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.

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[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:

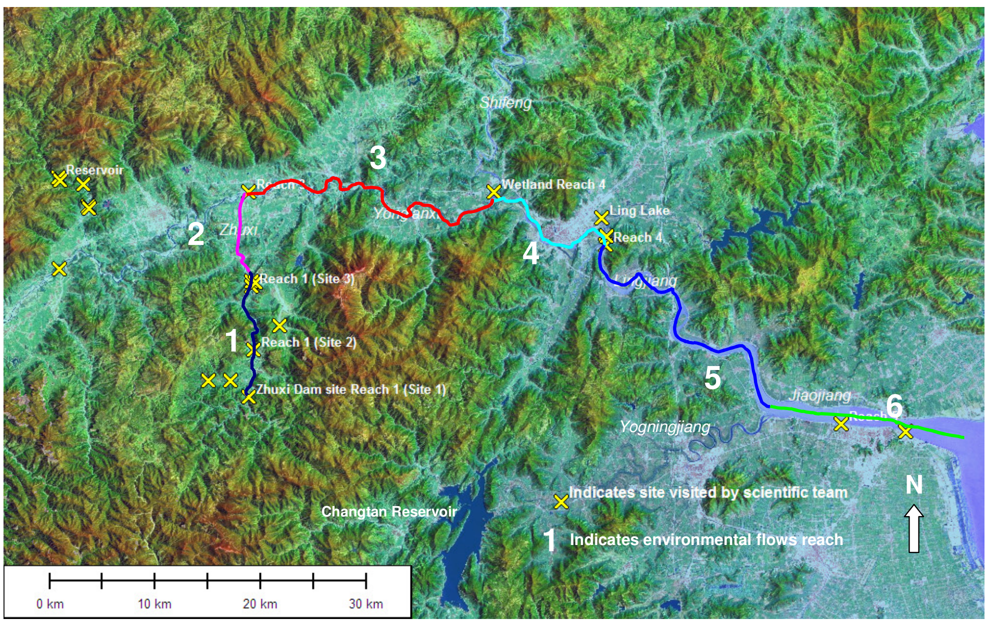
- Reach 1: Zhu Creek between the reservoir site and the first major downstream tributary entering Zhu Creek.
- Reach 2: Zhu Creek between the first major tributary below the reservoir site and the downstream confluence with Yong'an Creek.
- Reach 3: Yong'an Creek between the Zhu Creek confluence and 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

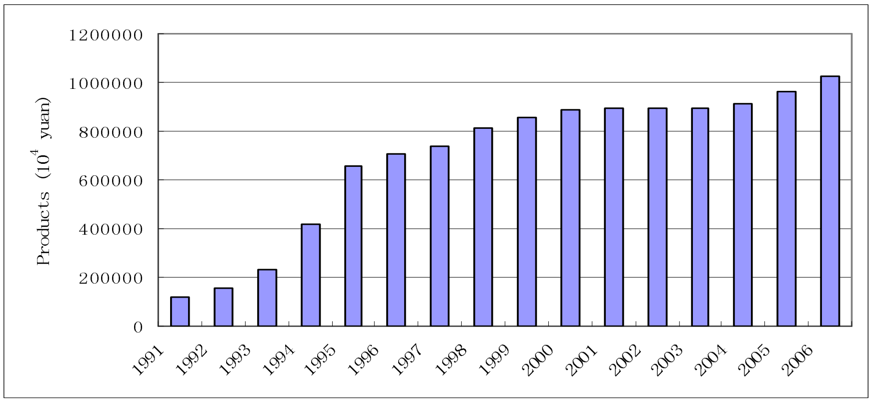
Importance of fisheries in Taizhou

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.

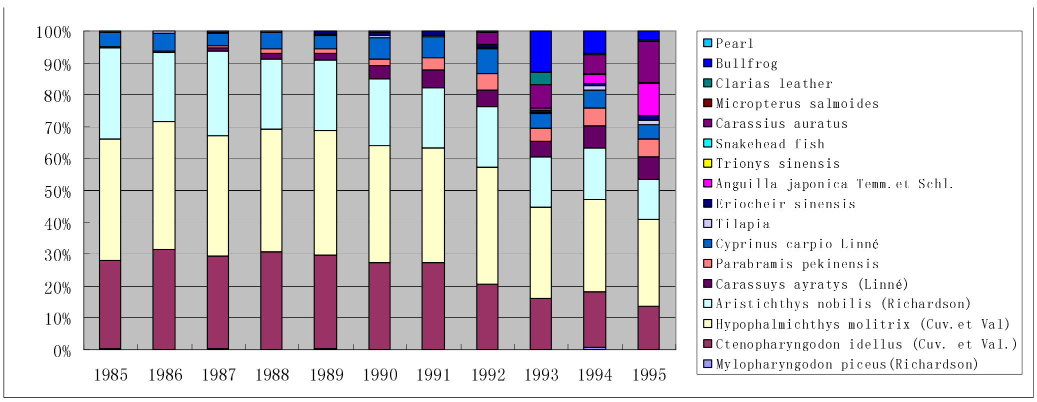
From 1985 to 1995, the contribution of the three most important economic species – Grass Carp, Silver Carp and Bighead Carp – towards total freshwater aquaculture production decreased (Figure 18). Of the increased production from other species, a number are new to the region.

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.

[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

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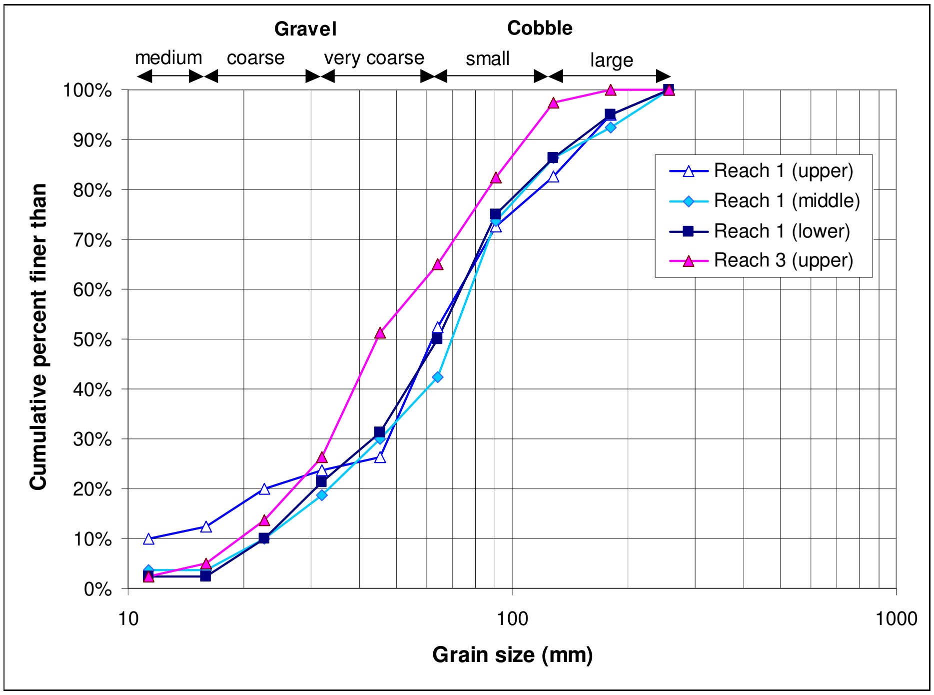
[40] including Naiman and Decamps (1997) and Nilsson and Svedmark (2002).
[41] Xie et al., 2001.
[42] Zhang et al. 2003.
[43] Bunn and Arthington, 2002.
[44] Guan et al., 2005.

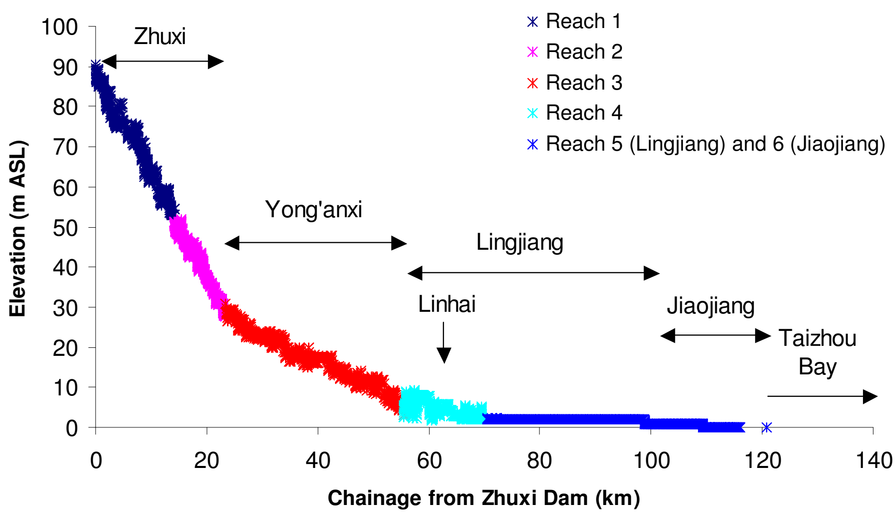
floodplain that is kilometres wide. Much of the river is lined with artificial levees, offering protection for the floodplain land.

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)

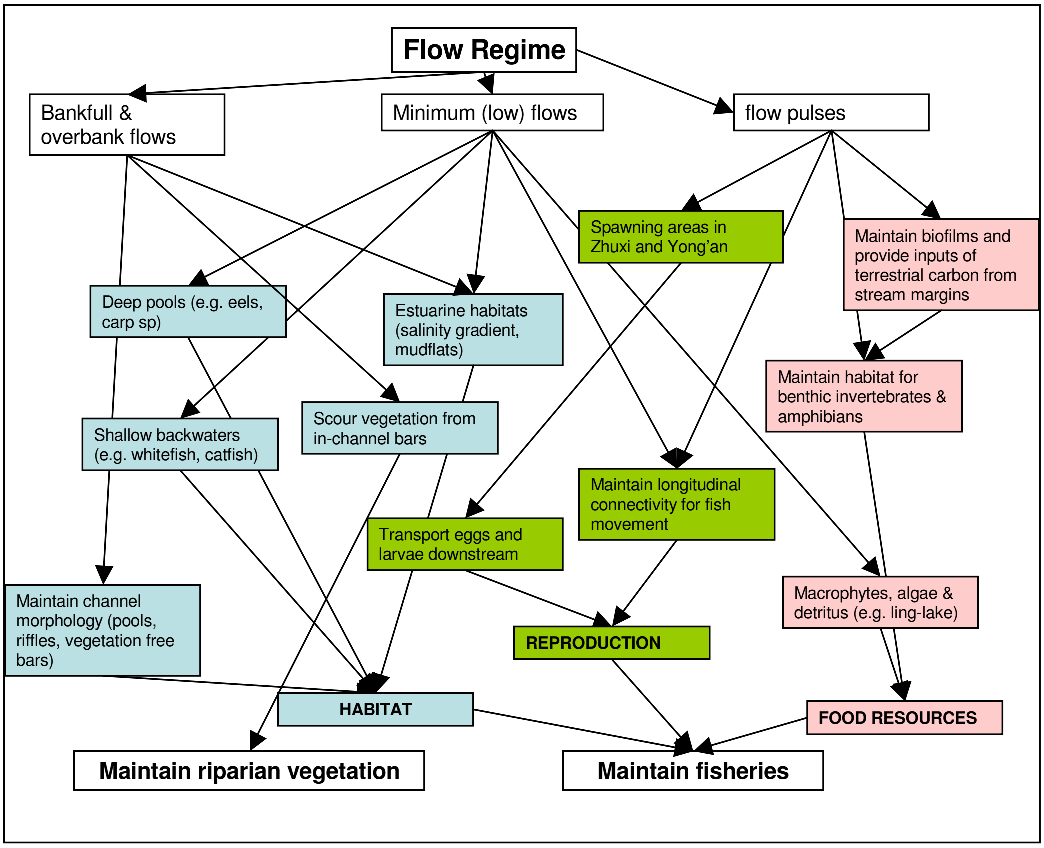
[50] Bunte, 2004.

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.

[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).

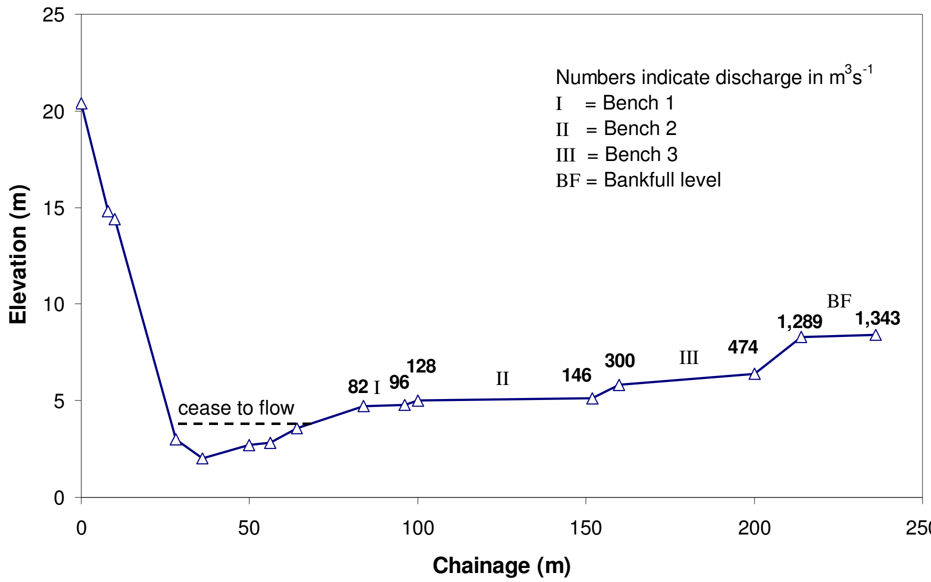
Bankfull Flow

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

Consequence	Likelihood 0	Likelihood 1	Likelihood 2	Likelihood 3
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

			Scenario 2		Scenario 3		Scenario 6	
	Asset code	Consequence	Likelihood	Risk level	Likelihood	Risk level	Likelihood	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

			Scenario 2		Scenario 3		Scenario 6	
	Asset code	Consequence	Likelihood	Risk level	Likelihood	Risk level	Likelihood	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 75th percentile flow").

Therefore, for each of the four main defined flow periods in a year, the flow thresholds corresponding to the 75th 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

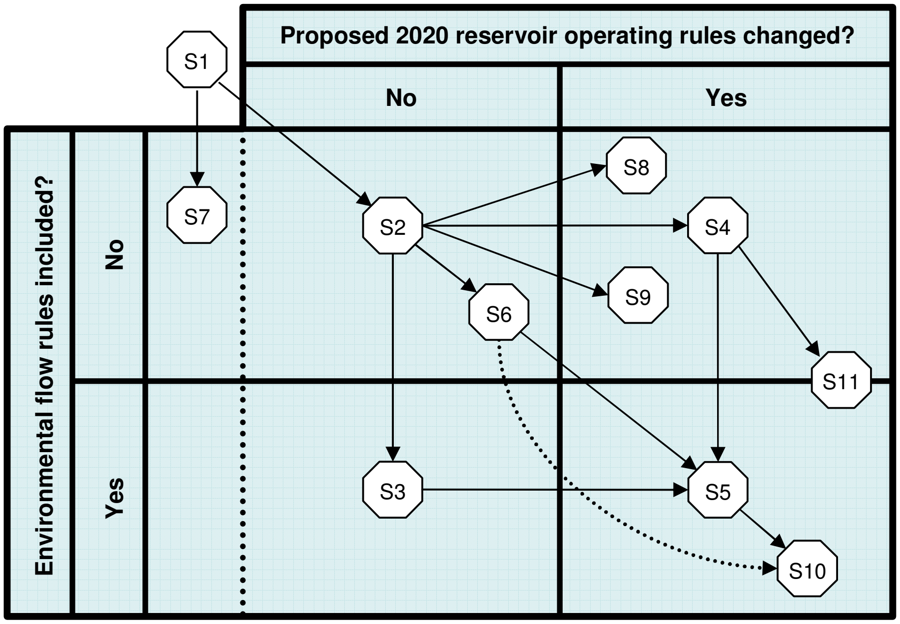
Scenario	Description
S1	Existing (2004) conditions
S2	Planned 2020 arrangements (demand based on Taizhou Comprehensive Plan; assumes construction of Zhuxi and Shisandu Reservoirs)
S3	Same as S2, but with environmental flow rules as recommended from the environmental flows assessment
S4	Same as S2, but 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

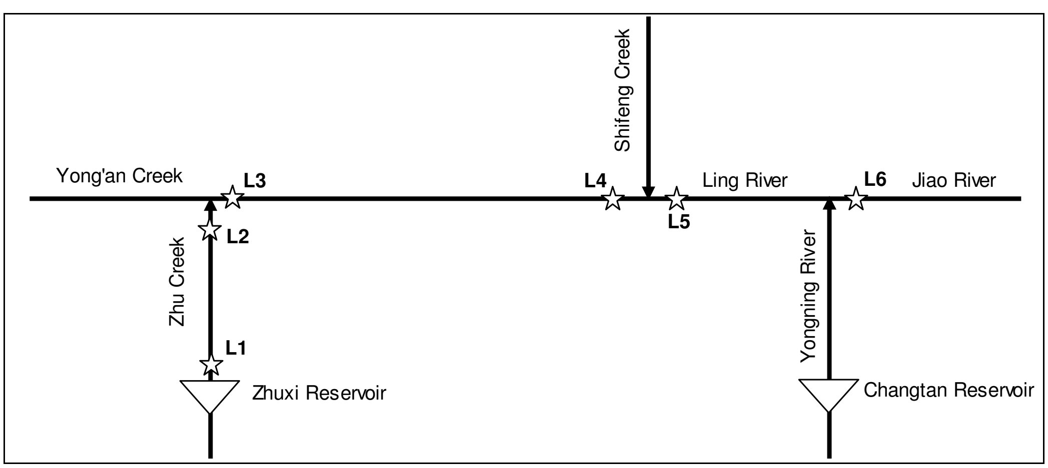


5.4 Water resource management model

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%

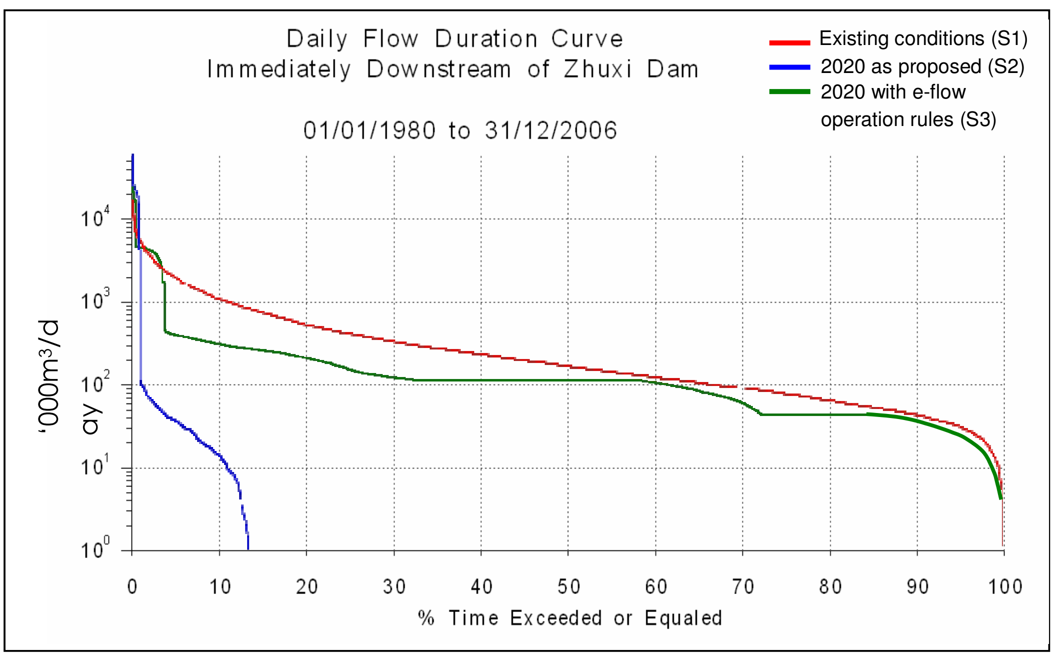
Table 27: Impact of development on the flow regime in first three reaches

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).

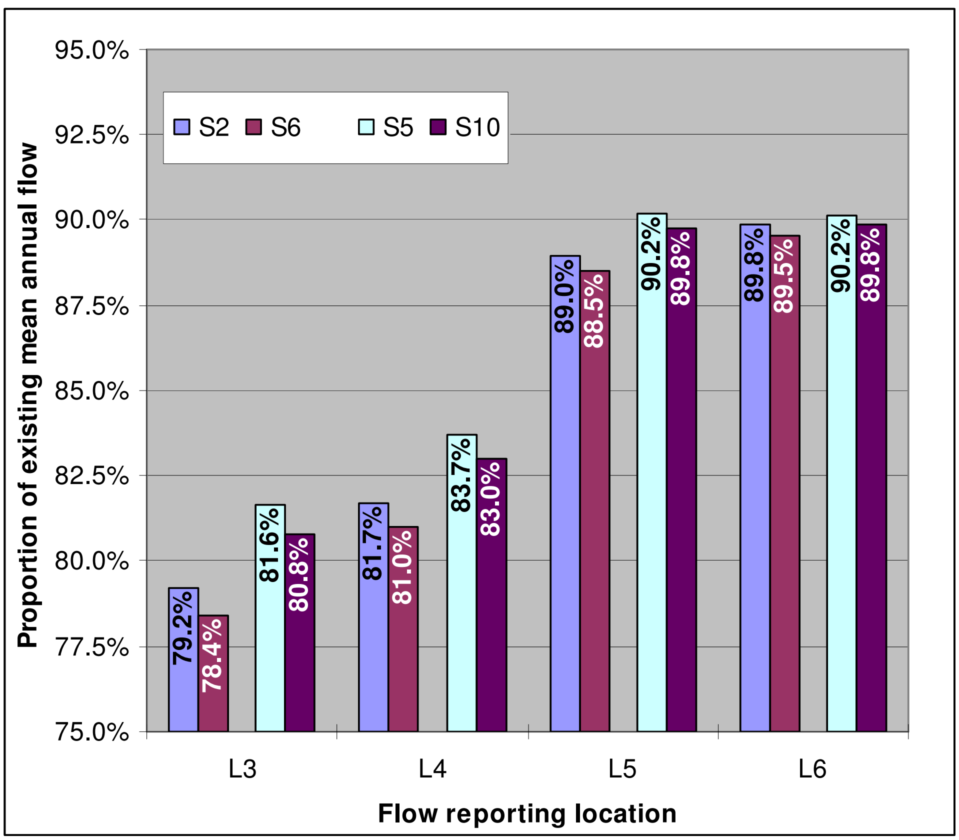
Scenario 10 is based on the 2020 arrangements with modified Changtan Reservoir operating rules and the provision of environmental flows. The model results for this scenario should be compared to the results from Scenario 5. This second scenario is the most extreme variation from the arrangements proposed 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.

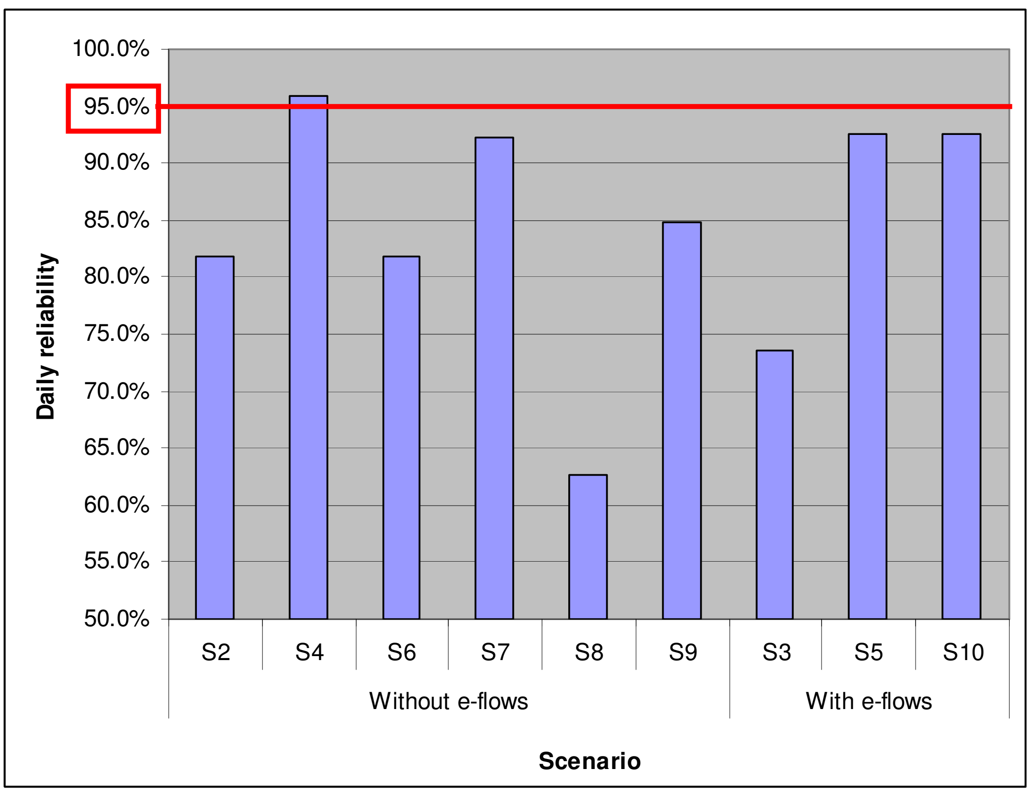
Consequently, transferring water via a pipeline from Shisandu Reservoir to Zhuxi Reservoir appears necessary to ensure the predicted 2020 demands for water from Changtan Reservoir can be met.

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
		Average annual supply (% of demand)	97%	97%
		Daily reliability (% of days full daily demand met)	93%	93%
	Irrigation	Average annual supply (ML)	151,089	162,024
		Average annual supply (% of demand)	60%	65%
		Annual reliability (% of years full annual demand met)	0%	0%
Zhuxi	Urban/Industrial	Average annual supply (ML)	13,514	13,513
		Average annual supply (% of demand)	100%	100%
		Daily reliability (% of days full daily demand met)	100%	100%
	Irrigation	Average annual supply (ML)	10,645	11,258
		Average annual supply (% of demand)	95%	100%
		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.

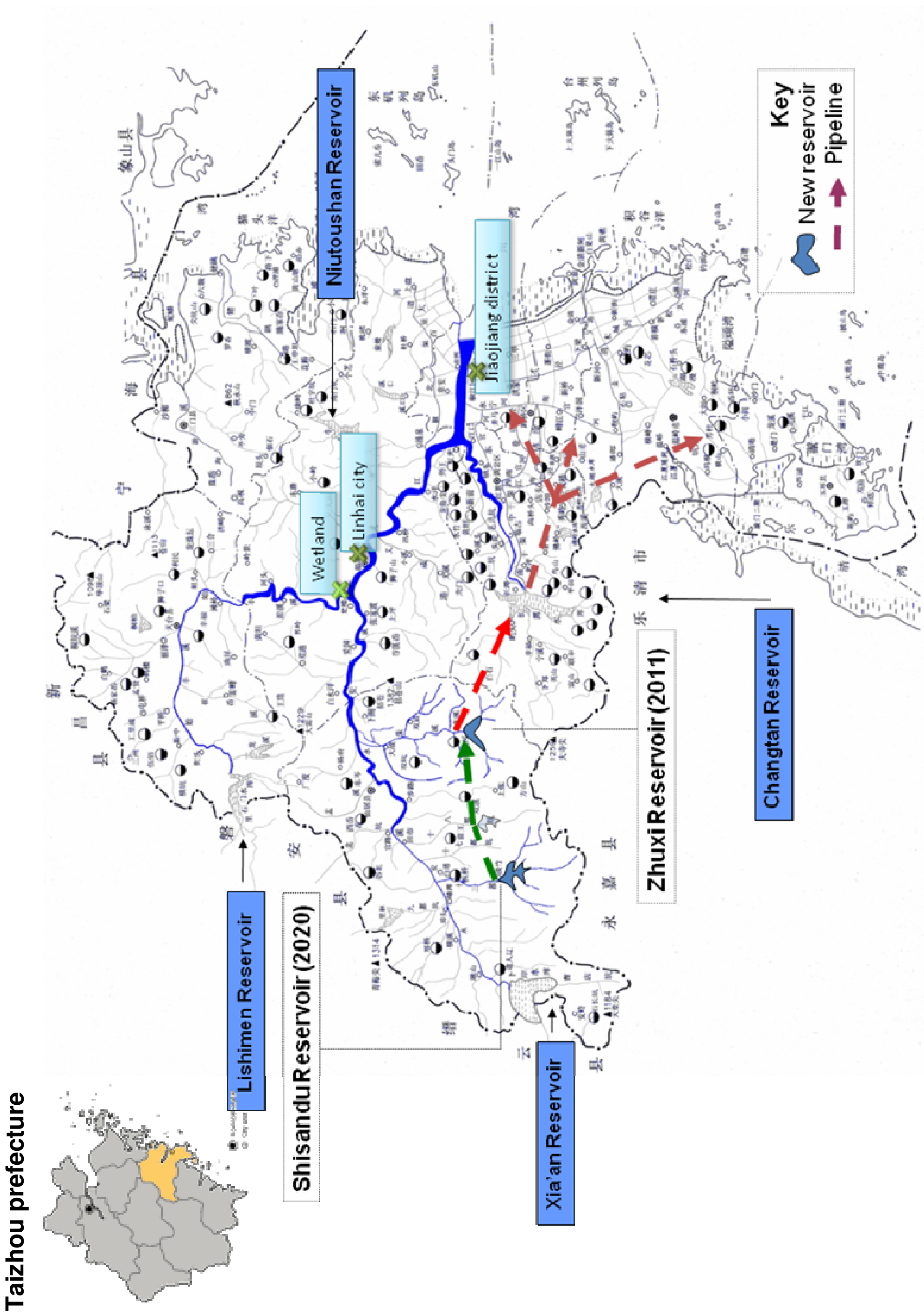
Table 33: Supply performance results – Scenario 11

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
Lishimen Reservoir
Shisandu Reservoir (2020)
Xia'an Reservoir
Zhuxi Reservoir (2011)
Changtan Reservoir
Wetland
Linhai city
Niutoushan Reservoir
Jiaojiang district
Key
New reservoir
Pipeline

Appendix 2: Information Sources for Asset Identification

Asset	Type	Information source				Information description		
		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