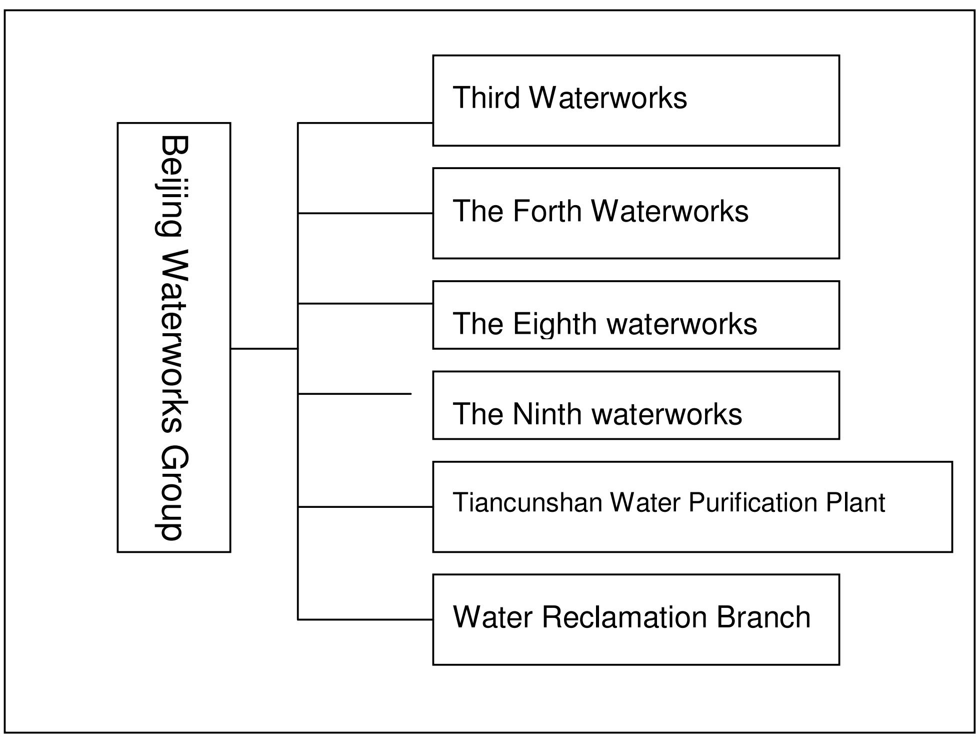
Beijing municipal commission of development and reform

Beijing Municipal Commission of Development & Reform is part of the municipal government body responsible for studying and initiating the economic and social development policies of the city, making comprehensive balancing between them, and directing the reform work of the overall economic system of the city.

One of Main Responsibilities (9) is Monitor and analyse the price situation, study and propose for the control targets of the overall price level, control policies and price reform of the city, prepare for and adjust the prices and fees and organize for the implementation of the key commodities, and public products according to relevant laws; organize to implement the price supervision and inspection.

Inner management system

Figure 64: The internal management structure of Beijing Waterworks Group



The Beijing Waterworks Group has responsibility for 7 districts' water supply, and specific tasks are under its six branch corporations' charge, which are the Third Waterworks, the

Fourth Waterworks, the Eighth Waterworks, the Ninth Waterworks, Tiancushan Water-purification Plant and the Reclaimed-water Factory. Each branch corporation is constituted of one or more water supply stations. These water supply pipes in urban area form a pipe net, whose length amounts to total 7,000 km. Every branch corporation is independent on production, likes a production department, but they are all under the regulation of dispatching centre office of the Group's planning production department. The Group also speculate the cost and the benefit of water supply. The construction fee of waterworks was invested by government, and the maintenance and the cost of constructing waterworks was paid by nation in the past. The equipment depreciation and management are in the charge of the company. However, at present, the company also commits the construction investment by bank loans.

3.4 The relationship between the water abstract permit and water supply/use/saving plan in urban water supply system

3.4.1 The water collection license system in urban water supply system

According to <Water Law of the People's Republic of China> Article 7, 48 and <Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees> Article 2, "The entities and individuals that collect water resources directly from rivers, lakes, or underground shall, in accordance with the provisions of the water collection license system and the system of paid use of state water resources, apply to the water administration departments or watershed authorities for a water collection license, pay the water resource fees and thus obtain the right to collect water." collect water resources directly from rivers, lakes, or underground shall, implement provisions of the water collection license system"

Urban water supply unit-waterworks need to apply for the water collection licence from the department of water administration. The Water Resources Division of Beijing Water Authority is in charge of examination and approval.

A water abstraction application entity or individual shall download and print application form from ‘http://www.bjwater.gov.cn/Portal0/default40.htm’ ——〉 fill the form ——〉 hand in the form and relative materials in administration permission hall on the first floor of Beijing Water Authority ——〉 Internet office procedure. The procedure contains five sections: Approval, treatment, check, determination and notification. The time limit is 20 working days (not contain approval and notification limit)

Examination and approval is not through pre-notification, publish the result on the internet, hearing. The hearing must be required by applicant. The permitting water abstraction amount is determined by water justification for construction project and is a constant amount.

No matter fetching ground water or surface water, the Waterworks Group had applied for and got the WAP from the Water Resources Department, a department of Beijing Bureau of Water Authority. However, the permit water amount is audited only according the examination and approval of supply capacity of waterworks, not considering the variation of source water amount in real time, and is not checked on a yearly basis.

3.4.2 Sectors and principles for making urban water supply and demand plans

The Water Resources Division of Beijing Water Authority is in charge of making urban middle and long-term water supply and demand plan and the annual water and water allocation program, in which water saving runs through them. According to the <.Beijing water saving methods> Article 5, The competent departments of water administration of the Beijing city people's governments shall take charge of organizing and implementing, supervising and administering water saving of Beijing. The competent departments of water administration of the people's governments at the county level and the appointed manage department without departments of water administration of the people's governments at the county level shall, take charge of supervising and administering water saving within their respective jurisdictional scopes.

The Beijing Water Saving Office is in charge of saving water in Beijing. The office take charge of water saving of the whole city; organizing and drafting water saving policy; abstraction up the saving water plan and organizing to put into practice; making relative standards and supervising; collecting, using and managing the water resources fee and the water rate over plan; participating in the design examination and project acceptance. Related Departments in municipal, prefecture, county government should do the work which was divided according to the responsibilities, and take in charge of the “Saving water use” work within the administrative section of their own.

According to <.Beijing water saving methods> Article 10, Beijing Water Saving Management Centre checks water use index of company according to the annual water use plan, the relevant quota of trade water and the living and producing need. And the centre will announce the next year water use index to relevant companies before Dec 31 rd every year. It is also in charge of authorizing the water using quota for an increase water using unit and new water using project. The water use quota has no linkage with water use amount by different water users in the public water supply system, also has little linkage with the permit of public water suppliers and the other water resources users. The annual water quota is controlled below the total permit water abstraction amount.

Mainly based on calculating water saving with water quota, the water use index is certain. And at the same time, it is also in the charge of the mandatory water saving requirements from government. It follows the principles of that it will meet most people’s demand, but be more strict with government and limit the water use of high costing water industries to protect public welfare entity (hospital and school) in water use. And Beijing compulsory local standards《public living water quota ,Part 2: school》,《public living water quota, Part 3: restaurant》,《public living water quota, Part 4: hospital》, which are drafted by Beijing Municipal Water Conservation Office and Institute of Geographic Sciences and Natural Resources Research ,CAS, are now open for comments online at the website of Beijing Bureau of Quality and Technical Supervision.

For the other cities (except Beijing and Shanghai), above work about the designing, supervision and execution on water saving and water use index in the urban planning areas is under the charge of water saving office of urban construction department. Water resources department also has water saving office, which is in charge of the saving water management outside the urban planning areas.

3.4.3 Daily water supply program making

Although the Waterworks Group has water supply plan, while it supplies water according to actual demands. In fact, the dispatching centre office of the Waterworks Group would predict the next day's water demand and make water supply plan and give the supply order for the next day according to demand and weather conditions on the day.

The actual water use amount is up to the users. The series tap water pipe network and centralized dispatching ensure the users' water demands. The water quality monitoring is also serious to ensure water supply quality.

3.4.4 Considerations on water abstraction permit in planning

The constructions of the waterworks are completed by the government, according to the construction planning. So, it has been issued the license actually on being built. The abstraction water amount relies on the construction scale and the water source, having no directly bearing on water abstraction permit. As the license is verified and issued based on the water supply capacity, the abstraction water amount will never exceed the permitting amount. Further, as all the waterworks in Beijing presently are built before the implementation of the water abstraction license system, licences were issued and reissued the license according to their actual capacity of water supply. It issued water abstraction license according to the legal person units.

The application materials for the water abstraction license handed in by the waterworks contains water resources demonstration and evaluation book for construction project, which is the basis for the examination and approval of the water amount. The book has considered the conditions of water source and water amount and its relationship with water resources planning. The water administrative department is mainly focus on whether the materials are comprehensive.

The public water supply system has residential water users and non-residential water users. For the residential water users, there is no water use quota control, but the non-residential user is controlled by the annual water use quota/annual water use amount. The annual water using plan for non-residential users is made by its actual water using amount last year, and simultaneously considered the total amount of water resources and water norm. This procedure considered the users' characters, as well as the shortage of the water resources. The water charging for the non-residential users implements an annual collection with progressive price mark-up.

3.5 Issues and Recommendations

3.5.1 Issues in Public Water Supply Management

The different administrative departments for public/urban water supply needs further linkage in managing

The urban construction administrative departments of the Ministry of Construction take charge in the external management of urban water supply system all over the country, except in Beijing and Shanghai, where its management is instead by water administrative department of the Ministry of Water Resources. Involving urban water supply, the Ministry of Construction has clearly appointed that it is in charge of the policy-making on urban water supply and drainage, urban water saving and water rate; the construction on reclaimed water utilization, urban water resource protection and water supply emergency system, the standard-making on drinking water security; the plan, design and construction on water supply and drainage system; the collection and treatment on urban sewage, and has set up the relative administrative departments and research institutions. In the Ministry of Construction, the department of comprehensive finance, the department of laws and regulations, the department of science and technology, the department of standard and norm, the urban water affairs office of the department of construction and three research institutions separately have the function of establishing water-related urban planning ,working out regulations, organizing science and technology tackling, issuing industry standards, managing urban water affairs and undertaking scientific researches. After reform in 2000, the management of urban water affairs in Beijing is belonged to Beijing Water Authority, a water administrative section of the Ministry of Water Resources. Beijing Water Authority adds the function on urban water supply system separately to the water resource office, water supply office, legal system office, water drainage office and water saving office. Therefore, the functions of departments from two ministries (Ministry of Water Resources and Ministry of Construction) overlap a little bit.

On urban water resources management, the Ministry of Water Resources is focus on the water resources planning and water consumption management in a watershed scale and the Ministry of Construction is focus on the urban planning areas management. The linkage between water management departments from the two ministries needs to be enhanced and the functions of different departments needs to be further enhance technological linkage among different administrative departments for public/urban water supply.

Regulations relating urban water supply promulgated by different ministries have few inconsistent parts

In general, the regulations issued by the Ministry of Water Resources and the Ministry of Construction are linked well, but still have few inconsistent parts. For example, <Methods of Water Function Region Management >, made by the Ministry of Water Resources and <Methods of Urban Blue line Management>, made by the Ministry of Construction, have overlapping in management. The implementation objects are rivers, lakes, reservoirs, cannels, channels and other surface water in the whole country in the methods of the Ministry of Water Resources, that involves the implementation Objects Rivers, lakes, reservoirs, cannels, channels, wetlands and other surface water in the urban in the methods of the Ministry of Construction. <Methods of Water Function Region Management > prescribes that the department of water administration under the State Council is in charge of organizing the division and supervision of the national water function area, while <Methods of Urban Blue line Management> prescribes that the department of construction under the State Council is in charge of the management of national blue line. The methods of both the Ministry of Water Resources and the Ministry of Construction all need to clearly define the water conservation objects and control requests and which can be not changed once it is authorized.

Taking another example, <The notice on some problems with ground water collection license management in the urban planning areas by the Ministry of Water Resources> promulgated by the Ministry of Water Resources on the 28th August, 1998, prescribes that the Ministry of Water Resources is in charge of organization and implementation of water abstraction permit system and the charging system of water resource fee. The function of guiding the ground water management and protection was handed to the Ministry of Water Resources from the Ministry of Construction in 2000. However, <Regulations of Urban Ground Water exploitation, utilization and protection> (The 30th Order Issued by the Ministry of Communications P.R.C) promulgated by the Ministry of Construction on 4th December 1993 is also effective, in which it prescribes that the department of construction under the State Council is in charge of the ground water exploitation, utilization and protection in the whole country. <Notice on ensuring the urban water supply> promulgated by the Ministry of Construction in 2000 also prescribes that the administrative department of construction is in charge of the management and distribution of all self-drilled wells by non agriculture users in the urban planning areas.

What's more, <The notice on some problems with ground water collection license management in the urban planning areas by the Ministry of Water Resources> prescribes that the ground water abstraction permit application for a new construction, reconstruction and extension project in the urban planning areas are all accepted by some levels water administration management department according to their authority and do not authorize and depute other departments. <Regulations of City Water Conservation > prescribes that ground water abstraction by the unit self-built facility must be approved by the construction administrative department. Thus it can be seen that there are conflicts among management authorities.

The water abstraction permit has little effect on the regulation of Beijing water supply

Urban water supply system, as one of the urban developing constructions, has been considered in urban planning. The license for water abstraction exists from the approval of the waterworks establishment and the water amount is determined according to the waterworks' construction scale. Although waterworks' construction passes the demonstration and evaluation on water resources, the promulgated license has only limit on total abstraction water amount and has no connection with time and water saving planning. For public water supply unit, the change of water abstraction amount and water supply amount is just affected by the users' demands and the daily water supply planning has little relationship to water abstraction license. The license is also lacks of control on a large number of the water users in the public water supply system. It needs to clear and abolish unused regulations and methods to keep the regulations uniform and consistent.

The making of water use index / plan for the users in and out of urban water supply system does not join with water abstraction permit

At present, water usage plan made by water-saving management centre does not include the suppliers of public water supply system and is aimed at none-residential users, but it has not been used to the linkage with water abstraction permit. For none-residents users in public water supply system, water abstraction permits are all conducted by the suppliers. They have annual water usage index, and will get penalty of accumulated increased priced for excess water for there is not compulsory controlling measures to avoid the exceeding the standards. For the users out of public water supply system, they need to get water abstraction permits, but the amount of water abstraction permit does not locked with water usage plan, and the planed amount is less than abstraction permit. Water abstraction permit could be conducted according to legal person entity，and there can be many water sources for one permit. Usually one permit has 10 wells. For approved water resources, permitted amount equals to proved amount. For the not approved, permitted amount equal to that is declared.

3.5.2 Preliminary suggestion on the urban public water supply system management

Determine the levels for water abstract permit implementation

First, define water abstraction rights of an urban planning area or administrative district.

The present <Water Law of the People's Republic of China>, <Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees> clearly states that, 'the individuals and entities which draw water directly from subterranean streams, rivers or lakes should apply for a license from the department of water administration or watershed management organizations, pay water resources fees and get water abstraction rights according to the regulations of license system and paid use of water resources'. This indicates water abstraction permit means abstraction rights. But, considering the various kinds users, the primary water right is not linked with water abstraction permit from the formation of water resources or regional aspects. As urban public water supply system is an important part of the city, the first implicational layer of abstraction permit should take urban planning areas or administrative districts as defined units, so as to increase convenience for the consistent of urban water abstraction right (total amount and water source) between watershed water allocation and watershed water rights trading.

Second, define water abstraction rights of different users inside the urban planning area or administrative district

Urban water users include resident, public living, urban construction and industry user and et al. They are mostly supplied by public water supply system and self-constructed water supply facilities. The water supply entities should apply water abstraction permit, obtain water abstraction right, and be regulated by the department of water administration uniformly. In this aspect, the priority of each permit owners (draw water directly from subterranean streams, rivers or lakes) should be firstly defined. The public supplier of any independent legal person entities is an independent user, and its water abstraction priority depends on the priority of the real user.

Generally speaking, urban public water supply, especially for citizen daily life and public use, should be a social welfare work, so urban public water supplier deserves higher water abstraction priority; nonetheless, this should be further defined by the users of the water supply system. In accordance with water abstraction priority, the improving of water license management according to the situation of water source and amount can be achieved. The present water abstraction permits preliminarily define water source, amount, usage，water drainage site, amount and drainage means. The priority of each user should be fixed; in this basis and according to water source, total amount and different users' water quota, the abstraction amount and different water source ratio can be defined. Make sure the allocation of urban water abstraction rights should correspond to the city's total abstraction permit.

Strengthen the link between water use planning and water abstraction permit

The implementation of water abstraction permit can not only materialize user's water consumption right, but also the more important is through the water abstraction permit management, achieve the water use's orderliness and sustainability. All the active urban water use plans just make sure the planned water use amount is lower than the total permit amount, but having no relation with the user's water abstraction permit.

In Beijing, the users involved in the water use planning are all the users through public water supply system and through self-drilled well, except resident living water. The making of the water use plan is on the basis of quota and on the principle of saving water, has little considering of the specific water source conditions as well as the user's water abstraction permit. In fact, water use planning is disjointed with the water abstraction permit and is not influenced by it. In other words, water abstraction permit has little control on the user's water consumption amount.

For fulfilling the water abstraction permit's function completely, it suggested that water abstraction permit management enhance the annual verifying system and the specific water abstraction index can be given referring to the annual water consumption planning index. For public water supplier, it checks and determines the annual water abstraction permit amount according to the type and amount of water users and the suitable ullage in the public water supply system. It is considered public water supplier, as a special water utilization unit, also carry out annual verifying system and economic punishment for the excess water amount. Accordingly, it need further perfect the management of non-resident in the public water supply system.

Perfect water abstraction permit and carry out dynamic management for the users' abstraction/drainage information

The active water abstraction permit is mainly according to the water resources assessment for the project construction on the water abstraction amount determination, and for the project with no water resources assessment, it according to the users' application amount. For the users who have several abstraction/ drainage site, water abstraction permit has no control on the specific abstraction/drainage amount for one certain abstraction/drainage site. If one user draws water from 10 wells, he/she just needs one water abstraction permit and just show the total abstraction water amount from the 10 wells with on regulated water abstraction amount for each well. It may cause local overdraft and other problems. Therefore, it needs further perfect water abstraction permit; make sure each water abstraction site information (coordinate, uniform coding) and annual permit water abstraction amount. The water abstraction permit for the water public water supply system should add information about the water user's type, large customers and so on.

To check and determine the permit water abstraction amount reasonably, it needs to master dynamic information about each water abstraction amount and water abstraction source conditions, such as river current, lake water level, ground water level, source water quality. So it needs real-time monitoring for the water abstraction amount and water source conditions in each water abstraction site. It suggests carrying out water users periodic report system combined with administrative department random visits. At the same time, according to the existing regional ground water and surface water observation stations, it can increase necessary observation stations and public water sources dynamic by the real-time monitoring result which can be combined with active ground water and surface water monthly report. This information and yearly change should be as one of the basis to determine the next year water abstraction amount and water distribution amount among different water abstraction sites.

Water user not only has water abstraction but also water drainage. Therefore, outfall and water drainage amount and quality also needs dynamic monitoring. It needs cooperation of water drainage permit determination department to make sure the information exchange smoothly.

Further improve the information exchange among administrative sections and public water supply system

Urban public water supply system is an important water abstractor which falls under the charge of many administrative sections. And it's also an essential consumer which should be considered in water allocation in a basin. Perfecting water abstraction permit of public water supply system needs further improvement in the relative information exchange.

Although the existing regulation has defined clearly, such as in <Regulations Governing the Licensing for Water Abstraction and the Levying for Water Resource Fees>, "as to the application of groundwater use in planed area, the department in charge of approval should consult to the administrative department of urban construction, and the annual information of groundwater of planed areas should be sent." The formality needs to be improved in order to achieve the efficiency of information communication and avoid conflicts.

For example (except Beijing) urban ground water use permission is under the charge of water resources administrations while urban water-saving and public water supply are under the charge of the Ministry of Construction.

Therefore, the Ministry of Construction needs to get the information of changes in the groundwater table and changes to sources for public water supply from the Ministry of Water Resource when it makes the water use index and decides the water supply proportion of tap water and groundwater. On the other hand, the Ministry of Water Resource not only needs to acquire the information of water usage but also the water discharge when making the water resource allocation. The information of drainage and discharge amount from the Ministry of Construction, and the information of discharged water quality from the Environment Conservation Council are very important.

Another example is that, the plan and construction of public water supply facilities and the location of self-drilled wells refer to the construction of other underground-facilities in the urban plan, and the secondary water supply and water-meter installation all need to be reported to the construction administration timely. At the same time, the construction administrative sections should take the initiative to comprehend the plan of public water supply which is an important part of urban construction.

Relative urban public water supply administrative department has built up certain information publication; however, its effect is not enough for the perfect water abstraction permit management. It needs to improve the information exchange among administrative sections and advance the information exchange efficiency.

What should be emphasized is that, public water supply units should provide the information such as annual water supply plan, abstracting water source and the abstracting amount, main consumers etc, to the administrative management sections in time so that the water administrative management sections make rational water allocation and guarantee high reliability for public water supply. If there are any changes in water supply plan, such an additional supplier, change of source (including different proportions of sources) and water access methods etc, public water supply units should report to water abstraction permit authority.

Enhance the International Corporation and public participation on the urban water abstraction permit management

Enhance the international corporation about urban water abstraction permit, absorb the international management experience and carry out national orientated water abstraction permit pilot study. There is little experience about how the water abstraction permit works in urban water resources management in different cities with different water resources conditions. And to summarize experiences.

At the same time, it should enhance the public participation on the urban water abstraction permit management. And in the relative regulations, it should be defined the way of public participation and the role of public as an interest's relevant side in the water supply management.

Perfect related regulations and make sure the effective management of water abstraction permit

The urban water administrative management sections need to clear and abolish redundant regulations and methods, solve the contradiction problems, amend and integrate the related regulation to keep the regulations unitive and consistent.

On the basis of further investigation and pilot research, it suggests to make urban water abstraction permit implementation detailed rules to make sure the effective management of water abstraction permit. Furthermore, the water administrative department, assisted by the urban construction administrative department, and combined with municipal commission of development and reform, ministry of health, ministry of land and resources, draft and promulgate the guideline for urban water management to guide the urban water management.

PART 6: POTENTIAL BENEFITS FROM WATER TRADING IN THE YELLOW RIVER

Chapter 1: Introduction

Rapid economic growth and an increasingly wealthy urban population are driving increased demand for water in China. Despite the ambitious South-North Water Transfer Project — that seeks to increase the flow of the Yellow River by diverting water north from the Yangtze River — over recent decades there has been a policy shift in China away from increasingly expensive water resource development to water management reform. This shift, toward policies and institutions that are designed to allocate existing resources more efficiently, provides an opportunity to increase rural incomes by allowing the movement of water from low value staple crops to high value horticulture crops.

The broad objective of this project is to facilitate the development of policy frameworks that promote greater water use efficiency and higher rural incomes in China through the evaluation of institutional reform options. The project focus is on the Yellow River Basin — an area where surface water is fully appropriated and ground water resources are stressed in some regions. Although improved water use efficiency includes greater allocative efficiency and technical efficiency, the focus will be on improved allocative efficiency as this is where the greatest overall gains are likely to be made.

Given information asymmetry, and the implications for administrative reallocation, market reform is likely to deliver the most efficiency gains. To improve allocative efficiency using a market and trade, a system for the transfer of water resources is required. In economic terms this is achieved through a system of property rights where users can trade their share of the resource that the property right entitles them to.

The absence of a system of water property rights, however, is not the only impediment to trade and the efficient reallocation of water. Physical infrastructure constraints, environmental considerations and existing institutional arrangements have the potential to limit trade after the introduction of a system of property rights

The objective of this paper is to estimate the value of water trading in Northern China and the impact of water trade on rural incomes. First we estimate the gains from trade in surface water at the household, village, county and provincial level, assuming there are no significant infrastructure constraints. Following this we develop a methodology that incorporates ground water use and infrastructure constraints so that the impact of surface water delivery constraints on the potential gains from trade can be estimated.

The results of this paper will form the basis of two policy briefs for consideration of policy makers in China;

- The value of water trading in Northern China: setting priorities for reform; and
- Water trade and rural incomes.

Chapter 2: Background

2.1 The Yellow River Basin

The Yellow River is the second largest river in China at a length of almost 5 500 kilometers. It traverses northern China from the west to the east covering nine provinces and autonomous regions; Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan and Shandong.

The Yellow River Basin has an average annual rainfall runoff of 58 billion cubic metres (58 000 GL[77]) (MWR 2007). Average annual diversions are 39.5 billion cubic metres and surface water consumption is 30.7 billion cubic metres (YRCC 2007). Irrigation is the main use, accounting for 92 per cent of both total surface water consumption (28.4 billion cubic metres / year) and diversions (36.2 billion cubic metres / year). Average annual ground water extractions in the basin are estimated at around 9.7 billion cubic metres.

The Yellow River Basin covers an area of 795,000 square kilometres. The cultivated area is around 189,000,000 mu (just over 12 million hectares[78]), with just under half of this area (75,900,000 mu) irrigated. The Gross Domestic Product of the Yellow River basin is 484 billion yuan with the gross value of agricultural output is 151 billion yuan, accounting for 6.1 per cent of the national value (MWR 2007).

The Yellow River Basin is currently facing serious water scarcity issues. Located in the dry and semi-dry areas of North China, runoff which feeds the river is very low and consequently water is in short supply. Average annual runoff of the Yellow River Basin is only 58 billion cubic metres which is just 2 per cent of the national total. Per capita and per hectare water availability in the Yellow River Basin are 593 cubic metres and 4860 cubic metres, which accounts for 27 per cent and 17 per cent of the respective national averages. The area covered by the Yellow River Basin is 42 per cent of that of the Yangze River Basin, however, available water resources in the Yellow River Basin is less than eight per cent of that in the Yangze River Basin. The runoff in the Yellow River Basin has declined by 15 per cent over the last 20 years largely due to land use changes.

2.2 The case study area

The case study is of the Ningxia and Henan provinces in the Yellow River Basin. Ningxia is located in the upper reach of the Yellow River and Henan is located downstream in the lower reaches of the Yellow River.

The Ningxia province depends primarily on the Yellow River as a source of water while the Henan province depends on the Yellow River and several other large rivers which traverse the province. Ningxia province is located in the north west of China. The total length of the Ningxia segment of the Yellow River is 397 kilometres and the irrigated area in the province is about 30,000 hectares (Ningxia Statistical Bureau, 2000). Located in the middle of China, Henan province has branches of the Huai River, the Yellow River, the Hai River and the Yangzi River. The Huai River branch in the province is the longest

[77] One giga litre (GL) is 1,000,000 m^3
[78] One hectare is equal to 15 mu

(88.3 kilometres) followed by the Yellow River branch (36.2 kilometres), the Yangzi River branch (27.2 kilometres), and the Hai River branch (15.3 kilometres).

Despite being endowed with more than three times the area of the Ningxia province (160,000 square kilometres), Henan province faces more pressure on its land because of its higher population density. The population density in Henan province is 587 people per square kilometre, which is 30 times that of Ningxia province and more than four times the national average (China Statistical Bureau, 2000). Mountainous regions in both Ningxia and Henan provinces occupy more than 70 per cent of the land. The agricultural industries are important to the economies of these two provinces as they provide employment to about 70 per cent of the population.

Despite the fact that the Ninxia province is located in the upstream reaches of the Yellow River it is a water deficit region. Per capita water availability in the province is only about 300 cubic meters compared to the national average of 2200 cubic meters. It is a very dry province with average annual rainfall varying from 200 millimetres in the north to 5 millimetres in the south. In addition, the rainfall distribution within a year is such that more than 60 per cent of the rain falls between June and September and is used less effectively for crop production (Ningxia Statistical Bureau, 2000).

Located in the semi-humid area, though not a water abundant province, Henan has a smaller water deficit than Ningxia. Within the Henan province, average annual rainfall varies from 700 millimetres to 1100 millimetres and 55 per cent of this rain falls in the summer months from June to September (Henan Statistical Burau, 2000). The per capita availability of water in Henan province estimated at 2100 cubic metres is very close to the national average of 2200 cubic meters.

In Ningxia, average per hectare agricultural water use reached 16 524 cubic metres, in 2000, which is around three and a half times the national average. In contrast, farmers in Henan used about 3 810 cubic metres per hectare which is just 23 per cent of that of Ningxia. The large difference in water access between the two provinces means that there will likely be significant differences in the efficiency with which the water is used by farmers and managed by the irrigation districts and villages. It also suggests that it is worth looking at the feasibility of transferring water from upstream Ningxia province to downstream Henan province. Such a transfer would invariably entail significant changes in the cropping areas, land use pattern, water values, and average farm incomes between the provinces. At the same time, any move to transfer water administratively without compensation would have implications for rural poverty.

In Ningxia, in 2000, irrigated land accounted for 48 per cent of the province's cultivated land compared to 66 per cent in Henan and a national average of 55 per cent. Access to both surface water and groundwater partly explains a relatively higher proportion of cultivated land being irrigated in the Henan province. In 2000, in Ningxia, surface water accounted for 94 per cent of the total irrigation water use while in Henan, farmers used both surface water and groundwater conjunctively.

Chapter 3: Water trade

The overall aim of economic reform is to increase economic efficiency and hence social welfare — by improving total industry profits and hence ultimately increasing national incomes. Reform is motivated by the principle that welfare can be improved by maximising the difference between the cost and value of production. For a given technology, this will occur when resources are allocated to those producers who value them most highly. The case for water trade rests on the view that the same level of inputs that is currently being used can, through voluntary reallocation, be used to produce higher levels of profit and hence contribute more to the national economy.

At the farm level, efficiency requires that the gains from an additional unit of water be the same for all irrigators — that all receive the same return from an additional unit of water. To understand why this is, imagine that low return water users can sell their water to high return water users, and both are initially allocated the same quantities of water. Trade will be mutually beneficial, because it will result in increased total profits — that is, the high return irrigator can profit from additional water use even after compensating the low return irrigator for lost production. The low return irrigator is more than compensated for lost production. This trade will continue to the point where a further unit of water traded would have the same value to both participants. This value will be the (marginal) opportunity cost, at least with respect to opportunities available in that particular market.

It is important to distinguish the (often subsidised) government charges for water supply from the prices at which irrigators trade water. The charge for the delivery of water compensates the state for at least some of the costs incurred in maintenance of storages and running the distribution system. While the traded price of water compensates irrigators for foregone water use — and will be equal to the marginal value of water use less the delivery charge. Using the value of marginal product of water we can see that the marginal cost of water use will be equal to the delivery charge for water plus the scarcity value of water.

The value of the marginal product of water can be derived from a simple profit maximisation problem for single input model — with water the one input.

$$\max \pi = pf(x) - cx \tag{1}$$

subject to $$x \le X \tag{2}$$

Where *p* is price of produce, *f(x)* is the production function (or the quantity of output produced from *x* water inputs), *c* is the delivery charge for water, and *X* is some endowment of water. Setting up the Lagranian and Kuhn-Tucker necessary conditions for profit maximisation we have;

$$L = pf(x) - cx + \lambda(X - x) \tag{3}$$

$$pf'(x) - c - \lambda \le 0 \tag{4}$$

where λ is the price of the constraint given in equation 2. Rearranging equation 4 gives the value of the marginal product of water;

$$pf'(x) = c + \lambda \tag{5}$$

Equation 5 simply states that the value of the marginal product of water use ($pf'(x)$) is equal to the marginal cost of water use ($c + \lambda$), where the marginal cost of water use is the cost of water delivery *c* plus the scarcity value of water λ. When water is not a binding constraint (that is, when $x < X$) the scarcity value of water is zero, and the value of the marginal product of water will be equal to the delivery charge.

When an irrigators' present endowment of water (*X*) is greater than required, at the present delivery charge, water trade would allow some of it to be sold to farms where the present endowment of water is less than desired. Water use would be reduced in some areas and increased in others. The total cost of water, including the market determined price of water would come to equal the opportunity cost at the margin.

Making water tradeable is a 'market solution' to the water allocation problem. The view that access rights should be vested with individual water users and that markets should be allowed to resolve resource use conflicts is due to information asymmetry. As an irrigator is better informed about the marginal value and opportunity cost of water use than the government, market reallocation will achieve a more efficient outcome than administrative reallocation. In other words, an administrative reallocation is likely to be imperfect (and inefficient) as it will be based on imperfect information.

3.1 Water rights

From a public policy perspective, the objective of market based water reform is to establish a set of water rights that facilitate the transfer of water between a wider range of alternative uses at the lowest possible cost. The greater the prospective range of uses that water can be directed to, the greater can be the value of the resource. The efficiency of the market outcome is affected by how the rights and responsibilities of individual water rights are defined. Ideally property rights allow individual water users full access to the benefits of water use and hold them accountable for all the costs imposed on other users and the environment. This allows the full benefits and costs of transferring water between alternative uses to be accounted for through trade. As with most common resources, however, the definition, monitoring and enforcement costs of establishing individual access rights that account for the full benefits and costs of resource use can generate significant transactions costs. In some cases, these transactions costs will be greater than the benefits derived from trade.

If the availability of storage and delivery infrastructure does not constrain the level and efficiency of water use, there is no need to define separate access rights to these resources. When access to infrastructure is a binding constraint on water use, failure to define separate access rights will create a market failure that will impinge on the allocative efficiency of all other access rights. However, when access rights are costly to define, monitor and enforce it may be more efficient to 'bundle' these rights for the purpose of trade.

Although property rights for water are often referred to as a single right, embodied in this right are three resource access rights — in this way the rights to water are 'bundled' together. The first access right is the right to access water generally and is defined as the right to take a proportion or volume of surface water flows or ground water stocks. The second access right is the right to access storage and delivery infrastructure. The third access right is the right to use water. Use rights allow irrigators to use water under a specified set of conditions. Use rights are important where, for example, the location and intensity of water use can significantly affect the level of return flows.

There are two alternative models for allocating access to irrigation infrastructure. The first is to allocate explicit infrastructure access rights to irrigators and to make these rights tradable. There may be a large number of implicit property rights embodied in an infrastructure access right which will result in significant costs in establishing and maintaining the institutional arrangements required to define and enforce those rights individually. The second alternative is to charge a congestion fee when capacity constraints are met. Under these circumstances, irrigators requiring access during congested periods will pay a congestion fee. Moreover, where irrigators encounter multiple constraints (for example, the main delivery channel plus several smaller channels), the transaction costs of trading multiple access rights may be significant. The transaction costs associated with capacity charge are likely to be lower — although there will be transaction costs in identifying the appropriate fee to charge irrigators when delivery constraints are binding.

The problem for policy makers when establishing tradeable water rights is determining which access rights are necessary to define and establish institutional arrangements to promote trade, and those that should be left unstated and tied, or 'bundled', with other resource access rights. In other words, which property rights should be made explicit and which should be implicit. If the gains from 'unbundling' these rights do not outweigh the transactions costs then it is also important to consider whether the benefits of trading incomplete property rights outweigh the costs. Even though introducing trade with poorly defined property rights may generate some forms of market failure — by imposing external costs or benefits to water users and the environment — imperfect rights may still generate a more efficient reallocation of water resources than under no trade.

The purpose of this paper is to investigate the value of trade and the impact on rural incomes. First, assuming no constraints on trade, we estimate the value of trade in surface water and the impact on rural incomes at the household level. Following, we develop a methodology to estimate the value of trade that incorporates groundwater use and allows for surface water delivery constraints to be considered in a conjunctive use setting.

This paper does not investigate how a system of property rights would be implemented. Other research, for example, the AusAID Water Entitlements and Trading (WET) project, is developing a number of system tools necessary to support a water rights system in the Yellow River Basin.

Chapter 4: The gains from trade

To estimate the gains from trade information, the value of marginal product of water to different crops and scarcity value of water needs to be known. Given significant heterogeneity between farm households in the quantity and quality of resource available, crop production technologies and producer behaviour, the value of marginal product and scarcity values of water can vary significantly within a rural entity such as a village or county.

Trade would most likely be introduced incrementally — first at the village level and then once all the trading opportunities at the village level are exhausted at the county level, then at the irrigation district level and finally the province level. The introduction of trade in this way will results in a transitional change and allows for adjustments to be made gradually before the market extends across the basin. The model is constructed to reflect this gradual introduction of trade.

4.1 Methodology

The value of water trade was estimated in a three step process;

- **step 1** – for each county and crop a production function was estimated to characterise the production technology used.
- **step 2** – a farm household profit maximisation problem was formulated using the county level production function (from step 1) and a set of resource constraints. The profit maximisation problem was then used to estimate the scarcity value and optimal quantity of water use for each farm household.
- **step 3** – a village level water trade model was formulated using the farm households as trading entities to estimate the gains from trade at the village level. The water trade model was replicated three times; using the villages as trading entities to estimate the county level gains from trade; using the counties as trading entities to estimate the irrigation district level gains from trade; and finally, using the irrigation district as trading entities to estimate the provincial level gains from trade.

After estimating the traded price of water at the different levels, the impact of trade on incomes at the farm household can be estimated.

4.1.1 Step 1 – county level production function

The county level production functions were estimated using 2004 cost of production survey data at the farm household level for rice, maize and wheat in Henan and Ningxia provinces[79] (see Table 75). Data on the use of fixed resources, land, water and family labour; and variable resources, such as fertiliser, chemicals, hired labour and other capital expenditures; area planted; production; and prices of outputs and inputs were compiled. (It should be noted that hired labour accounted for only a small percentage of labour used.)

Table 75: Distribution of the sampled farms by province, county and village

Province	County	Irrigation District (u=upstream, d=downstream)	No of villages selected	No of farm households per village	No of farm households for the county
Henan	Yuanyang	Renminshengli(u)	4	4	16
	Huojia	Renminshengli(u)	2	4—5	9
	Xinxiangshi	Renminshengli(u)	4	2—4	13
	Yanjing	Renminshengli(u)	4	1—4	11
	Weihuishi	Renminshengli(u)	2	4	8
	Kaifengshijiaoqu	Liuyuankou(d)	7	2—6	21
Ningxia	Zhongwei	Weining (u)	4	3—6	17
	Zhongning	Weining (u)	4	4	16
	Qingtongxiashi	Qingtongxia (d)	8	3—4	31
	Helan	Qingtongxia (d)	8	4	32
	Pingluo	Qingtongxia (d)	8	4	32

[79] This data was collect by the Centre for Chinese Agricultural Policy (CCAP) at the Chinese Academy of Sciences

Due to limited sample sizes (see Table 75), aggregation of the sample data was necessary before estimating the parameters of the different crop production technologies. When choosing an appropriate level of aggregation, care must be taken so that existing heterogeneity in the quantity and quality of resources available, crop production technology, and producer behaviour are still adequately represented. In other words, the best level of aggregation should provide a minimum aggregation bias. This is important so that the adverse distributional impacts or equity issues of policy intervention are minimised. However, because of the small sample sizes, the lower the level of aggregation the lower the reliability of the parameter estimates due to the limited degrees of freedom.

The aim is to reach a trade off between the small sample problem and the aggregation bias. Huang (2005) studied this issue by disaggregating from the province to county level and then to village level using a farm household data set for the Hebei province, and found that the county level to be the optimal level of disaggregation. Following Huang (2005), and due to small samples at village level, it was decided to aggregate the sample up to the county level to estimate the production function.

For each county and crop, a flexible functional form was used to characterise the production technology. The advantage of using a flexible production function is that input demand elasticities are not influenced by the functional form assumed. A quadratic specification in the form of equation 6 is used.

$$q_j = \mathbf{A}_\mathbf{j}^{'}\mathbf{X}_\mathbf{j} - \mathbf{X}_\mathbf{j}^{'}\mathbf{Z}_\mathbf{j}\mathbf{X}_\mathbf{j} \quad (6)$$

Where: $\mathbf{X}_\mathbf{j}$ and $\mathbf{A}_\mathbf{j}$ are each $I \times 1$ vector, $\mathbf{Z}_\mathbf{j}$ is an $I \times I$ matrix.

For each county, data collected from n farm households (given in column 5 of Table 75) was used to estimate the parameters $\mathbf{A}_\mathbf{j}$ and $\mathbf{Z}_\mathbf{j}$ of the production functions. For each county, household and crop j, data used included X_j vector of input levels and quantity of production q_j The parameters $\mathbf{A}_\mathbf{j}$ and $\mathbf{Z}_\mathbf{j}$ were estimated by employing Generalized Maximum Entropy (GME) (outlined in Howitt and Msangi (2005)). The GME approach was used to estimate parameters $\mathbf{A}_\mathbf{j}$ and $\mathbf{Z}_\mathbf{j}$ by maximizing the entropy criterion subject to a number of constraints. There are three sets of constraints. The first two sets of constraints are for achieving consistency with the production levels and the marginal response observed in the data set, while the third constraint set is required by the numerical process involved in the GME estimation. It should be noted that even though the $\mathbf{A}_\mathbf{j}$ and $\mathbf{Z}_\mathbf{j}$ parameters are estimated at a county level, the first two categories of constraints are observed for each household within a county, with an error term in the respective constraint equation accounting for any difference between the actual and estimated levels. Therefore, for each county and crop, the process of estimating parameters $\mathbf{A}_\mathbf{j}$ and $\mathbf{Z}_\mathbf{j}$ can be likened to fitting (equation 6) to a household level data set collected from that county.

The advantage of using GME over econometric estimation is that it provides better estimates with small number of observations, and that the marginal response conditions can be incorporated.

4.1.2 Step 2 – estimating the farm household scarcity value and optimal quantity of water use

The farm household profit maximisation problem is specified by assuming that for each crop *j* produced the county level production function (from step 1) is used. So for each farm household the profit maximisation problem (equation 7) is solved by maximising profit subject to the county level production function (equation 8) and a set of resource constraints (equation 9), including water.

$$\text{Max} \quad \pi = \sum_j \left(p_j q_j - \sum_i c_i x_{ij} \right) \tag{7}$$

subject to

$$q_j = \sum_i \alpha_{ij} x_{ij} - \sum_i \sum_{i'} x_{ij} z_{ii'j} x_{i'j} \tag{8}$$

$$\sum_j x_{ij} \le B_i \tag{9}$$

The production function given in equation 8, is the same as the production function in equation 6 (step 1) but has been respecified using summation notation, where, α_{ij} and x_{ij} are the *i*th element of vectors : $\mathbf{A_j}$ and $\mathbf{X_j}$ respectively and $z_{ii'j}$ is the ii'th element of matrix $\mathbf{Z_j}$. Other notations introduced are; p_j, the output price of crop *j*, c_i the unit cost of input *i,* and B_i the endowment of resource *i*.

After running the model (given in equations 7 to 9) for each farm household, the optimal level of input use and scarcity values (the shadow price of equation 9) were estimated. Using the conditional factor demand functions a new data set was complied containing the optimal level of water use, the scarcity value of water and elasticity of demand for water, for use in step 3.

4.1.3 Step 3 – estimating impacts of water trading

The village level water trade model is formulated taking the farm households as trading entities. Water trade between farm households in a village will result in a common price for water, with a consequent reallocation of water from low value to high value uses. The county water trade model is formulated by taking villages within the county as trading entities. The common prices of water derived at the village level is used to investigate the impacts if water trading between villages within a county occurs. The common price for each county is then used in the irrigation district level trade model to estimate the irrigation district level gains from trade, with the common irrigation district level price used to estimate the gains from trade at the provincial level.

For each trade model a set of trade flow equations and price arbitrage conditions were used. Trade flow equations and price arbitrage conditions are linked together through their price and trade implications, respectively. The general form of these trade models is presented using the case of village level trade (the same approach is used for each estimating the county, irrigation district and provincial level gains from trade).

Trade flows

$$\phi_s p_s^{\eta_s} + \sum_r q_{sr} \le s_s + \sum_r q_{rs}, \; p_s \left[\phi_s p_s^{\eta_s} + \sum_r q_{sr} - s_s - \sum_r q_{rs} \right] = 0, \quad \text{for} \quad s = 1,....,10 \tag{10}$$

For each farm household *s*, water use ($\varphi_s p_s^{\eta s}$) plus water sold to other farm households, q_{sr}, cannot exceed its water supply, *s*, plus water purchased from other farm households, q_{rs}. If the water use by the farm household plus water sold is less than the supply plus water purchased from other farm households, the price of water is zero, and if the price is positive then the first expression is satisfied with strict equality.

Farm household water use ($\varphi_s p_s^{\eta s}$), is a declining function of the user price, p_s. Assuming a constant elasticity specification, the demand function can be given as $d_{rv} = \varphi_s p_s^{\eta s}$, where: φ_s is the scale parameter and η^s is the elasticity of demand. The elasticity of demand is estimated from the conditional factor demand functions derived in step 2.

Price arbitrage conditions

$$p_r \ge p_s, q_{rs}[p_r - p_s] = 0, \text{for } r = 1,....,10 \tag{11}$$

For each farm household, *r*, the price of water traded, p_r, cannot be lower than the price of water in the other farm household, *s*. If the price in farm household *r* exceeds the price in farm household *s* there will be no sale of water to farm household *s*. If water trade between the two farms households is positive, the price in these two farms will become equal.

4.2 Results

The introduction of trade in Henan and Ningxia provinces is estimated to significantly increase the value of water. Figure 65 demonstrates that before trade in the Henan province water was not a binding constraint for almost 40 per cent of farm households (with a scarcity value of zero). While the top 20 per cent of households had a binding constraint that resulted in water scarcity values of between 175Y/000m^3 and 375Y/000m^3. When trade is allowed between households, the binding constraint becomes redundant as excess demand can be met by purchasing water. However, the pool of water available to the villages is still limited resulting in a common scarcity value. After village trade between households this common scarcity value of water would be lower, for the majority of farm households, than the scarcity value before trade. Following county trade water becomes a binding constraint for all farm households with positive scarcity value for water for all users. For the most water constrained farm households (top 20 per cent) scarcity values for water significantly decrease representing a reduction in the marginal cost of the water constraint. The common price for water after provincial level trade is 103Y/000m^3.

The impact of trade in the Ningxia province is similar to that for Henan (see Figure 66). Before trade, water use is a binding constraint for around 40 per cent of farm households with the top 20 per cent of farm households having a scarcity value of between 150Y/000m^3 and 375Y/000m^3. The impact of village level trade is small, with only a slight increase in the scarcity value of water to the bottom 40 per cent of water users. The gains from county trade in the Ningxia province are less than those in the Henan province. With only the top 10 per cent of the most water constrained farm households experiencing a significant reduction in the marginal cost of the water. The common price for water after provincial level trade is 58Y/000m^3.

Figure 65: Cumulative frequency distribution of households by water scarcity after trade within villages in Henan province

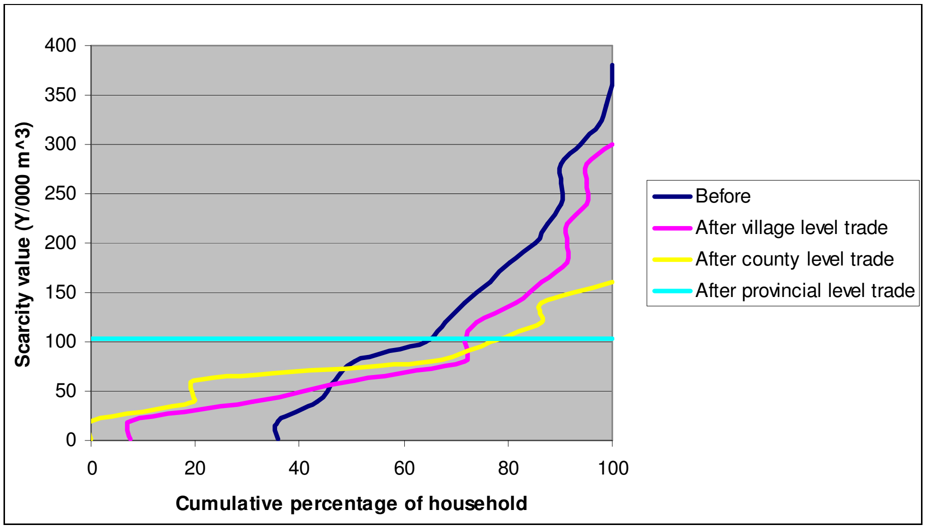
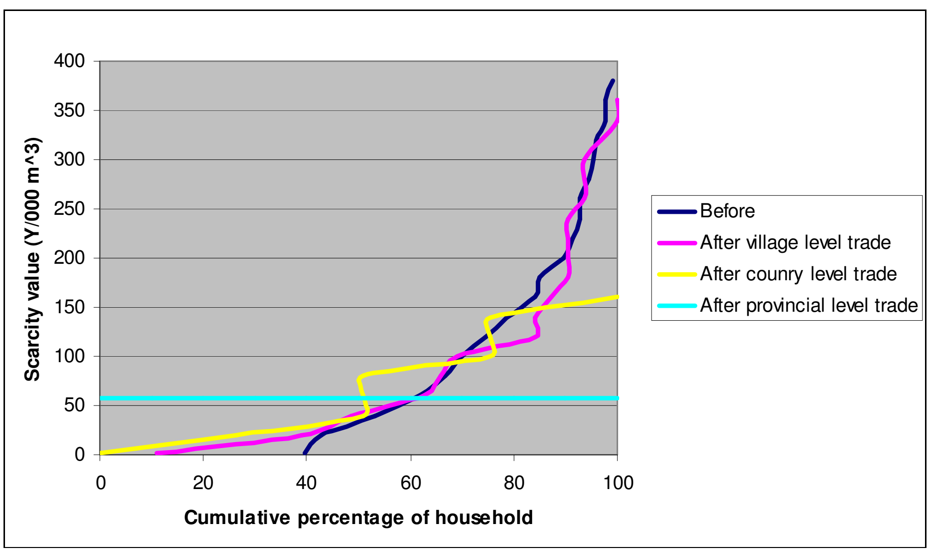
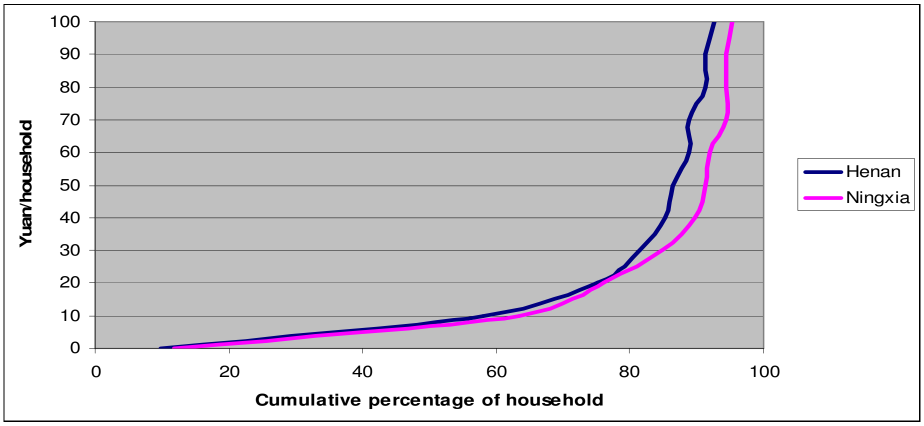


Figure 66: Cumulative frequency distribution of households by water scarcity after trade within villages in Ningxia province



The gains from trade for the two provinces are shown in Figure 67. As indicated by the changes in the water scarcity values following trade, the gains to trade accrue to the top 20 per cent of the most water constrained farm households, with gains for this group between 20 Yuan per household to more than 100 Yuan per household. The average gain from trade is a 2.5 per cent increase in household income.

Figure 67: Gains from trade by households in Henan and Ningxia provinces after trade within villages



4.2.1 Aggregate gains

The gains from trade discussed to this point are only for the sampled farms. The aggregate gains from trade can be estimated if aggregate level data for villages and counties is available. Due to data limitations aggregate gains to individual villages could not be estimated. The following section discusses aggregating the value of trade for counties.

To estimate the aggregate value of trade, information about the aggregate county level area planted (by crop) and water use (by crop) is required. For each county, aggregate water use is estimated as the product of the water use for each crop and the area of each crop summed across all crops. Similarly, the aggregate income of each county is estimated as the product of the area of each crop and the gross margin of each crop summed across all crops. Data for six crops was used; rice, wheat, corn, soy bean, cotton and vegetables.

The county level gains from trade are shown in Table 76. All counties experience an increase income, varying from around 0.1 per cent in Huojia and Weihuishi counties in Henan, to just over 10 per cent in the Qingtongxiashi county in Ningxia.

Table 76: Impact on aggregate farm income from water trade between counties

Province	County	Irrigation District (u=upstream, d=downstream)	Gains from trade (Y million /year)	Aggregate farm income (Y million /year)	Percentage increase (%)
Henan	Yuanyang	Renminshengli(u)	6.46	129.61	4.99
	Huojia	Renminshengli(u)	0.09	128.43	0.07
	Xinxiangshi	Renminshengli(u)	1.34	75.57	1.77
	Yanjing	Renminshengli(u)	4.42	147.14	3.01
	Weihuishi	Renminshengli(u)	0.11	129.26	0.08
	Kaifengshijiaoqu	Liuyuankou(d)			
Ningxia	Zhongwei	Weining (u)	5.41	170.16	3.18
	Zhongning	Weining (u)	6.96	73.79	9.43
	Qingtongxiashi	Qingtongxia (d)	10.44	98.95	10.55
	Helan	Qingtongxia (d)	2.04	112.27	1.81
	Pingluo	Qingtongxia (d)	5.71	136.28	4.19

These gains result from a reallocation of water from low value to high value production. Figure 68 demonstrates the reallocation of water, showing water use before and after trade in Henan province. In Henan, water use decreases significantly in Yuanyang and Xinxiang counties while water use more than doubled in Yanjing county. Water use decreased slightly in Huojia county and increase slightly in Weihui.

Figure 68: Impact on water use of trade between counties in Henan province

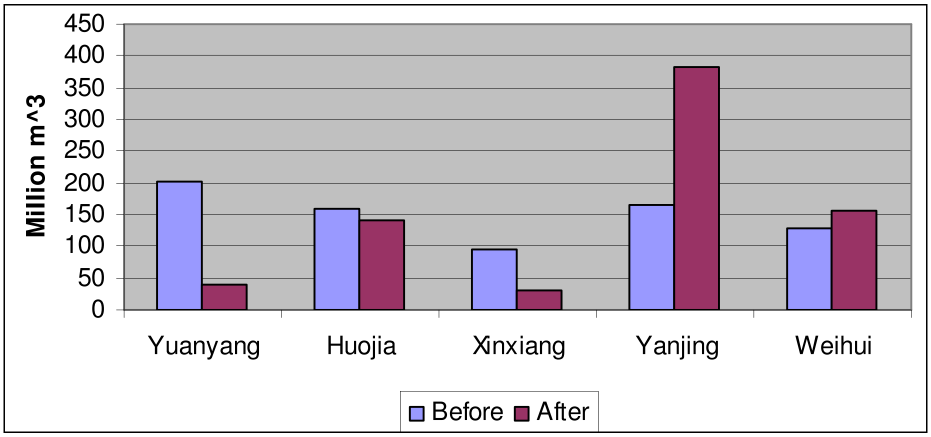
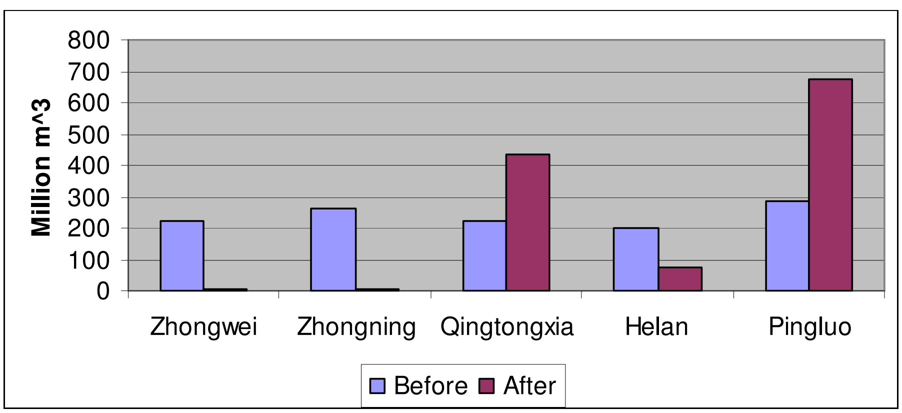


Figure 69 shows that water use significantly decreases in the upstream counties of Zhongwei and Zhongning. Downstream water use significantly increases in Qingtongxia county and more than doubles in Pingluo county, while water use decreases by around half in Helan county.

Figure 69: Impact on water use of trade between counties in Ningxia province



4.3 Limitations

The gains from trade estimated for sample households at the village level are likely to be an under estimate because only trade between similar (relatively) low value cropping systems were analysed. While the gains from trade estimated at the county level accounts for trade between higher value crops.

Due to the surface water delivery constraints most high value horticultural cropping in the Yellow River Basin relies on ground water. Consequently, before the potential for trade between low value and high value farming activities can be considered groundwater use and surface water delivery arrangements must be included in the analysis.

The estimated gains from trade that have been presented thus far may not be realised if surface water delivery constraints are significant. When capacity constraints are significant, property rights to water will not necessarily result in an efficient reallocation of water because it may not be possible to have additional water delivered — even if water can be bought in the market. The cost of alleviating any surface delivery constraints must be compared to the gains from trade.

The following chapter develops a methodology that incorporates ground water and surface water delivery constraints. One use of this methodology is to calculate the impact of the surface water delivery constraints on the gains from trade.

Chapter 5: Surface water delivery constraints

Many of the irrigation systems in the Yellow River Basin were built to supply irrigation water for staple grain crops — to support the policy of grain self sufficiency. This historical legacy is still evident in the institutional arrangements for surface water delivery.

Evidence from field work suggest that, on average, each farm located along a supply lateral is supplied with surface water only once in every 30 days. Given the low overall net irrigation requirement of individual grain crops and the fact that this water can be supplied at a frequency of one in 30 days without causing crop water stress, irrigators use the bulk of surface water for grain crops. More water intensive horticultural vegetable and tree crops, that require frequent irrigation, are generally irrigated with ground water. Irrigation of vegetable and tree crops using surface water is an opportunistic decision made depending on whether any surplus water is available after irrigating grain crops.

The conjunctive use of ground water and surface water for irrigation has arisen due to the constraints on surface water delivery rather than the supply of water itself. However, growing demand for horticultural crop produce, no short term prospects of reduced water demand for grain or significant enhancements to irrigation infrastructure capacities mean that regional ground water resources will continue to be over drawn. Moreover, water is prevented from moving to its highest value use.

To improve the allocative efficiency of ground water and surface water resources in the presence of surface water delivery constraints a system for more efficient management of delivery constraint is required. Managing the surface water delivery constraint more efficiently provides the potential to:

- increase the reliability of water supply over a broader area;
- expand the irrigated area of high value crops;
- prevent excess drawdown of ground water reserves;
- increase the overall value of water;
- increase the value of infrastructure; and
- provide the incentives for investment in expanding existing delivery capacity.

Increased reliability of water supply, a key condition for the planting of high value crops, allows a different mix of cropping activities.

Given the current arrangements, even if property rights to water were introduced, water would be prevented from moving to those who value it most highly because there is no mechanism for allocating infrastructure to those who value it most highly. The cost of the capacity constraint in terms of lost production (of high value crops) is spread over all irrigators. To determine if the benefits of introducing a system to more efficiently manage the constraint will outweigh the cost of doing so, the cost of the capacity constraint must be known. The methodology for calculating the cost of the constraint is developed below.

5.1 Methodology

The model has three linked components; a lateral surface water delivery system, the ground water aquifer system and the farms located along the supply laterals.

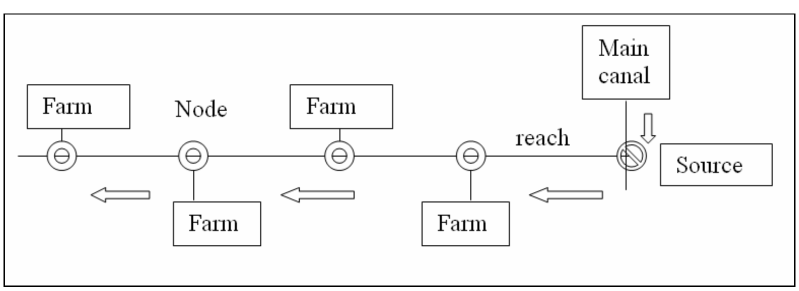
- **component 1 – the off farm water delivery system**. The off farm delivery network is represented by a supply lateral with a number of sequential reaches separated by nodes. For simplicity it is assumed each channel reach supplies only one farm and therefore the number of farms equals the number of reaches. Institutional arrangements for the whole supply lateral specifies surface water delivery frequencies and charging for surface water (and ground water).
- **component 2 – ground water aquifer system**. For each farm or a group of farms, the ground water flow process is specified by a state transition equation.
- **component 3 – farm production**. For each farm, an economic and agronomic component models the use of water deriving the optimal allocation of land, surface water and ground water resources in agricultural production subject to the availability of surface water, ground water, rainfall and crop evaporative demand at different times of the irrigation season.

The model is formulated on an annual basis but can be run over a number of years to study the impacts on ground water table. The water balancing is done on a weekly basis while labour supply and use are expressed on a seasonal basis within a year. For each farm, in addition to constraints on surface water delivery frequencies a number of resource constraints are also specified which include constraints on the quantity of land, family labour, surface water and ground water available. The economic parameters used in the model include, prices of crops, variable input cost, cost of ground water pumping.

5.1.1 Component 1 – Off farm surface water delivery system

The model covers an irrigation supply lateral with a number of channel reaches. Individual reaches are separated by nodes. Water is diverted to the lateral at source from a main channel. There are farms (one per reach) drawing water from the system. The farms are located at varying distances from the source as shown in the Figure 70.

Figure 70: Schematic supply lateral with a number of reaches and farms



Let *N* and *L* be the number of farms located along the lateral and the length of the irrigation season in days, respectively. If each farm is supplied surface water once in 30 days then each will receive $L/30$ deliveries per irrigation season. The number of farms that can be supplied on a given day depends on the size and the location of the orders and the daily peak delivery capacities at different nodes.

For simplicity, the model focus on a $n \in N$ subset of farms that are supplied water on the same day so that daily peak delivery capacities can be related to their total water requirement. Despite the existing delivery arrangements are geared to supply these farms only once in 30 days, the model is designed to supply water 4 times in 30 days or once in 7.5 days (week) so that a range of delivery frequency options can be investigated.

Off farm delivery system is represented by a set of constraints on water flows along the lateral. These constraints are introduced as follows. Note that for simplicity, the subscript, *t* which denotes year is dropped in this section.

The sum over the year of the water flows in week *w* from the source through node 1 to reach 1 cannot exceed the annual allocations from the river to the farms located along the lateral.

$$\sum_{w} Q_w^{11} \leq \Omega \qquad (12)$$

For each reach *i* the daily water flow should be no greater than the peak design daily flow.

$$Q_w^i \leq \chi_i \qquad (13)$$

For each farm *i*, crop, *c* and week *w*, the net irrigation requirement to be met by surface water deliveries is given by q_{iwc}^s. Assume that the irrigation season runs over 40 weeks,

$w = 1, 2, \ldots\ldots, 40$ and with every 4[th] week denoted by $\tilde{w} \in w = 1, 5, 9, \ldots\ldots, 37$. For horticultural crops $h \in c$ the weekly water requirement needs to be delivered at a weekly interval so that the delivery in week *w* is given by $\sum_{h \in c} q_{i,w=\tilde{w},h}^s$. However, for grain crops, $g \in c$, at a once in 30 days interval, the water requirement for the next 4 weeks can be delivered in weeks $\tilde{w} \in w = 1, 5, 9, \ldots\ldots, 37$. Therefore, the once in 30 days delivery requirement of grain crops is given by $\sum_{w=\tilde{w}}^{\tilde{w}+3} \sum_{g \in c} q_{iwg}^s$.

For each reach *i*, in each week *w*, the daily water flow from the supplying node cannot be less than the water ordered by farm *i*, plus water flows to the next downstream node plus daily conveyance losses in reach *i*. This constraint for the once in 30 day delivery schedule for weeks $\tilde{w} \in w = 1, 5, 9, \ldots\ldots, 37$ is given in equation 14. Different variants of this constraint can be formulated depending on the alternative delivery options to be investigated.

$$\sum_{w=\tilde{w}}^{\tilde{w}+3} \sum_{g \in c} q_{iwg}^s + \sum_{h \in c} q_{i,w=\tilde{w},h}^s + Q_{\tilde{w}}^j + \varepsilon_i \mu_i Q_{\tilde{w}}^i \leq Q_{\tilde{w}}^i \qquad (14)$$

Note that, for each reach *i* and week *w,* the daily water flow, Q_w^i cannot exceed the peak design daily flow of χ_i as given in equation 13. Changes to delivery arrangements to supply water more frequently, say once a week, means that the $n \in N$ farms are delivered water in weeks $w \neq \tilde{w}$ as well. It should be noted that in those $w \neq \tilde{w}$ weeks another subset of farms, $\tilde{n} \neq n \in N$ are to be supplied with their once in 30 day water deliveries. In other words, the new delivery arrangements with peak delivery capacity fixed at χ_i means some of the water ordered for grain crops needs to be cut back.

5.1.2 Component 2 – Ground water process

For simplicity, it is assumed that each farm or a group of farms has only one bore. It is also assumed that hydrological connections between ground water tables in all such bores are negligible. For each farm *i* and each year *t,* the hydraulic head is given in equation 15:

$$h_{i,t+1} = h_{it} - \kappa_i \left(\sum_c \sum_w q_{itwc}^g - r_{it} \right) \tag{15}$$

Where;

κ_i	=	coefficient for converting volume to head for farm *i* (metre/000m^3).
h_{it}	=	the hydraulic head of the ground water table in the aquifer under farm *i* at the beginning of year *t* (metres).
q_{itwc}^g	=	the volume of ground water pumped from the aquifer by farm *i* in year *t,* in week *w* for crop *c* (000m^3).
r_{it}	=	recharge to aquifer in zone *i* in year *t* (000m^3).

For each farm *i*, the water table at the beginning of year $t+1$ is equal to the water table at the beginning of year t less the water table equivalent of the net volume of water extracted in year t (the second term on the RHS). The term κ_i measures the rate of fall in water table (metres) per volume unit (000m^3) of flux (pumping/recharge). The flux components considered in equation 15 include ground water pumping $\left(x_{it}^g \right)$, and aquifer recharge $\left(r_{it} \right)$.

5.1.3 Component 3 – On farm component

In a conjunctive surface water and ground water system, water from surface sources such as rainfall and river flows is used along with aquifer water as well as land in commercially viable agricultural production, thereby giving the water and land resources their economic value.

In estimating annual profits, the problem of deciding areas planted to different crops, the allocation of water between crops and over weeks of the year is addressed as follows:

i. As yield response to moisture stress varies through the year, the growing season is divided into distinct growth stages such as establishment, vegetative, flowering and yield formation.
ii. For each year, crop and week, the optimal use of ground water and surface water is derived for given commodity prices, water charges, pumping costs,

variables costs of crop production and harvesting and constraints on surface water, ground water and land availability and institutional arrangements on surface water and ground water delivery.

iii. The model accounts for moisture stress and consequent yield reductions rather than abandonment of whole or part of the irrigated crop area to dryland status. The intra year irrigation policy is driven by attempting to strike a balance between crop yield and area planted.

iv. An open access behaviour within the existing institutional arrangements for surface water and ground water is modelled, that is, future costs imposed by current pumping activities are not directly incorporated.

Optimal crop yield under water stress

For each year *t,* farm *i,* and crop *c*, the optimal yield Y_{itc}^{a} (sometimes defined as the actual yield in the agronomy literature), can be lower than the maximum yield, Y_{ic}, due to moisture stress. Moisture stress is measured, for each week, by the difference between 1 and the ratio of actual evapotranspiration, ET_{itcw}^{a}, to maximum evapotranspiration, $ET_{tcw}^{\max}$. For each crop and week, the sensitivity of yield to moisture stress, ky_{wc}, depends on the crop and the growth stage. Parameters describing the sensitivity of yield to moisture stress can be obtained from Doorenbos and Kassem (1979).

The yield response to different levels of ET_{itcw}^{a} is given in equation 16. Both $ET_{tcw}^{\max}$ and ET_{itcw}^{a} are measured in '000m^3 per hectare.

$$Y_{itc}^{a} \le Y_{c}^{\max}\left[1-\sum_{w} ky_{cw}\left(1-ET_{itcw}^{a}/ET_{ctw}^{\max}\right)\right]$$

Determination of actual evapotranspiration

For each week and crop, actual evapotranspiration is determined by the depth of soil moisture available, which includes the soil moisture added through irrigation with surface water, q_{itwc}^{s}, ground water pumped, q_{itwc}^{g}, and effective rainfall, ER_{tw}.

$$ET_{itwc}^{a} \le q_{itwc}^{s} + q_{itwc}^{g} + \min(ER_{tw}, ET_{twc}^{\max}) \quad (17)$$

$$q_{itwc}^{g} + q_{itwc}^{s} \le ET_{twc}^{\max} - \min(ER_{tw}, ET_{twc}^{\max}) \quad (18)$$

Other constraints

For the whole irrigation season, the quantity of surface irrigation water used cannot exceed the volume of surface water allocated $\left(X_{i}^{s}\right)$.

$$\sum_{c}\sum_{w} q_{itwc}^{s} \le X_{i}^{s}, \text{ for } \forall\ t \quad (19)$$

Over an irrigation season, the quantity of ground water used cannot exceed the volume of ground water allocated $\left(X_{i}^{g}\right)$.

$$\sum_{c}\sum_{w} q_{itwc}^{g} \le X_{i}^{g}, \text{ for } \forall\ t \quad (20)$$

For the irrigation season the total area cropped cannot exceed the total land area available $\left(X_i^l\right)$ times copping intensity $\left(I_i\right)$.

$$\sum_{c=1}^{n} a_{itc} \leq X_i^l * I_i \tag{21}$$

Objective function

The objective function given in equation (22), which specifies profits for each farm and year, is maximised subject to constraints (12) — (21). Alternatively, depending on the scenario investigated the objective function can be specified to maximise the aggregate profit of the entire system.

For each year, aggregate farm profit is the gross revenue obtained from selling agricultural produce net of the cost of harvesting, the cost of pumping of surface water from the river, the cost of pumping ground water from the underlying aquifer and other variable costs of production. Prices of agricultural produce and non-water inputs used in production are assumed to be unaffected by the actions of water users individually and collectively. However, the unit-pumping cost of ground water increases with the pump lift $\left(h_i^{\max} - h_{it}\right)$, so that the lower the ground water table $\left(h_{it}\right)$ the higher the unit pumping cost. For each farm and year, the unit cost of ground water pumping is defined to be equal to the unit cost of pumping, before the extraction policy was implemented (the green field situation with ground water table at $h^{\max}$) plus the increase in the cost of lifting water with the current water table being at h_{it}. The unit cost of ground water pumping is given in equation (22).

$$\begin{aligned} &\sum_{c} a_{itc} \left\{ Y_c^{\max} \left[1 - \sum_{w} ky_{cw} \left(1 - ET_{itcw}^{a} / ET_{itcw}^{\max} \right) \right] \left(P_c - HC_c \right) - VC_c^{a} \right\} \\ &- \sum_{c,w} q_{itcw}^{s} P^{SW} - \sum_{c,w} q_{itcw}^{g} P_{it}^{GW} \end{aligned} \tag{22}$$

$$P_{it}^{GW} = \gamma_0 + \sigma\left(h_i^{MAX} - h_{it}\right), \text{ for } \forall \; t \tag{23}$$

Where;

ET_{itcw}^{a} = actual evapotranspiration in farm *i* in year *t* by crop *c* in week *w* (000m3/ha).

$ET_{tcw}^{\max}$ = potential evapotranspiration in year *t* by crop *c* in week *w* (000m3/ha).

q_{itcw}^{s} = quantity of surface water used by zone *i* in year *t* for crop *c* in week *w* (000m3/ha).

q_{itcw}^{g} = quantity of ground water used by zone *i* in year *t* for crop *c* in week *w* (000m3/ha).

ky_{cw} = *ky* factor for crop *c* in week *w* (percentage decline in yield due to 1 per cent moisture deficit).

a_{itc} = area planted to crop *c* by zone *i* in year *t* (ha).

$Y_c^{\max}$ = maximum yield of crop *c* (t/ha).

Y_{itc}^a = actual yield of crop *c* in zone *i* in year *t* (t/ha).

P_c = price of produce of crop *c* ($/t).

HC_c = cost of harvesting produce of crop *c* ($/t).

VC_c = other variable cots of crop *c* ($/ha).

σ = unit pumping cost per metre drop in the hydraulic head ($/m/000m^3).

γ_0 = ground water pumping cost with hydraulic head at $h_i^{\max}$ ($/000m^3).

5.2 Application of the model

The model can be run by specifying the objective function to maximise the aggregate system-wide profits or individual farm profits. The value of the surface water delivery constraints can be found by running the model with the surface water delivery constraints removed and again with the constraints in place while the objective function is being specified to maximise system-wide aggregate profits . The cost of the surface water delivery constraint can then be used to assess the management options. Infrastructure access rights would only be introduced if the costs of doing so are less than the cost of the constraint. In the event that infrastructure access rights or a system for congestion charging would impose greater transaction costs than the cost of the constraint investment options may be considered. If investment in supply capacity to reduce or remove the constraint is less than the cost of the constraint it would be socially optimal to invest.

Besides the application considered thus far the methodology developed provides a useful framework to investigate institutional arrangements governing water delivery, allocation and pricing within the system. The model can be used to investigate the impact of changes to a wide range of institutional arrangements within an irrigation district and village. The impact measured can include, off farm investments in conveyance improvements, on farm investment in more efficient water application technologies, on farm and off farm irrigation efficiency, changes in cropping practices, use of ground water and its impacts on ground water stocks. The different institutional arrangements that can be handled in the model are:

- Alternative surface water delivery schedules, for example, increasing the frequency of surface water delivery for higher value crops
- Pricing for delivery constraints in place of rationing of water
- Alternative delivery charging arrangements at farm level, for example, introducing a two part pricing (fixed and a volumetric component) instead of a fixed area and/or crop based fee.
- Recovering the cost of off farm infrastructure improvements and water lost in transmission through delivery charging
- If the village or irrigation district trades water with other entities, reflecting the market price of water through water charges

- Price of fuels used for ground water pumping as a result of changes to subsidies
- Pricing for ground water to reflect the future costs of current extractions
- Institutional changes resulting in timely water availability and/or delivery in response to irrigators' demand
- Institutional changes resulting in more freedom for irrigators to choose crops
- Institutional arrangements for ground water use; and
- Allocation of water saved through conveyance improvements.

Chapter 6: Conclusions

The goal of water reform is to increase the net social benefits from water use. For this to occur, water will need to be traded to those who value it most, while holding those engaging in trade responsible for the full social costs and benefits of these transfers.

The average gain from trade after trade at the household level is a 2.5 per cent increase in farm household income in the Yellow River Basin. After trade at the county level the average increase in household income is 7.8 per cent. This analysis does not consider the impact of surface water delivery constraints and its implications on ground water use. The cost of the surface water delivery constraint will determine if it is optimal to introduce a system of infrastructure access rights.

A well defined access right to infrastructure should be capable of allocating access on the basis of willingness to pay when capacity constraints are reached. One option is for irrigators to hold these rights and to trade access when constraints are reached. This may be a practical option where relatively few constraints exist; however, the transaction costs of trading access rights where multiple constraints exist may be significant. An alternative to allocating access rights to irrigators is for the service provider to retain the access rights to infrastructure, and to differentially price when constraints are reached in order to allocate access to those that value it most highly. Either approach will provide more secure infrastructure access to irrigators, and encourage investment in higher value activities where access is critical at certain times of the year. It will also encourage irrigators to invest in more water use efficient technologies.

It is important that integrated surface water, ground water and delivery systems modelling be conducted — unless the system is specified correctly the benefits of reallocation may be unrealised. In recognising the potential role of delivery constraints and ground water drawdown we have expanded our conceptual modelling framework. With additional field work and secondary data collection we should be able to clearly show the benefits of an integrated approach.

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PART 7: SUPPLEMENTARY PAPER – TAIZHOU ENVIRONMENTAL FLOWS REPORT AND RECOMMENDATIONS

Chapter 1: Introduction to Taizhou Pilot Project

1.1 Project context

The Water Entitlements and Trading ('WET') project is a joint initiative of the Australian Department of Environment and Water Resources ('DEW') and the Chinese Ministry of Water Resources ('MWR'), with funding provided by the Australian Agency for International Development ('AusAID'). The project aims to assist MWR in the development of a WET system suitable for implementation in China. The project aims to do so through reviewing current arrangements, and making policy recommendations, on seven components identified as critical to the establishment of a WET system. This report is primarily concerned with one of those components: environmental flow definition and management, although another of the components: water resources management modelling, is utilized as part of the environmental flow assessment process.

For each of the components, the WET project is undertaking research work and will make policy recommendations with a central government focus. This work is coupled with research in two pilot sites. One is the Jiao River (Jiaojiang) in Taizhou prefecture, in Zhejiang province. The other is the Hangjin irrigation district in Inner Mongolia autonomous region. The pilot sites are being used to inform the national-level recommendations, to test the practicality of the WET system being proposed, and to demonstrate its application. This report is concerned only with the Taizhou case study. A dam is proposed for Zhuxi, one of the headwater creeks of the Jiaojiang system, and there is a desire to establish a suitable environmental flow regime so that undesirable ecological impacts to the river are avoided.

The WET project adopts the philosophy that water is first divided amongst environmental and consumptive purposes; the water available for consumptive use is then shared amongst different users. The project is developing a decision-support tool to assist water resources managers in identifying key river assets, determining the flow requirements for those assets (i.e. what flows need to be provided for a healthy ecosystem), and modifying or implementing regulatory arrangements to provide for those flows.

In August 2007 the *Water Entitlements and Trading Project Phase 2 Mid-Project Report* (WET Project, 2007) provided background information on methods of environmental flow assessment, and suggested a framework for application to the WET project. In October 2007 an assessment was undertaken on the Zhuxi-Jiaojiang system. The review of information on the study area and the methodological details are reported elsewhere – the focus of this report is to document preliminary flow requirements to maintain and/or restore identified key ecological and environmental assets.

1.2 Pilot project objectives

Over the coming years, economic development and an increase in the standard of living are likely to combine to increase demand for water supplies in Taizhou. At the same time, Taizhou will need to ensure that its development is consistent with building a water saving society (WET Project, 2007). Taizhou receives relatively high and regular rainfall. These circumstances have meant that Taizhou has generally had more than enough water available to meet its consumptive needs. However, this culture has given rise to a number of water resource management issues (WET Project, 2007). One consequence of the assumption that there is an abundant supply of water is that little consideration has been given to environmental flow requirements. Over the long term, this is likely to pose risks to ecological health in the basin (WET Project, 2007). In this respect, Wet Project (2007) identified four main aspects of the problem:

i. Limited understanding of ecological needs for water. There is currently virtually no recognition of ecological needs for water in the basin.
ii. Management of resource availability. There is no mechanism to prevent total abstractions from exceeding the resource availability and, hence, becoming unsustainable and impacting on the natural environment
iii. Infrastructure design and operation. In designing infrastructure and determining operational rules, consideration is not given to environmental requirements.
iv. The impact of existing constraints need consideration. Extensive floodplain development will make it difficult to recreate previously occurring flood events because this would have major social and economic implications.

The Taizhou environmental flows pilot project aims to demonstrate how these issues can be addressed by undertaking a formal environmental flows assessment for Zhuxi downstream of the proposed reservoir (including the stream system down to the estuary). The main objectives of the environmental flows pilot project are to:

- Refine the suggested environmental flow assessment methodology described in Wet Project (2007) to suit the local physical and ecological conditions, data availability, resources available and time limitations;
- Demonstrate application of the refined methodology to the Zhuxi-Jiaojiang system by undertaking an environmental flow assessment;
- Produce a set of environmental flow recommendations for the Zhuxi-Jiaojiang system; and
- Transfer the technology through field demonstration, data analysis sessions, flow assessment workshops, and documentation (e.g. this report).

1.3 Purpose of this report

This report documents the work undertaken for the environmental flow assessment component of the Taizhou (Zhuxi-Jiaojiang system) pilot project. The environmental flow recommendations presented in this report should be regarded as preliminary, primarily because the limited timeframe over which the work was undertaken prevented full consideration of all of the issues. Future, more detailed, consideration of any aspect of the work described here can be used to refine the recommendations. Despite the preliminary nature of the recommendations, the methodology is regarded as appropriate for the situation.

The wide range of hydrological, geomorphological, ecological and water resource development conditions in China means that it is unlikely that a single environmental flows methodology will be universally applicable. This report is meant to provide a framework that can be used to guide future environmental flow assessments in China, but individual studies will still have to decide on which particular techniques (for data collection and analysis) are the most appropriate for the local conditions. To this end, this report provides a brief methodological review to assist practitioners in method selection.

Chapter 2: Methodology

2.1 Brief review of available methods

Tharme (2003) grouped environmental flow methodological types into four main categories, namely hydrological, hydraulic rating, habitat simulation (or rating), and holistic methodologies. Tharme (2003) also recognized two minor classes of methodologies: 'combination' (or hybrid) approaches which had characteristics of more than one of the four basic types, and a group termed 'other' which comprised techniques not specifically designed for environmental flow assessment, but which had been adapted, or which had potential, to be used for that purpose. Assessment of flood flows necessary for channel formation or maintenance is an important aspect of many environmental flow assessments. There exists a group of geomorphic techniques that are used for this purpose in association with some of the environmental flow methodologies. Brown and King (2003) classified environmental flow methodologies into two categories - prescriptive and interactive - from the perspective of their usefulness as a tool for negotiating trade-offs between stakeholders.

2.1.1 Hydrological methods

Hydrological methods are generally used only at the basin-wide planning level, or where resources do not permit a more detailed investigation. Most hydrological methodologies use simple rules based on flow duration or mean discharge to scale down the natural flow regime, while others accept flow reductions as long as flow variability is maintained within a certain range. Some hydrological methods lack a sound ecological basis, but most, at least in their original formulation, are at least partly based on observed or modelled flow-ecology and/or flow-geomorphology relationships. While numerous hydrological methods are described in the literature (Tharme, 2003; Gordon et al., 2004), only three are discussed here: Tennant method, Range of Variability / Indicators of Hydrological Alteration (RVA/IHA), and Ecological Limits Of Hydrologic Alteration (ELOHA).

Tennant Method

The Tennant method (Tennant, 1976) also referred to as the "Montana" method, is the most commonly applied hydrological methodology worldwide (Tharme, 2003), and it is in widespread use in China (Wang, 2006; Wang et al., 2007).

In the Tennant method, recommended minimum flows are based on percentages of the average annual flow, with different percentages for winter and summer months (Table 77). The recommended levels are based on Tennant's observations of how stream width, depth and velocity varied with discharge on 11 streams in Montana, Wyoming and Nebraska. At 10% of the average flow (the mean daily flow, averaged over all years of record), fish were crowded into the deeper pools, riffles were too shallow for larger fish to pass, and water temperature could become a limiting factor. A flow of 30% of the average flow was found to maintain satisfactory widths, depths and velocities. The choice of a maximum flow was based on the theory that prolonged large releases would result in severe bank erosion and degradation of the downstream aquatic environment. The method was designed for application to streams of all sizes, cold and warm water fish species, as well as for recreation, wildlife and other environmental resources.

Table 77: Critical minimum flows required for fish, wildlife, recreation in streams identified by Tennant (1976).

	% of mean annual flow	
Description of flows	**Dry season**	**Wet season**
Flushing or maximum	200% of the mean annual flow	
Optimum range	60 - 100% of the mean annual flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	0 - 10% of the mean annual flow	

One main limitation of Tennant's method is that application of the technique to other streams requires that they be morphologically similar to those for which the method was developed. The required criteria, however, are not given by Tennant, making direct transfer of the technique difficult. Field observation of the stream at the various base flow levels is recommended for verification. Also, as the method is based on the average flow it does not account for daily, seasonal or yearly flow variations.

Range of Variability / Indicators of Hydrological Alteration

The Indicators of Hydrologic Alteration (IHA) is a software program developed by The Nature Conservancy (http://www.nature.org/initiatives/freshwater/conservationtools/) that examines 33 IHA parameters (originally there were 32 parameters) and 34 Environmental Flow Component (EFC) parameters. The ecological relevance of the IHA statistics presumably (Table 78) derives from North American experience. While the ecological relevance of the IHA parameters are presented in a comprehensive fashion (Table 78), King County (2000) found that some of the parameters did not hold much ecological relevance for rivers in the northwestern USA. King County (2000) recommended that some of the parameters should be calculated using seasonal, rather than annual data. To our knowledge, the authors of the IHA have never published quantitative evidence of the link between the IHA parameters and the claimed “ecosystem influences”, and, to our knowledge, neither has anyone else. Smakhtin (2001) and Pyrce (2004) reviewed low flow indices used in the literature and did not report any such relationships. Thus, calculating IHA indices does not, on its own, constitute an environmental flows assessment, because (i) there is no quantitative link between the calculated flow and expected ecological response or level of environmental protection offered by the particular flow indices that are calculated, and (ii) having calculated the indices, the problem of how to build a flow regime recommendation still remains, i.e. how would these 33 numbers be used to instruct the operator of an existing or proposed dam to manage flow releases?

Table 78: IHA flow characteristics and their ecological relevance (North America). Taken from The Nature Conservancy (2007a).

IHA Parameter Group	Hydrologic Parameters
Ecosystem Influences	
Group 1: Magnitude of monthly water conditions	Mean value for each calendar month *12 Parameters*
• Habitat availability for aquatic organisms • Soil moisture availability for plants • Availability of water for terrestrial animals • Availability of food/cover for fur-bearing mammals • Reliability of water supplies for terrestrial animals • Access by predators to nesting sites • Influences water temperature, oxygen levels, photosynthesis in water column	
Group 2: Magnitude and duration of annual extreme water conditions	Annual maxima and minima: 1-, 3-, 7-, 30-, and 90-day means *12 Parameters*
• Balance of competitive, ruderal, and stress- tolerant organisms • Creation of sites for plant colonization • Structuring of aquatic ecosystems by abiotic vs. biotic factors • Structuring of river channel morphology and physical habitat conditions • Soil moisture stress in plants • Dehydration in animals • Anaerobic stress in plants • Volume of nutrient exchanges between rivers and floodplains • Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments • Distribution of plant communities in lakes, ponds, floodplains • Duration of high flows for waste disposal, aeration of spawning beds in channel sediments	
Group 3: Timing of annual extreme water conditions	Julian date of each annual 1-day maximum and each annual 1-day minimum *2 Parameters*
• Compatibility with life cycles of organisms • Predictability / avoidability of stress for organisms • Access to special habitats during reproduction or to avoid predation • Spawning cues for migratory fish • Evolution of life history strategies, behavioral mechanisms	
Group 4: Frequency and duration of high and low pulses	No. of high pulses each year; No. of low pulses each year; Mean duration of high pulses within each year; Mean duration of low pulses within each year *4 Parameters*
• Frequency and magnitude of soil moisture stress for plants • Frequency and duration of anaerobic stress for plants • Availability of floodplain habitats for aquatic organisms • Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses) • Nutrient and organic matter exchanges between river and floodplain Soil mineral availability • Access for waterbirds to feeding, resting, reproduction sites	
Group 5: Rate and frequency of water conditions change	Means of all positive differences between consecutive daily values; Means of all negative differences between consecutive daily values; No. of rises; No. of falls *3 Parameters*
• Drought stress on plants (falling levels) • Entrapment of organisms on islands, floodplains (rising levels) • Desiccation stress on low-mobility stream edge (varial zone) organisms	

The IHA parameters have been adapted for Taiwan (Table 79) by Herricks and Suen (2003). In developing an IHA for Taiwan, it was necessary to consider the timing and sequence of hydrologic events in the subtropical climate, so several parameters were calculated using seasonal data (resulting in a total of 65 parameters). In the Taiwan IHA the wet season is June to October. This includes the plum rain season beginning in late May to June and the typhoon season in summer. The dry season is November to May (Herricks and Suen, 2003). The claimed ecological influences of the IHA parameters for Taiwan were much less detailed than those claimed for North America.

Table 79: IHA flow characteristics and their ecological relevance (Taiwan). Taken from Herricks and Suen (2003). Wet season: from June to October, Dry season: from November to May.

IHA Parameter Group	Hydrologic Parameters
Ecosystem Influences	
Group 1: Magnitude of 10-day water conditions	Mean value for each 10 day period *36 Parameters*
• Availability of water • Availability of habitat	
Group 2: Magnitude and duration of annual extreme water conditions	Annual maxima and minima: 1-, 3-, 10-, 30-, and 90-day means *14 Parameters*
• Lateral connectivity • Habitat complexity • Patch disturbance • Colonizing ability • General mobility	
Group 3: Timing of annual extreme water conditions	Julian date of each dry season 1-day maximum and 1-day minimum, and wet season 1-day maximum *3 Parameters*
• Spawning	
Group 4: Frequency and duration of high and low pulses	No. of high pulses each season; No. of low pulses each season; Mean duration of high pulses within each year; Mean duration of low pulses within each year *6 Parameters*
• Spawning • Recruitment • Species richness • Length of life cycles • Age at maturity	
Group 5: Rate and frequency of water conditions change	Means of positive differences between consecutive daily values for wet season, and for dry season; Means of negative differences between consecutive daily values for wet season, and for dry season; No. of hydrologic reversals in dry season, and No. in wet season *6 Parameters*
• Length of breeding season • Spawning periodicity • Reproductive strategies • Drought stress	

In a refinement of the original IHA method, Richter, et al. (1997) introduced the Range of Variability Approach (RVA) in order to facilitate application of IHA to the problem of setting hydrologic restoration targets in managed river systems. Whereas the IHA identifies the degree of change in the indicators (from one period to another, or pre- and post-regulation), the RVA takes another step and develops ranges for natural variation of each characteristic. The method can be used to identify annual river management targets based on an allowable range of variation (e.g. ±1 standard deviation from the mean, or at the 16th and 84th percentiles) in each of 33 parameters. The method prescribes that environmental flow regime characteristics should lie within the targets for the same percentage of time as they did prior to regulation. This method has been applied in numerous environmental flow related studies (although mainly to examine the degree of flow alteration in already regulated systems) in North America and has attracted interest in a few other countries (Tharme, 2003). The IHA/RVA literature does not explicitly state how the IHA/RVA calculations are used to specify a practical flow regime that can be used to manage a river. River operators need specific instructions regarding magnitude, frequency, duration and timing for flow releases – arcane hydrological statistics are not implementable. This is especially the case for devising a flow regime for a proposed dam on an unregulated river (such as the Zhuxi case), because IHA and RVA both rely on comparing an impacted with an unimpacted time series.

The EFC is a suite of hydrologic flow parameters (part of the IHA software program), which represent an attempt to automatically identify and compute statistics on five flow components: low flows, extreme low flows, high flow pulses, small floods, and large floods (Richter and Thomas, 2007). This delineation of EFCs is based on the assumption that river hydrographs can be divided into a repeating set of hydrographic patterns that are ecologically relevant. According to The Nature Conservancy (2007a) the full spectrum of flow conditions represented by these five types of flow events must be maintained in order to sustain riverine ecological integrity. Richter et al. (2006) and The Nature Conservancy (2007a) provides a list of the hydrological parameters and associated ecological influences for the five flow component groups. Note that RVA analysis is only available for IHA parameters, and not for EFC parameters.

The IHA User's Manual (The Nature Conservancy, 2007a) provides no guidance as to how an analysis of EFC parameters can be used to make environmental flow recommendations (other than stating that the flow components must be maintained). While EFC analysis is useful for characterizing the flow regime, a separate process is required for shaping the environmental flow regime. For example, Richter and Thomas (2007) discuss several environmental flow case studies in which they have been involved, but make mention of IHA and EFC only in the context of using these tools to assess the degree of flow alteration as a preliminary step in the process.

Ecological Limits Of Hydrologic Alteration (ELOHA)

Apse et al. (2007) were of the opinion that none of the existing methods being applied in regional-scale water planning and allocation adequately address flow-ecology linkages in a manner that can be adapted for application globally across different regions and contexts. Also, Arthington et al. (2006) rightly took issue with a few recently recommended hydrological "rule of thumb" methods of setting limits on extractions on the basis that they lacked an empirical basis and did not consider the importance of flow variability. Arthington et al. (2006) and Apse et al. (2007) proposed an approach to the identification of environmental flow guidelines that bridges the gap between simple hydrological ''rules of thumb'' and more comprehensive (but expensive), river-specific, environmental, flow assessments. The approach is known as the Ecological Limits Of Hydrologic Alteration (ELOHA) and is described in The Nature Conservancy (2007b).

ELOHA is a general framework for developing scientifically-credible, environmental flow standards applicable at the multi-river ("regional") scale, based on flow-ecology linkages, that can be applied anywhere in the world, across a range of data availability, scientific capacity and social/institutional context. This proposed framework is a consensus view of a wide range of scientists actively engaged in the area of environmental flows and hydroecology.

ELOHA utilizes both local and regional hydrologic and biological databases to generate robust flow-ecology response curves for different types of rivers. These flow-ecology functions correlate ecological risk, which cannot be managed directly, to streamflow conditions, which can be managed through water-use policies. Based on these flow-ecology relationships, regional environmental flow standards can be developed.

The Scientific Process of developing flow-ecology response curves involves four steps (The Nature Conservancy, 2007b):

- Step 1 is to compile a regional database of daily or monthly streamflow hydrographs representing both baseline (undeveloped) and developed conditions for "control points" (management points or sites of ecological data) throughout the region. Hydrologic modeling is used to extend the periods of streamflow data for gauged control points and to synthesize data for ungauged control points as needed.
- Step 2 is to classify river segments based on similarity of flow regimes, using hydrologic statistics computed from the baseline flow series developed in Step 1. The number of river types in a region ranges from one to as many as ten.
- Step 3 is to compute hydrologic alteration for each control point, expressed as the percentage deviation of developed-condition flows from baseline conditions at each control point, using six to ten flow variables that are strongly linked to ecological conditions and are amenable for use as water management targets.
- Step 4 is to develop flow-ecology response curves by associating percentages of hydrologic alteration with associated changes in ecological condition. A family of curves is developed for each river type, using a variety of flow and ecology variables.

The Social Process of using the flow-ecology response curves to manage environmental flows involves three steps (The Nature Conservancy, 2007b):

- Step 1 is to determine acceptable ecological conditions for each river segment or river type, according to societal values (i.e. it is accepted that the management target is not pristine condition).
- Step 2 is to develop environmental flow targets for each river segment or river type by using flow-ecology response curves to associate the desired ecological condition with the corresponding degree of flow alteration. The allowable degree of flow alteration is the environmental flow target.
- Step 3 is implementation of environmental flow management by incorporating environmental flow targets into the hydrologic model developed in Step 1 of the Scientific Process (above). As that model accounts for the cumulative effects of all water uses, it can be used to assess the practical limitations to, and

opportunities for, implementing environmental flow targets at any control point in the project area, or for every point simultaneously.

Discussion

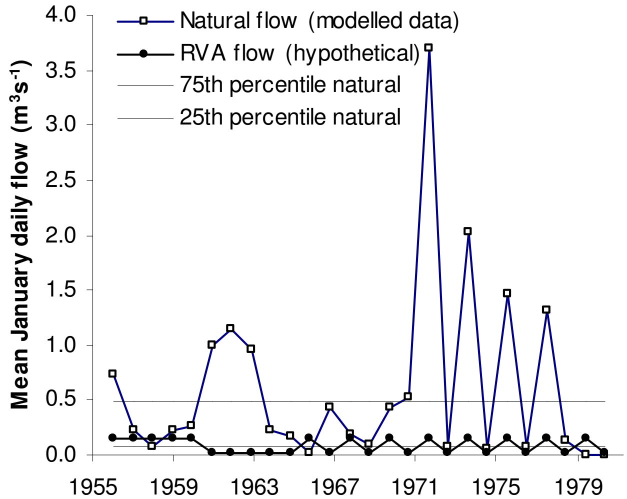
Orth and Leonard (1990), Dunbar et al. (1998) and Tharme (2003) concluded that simple hydrological methods requiring little or no field-work are most appropriate for basin-wide planning purposes, or for providing preliminary estimates in low controversy situations. A number of studies have compared hydrological methods with more sophisticated approaches (e.g. Orth and Maughan, 1981; Orth and Leonard, 1990; Caissie et al., 1998; Bureau of Reclamation, 1999). These comparisons were reviewed by Stewardson and Gippel (1997), who concluded that there was no consistent or reliable pattern in the relative magnitude of flows recommended by these methods.

The translucent dam principle (i.e. a percentage of the inflows are released downstream) aims to preserve temporal flow variability. While this may be desirable in some respects, the channel dimensions are not reduced, so the flows are under-sized with respect to hydraulics (i.e. tending to be shallower and lower velocity). This could mean that ecologically important depth and velocity thresholds are not achieved. Also, releasing water in this fashion (as opposed to targeted releases of certain flow components in their entirety) can have the effect of reducing mean dam levels (i.e. increasing airspace), leading to reduced probability of spills. This could have negative consequences for floodplain elements such as wetlands that rely on high flow events for inundation.

The RVA/IHA approach does not make specific recommendations for environmental flows. It is most often used to characterize the departure of regulated hydrological regimes from natural, rather than to build an environmental flow regime. However, it could be useful in demonstrating what components are missing from an existing regulated regime. Management of a regulated regime according to the range of variability would be difficult to implement, as calculation of the RVA statistics normally requires a time series of data (i.e. they can only be calculated retrospectively). However, it would be technically possible, if difficult, to manage river flows within the range of variability, so that at the end of each year the flows were compliant. This would be a particularly difficult task if the flow regime was required to be compliant with 33 parameters. It is worth noting that a conservative river manager could manage a river within the specified range of variability and still produce a river flow with relatively low variability compared to natural (Figure 71).

The empirical process of establishing flow-ecology response curves in ELOHA is similar to that used in some of the earlier “rule-of-thumb” methods. For example, the Tennant (1976) method was based on hydrological, hydraulic and ecological observations in 11 streams in Montana, Wyoming and Nebraska. The method was originally developed for application in that area, not worldwide. The difference with ELOHA is that the flow-ecology relationships are sought for smaller areas within regions (even though it may eventuate that a single set of relationships are adequate). Also, ELOHA seeks relationships for a number of ecological components, such as aquatic invertebrate species richness, riparian vegetation recruitment, or larval fish abundance (The Nature Conservancy, 2007b), while the earlier “rule of thumb” methods tended to have a more narrow focus on particular species’ of fish. However, it should be noted that Tennant considered aspects of water quality, channel stability and recreation needs in developing his flow-ecology relationships.

Figure 71. Natural (unregulated) mean January daily flow in the Fish River, NSW Australia (inter-annual C_v = 2.2), Range of Variability Approach (RVA) targets, and a hypothetical regulated flow regime that satisfies the RVA targets (inter-annual C_v = 0.9). Source: Gippel (2001).



Application of ELOHA would generally not be limited by the hydrological requirements of the method. Where adequate gauged streamflow records are unavailable, it is usually possible to model daily streamflows, although estimates of peak flows, low flows and cease to flow can be problematic in ungauged and poorly gauged catchments. Development of flow-ecology response relationships for streams within regions will potentially be time consuming and costly, although some regions will already have data available on which to base such relationships. Arthington et al. (2006) recognized that in establishing flow-ecology relationships, sophisticated sampling design will be required in order to separate the effects of flow modification per se from the effects of land use that often accompany major water resource developments (Bunn and Arthington, 2002).

One disadvantage of ELOHA is that it cannot be applied in regions where the streams are relatively un-impacted by flow regulation, because such areas lack opportunities to calibrate ecological response to existing gradients of flow alteration. In such circumstances, Arthington et al. (2006) recommended the use of methods such as DRIFT (Downstream Response to Imposed Flow Transformation) (King et al., 2003) that rely substantially on expert knowledge to describe and rank, from low to high, the probable ecological consequences of proposed hydrologic alterations.

One potential difficulty with ELOHA is that it appears to take no account of the geomophological and hydraulic dimensions of rivers. The method assumes that streams in a region with similar hydrological regimes will have similar ecological responses to flow. In many places, this may not hold, because streams within a region can have similar hydrology, but very different hydraulics, due to geomorphological variation. It cannot be assumed that the geomorphological characteristics of steams vary regionally with hydrological characteristics. The geomorphological variation of most interest would be degree of incision and aggradation, and sediment transport dynamics. For the same flow regime, the shear stress and sediment transport conditions in an incised channel are very different to those in an aggraded channel (Poff et al., 2006), and degree of floodplain connectivity would also be very different. These geomorphic/hydraulic differences would almost certainly give rise to different flow-ecology relationships.

2.1.2 Hydraulic rating methods

Hydraulic rating methods utilise a quantifiable relationship between the quantity and quality of an instream resource, such as fishery habitat, and discharge, to calculate flow recommendations (Gordon et al., 2004). Most emphasis has been placed on the passage, spawning, rearing and other flow-related maintenance requirements of individual, economically or recreationally important fish species. This approach is sometimes known as a 'transect method' or 'wetted perimeter method' because it involves measuring and interpolating changes in simple hydraulic variables, such as wetted perimeter or maximum depth, usually measured across single river cross-sections, as a surrogate for habitat factors known or assumed to be limiting to target biota. Commonly, shallow riffled reaches are chosen for analysis as these areas are the first to be affected by flow alterations, and because it is reasoned that maintenance of suitable riffles will also maintain suitable pool conditions. There is an implicit assumption in this method that there is a threshold value of the selected hydraulic parameter that if maintained in the regulated flow regime will maintain stream health (Gordon et al., 2004).

Simple wetted perimeter methods (Nelson, 1980) have been widely applied for many years (Tharme, 2003), and have been used relatively recently to make important environmental flow determinations (e.g. McCarthy, 2003). In the State of Washington, if fish habitat criteria are not available, then a wetted-perimeter method is used (Department of Ecology, 2003). When applied in its simplest form, transects are located in several representative riffles, and measurements of depth and velocity are taken over a range of different flows. A plot of wetted perimeter against discharge is drawn and the first break in slope in the curve is taken as an indication of the optimum, adequate or minimum discharge for the biota of interest.

As compared with hydrological methods, transect techniques take into consideration simple hydraulic requirements of biota and the availability of this habitat at various discharge levels. The need for field data makes the techniques more time-consuming and costly than hydrology-only methods. Hydraulic rating methodologies were the precursors of more sophisticated habitat rating or simulation methodologies, also referred to as microhabitat or habitat modelling methodologies (Tharme, 2003).

2.1.3 Habitat simulation methods

Habitat rating methods consider not only how physical habitat changes with stream flow (hydrology) but combine this information with the habitat preferences of a given species to determine the amount of habitat available over a range of stream flows. Results are normally in the form of a curve showing the relationship between available habitat area and stream discharge. From this curve, the optimum stream flows for a number of individual species can be ascertained and the results used as a guide for recommending environmental flows.

The most well known of the habitat rating methods is the Instream Flow Incremental Methodology (IFIM) (Bovee, 1982) and this method has been widely used throughout the world (Tharme, 2003). IFIM is much more than a habitat rating method. It is a problem-solving tool made up of a collection of analytical procedures and computer models. It was designed as a communication link between fishery biologists, hydrologists and hydraulic engineers. The aim of IFIM is normally to determine the effect of some activity such as irrigation withdrawals, dam construction or channel modification on aquatic habitat. As each riverine system will have different sets of flora, fauna, hydrological and hydraulic characteristics, types of disturbances and. regulating agencies, the IFIM allows the development of a different approach for each situation.

A number of alternative software systems with the same or similar components as PHABSIM have been developed for use with IFIM. These include EVHA, which is an adaptation of PHABSIM for use in French streams, RHABSIM, which is a commercial version of PHABSIM, and RYHABSIM, which is a New Zealand adaptation of PHABSIM with a simpler interface and fewer options (Gordon et al., 2004).

A critical limitation on the use of habitat simulation models is the lack of well-defined habitat-suitability curves. As these curves are essentially empirical correlations, the curves may not be transferable from one stream to another. However, the development of these curves is costly.

2.1.4 Holistic methods

Holistic approaches are essentially frameworks for organizing and using flow-related data and knowledge (Brown and King, 2003). This approach is not constrained by the analytical tools, and it is not unusual to make use of several different methodologies. While the hydrological, hydraulic rating and habitat rating methods usually focus on key sport fish such as salmonids, or fish with a very high conservation value, the holistic approach attempts to consider the entire ecosystem, using all available information, much of which may be little more than working hypotheses. The problem of uncertainty is overcome by adopting a conservative “precautionary principle”, and by recommending ongoing monitoring and adaptive management (e.g. Poff et al., 1997; Richter et al., 1997; Richter et al., 2006).

Holistic approaches cover a wide range of methodologies, including the Expert Panel Assessment Method, the River Babingley (Wissey) method, the Scientific Panel Assessment Method, the Building Block Method, the Holistic Approach, the Flow Restoration Methodology, the Benchmarking methodology and the DRIFT process (see Gordon et al., 2004 for references).

The holistic method is based on the natural hydrological regime and is intended to provide water required for the complete ecosystem including the river channel, riparian zone, floodplain, groundwater, wetlands and estuary. Explicit numerical models that relate discharge to aspects of the river’s hydraulics, geomorphology, water quality or ecology may be available, or even developed through the course of the investigation. Holistic methods typically build the environmental flow regime from key flow components that are known to be related to ecological processes. The magnitude of the flow components can be derived using a hydraulic model that relates water surface elevation, velocity, depth and/or shear stress to discharge, with field inspection relating these variables to important ecological components or processes. In the absence of hydraulic models, flow components can be defined on the basis of hydrological criteria alone, as is done in EFC (part of the IHA software program) (The Nature Conservancy, 2007a).

The Building Block Method builds the environmental flow regime from 3 main groups of flow components: low flows, channel and habitat maintenance flows, and spawning/migration freshes. The strength of the Building Block Method lies in its ability to incorporate any relevant knowledge, and to be used in both data-rich and data-poor situations (Brown and King, 2003).

The FLOWS method (SKM et al., 2002) is a derivative of the Building Block method, but it incorporates 7 season-specific flow components. This method uses a framework with a series of logical steps undertaken by a small team of experts in cooperation with the river manager: site paper; field inspection; issues paper (incorporating literature and data review and statement of flow objectives for ecology, geomorphology, water quality and hydrology); field topographic survey; hydraulic modelling; flows assessment workshop; flows recommendations paper. The recommendations are strongly linked to ecological and geomorphological objectives via the hydraulic models. The FLOWS method is the standard environmental flow method applied in Victoria, Australia.

The collaborative and adaptive method proposed by Richter et al. (2006) involves five steps: (1) an orientation meeting; (2) a literature review and summary of existing knowledge about flow-dependent biota and ecological processes of concern; (3) a workshop to develop ecological objectives and initial flow recommendations, and identify key information gaps; (4) implementation of the flow recommendations on a trial basis to test hypotheses and reduce uncertainties; and (5) monitoring system response and conducting further research as warranted. A range of recommended flows are developed for the low flows in each month, high flow pulses throughout the year, and floods with targeted inter-annual frequencies. Richter et al. (2006) presumably used an application similar to EFC to define flow components, but that study was based on only three of the five flow components identified by EFC: low flows, high flow pulses, and floods. The environmental flow method of Richter et al. (2006) involves much more than hydrological analysis. It also involves consideration of geomorphology and hydraulics (if available).

Like the FLOWS method, the collaborative and adaptive method proposed by Richter et al. (2006) also involves flow components, experts, managers and workshops. However, unlike the FLOWS method, the workshops involve up to 50 people, there is no survey and modelling step, and the 3-day post data review workshop process is expected to recommend environmental flows on the basis of existing information and expert knowledge alone (if hydraulic data are unavailable this is noted as a data gap). Richter et al. (2006) incorporate two post-recommendations steps: implementation and monitoring. An attractive aspect of this approach is that it accepts uncertainty in the recommendations and aims to refine them over time as knowledge of the managed system improves.

The benchmarking methodology undertakes basin-scale evaluation of the potential environmental impacts of future scenarios of water resource management (Arthington, 1998). In this method, flow alteration data and ecological impairment data are used to set two critical benchmarks (or risk levels); the first benchmark is the limit that must be placed on flow modification to achieve protection of the natural assets of the stream or river, whereas the second benchmark represents the degree of flow alteration associated with severely degraded river conditions. Benchmarking has become the standard method for setting limits to flow regime modification in rivers in Queensland, Australia.

The DRIFT methodology developed for use in southern Africa (King et al., 2003), evaluates links between flows and social consequences for subsistence users alongside ecological and geomorphological ones, and considers economic implications in terms of mitigation and compensation.

Holistic approaches share four main assumptions regarding achievement, or maintenance, of ecological integrity:

- some components of the natural flow regime cannot be scaled down, and must be retained in their entirety
- some components of the natural flow regime can be scaled-down
- some components of the natural flow regime can be omitted altogether
- variability of the regulated flow regime should mimic that of the natural flow regime, in certain respects

These assumptions arise from the notion that high- and low-flow events are more important than in-between conditions because of the stresses and opportunities they present to the biota (Poff et al., 1997). Also, many geomorphic and ecological processes show non-linear responses to flow, requiring a threshold to be exceeded before the process is activated (i.e. they cannot be scaled-down).

2.2 Brief review of methods used in China

In China, environmental flow requirements are variously termed “ecological water requirements/demand” or “environmental water requirements/demand” (Jiang, 2007), prompting Jiang et al. (2006) to adopt the general term “ecological and environmental water requirements” (EEWR). Environmental flows include water use not only for riverine ecosystems but also terrestrial ecosystems. Environmental flows may encompass water use for both for both natural and artificial ecosystems (Jiang, 2007). In general, there remains little use of theoretical models and quantitative methods for the assessment of EEWR in China (Jiang et al., 2006).

Most river EEWR studies are conducted in environmentally fragile areas, or in important basins in the northwestern and semi-arid regions, the Haihe Basin, the Luanhe River Basin and the Yellow River Basin. In general these studies have considered the requirements for sediment transport (generally related to bankfull flow), pollution dispersion, maintenance of aquatic life and prevention of excessive seawater intrusion into estuaries. A number of quantitative methods have been used to model the hydrodynamics and chemical balances of estuaries (Wang, 2007). Other studies have assessed the water requirements of groundwater systems and the needs of vegetation in arid and semi-arid regions, and lakes and wetlands, using water balance approaches (Jiang et al., 2006).

A recent study by Hou et al. (2007a, 2007b) assessed the impact of environmental flow releases made to the Tarim River in western China on water-table dynamics and vegetation, using a pristine reference site for comparison. This study found that in dryland areas, the underground water table is the most important and sensitive indicator of ecosystem response to environment flows. It is the constraining factor for riparian community restoration.

Wang (2006) reviewed the main calculation methods used to estimate environmental flow needs of rivers China. These methods are principally hydrological in nature and include the Tennant method (very widely applied), a monthly percentile method [monthly (yearly) guarantee rate], the method of assumption (which assumes that the average year will sustain the ecology, so this is the model for the environmental flow regime), and method of minimum flow in low flow season (the average discharge of the driest month over a ten year period as the ecological water requirement in low flow seasons). Wetted perimeter approaches have also been utilized.

Hydraulic methods are limited by the lack of detailed information on the hydraulic habitat needs of the biota, and the resources required for field survey appears to discourage this approach (Wang, 2006). The lack of information relating fish diversity to flow means that that diversity is replaced by biomass (the surrogate of which is available data on numbers of fish caught). In general, application of methods that relate biota to hydrology, hydraulics, and other requirements have been constrained by lack of ecological data, and the problem of pollution often being a dominant control on the distribution of biota (Wang, 2006).

2.3 Recommended methodology for Taizhou pilot study

In selecting an environmental flow methodology appropriate to the Taizhou pilot study, several factors need to be considered. The first group of factors concerns the local site factors, which relate to site complexity, resources available, practical constraints, and data availability (Table 80). When compared with the site limitations and requirements, each environmental flow methodology can be seen to have certain advantages and limitations (Table 81). Overall, it is apparent that holistic methodologies are the most appropriate for the Taizhou pilot study.

For this study it was decided to roughly follow the FLOWS framework. The Taizhou case study was essentially completed in only 2 weeks, while a FLOWS study would normally be undertaken over several months. This required substitution, modification or omission of certain tasks. The critical methodological steps were retained: determining the reaches (although site selection remained essentially ad hoc); reviewing the literature; making observations on the river; setting the flow objectives in terms of flow components; describing flow objectives using hydraulic criteria where possible; undertaking hydraulic analysis to link ecological and geomorphological processes to hydrology (although this was simplified); describing the current hydrological regime; defining the recommended flow components in terms of magnitude, frequency, duration an timing; and checking the compliance of the future (with dam) scenarios.

It should be noted that it will not always be possible or necessary in China to undertake an environmental flows assessment using the methodology described here. The method adopted for the Taizhou pilot study was deemed appropriate given the time and resources available. Also, it was considered desirable to demonstrate the advantages and limitations of including hydraulic analysis, i.e. going beyond a simple hydrological analysis approach.

2.4 Outline of methodological steps for the Taizhou pilot study

The environmental flows assessment was based on a combination of methodologies found in the literature, including hydraulic modelling. It is always preferable to include hydraulic assessment to support the hydrological analysis and ecological assumptions. Hydraulics, which is concerned with flow depth, velocity and shear stress, links ecology, geomorphology and hydrology by numerically defining habitats and ecological requirements. In this way, a particular objective, such as inundating a wetland, is defined in terms of one or more hydraulic criteria (in this case, a water elevation required to reach the sill), which can then be converted to a flow for specification as a requirement. Some processes cannot be readily defined in terms of hydraulic criteria, in which case expert knowledge is used to make recommendations based on knowledge of the natural hydrological pattern in the river.

Table 80: Taizhou pilot study relevant site factors for consideration of appropriate environmental flows methodology.

Factor for consideration	Relevant details for Taizhou pilot study	Implications
Time available	1 week allocated for field inspection; 1-2 week allocated for analysis and workshop	Relatively rapid field and analysis methods required
Resources available	Core team of fish biologist; hydrologist/geomorphologist; vegetation ecologist; 2 water resources modelers; 2 managers; 2 generalists; 3 translators (plus local field logistical support); no surveyor; no boat	Small team but high level of expertise available; relatively low cost field and analysis methods required; testing of scenarios possible
Importance of river assets	High rainfall zone; moderate ecological importance; good opportunity to recommend guidelines for operation of proposed dam; pilot study can demonstrate methods applicable to many other rivers	In some respects a high priority site deserving of high level of effort
Length and complexity of stream under consideration	Reaches from headwater (dam site) to estuary; complex issues (e.g. gravel extraction, diversions; groundwater interaction, angling, levees)	Requires flexible approach; a range of techniques likely to be required
Hydrological information availability	IQQM model of system available to report on current and future (with development) daily flow scenarios; limited stage height data from one gauge, modelled design flood peaks at dam site; virtually no knowledge of groundwater/surface water interactions	Not limited by availability of surface hydrology data; groundwater cannot be considered in any detail
Ecological information availability	Published literature from region and limited scientific surveys; local fisher survey; very limited vegetation data; limited habitat preference information and flow-ecology relationships	Reasonable knowledge of fish diversity; reasonable knowledge of key fish life cycles and habitat requirements; vegetation data to be collected in field
Geomorphological information availability	Good knowledge of estuary sediment dynamics; virtually no knowledge of stream geomorphology; no topographic or bathymetric data	Field survey required
Hydraulic information availability	Good knowledge of hydrodynamics of estuary, rating curve from one gauge; no hydraulic models of stream channel	Field survey required

Table 81: Appropriateness of a range of environmental flow methods to the Taizhou pilot study, given known site factors. See text for explanation of methods.

Method	Main limitations	Appropriate
Hydrological methods		
Range of methods used in China to date	Not well grounded in ecologic and geomorphic theory or local observations	No
Tennant	Derived in USA on the basis of site specific ecology and geomorphology; relevance of flow-ecology relationships to Chinese rivers questionable	No
RVA/IHA	Not designed for making specific environmental flow recommendations; relevance of IHA parameters to ecology of Chinese rivers questionable	No
EFC (IHA)	Not designed for making specific environmental flow recommendations; flow components appropriate but arbitrarily determined on the basis of hydrology rather than hydraulic-geomorphic-ecologic factors	No
ELOHA	Requires numerical flow-ecology relationships and regionalized hydrology – neither available	No
Hydraulic rating methods		
Wetted perimeter	Only appropriate for low flows; requires physical channel surveys	Maybe
Habitat simulation methods		
IFIM	Requires habitat preference relationships for key species – not available	No
Holistic methodologies		
Building Block method	Only uses 3 flow components; with expanded flow components the framework is appropriate	Partly
FLOWS	Normally requires channel surveys and 1-D hydraulic models which are beyond the resources of this project; with alternative hydraulic method the framework is appropriate	Partly
Collaborative and adaptive method	Only uses 3 flow components; requires large workshop groups and a high level of existing knowledge – not practical and data not available; adaptive management steps desirable	Partly
Benchmarking	Requires ecological condition and hydrological alteration data – neither available	No
DRIFT	Requires resources beyond the capacity of the project; the biophysical module may be appropriate	Partly

The main steps in the selected methodology for the Taizhou pilot study (Zhuxi-Jiaojiang system) were:

i. Divide the entire stream length of interest into manageable reaches, based on hydrological, geomorphological and ecological factors.

ii. For each Reach, identify valued ecological and environmental assets based on:

   a. existing reports, published and unpublished literature,

   b. field investigations, and

   c. discussions with project team members and interviews with water managers, fisheries officers and river users (e.g. fishermen).

iii. Use the same sources of information (existing reports, field investigations, interviews) to develop a conceptual model linking the identified assets to key aspects of the flow regime. The conceptual model provides a means of communicating important linkages between the identified ecological assets and specific flow related processes that must be maintained in order to protect those assets. These processes define the flow objectives.

iv. Having identified each of the important flow objectives for each Reach, use hydraulic and hydrologic models to determine the magnitude, duration, frequency and timing of flows required to meet these objectives. Note that due to practical limitations, Reaches 4, 5 and 6 were not hydraulically modelled, so flow recommendations were made using an alternative methodology. For these sites, a risk assessment was used to explore the likely consequences of flow alterations.

v. For each Reach, develop a set of specific flow rules for inclusion in a river operations model (in this case, IQQM). Note that these rules are designed to meet the objective of providing the minimum flow regime to sustain the ecological integrity of the river in the long-term at a low level of risk (i.e. it is not a “survival” flow regime that cannot be sustained in the long-term, nor is it an “ideal” flow regime, which is in fact the natural regime).

vi. Use IQQM to model the water resources availability with the dam in place and under the recommended environmental flows scenario. Based on need to meet security of supply objectives, review the environmental flow objectives to suggest alternative options. Each option will have associated risks. From a ecological perspective, assessment of the options should be based on the priority given to individual objectives outlined in the initial recommendations.

The final step 6 is not fully reported here.

2.5 Components of the flow regime

Although the flow in a river varies continuously from nothing up to major floods, most conceptual models exploring the influences of flow variation on river ecosystems identify key flow components (parts of the hydrograph) that serve important physical and biological functions [e.g. maintaining the channel morphology or sufficient minimum habitat during periods of low flow, as described in section 3.4 of Wet Project (2007)]. In this report, specific terminology has been adopted to describe each of the flow components (Table 82). Note that not all of these components are necessarily important or referred to in relation to in all reaches of the Zhuxi-Jiaojiang system, but they are noted here for potential application to other rivers in China.

The flow components were broadly associated with particular times of the year (Table 82), following the seasonal pattern of river flows (Figure 72). For the purposes of this study, the seasons were subdivided into four groups (Table 83).

Table 82: Description of flow components referred to in this report. EFC is Ecological Flow Components (Richter and Thomas, 2007).

Flow component	EFC equivalent	Hydrological description	Relevant season for Zhuxi-Jiaojiang
Cease-to-Flow	Closest is: 2. Extreme low flows	No discernible flow in the river, or no measurable flow recorded at a gauge.	Not characteristic of Zhuxi-Jiaojiang system
Low Flow	1. Monthly low flows	Provides a continuous flow through the channel during the low flow (dry) season, keeping in-stream habitats wet and pools full.	October – March
Low Flow Pulse	Closest is: 3. High flow pulses	Frequent, low magnitude, and short duration flow events that exceed the baseflow (Low Flow) for one to several days as a result of localised rainfall during the dry season.	October - March
High Baseflow	1. Monthly low flows	Persistent increase in baseflow that occurs with the onset of the wet season.	April - September
High Flow Pulse	3. High flow pulses	Increases in flow that exceed the baseflow (High Baseflow) as a result of sustained or heavy rainfall events in the wet season.	April - September
Bankfull Flow	4. Small floods	Completely fill the channel, some localized inundation, but no general spill onto the floodplain.	More common in wet season (April - September), esp. associated with typhoons (August – September)
Overbank Flow	5. Large floods	Higher and less frequent than bankfull flows, and spill out of the channel onto the floodplain.	More common in wet season (April - September), esp. associated with major typhoons (August – September)

Figure 72: Distribution of high flows, represented by 5th percentile daily discharge, in the Zhuxi-Jiaojiang system. IQQM modelled current scenario.

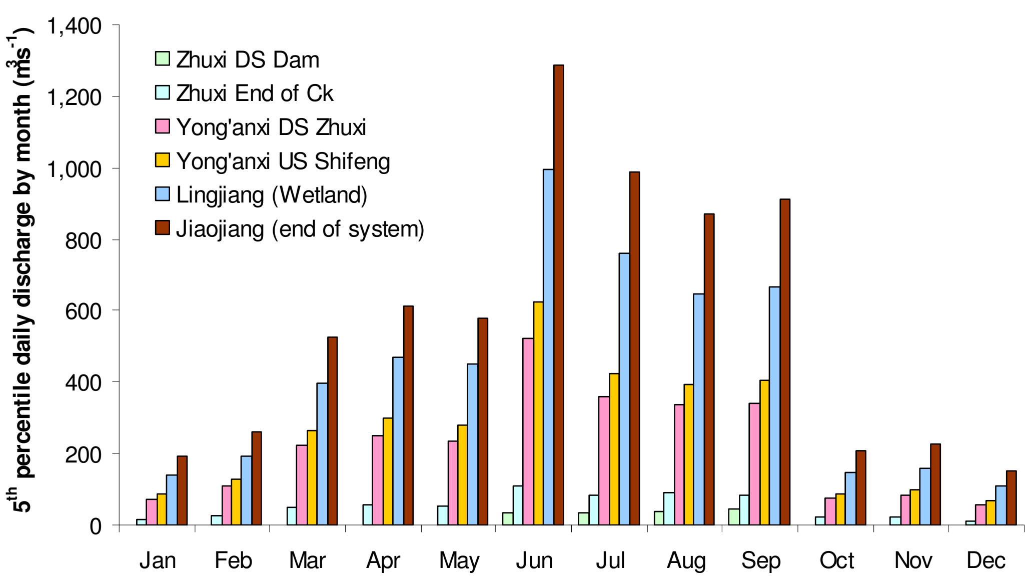


Table 83: Seasonality of flows in Zhuxi-Jiaojiang system

Month	Seasonal description
January	Autumn
February	Winter
March	Winter
April	Spring
May	Spring
June	Spring
July	Spring
August	Typhoon
September	Typhoon
October	Autumn
November	Autumn
December	Autumn

Chapter 3: Site and Reach Description

3.1 Mapping tools

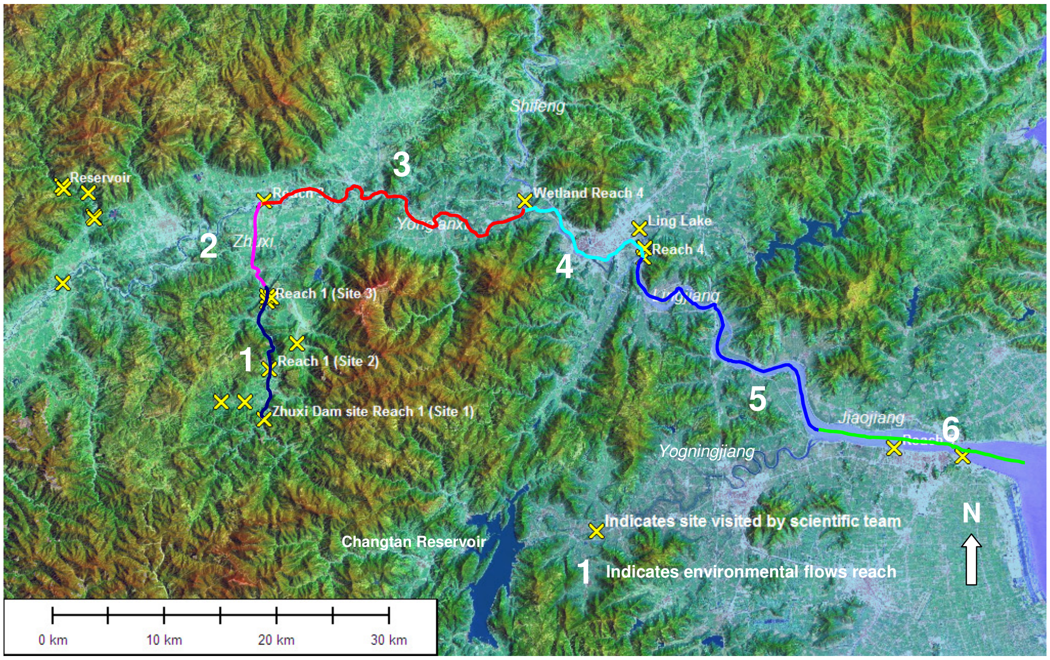
The environmental flows project required a topographic map of the catchment to assist with location of field sites, selection of reaches, estimation of stream gradient and geomorphological interpretation. Such a map was not immediately available to the project team, which may be a common situation in some parts of China. A digital georeferenced satellite image of the site area (as can be viewed on Google Earth) was downloaded for a cost of approximately US$90. The map was purchased from TerraServer® (http://www.terraserver.com/home.asp). Shuttle radar terrain model data were downloaded (free of charge) from NASA (ftp://e0srp01u.ecs.nasa.gov/srtm/). The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). For China, data are available at 3 arc-seconds (90 metres) resolution. There are some issues with the accuracy of SRTM data as a DEM, particularly in forested and wooded areas, as the radar was reflected by dense vegetation. However, the SRTM is an adequate DEM when used at the catchment and sub-catchment scale.

The satellite image and SRTM data can be loaded by any GIS software; in this case Global Mapper (http://www.globalmapper.com/) was used to produce a composite map that allowed examination of the topography and main land use features (Figure 73). Global Mapper software can be purchased for a cost of approximately US$300.

3.2 Current basin water resources

Taizhou prefecture is located in the mid-coastal region of Zhejiang province. Taizhou has 21 rivers (including tributaries) each covering a basin area of over 100 km^2. The most significant is the Jiaojiang (Jiao River) (Figure 73). With a catchment area of 6,750 km^2 at the estuary (Zhang and Liu, 2002), the Jiaojiang basin is the third largest in Zhejiang province. Mean annual river discharge to the estuary is 211 m^3s^{-1} (Guan et al., 2005). The river transports a gravel/cobble bedload, and flows into an estuary characterized by inter-tidal mudflats.

Figure 73: Location of Zhuxi-Jiaojiang study area, showing 6 defined reaches for environmental flows assessment. Basemap is a composite of SRTM DEM and satellite image.



Taizhou receives regular and relatively high wet season rainfall due to monsoonal and typhoon influences. Average annual precipitation across Taizhou is 1,632 mm and average annual runoff ranges between 600 mm and 1,200 mm (WET Project, 2007)..

Floods are common in the wet season. However, a distinct dry season exists over winter. Periods of drought (or periods when rationing may be required) are of relatively short duration, as indicated by the current drought response arrangements that describe "extreme droughts" as those enduring more than 90 days (WET Project, 2007).

On average, about 9.08 billion m^3 of water resources is available annually. In 2005, about 1.54 billion m^3 was used throughout Taizhou (Taizhou Water Resources Bulletin, 2006, cited in WET Project, 2007).

Currently, there are four major storages in Taizhou (as described by WET Project, 2007):

i. The Changtan Reservoir (Figure 73) in Huangyan District is the biggest storage in Taizhou. It was built in the late 1950s – early 1960s on Yongningjiang. It has a capacity of 732 million m^3 and is used predominantly for urban supply to Jiaojiang township (the largest population centre in Taizhou). It also supplies water for the irrigation of about 66,667 ha (one million mu) of cultivated land. Dam releases are first directed through a hydropower station.

ii. The Niutoushan Reservoir in Linhai city was built in 1989 and is mainly used to supply two irrigation districts. About two-thirds of its 302 million m^3 capacity is used to irrigate almost 2100 ha (about 313,000 mu).

iii. The Lishimen Reservoir is on the upper reaches of the Shifengxi (which joins the Yong'anxi). It has a capacity of 199 million m^3 and is used for urban water supply (to the township of Tiantai), irrigation supply and hydropower generation.

iv. The Xia'an Reservoir is on the western boundary of Taizhou prefecture. It has a capacity of 135 million m^3.

There is also a large number of smaller storages throughout the prefecture, generally maintained by villages.

Groundwater resources are limited, generally very shallow and over-exploited. The extent of artesian groundwater development has caused serious land subsidence (Xue et al., 2005). Consequently, most artesian bores are being closed progressively (with only some to be retained for contingencies). Areas of restriction or prohibition have been established in the most overdeveloped sub-artesian groundwater areas. Groundwater resources are essentially reserved for low impact use such as stock and domestic (WET Project, 2007).

3.3 Proposed water resources development

Total water demand in the south of Taizhou (which is largely supplied by the Changtan Reservoir) is expected to increase from 76.5 million m^3 in 2010 to 117.7 million m^3 in 2020. Most of the additional demand will come from growth in urban and industrial consumption (WET Project, 2007).

A comprehensive water resources plan for Taizhou prefecture was finalised in 2004. This was prepared in accordance with central level and provincial requirements and in the context of water shortages that occurred throughout Taizhou in 2003 (WET Project, 2007).

A pipeline currently is being constructed to deliver water from the Changtan Reservoir to Yuhuan. It is due to be completed in 2009 and will relieve the water storage and distribution problems on the island, which required water shipments via tankers from Wenzhou prefecture in 2003 and again this year (WET Project, 2007).

Two major new dams have been proposed in the south-west of Taizhou to accommodate projected increases in water demand: the Zhuxi and Shisandu Reservoirs. The two new storages, when combined with the Changtan Reservoir, are expected to provide sufficient supplies (totalling 145 million m^3) for development in the south of Taizhou beyond 2020. A few other new storages are also proposed to be constructed in Taizhou by 2020 (WET Project, 2007). The Taizhou environmental flows pilot project is principally concerned with the Zhuxi Reservoir.

Zhuxi Reservoir is due to be operational by 2011. It will be located on Zhuxi (Zhu Creek) (Figure 73) in Xianju county. The construction of two or three new weirs on the tributary downstream of the dam is also proposed. The catchment area is 172.3 km^2 and the mean annual flow is 19 million m^3 (WET Project, 2007). The area to be inundated will be about 174 ha (2613 mu). The dam wall for Zhuxi Reservoir will be about 70 metres high. The storage capacity will be about 125 million m^3 and the effective storage volume will be 98.67 million m^3 (WET Project, 2007). The beneficial capacity (excluding the dead storage) is 93.53 million m^3. The dam will also have a flood mitigation function with a defence capability of 28.31 million m^3. The dam will increase the total annual volume of water supply by about 122 million m^3 (WET Project, 2007). The dam will also be used for opportunistic hydropower generation (that is, usually only when releases are made for other purposes) (WET Project, 2007).

There is a general expectation that urban and industrial users will receive an annual reliability of 95 or 97 per cent, while agricultural users will have 75 per cent reliability.

Designs for future water supply projects typically aim to achieve these reliabilities (WET Project, 2007).

3.4 Reach definition

The problem of environmental flow assessment and the issue of implementation of the agreed regime requires simplification of the river system into a manageable number of reasonably homogeneous reaches. The Jiaojiang study area was divided into 6 distinct river/estuary reaches (Figure 73, Table 84):

- Reach 1. Zhuxi (Zhu Creek) between the dam site and the first major downstream tributary entering Zhuxi.
- Reach 2. Zhuxi between the first major tributary below the dam site and the downstream confluence with Yong'anxi.
- Reach 3. Yong'anxi between the Zhuxi confluence and Shifengxi junction, the approximate upper limit of tidal influence.
- Reach 4. The freshwater estuarine section of Lingjiang (downstream of Shifengxi junction), which is under tidal influence but above the upper limit of saltwater intrusion from the sea.
- Reach 5. The estuarine section of Lingjiang (to Yogningjiang junction) that is influenced by both tidal and salinity fluctuations.
- Reach 6. The estuarine section of Jiaojiang (downstream of Yogningjiang junction to Taizhou Bay) that is influenced by both tidal and salinity fluctuations.

Table 84: Zhuxi and Jiaojiang system environmental flow assessment reaches

Reach number	Stream	Description	Stream type	Boundaries	Gradient (%)	Length (km)
1	Zhuxi	Directly downstream of dam	Freshwater, non-tidal	Dam to 1st major tributary (on right)	0.242	14.2
2	Zhuxi	Downstream of dam and tributary inflows	Freshwater, non-tidal	1st major tributary to Yong'anxi junction	0.242	9.3
3	Yong'anxi	Main stem fluvial	Freshwater, non-tidal	Zhuxi junction to Shifengxi junction (Sanjiangcun)	0.066	32.0
4	Lingjiang	Main stem fluvial	Freshwater (salt wedge limit downstream of Linhai), tidal at non-flood times	Shifengxi junction to tributary 15.1 km downstream	0.034	15.1
5	Lingjiang	Main stem estuary	Estuarine, tidal	31.5 km reach upstream of Yogningjiang junction	0.004	31.5
6	Jiaojiang	Main stem estuary	Estuarine, tidal	18.8 km downstream of junction to Taizhou Bay (Niutoujing)	0.000	18.8

Chapter 4: Identifying Environmental Assets

4.1 Asset identification

Information on ecological assets relevant to the flow recommendations was collected from background reports, literature surveys, field visits, discussions with Bureau of Water Resources and Fisheries Bureau staff, and interviews with local fishermen. In general, fish and fisheries emerged as the most highly valued asset, particularly those species of economic importance. Fish populations therefore form a core component of the environmental flows assessment. However, in recognition of the strong interdependencies between fish and other components of the riverine ecosystem, such as plants (aquatic and riparian), geomorphology, and water quality, these other factors were also considered for each reach. For example, flows to maintain fish must consider the effects of flow not just on fish directly (e.g. spawning cues), but also on flows to maintain habitat (e.g. geomorphology and macrophytes), food resources (e.g. invertebrates) and water quality (e.g. dissolved oxygen, nutrient loads etc.).

4.2 Geomorphology

4.2.1 Rivers and streams

Zhuxi is a cobble-coarse gravel bed river, with sand-sized material present within in the substrate. The bed material particle size was sampled at four sites using the Wolman Pebble Count method (Gordon et al., 2004, p. 105) (Figure 74). The creek bed is actively mined for sand and gravel in many places. In the lower reaches, downstream of Linhai city, the bed particle size changes to sand, and the estuarine section has a mud bed (Guan et al., 2005).

The morphology of the river varies throughout the study area. In overall size it increases from the dam site towards the sea. All along the system can be found long pools of variable depth (reportedly up to around 2 m at baseflow), separated by fast flowing runs and glides. There are occasional bedrock outcrops, especially noticeable in constricted sections. Large woody debris is not a feature of this river system.

The river appears to have a high sediment supply, which gives to a wandering gravel bed form. The bedload is shaped by high flows into large bars. Mounded gravel and cobbles form the banks in places, although most areas also have a fine grained (loamy sand and silt) floodplain present. The width of the floodplain varies enormously. In places the river is tightly constrained between valley walls, and in others it opens onto a floodplain that is kilometres wide. Much of the river is lined with artificial levees, offering protection for the floodplain land from floods of 20 – 50 year ARI. There was only one substantial floodplain wetland observed, on the left bank of the river just downstream of the Shifengxi junction (Figure 73).

Channel gradient varies from 0.24% for Zhuxi to virtually flat for the lower reach (Figure 75). There is a clear change in gradient just downstream of Linhai city, where the river is close to sea level. This is the natural limit of the upstream migration of the salt wedge from the estuary.

The relatively high channel gradient of Zhuxi and Yong'anxi, combined with ample supply of coarse bed material, meandering course and bedrock outcrops, generates a wide variety of hydraulic habitat. As well as fast flowing sections, there are deep pools, eddies and backwaters present.

Figure 74: Particle size of bed surface materials in Zhuxi (Reach 1) and Yong'anxi (Reach 3), determined by Wolman pebble count. It was not possible to sample the bed material at other reaches.

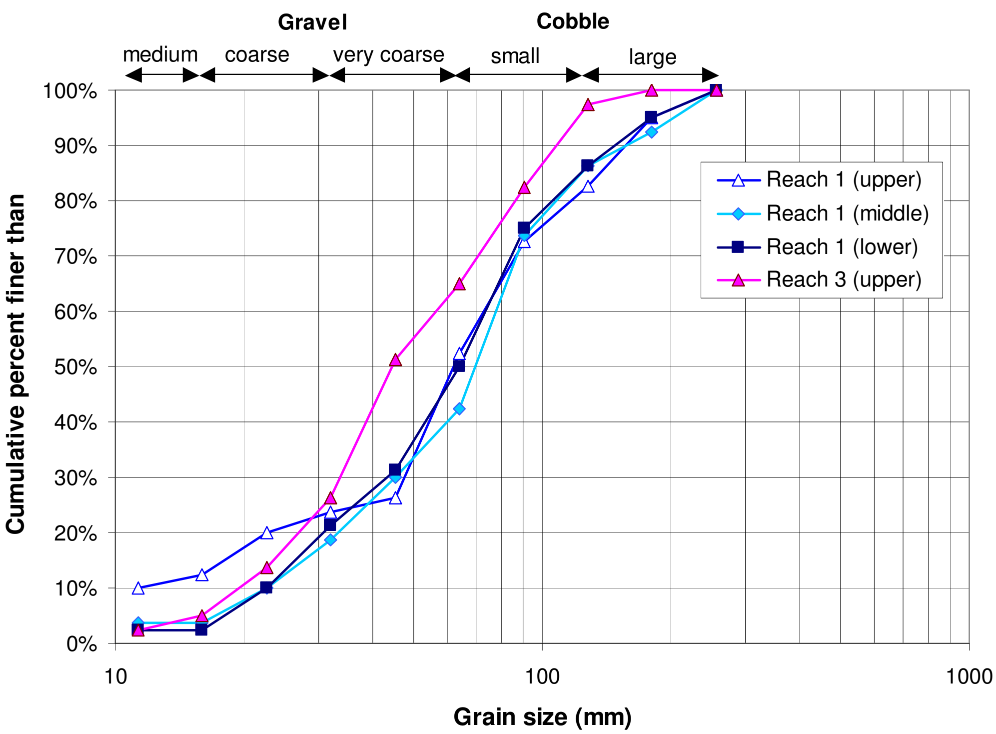
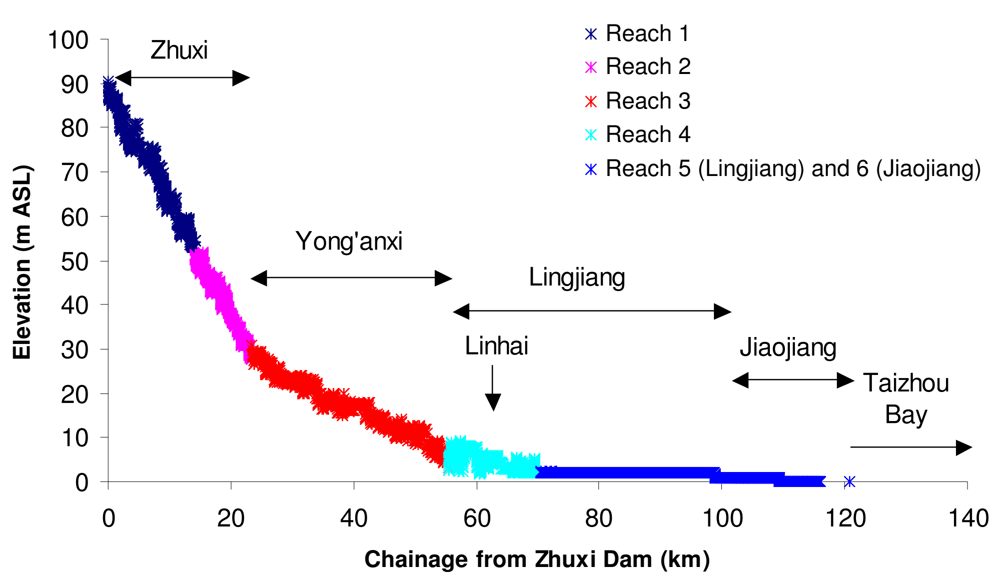


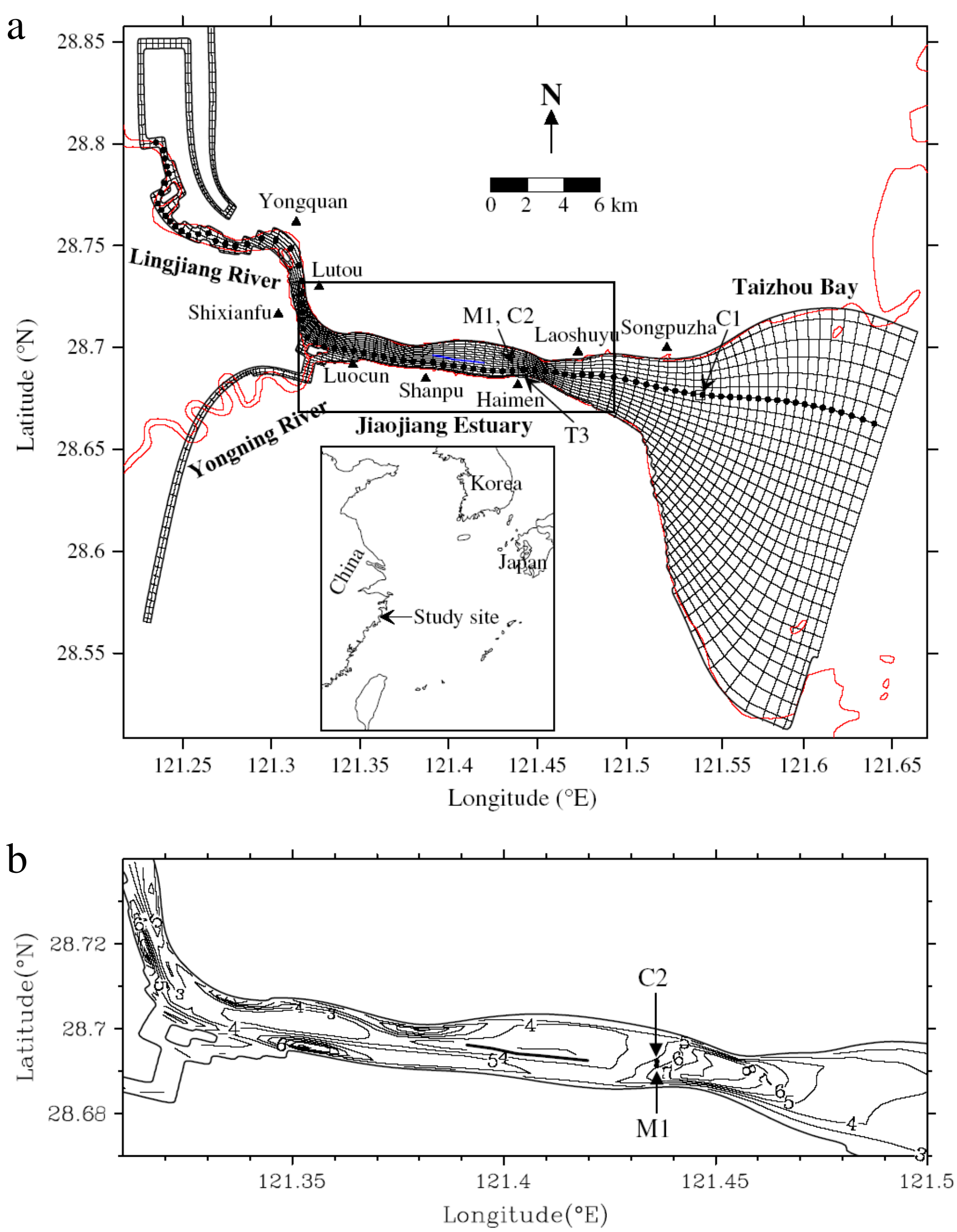
Figure 75. River profile for Zhuxi-Jiaojiang system determined from sampling the SRTM DEM.



4.2.2 Jiaojiang estuary

The water quality, sediment dynamics and hydrodynamics of the Jiaojiang estuary are well understood. According to Guan et al. (2005) the Jiaojiang Estuary is about 35 km long, although local knowledge suggests that saline water can reach almost as far as Linhai city. In the estuary, the mean width of the channel is about 1.2 km with a maximum of 1.8 km at the mouth (Figure 76). The estuary faces Taizhou Bay. The Jiaojiang River estuary was found by Guan et al. (1998) to be shallow with a depth of 1 – 3 m at low tide, although there are deeper sections of 6 – 8 m (Figure 76) (Guan et al., 2005).

Figure 76: (a) Orthogonal curvilinear grid used in the 3-D model simulations of Guan et al. (2005). M1 is the mooring stations; C1 and C2 are anchor stations; T3 is the tide station. (b) Bathymetry (in metres) for part of the estuary. Taken from Guan et al. (2005).



Semi-diurnal macro-tides prevail, with a mean tidal range of about 4 m and a maximum tidal range of 6.3 m. The vertically-averaged tidal current peaks at 2·0 ms^{-1}. At Haimen, the flood tide lasts 5.1 h while the ebb tide lasts 7.3 h (Dong et al., 1997). Off Haimen, the maximum flood and ebb currents are, respectively, 2.1 and 1.8 ms^{-1} (Zhu, 1986). The ratio of the freshwater volume to the tidal volume is about 0.04, but more than 0.1 during periods of very high river discharge. The estuary bed is covered everywhere with cohesive sediment (clay and fine silt with a diameter less than 8 μm). The estuarine waters are extremely turbid with suspended sediment concentration values at times exceeding 40 kg m^{-3} during spring tides in calm weather. The total mass of mobile sediment trapped in the estuary is around 1.2 x 10^6 tons, which is a value comparable to the annual river load (Guan et al., 2005).

In order to maintain a constant bed elevation, the Jiaojiang estuary is dredged at an annual rate of about 0.05 – 0.3 m per year (Guan et al., 1998). Guan et al. (2005) cited Bi and Sun (1984) and Fu and Bi (1989), who estimated that the average fluvial sediment inflow to Jiaojiang estuary is about 1.2 x 10^6 tons per year, corresponding to a mean sediment concentration of 0.18 g L^{-1}. Of the sediment deposited on the bed of the estuary, only 5% is due to locally derived fluvial material. The sediment infilling the estuary originates from the Changjiang (Yangtze River). The mouth of the Changjiang is located 200 km further north and the Changjiang sediment is known to travel long distances along the coast (Figure 77) (Liu et al., 2007). The Changjiang river plume is especially marked during the summer(Typhoon) season (Hung et al., 2007). .

The 3-D hydrodynamic model of Guan et al. (2005) (Figure 76) predicted that during a low river discharge, the total mass of suspended mass decreases, and this results in increased sedimentation. Saline water moves further upstream, and the vertically-averaged and time-mean values of suspended sediment concentration are reduced. During high river discharge, the sediment is gradually carried out of the estuary. The kinetic energy increases during ebb and decreases during flood. The masses of mobile sediment, stationary sediment, and total sediment are reduced, while turbidity maximum moves seaward to Taizhou Bay.

On a list of the 13 major coastal rivers in China (Figure 77) compiled by Zhang and Liu (2002), the Jiaojiang has the smallest catchment area (half the size of the second smallest), but was ranked 11th for discharge, 8th for sediment load, and 2nd for sediment yield (Figure 78). These data suggest that in terms of sediment yield, the Jiaojiang and the Huanghe (Yellow River) are in a class of their own (Figure 78). Given that the majority of the suspended solids in the Jiaojiang Estuary are sourced from coastal water transport (Figure 77) rather than riverine discharge, the river sediment load and yield data in Zhang and Liu (2002) are questionable. The value of fluvially derived sediment load to Liaojiang estuary reported in Guan et al. (2005) is more consistent with the yield data from the other major rivers in China (except the Huanghe) (Figure 78). This suggests that the Liaojiang catchment is not exceptional with respect to suspended sediment transport.

Figure 77. (a) Major coastal rivers in China, from Zhang and Liu (2002), and (b) schematic representation of various waters in the East China Sea from Hung et al. (2007). CJCW, Changjiang Coastal Water; KW, Kuroshio Water; TCWW, Taiwan Current Warm Water; UW, Upwelling Water; YSCW, Yellow Sea Cold Water.

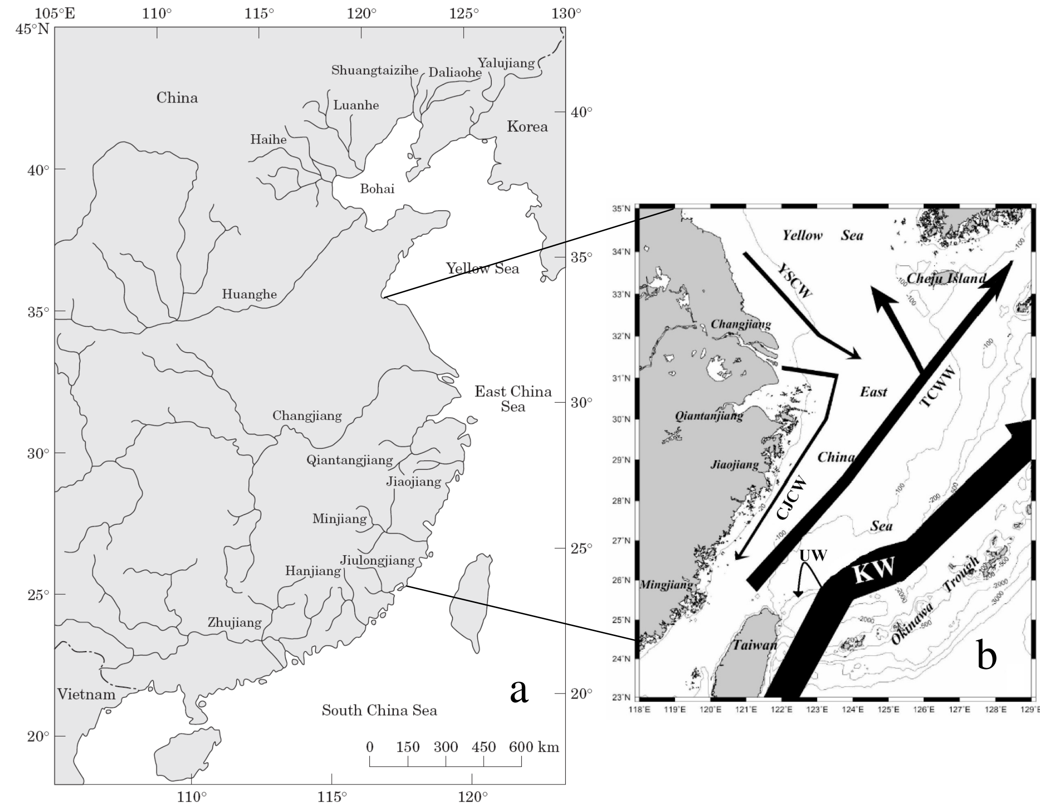
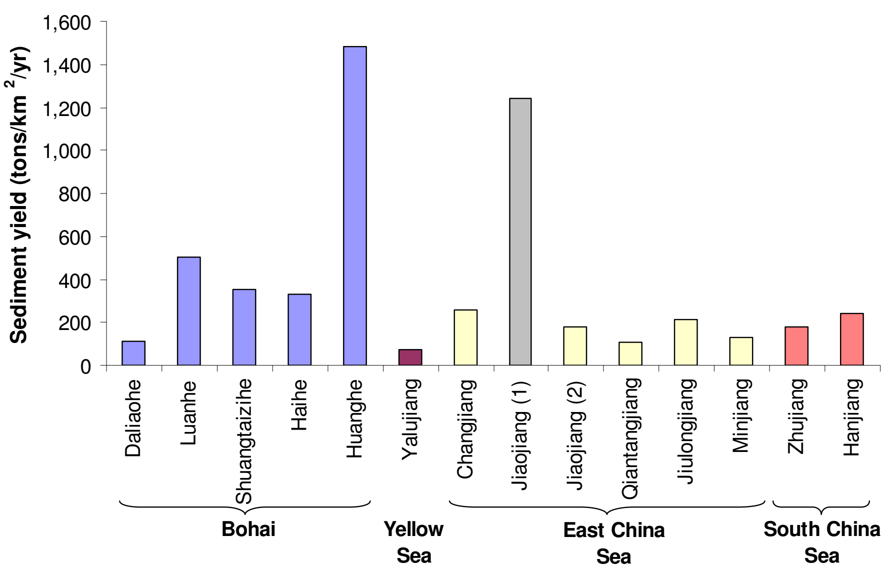


Figure 78. Average annual sediment yield for major Chinese rivers. Source: from data in Zhang and Liu (2002), except for Jiaojiang (2) which is reported in Guan et al. (2005). Jiaojiang (1) value is doubtful.



4.2.3 Flow-related geomorphic issues

In the fluvial reaches of the Zhuxi-Jiaojiang system it is important to maintain bed material disturbance (i.e. sediment transport) to maintain ecological processes. One component of this process is reasonably frequent flushing of fine deposits from the bed. The other major geomorphological issue is maintenance of channel form, with respect to the overall channel size, and the physical forms within the channel. Once again, this relates to maintenance of sediment transport processes.

Zhuxi Reservoir will trap the entire bedload at that point. Downstream of the dam the river channel will incise into the dominantly gravel and cobble-sized bed material to bedrock or until the remaining bed material is coarse enough to resist mobilization (to create an armoured bed). The results of this process were observed downstream of an existing reservoir flowing on a northern tributary of Yong'anxi (Figure 79). In this case the bed downstream of the dam was either bedrock or boulder-size. At a distance of around 1 km from the dam the bed material contained some finer material, and within 5 km downstream of the dam the bed material contained gravel and cobbles. Thus, in this case the incision recovered over a reasonably short distance downstream of the dam, indicating ample local sediment supply. There is little that can be done to prevent this scour process downstream of dams, short of ongoing augmentation of the sediment supply (Bunte, 2004). Merz and Ochikubo Chan (2005) found that cleaned gravels artificially sourced from adjacent floodplain materials were quickly incorporated into the stream ecosystem. Benthic macroinvertebrate assemblages on salmonid spawning enhancement materials, as indicated by species richness, diversity and evenness, were similar to those of adjacent un-enhanced spawning areas within 4 weeks of augmentation and supported higher benthic density and dry biomass for up to 22 weeks after placement. Bed material agumentation downstream of dams is an expensive and logistically difficult procedure and would only be warranted if it could be demonstrated that there would be no significant negative impacts and the gravel-dependent ecological, economic and social assets of the river were of sufficient value.

The bed load of channels of the Zhuxi-Jiaojiang system is sourced from inflowing tributaries, the channel bed itself and the channel banks. Ongoing construction of dams will reduce tributary sediment supply, and gravel extraction, which is prolific in the Zhuxi-Jiaojiang system, will reduce in-channel supplies. The expected response will be channel incision (sourcing material stored from the bed), followed by a phase of channel widening (sourcing material from the floodplain) and bed material coarsening. This process has been observed elsewhere, with one recently documented case being the gravel-bed Brenta River in the Italian Alps (Surian and Cisotto, 2007). In this case, bed incision following gravel mining ranged from 1 – 9 m and averaged 5 m. A phase of bank erosion followed, resulting in channel widening. Surian and Cisotto (2007) warned that future bank protection works or removal of gravels from the channel could induce a new incision phase. The Zhuxi-Jiaojiang system is particularly prone to this form of channel adjustment because of the high sediment transport capacity, the current intensity of gravel extraction, and the extensive confinement of the river within rock levees (limiting the supply of sediment from the banks). Reduced sediment transport capacity (through dam construction) could slow this process. However, sediment mobilization is important for maintenance of habitat conditions, so the more appropriate response would be to maintain floods, but manage (i.e. maintain) sediment supply. This could mean cessation of gravel extraction activities, allowing bank erosion to proceed, and augmentation of bedload downstream of dams.

Figure 79. Effects of sediment starvation immediately downstream (top left and top right) and approx. 1 km downstream of reservoir (lower) located on northern tributary of Yong'anxi at 28° 53' 18" N, 120° 38' 12" E (location marked on Figure 73).

It seems quite clear that the flow and sediment processes in the Jiaojiang estuary are largely controlled by marine rather than fluvial inputs. The estuary will require regular dredging regardless of any periodic scouring that might be provided by high river flows. During large floods, freshwater will extend further into Taizhou Bay, and sediment will be transported offshore. This may create ecological responses in the estuary and offshore (conflicting anecdotal evidence was provided by local fishermen). During low flow periods, the rate of fine sediment deposition on the bed of the estuary tends to increase. At these times, salt water will migrate further upstream.

Thus, the issues for environmental flows in the estuary are mainly to do with maintaining the mean position of the salt wedge, by maintaining river flows. Inland migration of the salt wedge due to reduced flows will not change the overall character of the estuary, but it may slightly increase the size of the tidal prism. The ecological consequences of this cannot be determined, as it is not known if there are any habitats or biota in the upper Lingjian part of Reach 5 (Figure 73) that are particularly sensitive to salinity change.

4.3 Vegetation

The Jiaojiang Basin lies within the evergreen broad-leaved forest vegetation region of China (Hou, 1983). The natural vegetation in the basin consists of subtropical evergreen broad-leaved forests and needle leaved evergreen forests. Typically central subtropical evergreen broad-leaved forests are distributing in areas at altitudes from 650 m to 1250 m. Mason Pines forests are distributed in hilly regions below 800 m. Chinese fir forests grow at altitudes below 1200 m. Higher altitude mountain regions are occupied by secondary shrubs and herbs. Lowland floodplain areas have been extensively cultivated for rice, wheat and other crops such as fruit and vegetables.

Background searches did not identify any specific information on riverine plant species or communities in the Jiaojiang basin and no species related to riverine systems were identified from lists of protected species (at both the national and regional level). No formal nature reserves or protected areas encompassing riverine habitats were identified within the basin. However, an area of wetland near Linhai city at the confluence of Yong'anxi and Shifengxi was identified. This is characterised by mixed woodland (including Populus sp.) with some open marshland. Useful background information on the ecology of riverine vegetation and its relationship to river flows was obtained from a number of international publications including Naiman and Decamps (1997) and Nilsson and Svedmark (2002).

A number of invasive aquatic plant species are recorded as widespread in southern and eastern China and are likely to occur in the prefecture. These include *Alternanthera philoxeroides* (Alligator weed) and *Eichhornia crassipes* (Water hyacinth) (Xie et al., 2001). *Cabomba caroliniana* (Fanwort) was also recently (1993) recorded in Zhejiang province (Zhang et al. 2003). Alterations to river flow regimes are considered to be important in facilitating the establishment and proliferation of invasive aquatic species (Bunn and Arthington, 2002).

Environmental flow objectives focus upon the flows necessary to maintain existing riparian and wetland plant communities and provide opportunities for recruitment through the maintenance of habitats and, periodic scouring of vegetation. Scouring provides opportunities for recruitment of riparian species on areas of open ground and transfers organic material to the stream. Flows were also considered to prevent encroachment of terrestrial species into the river channels.

4.4 Fish

The most detailed assessment of fish and fisheries available for the Jiaojiang basin comes from a 1971 survey of aquatic resources in Linjiang, by the Zhejiang Fishery Bureau and Zhejiang Institute of Freshwater Fisheries. The findings from this study are outlined in the WET project report "*Background data relevant to ecological assets in Jiaojiang Basin*". In summary, close to 100 species of fish were reported from the basin. Of these just over half (59) were entirely freshwater, nearly a third were from the lower (saline) estuary (24), and approximately 14 were diadromous meaning they migrate between fresh and saltwater. This last group contains many of the species that are of conservation and/or economic importance. Appendix 1 lists the species that were considered in detail in developing the environmental flow recommendations. The inclusion of species in the detailed analysis was based on two factors: conservation and economic significance and the availability of information on biology, habitat requirements etc. One species of particular conservation significance observed during the field surveys was the Chinese Sturgeon, *Acipenser sinensis*. Review of the literature suggest that breeding populations are restricted to the Pearl and Yangtze Rivers (Wei, 1997), although individuals may move in and out of estuaries along the east China coast. In light of this, the species was not specifically considered in developing the flow recommendations.

As a first step the international online “Fishbase” database (www.fishbase.org) was used to establish the availability of information, together with more general online searches of the literature. Fishbase was also useful in formally identifying species from local names as the site provides common species names in numerous languages, including Mandarin. The work of Welcomme et al. (2006) describing fish guilds of tropical floodplain rivers and Dudgeon (1999) describing the dynamics of tropical streams also provided useful background information. It must be stressed at this point that much more information is probably available from internal Chinese reports and from Chinese research/fisheries agencies, but only some of this material was accessible within the available time frame.

Chapter 5: System Hydrology

5.1 Data availability

The Zhuxi-Jiaojiang hydrological system was modelled over the period 1980 – 2006 on a daily time-step using IQQM (Integrated Quantity-Quality Model). Output files were mean daily discharge for the current scenario and a range of future scenarios involving Zhuxi dam operation, environmental flows and construction or modified operation of other dams in the system.

The IQQM model reported at 6 environmental flow nodes (Figure 80). There was a general correspondence between the reporting nodes and the defined environmental flows reaches (Table 85).

Figure 80: Conceptual node diagram for IQQM model.

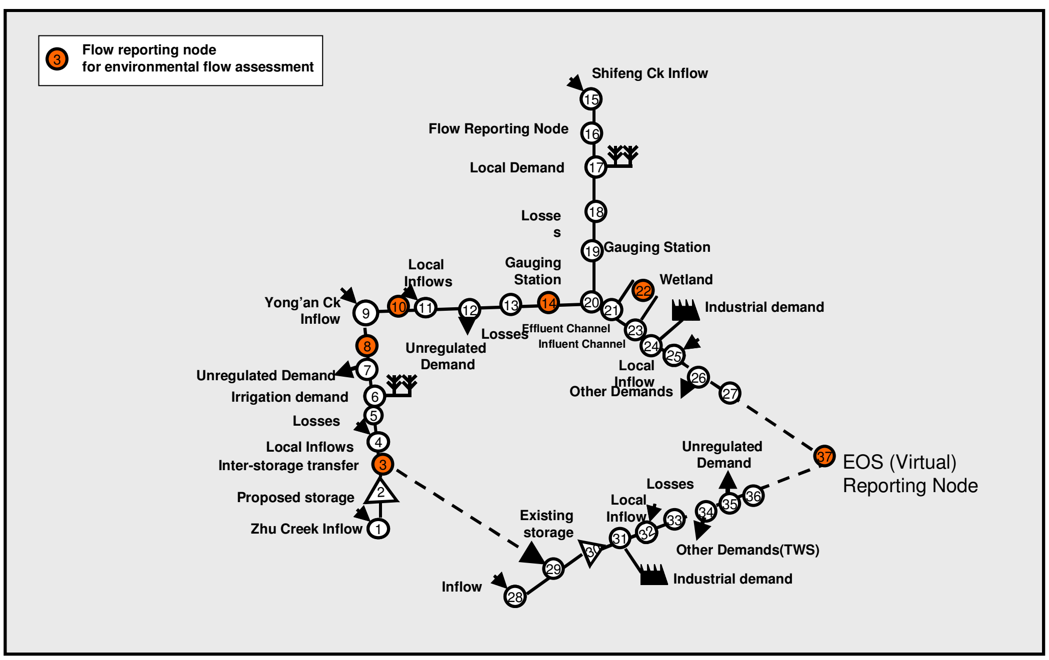


Table 85: IQQM reporting nodes and correspondence with environmental flows reaches

IQQM reporting node	Corresponding section of environmental flows reach
Zhuxi downstream of proposed dam	Upper end of Reach 1
Zhuxi end of Creek	Lower end of Reach 2
Yong'anxi downstream of Zhuxi	Upper end of Reach 3
Yong'anxi upstream of Shifenxi	Lower end of Reach 3
Lingjiang (wetland)	Reach 4 and upper end of Reach 5
Jiaojiang (end of system)	Reach 6

5.2 Methods of data analysis

Hydrology data can be analysed using readily available commercial software, free software (see below for description of three examples) or using purpose-built spreadsheets in Excel.

i. AQUAPAK is a general-purpose program that can be used for the processing of time series data. The software was developed as part of the hydrology text written by Gordon et al. (2004). AQUAPAK handles data based on daily, monthly, and annual periods. Data may be viewed and/or edited via a worksheet (Excel-type) interface. The program can read in a total of 200 x 366 records (i.e. 73,200 data points), which is equivalent to around 200 years of daily data. The program has the capability to calculate virtually any statistic likely to be of interest to environmental flow practitioners. Although the software can be downloaded for free from the SKM website (http://www.skmconsulting.com/Markets/environmental/resource_management/AQUAPAK_Download.htm) SKM requires that users agree to the terms and conditions of a non-commercial software licence.

ii. RAP (River Analysis Package) is a toolbox of quantitative techniques originally developed for environmental flow assessment. RAP includes a 1-D hydraulic model, and a time series analysis module that calculates a range of statistics likely to be of interest to environmental flow practitioners. RAP is one of the Catchment Modelling Toolkit products developed jointly by the CRC for Catchment Hydrology (CRCCH) and CRC for Freshwater Ecology (CRCFE). The Catchment Modelling Toolkit is now supported by the eWater CRC. RAP can be downloaded for free from the eWater website (http://www.toolkit.net.au/cgi-bin/WebObjects/toolkit), but first it is necessary to register (free) and to agree to the terms and conditions of a non-commercial software licence.

iii. IHA (Indicators of Hydrological Alteration) software has been developed by The Nature Conservancy (TNC) as tool for calculating the hydrological characteristics of natural and altered flow regimes. The IHA calculates 33 flow parameters that are thought to have ecological significance. When analyzing the change between two time periods, the software enables users to implement the Range of Variability Approach (RVA) described in Richter et al. (1997). The IHA software also includes calculation of 34 EFC (environmental flow component) parameters, which attempt to automatically identify and compute statistics of hydrological events such as floods and droughts (RVA cannot be applied to EFC). The software can be downloaded for free from The Nature Conservancy website (http://www.nature.org/initiatives/freshwater/conservationtools/art17004.html) but the users manual warns that any commercial use of this software is prohibited without the express, written consent of The Nature Conservancy.

iv. Microsoft Excel is a spreadsheet program within the Office suite of programs. Spreadsheets can be written to undertake any of the calculations performed by AQUAPAK, RAP or IHA, although programming skill will be required in the case of some parameters. The advantage of using Excel (or any other programming language) is that the calculations and graphical outputs can be made specific to the user's needs.

The methodology adopted for the Taizhou pilot study was based primarily on linking hydraulics to ecology. As it was not driven by a hydrological method, there was no need to calculate specific indices, as is done by RAP and IHA. All hydrological analyses undertaken for the Taizhou pilot project were performed using purpose-built Excel spreadsheets.

Hydrological analysis was undertaken: (i) initially, to provide the expert team with an overall understanding of the hydrological characteristics of the streams, (ii) interactively during the environmental flow assessment workshop to characterize the hydrology of particular hydraulically defined events of interest, and (iii) after the flow recommendations had been made to check for compliance.

5.3 Low flows and median flows

Cease to flow is not a characteristic of the Zhuxi-Jiaojiang system, with only a handful of days with cease to flow expected in Zhuxi over the 27 year modelled period (1980 – 2006).

An index of low flows is the 95th percentile flow. There is a marked difference in the magnitude of low flows in the upper part of the system, in Zhuxi, compared to further downstream in the system (Figure 81). The driest period is November to February. Median flows are similarly distributed, with the March to September period consistently showing higher flows throughout the system (Figure 82).

5.4 Flow duration

Flow duration curves summarise the distribution of all flows by depicting the percent of time flows are exceeded. Flow duration curves are well suited to depicting the middle-level flows, with flows falling between the 25th and 75th percentiles (i.e. half of the time) generally covering the normal range of baseflows. Seasonal flow duration curves show the flow distributions for the main seasons defined in the Zhuxi-Jiaojiang system (Figure 83).

5.5 High flows

High flows can be described in terms of the average recurrence interval (ARI) in years. The partial flood series was constructed for each station, using the Cunane plotting position formula (Gordon et al., 2004) (Figure 84). These plots allow estimation of the return period of events of any given magnitude.

Figure 81: Distribution of low flows, represented by 95th percentile daily flows, in the Zhuxi-Jiaojiang system. IQQM modelled current scenario.

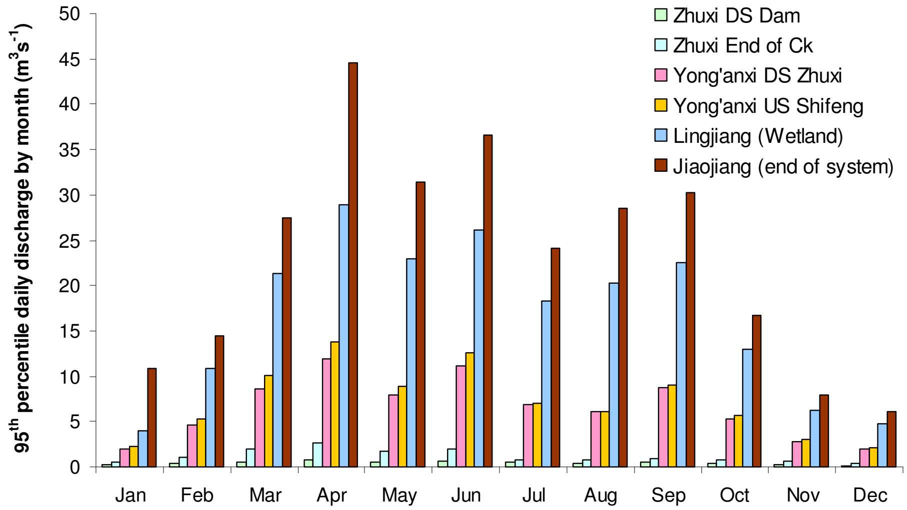


Figure 82: Distribution of median daily flows in the Zhuxi-Jiaojiang system. IQQM modelled current scenario.

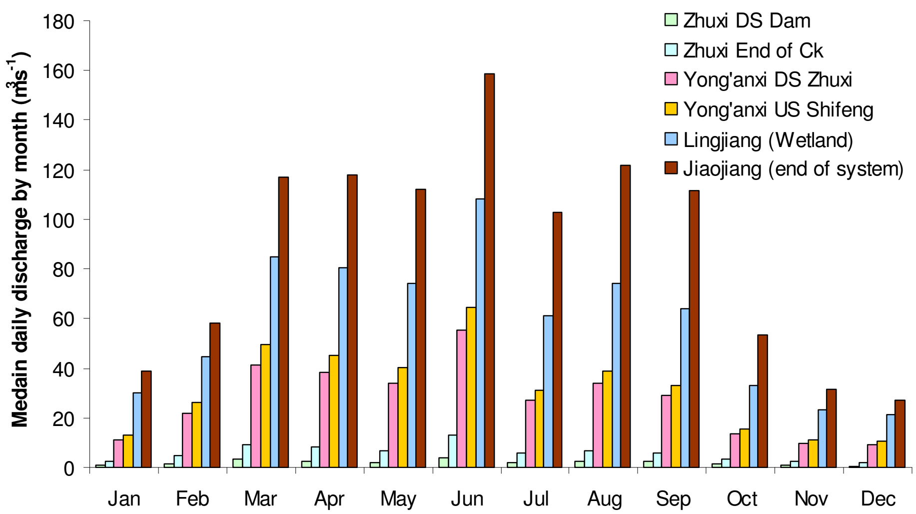


Figure 83: Flow duration curves for mean daily discharge, in the Zhuxi-Jiaojiang system. IQQM modelled current scenario.

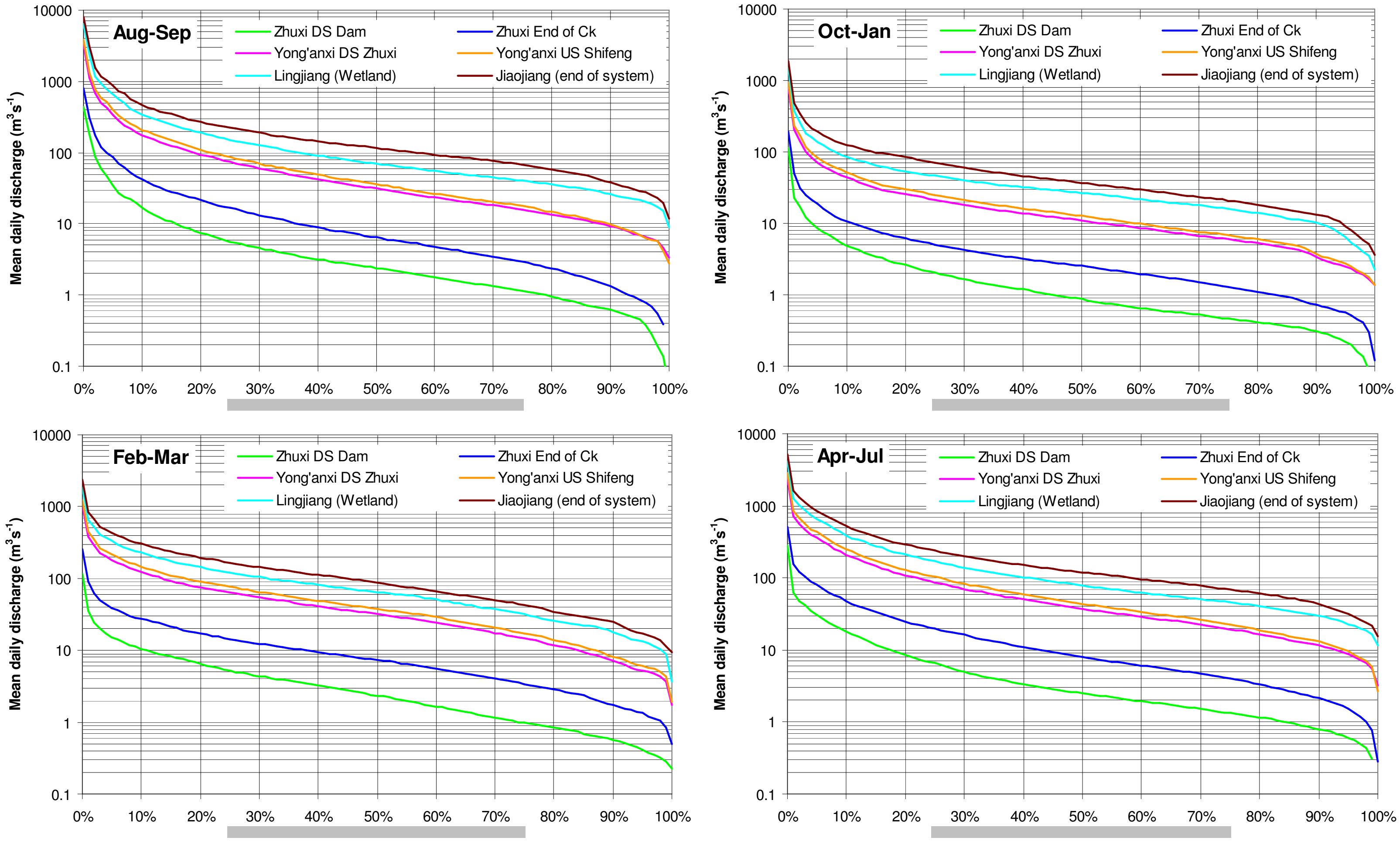
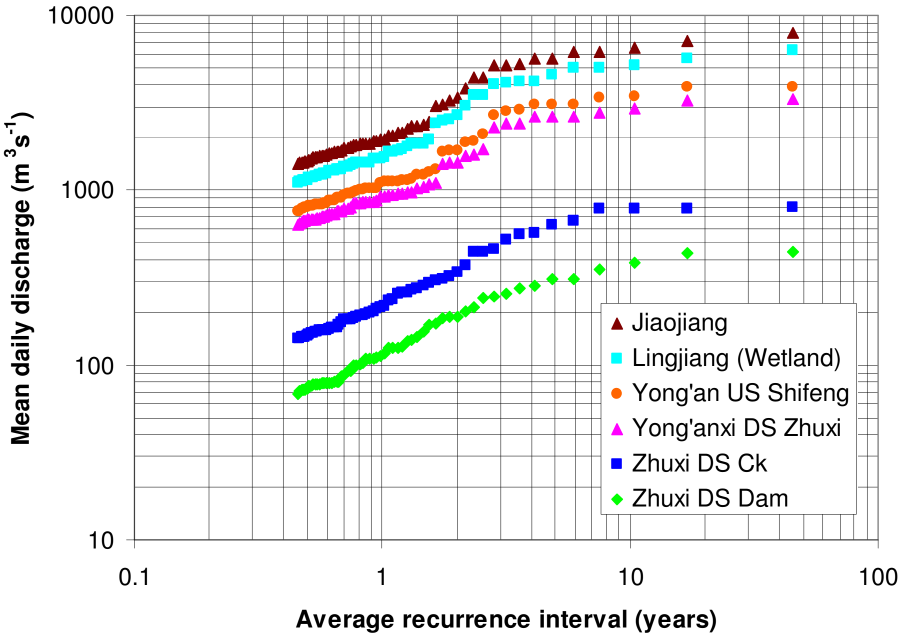


Figure 84: Partial flood series' based on mean daily discharge, in the Zhuxi-Jiaojiang system. IQQM modelled current scenario.



Baxter and Hauer (2000) found that among spawning tributary streams of the Swan River basin, northwestern Montana, the abundance of bull trout redds increased with increased area of alluvial valley segments that were longitudinally confined by geomorphic knickpoints). Among all valley segment types, bull trout redds were primarily found in these bounded alluvial valley segments (BAVS), which possessed complex patterns of hyporheic exchange and extensive upwelling zones (Figure 85).

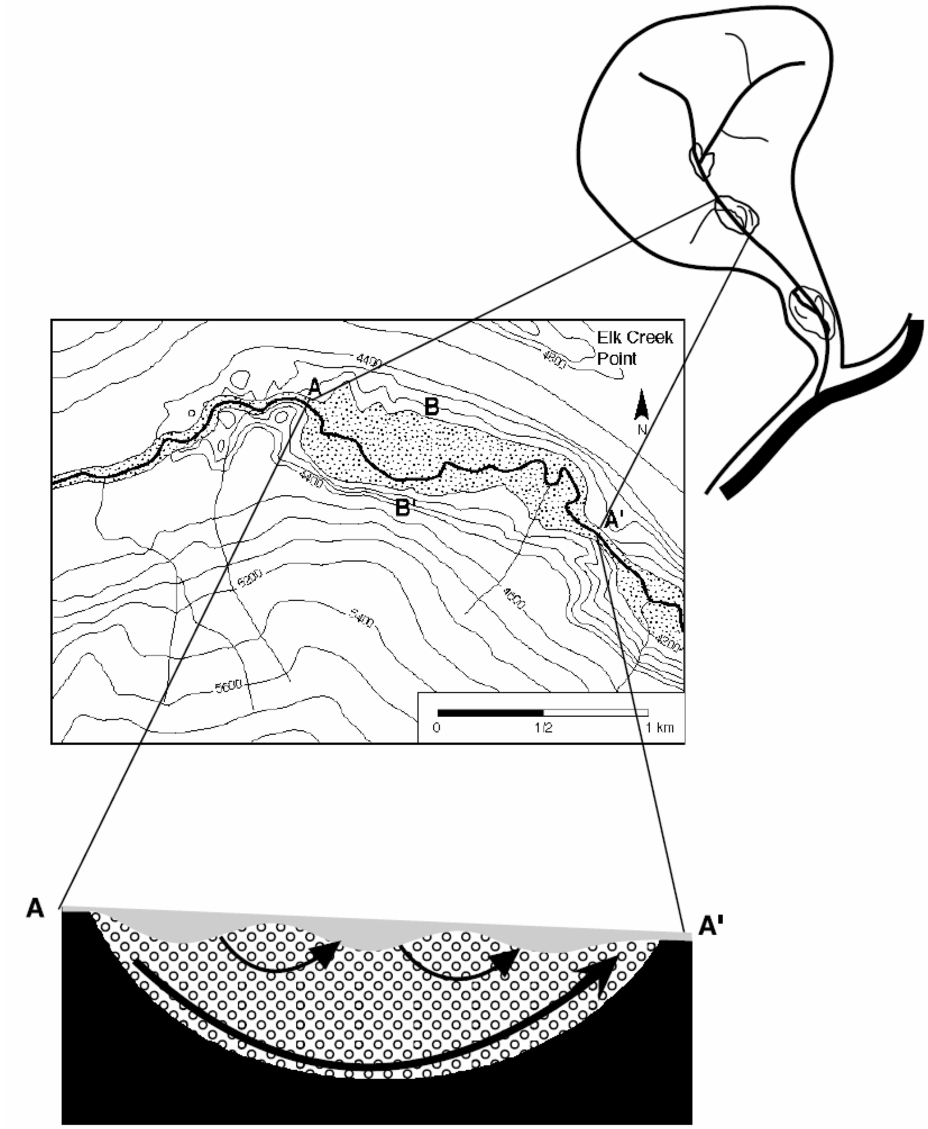
Poole et al. (2006) observed a three layer hyporheic zone in the cobble/gravel-bed Middle Fork Flathead River, Montana. The lower layer (10 m thick) had horizontal hydraulic conductivities of 0.9 cm/s, the middle layer was around 2 m thick and had hydraulic conductivities of 4.3 – 11.6 cm s^{-1}, and the upper layer of 1.6 – 4.3 m thickness had hydraulic conductivities of 1.4 – 2.3 cm s^{-1}.

Baxter and Hauer (2000) estimated vertical hydraulic conductivity (K) for the cobble-bed Swan River basin in Montana ranging from 2.32×10^{-6} cm s^{-1} to a maximum of 3.37×10^{-1} cm s^{-1}s, a difference of more than five orders of magnitude. Subsurface flow rates were grouped into three classes: low (<0.001 cm s^{-1}), medium (0.001–0.01 cm s^{-1}), and high (>0.01 cm s^{-1}).

For the sand-gravel bed Platte River in south-central Nebraska Chen (2005) measured a mean K value of 0.05 cm s^{-1}. A site in eastern Nebraska had lower mean K values of 0.03 and 0.013 cm s^{-1}, because of fine sediment within the substrate. For this river, Chen (2005) reported that horizontal flow rates exceed vertical rates by a factor of 10.

For the gravel and sand bed Willamette River, Oregon, Fernald et al. (2006) measured horizontal hyporheic flow rates of 0.02 - 0.04 cm s^{-1}.

Figure 85: A bedrock-bounded alluvial valley segment (BAVS) in the Elk Creek drainage basin, Montana. The cross-sectional diagram (A – A' illustrates how reach-scale (large arrow) and bedform-scale (small arrows) hyporheic exchange typically occurs within a BAVS. The stippling denotes the alluvial valley fill. From Baxter and Hauer (2000).



In the Hanford Reach of the Columbia River where hyporheic water discharged into the river channel, Geist (2000) measured rates of upwelling into spawning areas averaged 1200 L m^{-2}·day^{-1}as compared with approximately 500 L m^{-2}·day^{-1} in nonspawning areas.

No attempt was made to measure hyporheic flow rates in the Zhuxi-Jiaojiang system, and there is insufficient information available on which to quantify environmental flow recommendations for this flow component. Studies elsewhere suggest that downriver hyporheic flow rates in gravel/cobble bed streams in the order of 0.001 – 0.1 m s^{-1} should be expected. Thus, for example, an unimpeded gravel layer 2 m thick, and 30 m wide would have the capacity to convey 0.06 – 6 m^3s^{-1}. Conceptually, the reach-scale downstream hyporheic flow rate is limited by the hydraulic constraints of the bedrock-constrained sections of the channel (Figure 85). Subsurface water will pool behind these constrictions, emerging at the surface (upwelling) in a zone of the bed upstream of the constrictions. Thus, at the reach-scale, the upstream ends of BAVS will be losing surface water flow and the downstream ends of BAVS will be gaining.

In managing low flows in Zhuxi (under a future scenario with the dam in place) it will be necessary to adaptively manage the hyporheic flow component. To comply with the surface flow requirement, it may be necessary to release more than the recommended threshold discharge in order to first supply the hyporheic flow component.

5.6 Relationships between daily mean and daily instantaneous peak discharge

Environmental flow assessments are almost universally based on mean daily discharge time series'. This is because mean daily discharge is readily available from the agencies responsible for hydrometrics, the length of the data series is manageable for analysis and plotting, and most programs that calculate hydrological statistics require a fixed time-step, either daily or monthly. Discharge is actually measured at sub-daily time intervals, which may be fixed steps (of say 6 minutes) or variable time intervals that depend on the rate of change in stage height (i.e. less frequent measurements are made when stage height is changing slowly).

When a hydraulic method is used to determine the environmental flow event magnitudes, such as flow required to inundate a bench or reach the top of bank (bankfull) these flows represent instantaneous peak discharges (Q_{PEAK}). It may not be necessary to achieve that instantaneous peak discharge for the entire day, in which case the environmental flow should be specified as both a peak (to achieve the event threshold) and a mean daily discharge (Q_{DAILY}) (as this is the common unit of discharge used by river managers, scientists and stakeholders, and it is the base unit used in hydrologic models, such as IQQM). For events that require the threshold to be achieved for a duration of 1 day or longer (such as pulses and baseflows), the Q_{PEAK} and Q_{DAILY} specification are the same. It should be noted that although the difference between mean daily and daily instantaneous peak is well-known to hydrographers and hydrologists, we are not aware of any published or unpublished environmental flow study that has taken it into account in making the recommendations. Rather, it is assumed that either there is not a large difference between Q_{PEAK} and Q_{DAILY} or the hydraulic events have to be achieved for a minimum duration of one day. For the Taizhou pilot study neither of these assumptions were considered valid, so relationships were developed between Q_{PEAK} and Q_{DAILY}.

Design flood discharges were supplied for the Zhuxi Dam site and for a location close to the end of Zhuxi (Table 86). The catchment area at this location is 337 km^2, compared to the catchment area at the junction of Yong'anxi of 372 km^2. For the IQQM modelled daily flow series' for Zhuxi, discharges corresponding to a range of ARIs from 1 – 20 years were calculated using RAP (Table 87). These two sets of data allow a comparison to be made between peak instantaneous discharge and mean daily discharge for flood events for Zhuxi at the dam site, and at the end of Zhuxi (Figure 86). This comparison results in general relationships for converting Q_{PEAK} (the hydraulically defined threshold) to Q_{DAILY} (for use in IQQM modelling):

- Zhuxi at Dam site (Reach 1): $Q_{PEAK} = 0.2922\ Q_{DAILY} + 23.7$
- Zhuxi at end of creek (Reach 2): $Q_{PEAK} = 0.3445\ Q_{DAILY} + 48.8$

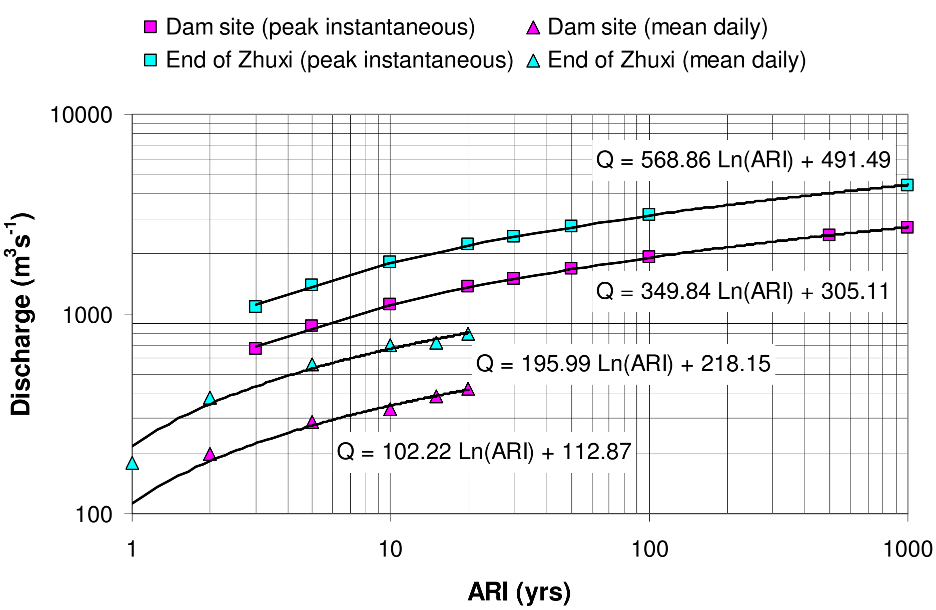
Table 86: Design flood discharges for Zhuxi (annual series).

ARI (Years)	Peak instantaneous discharge (m^3s^{-1})	
	Zhuxi at dam site	Zhuxi near end of creek
1,000	2,707	4,391
500	2,472	
100	1,926	3,124
50	1,684	2,731
30	1,509	2,448
20	1,365	2,214
10	1,115	1,808
5	865	1,402
3	664	1,078

Table 87: Calculated discharges for a range of ARI based on IQQM modelled daily flows for 1980 - 2006 for Zhuxi (partial series for ARI 1-5, annual series for ARI 10-20).

ARI (Years)	Mean daily discharge (m^3s^{-1})	
	Zhuxi at dam site	Zhuxi at end of creek
20	422	792
15	387	720
10	335	695
5	288	559
2	201	383
1	98	181

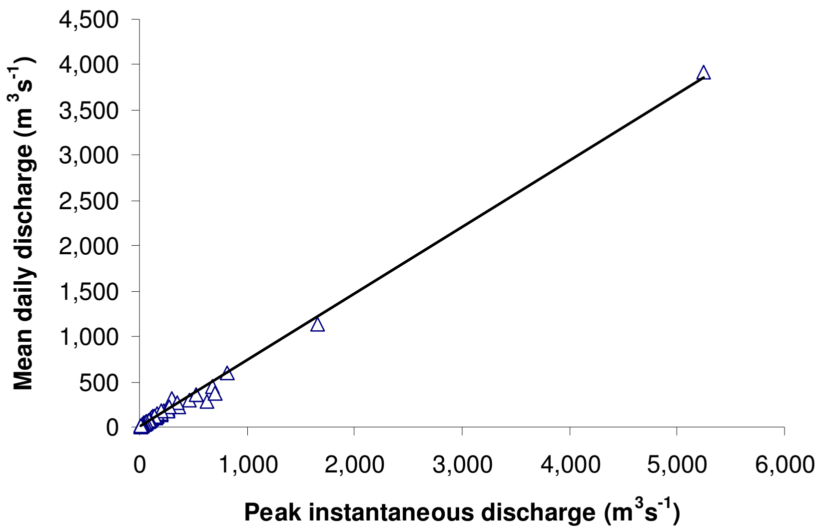
Figure 86: Relationship between mean daily discharge and daily peak instantaneous discharge for Zhuxi.



One year of sub-daily flow observations at Baizhiao gauge on Yong'anxi upstream of Shifengxi junction (Reach 3) were supplied (for 1997). From these data a relationship was established between mean daily discharge and daily instantaneous peak discharge (Figure 87):

- Yong'anxi at Baizhiao (Reach 3): $Q_{PEAK} = 0.7334\ Q_{DAILY} + 3.1$

Figure 87: Relationship between mean daily discharge and daily peak instantaneous discharge for Baizhiao gauge, based on sub-daily recorded flow data from 1997.



There were no data available to determine the relationship between Q_{PEAK} and Q_{DAILY} for Reach 4, and for the tidally influenced Reaches 5 and 6 there was no need to establish this. For Reach 4 the factor was set a little higher than that established for Reach 3 (Figure 87) on the basis that Q_{PEAK} becomes closer to Q_{DAILY} in the downstream direction:

- Lingjiang above Linhai (Reach 4): $Q_{PEAK} = 0.8\ Q_{DAILY}$

5.7 Alternative hydrological analyses

As previously discussed in this report, some environmental flow methodologies are based purely on hydrological analysis, whereby certain hydrological components are statistically described and the environmental flow recommendations are based around preserving those hydrological components considered necessary to maintain ecological health. Most of these methods have some ecological basis, with the flow components being related to certain ecological functions or processes through local empirical studies or literature review. For the Taizhou pilot study there were no such simple flow-ecology relationships available, so this approach was not adopted. However, the Tennant method and IHA method hydrological indices were calculated here mainly as a demonstration of what this achieves, and the data provide a point of comparison for the flow recommendations made for Zhuxi-Jiaojiang based on the adopted holistic hydraulic/hydrologic methodology.

5.7.1 Tennant method

The Tennant method was applied to the modelled discharge time series' for the 6 IQQM nodes (Table 88).

Table 88: Calculated discharges corresponding to the environmental flow – management condition classes defined by Tennant, for the Zhuxi-Jiaojiang system. W = wet season (Oct-Mar), D = dry season (Apr-Sep).

Management condition class	Reach 1		Reach 2				Reach 3		Reach 4 /Reach 5		Reach 6	
	Zhuxi DS Dam		Zhuxi End of Ck		Yong'anxi DS Zhuxi		Yong'anxi US Shifeng		Lingjiang (Wetland)		Jiaojiang (end of system)	
	D	W	D	W	D	W	D	W	D	W	D	W
Flushing or maximum	11	11	28	28	122	122	145	145	240	240	329	329
Optimum range	3.4	5.6	8.4	14	37	61	43	72	72	120	99	164
Outstanding	2.2	3.4	5.6	8.4	24	37	29	43	48	72	66	99
Excellent	1.7	2.8	4.2	7.0	18	31	22	36	36	60	49	82
Good	1.1	2.2	2.8	5.6	12	24	14	29	24	48	33	66
Fair or degrading	0.6	1.7	1.4	4.2	6.1	18	7.2	22	12	36	16	49
Poor or minimum	0.6	0.6	1.4	1.4	6.1	6.1	7.2	7.2	12	12	16	16
Severe degradation	0.0	0.6	0.0	1.4	0.0	6.1	0.0	7.2	0.0	12.0	0.0	16

5.7.2 IHA

The IHA program allows users to adjust the thresholds used to define events. As there was no ecological basis for selecting particular thresholds on the Zhuxi-Jiaojiang system, the IHA was run using the default values. The analysis was run only for four flow time series' – the ones corresponding to the environmental flow reaches. The IHA program calculates statistics according to 5 Parameter Groups (Table 89, Table 90, Table 91) and EFC Low Flows (Table 92) and EFC Parameters (Table 93). The EFC Low flows parameter is described by The Nature Conservancy (2007a) as “Mean or median of low flows” (it is not stated which one is calculated, the mean or the median?, and this is not a selectable option). In the program, low flows are flows between the lowest 10th percentile and the 50th percentile, but there are other conditional filters associated with rates of rise and fall.

Table 89: IHA Parameter Group #1 - Monthly mean discharge (m^3s^{-1}).

	Reach 1 Zhuxi DS Dam	Reach 2 Zhuxi end of creek	Reach 3 Yong'anxi US Shifengxi	Reach 4 Lingjiang (Wetland)
January	1.1	2.7	12.3	29.6
February	1.2	4.1	23.8	37.8
March	3.4	8.9	48.5	88.6
April	2.9	10.4	53.7	90.2
May	2.1	7.4	43.6	76.6
June	4.2	13.2	68.0	100.7
July	1.8	5.6	35.1	64.7
August	2.1	7.0	37.6	71.6
September	2.3	5.8	31.8	61.7
October	0.9	2.9	15.2	32.5
November	0.8	2.3	11.2	24.9
December	0.6	2.0	11.4	19.9

Table 90: IHA Parameter Group #2 - Magnitude and duration of annual extreme water conditions (all discharge indices in m^3s^{-1}) and IHA Parameter Group #3 - Timing of annual extreme water conditions (Julian day).

	Reach 1 Zhuxi DS Dam	Reach 2 Zhuxi end of creek	Reach 3 Yong'anxi US Shifengxi	Reach 4 Lingjiang (Wetland)
Parameter Group #2				
1-day min.	0.3	0.6	3.0	9.0
3-day min.	0.3	0.6	3.1	9.8
7-day min.	0.3	0.6	4.0	10.9
30-day min.	0.5	1.3	6.9	14.5
90-day min.	1.4	3.5	17.7	36.8
1-day max.	137	261	1230	1836
3-day max.	73	155	849	1277
7-day max.	40	98	558	909
30-day max.	19	48	247	395
90-day max.	11	29	152	241
No. of zero days	0	0	0	0
Base flow index	0.058	0.051	0.046	0.078
Parameter Group #3				
Date of min.	352	210	1	2
Date of max.	214	226	219	213

Table 91: IHA Parameter Group #4 - Frequency and duration of high and low pulses and IHA Parameter Group #5 - Rate and frequency of water conditions change. All discharge indices (including rates) in m^3s^{-1}. Duration in days.

	Reach 1 Zhuxi DS Dam	Reach 2 Zhuxi end of creek	Reach 3 Yong'anxi US Shifengxi	Reach 4 Lingjiang (Wetland)
Parameter Group #4				
Low pulse count	8	7	7	7
Low pulse duration	6.5	5	7	6
High pulse count	21	18	16	15
High pulse duration	3	3.5	4	3.5
Low Pulse Threshold	0.8	2.3	12.4	27.2
High Pulse Threshold	4.4	12.4	65.0	110.1
Parameter Group #5				
Rise rate	0.4	1.2	5.9	7.9
Fall rate	-0.3	-0.7	-2.8	-5.7
Number of reversals	128	117	106	124

Chapter 6: Environmental Flow Objectives

6.1 Overarching objectives

Based on the identified environmental assets, the environmental flow recommendations presented in this report are designed to:

i. Maintain fish diversity and abundance

ii. Maintain subsistence and commercial fisheries

iii. Maintain water quality at a level capable of supporting objectives 1 and 2 together with existing uses of the river.

iv. Maintain riparian vegetation in its current form in riparian and low-lying floodplain habitats.

v. Maintain geomorphic processes that are required to support objectives 1 - 4.

Table 92: EFC Low flows – "Mean or median of low flows" (low flows are flows between the lowest 10th percentile and the 50th percentile) (m^3s^{-1}).

	Reach 1 Zhuxi DS Dam	Reach 2 Zhuxi end of creek	Reach 3 Yong'anxi US Shifengxi	Reach 4 Lingjiang (Wetland)
January	0.9	2.7	14.3	29.8
February	1.0	3.2	18.4	31.1
March	1.5	4.9	26.0	46.4
April	1.5	4.9	29.2	52.2
May	1.2	4.1	24.7	47.1
June	1.3	4.0	21.4	45.1
July	1.1	2.7	15.0	38.2
August	1.2	3.4	18.8	42.8
September	1.3	3.3	19.0	41.4
October	0.9	2.5	13.2	28.5
November	0.8	2.0	10.1	26.7
December	0.6	2.5	11.9	23.1

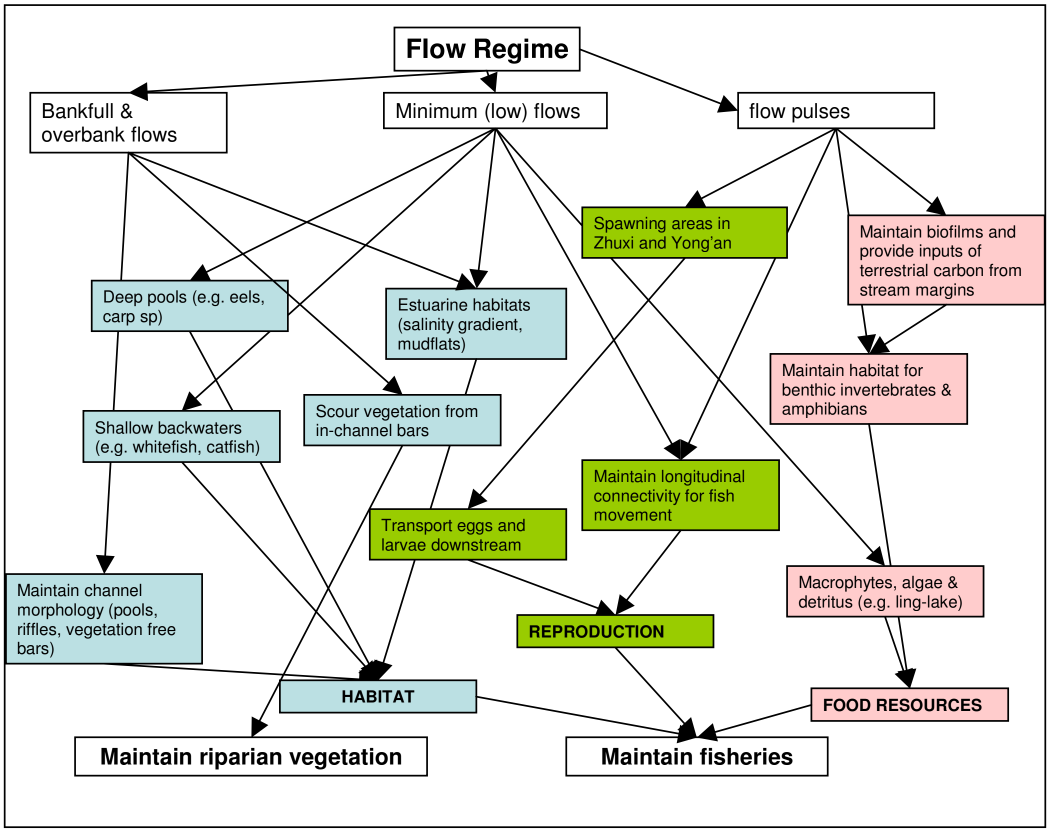
Table 93: EFC Parameters. Frequency is mean number of events per year, timing is Julian Days, duration in days, magnitudes (including rates) in m^3s^{-1}.

	Reach 1 Zhuxi DS Dam	Reach 2 Zhuxi end of creek	Reach 3 Yong'anxi US Shifengxi	Reach 4 Lingjiang (Wetland)
Extreme low peak	0.3	0.6	3.7	10.7
Extreme low duration	3	4.5	6	2
Extreme low timing	7	219	343	350
Extreme low freq.	2 per yr	2 per yr	1 per yr	2 per yr
High flow peak	10	26	129	209
High flow duration	6	5.5	6	6
High flow timing	170	172	178	158
High flow frequency	19 per yr	18 per yr	17 per yr	17 per yr
High flow rise rate	3.9	8.7	43.4	71.7
High flow fall rate	-1.8	-3.8	-19.8	-31.4
Small Flood peak	221	394	1,784	2,997
Small Flood duration	13	15	15	16
Small Flood timing	233	232	213	213
Small Flood freq.	1 in 1 yr	1 in 1 yr	1 in 2 yr	1 in 2 yr
Small Flood rise rate	57	118	723	1172
Small Flood fall rate	-23	-43	-131	-197
Large flood peak	438	793	3,794	6,012
Large flood duration	25	23	16	26
Large flood timing	247	244	243	238
Large flood freq.	1 in 10 yr	1 in 10 yr	1 in 10 yr	1 in 10 yr
Large flood rise rate	146	244	715	1,139
Large flood fall rate	-20	-45	-365	-400

6.2 Linking multiple flow components

Flow related objectives pertaining to geomorphology, vegetation, fish and water quality were determined independently from one another for each reach. Also, associations were made between each objective and the components of the flow regime on which it depends. These associations are broadly represented as a conceptual model of flow/ecology/geomorphology relationships (Figure 88). This model illustrates the role of multiple specific flow components in achieving the overall flow objectives. Note that whilst individual flow components may relate to several objectives, typically there is one objective that acts as the key constraint, and during the environmental flow assessment procedure, this was noted as the controlling objective.

Figure 88: Conceptual diagram showing the links between individual flow related objectives and multiple specific flow components.



6.3 Objectives related to flow components

Environmental flow objectives were formulated for geomorphological (Table 94), vegetation (Table 95), and fish (Table 96) aspects. Each geomorphological objective was linked to critical ecological processes; each ecological objective was included on the basis of its perceived importance to maintaining ecological function, as derived from literature review, survey and informal discussions with locals, and field observations. A hydraulic criterion was assigned for each geomorphological and ecological objective as the means of deriving a flow recommendation to satisfy the objective.

Table 94: Flow components relevant to geomorphological objectives.

ID	Objective	Flow component	Hydraulic criteria	Timing	Reach	Reference
1a	Maintain channel form	Bankfull	Morphologically defined levels	anytime	1, 2, 3, 4	Gippel, 2001; Gippel, 2005
1b	Flush fine sediment from surface of bed	Low flow pulse and High flow pulse	Critical shear stress to mobilise silts	Low flow and High flow	1, 2, 3, 4	Gippel, 2001; Gippel, 2005; Wu and Chou, 2004
1c	Mobilise coarse bed sediments	High flow pulse/Bankfull	Critical shear stress to mobilise >50% of bed material	anytime	1, 2, 3, 4	Gippel, 2001; Gippel, 2005
1d	Maintain channel form and key habitats	High flow pulse/Bankfull	Morphologically defined levels	anytime	1, 2, 3, 4	Gippel, 2001; Gippel, 2005

Table 95: Flow components relevant to vegetation objectives.

ID	Objective	Flow component	Hydraulic criteria	Timing	Reach	Reference
2a	Scour vegetation from gravel bars and transfer organic material to the stream	High flow pulse	Sufficient to scour vegetation	high flow season (Apr - Sep)	1, 2, 3	
2b	Maintain vegetation neighbouring the river channels (riparian vegetation)	Overbank flow	Morphologically defined levels	anytime	1, 2, 3, 4, 5	Naiman and Decamps, 1997
2c	Prevent encroachment from terrestrial species into river channels (e.g. *Salix* sp.)	Bankfull	Critical shear stress	anytime	1, 2, 3	
2d	Maintain floodplain wetland communities (perennial and annual species)	Overbank flow	Morphologically defined levels	high flow season (Apr -Sep)	1, 2, 3, 4, 5	

Table 96: Flow components relevant to fish objectives. D = depth, V = velocity.

ID	Objective	Relevant species	Flow component	Hydraulic criteria	Timing	Reach	Reference
3a	Maintain sufficient water depth in pools for large bodied fish	Pool Guild (e.g. Eels, *Spinibarbus*, Carp species)	Low flow	D > 1.5 m in pools in reaches 1 – 3 D > 3 m in reaches 4 & 5	Oct-Mar	1, 2, 3, 4, 5, 6	Welcomme, 2006
3b	Maintain sufficient depth in riffles and in depositional habitats out of the flow	Pool Guild (e.g. whitefish, catfish) and Riffle species	Low flow	D > 0.2 m	Oct-Mar	1, 2, 3, 4, 5, 6	
3c	Localised movement of resident fish	Whitefish, catfish	Low Flow Pulse	D > 0.2 m over riffles	Oct-Mar	1,2,3	
3d	Maintenance of benthic habitats &hyporheic flushing	Spinibarbus, Misgurnus mizolepis	Low flow Pulse	Sufficient to flush fine sediments from gravel	Oct-Mar	1,2,3	
3e	Flows to provide habitat during the high flow period, to induce spawning of grass, silver and bighead carp & to maintain transport of semi-buoyant eggs within the water column	Grass, silver, bighead carp	High flow	Mean V >0.15 - 0.25 ms^{-1}	Apr-Sep	1,2	Tang et al, 1989
3f	Stimulate spawning migration & maintain longitudinal connectivity (estuary to headwaters)	Anadromous and Potamodromous guilds. (e.g. carp, *Coilia ectenes*, *Macrura reevsii*)	High flow pulse	Inundate barriers. Increase D >0.25 m over riffles	April	1,2,3	Welcomme, 2006; Dudgeon, 1999;
3g	Provide access to floodplain habitats	Species that spawn on floodplains (no local information supplied).	Overbank flow	Sufficient depth to inundate low lying areas of the floodplain such as wetlands	Anytime	2, 3, 4, 5, 6	Welcomme, 1985; Welcomme, 2006
3h	Flow to prevent increases in the upstream intrusion of saline water during low flows	Freshwater estuarine guild (e.g. *Lateolabrax japonicus*)	Low flow & High flow	Non-hydraulic criteria	All year	4, 5, 6	Welcomme, 2006, Guan et al., 2005
3i	Flow to maintain salinity and sediment dynamics at the mouth of the estuary. Physical habitat is mudflats & river-channel	Estuarine Guild (e.g. *Acanthopagrus* schlegelii; *Mugil* spp.; purple spotted mudskipper)	Low Flow	Complex hydro and sediment dynamics. Estuarine hydrodynamic modelling	Summer	5, 6	Welcomme, 2006, Guan et al., 1998; Guan et al., 2005
3j	Flow to maintain salinity & sediment dynamics at the mouth of the estuary. Physical habitat is mudflats & river-channel	Estuarine Guild (e.g. *Acanthopagrus* schlegelii; *Mugil* spp.; purple spotted mudskipper)	High Flow	Complex hydro and sediment dynamics. Estuarine hydrodynamic modelling	Summer	5, 6	Welcomme, 2006, Guan et al., 1998; Guan et al., 2005

Chapter 7: Specifying Flow Components Using Hydraulics and Hydrology

7.1 Principles of hydraulic models

Hydrology of flowing water is concerned with rates of flow (or discharge), expressed in m^3s^{-1}, and the way the flow varies through time. Hydraulics of flowing water is principally concerned with depth (m), velocity (ms^{-1}), and shear stress (Nm^{-2}).

In order that environmental flow recommendations can be implemented by river managers (or dam operators), each component making up the regime has to be specified as a discharge value, with associated frequency, timing and duration. While it may be possible to state with a high degree of confidence that certain ecological processes are associated with certain flow components (e.g. low flows, high flow pulses, bankfull flows etc.), it is rarely possible to make a confident direct link from an ecological process to a specific flow magnitude. Rather, the ecological processes of interest are more readily defined as a depth of water in the channel (e.g. a minimum depth over riffles to sustain macroinvertebrates), an elevation in the channel (e.g. corresponding to the location of a particular flow dependent vegetation community, or the top of the banks), maximum or minimum velocities (e.g. limits of swimming capability of a fish species), or shear stresses (e.g. sufficient to mobilize bed material, or scour vegetation from the bed). Thus, the magnitude of flow components is derived from hydraulic information. Knowledge of the channel morphology and roughness allows the hydraulic characteristics to be described for any given flow (and vice-versa). A hydraulic model provides the numerical link between hydraulics and flow.

Hydraulic models can be 1-D, 2-D or 3-D, in order of complexity to set up and run, and in order of the detail they provide. For most environmental flow applications, 1-D models are considered adequate. It is preferable to model the hydraulics over a reach of at least a few 100 metres long. This allows consideration of conditions as the morphology changes (e.g. pools and riffles), and the models account for the longitudinal interactions through the reach. For example, a riffle usually acts as the hydraulic control over flow for a certain distance upstream, and all areas upstream from this control point will fall under its influence. The most popular 1-D model for application to environmental flow studies is HEC-RAS, but there are other alternatives available.

HEC-RAS has been developed for the U.S. Army Corps of Engineers. It is also available for download (http://www.hec.usace.army.mil/SOFTWARE/hec-ras/) and use by individuals outside of the Corps of Engineers without charge. HEC will not provide user assistance or support for this software to non-Corps users. However, certain organizations provide the program, documentation, and support services for a fee. Downloading, installing, and using the HEC-RAS software indicates the user's acceptance of HEC's Terms and Conditions for use of HEC Software. These Terms and Conditions do not exclude commercial use. The basic computational procedure in HEC-RAS is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation may be used in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e. hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions. Running a HEC-RAS model requires a series of professionally surveyed cross-sections through the reach of interest (i.e. the cross-sections must have a common datum).

The Hydraulic Analysis Module in the (free to download) River Analysis Package (RAP) (http://www.toolkit.net.au/cgi-bin/WebObjects/toolkit) allows the importation of HEC-RAS cross-section data, as well as user input cross-section data, to create a 1-D hydraulic model of a river reach. The FldWav (USA National Weather Service) 1-D hydraulic model is used to calculate a hydraulic parameters in the reach for multiple alternative discharges. The hydraulic parameters are presented as a rating curve against discharge. If a time series of discharge is provided this can be converted to a time series of hydraulic parameters that can be subsequently analysed in the RAP Time Series Analysis Module.

It is not always feasible to undertake channel surveys or to develop a reach-scale hydraulic model, either due lack of resources to hire surveyors, or lack of personnel with qualifications in hydraulics. However, it is feasible for non-expert surveyors to undertake field cross-sections using simple methods, such as rod and level, tape measure, or range finder and inclinometer. In this case, one or more cross-sections are surveyed at the identified hydraulic control points (riffle crests), and the hydraulics of each cross-section is determined separately. Rather than use HEC-RAS or RAP to analyse the hydraulics of single cross-sections, a simpler alternative is the program WinXSPRO.

WinXSPRO is a software package designed to analyze stream channel cross-section data for geometric, hydraulic, and sediment transport parameters. WinXSPRO was specifically developed for use in high-gradient streams (gradient >0.01) and supports four alternative resistance equations for computing boundary roughness and resistance to flow. Cross-section input data may be from standard cross-section surveys using a rod and level or sag-tape procedures.

WinXSPRO was developed by the USDA Forest Service, Stream Systems Technology Center. WinXSPRO is Government-produced software in the public domain and is provided "as-is" without warranty of any kind, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose. The user assumes all responsibility for the accuracy and suitability of this program for a specific application. Limited technical support is available from USDA Forest Service, Washington Office Watershed, Fish, Wildlife, Air, & Rare Plants Staff, Streams Systems Technology Center, Fort Collins, CO. A copy of WinXSPRO can be downloaded free of charge from http://www.stream.fs.fed.us/publications/winxspro.html.

In some cases it may not be possible to undertake cross-section surveys. For example, the river may be too deep to allow easy access, or there may be time and resource constraints. In this case, it may still possible to obtain useful hydraulic information. The most likely source of existing hydraulic information is a discharge gauge. Established flow gauges are periodically “rated”, which involves hydrographers carefully measuring the discharge and noting the height of the water (the “stage height”). Over time a “rating curve” is built-up, which is an empirical relationship between discharge and the stage height at the gauge location. Gauges usually have cross-section data available, so by calculating cross-sectional area, mean velocity and shear stress can be estimated for any selected stage height. The main caution with gauge hydraulic relationships is that gages are not necessarily located in a typical section of the river; rather, hydrographers intentionally try to select a stable cross-section so that the rating curve is stable through time (reducing the work required to update the rating curve over time). Also, it would be coincidental if the gauge was located at a point on the river that was of particular interest to the environmental flows assessment.

Some river gauges do not measure discharge but they do measure stage height. These gauges have never been rated. Data from stage-only gauges can provide valuable information on the variation in river height over time. If a cross-section is available, surveyed to the same datum, a rating curve can be derived through a program such as WinXSPRO.

When undertaking a hydraulic analysis as part of an environmental flow assessment, it is important to seek out any local information that relates the height of features of ecological interest (such as the sill of a wetland) to the flow of the river. For example, local residents may be able to indicate the relative heights that the most recent (or most memorable) floods reached, and an examination of the flow record will indicate the peak discharge for those events. If the heights of features of ecological interest (e.g. wetland or floodplain surface) can be related to these culturally related flood heights (e.g. heights reached on a bridge, over a road, or within a building) then the discharge required to inundate these features can be estimated by examining the flow record.

7.2 Specifying ecologically meaningful hydraulic thresholds

There is no point developing hydraulic models unless the ecological processes of interest can be expressed in hydraulic terms, preferably as a threshold (or range of) depth, velocity, or shear stress. This is the task of the expert panel. For example, the vegetation specialist should be able to note the position of plants of interest on the surveyed cross-sections, and might have empirical knowledge of the threshold shear stress that will dislodge certain types of plant; the macroinvertebrate specialist will be able to specify the depth of water required over riffles in order to maintain the community; the fish specialist will know something about the hydraulic preferences of key species or guilds at different times of the year; and the geomorphologist will have measured particle size and know the shear stress required to mobilize a certain proportion of the bed material. Hydraulic criteria were developed for geomorphological (Table 94), vegetation (Table 95), and fish (Table 96) objectives for the Taizhou pilot study.

7.2.1 Mobilisation of bed material

For sediment mobilisation, shear stress thresholds were computed by applying Shields Critical Shear Stress Method (Gordon et al., 2004, p.193-195). Two generic sediment thresholds were computed, specifically the shear stress (τ) required to: a) flush fine silt from a gravel surface (τ_c = 0.34 D); b) to mobilise the coarse bed material (τ_c = 0.97 D). Bed material particle size (D in mm) was characterised at four sites (representing Reaches 1 and 3) using a Wolman Pebble Count. The equation above for coarse bed material mobilization is appropriate for “normal settled bed” if the particles are spherical and for “highly imbricated bed” for flat shaped particles. The bed materials of Zhuxi Creek were deemed to be a mix of spherical and flat shaped particles and moderately imbricated. The shear stress for bed mobilization was calculated for D_{50} (median particle size) and D_{16} (16% of the distribution of sizes is finer than this size). The fine sediment flushing shear stress was calculated for D_{50}.

7.2.2 Vegetation disturbance

For local vegetation, data on thresholds for disturbance were not available. As an alternative, the thresholds for removal of grasses and rupture ('lodging') of macrophytes were computed. The minimum shear stress required to impact the least hardy of grasses (i.e. poorly established bunch grass) is 80 N/m^2 (Reid, 1989; Hudson, 1971). The discharge required to rupture macrophytes was computed by application of Groeneveld and French's (1995) relationship. The diameter of the macrophyte stems was set, as recommended by Groenveld and French (1995), to 11.9 mm. Two thresholds were then evaluated to give a 95% and 99.9% chance of stem rupture respectively. The thresholds are reported as a discharge (Q) required for the product of flow depth and velocity to exceed either 0.152 ($Q_m^{95\%}$ - referred to here as Q95) or 1.52 ($Q_m^{99.9\%}$ - referred to here as Q99.9). Depth in this context was assumed to be hydraulic depth (ratio of cross-sectional area to top width), rather than maximum depth.

Shrubs and small trees are present on the margins of the channels, and it is ecologically desirable to occasionally check their growth to prevent them colonizing the channel. There are no published data available on which to base an index for removing shrubs and small trees, so here we assumed that the shear stress to remove grass and macrophytes would disturb shrubs, as shrubs are less flexible and present a greater drag on the flow (due to larger projected area) - countering this is the possibility of greater rooting strength. It is emphasised that the removal of vegetation can only be predicted as a probability, and that for any given event only a proportion of vegetation will be disturbed. Vegetation may remain undisturbed due to variations in flow velocities within a stream, the stability provided by the substrate in which plants grow or the path taken by debris entrained by the flow. For this reason, this criterion is expressed in terms of 'checking the growth of' or 'disturbing' shrubby vegetation. It is not intended to represent the removal of all shrubby vegetation.

7.2.3 Depths and velocities for biota

A number of depth and velocity thresholds were defined for fish (Table 96). These were drawn from the literature as being suitable for the guilds present in the Zhuxi-Jiaojiang system.

7.2.4 Channel maintenance

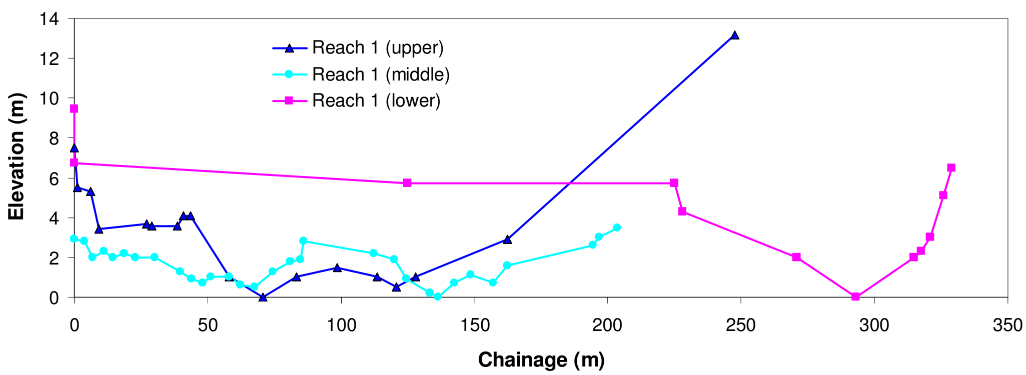
Channel maintenance was assumed to be associated with bankfull flows. Morphological bankfull level was determined in the field and noted on the cross-section surveys.

7.3 Hydraulic models

7.3.1 Reach 1 and Reach 2

Hydraulic models were developed for Reach 1 by undertaking 2 cross-section surveys in the field using a range finder and inclinometer, and analyzing the data in WinXSPRO. A third cross-section located at the downstream end of Reach 1 was used to generate a hydraulic model for Reach 2 (Figure 89). The model was run assuming the resistance equation of Thorne and Zevenbergen, and using the mean reach gradient derived from the SRTM DEM. One cross-section was located near the proposed dam site, and the other was mid-reach. Results from the mid-reach cross-section were regarded superior to those from the upper cross-section, because the mid-reach cross-section was located on a better-defined riffle crest. The hydraulic models are regarded as relatively low accuracy for low discharges and depths. This is because of the relatively low resolution of the survey, and the high sensitivity of the predicted flows to the roughness factor. Thus, the results for low flows and low flow pluses (driven by fish depth and velocity criteria) should be interpreted with a degree of caution. Because of this problem the low flows and high flows (the baseflow components) were also estimated using a hydrological index - equivalent to the flow exceeded 75% of the time for the defined season. This reflects the low end of the normal baseflow range.

Figure 89: Three surveyed cross-sections on Zhuxi. Arbitrary datum in each case. Reach 1 (lower) is near the upper boundary of Reach 2.



The hydraulic models generated rating curves of mean velocity, mean shear stress and discharge against depth (Figure 90). Bankfull level was defined using morphological criteria – as defined in the field. These rating curves were used to convert each of the defined geomorphological, fish and vegetation hydraulic indices into discharge values. The discharges corresponding to the geomorphic and vegetation indices are provide in Table 97. The fish indices were more straightforward, being re based on simple depth and velocity criteria. The magnitudes for the environmental flow components were selected from these hydraulically modelled discharge values.

The hydraulic models predict increasing bankfull discharge downstream, which is the expected pattern. Mobilisation of a high percentage of the bed material and removing stout shrubs and small trees requires overbank flows. A percentage of the bed material is mobilized at sub-bankfull flows, so pulses of any magnitude will achieve some bed mobilization. Growth of vegetation on bars is likely to be frequently checked, as small pulses are predicted to achieve this. Macrophytes will be kept in check by sub-bankfull flows.

7.3.2 Reach 3

This reach was not physically surveyed (due to excessive water depth). However, a gauge is located at the downstream end of this reach (Baizhiao). A cross-section and rating curve were obtained for this gauge. The cross-section showed well-defined benches, and it was assumed that the top right bank corresponded to bankfull (Figure 91). At cease to flow there was depth of 1.74 m of water at the cross-section. The reason for this is unknown, but most likely it relates to a downstream control.

Figure 90: Hydraulic relationships derived for three cross-sections in Zhuxi, a) Reach 1 upper-reach cross-section , b) Reach 1 mid-reach cross-section and c) Reach1/Reach 2 boundary cross-section. BF is depth corresponding to morphologically defined bankfull.

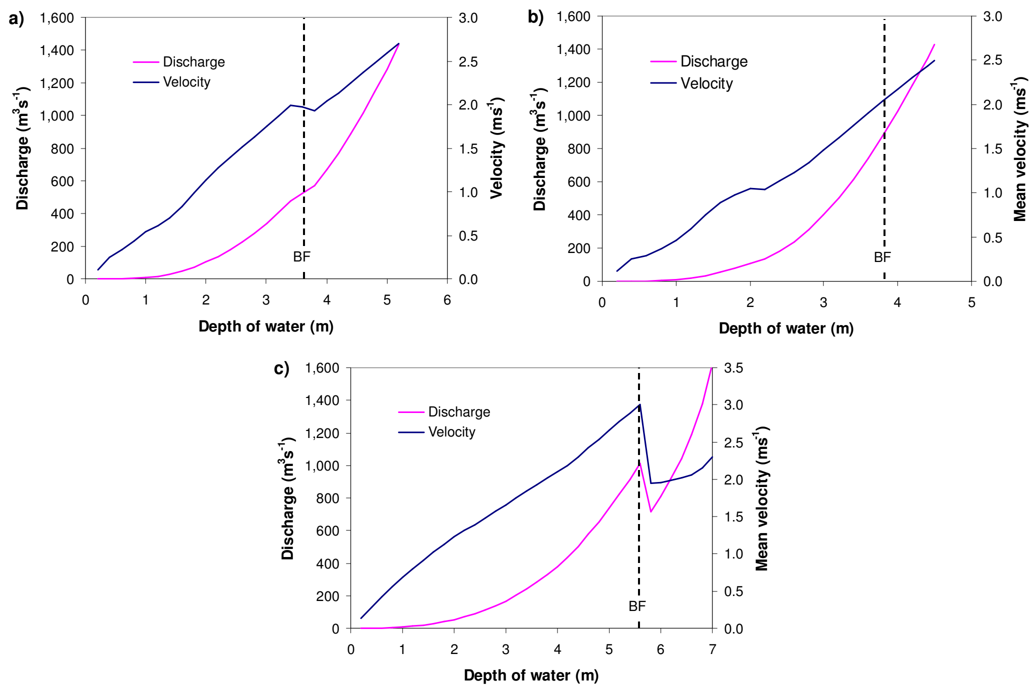


Table 97: Flow threshold magnitudes calculated from hydraulic models to achieve geomorphological and vegetation objectives.

Geomorphological/vegetation indices	ID	Flow threshold magnitudes (m^3s^{-1}) Reach 1 (upper)	Reach 1 (mid)	Reach 2 (upper)
Flushing of fines from the surface	1b	85	208	45
Mobilisation of 16% of the bed material	1c	69	310	83
Mobilisation of 50% of the bed material	1c	1,013	>1,430	654
Morphological bankfull	1a, 1d, 2b, 2c, 2d	524	878	1,011
Q95 - 95% chance of macrophyte stem rupture (scour vegetation from bars)	2a	4.9	8.0	2.3
Q99.9 - 99.9% chance of macrophyte stem rupture (shrub disruption)	2a, 2c	149	288	80
Scour grass (minimum) (shrub/tree disruption)	2c	1,900	>1,500	>3,000

7.3.3 Reach 4

This reach was not physically surveyed (due to excessive water depth). However, an important wetland was observed on the left bank of Lingjiang just downstream of Shifengxi. Local knowledge suggested that the wetland was inundated at a sill level of 7.5 m (relative to sea level).

A tide gauge is located just downstream of the wetland (Linhai chaowei). It is of interest that the median tidal range at this gauge from 1996 to 2006 was 5.15 m (Figure 92), which is greater than the mean tidal range of 4 m reported by Guan et al. (2005) for the tide gauge at Haimen near the mouth of the estuary. Tidal amplification is to be expected in this estuary due to the narrowing of the channel cross-section in the upstream direction, so the entire Lingjiang reach up experiences a strong daily variation in water level.

Figure 91: Cross-section at Baizhiao gauge, showing discharge corresponding to morphologically defined levels. Note that there is a 1.74 m depth of water when the river ceases to flow. Datum of elevation is unknown.

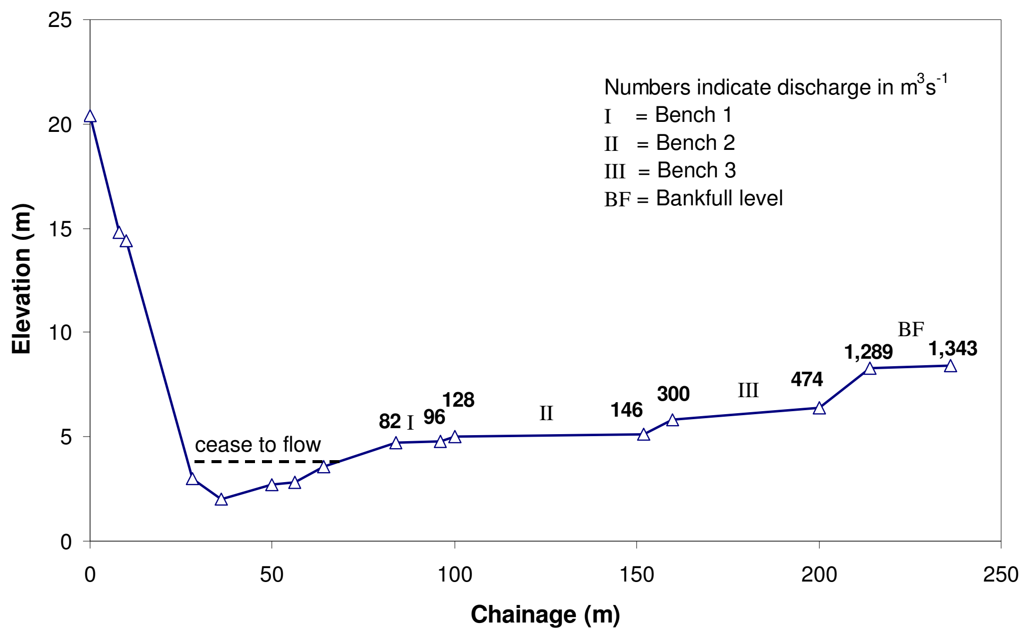
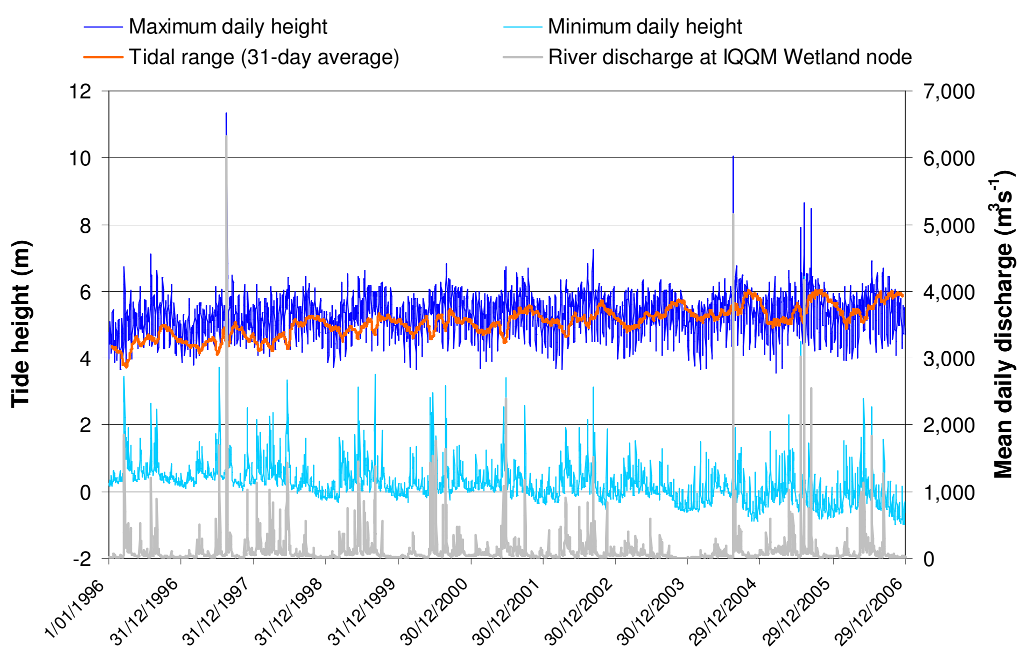


Figure 92: Observed daily tide height extremes and tidal range at Linhai tide gauge from January 1996 to December 2006 and modelled river discharge.



There has been a trend of lowering daily minimum tide levels and increasing maximum tide levels at Linhai chaowei, giving an increasing trend in daily tidal range (Figure 92). The daily minimum tide level in 2006 was more than 1 m lower than it was in 1996. Overall, the tidal range gradually increased over this period by around 1.8 m. This could possibly be related to channel dredging, as tidal propagation in estuaries is very sensitive to water depths over the first several kilometres upstream from the estuary mouth. The trend is not explained by river hydrology as there was no trend of lowering flows over this period. The apparent trend of lower minimum tide levels at Linhai has implications for the biota in Reach 4 and Reach 5. The slack of the low tide is now lower than it once was, exposing a greater area of the channel banks and bed, and lowering depths over the entire bed. This has contracted the area of available habitat. The trend of increasing maximum tide heights means that the upper approx. 0.5 m of the bank that was formerly mostly dry is now mostly wet, which would have altered the vegetation.

A simple hydraulic model was generated by relating the maximum tide heights to river discharge (as predicted for the current model run at the IQQM Wetland node). This relationship demonstrated that peak daily water level in the river at the tide gauge was controlled by the tide for 99.6% of days (Figure 92). However, daily peak river height was significantly related to discharge for discharge greater than approximately 1,500 m^3s^{-1} (Figure 93). The scatter in the relationship is due to the variable effects of tides and the fact that mean daily discharge was used rather than peak discharge (and the ratio of daily peak to daily mean discharge varies between events). This relationship was used to predict the mean daily discharge corresponding the wetland sill level 7.5 ±0.5 m (which allows for uncertainty in the sill level). It can be assumed that on the days when the sill level was exceeded, that the peak daily flow was higher than the mean daily flow. A ratio of peak to mean daily discharge of 1.25 was assumed (based on the observed relationships between peak and mean daily discharge further upstream) to give thresholds for wetland inundation. If it is assumed that 7.5 m is the wetland sill level, then a river stage of 8 m (instantaneous discharge of 3,980 m^3s^{-1}) will inundate it to a depth of 0.5 m (Table 98).

Figure 93: Relationship between daily maximum tide height at Linhai tide gauge and modelled river discharge.

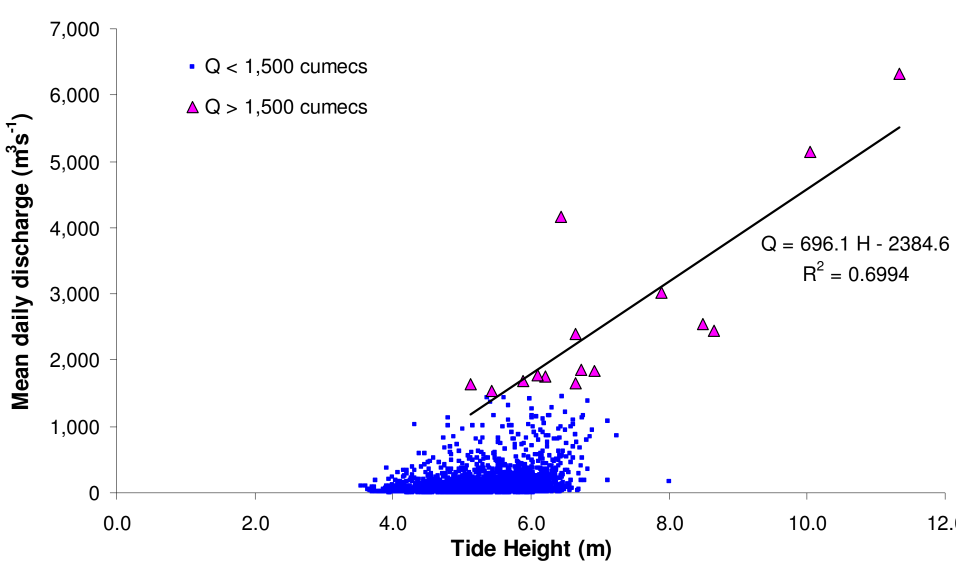


Table 98: Thresholds of inundation for wetland in Reach 4. An elevation of 7.5 m is the sill level, while a river stage of 8 m will inundate it to a depth of 0.5 m.

Wetland inundation sill (m)	Peak daily discharge (m^3s^{-1})	Mean daily discharge (m^3s^{-1})
7.0	3,110	2,488
7.5	3,545	2,836
8.0	3,980	3,184

Chapter 8: Flow Recommendations

This section presents the flow recommendations for each reach. One or more photographs of each reach are provided, together with a table of flow rules for input into the IQQM model. A description of how each flow component relates to the objectives follows. Note that because of the limited information available for each reach there is a high degree of similarity in these descriptions, especially for reaches 1, 2 and 3, which were broadly similar in terms of their physical, and presumably their biological, characteristics.

In order to fully specify the event components, it is necessary to describe them in terms of magnitude, frequency, duration, timing, and rates of change. Magnitude was derived from hydraulics, frequency and duration were derived from the natural frequency and duration, timing was specified as within a pre-determined season, and rate of rise and fall had to be determined from the natural flow series'. Once the magnitudes of events were established, it was possible to determine the maximum allowable and target rates of rise and fall.

8.1 Event rates of rise and fall

Rates of rise and fall were calculated for the flow Pulses, Bankfull and Overbank events for each relevant reach (Reaches 1 – 4). First, the components were separated from the record. This was done, for each component, by selecting all flows equal to the magnitude of the flow component ±20% (the results were relatively insensitive to the width of this band). Then, for each flow component the rises and falls associated with all the events identified in the record were separated, and descriptive statistics calculated for each.

The maximum allowable rate of rise and fall was described by the 5th percentile rate, rather than the maximum observed rate (which, representing only a single observation in the record, is not statistically useful). The median values were calculated as an index of the normal target rates of rise and fall.

For every flow component (e.g. Bankfull) the flow could allowably rise from the magnitude of the flow component below it (e.g. High Flow Pulse) to the magnitude of the flow component in just one day. However, the target rate of rise was 2 days for most of the Pulses. The target rise for Bankfull and Overbank remained at 1 day except in the case of Bankfull for Reach 3. In general, rates of fall were lower than rates of rise, but they were still relatively fast. Maximum allowable rates of fall for Pulses were 1 – 2 days, and 1 day for Bankfull and Overbank. Target rates of fall for Pulses were 2 – 3 days, and 1 – 2 days for Bankfull and Overbank. This analysis highlights the very flashy nature of the pulses and flood events in this stream system.

Table 99: Statistics describing rates of rise and fall associated with the event flow components (calculated from the current flow series'). The rise and fall durations were calculated assuming a rise from the magnitude of the flow component below it. Durations rounded to nearest day.

Component and rise/fall statistic	Reach 1	Reach 2	Reach 3	Reach 4
Low Flow Pulse				
5^{th}%-ile rise (m^3s^{-1})	20	52	78	-
Median rise (m^3s^{-1})	13	29	38	-
Max. rise duration (days)	1	1	1	-
Median rise duration (days)	2	2	2	-
5^{th}%-ile fall (m^3s^{-1})	-14	-37	-45	
Median fall (m^3s^{-1})	-10	-23	-25	-
Max. fall duration (days)	1	1	2	
Median fall duration (days)	2	2	3	-
High Flow Pulse				
5^{th}%-ile rise (m^3s^{-1})	20	52	120	-
Median rise (m^3s^{-1})	13	29	61	-
Max. rise duration (days)	1	1	1	-
Median rise duration (days)	1	2	2	-
5^{th}%-ile fall (m^3s^{-1})	-14	-37	-80	
Median fall (m^3s^{-1})	-10	-23	-47	-
Max. fall duration (days)	1	1	2	
Median fall duration (days)	2	2	3	-
Bankfull				
5^{th}%-ile rise (m^3s^{-1})	190	437	809	5,171
Median rise (m^3s^{-1})	150	294	453	3,674
Max. rise duration (days)	1	1	1	1
Median rise duration (days)	1	1	2	1
5^{th}%-ile fall (m^3s^{-1})	-165	-382	-801	-4,481
Median fall (m^3s^{-1})	-134	-285	-499	-2,963
Max. fall duration (days)	1	1	1	1
Median fall duration (days)	1	1	2	1
Overbank				
5^{th}%-ile rise (m^3s^{-1})	200	440	-	-
Median rise (m^3s^{-1})	158	323	-	-
Max. rise duration (days)	1	1	-	-
Median rise duration (days)	1	1	-	-
5^{th}%-ile fall (m^3s^{-1})	-182	-387	-	-
Median fall (m^3s^{-1})	-141	-340	-	-
Max. fall duration (days)	1	1	-	-
Median fall duration (days)	1	1	-	-

8.2 Reach 1: Zhuxi between the dam site and the first major downstream tributary

Site at the upper section of Reach 1 looking downstream (L) and upstream (R).

Table 100: Summary of flow requirements for Reach 1.

Flow component	Timing	Months	Q_{PEAK} m^3s^{-1}	Q_{DAILY} m^3s^{-1}	Frequency (per year)	Duration	Rise/fall target(max) m^3s^{-1}‡	Indices
Low flow	Low flow season	Oct-Mar	0.5	0.5	continuous or less than if natural			3a, 3b: 75th%-ile
High flow	High flow season	April-Sep	1.3	1.3	continuous or less than if natural			3e; 75th%-ile
Low flow pulse	Low flow season	Oct-Dec; Jan-Mar	20	20	2	1 day in Oct-Dec and 1 day in Jan-Mar	+13(+20)/ -10(-14)	1b 2a 3c, 3d
High flow pulse	Spawning period	April	20	20	1	2 consecutive days	+13(+20)/ -10(-14)	1b 2a 3d, 3f
High flow pulse	High flow season	May-Sep	20	20	4	2 consecutive days	+13(+20)/ -10(-14)	3f
Bankfull†	high flow season	anytime	524	177	0.52	1 d peak; Achieve Q_{PEAK} and Q_{DAILY} on day of peak	+150(+190) / -134(-165)	1a, 1c, 1d 2c
Overbank	High flow season	anytime	571	191	0.52	1 d peak; Achieve Q_{PEAK} and Q_{DAILY} on day of peak	+158(+200) / -141(-182)	2b, 2d

† If Overbank delivered then Bankfull component can be omitted.

‡ Rate is maximum change in discharge that is allowed from one day to the next. Target is recommended rate change, but maximum can be used (at higher environmental risk). If allowable rate change exceeds the required event magnitude then discharge can be raised to the event magnitude over one day.

8.2.1 Cease-to-flow

Not recommended and unlikely to occur naturally. Acceptable in the future if natural occurrence, although prolonged events may have adverse effects on fish, invertebrates and water quality in Zhuxi.

8.2.2 Low Flow

A dry season (Oct-Mar) base-flow of 0.5 m^3s^{-1} is recommended to maintain adequate minimum water depths in riffle habitats and sufficient wetted area and depths in pools and shallow runs (3a and 3b). Water depth in pools should be adequately maintained by the presence of riffles acting as a downstream control on depths. Lower flows are acceptable whenever they would occur naturally (i.e. when inflows to the reservoir fall below 0.5 m^3s^{-1}). The threshold of 0.5 m^3s^{-1} was derived from the hydraulic model to achieve 0.2 m depth over riffles. However, the model is not reliable at these low depths, so the alternative hydrological index was also used. Over the Oct-Mar season the 75th percentile flow was 0.55 m^3s^{-1}. Given that these two estimates were so close, the hydraulically determined value was adopted.

8.2.3 Low Flow Pulse

Periodic flow pulses of 20 m^3s^{-1} have been recommended to flush fine sediments and algae from interstitial spaces and the surfaces of cobbles (3d) and to maintain water quality by 'turning over' pools and re-oxygenating the hyporheic zone. The flushing of fine sediments (1b) (only partially achieved) and the scouring of vegetation from bars (2a) are the controlling objectives for this flow. These flow pulses also provide opportunities for fish to move between pools (3c) that might otherwise be isolated by shallow water over riffles during low flows and mobilise terrestrial organic material thereby providing a potentially important source of carbon for aquatic food webs (2a). Two such events have been recommended, each lasting a minimum of 1 day.

8.2.4 High Flow

A wet season (Apr-Sep) baseflow of 1.3 $m^3s^{-1}y$ is recommended to maintain sufficient water depths for fish movement into and out of spawning areas (3e), and to ensure that average flow velocities in the channel exceed 0.25 ms^{-1} (3e), which is necessary to maintain the neutrally buoyant and drifting eggs or grass carp, silver carp and black carp in the water column (Tang, 1989; Zhong, 1996). The high baseflow will also ensure sufficient backwater habitats exist for juvenile and young of the year fish (3a and 3b). The threshold of 1.3 m^3s^{-1} was derived from the hydraulic model to achieve velocity >0.15 – 0.25 ms^{-1} over riffles. However, the model is not reliable at these low velocities, so the alternative hydrological index was also used. Over the Apr-Sep season the 75th percentile flow was 1.2 m^3s^{-1}. Given that these two estimates were so close, the hydraulically determined value was adopted.

8.2.5 High Flow Pulse

Periodic flow pulses of 20 m^3s^{-1} have been recommended to flush fine sediments and algae from interstitial spaces and the surfaces of cobbles respectively (1b, 3d) and to maintain water quality by 'turning over' pools and re-oxygenating the hyporheic zone (3d). The mobilisation of fine sediments and the scouring of vegetation from bars are the controlling objectives for this flow. An event has been specifically recommended during April to coincide with the onset of spawning by several carp species – both to potentially stimulate spawning and to provide opportunities for upstream migration (3f). An additional 4 events are necessary in the period May-September to scour detritus and algae from the streambed (1b, 3d) and vegetation from bars (2a). Releases can coincide with natural increases in discharge downstream to reduce the volume of water released from the dam. Each high flow pulse should be of 2 days minimum duration.

8.2.6 Bankfull Flow

Zhuxi is a typical gravel bed river in which many of the natural channel features (pools, riffles, bars) are maintained by bankfull flows mobilising bed material (1a, 1c, 1d) and scouring encroaching terrestrial vegetation (2a, 2c). These geomorphic features create unique habitats that must be maintained to meet the fish and vegetation objectives. The peak discharge required to reach the top of the bank at the surveyed cross-section was estimated to be 524 m^3s^{-1}, but this need only be reached instantaneously. The associated mean daily flow for input to the IQQM model is 177 m^3s^{-1}. These flows should on average occur once every 2 years.

8.2.7 Overbank Flow

Overbank flows have been recommended to maintain the natural disturbance regime in riparian areas, where periodic floods can play a key role in structuring the vegetation (2b), including wetland communities (2d). Flows necessary to inundate riparian areas in close proximity to the channel were estimated at 571 m^3s^{-1} (instantaneous), or 191 m^3s^{-1} (for daily flow for IQQM input). Overbank flows are less likely to be important for fish in reach 1 due to the absence of extensive floodplain areas. In reach 1 overbank flows should on average occur once every 2 years.

8.3 Reach 2: Zhuxi between the first major tributary below the dam site and the downstream confluence with Yong'anxi

Site in the mid-section of Reach 2 looking upstream before (L) and after (R) flooding

Hyporheic flow emerging from the streambank (L); riparian vegetation (R) in Reach 2

8.3.1 Cease-to-flow

Not recommended and unlikely to occur naturally. Acceptable in the future if natural occurrence, although prolonged events may have adverse effects on fish, invertebrates and water quality in Zhuxi.

Table 101: Summary of flow requirements for Reach 2.

Flow component	Timing	Months	Q_{PEAK} m^3s^{-1}	Q_{DAILY} m^3s^{-1}	Frequency (per year)	Duration	Rise/fall max.(target) m^3s^{-1}‡	Indices
Low flow	Low flow season	Oct-Jan	1.3	1.3	continuous or less than if natural			3a, 3b 75th%-ile
Low flow	Low flow season	Feb-Mar	3.4	3.4	continuous or less than if natural			3a, 3b 75th%-ile
High flow	High flow season	April-Sep	4.0	4.0	continuous or less than if natural			3e 75th%-ile
Low flow pulse	Low flow season	Oct-Dec; Jan-Mar	53	53	2	2 consecutive days in Oct-Dec and 2 days in Jan-Mar	+29(+52)/ -23(-37)	1b 3c, 3d
High flow pulse	Spawning period	April	53	53	1	2 consecutive days	+29(+52)/ -23(-37)/	2a 3f
High flow pulse	High flow season	May-Sep	53	53	4	2 consecutive days	+29(+52)/ -23(-37)/	3f
Bankfull†	anytime	anytime	1,011	397	0.58	1 d peak; Achieve Q_{PEAK} and Q_{DAILY} on day of peak	+294(+437)/ -285(-382)	1a, 1b, 1c 3c
Overbank	High flow season	April-Sep	1,102	428	0.58	1 d peak; Achieve Q_{PEAK} and Q_{DAILY} on day of peak	+323(+440)/ -340(-387)	2b, 2d 3g

† If Overbank delivered then Bankfull component can be omitted.

‡ Rate is maximum change in discharge that is allowed from one day to the next. Target is recommended rate change, but maximum can be used (at higher environmental risk). If allowable rate change exceeds the required event magnitude then discharge can be raised to the event magnitude over one day.

8.3.2 Low Flow

Due to marked seasonal variation in natural low flows over the dry season, a separate low flow has been specified for Oct-Jan (1.3 m^3s^{-1}) and Feb-Mar (3.4 m^3s^{-1}). These thresholds are based on the 75th flow percentile values for those periods, as the cross-section for this reach was not conducive to good model performance at low depths. These flows should both be sufficient to maintain adequate minimum water depths in riffle habitats (3b) and sufficient wetted area and depths in pools and shallow runs (3a). Water depth in pools should be adequately maintained by the presence of riffles acting as a downstream control on depths. The higher flow for Feb-Mar ensures that the recommended regime remains within the historical range. Lower flows are acceptable whenever they would occur naturally.

8.3.3 Low flow Pulse

Periodic flow pulses of 53 m^3s^{-1} are recommended to flush fine sediments and algae from interstitial spaces and the surfaces of cobbles (1b, 3d) and to maintain water quality by 'turning over' pools and re-oxygenating the hyporheic zone. The mobilisation of sediment (1b) and the scouring of vegetation from bars (2a) are the controlling objectives for this flow. These flow pulses also provide opportunities for fish to move between pools (3c) that might otherwise be isolated by shallow water over riffles during low flows and mobilise terrestrial organic material thereby providing a potentially important source of carbon for aquatic food webs (2a). Two such events (1 Oct-Dec and 1 Jan-Mar), each lasting 2 consecutive days, are recommended to reflect the natural frequency of these events.

8.3.4 High Flow

A wet season (Apr-Sep) baseflow of 4 m^3s^{-1} is recommended to maintain sufficient water depths for fish movement into and out of spawning areas (3e), and to ensure that average flow velocities in the channel exceed 0.25 ms^{-1} (3e), which is necessary to maintain the neutrally buoyant and drifting eggs or grass carp, silver carp and black carp in the water column (Tang, 1989; Zhong, 1996). The high baseflow will also ensure sufficient backwater habitats exist for juvenile and young of the year fish (3a and 3b). The estimate of 4 m^3s^{-1} should be regarded as uncertain because the performance of the hydraulic model is poor at low depths and discharges. The 75th percentile flow for Apr-Sep was 3.6 m^3s^{-1} and for the shorter Apr-Jul period it was 4.0 m^3s^{-1}. Given the proximity of these estimates for the High Flow component the higher, more conservative, value of 4.0 m^3s^{-1} was adopted.

8.3.5 High Flow Pulse

Periodic flow pulses of 53 m^3s^{-1} have been recommended to flush fine sediments and algae from interstitial spaces and the surfaces of cobbles respectively (1b, 3d) and to maintain water quality by ‘turning over’ pools and re-oxygenating the hyporheic zone (3d). The mobilisation of sediments and the scouring of vegetation from bars are the controlling objectives for this flow. An event has been specifically recommended during April to coincide with the onset of spawning by several carp species – both to potentially stimulate spawning and to provide opportunities for upstream migration (3f). An additional 4 events are necessary in the period May-October to scour detritus and algae from the streambed (3d) and vegetation from bars (2a). Releases can coincide with natural increases in discharge downstream to reduce the volume of water released from the dam. Each high flow pulse should be of 2 days minimum duration.

8.3.6 Bankfull Flow

Zhuxi is a typical gravel bed river in which many of the natural channel features (pools, riffles, bars) are maintained by bankfull flows mobilising bed material (1a, 1c, 1d) and scouring encroaching terrestrial vegetation (2a, 2c). These geomorphic features create unique habitats that must be maintained to meet the fish and vegetation objectives. The peak discharge required to reach the top of the bank at the surveyed cross-section is estimated to be 1,011 m^3s^{-1}, but this need only be reached instantaneously. The associated mean daily flow for inclusion in the IQQM model is 397 m^3s^{-}. These flows should on average occur approximately once every 2 years.

8.3.7 Overbank flows

Overbank flows have been recommended to maintain the natural disturbance regime in riparian areas, where periodic floods can play a key role in structuring the vegetation (2b), including wetland communities (2d). Flows necessary to inundate riparian areas in close proximity to the channel were estimated at 1,102 m^3s^{-1} (instantaneous), or 428 m^3s^{-1} (daily flow for IQQM input). Overbank flows may also play a role in allowing fish to access floodplain habitats in the lower reaches of Zhuxi where a more extensive floodplain occurs (3g). In reach 2 overbank flows should on average occur just over once every 2 years.

8.4 Reach 3: Yong'anxi between the Zhuxi confluence and Shifengxi confluence

Site on Yong'anxi at junction of Zhuxi, looking upstream during high flow post Typhoon event (L); fish buried in stones on bars during the previous recent flood (R)

Table 102: Summary of flow requirements for Reach 3.

Flow component	Timing	Months	Q_{PEAK} m^3s^{-1}	Q_{DAILY} m^3s^{-1}	Frequency (per year)	Duration	Rise/fall max.(target) m^3s^{-1}‡	Indices
Low flow	Low flow season	Oct-Jan	6.8	6.8	continuous or less than if natural			3a, 3b 75th%-ile
Low flow	Low flow season	Feb-Mar	17.3	17.3	continuous or less than if natural			3a, 3b 75th%-ile
High flow	High flow season	April-Sep	22.2	22.2	continuous or less than if natural			3e 75th%-ile
Low flow pulse	Low flow season	Oct-Mar	96	96	4	4 consecutive days	+38(+78)/ -25(-45)	1b 3c, 3d
High flow pulse	High flow season	April-Sep	146	146	6	7 consecutive days	+61(+120)/ -47(-80)	2a 3f, 3g
Bankfull	anytime	anytime	1,289	948	1.3	1 d peak; achieve Q_{PEAK} and Q_{DAILY} on day of peak	+453(+809)/ -499(-801)	1a, 1b, 1c 2c
Overbank					None specified			

‡ Rate is maximum change in discharge that is allowed from one day to the next. Target is recommended rate change, but maximum can be used (at higher environmental risk). If allowable rate change exceeds the required event magnitude then discharge can be raised to the event magnitude over one day.

8.4.1 Cease-to-flow

Not recommended and unlikely to occur naturally. Acceptable in the future if natural occurrence, although prolonged events may have adverse effects on fish, invertebrates and water quality in Yong'anxi.

8.4.2 Low Flow

Due to marked seasonal variation in natural low flows over the dry season, a separate low flow has been specified for Oct-Jan (6.8 m^3s^{-1}) and Feb-Mar (17.3 m^3s^{-1}). Empirical surveys of the channel cross-section were not conducted in this reach, so a project-derived hydraulic model was not available for this reach.

However, a stream flow gauge was located just at the downstream end of the reach. A hydraulic model was derived on the basis of a cross section from the gauge, combined with the gauge rating curve. At cease to flow there was 1.74 m depth of water at the cross-section, suggesting that the control for the gauge was further downstream. Thus, this hydraulic relationship could not be used to specify low flows. As an alternative, the low flow thresholds were set equivalent to the flow exceeded 75% of the time for the defined season. This reflects the low end of the normal baseflow range.

The expectation is that these flows will maintain adequate minimum water depths in riffle habitats (3b) and sufficient wetted area and depths in pools and shallow runs (3a). Note that these riffle and pool habitats were not observed in the field (as this reach was in flood at the time of inspection), but exposed bed material was visible on the satellite image, and the reach is sufficiently high gradient to have pool/riffle morphology. Water depth in pools should be adequately maintained by the presence of riffles acting as a downstream control on depths. The higher flow for Feb-Mar ensures that the recommended regime remains within the historical range. Lower flows are acceptable whenever they would occur naturally. Note that in this section of Yong'anxi low flows will reflect overall levels of water extraction from the entire upstream catchment, not just diversions from Zhuxi.

8.4.3 Low flow Pulse

The low flow pulse component was assumed to correspond to inundation of the lower Bench I (Figure 91). Periodic flow pulses of 96 $m^3s^{-1}$are recommended to flush fine sediments and algae from interstitial spaces and the surfaces of cobbles (1b, 3d) and to maintain water quality by 'turning over' pools and re-oxygenating the hyporheic zone. The mobilisation of sediment (1b) and the scouring of vegetation from bars (2a) are the controlling objectives for this flow. These flow pulses also provide opportunities for fish to move between pools (3c) that might otherwise be isolated by shallow water over riffles during low flows and mobilise terrestrial organic material thereby providing a potentially important source of carbon for aquatic food webs (2a). These events should occur approximately 4 times each year during the period October-March (natural frequency), and each event should last 4 consecutive days (natural median duration).

8.4.4 High Flow

At cease to flow there was 1.74 m depth of water at the gauge cross-section, suggesting that the control for the gauge was further downstream. Thus, the hydraulic relationship for this reach could not be used to specify low flows. As an alternative, the high flow thresholds was set equivalent to the flow exceeded 75% of the time for the defined season. This reflects the low end of the normal baseflow range. The 75^{th} percentile flow for the entire Apr-Sep period was 20.7 m^3s^{-1} and for the shorter Apr-Jul period it was 22.2 m^3s^{-1}. The higher, more conservative, value of 22.2 m^3s^{-1} is recommended to maintain sufficient water depths for fish movement into and out of spawning areas (3e). The high baseflow will also ensure sufficient backwater habitats exist for juvenile and young of the year fish (3a and 3b). Note that in this section of Yong'anxi high flows will reflect overall levels of water extraction from the entire upstream catchment, not just diversions from Zhuxi.

8.4.5 High Flow Pulse

The low flow pulse component was assumed to correspond to inundation of the middle Bench II (Figure 91). Periodic flow pulses of 146 m^3s^{-1} are recommended to periodically flush fine sediments and algae from interstitial spaces and the surfaces of cobbles respectively (1b, 3d) and to maintain water quality by 'turning over' pools and re-oxygenating the hyporheic zone (3d). The mobilisation of sediments (1b) and the scouring of vegetation from bars (2a) are the controlling objectives for this flow. High flow pulses should occur 6 times annually (natural frequency) during the period April-September, with each event lasting 7 consecutive days (natural median duration).

8.4.6 Bankfull Flow

Like Zhuxi, Yong'anxi is a typical gravel bed river in which many of the natural channel features (pools, riffles, bars) are maintained by bankfull flows mobilising bed material (1a, 1c, 1d) and scouring encroaching terrestrial vegetation (2a, 2c). These geomorphic features create unique habitats that must be maintained to meet the fish and vegetation objectives. The peak discharge required to reach the top of the bank at the gauge cross-section is 1,289 m^3s^{-1} (Figure 91), but this need only be reached instantaneously. The associated mean daily flow for inclusion in the IQQM model is 948 m^3s^{-1}. These flows should on average occur 1.3 times per year, or 4 events every 3 years (based on natural frequency of occurrence).

8.4.7 Overbank flows

Overbank flows were not recommended for this reach due to the presence of extensive levee banks that limit the potential benefits of overbank flows.

8.5 Reach 4: The freshwater estuarine section of Lingjiang from Shifengxi confluence to downstream of Linhai city

Floodplain inundation at Ling Lake (L); the wetland site upstream of Linhai city (R). Photos taken on 12/10/2007, the week following a major inundation event. Note thick layer of silt deposited at both locations.

8.5.1 Low Flow

Due to marked seasonal variation in natural low flows over the dry season, a separate low flow has been specified for Oct-Jan (16.0 m^3s^{-1}) and Feb-Mar (31.8 m^3s^{-1}). Lower flows are acceptable whenever they would occur naturally. The low flow thresholds were not based on hydraulic criteria (due to lack of information), but were equivalent to the flow exceeded 75% of the time for the defined season. This reflects the low end of the normal baseflow range. It is expected that this flow will maintain low salinity flowing water on the ebb tide in the upper part of the reach (helping to maintain the position of the fresh/brackish/saline interface), otherwise this flow component does not have a strong ecological role. Note that in this section of Lingjiang, low flows will reflect overall levels of water extraction from the entire upstream catchment, not just diversions from Zhuxi.

Table 103: Summary of flow requirements for Reach 4.

Flow component	Timing	Months	Q_{PEAK} m^3s^{-1}	Q_{DAILY} m^3s^{-1}	Frequency (per year)	Duration	Rise/fall max.(target) m^3s^{-1}‡	Comment	Indices
Low flow	Low flow season	Oct-Jan	16.0	16.0	continuous or less than if natural			Will maintain low salinity flow on the ebb tide in the upper part of the reach	3h, 3i, 3j 75th%-ile
Low flow	Low flow season	Feb-Mar	31.8	31.8	continuous or less than if natural				3h, 3i, 3j 75th%-ile
High flow	High flow season	April-Sep	46.0	46.0	continuous or less than if natural				3h, 3i, 3j 75th%-ile
Low flow pulse	None specified. Pulses will not influence water level; a minor and temporary influence on downstream salinity gradient is possible but cannot be linked to known ecological processes								
High flow pulse									
Bankfull†	anytime	anytime	3,110	2,488	0.59*	1 d	+3,674(+5,171)/ -2,963(-4,481)	Event to reach 7.0 m at wetland	1a, 1c, 1d 2b, 2d 3g, 3i, 3j
Bankfull†	anytime	anytime	3,545	2,836	0.48*	1 d	+3,674(+5,171)/ -2,963(-4,481)	Event to reach 7.5 m at wetland	
Bankfull†	anytime	anytime	3,980	3,184	0.45*	1 d	+3,674(+5,171)/ -2,963(-4,481)	Event to reach 8.0 m at wetland	
Overbank	None specified								

† Due to uncertainty in the stage required to inundate the wetland in this reach, three scenarios spanning 7.0 - 8.0 m have been identified. Only one of these events needs to be implemented. The higher level is preferred to ensure full inundation of the wetland, provided this can be achieved with minimal additional impacts on security of supply over the lower scenarios. Duration is 1 day at peak, and to achieve Q_{PEAK} and Q_{DAILY} on day of peak.

‡ Rate is maximum change in discharge that is allowed from one day to the next. Target is recommended rate change, but maximum can be used (at higher environmental risk). If allowable rate change exceeds the required event magnitude then discharge can be raised to the event magnitude over one day.

* Probability (P) of exceedance in current flow series (ARI = 1/P).

8.5.2 High Flow

A wet season (Apr-Sep) baseflow of 46.0 m^3s^{-1} is recommended to maintain low salinity flowing water on the ebb tide in the upper part of the reach (helping to maintain the position of the fresh/brackish/saline interface), otherwise this flow component does not have a strong ecological role. Lower flows are acceptable whenever they would occur naturally. The low flow threshold was not based on hydraulic criteria (due to lack of information), but was equivalent to the flow exceeded 75% of the time for the defined season. This reflects the low end of the normal baseflow range. Note that in this section of Lingjiang, low flows will reflect overall levels of water extraction from the entire upstream catchment, not just diversions from Zhuxi.

8.5.3 Pulses

A convincing ecological basis for pulses could not be established in this reach. Pulses will not influence water level, but may have a minor and temporary influence on downstream salinity gradient.

8.5.4 Bankfull Flow

The upper limit of Reach 4 defines the approximate upstream extent of significant tidal influence in Lingjiang, whilst the downstream limit (just below Linhai city) defines the upstream extent of saline water intrusion. As a result of the tidal influence, hydraulic conditions within the river are controlled more by tidal processes than inflows from upper reaches. The exception is under high flow conditions (Figure 2a and 2b). As water levels are controlled by river discharge only during high flow events, recommendations have been made only for Bankfull flows, primarily to maintain periodic inundation of and access to an important riparian wetland area (2d). To this end, these Bankfull recommendations also address the Overbank flows recommendation for fish (3g). A separate Overbank flow component was not specified due to the widespread floodplain levees in this Reach. The potential impacts of reduced low flows on upstream intrusion of saline water is covered as part of the risk assessment for Reach 5.

For Reach 4 the estimated flows required to achieve Bankfull and inundate the fringing wetland areas range between 3,110 m^3s^{-1} (instantaneous) and 3,980 m^3s^{-1} (instantaneous). This uncertainty is due to the lack of a detailed survey of the bank height adjacent to the wetland to accurately determine the sill level. Monitoring of the flows required to inundate the wetland could quickly address this uncertainty. The frequency of these events ranges between 0.45 - 0.59 times per year (i.e. about once every 2 years).

8.5.5 Overbank flows

Overbank flows were not recommended for this reach as the bankfull component achieves inundation of the important ecological asset (wetland).

8.6 Reach 5 and Reach 6: The saltwater estuarine section of Lingjiang/Jiaojiang

Mudflats at the mouth of the estuary in Reach 6

Due to lack of resources, it was not possible to derive specific flow rules for Reach 5 and Reach 6 using the hydraulic-based methodology used in the other reaches. The hydrodynamics of the estuary are complex, and derivation of flows based on an understanding of the hydrodynamics would require a separate investigation. Interestingly, the hydraulics of the Jiaojiang estuary have been very well studied, and there is an existing hydrodynamic model, so the tools to conduct such an estuarine environmental flows investigation are available.

For Reaches 5 and 6, a risk assessment was undertaken to explore the potential impacts associated with the following key hydrological change indices:

i. Reduction in summer baseflow
ii. Reduction in winter baseflow
iii. Reduction in the frequency of bankfull floods

While the open Jiaojiang estuary is dominated by marine influences, freshwater flows are also ecologically important. During high river flow events the saline estuarine water is pushed out to sea. This causes a major disruption to the normal ebb and flow cycle; the biota have evolved to either take advantage of this sudden and perhaps persistent change in the hydraulics and salinity regime, or to minimise negative impacts. A significant reduction in the frequency of major runoff events, or similarly, a significant reduction in the volume of water passing to the estuary during major rainfall events could have significant ecological consequences. Baseflows determine the longitudinal position of the salinity gradient during non-flood times. Weaker baseflows allow saline water to penetrate further upstream.

The degree of hydrological change in the Lingjiang-Jiaojiang estuary is analysed in the following section of this report. In this section the results of that analysis are used in a risk assessment.

For each of these hydrological changes, a list was made of the ecological assets that were potentially at risk of impairment from such a change (Table 104). The assets were rated according to three conservation status classes, with the consequence of change (consequence) being higher the higher the conservation status (Table 105). Degree of change (likelihood of impairment due to hydrological change) was ranked into 4 classes (Table 106). The product of consequence and likelihood gives risk of impairment, which was grouped into 5 classes, ranging from insignificant to very high (Table 106).

Consequence and likelihood scores were assigned to each ecological asset, and risk scores were calculated for each asset for five future scenarios for Reach 5 (Table 107) and Reach 6 (Table 108):

i. R0E0, Zhuxi 2020 with Shisandukeng water transfers
ii. R0E1, Zhuxi 2020 with Shisandukeng water transfers plus Environmental Flow Rules
iii. R1E0, Zhuxi 2020 with Shisandukeng water transfers plus Modified Changtan Operation Rule (Reduce valve operating storage)
iv. R1E1, Zhuxi 2020 with Shisandukeng water transfers plus Environmental Flow Requirements plus Modified Changtan Operating Rule (Reduced valve operating storage level)
v. R2E0, Zhuxi 2020 with Shisandukeng water transfers plus Dam on the Yong'anxi system upstream of Zhuxi

Table 104: Main hydrological and resultant physical and ecological changes likely due to reduction in freshwater inflows into Lingjiang/Jiaojiang estuary.

Key hydrological change index	Potential environmental changes	Ecological asset potentially at risk of impairment	ASSET CODE
Reduction in Oct-Mar baseflow	‣ Upstream migration of salt wedge ‣ Increased sediment influx from the Yangtze River (Changjang) ‣ Increased salinity within near-shore environments ‣ Reduced depths in the river channel due to sedimentation ‣ Altered biogeochemical cycling	Upstream migration of anadromous fish (e.g. Plecoglossus, Macrura reversii, Coilia ectenes, Coilia mystus)	1A
		Marine derived freshwater opportunists (Lateolabrax japonicus)	1B
		Estuarine resident fish (e.g. Large Yellow Croaker, Acanthopagrus schlegel)	1C
		Species inhabiting tidal mudflats (e.g. Crabs, Blue-spotted mudskipper, shellfish)	1D
		Freshwater dependent vegetation (e.g. fringing reed beds and low lying forests)	1E
Reduction in April-Sep baseflow	‣ Upstream migration of salt wedge ‣ Increased sediment influx from the Yangtze River (Changjang) ‣ Increased salinity within near-shore environments ‣ Reduced depths in the river channel due to sedimentation ‣ Altered biogeochemical cycling	Upstream migration of anadromous fish (e.g. Plecoglossus, Macrura reversii, Coilia ectenes, Coilia mystus)	2A
		Marine derived freshwater opportunists (Lateolabrax japonicus)	2B
		Estuarine resident fish (e.g. Large Yellow Croaker, Acanthopagrus schlegel)	2C
		Species inhabiting tidal mudflats (e.g. Crabs, Blue-spotted mudskipper)	2D
		Freshwater dependent vegetation (e.g. fringing reed beds and low lying forests)	2E
Reduction in flood magnitude and frequency	‣ Upstream migration of salt wedge ‣ Increased sediment influx from the Yangtze River (Changjang) ‣ Increased salinity within near-shore environments ‣ Reduced depths in the river channel due to sedimentation ‣ Altered biogeochemical cycling	Upstream migration of anadromous fish (e.g. Plecoglossus, Macrura reversii, Coilia ectenes, Coilia mystus)	3A
		Marine derived freshwater opportunists (Lateolabrax japonicus)	3B
		Estuarine resident fish (e.g. Large Yellow Croaker, Acanthopagrus schlegel)	3C
		Species inhabiting tidal mudflats (e.g. Crabs, Blue-spotted mudskipper)	3D
		Freshwater dependent vegetation (e.g. fringing reed beds and low lying forests)	3E

Table 105: Three key classes of ecological assets, and score for consequence to ecosystem if a change occurs. Also, score for likelihood of impairment due to hydrological change corresponding to four degrees of change.

Asset	Consequence score
Species of commercial or national conservation significance	3
Species of recreational or regional conservation significance	2
Native spp. with no particular commercial, recreational or conservation status	1
Degree of change	**Likelihood score**
No significant change in quality or extent of habitat / process	0
Minor change in quality or extent of habitat / process	1
Major change in quality or extent of habitat / process	2
Loss of habitat or process	3

Table 106: Risk matrix, showing classes of risk of impairment for product of consequence and likelihood scores.

Consequence	Likelihood 0	Likelihood 1	Likelihood 2	Likelihood 3
1	very low	low	moderate	moderate
2	very low	moderate	high	high
3	very low	moderate	high	very high

Table 107: Risk of impairment to three key classes of ecological assets in Reach 5 (Lingjiang section of estuary) in response to hydrological changes associated with five alternate future scenarios of reservoir construction and operation. L = Likelihood, R = Risk. Future scenarios explained in text.

Future scenario			1		2		3		4		5	
Index	Asset code	Con-sequence	L	R	L	R	L	R	L	R	L	R
Reduction in Low Flow baseflow			8-10%		5-7%		8-10%		6-7%		9-11%	
	1A	3	1	3	1	3	1	3	1	3	1	3
	1B	2	0	0	0	0	0	0	0	0	0	0
	1C	3	0	0	0	0	0	0	0	0	0	0
	1D	3	0	0	0	0	0	0	0	0	0	0
	1E	1	0	0	0	0	0	0	0	0	0	0
Reduction in High Fflow baseflow			4-9%		3-7%		4-9%		3-7%		4-10%	
	2A	3	1	3	1	3	1	3	1	3	1	3
	2B	2	0	0	0	0	0	0	0	0	0	0
	2C	3	1	3	1	3	1	3	1	3	1	3
	2D	3	0	0	0	0	0	0	0	0	0	0
	2E	1	0	0	0	0	0	0	0	0	0	0
Reduction in flood magnitude and frequency			14%		7%		14%		7%		14%	
	3A	3	1	3	0	0	1	3	0	0	1	3
	3B	2	0	0	0	0	0	0	0	0	0	0
	3C	3	0	0	0	0	0	0	0	0	0	0
	3D	3	0	0	0	0	0	0	0	0	0	0
	3E	1	1	1	0	0	1	1	0	0	1	1

Table 108: Risk of impairment to three key classes of ecological assets in Reach 6 (Jiaojiang section of estuary) in response to hydrological changes associated with five alternate future scenarios of reservoir construction and operation. L = Likelihood, R = Risk. Future scenarios explained in text.

Future scenario			1		2		3		4		5	
Index	Asset code	Con-sequence	L	R	L	R	L	R	L	R	L	R
			13-17%		11-14%		13-17%		11-15%		13-17%	
Reduction in Low Flow baseflow	1A	3	1	3	1	3	1	3	1	3	1	3
	1B	2	0	0	0	0	0	0	0	0	0	0
	1C	3	0	0	0	0	0	0	0	0	0	0
	1D	3	0	0	0	0	0	0	0	0	0	0
	1E	1	0	0	0	0	0	0	0	0	0	0
			6-8%		5-6%		6-8%		5-6%		6-8%	
Reduction in High Fflow baseflow	2A	3	1	3	1	3	1	3	1	3	1	3
	2B	2	0	0	0	0	0	0	0	0	0	0
	2C	3	1	3	1	3	1	3	1	3	1	3
	2D	3	0	0	0	0	0	0	0	0	0	0
	2E	1	0	0	0	0	0	0	0	0	0	0
			16%		17%		16%		17%		16%	
Reduction in flood magnitude and frequency	3A	3	1	3	1	3	1	3	1	3	1	3
	3B	2	0	0	0	0	0	0	0	0	0	0
	3C	3	0	0	0	0	0	0	0	0	0	0
	3D	3	0	0	0	0	0	0	0	0	0	0
	3E	1	1	1	1	1	1	1	1	1	1	1

The 5 scenarios examined appear to pose a fairly minimal threat to the ecological assets in reaches 5 and 6, with the greatest, yet still only *moderate*, threat being posed to the upstream movement of migratory fish and to estuarine resident fish species. The main threat to the latter group is likely to be a change in the distribution and availability of suitable spawning habitats, which are often located in areas with salinity levels below that of seawater. Reductions in High Flow baseflows during the spawning period may cause changes in salinities in the middle and upper estuary that may isolate appropriate spawning sites in terms of habitat from areas with appropriate water chemistry.

Whilst specific information on *Acanthopagrus Schlegelii* is unavailable, salinity levels are known to influence spawning behaviour in closely related species. For example, a review by Norriss et al. (2002) indicates that *Acanthopgrus butcheri* (Australian Black Bream) spawn in salinities ranging between 8 – 45 ppt, but that spawning is often more successful at intermediate salinities. Floods also play a major role in periodically flushing estuaries and redistributing salinity gradients, and in inundating low lying wetland areas dependent on freshwater. Hence these also were identified as an important component of the flow regime to consider. It is worth noting that in Reach 5, scenarios that included environmental flow rules ameliorated the risks associated with a reduction in flood frequency for asset classes 3A and 3E (migratory fish and freshwater dependent vegetation).

Overall, it would appear that construction of dams on Zhuxi and Yong'anxi would cause small but incremental changes in the baseflow volume and flood magnitude and frequency in reaches 5 and 6. This incremental change highlights the importance of assessing the impacts of water resource development at the basin scale, as further development in other sub-catchments will almost certainly increase the risk posed to ecological assets over the levels reported here.

The following section details how hydrological indices were derived to assess the risk associated with the future management scenarios.

Chapter 9: Hydrological Impacts of Future Management Scenarios

9.1 Baseflows

Baseflows were analysed by examining a single index. The dry period and wet period baseflows recommended as the minimum environmental flows for the reaches corresponded to the flows exceeded 75% of the time. Under a managed regime, flows do not have to exceed this threshold all of the time, with the "or natural" clause meaning that if natural inflows to the reach are lower than the threshold then natural flows apply. In this environmental flows assessment the current regime was considered equivalent to the "natural" scenario, because the dam is yet to be constructed on Zhuxi. However, there are other dams in the Jiaojiang system, so the current flow series for Yong'anxi and further downstream are not "natural".

It would be expected that under the current regime, the "or natural" case will apply on average for 25% of the time. For the two estuarine reaches (Lingjiang and Jiaojiang) the flow thresholds corresponding to the 75th percentile flow were determined for the current flow regime, with a value calculated for the four main defined flow periods. Then the percentages of time that these thresholds were exceeded in the future scenarios were calculated for each of the seasons. The difference in these percentages from 75% represents a deviation from the current baseflow regime. The period of time represented by the difference will experience flows less than the recommended baseflow threshold, while under the current regime the flow would have been at least equal to the threshold.

The baseflow analysis revealed that the high flow April-July and August-September periods suffered greater reduction in baseflows than did the low flow October-January and February-March periods (Table 109). This is probably explained by the water resources development tending to capture water in the high flow periods. Also, the Jiaojiang reach was consistently more affected than Lingjiang in the wet period, while in the dry period there was no difference between the sites (Table 109).

Table 109: Percent of time that the 75th percentile flows under current regime are exceeded under future water resources development scenarios. Future scenarios explained in text.

Scenario	Location	Aug-Sep	Oct-Jan	Feb-Mar	Apr-Jul
		Percent of time that the 75th percentile flows under current are exceeded under future water resources development scenarios			
1. R0E0	Lingjing	65%	66%	71%	67%
	Jiaojiang	58%	67%	69%	62%
2. R0E1	Lingjing	68%	68%	72%	70%
	Jiaojiang	61%	69%	70%	64%
3. R1E0	Lingjing	65%	66%	71%	67%
	Jiaojiang	58%	67%	69%	62%
4. R1E1	Lingjing	68%	68%	72%	69%
	Jiaojiang	60%	69%	70%	64%
5. R2E0	Lingjing	64%	65%	71%	66%
	Jiaojiang	58%	67%	69%	62%
		Reduction from 75% under future water resources development scenarios			
1. R0E0	Lingjing	10%	9%	4%	8%
	Jiaojiang	17%	8%	6%	13%
2. R0E1	Lingjing	7%	7%	3%	5%
	Jiaojiang	14%	6%	5%	11%
3. R1E0	Lingjing	10%	9%	4%	8%
	Jiaojiang	17%	8%	6%	13%
4. R1E1	Lingjing	7%	7%	3%	6%
	Jiaojiang	15%	6%	5%	11%
5. R2E0	Lingjing	11%	10%	4%	9%
	Jiaojiang	17%	8%	6%	13%

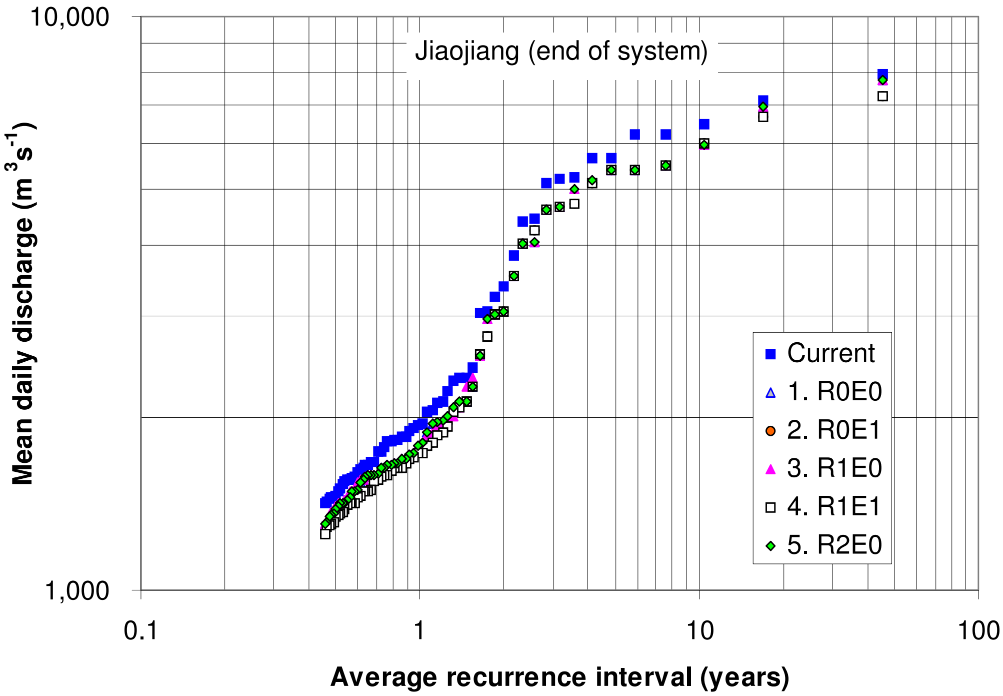
9.2 Flood frequency

One way of assessing the impact of water resources development on flood frequency is to plot and compare the partial duration flood frequency curves for the various scenarios. These curves suggest that modelled development scenarios lead to only a modest decline in flood frequency for any given discharge, and the scenarios all have a similar level of impact (Figure 94).

For Reach 4, the estimated flows required to achieve bankfull and inundate the fringing wetland areas ranged between 2,488 m^3s^{-1} and 3,184 m^3s^{-1} when measured as mean daily flows. The highest of these thresholds occurred with an average recurrence interval of 2.2 years, or a probability of exceedance of 0.45. For the purposes of assessing the impact of water resources development on flood frequency, it is assumed that this event represents the bankfull discharge for the upper end of the estuary, and that the event occurring with a probability of exceedance of 0.45 at the end of system represents the bankfull discharge there. At the end of system IQQM reporting node the equivalent discharge is 4,040 m^3s^{-1}.

For the future scenarios, for Reach 5, the probability of exceedance of the bankfull event declines by either 7% or 14% depending on the scenario (Table 110). For Reach 6, the decline is 16% or 17%. For the future scenarios, for Reach 5, the discharge associated with a probability of exceedance of 0.45 declines by 10% for all scenarios (Table 110). For Reach 6, the decline is 8%.

Figure 94: Partial flood series' based on mean daily discharge, at the upper (Lingjiang) and lower (Jiaojiang) ends of the Lingjiang-Jiaojiang estuary. IQQM modelled current scenario and 5 future scenarios (see text for explanation).



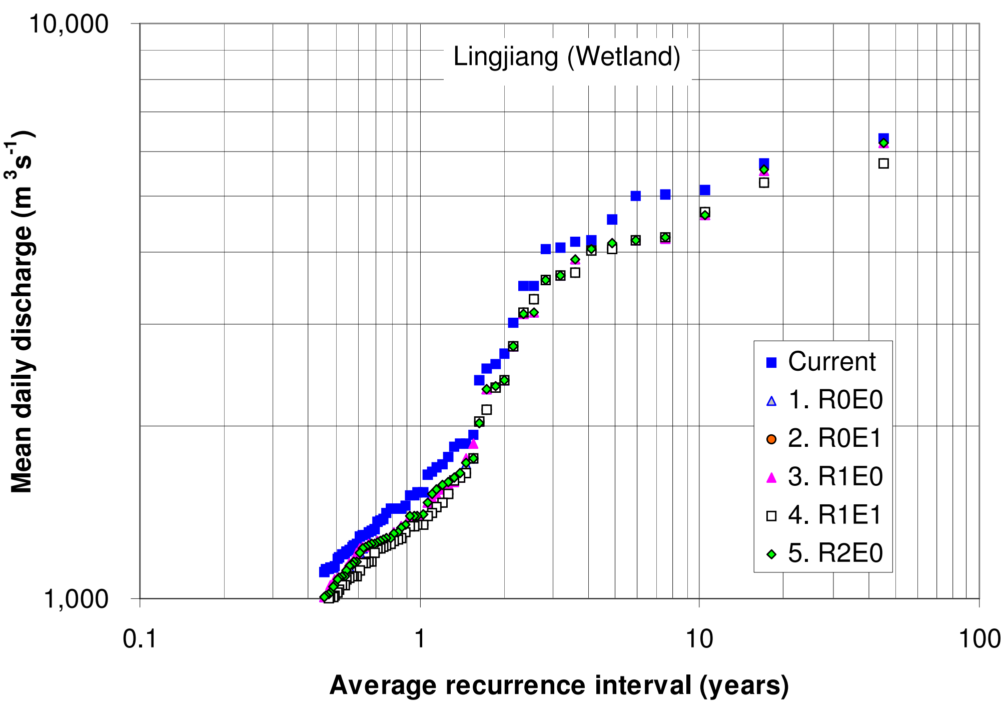


Table 110: Changes in frequency and magnitude of bankfull flows (P = 0.45, or 1 in 2.2 years ARI) for estuarine Reach 5 (Lingjiang) and Reach 6 (Jiaojiang) associated with alternate future scenarios of reservoir construction and operation. P = Probability of exceedance (events/year), Q_{DAILY} = Flood discharge peak (mean daily discharge in m^3s^{-1}). Future scenarios explained in text.

Reach	Index	Scenario					
		Current	1. R0E0	2. R0E1	3. R1E0	4. R1E1	5. R2E0
Lingjiang	P for Q_{DAILY} = 3,110 m^3s^{-1}	0.45	0.39	0.42	0.39	0.42	0.39
	Difference		-14%	-7%	-14%	-7%	-14%
	Q_{DAILY} for P = 0.45 events/yr	3,110	2,804	2,811	2,804	2,811	2,806
	Difference		-10%	-10%	-10%	-10%	-10%
Jiaojiang	P for Q_{DAILY} = 3,980 m^3s^{-1}	0.45	0.38	0.37	0.38	0.37	0.38
	Difference		-16%	-17%	-16%	-17%	-16%
	Q_{DAILY} for P = 0.45 events/yr	3,980	3,650	3,649	3,654	3,653	3,652
	Difference		-8%	-8%	-8%	-8%	-8%

Chapter 10: Comparison of Flow Recommendations with Tennant Method and IHA Indices

10.1 Tennant method

The only aspects of Tennant method recommendations (Table 88) that bore any resemblance to the recommendations made here were the basefow components (Low Flows and High Flows). For these, the Tennant management condition class that compared closest to the recommendations made here varied from "Poor" at Reach 1 downstream of Zhuxi Dam to "Excellent" at Reach 4 Yong'anxi upstream of Shifeng. Specific baseflow recommendations were not made for estuarine Reaches 5 and 6. It is interesting that the correspondence between the Tennant recommendations and the recommendations of this study changed in a systematic way in the downstream direction. This is because the Tennant method calculates values as a percentage of mean annual discharge, while for this study the baseflows were based on flow percentile, and the relationship between these two indices varies downstream, i.e. in the downstream direction, the flow exceeded 75% of the time increases as a percentage of the mean annual flow. This prevents consistent application of the Tennant method and is sufficient reason for not using it as a rapid method for estimating environmental flow needs.

10.2 IHA

The magnitudes, frequencies and durations of the recommended flow components were compared with the standard hydrological statistics calculated by the IHA (Table 89, Table 90, Table 91, Table 92, Table 93). To summarise, there was no set of IHA parameters that consistently predicted the recommended flow components. However, some statistics did give similar values in some cases, as described below.

The IHA 30-day minimum (IHA Parameter Group #2) closely predicted the Low Flows (Oct-Jan) components for Reaches 1, 2 and 3, and under predicted by 9% for Reach 4. The IHA 90-day minimum closely predicted the High Flows component for Reaches 1 and 2, and under predicted by 20% for Reaches 3 and 4. The EFC Low Flows over predicted the Low Flows (by a factor of around 2); the EFC Low Flows February value closely predicted the Low Flow Feb-Mar component; the EFC Low Flows (Apr-Sep) was a reasonable predictor of High Flows (Apr-Sep).

Table 111: Calculated discharges corresponding to the environmental flow – management condition classes defined by Tennant, compared with the baseflow recommendations made for this study. W = wet season (Oct-Mar), D = dry season (Apr-Sep). The Tennant values most closely corresponding to the recommendations of this study are shaded.

Tennant class and this study	Reach 1 Zhuxi DS Dam		Reach 2 Zhuxi End of Ck		Reach 3 Yong'anxi US Shifeng		Reach 4 Lingjiang (Wetland)	
	D	W	D	W	D	W	D	W
"Outstanding"	2.2	3.4	5.6	8.4	29	43	48	72
"Excellent"	1.7	2.8	4.2	7.0	22	36	36	60
"Good"	1.1	2.2	2.8	5.6	14	29	24	48
"Fair or degrading"	0.6	1.7	1.4	4.2	7.2	22	12	36
"Poor or minimum"	0.6	0.6	1.4	1.4	7.2	7.2	12	12
"Severe degradation"	0.0	0.6	0.0	1.4	0.0	7.2	0.0	12.0
This study	0.5	1.3	1.3 - 3.4	4.0	6.8 - 17.3	22	16 - 32	46

The IHA 30-day maximum closely predicted the Low Flow Pulse magnitude for Reaches 1 and 2, but for Reach 3 no statistic predicted the Low flow Pulse, and the IHA 90-day maximum was close to the High Flow Pulse (no pulses were recommended for Reach 4). For Reach 1, the EFC Small Flood over predicted the Bankfull magnitude by 25%, for Reach 2 it predicted Bankfull; for Reach 3 the EFC Small Flood over predicted the Bankfull magnitude by 88% and for Reach 4 it under predicted by 6%.

The lack of a consistent comparison between any of the IHA statistics and the recommended flow components was not unexpected. Firstly, this study used carefully selected seasons to match the local hydrological and ecological situation. Secondly, this study selected event magnitudes on the basis of hydraulic thresholds, and because the river's geomorphologic characteristics naturally vary downstream, a consistent relationship between hydrological indices and relative water levels should not be expected. The IHA statistics could have been forced to predict our recommended flow magnitudes by adjusting the flow thresholds in the program, but the relevant point is that the information necessary to do this only becomes available *after* the hydraulic analysis has been undertaken.

The failure of hydrology-only methodologies to take into account the downstream change in the relationship between a river's geomorphic and hydrologic characteristics (i.e. expressed as hydraulics) is a major weakness that cannot be easily overcome. This problem does not bode well for attempts to regionalize environmental flow recommendations on the basis of hydrology (i.e. ELOHA). One possible way of addressing this problem would be for the initial river classification (currently based on hydrology only in ELOHA) to also take geomorphology into account.

Chapter 11: Alternative Environmental Flow Regime Options

11.1 Introduction

Inclusion of the environmental flow rules in an IQQM model allows for an investigation of the impacts of the environmental flow recommendations on water availability and security of supply. Environmental flows normally reduce security of supply, so it is often the case that managers seek a recommendation from scientists on alternative (sub-optimal) environmental flow regime options that will achieve higher security of supply. Having environmental flow options available allows environmental outcomes to be traded off against security of supply. Reducing the environmental allocation requires prioritization of the identified assets and objectives to determine where reductions in the environmental allocation are best made. This process was undertaken here mainly as an example of how this might be done - it was not undertaken with a high degree of rigour. It must be clearly recognised that the sub-optimal environmental flow options represent a departure from the recommended flow regime, so they carry a higher risk that the identified assets will not be protected. Accepting a higher risk is a management decision, not a scientific one.

11.2 Methodology

In providing an alternative set of environmental flow recommendations, there are a number of options to consider. The relative potential to modify (i.e. reduce) a flow component depends on two things: the relative potential to improve security of supply, and the relative risk to the environment, of undertaking that reduction. If reducing a flow component has negligible impact on security of supply then there is little point in taking the environmental risk associated with the reduction. However, if reducing a flow component carries a high risk to the environment, then the reduction should not be considered.

The relative potential to improve security of supply (Table 112) was determined by roughly calculating the volumes of water required to supply the various flow components, and then determining the relative impact on total system savings by halving the flow component volume. The relative impact depends on the magnitude/frequency/duration characteristics of the component. For example, High Flows are of a relatively low magnitude, but long duration, so they account for a large percentage of the total flows, while Overbank flows are infrequent but of high magnitude so they also account for a high percentage of the total flows. This is a relatively coarse procedure (running the IQQM model for a range of scenarios would be a technically superior method, but it was considered impractical for this exercise).

The relative environmental impact of reducing the facets of a flow component (Table 112) was based on the principle that reducing a component's magnitude carried the greatest risk (as the necessary hydraulic threshold might not be achieved); Low Flows and High Flows magnitudes are low in the channel, and a 50% reduction is likely to create a severe reduction in available habitat, however the high flow season was considered less important than the low flow season in this respect; Bankfull and Overbank are less frequent than Pulses, so reducing their frequency was considered more detrimental than reducing frequency of Pulses (which would still occur at least once per year); we regarded Pulse duration as being possibly more important than frequency, as a certain duration is needed in order to allow the ecological process to be completed (i.e. water could be wasted if an inadequately short event was released, so it would be preferable to save the water for an effective event); Bankfull and Overbank components were specified with a peak duration of only 1 day, so total event duration cannot be reduced without increasing the rate of rise and fall.

Table 112: Relative potential to modify flow components (assuming equal reduction in all components) from perspective of improving security of supply and risk to environment.

Flow components (and hydrological facets)	Relative security of supply improvement	Relative risk to environment	Relative potential to modify	Rank potential to modify
Low Flow magnitude	Moderate	High	Nil	-
High Flow magnitude	Mod.-High	Moderate	Moderate	4
Low Flow Pulse magnitude	Low	High	Nil	-
Low Flow Pulse duration	Low	Moderate	Low	7
Low Flow Pulse frequency	Low	Low	Low	6
High Flow Pulse magnitude	Moderate	High	Nil	-
High Flow Pulse duration	Moderate	Moderate	Moderate	5
High Flow Pulse frequency	Moderate	Low	High	1
Bankfull magnitude	Mod.-High	High	Nil	-
Bankfull duration	Nil†	Moderate	Nil†	5†
Bankfull frequency	Mod.-High	Moderate	Mod.-High	2
Overbank magnitude	High	High	Nil	-
Overbank duration	Nil	Moderate	Nil	-
Overbank frequency	High	Moderate	Mod.-High	3

† Reach 3 an exception, with moderate potential to improve security of supply. Implement with High Flow Pulse duration reduction.

To achieve a ranking of potential to modify (reduce) the facets of the flow components, a simple risk assessment was undertaken based on the following rules:

i. Relative potential to modify was higher the lower was the risk to the environment and the higher was the potential for improving security of supply.

ii. Reduction in event magnitude resulted in High risk to the environment due the failure to achieve the threshold required to initiate the ecological/geomorphological process.

iii. A High risk to the environment resulted in no potential to modify the component.

iv. A Nil potential to improve security of supply resulted in no potential to modify the component.

v. Reduction in Pulse frequency was favoured over reduction in duration (as duration may be important to allow the ecological process to be completed).

vi. Pulse durations of 1 day cannot be reduced.

vii. Bankfull event duration can only be reduced for Reach 3, and Overbank duration cannot be reduced.

viii. The procedure for ranking options to modify the hydrological facet of flow components did not allow sequential ranking within a component, i.e. if reduction in frequency of a component ranked highly, the duration of that component could not be ranked immediately after it. The intention of this was to reduce the likelihood that the final alternative environmental flow regime would involve a reduction of both duration and frequency to any one component.

11.3 Alternative Options

The final rank of potential to modify (Table 112) enabled the generation of alternative environmental flow scenarios (Table 113, Table 114 and Table 115). As additional changes are progressively included (in the order indicated by the rank) the potential to achieve an improvement in security of supply increases but so too does risk to the environment. These potentials and risks are not numerically related. For this exercise we generated two alternative environmental flow options. The first (**Option 2: Sub-Optimal Environmental Flow Regime No. 1**) included the top 4 ranked changes, and the second (**Option 3: Sub-Optimal Environmental Flow Regime No. 2**) included the top 7 ranked changes. In each case, apart from a number of exceptions, the change was to halve the value of the hydrological facet of the flow component. The exceptions were:

- High Flow magnitude, which we felt carried excessive risk to the environment by halving, so we revised this to 25% reduction;
- The High Flow Pulse associated with spawning was regarded as high risk to the environment if reduced in any way, so it was not modified;
- The Overbank component is a special case. The way the environmental flows are specified, if Overbank is supplied, then Bankfull objectives are also considered to be achieved, so Bankfull does not have to be delivered. In this system Overbank would currently achieve little more than Bankfull, as most of the potential floodplain asset is protected by levees. Overbank is a realistic option only if some areas of floodplain are re-connected. Thus, the Overbank component was removed from consideration for the more severe alternative flow Option 3.

Chapter 12: Non-flow Related Issues

A number of non-flow related issues impact the Zhuxi-Jiaojiang system, and these represent threats to the success of any implemented environmental flow regime in achieving the objective of a healthy river. It is suggested that these issues be further investigated and appropriately managed.

12.1 Sand and gravel extraction

Sand and gravel extraction is widespread in the river system. The process appears to be one of removing the desired sand and gravel-sized fractions and leaving the coarser cobbles behind. Apart from the disruption caused by the process of extraction, the practice can have longer-term repercussions. The types of changes that can occur are:

- Loss of bed volume
- Change in the particle size of the bed material
- Disruption of armoured surface layers
- Alteration of natural bedforms that may be important habitats in their own right, or they may be important because they generate desirable hydraulic habitats under certain flow conditions
- Potential for extraction exceeding the rate of supply, leading to downstream or upstream progression of bed incision. Incision can be followed by a phase of widening

Table 113: Summary of Option 1: Recommended Environmental Flow Regime. BF can be omitted if OB implemented (for reaches where OB specified).

Component	Timing	Magnitude (m^3s^{-1})	Frequency (per year)	Duration (days at peak)	Magnitude condition	Frequency condition	Rise/event/fall (day/day/day)
Reach 1							
LF	Oct-Mar	0.5	Continuous			Or natural	
HF	Apr-Sep	1.3	Continuous			Or natural	
LFP	Oct-Dec; Jan-Mar	20	1 each period	1 day / period		Each year	2/1/2
HFP	Apr	20	2	2		Each year	1/2/2
HFP	May-Sep	20	4	2		Each year	1/2/2
BF	Anytime	177	0.52	1	524 inst. peak to be achieved	Long-term average	1/1/1
OB	Anytime	191	0.52	1	571 inst. peak to be achieved	Long-term average	1/1/1
Reach 2							
LF	Oct-Jan	1.3	Continuous			Or natural	
LF	Feb-Mar	3.4	Continuous			Or natural	
HF	Apr-Sep	4.0	Continuous			Or natural	
LFP	Oct-Dec; Jan-Mar	53	1 each period	2 days / period		Each year	2/2/2
HFP	Apr	53	1	2		Each year	2/2/2
HFP	May-Sep	53	4	2		Each year	2/2/2
BF	Anytime	397	0.58	1	1,011 inst. peak to be achieved	Long-term average	1/1/1
OB	Apr-Sep	428	0.58	1	1,102 inst. peak to be achieved	Long-term average	1/1/1
Reach 3							
LF	Oct-Jan	6.8	Continuous			Or natural	
LF	Feb-Mar	17.3	Continuous			Or natural	
HF	Apr-Sep	22.2	Continuous			Or natural	
LFP	Oct-Mar	96	4	4		Each year	2/4/3
HFP	Apr-Sep	146	6	7		Each year	2/7/3
BF	Anytime	948	1.3	1	1,289 inst. peak to be achieved	Long-term average	2/1/2
Reach 4							
LF	Oct-Jan	16.0	Continuous			Or natural	
LF	Feb-Mar	31.8	Continuous			Or natural	
HF	Apr-Sep	46	Continuous			Or natural	
BF	Anytime	3,184	0.45	1	3,980 inst. peak to be achieved	Long-term average	1/1/1

Table 114: Summary of Option 2: Sub-Optimal Environmental Flow Regime No. 1. BF can be omitted if OB implemented (for reaches where OB specified).

Component	Timing	Magnitude (m^3s^{-1})	Frequency (per year)	Duration (days at peak)	Magnitude condition	Frequency condition	Rise/event/fall (day/day/day)
Reach 1							
LF	Oct-Mar	0.5	Continuous			Or natural	
HF	Apr-Sep	1.0	Continuous			Or natural	
LFP	Oct-Dec; Jan-Mar	20	1 each period	1 day / period		Each year	2/1/2
HFP	Apr	20	2	2		Each year	1/2/2
HFP	May-Sep	20	2	2		Each year	1/2/2
BF	Anytime	177	0.26	1	524 inst. peak to be achieved	Long-term average	1/1/1
OB	Anytime	191	0.26	1	571 inst. peak to be achieved	Long-term average	1/1/1
Reach 2							
LF	Oct-Jan	1.3	Continuous			Or natural	
LF	Feb-Mar	3.4	Continuous			Or natural	
HF	Apr-Sep	3.0	Continuous			Or natural	
LFP	Oct-Dec; Jan-Mar	53	1 each period	2 days / period		Each year	2/2/2
HFP	Apr	53	1	2		Each year	2/2/2
HFP	May-Sep	53	2	2		Each year	2/2/2
BF	Anytime	397	0.29	1	1,011 inst. peak to be achieved	Long-term average	1/1/1
OB	Apr-Sep	428	0.29	1	1,102 inst. peak to be achieved	Long-term average	1/1/1
Reach 3							
LF	Oct-Jan	6.8	Continuous			Or natural	
LF	Feb-Mar	17.3	Continuous			Or natural	
HF	Apr-Sep	16.7	Continuous			Or natural	
LFP	Oct-Mar	96	4	4		Each year	2/4/3
HFP	Apr-Sep	146	3	7		Each year	2/7/3
BF	Anytime	948	0.7	1	1,289 inst. peak to be achieved	Long-term average	2/1/2
Reach 4							
LF	Oct-Jan	16.0	Continuous			Or natural	
LF	Feb-Mar	31.8	Continuous			Or natural	
HF	Apr-Sep	34.5	Continuous			Or natural	
BF	Anytime	3,184	0.23	1	3,980 inst. peak to be achieved	Long-term average	1/1/1

Table 115: Summary of Option 3: Sub-Optimal Environmental Flow Regime No. 2.

Component	Timing	Magnitude (m^3s^{-1})	Frequency (per year)	Duration (days at peak)	Magnitude condition	Frequency condition	Rise/event/fall (day/day/day)
Reach 1							
LF	Oct-Mar	0.5	Continuous			Or natural	
HF	Apr-Sep	1.0	Continuous			Or natural	
LFP	Oct-Dec; Jan-Mar	20	1 each period	1 day / period		Each year	1/1/1
HFP	Apr	20	2	2		Each year	1/2/2
HFP	May-Sep	20	2	1		Each year	1/1/1
BF	Anytime	177	0.26	1	524 inst. peak to be achieved	Long-term average	1/1/1
Reach 2							
LF	Oct-Jan	1.3	Continuous			Or natural	
LF	Feb-Mar	3.4	Continuous			Or natural	
HF	Apr-Sep	3.0	Continuous			Or natural	
LFP	Oct-Dec; Jan-Mar	53	1 each period	1 day / period		Each year	1/1/1
HFP	Apr	53	1	2		Each year	2/2/2
HFP	May-Sep	53	2	1		Each year	1/1/1
BF	Anytime	397	0.29	1	1,011 inst. peak to be achieved	Long-term average	1/1/1
Reach 3							
LF	Oct-Jan	6.8	Continuous			Or natural	
LF	Feb-Mar	17.3	Continuous			Or natural	
HF	Apr-Sep	16.7	Continuous			Or natural	
LFP	Oct-Mar	96	2	2		Each year	1/2/2
HFP	Apr-Sep	146	3	4		Each year	1/4/2
BF	Anytime	948	0.7	1	1,289 inst. peak to be achieved	Long-term average	1/1/1
Reach 4							
LF	Oct-Jan	16.0	Continuous			Or natural	
LF	Feb-Mar	31.8	Continuous			Or natural	
HF	Apr-Sep	34.5	Continuous			Or natural	
BF	Anytime	3,184	0.23	1	3,980 inst. peak to be achieved	Long-term average	1/1/1

12.2 Estuary channel dredging

The estuary requires constant dredging in order to overcome the naturally high rate of sediment deposition (with the vast majority of the sediment being sourced from the sea, not the Jiaojiang itself). However, dredging at a rate exceeding the deposition rate will deepen the estuary and this could have the effect of increasing the tidal range. The impacts of this have not been considered in any detail, but it will almost certainly have some impact.

12.3 Pollution

There are numerous point and non-point sources of pollution in the catchment (agricultural, urban and industrial). If pollution exceeds the limits of the biota, then the environmental flows will be obsolete.

Cold-water pollution is caused by cold water being released below reservoirs that have deep releases. This generally causes severe ecological disruption for a distance downstream, but it can be easily overcome by designing the reservoir with a multi-level offtake.

12.4 Over-fishing

According to the “Background report on Ecological Assets in the Jiaojiang Basin” prepared as part of the WET project, both freshwater and marine fisheries yields have stabilized over the last 10 years (1997-2006) at around 1,000,000 tons per annum. At the same time there has been a marked rise in aquaculture production. It is beyond the scope of this report to comment in detail on the sustainability of fishing practices in the Zhuxi and Jiaojiang system, although it is clear that ongoing monitoring of fisheries is warranted. Fisheries sustainability is exceptionally difficult to measure, but should take into account both yields, efforts, and the species that make up the catch. Declines in resource availability are often masked by increased catch effort or a shift toward more abundant species.

Aquaculture also warrants some mention. Major aquaculture species in the Taizhou region include several native species such as (*Ctenopharyngodon idellus*, *Aristichthys nobilis*, *Hypophalmicthys molitrix*). Given the ease with which these species can be spawned and reared in captivity, it is tempting to place a reduced importance on natural recruitment of wild populations, and the environmental conditions that maintain these populations. We would advise caution in this regard and point to the vast literature on the joint sustainable management of aquaculture and wild-fish stocks.

12.5 Catchment planning

This report has focused primarily on the flow related impacts associated with the construction of a dam on Zhuxi. It is possible to both recommend and implement an environmental flow regime to protect the assets of this system, but as development expands across the basin, maintaining ecological assets, particularly in the lower reaches will become a much greater challenge, both in terms of water availability, and in ensuring that diversions and releases are managed in a coordinated fashion. At the simplest level, the setting of a cap (stated in water volume) on basin-wide water use will provide the appropriate starting point from which to ensure water can be managed in a sustainable fashion. Without this initial constraint to ensure some water is available to protect environment assets, the development of environmental flow regimes simply will not be possible. These issues are discussed more broadly in WET Project (2007).

Chapter 13: Conclusion

The recommendations presented in this report identified the flow regime required to sustain, with relatively low risk, the ecological and geomorphic assets and processes in the Zhuxi-Jiaojiang system. The recommendations have been based around a number of existing methodologies outlined in the literature, which broadly combine information on ecological and other assets associated with the river system (in this case fish, vegetation, water quality and geomorphology) together with information that links these assets to aspects of the flow regime via hydraulic relationships. Using a combination of hydraulic and hydrological modeling, a specific set of flow rules were defined for input into an IQQM catchment-scale hydrological model. As well as providing environmental flow recommendations for this particular river system, this report is intended as a guide to assist practitioners with the methodological aspects of future environmental flow assessments undertaken in China.

The flow recommendations were compared against recommendations made by the Tennant method and against a raft of hydrological statistics calculated by the IHA software. There were no consistent relationships between the numbers produced by these hydrological methods and the environmental flow recommendations made in this study. This is largely because hydrology-only methods cannot account for the reality of the downstream change in the relationship between a river's geomorphic and hydrologic characteristics.

Inclusion of the environmental flow rules in an IQQM model allows for an investigation of the impacts of the environmental flow recommendations on water availability and security of supply. Environmental flows normally reduce security of supply, so it is often the case that managers seek a recommendation from scientists on alternative (sub-optimal) environmental flow regime options that will achieve higher security of supply. Having environmental flow options available allows environmental outcomes to be traded off against security of supply. Reducing the environmental allocation requires prioritization of the identified assets and objectives to determine where reductions in the environmental allocation are best made. This process was undertaken here mainly as an example of how this might be done - it was not undertaken with a high degree of rigour. It is stressed that this step was secondary to the main task undertaken in this report, which was to document a process for assessing the environmental flow requirements that would have a high probability of achieving the environmental objectives (i.e. protection of the identified environmental assets). It must be clearly recognised that the sub-optimal environmental flow options represent a departure from the *recommended* flow regime, so they carry a higher risk that the identified assets will not be protected. Accepting a higher risk is a management decision, not a scientific one.

This report provides a brief discussion of non-flow related issues pertaining to river health in the Zhuxi-Jiaojiang catchments. While these were not discussed in depth, it must be recognized that they will need to be addressed alongside the implementation of environmental flows if the desired flow-related objectives are to be achieved with a high degree of certainty.

Chapter 14: References

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Appendix: Table of Fish Species Included in Detailed Review

Family	Scientific name	Common name	Adult habitat	Spawning habitat	Larval habitat	Feeding	Migratory pattern	Spawning period
Engraulidae	Coilia mystus	Osbeck's grenadier anchovy	coastal waters; easturies; mid river reaches				Amphidromous	May
Engraulidae	Coilia ectenes	Tapertail anchovy	coastal waters; easturies; mid river reaches	among reeds, mid river reaches	eggs drift to eastuary	omnivorous (planktivore)	anadromous	May-August; 3 times
Clupeidae	Macrura reevsii	Hilsa Herring	coastal waters; easturies	freshwater, among reeds	tide pools; estuaries	zooplankton	Anadromous	May-July
Plecoglossidae	Plecoglossus altivellis	Sweet fish, Ayu	coastal waters, estuaries	freshwater, lower reaches, silt free gravel beds	drift to sea	omnivorous (benthivore)	Anadromous	March (spring)
Sparidae	Acanthopagrus schlegelii	Black Porgy	coastal waters, estuaries	upper estuary, seagrass beds?	seagrass beds?	zooplankton, benthos	Anadromous	spring-summer
Bagridae	Anguilla japonica	Freshwater eel	deep pools in rivers	Ocean	ocean-estuary	fish & invertebrates	Catadromous	Autumn
Bagridae	Anguilla marmoratus	Giant mottled or marbled eel	deep pools in rivers	Ocean	ocean-estuary	fish & invertebrates	Catadromous	spring?
Serranidae	Lateolabrax japonicus	Japanese sea bass	inshore reefs	estuaries			Catadromous	
Mugilidae	Liza so-iuy	Far Eastern Mullet	lowland river	estuaries			Catadromous	
Periophthalmidae	Boleophthalmus pectinirostris	Blue spotted mud skipper	intertidal mudflats	mudflats	mudflats	omnivorous	Non-migratory	autumn?

Family	Scientific name	Common name	Adult habitat	Spawning habitat	Larval habitat	Feeding	Migratory pattern	Spawning period
Sciaenidae	Larimichthys croceus	Large yellow croaker	coastal waters, estuaries			fish, zooplankton	oceanodromous	October-January
Cyprinidae	Aristichthys nobilis	Bighead carp	riverine	flowing waters; upper reaches;	riverine	zooplankton; benthic and planktonic	Potamodromous	summer?
Cyprinidae	Ctenopharyngodon idellus	Grass carp	riverine	flowing waters; upper reaches;	lowland rivers	vascular plants; algae	Potamodromous	
Cyprinidae	Hypophalmichthys molitrix	Silver Carp	riverine	flowing waters; upper reaches;		phytoplankton ; detritus	Potamodromous	spring (April-May)
Cyprinidae	Mylopharyngodon piceus	Black carp	rivers; lakes; reservoirs	flowing waters; upper reaches;	lowland rivers	zooplankton; benthic and planktonic	Potamodromous	April-May