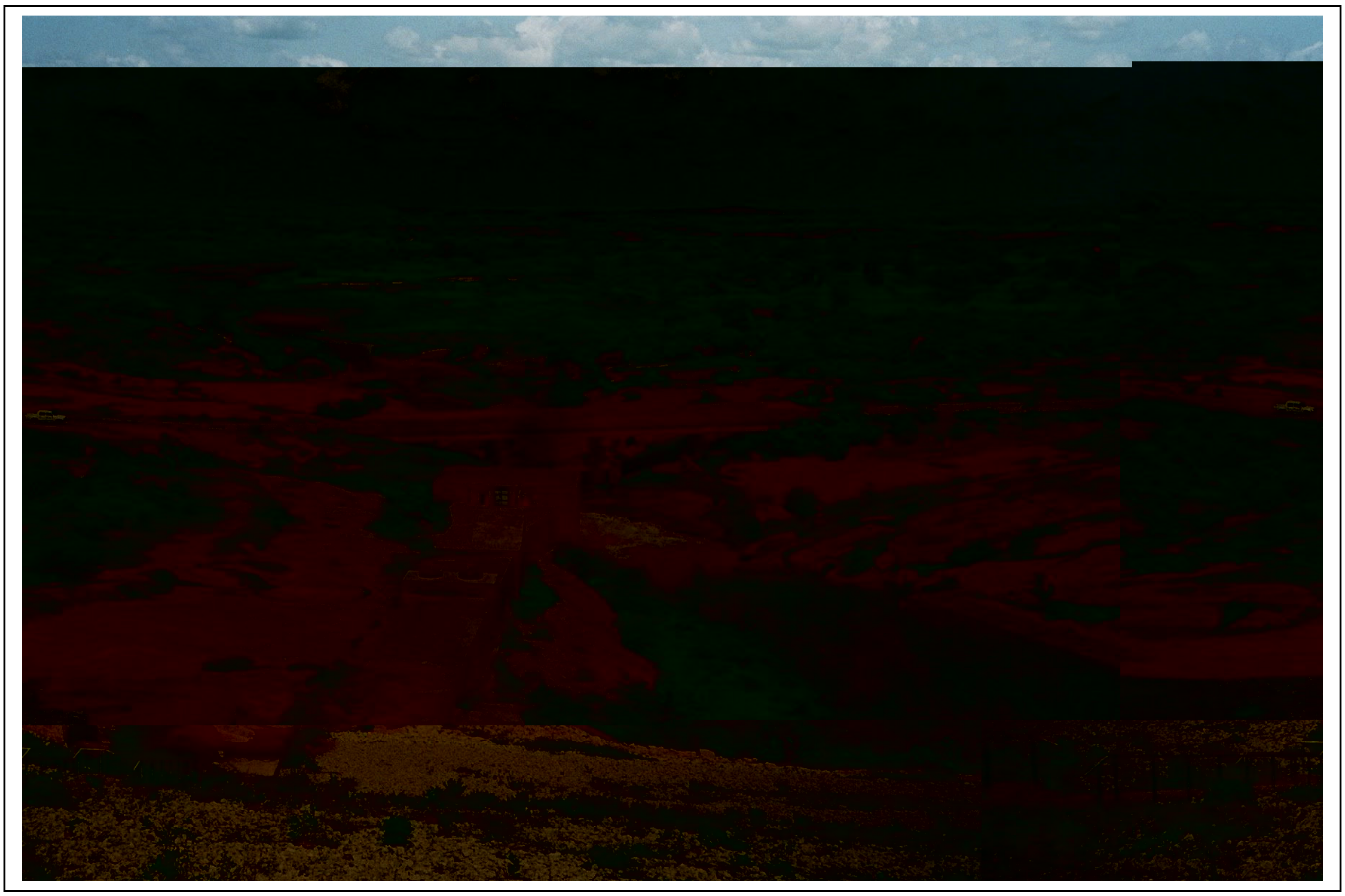
Pre-water audit for the Komadugu-Yobe River Basin, northern Nigeria and southern Niger



(Challawa Dam releasing water into Challawa River, August 20th, 2005)

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Executive Summary

A water audit is an assessment of current, and anticipated water availability and demand. This report is a pre-water audit that is defined as the preparation for the water audit by determining the available and missing data for the work and a proposed step-by-step work plan on how the water audit can be executed. The pre-water audit study was executed for the Komadugu-Yobe Basin in Sudan-Sahel zone of northeast Nigeria and southeast Niger.

The study (12 working days) relied substantially on: existing sources of data, articles, short field trips, discussions with experts working in the basin, the consultants previous working experience in the basin and his database for the basin. The study: 1) provided an overview of the water audit relevant and accessible data (water availability and water uses); 2) gave an initial impression of the quality of the available data and made recommendations on more elaborate data quality checks, 3) added relevant hydrological and meteorological data, reports and articles from the consultants database, 4) identified data gaps that need to be filled for the water audit, 5) assessed the hydrometric network, 6) proposed a step-by-step work plan (surface and groundwater) on how the water audit can be executed , 7) identified a number of consultancy firms who may be considered for the water audit, 8) estimated the required time (workdays) and personnel for the audit, 9) made an inventory of accessible water quality studies, 10) executed ~20 surface water quality field tests, 11) prepared a work plan for a surface water quality study, 12) assessed briefly the rainfall data for the basin.

The identified information gaps for the surface water audit are:

- The availability of recent (1999 to date) river flow data.
- The availability of data on water uses and hydrology for Niger.
- Information on the Komadugu River (water uses and availability).
- Information on in- and outflow rates from the two large dams and the Hadejia Barrage.
- Prediction on the impact of climate change scenarios on the rainfall and river flow in the basin.
- Information on environmental river flow requirements.
- The scale of the landuse change in the basin and its consequences on the river flow (in the Basement Complex area) and the groundwater recharge (whole basin).

<u>Key-findings concerning surface water, groundwater and water quality</u>

The ongoing work of the KYB Project and visits to relevant institutions for this assignment revealed a lot of unexpected relevant hydrological data, especially ongoing river level and groundwater level monitoring. Due to a lack of funds and access to gauging equipment the monitored recent (1999 to date) river levels have not been recalculated into actual discharge data. In the light of the most urgent requirements for the water audit, recent river flow data, it is recommended that the KYB Project sets up a 'fire-brigade' team to do as many river discharge measurements as possible during the ongoing wet-season at the identified sites with recent stage level data. The KYB Project can also encourage the relevant organisations to do water level measurements at the identified crucial sites in the basin.

Generally, there are no indications for a long-term decrease in shallow groundwater level in the basin. Expansion of existing shallow groundwater monitoring network in the basin may be required depending on the outcome of the water audit. Emphasis for locations of additional monitoring wells should be put on areas with significant groundwater abstractions and areas where the river flow reductions have been or are expected to decrease.

No water quality monitoring network has been identified for the basin. Only some ad-hoc water quality studies have been carried out. These studies have indicated a poor shallow groundwater quality (nitrate content up to 500 mg l^{-1}) inside villages and towns. This is probably due to poor sanitation. Especially, in the upstream part of the Hadejia River the available studies show a poor surface water quality. The analysis revealed extremely high (sometimes more than 100 times the WHO limits) levels of toxic wastes. The main pollution source for the toxic waste is discharge from industries. Urban waste, large and small irrigation projects also contribute to the worsening of the water quality in the basin. A very limited water quality survey is recommended, to be carried out by KYB Project staff, in order to get a clearer picture of seriousness of the water pollution in the basin. This

will hopefully help the Ministries of Environment and Water Resources (national and state) in making informed decisions on the need for the enforcement of the environmental laws.

Key-findings concerning institutional aspects

The most essential participating partner of the Komadugu-Yobe Basin Project is the Federal Ministry of Water Resources because they are responsible for the coordination of the development of the water resources in the basin. It is therefore recommended to involve the FMWR very closely with all the stages of the coming water audit.

For the water audit it is also important to stay in close contact with the DFID-JWL Project on their proposed and ongoing interventions in the basin. Especially, the proposed and partly executed improvements on the intake works of Kano City Water Supply is a crucial progress for the sustainable water management in the basin that should be continued after the DFID-JWL Project ends (December 2006).

Table of contents

Figure

List of tables

List of appendices

Abbreviations

ADP	Agricultural Development Project (part of state ministries of agriculture)
BSMWR	Borno State Ministry of Water Resources (Maiduguri)
BaSADP	Bauchi State Agricultural Development Project
BaSWB	Bauchi State Water Board
CAZS	Centre of Arid Zone Studies (Maiduguri)
CBDA	Chad Basin Development Authority
DFID-JWL	Department for International Development - Joints Wetlands Livelihoods Project (Dutse).
DSS	Decision Support System
EC	Electrical Conductivity of water
FME	The Federal Ministry of Environment (Abuja, formerly FEPA)
FMWR	Federal Ministry of Water Resources (Abuja)
FMARD	Federal Ministry of Agriculture and Rural Development (Abuja)
GEF	Global Environmental Facility (from UNEP)
GIS	Geographical Information System
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Ministry for Technical Cooperation)
HJRBDA	Hadejia-Jama'are River Basin Development Authority (Kano)
HNW	Hadejia-Nguru Wetlands
HNWCP	Hadejia-Nguru Wetlands Conservation Project (Nguru, Yobe State)
HVIP	Hadejia Valley Irrigation Project
HYCOS	Hydrological Cycle Observing System (WMO)
IUCN-BRAO	The West Africa Office of the World Conservation Union (Ouagadougou, Burkina Faso)
JICA	Japanese International Cooperation Agency
JSMWR	Jigawa State Ministry of Water Resources (Dutse)
KCWS	Kano City Water Supply
KNARDA	Kano State Agricultural and Rural Development Authority (or Kano State ADP)
KRIP	Kano River Irrigation Project
KSMWR	Kano State Ministry of Water Resources
KSWB	Kano State Water Board
KYB	Komadugu-Yobe Basin
LCBC	Lake Chad Basin Commission (Maiduguri)
MA	Ministry of Agriculture (state level)
NCF	Nigerian Conservation Foundation (Lagos)
NEAZDP	North East Arid Zone Development Programme (Gashua, Yobe State)
NGO	Non-Governmental Organisation
NWRI	National Water Resources Institute (Kaduna)
PTF	Petroleum Trust Fund
RUWASA	Rural Water Supply and Sanitation Agency (Yobe State, under YSMWR)
RBDA	River Basin Development Authority
SCIP	South Chad Irrigation Project
TAC	Technical Advisory Committee
TOR	Terms Of References
UNEP	United Nations Environment Programme
UNIMAID	University of Maiduguri
WB	Water Board
WC	Water Cooperation (under State Ministry of Water Resources)
WEAP	Water Evaluation And Planning, water management software developed by the Stockholm Environment Institute
WRECA	Water Recourses and Engineering and Construction Agency (Kano State)
WHO	World Health Organisation
WMO	World Meteorological Organisation
YSADP	Yobe State Agricultural Development Project
YSMWR	Yobe State Ministry of Water Resources

1 Introduction

1.1 The Komadugu-Yobe River Basin

1.1.1 Description of the Komadugu-Yobe River Basin

The Komadugu-Yobe River Basin (Figure 1) is situated in the Sudan-Sahel zone of northeast Nigeria (~85,000 km^2; WRECA, 1972) and southeast Niger (~63,000 km^2; Oyebande, 2001). Most of the flow (~80%) in the Hadejia River system, which is a tributary of the Yobe River, is controlled by the upstream Tiga Dam (completed in 1974) and Challawa Dam (completed in 1992, Figure 1). The Jama'are River is presently uncontrolled but plans exist to build a dam at Kafin Zaki (Figure 1). The Komadugu River, another tributary of the Yobe River, forms a wide floodplain downstream of Dapchi. The confluence of the Komadugu and Yobe rivers is largely silted up. This river thus provides only a small and unreliable contribution to the Yobe River. All three tributaries of the Yobe River are effluent until they reach the geological boundary between the largely impermeable rocks of the Basement Complex and the permeable sands, gravels and clays of the fluviatile and lacustrine Chad Formation. The Hadejia River splits into three channels in the Hadejia-Nguru Wetlands (HNW): the northern channel (Marma Channel) flows into the non-returning Nguru Lake, the southern channel (Old Hadejia River) joins up with the Jama'are River to become the Yobe River and the relatively small channel in between is called the Burum Gana River (Figure 1). In the eastern part of the basin the Yobe River forms the border between Nigeria and Niger. There are no major tributaries to the Yobe River in Niger. The Yobe River empties into the northern pool of Lake Chad and is the only river flowing into the northern pool. The present contribution into the Lake Chad area is estimated at less than 2.5% of the total input (UNEP, 2004). The river gradients in the upper part of the basin are up to 5 m km^{-1}. The average gradient of the Hadejia River in the middle part of the basin is 0.13 m km^{-1} (IWACO, 1985). In the flat middle and lower parts of the basin, the river spills onto the floodplains during the wet season (June to October). The most extensive floodplain areas in the basin are the HNW between Hadejia and Gashua (Figure 1).

The mean annual rainfall ranges from over 1,000 mm in the upstream Basement Complex area to approximately 400 mm in the middle part of the basin and less than 300 mm near Lake Chad. However, climatic variability has resulted in these mean annual rainfall values being unrepresentative for different periods. Hess et al. (1995) calculated an average decline in annual rainfall of 8 mm yr^{-1} between 1961-90 for the north-eastern arid zone of Nigeria (i.e. the middle and lower part of the basin). Since the mid-1990s the decreasing trend in annual rainfall seems to have been reversed.

The dams at Tiga and Challawa supply water to two large, partly finished, formal irrigation schemes; namely the Kano River Irrigation Project (KRIP) and Hadejia Valley Project (HVIP). The dams also contribute to Kano City Water Supply (KCWS). The traditional farming system in the basin is predominantly rain-fed. Small-scale irrigation, which uses pumped water from the shallow aquifers, rivers and inundated flood plains has been stimulated through grants since the 1980s. Farmers in the middle and downstream parts of the basin depend largely on river flow because the rainfall is low and unreliable. Flood based rice farming and flood recession farming provide an important supplement in the HNW and along some parts of the Yobe River. Furthermore, the floodplains serve as a fishing area and a grazing area for cattle in the dry season. The ecosystems of the wetlands are very rich when compared to the surrounding dry uplands (Okali and Bdliya, 1998). The Marma Channel and Nguru Lake are designated Ramsar sites. Another important function of floods, for local farmers and village wells, in the HNW is groundwater recharge (Goes, 1999).

1.1.2 Water management problems in the basin

The hydrological issues of concern in the Komadugu-Yobe River Basin are:

1. Uncoordinated surface water uses. The potential surface water requirements in the Hadejia sub-basin are 2.6 and 1.8 times larger than the mean available surface water resources, for the Hadejia and Jama'are Rivers, respectively (IUCN-HNWCP, 1999).
2. The invasion of aquatic weeds, notably *Typha domingenis*, in the Hadejia sub-basin. The consequences of which are: a) macrophyte and silt blockages in the HNW which prevent the Hadejia River from contributing to the Yobe River; b) hindrance for the use of surface water bodies for fishing, navigation, etc.; c) the creation of a favourable environment for the multiplication of vectors of waterborne diseases; and d) a reduction in biodiversity.

3. Extremely large and small floods (e.g. 1998 and 2001; and 1992 and 1993 respectively). The extremely large floods resulted in the displacement of several hundred thousands of people in 1998. The floods in 2001 took the lives of over 200 people and displaced over 35,000 (HR Wallingford 2002; Niasse et al., 2004). Furthermore, contrary to what was expected after the completion of the dams the timing of the floods in the HNW became less predictable and even resulted in dry-season floods (Goes, 2002). Along the Marma Channel in the Hadejia-Nguru Wetlands the flooding has become more or less permanent since ~2001. Some villages had to be moved (e.g. Dabar Margini to the west of Nguru Lake) and the Hadejia-Nguru road is almost completely inaccessible during the wet-season.
4. The irregular and low flows in the Yobe River have affected the small and large irrigation schemes along this river; many of these schemes are now abandoned (Chiroma et al., 2005). With the exception of 2001 the flooding of the floodplains along the Yobe River have been very limited in the past five years (A. Barde NEAZDP, pers.com).
5. The shrinking and splitting of Lake Chad at the downstream part of the Yobe River (UNEP, 2004). Although the historical contribution from the Yobe River to Lake Chad had been small, under the present circumstances any little increase in inflow into the lake would be significant.
6. A suspected degradation in water quality.

1.2 The KYB Project

The Project for improving land and water resources in the Komadugu Yobe Basin (KYB) is a joint initiative of the World Conservation Union (IUCN), Nigeria Federal Ministry of Water Resources (FMWR) and the Nigerian Conservation Foundation (NCF). The Project is in its initial phase (early 2005 to May 2007) with the objective of improving the institutional framework for managing water resources in the Komadugu-Yobe Basin (see IUCN-BRAO & FMWR, 2004 for a complete outline of the Project). This will be done through consensus on key water management principles and institutionalised consultation and coordination mechanisms.

A major component of the KYB Project is the building of a 'Decision-Support Knowledge Base' so that water management options and other resources management decisions are taken on the basis of up-to-date information on water audit, socio-economic and ecological conditions in the basin.

1.3 Objectives and terms of reference

A water audit is an assessment of current, and anticipated water availability and demand. This report is a pre-water audit that is defined as the preparation for the water audit by determining the available and missing data for the work and a proposed step-by-step work plan on how the water audit can be executed. The KYB Project gave an assignment with the objective to carry out the pre-water audit. The itinerary can be found in Appendix 1. The scope of this study was modest in terms of time (12 working days) and relied substantially on accessible data sources (articles and reports), discussions with experts working in the basin as well as the consultant's previous working experience and his database on the basin.

The activities for the assignment consisted of:

- Examining the by the KYB Project identified sources information for the water audit and determining the adequacy of the sources. If not adequate, recommend a modified list and/or a list of additional sources of information and appraise the same.
- Pooling additional information from the consultant's knowledge base (e.g. consultant's library) and from other sources in the basin (such as study reports, etc.) together with information currently available in the KYB Project office, for an initial review exercise.
- Providing an overview of relevant and accessible data for the water audit (water availability and water uses)
- Giving an initial impression of the quality of the available data and make recommendations on more elaborate data quality checks for the water audit
- Identifying data gaps that need to be filled for the water audit
- Making for the water audit relevant recommendations on the hydrometric network (surface and groundwater) in the basin.

1.4 Submitted data to the KYB Project

A CD containing data is also submitted with this report to the Project Coordinator of the KYB Project. Most information on the CD is from the consultant's personal database. The CD includes:

- all hydrological data (daily river flow, river gaugings, rating curves, groundwater levels, etc.) from IUCN - Hadejia-Nguru Wetlands Conservation Project (HNWCP),
- the IUCN-HNWCP surface water model developed for the water management options,
- all hydrological reports from IUCN-HNWCP,
- about 40 scientific papers on the basin in a pdf format,
- monthly rainfall data for Nguru (1942-98, from Department of Meteorological Services - Nguru),
- meta-data files on river flow,
- a fairly complete monthly river flow database for the basin (based on Diyam, 1996, IUCN-HNWCP, WRECA and JICA, 1995).

The following analogue data from the consultant's personal database were also given for photocopying to the Database Coordinator of the KYBP:

- the Diyam (1996) report on river flow data,
- monthly river flow data (1967-90) for Bagara Diffa in Niger on the Yobe River (UNESCO, 1995),
- the IUCN-HNWCP hydrology reports,
- a map from Kano State Agricultural and Rural Development Authority (KNARDA) with locations of boreholes in Kano and Jigawa States,
- about 20 scientific papers on the basin.

1.5 Outline of report

Chapter 2 discusses the meteorological data (mainly rainfall). Chapter 3 presents information on surface water availability in the basin (current and predicted river flows). The hydrological characteristics of the rivers and the hydrometric network are also discussed. Chapter 4 continues with the groundwater resources in the basin. The different aquifers and groundwater recharge studies are summarised. Chapter 5 examines the demand side of the water audit; the present and potential future water uses. Chapter 6 is on surface and groundwater quality. The sediment in the rivers is also briefly discussed. Chapter 7 proposes a work method for the water audit. The last section of chapter 7 proposes a work method for a surface water quality study in the basin. Chapter 8 comprises a summary of the executed work, conclusions and recommendations.

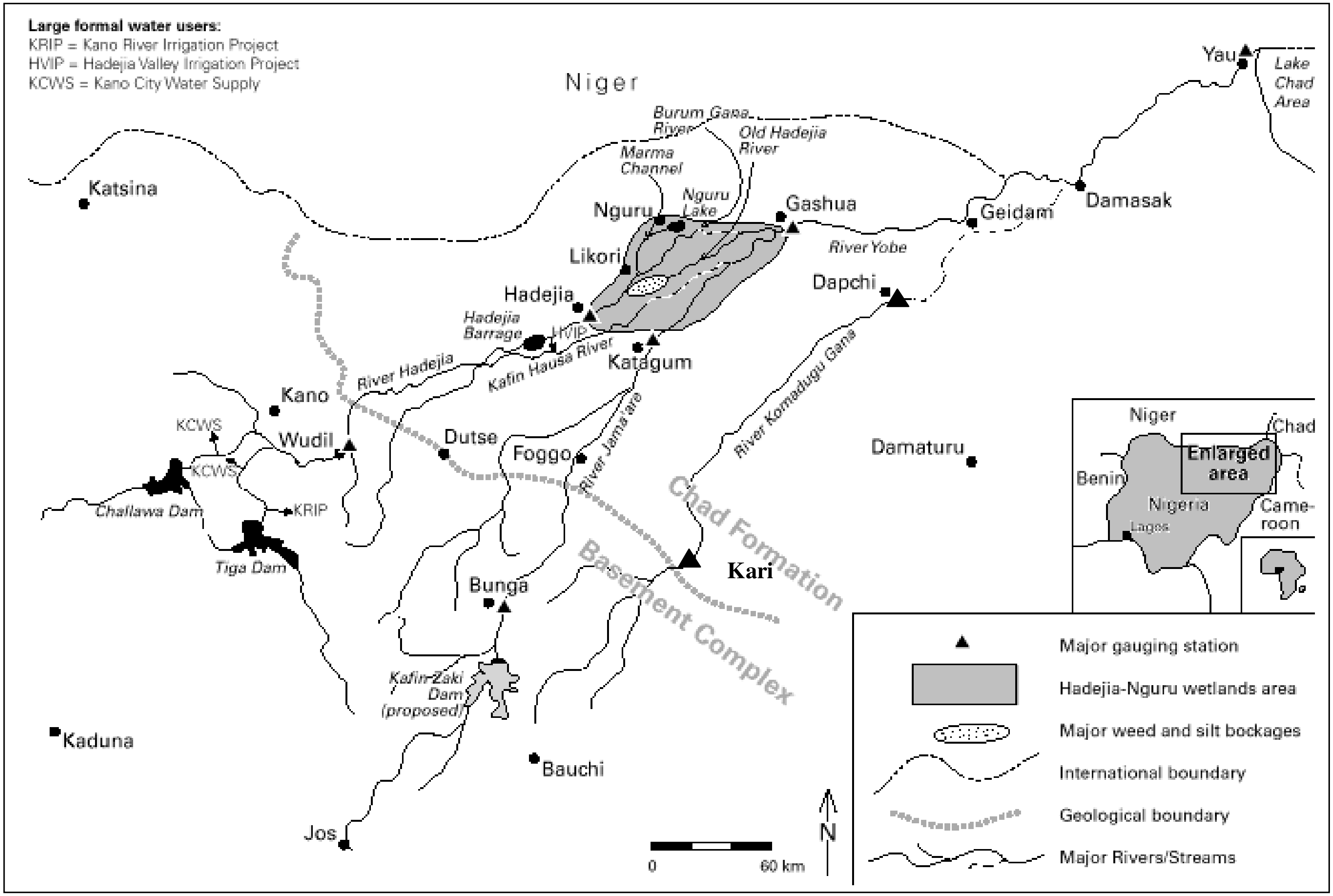

Figure 1 **Map of the Komadugu-Yobe River Basin (prepared by M. van der Valk for Goes, 2002).**

2 Meteorology

2.1 Meteorological data

The following governmental organisations monitor meteorological parameters in the basin:

- The Federal Department of Meteorological Services runs the following synoptic meteorological stations (e.g. rainfall and evaporation) in or near the basin: Nguru, Maiduguri, Potiskum, Kano, Jos, Zaria and Bauchi (the last two stations are just outside the basin). The data can be bought for a relatively high price. The stations situated in the upstream Basement Complex area (the four latter stations) are the most interesting stations for the water audit because they may be useful for rainfall-runoff modelling. It may also be worthwhile to purchase the few missing years of Nguru rainfall data (1999 to date) in order to get a complete long-term data set for the middle part of the basin.
- The Bauchi State Agricultural Development Project (BaSADP) runs nine meteorological stations (rainfall, evaporation, etc.) within the whole of Bauchi State.
- The Jigawa State Agricultural Development Project (ADP) collects meteorological data for 21 stations within their state (JSMWR, 2000).
- The Hadejia-Jama'are River Basin Development Authority (HJRBDA) and Kano State Ministry of Water Resources (KSMWR) have meteorological stations at three large reservoirs in the basin (Tiga Dam, Challawa Dam and Hadejia Barrage). These data are important for the water audit in order to determine the direct rainfall on the reservoirs and the evaporation from the reservoirs. The evaporation pan for Challawa was taken away for repairs during our visit (20 August 2005).
- The North East Arid Zone Development Programme (NEAZDP) runs a meteorological station (rainfall, evaporation, wind, temperature, humidity, etc.) within their compound at Garin Alkali. In addition, they run 17 meteorological stations in their project area (the northern part of Yobe State).
- KSMWR has 15 meteorological stations within Kano State. Many of the stations are at the sites of small dams.
- Meteorological data are most likely also collected in the part of the basin that is situated in Niger. The data may be obtained through the Lake Chad Basin Commission (LCBC, contact: Mohammed Bila).

The following organisations have a database on meteorological data:

- School of Agriculture Food and Environment, Cranfield University, Silsoe have rainfall and evaporation data for the stations in Nigeria (see Hess et al. 1996; Hess 1998). The data are probably also available at Centre of Arid Zone Studies (CAZS) and University of Maiduguri (UNIMAID).
- International Crops Research Institute for the Semi-Arid Tropics (Niamy, Niger) has rainfall data for Maine Soroa in Niger (see Hess et al. 1996).
- Meteorological data (evaporation and rainfall) were collected from the Meteorological Services Agency (for Nguru) and also measured by IUCN-HNWCP (available on enclosed data CD).

Selected reports and publications with meteorological data are:

- Older meteorological data for northern Nigeria can be found in the agroclimatological atlas (Kowal and, 1972).
- Mean monthly evaporation data for Kano and Nguru is provided in Hollis et al. (1993).
- Yearly (1970-1989) and mean monthly rainfall data for nine stations in the basin is presented in JICA (1995).

2.2 Analysis of meteorological data

There have been many publications that analyse rainfall in the Sahel (Hôte et al., 2002; Ozer et al., 2003; Dai et al., 2004). All these publications agree that there has been rainfall deficit in the Sahel during the 1970s, 1980s and the first half of the 1990s. Hess et al. (1995) calculated an average decline in annual rainfall of 8 mm y^{-1} during 1961-90 for the north-eastern arid zone of Nigeria. In the literature, there are some discussions on whether or not the rainfall deficit continued in the Sahel during the second half of the 1990s and beyond. A very recent publication (Nicholson, 2005) compared, for the West African Sahel, 1998-2003 rainfall data (satellite estimates) with older rain gauge data. For the southern Sahel, in which the Komadugu-Yobe basin is situated, the paper concluded that the rainfall (1998-2003) has returned to pre-drought levels of the 1950s and 1960s. Still, August remained relatively dry during the period 1998-2003. The rainfall data for Maiduguri confirms this positive trend from the late 1990s to 2003 (UNIMAID, 2004). Another interesting observation is the fact that large multi-year oscillations appear to be more frequent and extreme after the late 1980s (Dai et al., 2004). This may result in large inter-annual variations in river flow.

Hess (1998) has shown for three meteorological stations in the middle and lower part of the basin (Nguru, Potiskum and Maiduguri) that over the period 1961-91 there has been an increase of about 1.5^{o}C in mean air temperature during the growing season, dominated by an increase in minimum temperature. Still, the paper concludes that the observed increase in temperature has not be great enough to result in a significant increase in reference evapo-transpiration.

3 Surface water resources

3.1 River flow data

The following sources on river flow data for the Komadugu-Yobe Basin have been identified:

- The Diyam report (1996). The former Kano State Water Recourses and Engineering and Construction Agency (WRECA) took up daily stage board monitoring and regular river gaugings in the basin in 1963. In the early 1970s approximately 20 stations were monitored. From the late 1970s onwards the number of river flow monitoring sites and the quality of the collected data started to decrease due to a reduction in available resources. In the late 1980s the monitoring of the hydrometric network had ceased almost completely. The 'old' WRECA was dissolved in 1991 and the 'new' WRECA has no longer been involved with hydrological data collection. Published (WRECA 1970, 1972, 1974, FMWR) and previously unpublished river flow data collected by the former larger (including Jigawa) Kano State are presented, using upgraded rating curves, by Diyam Consultants (1996). The WRECA archives have been searched thoroughly for this study. Furthermore, the river flow data have undergone extensive quality checks. Therefore it is recommended to use this database as the base for the water audit. The digital daily rivers flow database from Diyam (1996) was made available to FMWR, Petroleum Trust Fund (PTF) and Federal Ministry of Environment (FME or FEPA). It should be noted that the stations on the Yobe River downstream of Gashua and on the Komadugu River are not included in this database. So for these data the WRECA yearbooks, unpublished data from the WRECA archives and JICA (1995) have to be consulted.
- The Hadejia-Nguru Wetlands Conservation Project (HNWCP) re-initiated river flow monitoring in the early 1990s (Morgan 1994, Goes and Zabudum 1996, 1998, 1999), but mainly in the middle part of the basin. The HNWCP database includes the stage-board data from NEAZDP (mainly Gashua) and Jigawa State Ministry of Water Resources (JSMWR, Hadejia). Due to a lack of funds HNWCP stopped river flow monitoring in the late 1990s. The HNWCP river flow database, including the rating curves, is made available to the KYB Project from the consultant's personal library (on enclosed CD). The 1994-98 data for Bunga are, until high discharge gaugings are carried out and the rating curve is updated, less reliable. The remainder of the HNWCP river flow database is considered reliable because it is based on regular gaugings. All the river flow data, including the gaugings, are available on the enclosed CD.
- Niger also monitored (and possibly still does) the river flow in the Yobe River. For one river flow station, Bagara Diffa (~25 km east of Damasak), monthly river flow data (1967-90) have been located (UNESCO, 1995) and made available to the KYB Project for this assignment. It is recommended to contact the relevant institution(s) in Niger in order to find out if more (daily) river flow data are available for this and other sites on the Yobe River. This may be done through the LCBC (contact: Mohammed Bila).
- Julius Berger (Kano) may have been monitoring (at least in the 1990s) the water level on the Jama'are River downstream of the proposed Kafin Zaki dam site (Bunga near Ningi). The status and accessibility of their data are unknown. It is probably most appropriate to make the request for the data through the HJRBDA.
- Based on a rainfall-runoff model (IHACRES) Afremedev (1999a) generated a complete 33-year (1950-83) monthly inflow series, in a situation of no dams, for the four major sub-catchments (Bunga, Challawa, Chiromawa and Wudil) that form the headwaters of the Hadejia-Jama'are River Basin. The generated natural runoff series were compared with the measured runoff for the period 1963-72. It should be noted that the relevant graphs that compare the measured (WRECA data) and the modelled runoff are not included in the draft report from Afremedev, which was available for this assignment. A first comparison (not in this report) reveals that the Afremedev estimates tend, especially for the dryer years, to be a bit higher than the measured annual river flow data from Diyam. The generated Afremedev data should be compared more elaborately with the measured 'Diyam data' in order to examine how useful it will be to fill in the data gaps, especially for the pre-Tiga (<1974) years. The Afrmedev data are available on the enclosed CD. Generating more recent data with the same rainfall-runoff relation will be difficult because the rainfall-runoff relation has probably changed due to landuse changes in the basin.

For recent river flow data the following organisations should be consulted:

- The FMWR installed automatic stage level recorders in ~2001 near Chiromawa Bridge (on Kano River downstream of Tiga and Bagauda dams) and Auyo Bridge (on Hadejia River upstream of Hadejia). The availability of the data from the recorders is unclear.
- In early 2005 the FMWR (department of Hydrology and Hydrogeology) installed automatic stage level recorders at Dabi (Hadejia River downstream of Wudil) and Jorda (on a tributary to Hadejia River near Gezawa). The HJRBDA installed automatic stage level recorders: downstream of Tiga Dam (Kura-Karaye Bridge), downstream of Challawa Dam, at Wudil (unfortunately the site of the recorder is wrongly placed), Kafin Hausa and Hadejia. The JSMWR also collaborated in this exercise. The FMWR is the only organisation that has the interface to retrieve the stage level data from all the (nine in total) automatic recorders. Plans exist to buy an additional interface next year for the JSMWR and/or HJRBDA.
- The HJRBDA has reported to have daily data on reservoir levels and rough outflow rates (based on the characteristics of the release structures) for the three large reservoirs in the basin (Tiga Dam, Challawa Dam and Hadejia Barrage). The HJRBDA also monitors the inflow into KRIP. The amount of water coming from the spillways is not monitored.
- The JSMWR (contact: Dr M. Idris) has stage-board readers at sites on: the Hadejia River (Dabi, Suntulmawa-Ringim, Nahuche, Marke, Haidin, Hadejia), the Kafin Hausa River (Kafin Hausa), the Marma Channel (Likori), a small river near Kazaure (Jekarada) and a tributary to the Jama'are River (Iggi). The water level data have kindly been made available to the KYB Project.
- NEAZDP has daily stage-board readers (since late 1990s) on the Yobe River (Gashua and Geidam) and on the Komadugu River (Gada near Dapchi). NEAZDP has made quite some effort in trying to get access to gauging equipment in order to recalculate the data into daily discharge rates. Unfortunately, they did not succeed. The stage data will be made available to the KYB Project.
- The Department for International Development - Joints Wetlands Livelihoods Project (DFID-JWL, contact: Alh. M. Chiroma) is doing regular (once a month in the dry season and twice a month in the wet season) river gaugings on the Hadejia River (at Hadejia), Marma Channel (at Likori) and Burum Gana River (at Guri and Wachakal) since June 2004. The data have kindly been made available to the KYB Project (on enclosed CD)[1].
- The Borno State Water Cooperation has been monitoring stage levels at Damasak from 1987 to date. The data have kindly been made available to the KYB Project.
- The Borno State Ministry of Water Resources (BSMWR) used to monitor the stage level at Yau. It should be verified if unpublished stage level data are available.
- The KSMWR say they are currently monitoring the stage levels at Tiga Dam, Chiromawa (Kano River), Tomas Dam, Kafin Chiri Dam and at Wudil. The data are reported to be in the Challawa office. At this moment it is not clear how accessible and complete these data are. The Database Coordinator of the KYB Project has collected some of the data.

The following current meters have been identified in the basin:
- The FMWR - Department of Hydrology & Hydrogeology has two new current meters (contact: Olufemi O. Odumosu - Deputy Director Operational Hydrology)
- The equipment from HNWCP is now being used by DFID-JWL (possibly faulty, contact: Alh. M. Chiroma).
- The JSMWR has two current meters, they are reported to be not in a good condition. One current meter has been lend to the DFID-JWL Project. The JSMWR lacks the resources to do the gaugings themselves (contact: dr. Muslim Idris).
- The KSMWR has two old current meters (possibly faulty).
- The YS Water Cooperation may have current meters (possibly faulty).

Furthermore, it should be noted that the monitoring of river flow in the Lake Chad Basin under the Hydrological Cycle Observing System (HYCOS) project is under consideration (WMO, 2004). An overview of the available river flow data is presented in Appendix 2.

2.1.2 Observations on the river flow data and the hydrometric network

The following observations are made on the hydrometric network in the basin:

[1] Some corrections are required in the way the field data have been put into the spreadsheet that calculates discharge. I have informed the PC and Hydrologist of the KYB Project on the required corrections. I will also e-mail the suggested corrections to Alh. Chiroma from DFID-JWL.

- From the early 1960s up to the late 1980s the river flow have been monitored by the relevant governmental institutions. The river flow database is fairly complete and has, for the upstream part of the basin (down to Gashua), undergone various data quality checks.
- Most of the available data is on a monthly basis (see enclosed data CD). Daily river flow data still need to be obtained from the relevant institutions. Daily river flow data from the IUCN-HNWCP is available on the enclosed CD (from the consultants personal database).
- After the 1980s the monitoring of the river flow has been done mainly by Non-Governmental Organisations (NGO). This is not a sustainable situation because: the projects have a limited time span, usually only focus on a limited part of the basin and stop the river flow monitoring when they run out of funds. The most notable consequence is the fact that there are, as far known, no stage level data from 1999 to present on the Jama'are River because the funding for the IUCN-HNWCP became minimal after April 1998. For the continuity it is therefore recommended that NGO's with a limited time-span, like the KYB Project, assist with capacity building on river flow monitoring within the relevant governmental institutions, notably the two River Basin Development Authorities (RBDA), NEAZDP and the active State Ministries of Water Resources.
- It is very encouraging that despite meagre funding some organisations have continued the stage level readings in some of the rivers. These organisations urgently require assistance with river flow gaugings in order to construct rating curves to calculate daily discharge. If there are time and budget constraints it is recommended to focus the river flow gaugings on the stations listed below (Table 1).When doing the gaugings the existence of the following should be confirmed: 1) a stage-board in a good condition, 2) the identity of the stage-board reader and 3) the sheets with the raw stage data. The gauging data are crucial for the water audit in order to quantify the river flows during the past six years. *It is strongly recommended that the KYB Project, possibly in cooperation with the DFID-JWL Project, takes up the gaugings with the highest priority during the ongoing wet season (starting August 2005).*
- The JSMWR is monitoring the stage levels at many stations between Wudil and Hadejia (Dabi, Suntulmawa-Ringim, Nahuche, Marke, Haidin). From a basin-wide perspective these are not stations with the highest priority for river gaugings. Still, the development of rating curves for these sites will be very useful to study the causes of the river flow reductions between Wudil and Hadejia that has frequently been discussed in the literature (e.g. Hollis et al. 1993; Thompson, 1995; Goes 2002).
- It is strongly recommended to arrange backup in the form of a stage-board reader for the relevant river flow monitoring sites that only have automatic gauges. This recommendation is made because, from the consultants personal experience in this basin and the Volta Basin, automatic gauges can and often will malfunction and the resources may be limited to extract the data in time before the battery runs out. Furthermore, it is recommended that effort to be made to enhance the commitment of the readers to the work by, for example, paying the readers in time, providing them with a bicycle if they live far from the stage-board and letting them have annual results of their work (river flow graph for the site).
- The most important river flow monitoring stations in the basin and their present status are summarised in Table 1.

Table 1 **Overview of the most important river flow monitoring stations in the Komadugu-Yobe Basin (see Appendix 1 for data availability)**

Location	River	Priority	Present status	Reason for being important
downstream of Tiga (Kano)	Kano	1	FMWR/HJRBDA automatic stage recorder installed in 2005, outflow estimated by HJRBDA, stage-board reader KSMWR?	to monitor releases from Tiga Dam
Challawa Gorge (Kano)	Challawa	1	FMWR/HJRBDA automatic stage recorder installed in 2005, outflow estimated by HJRBDA	to monitor releases from Challawa Dam (excluding water from the spillway)
Wudil/Dabi [2] (Kano/ Jigawa)	Hadejia	1	automatic stage recorder installed in 2005 in wrong location, stage-board reader KSMWR?	to monitor water availability in Basement Complex in Hadejia River System from the dams and uncontrolled flow, flows still well contained within river channel
Kafin Hausa (Jigawa)	Kafin Hausa	2	stage-board reader JSMWR, FMWR/HJRBDA automatic stage recorder installed in 2005	to monitor outflow from Hadejia River into Kafin Hausa River, baseline data for proposed flow proportioning structure at Miga
Hadejia (Jigawa)	Hadejia	1	stage-board reader JSMWR[3], FMWR/HJRBDA automatic stage recorder installed in 2005, four recent gaugings by DFID-JWL	to monitor river flow reductions between Wudil and Hadejia (natural and HVIP uses), and to monitor inflow into HNW
Likori (Jigawa)	Marma Channel	1	stage-board reader JSMWR, seven recent gaugings by DFID-JWL	to monitor flow into Marma Channel to Nguru Lake (too much water in recent years), baseline data for proposed flow proportioning structure at Magujin Idi
Guri[4] (Jigawa)	Burum Gana	2	no monitoring, seven recent gaugings by DFID-JWL	to monitor effects of dredging & weed clearance, baseline data for proposed flow proportioning structures at Likori
Wachakal (Yobe)	Burum Gana	3	no monitoring, seven recent gaugings by DFID-JWL	to monitor effects of dredging & weed clearance, outflow of Hadejia River System towards Yobe River
upstream of Gabarua[5] (Yobe)	old Hadejia	2	no monitoring	to monitor contribution from Hadejia to Yobe River (very low in recent years due to weed/silt blockages), baseline data for proposed 3-way flow proportioning structure at Likori or 2-way structure at Magujin Idi
Bunga (Bauchi)	Jama'are	1	no monitoring	to monitor water availability in Basement Complex in Jama'are River (downstream of proposed Kafin Zaki Dam), flows still well contained within river channel
Katagum (Bauchi)	Jama'are	2	no monitoring	to monitor river flow changes (flow reductions and contributions from tributaries) between Bunga and Katagum, and to monitor inflow into HNW
Kari (Bauchi)	Komadugu	1	no monitoring	to monitor water availability in Basement Complex area in Komadugu River System (no discharge data for past 20 years)
Dapchi (Yobe)	Komadugu	2	water level monitoring by NEAZDP	to monitor river flow reductions between Kari and Dapchi, and flow from Komadugu River towards Yobe River (no discharge data for past 20 years)
Gashua (Yobe)	Yobe	1	water level monitoring by NEAZDP	to monitor outflow of HNW (mainly from Jama'are River) and inflow into the Yobe River
Geidam (Yobe)	Yobe	2	water level monitoring by NEAZDP	to monitor river flow reductions and uses between Gashua and Geidam
Damasak (Borno)[6]	Yobe	2	water level monitoring by BS Water Cooperation	to monitor river flow changes and uses between Geidam and Damasak
Yau (Borno)	Yobe	1	no monitoring	to monitor the outflow from Yobe River into Lake Chad (no discharge data for past 20 years)

[2] if no reliable recent stage data are available for Wudil it is advised to focus the river gaugings on the next station downstream of Wudil where daily monitoring is taking place (Dabi)
[3] it is not clear if the stage-board reader has been reading the stage-board at Hadejia during the past six months because the recent embankment works may have affected the stage-board, I have received contradicting information on this issue.
[4] Discuss with M. Chiroma from JWL on which site in the Burum Gana, closest to the bifurcation with Marma Channel, is most suited for a stage-board
[5] One should select this site with care since cross-flow has been observed upstream of Gabarua bridge from the Jama'are to the Hadejia River (Goes and Zabudum, 1998)
[6] Damasak becomes priority 3 if the discharge data for Bagara Diffa (Niger) pass the quality check and if it is confirmed that the data are up to date.

3.2 Current river flow

3.2.1 Basin Characteristics

The main up- and downstream stations for the four rivers in the basin are: for the Hadejia River system Wudil and Hadejia, for the Jama'are River Bunga and Katagum, for the Komadugu River Kari and Dapchi, and for the Yobe River Gashua and Yau (Figure 1). Hadejia, Bunga and Gashua are the only stations in the basin with long-term (1964-98) records. Table 2 presents, for the eight stations, an overview of the mean annual flow and peak discharge before (1964-73) and after (1979-89) the construction of the Tiga Dam.

Table 2 Overview of the annual surface water resources in the Komadugu-Yobe River Basin

River	Site	Catchment area	Pre Tiga Dam construction					Post Tiga Dam construction			
			Mean annual flow		Mean annual rainfall #	Mean peak discharge	Period	Mean annual flow		Mean peak discharge	Period
		[km^2]	[10^{6}m^3]	[mm]	[mm]	[m^{3}s^{-1}]		[10^{6}m^3]	[mm]	[m^{3}s^{-1}]	
Hadejia	Wudil	16,380	1,915	117	927	946	1964-73	1,004	61	336	1979-89
	Hadejia	30,430	718	24		99	1964-73	523	17	65	1979-89
Jama'are	Bunga	7,980	2,061	258	1,036	1,227	1964-73	1,431	179	890	1979-89*
	Katagum	15,000						1,634	109	381	1979-89
Komadugu	Kari	5,865	542	92			1964-73	176	30		1979-88
	Dapchi	18,090						114	6		1973-78
Yobe	Gashua	62,150	1,397	22		182	1964-73	925	15	143	1979-89
	Yau	148,000	423	3		37	1964-72**				

* excluding 1987
** excluding 1968, 1969
# Wudil: using weighted rainfall from Bauchi, Kaduna and Kano
Bunga: using weighted rainfall from Bauchi, Jos and Kano (Afremedev, 1999)

The four sub-basins (Figure 1) are discussed below.

The Jama'are sub-basin.

The flow in the Jama'are River is ephemeral (June to October) because there are no major dams in this sub-basin. Plans exist to build a large dam at Kafin Zaki (see Section 5.2.2). The river is a gaining river until the geological boundary between the Basement Complex and the Chad Formation. In the Basement Complex area the soils tend to be sandy though shallower than those in the Hadejia sub-basin. The upstream Basement Complex region is hilly (up to 1700 m) with significant areas of bare rock. This implies that the river flow in the upstream part of the basin responds relatively fast to rainfall. Furthermore, the Basement Complex area has retained more of its natural vegetation than in the Hadejia sub-basin (Afremedev, 1999). Downstream of Katagum in the flat HNW the Jama'are River splits into a number of smaller channels. *Typha domingenis* and other weeds did not invade the channels of the uncontrolled ephemeral Jama'are River. The weeds cannot survive in this river because of a lack of water during the dry season and the high wet-season peak flows that flush the main channels clean.

The Hadejia sub-basin.

The river flow in the Hadejia sub-basin is largely (~ 80%) controlled by the upstream Tiga Dam on the Kano River (completed in 1974) and Challawa Dam on the Challawa River (completed in 1992). The dams lack adequate operational information and are (in most cases) operated based on the 'rule of thumb' (Chiroma et al., 2005). The third main river in the upstream part of the Hadejia sub-basin is the Watari River. This river has a small dam that does not influence the river flow significantly. The three rivers join upstream of Wudil to become the Hadejia River. The Hadejia River is a gaining river until the geological boundary between the Basement Complex and the Chad Formation. The upstream Basement Complex region is hilly (with peaks of up to 1200 m). In the upstream area from 1980 onwards there has been a tendency for the tree-dominated savannah to be replaced by landuse for rain-fed agriculture and grazing (Afremedev, 1999). The middle and downstream parts are, except for some ancient sand dunes, relatively flat.

The average annual flow in the upstream part of the Hadejia River (Wudil) reduced by 33% after the completion of Tiga Dam (1979-89). Furthermore, the peak flow is reduced and the river regime has, due to dry-season releases for the three large formal users upstream of Hadejia (i.e., KRIP, KCWS and HVP), changed from ephemeral to perennial. Especially KCWS augments the dry-season flow because a relatively high minimum river flow is required before sufficient water enters the intake-works (Diyam, 1996; Chiroma et al., 2005). A proposal on how the improve the intake-works has been prepared by Neville (2005). Some temporary improvements (sand bags) have already been affected which resulted in a decrease in dry-season flows in 2004 (M. Chiroma, pers.com.). The impact of the peak flow reductions is probably limited in the upstream section of the river due to the relatively high and more reliable rainfall, and the fact that flood rice farming, which depends on peak flows, is not widely practised in this area. The annual runoff and peak flows further downstream at Hadejia, just upstream of the HNW, did not reduce (1979-97) as a result of the construction of the control structures. This is due to the relatively low river flow reductions upstream for low flows at Wudil and the fact that the formal large upstream water users are not (yet) working at full capacity. Further study is needed on the causes and the quantities of these river flow reductions between Wudil and Hadejia. The Kafin Hausa River between Wudil and Hadejia only takes water when the Hadejia River flow at higher flows. This is due to a sand bar in the Kafin Hausa. The threshold above which the river carries water varies, depending on whether the blockages have been (partly) cleared or not. The dry-season river flows at Hadejia increased from 4% of the annual flow in the uncontrolled river to 32% after the completion of the two dams. These dry-season flows: 1) create favourable circumstances for the development of aquatic macrophyte and silt blockages in the HNW which prevent the Hadejia River from contributing to the Yobe River since at least the early 1990s, 2) lead to dry-season floods which are disadvantageous for farmers and herders ,and 3) waste water (Goes, 2002). An increase in nutrient rich water probably contributed as well to the development of the weeds.

Only one value (1,692 km^2 in 1969, Table 3) is available for the flood extent in the HNW for the pre-dams period. 1969 was a wet year with above average annual discharges at Bunga and Hadejia. In 1974 the flood extent in the HNW was 1,369 km^2. It should be noted that some publications do not make a clear distinction between the flood extent in the HNW (Gashua to Katagum and Hadejia) and the flood extent upstream of Gashua along the complete Jama'are and Hadejia rivers. This results in an over estimation of the historical flood extents in the HNW for the misquoted figures from the Schultz reports for 1969 and 1974 (Table 3). For the period 1990-93 a flood extent between 387 and 910 km^2 was observed. In the second half of the 1990s (1994-97) the flood extent was between 967 and 1,806 km^2. No recent flood extent figures are available but generally the flood extent was large or extremely large (e.g. 2001). Along the Marma Channel in the Hadejia-Nguru Wetlands the flooding has become more or less permanent since ~2001.

Table 3 Wet season flood extent along the Hadejia and Jama'are Rivers

Year	Month	Flood extent [km2]		Method and source
		Upstream of Gashua	Had./Katag. to Gashua (HNW *)	
1969	October	2,350	1,692**	aerial photographs (Schultz, 1976)
1974	September	2,004	1,369	aerial survey (Schultz, 1976)
	October	1,846	1,325	aerial survey (Schultz, 1976)
1978	November		1,825	Landsat MSS (Brown, 1987 in: Hollis et al, 1993)
1986	November		1,186	Landsat TM (Sule, 1993 in: Hollis et al, 1993)
1987	September		700	field & aerial surv. (Benthem, 1988 in: Hollis et al, 1993)
1990	September		910	Landsat TM (Sule, 1994 in: Hollis et al, 1993)
1991	September		893	aerial survey (HNWCP)
1992	October		545	aerial survey (HNWCP)
1993	October		387	aerial survey (HNWCP)
1994	October		1,728	aerial survey (HNWCP)
1995	October		967	aerial survey (IUCN-HNWCP)
1996	Oct./Nov.		1,567	aerial survey (IUCN-HNWCP)
1997	October		1,107	aerial survey (IUCN-HNWCP)
1998	October		1,806	estimated from river flow - flood extent relations (1991-97) (Goes and Zabudum, 1999)

* Hadejia-Nguru Wetlands
** estimated on basis of total flood extent in 1969 and percentage of total flood in HNW in October 1974

The Komadugu Gana (Misau River) sub-basin.

The river flow in the upstream part of the Komadugu River at Kari is in the pre-dams period roughly 25% of the flow in the upstream part of the Hadejia (Wudil) or Jama'are (Bunga) rivers (Table 2). The period of predominant flow is June to October (Kari) and August to December further downstream (Dapchi). The river is a gaining river until the geological boundary between the Basement Complex and the Chad Formation. The river flow reductions are, compared to the Jama'are and Hadejia rivers, relatively large. On average (1970-77) the river flow reduction between Kari and Dapchi is 73%. The river forms a wide floodplain downstream of Dapchi. The confluence of the Komadugu and Yobe rivers is largely silted up. This river thus provides only a small and unreliable contribution to the Yobe River. In almost all the studies on the Komadugu-Yobe Basin this river is neglected. So, for the water audit, special attention should be paid to filling in this information gap (e.g. determining river flow relations).

The Yobe River.

The Yobe River is situated in a very flat ancient alluvial plain overlying the lake sediments of the Lake Chad formation. Approximately 43% of the water that flows into the HNW flows into the Yobe River at Gashua. Due to the weed and silt blockages the contribution from the Hadejia to the Yobe River has been practically nil since at least the early 1990s (see above). NEAZDP and Yobe State Agricultural Development Project (YSADP) reported a slight increase in the contribution from the Hadejia to the Yobe River due to the clearing of weeds and silts in a part of the Burum Gana River. The clearing was initiated by DFID-JWL Project in the 2004/5 dry-season. If the Gashua annual discharge is taken as 100% then roughly 70% arrives at Geidam, 45% at Damasak and 28% at Yau. This relation was valid from 1963 to at least 1985. It is not known if this relationship has changed since then (IUCN-HNWCP, 1999). The period of predominant flow is June to October (Gashua) and August to January at the downstream end (Yau). The Yobe River ends into the northern pool of Lake Chad and is the only river flowing into the northern pool. The present contribution into the Lake Chad area is estimated at less than 2.5% of the total input (UNEP, 2004).

3.2.2 Influences on river flow

The four important factors that influence the river flow in the basin are: rainfall, water uses, weed and silt blockages and the landuse.

Rainfall. The rainfall in the upstream part of the basin, the Basement Complex area, determines the water availability in the rivers and the large reservoirs. So these data are relevant for rainfall-runoff modelling. Rainfall in downstream part of the basin is important for: rain-fed agriculture, groundwater recharge and the filling of small depressions with surface water.

Water uses. An increase in water uses and large reservoirs (see Section 5) lead to a decrease in river flow.

Weed and silt blockages. The weed and silt blockages affect the river flow in the HNW and the contribution from the Hadejia River to the Yobe River (see Section 3.2.1).

Change in landuse. A change in landuse can have a significant impact on the river flow. For example, in the upstream part of the White Volta in Burkina Faso there was an amplified runoff (108%) despite a reduction in rainfall. The increase was due to the following changes in land use; namely, increase in cultivated area, increase in area with bare soil and a decrease in area with natural vegetation (Mahe et al., 2003 and 2005). In the upstream part of the Hadejia Basin there have been reports of a decrease in area with natural vegetation (Simon, 1997; Afremedev, 1999). Still, presently there is a lack of information on the scale of changes in landuse in the upstream part of the Hadejia and Jama'are sub-basins and its possible effects on the inflow into the dams and the runoff. Downstream of the geological boundary between the Basement Complex and the Chad Formation a change in landuse will have less effect on the runoff because the river is no longer effluent but infiltrating.

3.2.3 Future river flow

The calibration of global climate models is strongly biased to western countries in the northern hemisphere, where the data collection network is most dense. This is a concern for developing countries where the impacts of climate change is expected to be the largest while the information on the coming/ongoing changes is generally poor. In the literature no information was found on the impact of downscaled global climate scenarios on the water resources in the Komadugu-Yobe Basin. This lack of information has also been identified by UNEP (2004). Most climate change scenarios for West Africa predict a decline in precipitation in the range of 0.5 to 40% with an average of 10 to 20% by 2025 (Niasse, et al 2005). However, the impact of climate change does not always predict a reduction in future water resources for all river basins in West Africa; for example for the Volta Basin two out of the three available studies predict an increase in rainfall and river flow (Kunstmann and Jung, 2005; Andah et al., 2003; and Opoku-Ankomah, 2000 cited in GEF 2002). What is important to note is that almost all the climate scenarios predict a high variability in rainfall and river flow. So for the water audit it is important to include scenarios with extreme (high and low) water availabilities.

4 Groundwater resources

4.1 Groundwater data

List of groundwater level monitoring and borehole inventory databases in the basin:

- YSADP reports to monitor (4 times per year) 10 shallow tube-wells in the whole of Yobe State since 1994.
- BaSADP reports to monitor (once per month) approximately 290 wells since 1994 (some of the data is summarised in BaSADP, 2004).
- BS Water Cooperation reports to monitor the groundwater level at ten sites in Borno State (a map with locations is available at the KYB Project).
- KNARDA reports to monitor (monthly) at least 46 wells within in Kano State. There are also 24 wells with a data logger that are operated by the FMWR. KNARDA is not able to retrieve these data themselves because they do not have the right equipment. KNARDA still has the groundwater level data for Jigawa State from the time it was still part of Kano State. KNARDA (Kano) also has, for the whole of the former Kano State, an extensive database on borehole information, with amongst others lithological descriptions, and geo-electrical measurements. The locations and a listing of boreholes with hand pumps can be found on a printed map (KNARDA, undated).
- The FMWR also has shallow groundwater levels from monitoring wells, equipped with a pressure logger, in Jigawa State. The measurements were taken for the 'National Fadama Phase 1 Project' evaluation report.
- NEAZDP monitored the groundwater level along the Yobe River and in the sand dunes north of Gashua (Kaska) in the 1990s. Some of the analysed data can be found in Carter et al. (1994) and Carter and Alakali (1996).
- From the early to the late 1990s IUCN-HNWCP had a well and later also a piezometer network in which the water level was monitored regularly (13 wells were monitored daily and 27 wells were monitored 2 to 5 times per year). Some of the analysed data can be found in Goes (1999). All the water level data are available on the enclosed CD.
- The FMWR has an unpublished borehole data inventory
- The LCBC has facilitated several studies on the groundwater in the basin (UNESCO/UNDP, 1972 and BRGM, 1993). The latter report selected 30 groundwater-monitoring sites but as far as known the groundwater monitoring programme has never materialised. Later this year the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) is likely to start together with the LCBC a groundwater study for the whole Chad Basin.

4.2 Aquifers in the Komadugu-Yobe Basin

Based on various studies a summary of the main characteristics from the aquifers in the basin has been compiled in Table 4.

Table 4 Summary of the characteristics of the aquifers in the Chad Basin.

Description	Depths	EC [µS/cm]	Yield [l/sec]	Recharge	Remarks
Phreatic aquifers (or Upper Zone aquifer) Quaternary sands and clayey sands	0 to 30 m (max. ~150 m)	50-5,000 (mean 340)	2-5	direct infiltration of rainfall, river bed, floodplains and Lake Chad	high nitrate concentrations have been observed, permeability 10-143 m d^{-1}, not exploited near Lake Chad because sediment is too fine
Middle zone aquifer, Early Pliocene	200-400 m (generally 10 to 40 m thick)	700-4,000 (mean 856)	5-10	none or minimal, possibly around outcrops of rocks	confined, used to be artesian, well exploited in Nigeria
Lower Zone aquifers, Continental Terminal, alternation of clay and sandstone, Oligocene-Miocene	420-650	mean 708	max. 30	none or minimal, possibly around outcrops of rocks	confined, used to be artesian

sources: Bunu 1999; Diyam 1987; Maduabuchi 2005; Odada et al. 1996; Olivry 1996; Olugboye 1995; UNEP 2004

In the wet season the groundwater head of the phreatic aquifer generally dips away from the Komadugu-Yobe River and its floodplains, this in agreement with the fact that it is an infiltrating river system downstream of the Basement Complex Area (see Section 3.2.1). Most information indicates that the phreatic groundwater level in the basin that falls within Jigawa, Yobe and Bauchi states has been, besides seasonal variations, relatively constant for the past 15 years. This conclusion is based on experiences from the NEAZDP drilling team (Ahmed Hamza, pers.com.), well monitoring networks from the YSADP and BaSADP and close contacts between the ADP's and local farmers (pers.com., A.J.Gashua form YSADP, M.A.Bello from BaSADP and dr. M. Idris form JSMWR). During the period IUCN-HNWCP operated the well water level monitoring network (1991-97) in the HNW, strong seasonal trends were measured but no long-term decline or increase in groundwater level has been observed. Also a comparison with scarce water level data from the 1970s and 1980s do not indicate a consistent change in groundwater level in the HNW (Goes and Zabudum, 1998). Still, water level monitoring data available at the FMWR is reported to indicate a shallow groundwater level drop of ~1 m y^{-1} within Jigawa State (data collected for an unpublished report prepared for the Fadama 1 project). Maduabuchi (2005) also reports a groundwater level drop in the phreatic aquifer (no data presented in this publication). These contradicting reports need to be clarified in the water audit. There are general concerns on the shallow groundwater levels for the near future since the number of shallow groundwater abstraction wells in the basin is increasing rapidly.

Using remote sensing and Geographical Information System (GIS) maps Leblanc et al. (2003) produced a map with recharge and discharge areas for the phreatic aquifer along the Yobe River. Based on these data they improved a groundwater model for phreatic aquifer in the area. The paper does not provide much information on the level of detail of the model (e.g. how many monitoring wells are used to calibrate the model?, are groundwater abstractions included?, how is the recharge estimated?).

There is probably hardly any hydraulic connection between the phreatic and middle zone aquifer. Both aquifers are, as far as known, separated by a clay layer that has in some places a thickness of up to 100 m (Goni et al., 2000). Based on a study in southeast Niger Le Gal La Salle (1996) concluded that the two groundwater bodies are well differentiated as regards both mineralisation and isotopes.

The head in the deeper aquifers generally dip away from the Maiduguri area towards Chad (Oteze and Fayose, 1988). Near Lake Chad there are still some artesian wells in the 2nd, or middle zone, aquifer. There are many, especially for the Maiduguri area, citations on uncontrolled over-abstraction of groundwater from the Middle zone aquifer in the Chad Formation leading to pressure decline and decline in yield (e.g. Olugboye, 1995; Bunu, 1999; Akujieze et al. 2003; Hazell, 2004; Maduabuchi 2005; UNEP 2004; UNIMAID 2004). As far as known there is no long-term hydrological monitoring to substantiate this. Water points at Ala near Marte (Nigeria) monitored by the LCBC have shown a decline of ~4.5 m within one year (UNEP, 2004). Goni et al. (2000) estimated an average rate of decline in the second aquifer for the area northeast of Maiduguri of 0.5 m y^{-1} over the period 1965-1995. There have also been reports of artesian boreholes wasting water continuously. Normally the local authorities cap the artesian wells, but local people uncap them and allow water to flow and cool so that their animals can use it (Bunu, 1999; UNEP 2005). Isotope data indicate that the water in the middle and lower aquifers are similar. This may indicate the possibility of hydraulic connection between both aquifers. Still, the connection may also have been induced by boreholes (Maduabuchi, 2005).

4.3 Groundwater recharge

4.3.1 Recharge of shallow aquifer

The possible mechanisms for shallow groundwater recharge in the Hadejia-Jama'are-Yobe River Basin are: (1) direct infiltration of rain into the ground, (2) infiltration through riverbeds, and (3) infiltration through inundated flood plains. Below is a summary of relevant studies on groundwater recharge in the river basin.

In a sand dune area 60 km northeast of Nguru, Carter et al. (1994) observe a mean annual water-table variation of 0.13 m in 11 piezometers during a one-year period. Carter et al. (1994) estimate the recharge, using a model simulating the shallow aquifer behaviour, to be 49 mm y^{-1}, which is 17% of the local annual rainfall. The authors consider local rainfall as the most likely recharge source. The relatively high recharge can be explained by a high infiltration rate and a low vegetation density in the sand-dune area. For the same area similar recharge rates, 14-49 mm y^{-1}, are obtained from a chloride mass-balance method using seven profiles from the unsaturated zone in the semi-arid Kaska area (Edmunds et al., 2002). Based on six unsaturated zone profiles and rainfall records from Maiduguri Goni et al. (in press) estimated a minimum long-term recharge rate for NE Nigeria of 19 mm y^{-1}. Edmunds et al. (1999) estimate the regional recharge rate in NE Nigeria at 60 mm y^{-1}.

Using an estimated mean gradient of 0.81 m km^{-1} and a mean shallow aquifer transmissivity of 100 m^2d^{-1}, IWACO (1985; quoted in Carter and Alkali 1996) estimate groundwater recharge along the Yobe River (286 km) between Gashua and Lake Chad (Figure 1) in 1984 to be 17 x 106 m^3. It should be noted that IWACO's survey was carried out in 1984 during a period (1982-85) of extremely low river flow. Studies in the Yobe floodplain near Gashua (Carter and Alkali, 1996; Hassan et al. 2004; Hassan et al., in press) conclude that, especially in the floodplains north of the Yobe River, there is a significant clay layer that hampers vertical infiltration through the floodplain and causes the aquifer to be locally confined. Still, there are sandy 'windows' in the clay (parts where the clay is thin and cracks in the clay) through which floodplain recharge occurs. These papers highlight that, in order to assess the potential of the groundwater resources in the floodplain areas, it is crucial to know whether a clay cover is present or not. According to the experiences of the YSADP drilling team there is no extensive clay layer in floodplains along the Yobe River in Yobe State (A. Gashua, pers.com.). Worries have been expressed that the riverbed and the floodplain recharge may be decreasing along the Yobe River due to a decline in runoff in this river (UNIMAID, 2004).

On the basis of a water budget method, the mean (1991-97) wet season unconfined groundwater recharge in the floodplain area between Hadejia and Nguru and in the immediate vicinity (1,250 km^2) has been estimated at 132 mm (range 73-197 mm). The studied floodplain aquifer was, unlike the floodplain near Gashua, not covered by an extensive clay layer and therefore unconfined (Goes, 1999).

4.3.2 Recharge of deeper aquifers

Based on isotopic and hydrochemical analysis of groundwater samples from the whole basin (Edmunds et al. 1999; Maduabuchi, 2005) it was concluded that the groundwater in the Middle and Lower aquifers is paleowater dating back from a wetter period between 20,000 and 40,000 years before present. Both studies concluded that the current recharge to these aquifers is minimal. However, it could be possible that the aquifers receive meteoric inputs from outcrop areas (possibly 'Pays Bas' in Chad) relatively far away associated with low groundwater flow velocities (Maduabuchi, 2005). The lack of recent recharge in the deeper aquifers is another indication that the thick (50 to over 100 m) clay layer between the phreatic aquifer and the Middle aquifer is extensive.

4.3.3 Future recharge

It should be noted that groundwater recharge may decrease if the climate in the basin becomes drier due to climate change. The possible consequences are a decrease in river flow and consequently a decrease in riverbed and floodplain recharge and a decrease in rain-fed recharge. Still, as discussed above not much is known on the consequence of climate change for the basin (see Section 3.2.3). In Niger a change in land use (increase in bare soil) is linked to a long-term rise in the groundwater table due to an increase in groundwater recharge (Leduc et al., 2001).

5 Water uses

5.1 Data on water uses

The management of the water resources in the basin is spread out over approximately 30 governmental institutions. There are two federal authorities, two river basin development authorities and five states (Kano, Jigawa, Bauchi, Yobe and Borno) responsible for developing the water resources in the Komadugu-Yobe Basin. Each state has at least three different institutions that are involved in the management of the water resources. The names and tasks may differ a bit per state.

The following governmental organisations have responsibility for the management of the water resources in the basin:

- The Federal Ministry of Water Resources (FMWR) is responsible for the formulation of the water policy and the coordination of the development of the water resources in the basin. The FMWR have delegated some of their tasks to the two RBDA and the ministries of water resources for the states..
- The Federal Ministry of Agriculture and Rural Development (FMARD) is responsible for the agricultural production (including cattle rearing and fisheries) in Nigeria.
- The River Basin Development Authorities (HJRBDA for the upstream states and Chad Basin Development Authority (CBDA) for the downstream states) are, formally, responsible for the development of groundwater and surface water resources. In reality their emphasis is on the development of large-scale irrigation projects that mainly use surface water. The HRBDA manages the large water structures in the basin (Tiga and Challawa dams and the Hadejia Barrage).
- The State Ministries of Water Resources are responsible for the formulation of the water policy and the coordination of the development of the water resources within their respective states. They are responsible for the management of most small dams.
- The State Water Boards (part of the State Ministries of Water Resources) are mainly responsible for urban (domestic and industrial) and for Kano State also for rural, water supply (mainly groundwater and some small dams). Yobe State does not have a Water Board.
- Four states have separate organs for rural and semi-urban water supply. Borno and Yobe states have a Water Cooperation for this task. In Bauchi State this task is executed by a Ministry for Rural Development. Jigawa State has a Small Towns Water Supply Agency and a Rural Water Supply Agency (both under JSMWR) for this task. For Yobe State the Water Cooperation takes care of (semi)urban water supply, while the Rural Water Supply and Sanitation Agency (RUWASA) handles the rural water supply.
- The State Ministries of Agriculture are responsible for the development of larger irrigation projects.
- The World Bank assisted Agricultural Development Programs (ADPs, part of State Ministries of Agriculture) promote, at the state level, the use of small irrigation pumps for the abstraction of shallow groundwater and surface water in the floodplains for small scale irrigation.
- The LCBC (contact: Mohammed Bila) and the FMWR (Director of Dams and Reservoirs) have information on water uses on the part of the Komadugu-Yobe Basin that falls within Niger. A visit to the relevant governmental institutions in Niger may be required to complete the data on Niger. Transboundary water issues are also discussed in the 'Nigerian-Niger Joint Commission'.

The following reports provide information on water uses for all sectors for the whole basin:

- The study on the National Water Resources Master Plan for Nigeria (JICA, 1995). The report also provides water uses details on existing and planned dams.
- Water Management Options for the Hadejia-Jama'are-Yobe River Basin (IUCN-HNWCP 1999, Chapter 4).

5.2 Analysis of water uses

5.2.1 Current water uses

Tables 5 to 10 present an overview of the identified major surface and shallow groundwater uses along the Hadejia, Jama'are, Yobe and Komadugu rivers, respectively.

Table 5 Overview of dams and other major water uses in Hadejia sub-basin upstream of Hadejia.

Sites	Type of use	References
Tiga Dam (1974) and Ruwan Kanya Reservoir on Kano River	live storage 1,845 $10^6 m^3$; large scale irrigation (13,300 ha, 1997) for Kano River Irrigation Project (KRIP), Kano City Water Supply (KCWS), fishing	HJRBDA; Adams (1991); Adams et al. (1993); Afremedev (1999d); Diyam (1986, 1996); IUCN-HNWCP (1999); Oyebande (2003); Oyebande and Nwa (1980); Simon (1997)
Tudun Wada Dam (1977) on Kano River	live storage 18 $10^6 m^3$; irrigation	KSMWR; WRECA (1980)
Bagauda small dam (1970) on a tributary to Kano River	live storage 21 $10^6 m^3$; Kadawa Irrigation Scheme; domestic water supply, dam collapsed in 1988	KSMWR; Diyam (1996); Oyebande and Nwa (1980); WRECA (1980)
Marashi Dam (1980) on Challawa River	live storage 6 $10^6 m^3$; irrigation	KSMWR; Diyam (1986, 1996); WRECA (1980)
Challawa Dam (1992) on Challawa River	live storage 904 $10^6 m^3$; Kano City Water Supply (KCWS), fishing	HJRBDA; Diyam (1996); IUCN-HNWCP (1999); Neville (2005)
Pada Dam (1980) on Challawa River	live storage 10.5 $10^6 m^3$; irrigation	KSMWR; Diyam (1986, 1996); WRECA (1980)
Karaye Dam (1971) on a tributary to Challawa River	live storage 16 $10^6 m^3$; urban water supply (Gwarzo, Karaye, Keru and others)	KSMWR; Diyam (1996); Oyebande and Nwa (1980); WRECA (1980)
Magaga Dam (1980) on Challawa River	live storage 17 $10^6 m^3$; irrigation	KSMWR; Diyam (1986, 1996); WRECA (1980)
Gunguzu Dam (1979) on a tributary to Challawa River	live storage 22 $10^6 m^3$; small scale irrigation; domestic water supply (Garo, Gude)	KSMWR; Diyam (1986, 1996); WRECA (1980)
Watari Dam (1980) on Watari River (tributary to Challawa River)	live storage 93 $10^6 m^3$; irrigation	KSMWR; Diyam (1986, 1996); WRECA (1980)
Kafin Chiri (1976) small dam near Wudil on tributary to Hadejia River	live storage 24.6 $10^6 m^3$; domestic water supply, irrigation, dam partly collapsed in 2001 (HR Wallingford, 2002)	KSMWR; WRECA (1980)
Challawa, Tamburawa and Joda	water treatment works for domestic water supply	
Wudil	domestic water supply Wudil (tubewells in the river bank), Gari irrigation project	KSWB; KSMWR
Hadejia Barrage	Hadejia Valley Irrigation Project (3,000 ha, gross; 2,200 ha net. in 2003), fishing	HJRBDA; Diyam (1996)
floodplains along the Hadejia River	small scale irrigation in floodplains using surface and shallow groundwater, groundwater recharge, cattle, domestic uses	ADP and WB Kano and Jigawa states
cities and some villages in the uplands of Kano and Jigawa states	rural and urban water supply, and irrigation(?) using groundwater from 1st aquifer	WB and Ministries of Agriculture of Kano and Jigawa states

Table 6 Dams on smaller rivers that are probably not directly draining into the Jama'are or Hadejia rivers

Sites	Type of use	References with information
Dambo small dam on Gari River near Kazaure	irrigation	MA Jigawa State; Muslim & Umar (1995)
Gari Marke small dam (1980) on Gari River near Kazaure	live storage 203 $10^6 m^3$; irrigation	MA Jigawa State; KSMWR; Muslim & Umar (1995); WRECA (1980)
Mohammad Ayuba Dam (1975) on Watari River near Kazaure	live storage 4.3 $10^6 m^3$; irrigation; domestic water supply	MA Jigawa State; WRECA (1980)
Ibrahim Adamu Dam (1974) near Kazaure	live storage 7.4 $10^6 m^3$; domestic water supply, irrigation	KSMWR; WRECA (1980)
Tomas Dam (1976) on Tomas River near Kunya	live storage 57 $10^6 m^3$; irrigation	KSMWR; WRECA (1980)
Jakara Dam (1976) on Jakara River near Kano	live storage 54 $10^6 m^3$; irrigation	KSMWR; WRECA (1980)
Rimin Gado dam in Gwarzo LGA on Jakara River (on Gwarzo Road)		

Warwade small dam on Warwade River near Dutse	live storage 9.7 $10^6 m^3$; irrigation, domestic water supply	MA Jigawa State; Muslim & Umar (1995); WRECA (1980)

Table 7 Overview of major water uses in the Jama'are sub-basin upstream of Katagum.

Sites	Type of use	References with information
cities and some villages in the uplands of Yobe and Bauchi states	rural and urban water supply and irrigation(?) using groundwater from 1st aquifer	WB for Bauchi and Yobe states
the floodplains along the Jama'are River	small scale irrigation using surface and shallow groundwater, groundwater recharge, livestock, fisheries	ADP for Bauchi and Yobe states
Kafin Gana/Iggi embankment (Kano-Maiduguri road)	irrigation	MA Jigawa State; Muslim & Umar (1995)
Birin Kudu Dam (1970) on Dogwala River tributary to Jama'are	live storage 1 $10^6 m^3$; irrigation, domestic water supply	MA Jigawa State; Diyam (1986, 1996); Muslim & Umar (1995); WRECA (1980)
Galaga Dam (1985) on Galaga River tributary to Jama'are	live storage 20 $10^6 m^3$	HJRBDA; Diyam (1986, 1996); Ben-Musa and Abubakar (1995)
Tsohowar Gwaram on a tributary to Jama'are		Jigawa State
Dogola Dam on a tributary to Jama'are		Jigawa State
Katagum Irrigation Project (no dam)	irrigation, active?	HJRBDA; BaSMWR

Table 8 Overview of the major water uses in the Hadejia-Nguru Wetlands (Hadejia and Jama'are rivers)

Sites	Type of use	References with information
Hadejia River, Marma Channel and Burum Gana River	small scale irrigation in the floodplain using surface and shallow groundwater	ADP for Bauchi, Jigawa and Yobe states; Acharya and Barbier (2000); Chiroma (1996); Goes (1999); IUCN-HNWCP (1999); Prat et al. (1997)
HNW	domestic water uses, livestock uses, groundwater recharge, ecological uses	WB for Bauchi, Jigawa and Yobe states, Chiroma (1996); Chiroma and Polet (1996); Goes (1999); IUCN-HNWCP (1999); Okali and Bdliya (1998a & b)
Wachakal on Burum Gana River	formal irrigation project (70 ha)	YSADP; Adams et al. (1993)

Table 9 Overview of the major water uses in the Komadugu sub-basin.

Sites	Type of use	References with information
cities and some villages in the uplands of Yobe and Bauchi states	rural and urban water supply and irrigation(?) using groundwater from 1st aquifer	YS WC & RUWASA, BaS WB & Ministry for Rural Development
the floodplains along the Komadugu river	small scale irrigation (less than along Yobe River), livestock, fisheries, groundwater recharge	ADP for Bauchi and Yobe states; NEAZDP

Table 10 **Overview of the major water uses in the Yobe sub-basin.**

Sites	Type of use	References with information
cities and some villages in the uplands of Yobe and Borno states	rural and urban water supply (usually ~100 m deep wells) and irrigation(?) using groundwater from 1st aquifer	Yobe and Borno State Water Boards and Ministries of Agriculture; NEAZDP (1990); Carter and Alkali (1996)
the floodplains along the Yobe River	small scale irrigation using surface water and shallow groundwater; YSADP has drilled 4892 shallow (max.~12 m) tube-wells that use ~239 $10^6 m^3 y^{-1}$ (July 2005); at Abadam ~200 ha (CBDA), groundwater recharge, livestock, fishing	Yobe and Borno State Ministries of Agriculture and ADP's; CBDA; NEAZDP Village Water Supply; NEAZDP (1990); Carter and Alkali (1996); Diyam (1996); Wardrop (1993)
Diffa Irrigation Project (Niger)	1,200 ha (1997)	relevant authorities in Niger, LCBC?, IUCN-HNWCP (1999)
Magura (150 ha), Bolorum (100 ha), Bululu (100 ha YSADP ~20 ha CBDA), Laba (~20 ha), Gashua (142 ha, 1997), Kellori/Balle (50 ha, 1997), Geidam (50 ha, 1997), Damasak (40 ha, 1997), Duji (500 ha, 1997), Yau	formal irrigation projects along the Yobe River (many projects are no longer active during past 5 years due to reduced flow quantity and flow period)	YSADP, BSADP, CBDA, IUCN-HNWCP (1999)
Baga Polder Project, water from Lake Chad	formal irrigation, problems with water supply, now concentrating on recession farming	UNEP (2004)
South Chad Irrigation Project (SCIP), water from Lake Chad	formal irrigation, problems with water supply, not functioning (2004), dried up irrigation canals are taken over by Typha	LCBDA; Adams (1991); Adams et al. (1993); IRIN (2003); UNEP (2004)

The most prominent anthropogenic water uses are in the middle and upstream part of the Hadejia River System. These uses are: Kano River Irrigation Project (KRIP), Hadejia Valley Irrigation Project (HVIP) and Kano City Water Supply (KCWS). The main reason for development of large formal irrigation projects is Nigeria's wish to be self-sufficient in food production. KRIP, KCWS and HVIP depend for their water on Tiga and Challawa dams (Figure 1). Most reservoirs are also used for fisheries (a secondary benefit). The water demand for the KRIP has been higher than expected; 24,000-30,000 $m^3 ha^{-1}$ as compared to the planned figure of about 18,000 $m^3 ha^{-1}$. Originally 355 $10^6 m^3 y^{-1}$ was embarked for irrigating 22,000 ha, but for the current area of 13,285 ha almost the same quantity is used (Eng. Kazaure, pers.com. in Oyebande, 2003). The higher demand is explained by changes in cropping pattern (rice irrigation instead of wheat) and excessive losses in the secondary and tertiary irrigation channels. The total water loss throughout the system was estimated at about 50% (Simon, 1997). Some measures to improve the water use efficiency have been undertaken in recent years: 1) desiltation of irrigation canals, 2) farmers in each section have to pay before water is delivered to their section, 3) no water is released into the irrigation sections if it rained the night before,4) there is less water logging of soils because farmers realise now that it affects the yield of the crops negatively (eng. Kazaure, pers.com.). It should be noted that accurate crop yield data, whether irrigated or rain-fed, are extremely difficult to collect and that some authors (e.g. Adams, 1991) suspect that most data are overestimated. So these figures need to be treated carefully when the used water quantities are calculated.

The water demand per ha for the HVIP is also higher than planned due to a high percent of rice cultivation and higher evaporation and lower rainfall than anticipated (Oyebande, 2003). No information was obtained on water losses within the HVIP.

The consequences of the poorly designed and ongoing improvements of the intake structures of KCWS are discussed above (Section 3.2.1). The efficiency of the delivery system of KCWS within Kano is not exactly known but it is probably not very high.

Along the Yobe, Jama'are and Komadugu rives no formal large water uses are present with a similar magnitude as the three projects in the Hadejia River System. Small-scale irrigation that uses surface water or shallow groundwater is the largest water use in the floodplains along these rivers. Other important water uses are livestock, fishing and ecological uses.

Olugboye (1995) provides cited estimates on total groundwater abstraction rates in the (entire?) Chad Basin for the three aquifers for 1985 and 1990. On which raw data the estimates are based is not clear. Goni et al. (2000) provide tables with boreholes and yields that abstract water from the second aquifer. Maduabuchi (2005) provides abstraction rates for the middle and lower aquifers (the source is not specified).

5.2.2 Possible future developments on water uses

In order to develop water management scenarios for the basin the possible future water uses need to be identified and quantified. The following possible future uses and expansions of current uses are identified (roughly ranked in order of likelihood, Table 11):

- The continuation of the ongoing expansion of small-scale irrigation in floodplains.
- Significant expansion of rural (domestic) and urban (domestic and industrial) water uses (notably in Kano). With this respect the millennium development goals ('reduce by half the proportion of people without sustainable access to safe drinking water by 2015') can be considered (www.un.org/millenniumgoals). For a longer timescale the complete fulfilment of the domestic water requirements is the goal.
- Completion of KRIP Phase 1 and HVIP Phase 1.
- The change to less water demanding crops at the formal irrigation schemes.
- Subsidising farmers for implementing water conservation measures (option suggested by UNEP, 2004).
- The construction of new small dams (notably the Gulka Dam on the Komadugu river) and its associated uses.
- The development of the smaller formal irrigation schemes along the Yobe River (if the water availability allows it).
- Full and downscaled versions of Kafin Zaki Dam (e.g. at 100, 70 and 40% of its originally proposed capacity) and its large-scale irrigation schemes.
- Increased evapo(transpi)ration from reservoirs if the temperatures rises in the basin due to climate change.
- Completion of KRIP Phase 2 and HVIP Phase 2 (funding for these projects is extremely unlikely at the moment).

In an appraisal of KRIP Afremedev (1999d) recommended that a decision on whether or not to proceed with the completion of the planned KRIP 1 area (21,850 ha) should be left until: a) the availability of irrigation water is confirmed and b) the existing command area is successfully operated and maintained. Based on economic analyses Barbier (2003) concludes that the expansion of the existing irrigation schemes within the river basin is effectively 'uneconomic' due to impacts on the floodplain uses downstream.

Figures on the population growth in the basin (~2.6% per year), the level of development and the mean domestic water uses are required to estimate future domestic water uses. These figures are generally available for both countries (e.g. United Nations Population Division, Gleick, 2002). Akujieze et al. (2003) gives estimates on the urban and rural water needs (2001) for all the states in Nigeria.

Table 11 Overview of possible expansions of currents water uses and proposed water uses

Sites	**Sub-basin**	**Type of use**	**References with information on quantities**
KRIP	Hadejia	expansion from 13,300 ha to 20,300 ha (Phase 1) and 62,000 ha (Phase 1 and 2)	HJRBDA; IUCN-HNWCP (1999); Simon (1997)
HVIP	Hadejia	expansion to 7,000 ha (Phase 1)	HJRBDA
Kunza Dam on Kano River (proposed)	Hadejia		Hollis and Thompson (1993)
Shimar Dam on Kano River (proposed)	Hadejia		Hollis and Thompson (1993)
Garanga Dam on Kano River (proposed)	Hadejia		Hollis and Thompson (1993)
Kango Dam on Challawa River (proposed)	Hadejia		Hollis and Thompson (1993)
Kafin Zaki Dam (proposed, suspended)	Jama'are	capacity 2,700 $10^6 m^3$, irrigation of 84,000 ha	HJRBDA; Adams et al. (1993); Schultz (1976)
Kawali Dam (proposed)	Jama'are		Schultz (1976); Diyam (1986, 1996)
Kiyako River Dam (proposed)	Jama'are		Diyam (1986, 1996)
Iggi River Dam (proposed)	Jama'are		Diyam (1986, 1996)
Dogwala River Dam (proposed)	Jama'are		Diyam (1986, 1996)
Marra Dam (proposed)	Jama'are		Hollis and Thompson (1993)
Kafin Gana Dam (proposed)	Jama'are		Hollis and Thompson (1993)
Kukuri	Komadugu	formal irrigation (50 ha), contract has been handed out in mid 2005	YSADP
Missau Dam (proposed)	Komadugu		HJRBDA
Gulka Dam (proposed) in Giade LGA	Komadugu	urban water supply for Jama'are, Azare and Misau, proposed capacity 48 $10^6 m^3$	BaSWB
Balle/Kellune and others (see above)	Yobe	revitalisation of formal irrigation projects	YSADP, BSADP
in the vicinity of all rivers	the whole basin	expansion small-scale floodplain farms using shallow groundwater and surface water	ADP's from the states; Diyam (1987); WARDROP (1993); JSMWR (2000)
Formal irrigation on shores of Lake Chad	Lake Chad	revitalisation of SCIP and Baga Polder irrigation projects (if Lake Chad expands again)	LCBDA; Adams (1991); Adams et al. (1993); IRIN (2003); UNEP (2004)

6 Water quality

6.1 Data on water quality

The following governmental organisations have responsibility for monitoring the quality of the water in the basin:

- The FMWR is responsible for the water quality in Nigeria. The ‘Water Quality Laboratories and Monitoring Network’ Department has done a groundwater quality assessment study in 2005 (supported by World Health Organisation (WHO) and UNICEF). The study includes approximately 35 groundwater samples from Yobe State. The samples have been analysed and the interpretation of the data is ongoing.
- The two RBDA’s have the function to control pollution in rivers, lakes, lagoons and creeks (Adams, 1985).
- The Federal Ministry of Environment (FME) has the responsibility to protect and to develop the environment, and to enforce environmental quality standards.
- The State Ministries of Environment have the responsibility to protect and to develop the environment, and to enforce environmental quality standards within their respective states.
- The State Water Boards are the most active on regular water quality checks since they supply water to the most critical water use (human consumption). The filters of the WB boreholes are usually in the deeper parts (>50 m) of the first aquifer. The Bauchi State Water Board (BaSWB) generally only tests the water quality of newly drilled boreholes. The Kano State Water Board (KSWB) reports to monitor the quality of the surface water for the intakes of Kano City hourly.
- The JSMWR monitors the surface water quality twice a year at three sites (Kazaure, Birnin Kudu and Hadejia).
- The ADP for Bauchi State has commissioned two studies that include water quality tests on shallow tube-wells: a study done by Alkachem (roughly 1999-2002) and an ongoing study that is being executed by Endotech.
- There are some ad-hoc groundwater quality tests done by drilling contractors for the CBDA.

The following research institutions have analysed the quality of the surface water in the basin:

- In the late 1990s UNIMAID (Dr Alkali) did some groundwater quality tests in collaboration with NEAZDP within the NEAZP Project area (northern Yobe). The data are not available at NEAZDP.

The ad-hoc water quality measurements and studies are, as far a known, summarised below.

6.2 Surface water quality field survey

For this assignment, field water quality tests were carried out on 24 surface water samples from various locations in the basin. An overview of the water quality tests is presented in Table 12. It should be noted that the survey is a one-time measurement and therefore not conclusive as the water quality is, amongst other things, a function of human activities upstream of the sampling sites, which change with time.

Table 12 Water quality parameters tested for this assignment.

Water quality parameter***	Explanation	Results of field tests	Accepted limits
Electrical Conductivity (EC)**	indication for the amount of ions in the water	< 100 µS/cm, most samples even < 50 µS/cm	750 to 1500 µS/cm*
pH	acidity of the water, 7 is neutral	6.4 to 7, generally ~6.4	6.5-8.5 (WHO)
Nitrite (NO_2)	indicates the presence of biological waste such as manure, nitrite is broken down by bacteria into nitrate	<0.5 mg/l	0 mg/l (WHO) 0.5 mg/l (EU)
Nitrate (NO_3)	indicates the presence of biological waste such as manure	20 to 70	10 mg/l (WHO) 50 mg/l (EU)
Total hardness	sum of ions which can precipitate as 'hard particles'; calcium, magnesium and sometimes iron	18 to 89	
Carbonate ($CaCO_3$) hardness	sum of calcium ions which can precipitate as 'hard particles'; influences pH and CO_2	9 to 179	500 mg/l (WHO)

* or roughly 500 to 1000 mg/l Total Dissolved Solids
** measured with an EC meter from Hanna Instruments (USA)
*** measured with HS test strips

All the results from the water quality test are presented in Appendix 3. Except for one small tributary on the Hadejia River (sample 3) all nitrate values are above the accepted WHO limits of 10 mg/l. The rivers with the least population and the least agricultural activities, the Jama'are and the Komadugu, have the lowest nitrate content (20 to 30 mg/l). The Hadejia and Yobe River (at Gashua) have a slightly higher nitrate content (generally ~40 mg/). The highest nitrate contents were measured in upstream part of the Hadejia River System (50-65 mg/l at Wudil, Kano-Kura Bridge, and in Challawa reservoir) and in the main drainage canal from HVIP (70 mg/l). Upstream of Challawa Reservoir are a lot of small-scale farms. Wudil and Kano-Kura Bridge are downstream of KRIP and Kano. These results indicate that the large and small scale irrigation projects and most likely also urban waste are contributing to the deterioration of the water quality in the basin. The nitrite values are low in all the tests (<0.5 mg/l). The Electrical Conductivity is low (<100 µS/cm and often even <50 µS/cm). In some of the samples the Ph is a bit low (slightly acidic. pH=6.4). The Ph value is similar as measured in the rivers by Schultz (1976). The hardness is well within the recommended limits.

6.3 Surface water quality

The potential sources for surface water pollution in the Komadugu-Yobe basin are mainly in the Hadejia sub-basin, which has the largest irrigation projects, most industries and the most densely populated areas. The potential pollution sources are:

- Drainage water from large (KRIP and HVIP) and small-scale irrigation projects (for sites see Section 5.2.1) may contain insecticides and nutrients from fertilisers. Especially rice and cotton require a high dosage of fertiliser.
- Waste water discharges from urban areas. Organised sewage collection and/or wastewater treatment is virtually non-existent. The largest urban areas near the rivers are: Kano, Wudil, Ringim, Hadejia, Nguru (Hadejia River System), Gashua, Geidam, Damasak and Diffa (Yobe River). The towns along the Komadugu and Jama'are rivers are relatively small.
- Industries, especially tanneries, textile mills and abattoirs, in Kano and other urban areas. About 70% of Nigeria's tanneries are located in Kano (World Bank, 1995). At Kano's three industrial estates industrial sludge and liquid waste are routinely deposited in open drains, sewer systems and watercourses without treatment. The waste treatment facilities that do exist are either inadequate or not functioning (Binns et al., 2003). The waste by-products from tanneries have high concentrations of the heavy metals chromium and cadmium.

It should be noted that pollution of surface water with nutrients (nitrate, phosphate) is a favourable factor for the development of aquatic weeds such as Typha.

Ahmed (1998 cited in Doody 2000) found in the Hadejia river system concentrations of trace elements, such as copper, cadmium and iron that were higher than permissible levels for irrigation and he concluded that this was a result of industrial discharge upstream. A 1989 study, which monitored the activities of 15 tanneries in Kano, found that in all cases permissible levels for effluent discharge were violated, with the exception of pH and temperature (World Bank, 1995). Binns et al. (2003) measured the surface and groundwater quality at different times at four sites in and near the Jakara River in Kano (40 samples in total). The analysis revealed extremely high (sometimes more than 100 times the WHO limits) levels of toxic waste in most of the surface water and in some of the shallow groundwater samples (e.g. Cd up 28.9 mg l^{-1} and Cr up to 49 mg l^{-1}). Although, the Jakara River does not directly drain into the Hadejia River it is not likely that the water quality of the tributaries to the Hadejia River originating from Kano will be much better. For example, it has been observed that there is a drainage canal on Challawa River, near KCWS intake no. 6, that empties thick black sludge into the river (Dr H. Bdliya, pers.com.). The KSWB reported that the intakes for KCWS are upstream of the drainage canals from Kano. Still, the shallow (~10 m) tubewells in the bank of the Hadejia River for the domestic water supply of Wudil are downstream of the drainage canals.

Further downstream in the Hadejia River System, Doody (2000) carried out a surface water quality survey at the end of the dry season (May/June) covering 20 sites in the Marma Channel and Nguru Lake in the HNW. The conductivity varied between 100 and 210 µ cm^{-1}. Nitrate (<2.5 mg l^{-1}) and phosphate (<1 mg l^{-1}) levels were low at all the sample sites. Arsenic (mean 0.018 mg l^{-1}, maximum 0.03mg l^{-1}) was the only trace element recorded in concentrations higher than the WHO limit (0.01 mg l^{-1}). The most likely source was pesticides on crops or birds (*Quela quela*). The conclusion of the study was that the surveyed waters were unpolluted but that there are indicators of threats to the water quality of the wetlands from agrochemicals such as fertilizers and pesticides.

As far as known there are no surface water quality studies for the three other major rives in the basin.

6.4 Groundwater quality

The most important factors that can cause a deterioration in the groundwater quality in the basin are:

- the presence of natural minerals especially in the deeper aquifers;
- the use of fertilisers and agrochemicals for large and small scale agriculture;
- leakage due to poor sanitation and waste dumps in densely populated areas;
- leakage from industrial waste.

A shallow groundwater quality field survey on 72 hand pump equipped wells in and around the HNW had the following worrying conclusion (Goes and Zabudum, 1998). More than half (57%) of the surveyed wells in Nguru and Gashua, and 11% of the surveyed village wells were polluted (nitrate content: 50 to over 500 mg l^{-1}, Electrical Conductivity (EC) 600 to 3,000 µS/cm^{-1}). The high nitrate concentration, which exceeds 5 to over 50 times the accepted WHO drinking water limit (10 mg l^{-1}), is a potential health hazard. The most important cause for the high nitrate levels in the surveyed wells is probably poor sanitation because, generally, the wells in densely populated areas are the most polluted. Nitrate contamination of shallow aquifers in northeast Nigeria was also observed along the Yobe River by IWACO (1985b). Out of 85 samples taken from mainly open wells in the phreatic aquifer north and south of the Yobe River, 51 samples showed nitrate level of 10 to 100 mg l^{-1}. In 7 samples values above 100 mg l^{-1}were measured. Even the eight village wells in the basin measured in 1974 showed a high nitrate content (mean 90 mg l^{-1}, range 7-374 mg l^{-1}; Schultz, 1976). In shallow boreholes used for irrigation at the HVIP also high nitrate levels were found indicating groundwater contamination from fertilisers (Essiet et al., 1995 cited in Doody, 2000).

The water from some of the boreholes from the deeper aquifers have a high (natural) iron, sulphate and/or manganese content (Bunu, 1999; Oteze and Fayose, 1988; Maduabuchi 2005).

6.5 Sediment in the rivers

In the reviewed literature there is not much information on the sediments in the rivers. The mean suspended sediment concentration in the headwaters of the Hadejia System (Wudil) was higher (3072 ppm)[7] than in the in Jama'are River (Bunga 1760 ppm, Oyebande 1979 cited in Olofin 1985). The sediment in the rivers have the following positive and negative impacts:

[7] In the citation of the reference it is not clear if the measurements were done before or after Tiga Dam was built (1974).

- Deposited sediments in the floodplains make the soils fertile for flood and flood recession farms.
- The ecology of the river and the growth of aquatic plants. In the Volta River clearer water as a result of a decreased sediment load due to dam construction is believed to be a favourable circumstance for the development of weeds (Chisholm and Grove, 1985).
- Siltation of river channels in combination with the development of weeds (notably in the HNW). Part of the channels of the old Hadejia River are now completely filled up with weeds and silts (Section 3.2.1). A small gradient of the river channel and reduced peakflows are also favourable circumstance for sedimentation in the HNW.
- Filling up of reservoirs with sediment. The capacity of the reservoirs of some of the smaller dams (e.g. Gunguzu, Marashi, Pada and Tomas) is decreasing significantly due to siltation problems (KSMWR). The sedimentation rate of Challawa Reservoir is probably higher than of Tiga Reservoir because the Challawa River is more turbid (HR Wallingford, 2002). The filling up also reduces the water availability for the uses of the dams. Still, siltation occurs in every reservoir. An important factor influencing the siltation rate is the land-use upstream of the reservoir.
- The control of flash flows by the Tiga Dam resulted in the contraction of the braided Kano River, which is within the Basement Complex just downstream of the dam, into a narrower meandering channel (Olofin, 1984).

7 Water audit

7.1 Introduction

A water audit consists of an assessment of current and anticipated water availability and demand. There are two important choices to be made before doing a water audit:

- The time scale of the audit (annually or monthly or weekly or daily),
- The spatial scale or the size of river sections for which the water audit is executed (whole basin, four sub-basins, four sub-basins each divided into 3 to 4 sections, all first order tributaries to the river, all second order tributaries, etc.).

The factors that influence the choice of time and spatial scales are:

1) The aim for the water audit, in other words, what KYB Project plans to do with the information. For example, a detailed time and spatial scale are required when the outcome of the water audit is going to be used for the management of dams and reservoirs in the basin. The first aim of the water audit is to help policy makers in the basin to take informed decisions on water management planning. Advice on the daily management of the dams would also be very useful because they are (in most cases) operated a 'rule of thumb' basis (Chiroma et al., 2005). Furthermore, the inclusion of flood extents in the water audit also requires a relatively detailed time scale.

2) The available data for the water audit. An important attribute of the presently available data is that there is more monthly than daily river flow data. This underlines the importance of obtaining the digital daily Diyam (1996) river flow database from the FMWR, FME or PTF.

3) The available financial budget for the water audit. The smaller the budget, the less detailed the water audit will be. For example, a water audit based on an annual time scale for the basin as a whole requires a relatively small budget, while a water audit on a daily time and detailed spatial scale would require a larger budget.

Basin wide annual water audits mask intra-annual and local variations on water availability and water uses and is therefore not very appropriate. Considering the urgent need for advice on daily management of the dams and the need for the inclusion of flood extents in the water audit it is recommended to build a model on a weekly time-scale (the same as the IUCN-HNWCP river flow model). A monthly model may be considered if the only goal of the audit is to assist policy makers in making informed decisions.

7.2 Potential consultants for the water audit

The following consultancy companies, with an office in Nigeria, have executed water related projects in northern Nigeria before and may be considered for the water audit (the list is not exhaustive):

- Afremedev - Abuja,
- Diyam Consultants - Kano,
- Enplan - Abuja,
- Jofral - Maiduguri,
- Olapedo Adenle (self-employed consulting hydrogeologist).

At first Royal Haskoning was also considered as a candidate but one of the partners did not feel comfortable with that suggestion. It should be noted that most, if not all, the above mentioned consultant companies do not have permanent qualified staff that can execute the water audit. The companies will most likely temporarily hire people from the same limited 'market' of experts in Nigeria. The team should at least comprise a senior surface water expert, a senior groundwater expert[8] and two young keen and talented juniors. Furthermore, it is recommended that the team also consults a hydro-ecologist on the issue of environmental flows[9]. A water audit is a dynamic process that requires regular updates. For the long-term capacity building of in-house experts within the FMWR it would be useful to look first within the Ministry for the keen and talented juniors. If

[8] It is up to the Consultant Company to propose experts. Still, it is worth to note that a shallow groundwater expert for the Chad Formation has been identified at UNIMAID (Dr. M. Hassan)

[9] IUCN has in-house experts on environmental flows (e.g. Dr. G. Bergkamp)

successful than hopefully these trained experts from the FMWR can take the lead in future updates of the water audit and in advising the senior staff of the FMWR on the management of the water resources in the basin.

In order for the work to become a real team effort it is recommended that Terms Of References (TOR) explicitly reflect that the experts physically share an office for at least two thirds of the time. This should be facilitated by providing them a room in the KYB Project office in Kano. This also ensures close collaboration with the KYB Project staff.

Another aspect that should be monitored, especially if many part-time university staff are hired, is that the work remains practical and does not go too deep into academic details that do not have a large impact on the outcome of the scenarios that are going to be developed within the water audit.

7.3 Proposed TOR for the water audit

7.3.1 Relevance of current activities in the basin

As shown above (Chapters 2 and 5), there is already a lot of work being done on water resources in the basin. The situation is a big advantage, as existing work can be used as building blocks, thereby releasing more energy that can be channelled into filling the information gaps. Hopefully this will produce a better outcome. Close cooperation with other organisations is also important in order to prevent policy makers from being fed with competing systems for the sustainable management of the water resources. The projects that do work that are most relevant to the water audit are: the LCBC/ Global Environmental Facility (GEF) Project who plans to set up an Integrated Water Resources Management Plan for the Chad Basin, including Komadugu-Yobe, and the DFID-JWL Project which is active in initiating water management improvements at various locations in the basin (e.g. Gabion flow proportioning structure at Likori and improvement of intake works of KCWS). Close collaboration with the relevant governmental organisations, notably the FMWR, is also essential in order to pave the ground for acceptance of the outcome of the work.

7.3.2 Relevant experiences and studies for the water audit

A crucial factor for the acceptance of the water audit is that the outcome be not a water management ‘plan’ but water management ‘scenarios’ or ‘options’ for the basin. The scenarios and their consequences for water availability for the uses in the basin will assist policy makers to make decisions based on sound scientific knowledge. The Water Management Options report from IUCN-HNWCP was not received very well by the FMWR, it was perceived as focussed on wetland conservation only (FMWR, 2000). This experience underlines that, in order to have outcome of the water audit accepted, it is very important for the coming water audit to be executed by consultant(s) who are considered unbiased by all stakeholders in the basin and that regular communications with the stakeholders take place. The IUCN river flow model (IUCN-HNWCP, 1999) and its upgraded version Afremedev (1999b) are digitally available (on enclosed CD). The models need to be upgraded further (see Section 7.3.5) but they can serve as a useful starting point for building the Decision Support System (DSS) for the coming water audit. Dyson et al. (2003) provide a guideline on determining environmental flow requirements.

7.3.3 Exclusions from the water audit

Some issues need to be excluded form the water audit in order to make sure that the consultants have a realistic workload given the available budget. If too much work is put in the TOR than the risk on low quality work will be high. It should be noted that the topics described below are all important issues that merit thorough studies.

It is recommended to exclude the groundwater in the deeper (2nd and 3rd) aquifers from the audit because a thick clay layer separates the second from the first aquifer, and because the deeper aquifers most likely don’t receive recharge (if they are recharged at all) from within the Komadugu-Yobe Basin (see Section 4.3). Furthermore, the LCBC plans to launch a groundwater study for the entire Chad Basin in 2005.

A water audit generally focuses on water quantity. Still, the water quality is important to determine if the available water is good enough for all the uses. For several reasons such as the facts that: 1) doing a water quality study requires a different discipline than a water quantity study, 2) the most relevant water quality studies have already been summarised in this report (see Chapter 6), 3) paying much more time on studying the identified water quality problem may just prove to be an academic exercise since the environmental laws are not being enforced on the polluters, and 4) the focus of the proposed limited water quality study will be more location specific (mainly downstream of potentially polluting activities) than the quantitative water audit (basin wide); it is recommended that the water quality study be separated from the water audit (see Section 7.5). Still, the predicted impact of water management scenarios on the water quality should be included in the water audit and the outcome of the water quality study can be included as a separate chapter in the water audit report.

Unless new studies come available it is recommended not to include the prediction of rainfall and river flow in the basin as a result of climate change. Investigating the impact of downscaled global climate scenarios on the water resources in the Komadugu-Yobe Basin is a highly specialised assignment and more suited for a university or a research institute than a consultant. However, the water audit should take into account extreme events for the water availability in the basin (dry and wet) since almost all regional climate scenarios predict a high variability in rainfall and river flow (see Section 3.2.3).

It is recommended to exclude inter-basin transfers from the water audit unless the environmental impact of the inter-basin transfer on the river basin from which the water is taken is included as well. Studying an additional basin will imply a lot of unforeseen extra work. The most suggested inter-basin is the 'Dindima' transfer that is proposed to carry water from the Gongola River to the Komadugu River (Diyam, 1986). The transfer is not very likely to happen since there are already two dams on the Gongola River.

It is recommended to exclude the small rivers that do not have surface drainage into the Hadejia or Jama'are rivers from the DSS Model that is going to be built for the water audit. These rivers are mainly located north of Kano near Kazaure. The small rivers are only of local importance and do not directly affect the runoff in the Komadugu-Yobe river system. Furthermore, not much recent data are available for these rivers. Still, there is a hydrological connection through groundwater flow and the small rivers form a part of the total water balance for the basin. So it is recommended to recognise these rivers, their dams and their uses in the water audit but not to study them in detail.

7.3.4 Strategy for minimizing delays during water audit

In the light of the most urgent data requirement for the water audit, recent river flow data, it is recommended to do at least four wet-season and three dry-season river gaugings at the following important current river flow monitoring sites (Table 1): downstream of Tiga (if recent stage data available at KSMWR), Wudil or Dabi, Kafin Hausa, Hadejia, Likori (some gaugings already done by DFID-JWL at the two latter sites), Dapchi, Gashua, Geidam and Damasak. The water audit consultants can use this data to construct rating curves and to update the river flow database. If the gaugings are not done than the work of the water audit will be delayed until the end of the next wet season, or the water audit will only include the old (up to 1998) river flow database that have already been analysed in various previous studies (e.g. IUCN-HNWCP, 1999).

7.3.5 Water audit components

It is suggested that water audit comprises the following components:

1) Collect, in close collaboration with the Database Coordinator of the KYB Project, all relevant hydrological (see sections 3.1 and 4.1), water use (Section 5.1) and meteorological (Section 2.1) data from all the above identified sources. Special attention should be paid to:

- Data on water uses, river flow, groundwater and meteorology for Niger. The data may possibly be collected through the LCBC, or directly from the relevant authorities. It is known that Niger measured (and probably still measures) the river flow in the Yobe River at Bagara Diffa (near Damasak).
- The collection of the digital daily river flow database that was submitted with the Diyam (1996) report. The monthly data are available on the enclosed CD. The database should be available at the FMW, FME (formerly FEPA) and PTF.
- Published and unpublished WRECA data on river flow stations on the Komadugu River and the Yobe River downstream of Gashua (since these stations were not included in the Diyam study).
- Information on in- and outflow rates from the two large dams (Tiga and Challawa) and the Hadejia Barrage.
- The data from the well monitoring networks in the basin (Bauchi, Yobe, Borno and possibly also in the other two states).

- Evaporation and rainfall data for the reservoirs.
- Rainfall data for the Basement Complex area and recent rainfall data for Nguru.

2) Construct rating curves and calculate daily discharge data for the sites with only water level data and recent gaugings. Fill data gaps in runoff series when they are limited and/or other data (e.g. discharge at neighbouring stations or rainfall-runoff modelling) are available. This can for example be done by using a procedure that was especially developed for rivers in West Africa (Gyau-Boyake and Schultz, 1994).

3) Execute data quality checks.

- Special attention should be given on quality checks of river flow data that has not undergone elaborate data quality checks in the past (most river flow data that does not originate from the Diyam or the HNWCP databases). Notably the data from 1999 onwards and the modelled Afrmedev runoff data require quality checks. The check can for example be done by comparing data from up- and downstream stations
- For the water uses as much as possible different sources on the same use should be used. Especially data on size of irrigated areas and crop yields should be reviewed critically (Adams, 1991).
- A sound estimate should be made on the percentage of drilled boreholes that are active. Also the abstraction rates should be reviewed critically.
- It should be established which meteorological stations provided reliable data with relatively little interruptions.
- It should be established which monitoring wells provided reliable data.

4) Determine the environmental river flow requirements of the HNW, Lake Chad and other ecological valuable areas. The starting point for the determination of environmental flows can be historical (before human induced changes in the river) daily hydrographs for sites upstream of the ecological sites. Collaboration should be sought with an hydro-ecologist to examine the impact of flow removal from the hydrographs on the ecosystem.

5) Divide, on the basis of the available hydrological data, hydrological characteristics and number of water uses, the four sub-basins into at least four sub-sections that will form the basis for the water audit. The proposed subdivision should be presented in the form of a schematic diagram with motivation and overview of data availability per element of the diagram.

6) Analyse the shallow groundwater data (first aquifer) in the basin. The analyses should at least comprise the following components:

- Interpret the data from the above identified monitoring well networks in the basin on long-term trends in water level (increase, decrease or stable). This exercise should clarify the contradicting information on the long-term trend of the shallow water level (see Section 4.2).
- Prepare a GIS map that contains: the monitoring wells with the identified long-term trends, the shallow groundwater abstraction points (with abstraction rates) and areas where the number of wells tapping the first aquifer will increase significantly.
- Compare, per sub-section, the estimated annual recharge of the shallow aquifer (river bed, floodplain and rain-fed) with the present and projected shallow groundwater abstractions.
- Identify, based on the above map, critical areas where over-abstraction from the first aquifer may occur.
- Propose locations of wells (and depths) that need to be included in the existing monitoring networks.

7) Determine the weekly surface water availability (very-dry year, dry year, normal year, wet year, very-wet year, standard deviation, etc.) for all the water audit sections in the basin on the basis of statistical analyses of river flow data. Estimate the annual shallow groundwater availability, or recharge rates, for the water audit sections (very-dry year, dry year, normal year, wet year, very-wet year).

8) Quantify, on a monthly basis, the present water uses for all water audit sections in the basin (groundwater in the first aquifer and surface water). Estimate future water uses for the water audit sections for three future years (e.g. 2010, 2020 and 2030) for at least eight different development scenarios. Rank the future water uses scenarios on the basis of their likelihood. For the development of the scenarios the following should be taken into account:

- The rainfall distribution over the basin. For example areas that have a low potential for rain-fed agriculture are more dependant on river flow than areas with a high potential for rain-fed agriculture

- Include extremely low and high water availabilities to account for the anticipated high annual variability in available water resources due to climate change. Also include series (~5) of dry years and series of wet years.
- The cultural practices of the farmers in the floodplains (flood and flood recession agriculture).
- The environmental flow requirements (notably in HNW and Lake Chad).
- Include scenarios with the above identified possible future trends in water uses (see Section 5.2.2).
- Include scenarios with the proposed engineering improvements (see Table 13).

Interpretation of all meteorological data collected by the Database Coordinator of the KYB Project. This should at least comprise:

- GIS maps (long-term mean and mean for the past five years) with isolines for rainfall and evaporation. The maps should also indicate all reservoirs in the basin.
- Tables with (measured or estimated based on the closest meteorological stations) current and long-term monthly evaporation and rainfall rates for all the reservoirs in the basin.
- Work done on the rainfall-runoff relations for the Basement Complex area on the three main rivers.

9) Build a Decision Support System (DSS) that calculates water balances on weekly, monthly and annual basis for all the water audit sections in the basin and all the combinations of the above mentioned present and future water uses and water availabilities. Create the possibility in the DSS for a non-technical user to prepare his/her own scenarios. It is recommended to build the DSS in a format that is easily accessible to all the relevant organisations in the basin. The DSS should include graphical presentations of the data and scenarios in the form of graphs and GIS based maps. The chosen software for the DSS should be approved by the KYB Project. At least the following software formats (in order of prevalence) should be evaluated for its suitability to develop water management scenarios:

- WEAP (Water Evaluation And Planning, software from the Stockholm Environment Institute). The software is based on monthly data, available free of charge (www.seib.org/weap) and communicates well with GIS. Unfortunately WEAP is a monthly model, part of it may need to be adjusted to a weekly time scale in order to include flooding.
- MS-Excel in combination with GIS. The advantage is that almost everybody with a computer has MS-Excel and that it is very flexible. The disadvantage is that it does not have a nice graphical interface and that it requires quite a lot of programming. Spreadsheets have also been used for the IUCN River flow Model and the updated model from Afremedev.

The IUCN-HNWCP (1999) and the Afremedev (1999) models should form the starting point of the DSS. At least the following updates should be made on the models:

- Improve river flow relations between all up- and downstream stations.
- Include the Komadugu River.
- Include the Kafin Hausa River.
- Include the small reservoirs that have a relatively large active storage ($\geq \sim 10\ 10^6 m^3$). Smaller reservoirs can be lumped together.
- Include flood extent estimates. For the HNW a river flow-flood extent relation was already developed (1991-97, Goes and Zabudum, 1999). For this application a small time step is probably required (1 week or less).
- Pay more attention to the Yobe River downstream of Gashua; notably the outflow from the Yobe River into Lake Chad.
- Include shallow groundwater recharge.
- Include groundwater uses from the first aquifer.
- Have the option to choose between the present situation and a situation with one or more proposed engineering improvements (Table 13) combined with clearance of weeds and dredging.

Table 13 Overview of proposed engineering improvements in the Komadugu-Yobe Basin.

Proposed engineering improvements	Sources
KCWS improved water intake for low river flows	Diyam (1996); IUCN-HNWCP (1999); Neville (2005)
A second valve at outlet of Tiga Dam	Diyam (1996); IUCN-HNWCP (1999)
Raising Tiga Dam to its original design level for flood control	HR Wallingford (2002)
Flow proportioning structure at Miga (Hadejia River and Kafin Hausa River)	DFID-JWL; Chiroma et al. (2005)
Flow proportioning structure at Magujin Idi (Marma Channel and old Hadejia River)	DFID-JWL; Chiroma et al. (2005)
Three-way flow proportioning structure at Likori/Gubusum (Marma Channel, Burum Gana River and old Hadejia River)	Diyam (1996); IUCN-HNWCP (1999)
Two-way flow proportioning structure at Likori/Gubusum (Marma Channel and Burum Gana River)	Neville (2003)

10) Write a report that should at least contain:
- An executive summary for policy makers.
- Description of the work done.
- An overview table with river flow and water uses data used to build the DSS (including an indication of their reliability, in an appendix).
- A manual on how to use the DSS (in an appendix).
- The limitations of the DSS.
- The outcome of the all the scenarios in tables and graphs. The tables should at least include the water availability and the water uses in all sections of the river. The smaller rivers and its reservoirs that do not drain directly into the Jama'are of Hadejia rivers should also be included in the tables (see Section 7.3.3).The scenarios should be ranked in order of decreasing likelihood.
- Discuss the expected impact on all downstream uses (large projects, floodplain farmers, cattle rearers, fisheries, ecology, shallow groundwater recharge, etc.), water quality, human health (notably, Onchocerciasis and Schistosomiasis, see e.g. Ofoezie, 2002) and the prevalence of invasive aquatic weeds of all the scenarios.
- Discuss the consequences of two different views to manage the reservoirs in the basin (lowering reservoir levels for anticipated floods or leave the reservoirs fairly full for anticipated droughts, see Kazaure, 2003).
- An elaborate evaluation of the impact of all the proposed engineering improvements (Table 13).
- The pros and cons of gabion (proposed by Neville, 2003) and concrete (proposed by Diyam, 1996) flow proportioning structures.
- An assessment on the efficiency of the large formal uses in the basin and recommendations for improvements if required.
- The outcome of the above described shallow groundwater and meteorological data assessment.
- A section on surface and groundwater quality in the basin (to be provided by the KYB Project).

11) Compile a CD that at least contains:
- a database on all the data that have been used for the assignment (MS-Excel),
- the report (word),
- maps as described above (GIS shape files),
- the scenarios,
- the DSS and its manual.

12) Organise, in cooperation with the FMWR and the KYB Project, a workshop for the stakeholders in the basin in which the DSS is presented and the outcome debated. Write a summary report on the outcome and recommendations of the workshop.

Regular evaluation moments are required at which the quality of the consultants work up to that point is thoroughly checked and approved by three technical experts representing each of the project partners (FMWR, IUCN and NCF). It is recommended to keep the evaluation purely technical, the political aspects can come in during the workshop. The evaluation can be done after steps 3, 6, 8, 9 and 11.

It may be worthwhile to also consider organising an interim workshop for the stakeholders between steps 8 and 9 in order to get input on the scenarios that are going to be developed. Furthermore, it may be useful to split the contract for the consultancy work into two parts; one for the building of a high quality database (steps 1 to 3) and one for the actual water audit (the remaining steps). The separation gives the opportunity to fine-tune the TOR on the basis of the available data (e.g. choice between weekly and monthly DSS depending on the availability of daily river flow data) and the time schedule for the actual water audit.

7.4 Estimated time to carry out the water audit

It is envisaged that two Nigerian water resources experts (surface water and groundwater), an ecologist and two juniors will carry out the water audit. Table 14 presents a rough estimate of the time required to carry out the water audit components. The estimate does not include data related delays such as obtaining difficult accessible data or transferring analogue data into a readable digital format. Furthermore, the water audit team needs an office space for a period of ~7 months[10], a licence to use GIS and access to a vehicle for a period of approximately 6 weeks.

Table 14 Estimated time required to carry out the Water Audit in working days.

Water audit component	Surface water expert	Groundwater expert	Ecological flows expert	Assistant - surface water	Assistant - groundwater
1	3	3	-	8	8
2	10	-	-	10	-
3	5	5	-	5	5
4	3	-	6	3	-
5	2	2	1	2	2
6	-	10	-	-	10
7	4	4	-	4	4
8	5	5	1	6	6
9	15	5	1	15	5
10, 11	15	15	2	10	10
12	2	2	2	2	2
unforeseen delays	9	6	1	9	6
Total	**73**	**52**	**15**	**74**	**58**

7.5 Surface water quality study

First it is recommended to try to obtain the water quality data from the relevant organisations and studies (Section 6.1) and to put them in a database. Second, a very limited water quality survey is recommended in order to get a clearer picture of seriousness of the water pollution in the basin. It is recommended for the study to be carried out by staff from the KYB Project, in close contact with federal and state environmental and water resources ministries.

As described in Section 6.2 simple and cheap field tests can easily give a rough indication of the water quality. So it is recommended to complement the survey that has been carried out for this report with more tests along the Yobe River (Geidam and Damasak) and in the upstream part of the Hadejia River System (main drainage canal from KRIP and on small tributaries and drainage canals from Kano City). It is also recommended to repeat the survey at the beginning of the dry-season. Consequently it is recommended to select four to eight sites with the most elevated pollution rates (high nitrate and/or EC) and to take additional samples for analyses in a laboratory. It is recommended to have samples analysed for at least the following parameters: EC, pH, dissolved oxygen, BOD, nitrates, phosphates, common ions (Na, K, Ca, Mg, Cl, HCO_3, SO_4, F), BOD, Total Coliforms, pesticides and trace elements (Arsenic, Lead, Zinc, Aluminium, Iron, Nickel, Cadmium, Chromium, Cobalt, Manganese, Copper). Prior to the submission of samples information should be obtained on how the selected laboratories ensure quality of their work. It is also recommended that at least two of the samples be analysed at different laboratories in order to ensure reliability of the result.

[10] Assuming that some of the consultants may only be par time available.

The following laboratories for analysing water samples have been identified:

- FMWR Department of Water Quality Laboratories and Monitoring Network, Minna and Akure.
- Bayero University, Kano (Binns et al. 2003 used this laboratory).
- KSWB at Challawa.
- FME in Lagos and possibly Abuja.
- NAFDAC in Kaduna and Abuja.

8 Conclusions and recommendations

8.1 Conclusions

The identified information gaps for the surface water audit are:

- The availability of recent (1999 to date) river flow data.
- The availability of data on water uses and hydrology for Niger.
- Information on the Komadugu River (water uses and availability).
- Information on in- and outflow rates from the two large dams (Tiga and Challawa) and the Hadejia Barrage.
- Prediction on the impact of climate change scenarios on the rainfall and river flow in the basin.
- Information on environmental river flow requirements.
- The scale of the landuse change in the basin and its consequences on the river flow (in the Basement Complex area) and the groundwater recharge (whole basin).

Data on surface and groundwater uses is in the process of being made available, thanks to the ongoing committed work by the Database Coordinator of the KYB Project. The task is very laborious since there are many institutions at national, regional and state level (about 30 in total) that have tasks relating to the management of the water resources in the basin. From time to time the task is also a bit confusing since names and tasks of institutions tend to differ a bit from state to state. Furthermore, the task is complicated by the fact that most recent data is only available in analogue format.

The ongoing work of the KYB Project and visits to relevant institutions for this assignment also revealed a lot of unexpected relevant hydrological data (especially ongoing river level and groundwater level monitoring). It is encouraging that some organisations in the basin continue river level monitoring (Hadejia, Yobe and Komadugu rivers). Due to a lack of funds and access to gauging equipment the monitored recent (1999 to date) river levels have not been recalculated into actual discharge data.

The ongoing work of the DFID-JWL Project, especially the active involvement in initiating water management improvements at various locations in the basin (improvement of intake works of KCWS, dredging and weed clearance in the Burum Gana River, Gabion flow proportioning structure at Likori), is also an exercise that is very relevant for the water audit.

There is a lack of continuity on sustainable water management related activities in the basin such as for example the organisation of regular stakeholder meetings and the execution of river gaugings. These activities require quite some resources, which are mostly only available at projects. The lack of continuity is caused by the fact that the projects have a limited time-span and because they do not always overlap in time. For example, now there are at least three projects that have the aim to assist the relevant institutions with the sustainable management of the water resources in the basin (KYB Project, DFID-JWL and LCBC/GEF Project). While from the late 1990s to early 2000 no water management related project with sufficient funds was active in the basin.

Generally, there are no indications for a long-term decrease in shallow groundwater level in the basin (confirmed for Yobe and Bauchi states). For Jigawa state there is contradicting information on the long-term groundwater level. Still, there is concern for the future since the number of shallow tubewells abstracting groundwater is increasing fast. Over-exploitation resulting in a water level decline is more rampant in the second aquifer.

No water quality monitoring network has been identified for the basin. Only some ad-hoc water quality studies have been carried out. A number of studies have indicated a poor shallow groundwater quality inside villages and towns; an extremely high nitrate content (up to 500 mg l^{-1}) was measured in a number of hand pump equipped wells. The elevated nitrate content is probably due to poor sanitation. A surface water quality survey carried out for this assignment revealed that nitrate is generally present in all the four rivers in the basin (20 to 70 mg l^{-1}). The highest nitrate contents were measured in the upstream part of the Hadejia River System (50-65 mg l^{-1}) and in the main drainage canal from HVIP (70 mg l^{-1}). These results indicate that the large and small irrigation projects and urban waste are contributing to the worsening of the water quality in the basin. Binns et al. (2003) measured the surface and groundwater quality in and near the Jakara River in Kano. The analysis revealed extremely high (sometimes more than 100 times the WHO limits) levels of toxic wastes in most of the surface water and at some of the shallow groundwater samples (e.g. Cd up 28.9 mg l^{-1} and Cr up to 49 mg l^{-1}). The main pollution source for the toxic waste is discharge from industries. Although, the Jakara River does not directly drain into the Hadejia River it is not likely that the water quality of the tributaries to the Hadejia River originating from Kano will be much better (e.g. a drainage canal emptying black sludge into Challawa River has been observed). There are no signs for improvement since the environmental laws are not being enforced on the polluters.

A very recent publication (Nicholson, 2005) concluded for the southern Sahel, in which the Komadugu-Yobe basin is situated, that the rainfall (1998-2003) has returned to pre-drought levels of the 1950s and 1960s. This is confirmed with recent rainfall data for Maiduguri.

8.2 Recommendations

8.2.1 Technical recommendations

In the light of the most urgent requirements for the water audit, recent (1999 up to date) river flow data, it is recommended that the KYB Project sets up a 'fire-brigade' team to do as many river discharge measurements as possible during the ongoing wet-season at above identified sites (Table 1) with recent stage level data. If the gaugings are not done than the work of the water audit will be delayed until the end of the next wet season, or the water audit will only include the old (up to 1998) river flow database that have already been analysed in various previous studies. For the longer term effort should be spend on assisting and building the capacity of the organisations that have continued the river level monitoring in the basin. This can be done by providing them access to gauging equipment, assisting them with the actual river flow gaugings and organising a course on the interpretation of the data. It would be helpful to build a more user friendly version of the old HNWCP spreadsheet that can interpret the gauging data for all the different types of gauging equipment available in the basin. It is recommended to collaborate with the DFID-JWL Project on this issue since they have hands on experience with river flow gaugings in the HNW. The FMWR or JSMWR can be approached to borrow the equipment. By the end of the life-span of the project it can be decided which organisation can take over the coordination of the use of the gauging equipment.

The KYB Project can also encourage the relevant organisations to do water level measurements at, at least, the following crucial sites in the basin: downstream of Tiga and Challawa dams, Wudil, Guri, a site at the end of the old Hadejia River (Hadejia River System), Bunga, Katagum (Jama'are River), Kari (Komadugu River) and Yau (Yobe River). It should be confirmed whether the stage-board at Hadejia is still being read at the moment or not. Because of the limited time-span of the KYB Project it is not very sustainable for the project to take care of the water level measurements themselves.

It is strongly recommended that the relevant institutions arrange backup in the form of a stage-board reader for the relevant river flow monitoring sites that only have automatic gauges. This recommendation is made because automatic gauges can and often will malfunction and the resources may be limited to extract the data in time before the battery runs out. Furthermore, it is recommended that effort to be made to enhance the commitment of the readers to the work by, for example, providing them with a bicycle if they live far from the stage-board and letting them have annual results of their work.

Some specific suggestions for the KYB Project issued questionnaires on hydro-meteorological and water uses data have been given to the Database Coordinator of the KYB Project. The main suggestions are to pay a bit more attention to: proposed new uses and future expansions of current uses (required to develop future water management options) and water quality aspects (e.g. use of fertilisers, drainage from large water uses). For the collection of rainfall data, that requires payment, it is recommended to focus on the upstream Basement Complex area of the basin because these data may prove to be useful for rainfall-runoff modelling.

Expansion of existing shallow groundwater monitoring network in the basin may be required depending on the outcome of the water audit. Emphasis for locations of additional monitoring wells should be put on areas with significant groundwater abstractions (to be identified in the water audit) and areas where the river flow reductions (partly groundwater recharge) have been or are expected to decrease (mainly between Wudil and Hadejia).

Concerning the water quality it is recommended to try to obtain the water quality data from the relevant organisations and studies and to put them in a database. Furthermore, a very limited water quality survey is recommended, to be carried out by KYB Project staff, in order to get a clearer picture of seriousness of the water pollution in the basin. This will hopefully help the Ministries of Environment and Water Resources (national and state) in making informed decisions on the need for the enforcement of the environmental laws.

In order to prevent the loss of lives as happened in the 2001 floods it is recommended to promote an early flood warning system in the Hadejia and Jama'are sub-basins. This can for example be combined with automatic river flow monitoring stations at Wudil and Bunga. These sites are very suited because downstream of these sites the rivers are no longer gaining water. The test releases from 1996 revealed that the travel time of the water between dams and Hadejia is ~13 days (Goes and Zabudum, 1996). Flood flows will take less travel time. Still, there will be at least several days notice for the people living in the area with the greatest flood risks (Hadejia-Nguru Wetlands).

Other relevant water related activities in the basin that are worth doing:

- The effect of landuse change on the river flow in the upstream part of the basin (Basement Complex Area). Collaboration on this issue can be sought with the LCBC who are interpreting monthly satellite data for the whole basin for a period of ~20 years. The KYB Project can contribute with the updated river flow database.
- The JSMWR is monitoring the stage height at many stations between Wudil and Hadejia. The development of rating curves for these sites will be very useful to study the causes of the river flow reductions between Wudil and Hadejia.
- A study on the second and third aquifer in the Chad Basin (recharge, abstractions, monitoring of water level). A groundwater study for the whole Chad Basin is already in the pipeline (LCBC with support from the GTZ).
- A water quality monitoring network is recommended since the ad-hoc water quality studies show high pollution rates of shallow groundwater in urban areas and at large irrigation projects, and of surface water in the upstream part of the Hadejia sub-basin. Still, monitoring of water quality will only be useful if there are realistic prospects that measures will be taken to improve the water quality by enforcing the environmental laws on the polluters. Otherwise, a water quality network will only be an academic exercise resulting in a more detailed analyses of the pollution.
- A study on the efficiency of the large formal water uses in the basin (the irrigation projects and Kano City Water Supply).

8.2.2 Collaboration and networking related recommendations

The most essential participating partner of the KYB Project is the FMWR because they are responsible for the coordination of the development of the water resources in the basin. It is therefore recommended to involve the FMWR very closely with all the stages of the coming water audit, which are: the finalisation of the TOR, the selection of the consultant and the quality control of the work.

Besides on the river gaugings it is also important to stay in close contact with the DFID-JWL Project on their proposed and ongoing interventions in the basin. Especially, the proposed and partly executed improvements on the intake works of KCWS is a crucial progress for the sustainable water management in the basin that should be continued after the DFID-JWL Project ends (December 2006).

On the building of the information database it is recommended that the KYB Project collaborates with the LCBC GEF Project since they are doing a similar activity for the whole Chad Basin. The hydrological and water uses data for Niger can possibly obtained through the LCBC.

It is recommended that the KYB Project already starts practicing the principle of 'data sharing'. During the visits to the institutions in the basin it was observed that their willingness to cooperate increased visibly after we also gave them relevant publications. For example, the KYB Project may start compiling CD's with data and scanned publications that are distributed on a regular basis among all stakeholders in the basin.

The LCBC also plans to prepare an Integrated Water Resources Management Plan for the Chad Basin (including Komadugu-Yobe), which is similar as the water audit. The LCBC has a longer time span and is very interested in using the outcome of the coming KYB Project water audit as a base for their activities on the sustainable water management in the basin. In order to ensure that the outcome of the water audit will be used it important to keep the LCBC informed on the progress of the water audit exercise.

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Appendix 1: Itinerary

Date	Day	Activities
July/August 2005		• Literature search in university libraries (the Netherlands) and on the Internet. • Obtain visa in The Hague (2 trips).
Aug.7th	1	• travel from Amsterdam to Kano
Aug.8th Monday	2	• Meeting with staff from KYB Project (Dr Daniel Kwesi Yawson - Project Coordinator, Mr. Anthony Ekpo - Database Coordinator, Engr. Peter Y. Manjuk - Water Resources Expert, Mal. Garba Hallai - Social Science Specialist) on the Water Audit. • Travel from Kano to Dutse and water quality checks at 4 sites in the upstream part of the Hadejia River. Meeting (together with Anthony Ekpo, Peter Manjuk and Garba Hallai from KYB Project) with: • DFID-JWL Project (Alhaji M. Chiroma).
Aug. 9th Tuesday	3	• Travel from Dutse to Gashua via Hadejia and Nguru (car got stuck due to flooding of Nguru road). • Short conversations with Isah Dutse and John Rowley at DFID-JWL office in Hadejia. • Visit to HNWCP library in Nguru. • Ten water quality tests at sites along the river.
Aug.10th Wednesday	4	• Travel from Gashua to Maiduguri via Damaturu. • One water quality test at a site along the river. Continued meetings: • NEAZDP (Ahmed Barde - Head of Agricultural Production Component, Eng. Ahmed Hamza - Head of Village Water Supply). • Yobe State Ministry of Water Resources (Eng. Idi Mamman Dapa - Director Water Supply and Quality Control). • Yobe State Ministry of Agriculture (Director of Irrigation - Audu Audu Daya) & Yobe State ADP (Eng. Mohammed M. Mustapha - Programme Manager, Abba Jambo Goohua - Director of Planning Monitoring and Evaluation). • University of Maiduguri (prof. F.A. Adeniji).
Aug.11th Thursday	5	Continued meetings: • CAZS (Dr. Bukar Babe - Director). • UNIMAID (Dr. Muhammed Hassan - snr. lecturer, geophysicist). • UNIMAID (Dr. Goni - Professor in Geology). • CBDA (E. Dumbai - Executive Director, Eng. Baba Alkali, Modu Sulum - Assistant Director/Drilling). • LCBC/GEF (Eng. Dr. Zaji Bunu - Project Coordinator Nigeria, Mohammed Bila - IT Scientific Officer) • Travel from Maiduguri to Bauchi. • One water quality test at a site along the river.
Aug.12th Friday	6	Continued meetings: • BaSADP (Musa A. Bello - Acting director irrigation). • Ministry for Rural Development BaS (A. Jumba - Director Water). • BaSWB (Eng. Saidu Wambai - Director Engineering Services, A.A. Salau - Deputy Director, Garba B. Magaji - DA). • Travel from Bauchi to Kano. • Make suggestions for the database manger of the KYB Project on the issued questionnaires for the relevant institutions in the basin. • Five water quality tests at sites along the river.
Aug. 13th Saturday	7	• Report writing.
Aug. 14th Sunday	8	• Report writing. Meetings (together with Daniel Yawson) with: • Dr. Muslim Idris (JSMWR). • Dr. Hassan Bdliya (DFID-JWL).
Aug. 15th Monday	9	• Travel from Kano to Abuja. Various meetings (together with Peter Manjuk) at the FMWR: • Engr. Joe Kwanashie - Director KYB Project and Engr. Razaq A.K. Jimoh (Deputy Directors at Irrigation & Drainage Department). • Olufemi O. Odumosu, John A. S. Hamonda and C. Maduabuchi (Deputy Directors at Hydrology & Hydrogeology Department) • C.O. Ikelionwu - Project Manager (Water Quality Laboratories and Monitoring Network).

Aug. 16th Tuesday	10	Continued meetings at FMWR: • Eng. I.K. Musa (Director of Irrigation and Drainage Department). • Eng. M. Gundiri (Director of Dams and Reservoirs) • Travel from Abuja to Kano via Kaduna. • Meeting with Dr Salisu Abdulmumin (Director NWRI). • Two water quality checks at sites along the river.
Aug. 17th Wednesday	11	Meetings with institutions in Kano (together with Anthony Ekpo, Peter Manjuk and Garba Hallai from KYB Project): • KSMWR (Eng. Danladi Mohammed - Director of Irrigation, Eng. Ayuba A. Balarabe - Director of Hydrology and Hydrogeology) • KSWB (Eng. Umaru R. Karaye - AGM Planning and Design, Eng. I U. Dederi). • HJRBDA (Alh. Shehu D. Abdulkadir - Managing Director, Eng. Y.D. Kazaure). • KNARDA (Adamu Ali Wudil - Director RID, D. Maikarofi - Deputy Director Water Resources, Bashir M. Foggi - Assistant Director Irrigation). • Report writing.
Aug. 18th Thursday	12	• Report writing. • Brief explanation to relevant project staff (Anthony Ekpo, Peter Manjuk) on: the interpretation of river gaugings, the construction of rating curves and the calculation of discharge data (within Ms-Excel).
Aug. 19th Friday	13	• Report writing.
Aug. 20th Saturday	14	• Submission of: draft report, equipment for water quality tests, CD with collected information (Project Coordinator) and photocopies of reports that are not digital to KYB Project (Database Coordinator). • Field visit to Challawa Gorge Dam.
Aug. 21st Sunday	15	• Preliminary discussion with Project Coordinator of KYB Project (Dr. Daniel Yawson) on draft report. • Travel from Kano to Amsterdam.
November 1st		• Reception of written comments on draft report from the Project Coordinator of the KYB Project.
November 7th		• Revise report. • Submission of final report to KYB Project (Dr. Daniel Kwesi Yawson - Project Coordinator).

Appendix 2: Metadata for river flow stations draining into the Komadugu-Yobe Rivers

No.	Station	River	Sub-basin	Catchm.	Coordinates		Data source(s)	Hydrological year (April-March)																			
				area [km²]	Lat.	Lon.		1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
1	Gwarzo Bridge	Watari	Hadejia	1,450	12°00'	08°24'	Sanyu (1993); WRECA														l	l	l	x	x	x	x
2	Dawakin Tofa	Watari			12°06'	08°20'	WRECA															x	x	x	x		
3	Challawa Gorge	Challawa		3,860	11°42'	08°02'	Diyam (1996)															m	m	m	m	m	m
4	**Challawa Bridge**	Challawa		6,890	11°43'	08°23'	Diyam (1996); Afremedev (1999)	m	m	m	m	m	m	m	m	m	m	m	m	m	m	x, m	x, m	x, m	x, m	x, m	x, m
5	**Tiga Dam**	Kano		6,553	11°28'	08°24'	Diyam (1986); WRECA?; HJRBDA															m	m	m	m	m	m
6	Chiromawa	Kano		6,975	11°43'	08°23'	Diyam (1996); Afremedev (1999)	m	m	m	m	m	m	m	m	m	m	m	m	m	x, m	x, m	x, m	x, m	x, m	x, m	x, m
7	Tamburawa A&B	Kano			11°50'	08°32'	WRECA															l	l	l	l		
8	**Wudil**	Hadejia		16,380	11°49'	08°50'	Diyam (1996); Afremedev (1999)	m	m	m	m	m	m	m	m	m	m	m	m	m	x, m	x, m	x, m	x, m	x, m	x, m	x, m
9	**Dabi**	Hadejia					JSMWR																				
10	Suntulmawa-Ringim	Hadejia					WRECA; JSMWR																	l	l		
11	Nahuche	Hadejia					JSMWR																				
12	Gaya	Gaya			11°37'	09°02'	WRECA														l	x	x	x	x		
13	Chai Chai	Gaya		1,710	12°01'	09°15'	Diyam (1996)															x	x	x	x	x	x
14	Marke	Hadejia					JSMWR																				
15	Haidin	Hadejia					JSMWR																				
16	Hadejia Barrage	Hadejia					HRBDA																				
17	**Hadejia**	Hadejia		30,435	12°26'	10°04'	Diyam (1996); HNWCP;JSMWR														(x)	x	x	x	x	x	x
18	**Kafin Hausa**	Kafin Hausa		30,435			Diyam (1996); HNWCP; JSMWR																				
19	**Likori**	Marma Channel					Diyam (1996); HNWCP, JWL Project (gaugings); JSMWR																				
20	Kasaga	Marma Channel					HNWCP																				
21	Gabarua	Hadejia					HNWCP																				
22	**Bunga**	Jama'are	Jama'are	7,980	10°56'	09°39'	Diyam (1996); HNWCP; Afremedev (1999); Julius Berger?	m	m	m	m	m	m	m	m	m	m	m	m	m	m	x, m	x, m	x, m	x, m	x, m	x, m
23	Foggo	Jama'are		9,840	11°25'	09°55'	Diyam (1996)															x	x	x	x	x	x
24	Walai	Jama'are			11°55'	10°09'	WRECA																	l	l		
25	Birnin Kudu	Dogwala		1,891	11°26'	09°35'	Sanyu (1993); WRECA														x	x	x	x			
26	Iggi Bridge	Iggi		1,334	11°32'	09°20'	Sanyu (1993); WRECA; JSMWR														x	x	x	x			
27	**Katagum**	Jama'are		15,000			Diyam (1996); HNWCP																				
28	**Kari**	Komadugu	Komadugu	5,865	11°15'	10°33'	Sanyu (1993)															x	x	x	x	x	x
29	**Dapchi/Gada**	Komadugu		18,090	12°30'	11°30'	Sanyu (1993); WRECA; NEAZDP																			(x)	(x)
30	**Gashua**	Yobe	Yobe	62,150	12°52'	11°94'	Diyam (1996); HNWCP; NEAZDP														x	x	x	x	x	x	x
31	**Geidam**	Yobe			12°05'	11°55'	Sanyu (1993); WRECA; NEAZDP														x	x	x	x	x	x	x
32	**Damasak**	Yobe			13°28'	12°31'	Sanyu (1993); WRECA; IWACO (1984); BS Water Cooperation														x	x	x	x	x	x	x
33	Bagara Diffa	Yobe					UNESCO (1995); Niger																		(x)	x	x
34	Gashagar	Yobe			13°22'	12°48'	WRECA														x	x	x	x	x		
35	**Yau**	Yobe		148,000	13°34'	13°15'	Sanyu (1993); WRECA; IWACO (1984); BSMWR?														x	x	x	x	x		

x: measured river flow data; (x): incomplete or unreliable river flow data; m: modeled (rainfall-runoff) runoff for a situation of no dams; l: water level data only; ?: possibly available but not confirmed

Station	Hydrological year (April-March)																																	
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Gwarzo Bridge	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)	x	x	x	x	x	x														
Dawakin Tofa																																			
Challawa Gorge	m	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x													
Challawa Bridge	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x	x	x	x	x	x	x	x	x												
Tiga Dam	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m																			
Chiromawa	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x	x	x	x	x	x	x	x	x												
Tamburawa A&B																																			
Wudil	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x	x	x	x	x	x	(x)	(x)													
Dabi																							l	l	l	l	l	l	l	l	l	l	l	l	l
Suntulmawa-Ringim																							l	l	l	l	l	l	l	l	l	l	l	l	l
Nahuche																						l	l	l	l	l	l	l	l	l	l	l	l		
Gaya																																			
Chai Chai	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x														
Marke																							l	l	l	l	l	l	l	l	l	l			
Haidin																										l	l	l	l						
Hadejia Barrage																																			
Hadejia	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)	(x)	x	x	x	x	x	x	l	l	l	l	l	
Kafin Hausa				x	x	x	(x)	x	x	x	x	x	x	x	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	l	l	l	l	l	l	l			
Likori				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	l	l	l	l	l	l
Kasaga																										(x)	x	x							
Gabarua																									x	x									
Bunga	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x, m	x	x	x	(x)	x	x	x	(x)	(x)	x	(x)	(x)	(x)	(x)	(x)						
Foggo	x	x																																	
Walai																																			
Birnin Kudu	x	x					x				x	x	x																						
Iggi Bridge	x	x	x	x	x		x			x	x	x	x									l	l	l	l	l	l	l	l	l	l	l			
Katagum						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	(x)	(x)	x	x	x						
Kari	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x																
Dapchi/Gada	x	x		(x)	x	x	x	x	x																					l	l	l	l	l	l
Gashua	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	(x)	x	x	x	l	l	l	l	l	l
Geidam	x	x	x	x	x		x			(x)	x	x	x	x	x	x														l	l	l	l	l	l
Damasak	x			x	x			x	x						x			l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l	l
Bagara Diffa	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Gashagar																																			
Yau	x	x	x	(x)	x		x	x	x						x																				

Appendix 3: Results of field surface water quality tests

No	Site	River	Date	EC (at 25°C) [uS/cm]	Temp. [°C]	Ph	Hardness carbonate [mg/l]	Hardness general [mg/l]	NO_3 [mg/l]	NO_2 [mg/l]	Observations
1	Wudil Bridge	Hadejia	8-8-05	97	26.2	7	71	89	50	<0.5	old faded stage-board
2	Bridge just before Dambale (Wudil-Kari road)	small tributary to Hadejia River	8-8-05	42	24.2	6.6	36	71	35	<0.5	probably downstream of a small dam (Kafin Chriri)
3	Bridge between Dambale & Panda (Wudil-Kari road)	Durun Kaya (tributary to Hadejia River)	8-8-05	7	22.5	6.5	36	54	10	<0.5	no stage-board
4	Panda Bridge (Wudil-Kari road)	Durun Kaya (tributary to Hadejia River)	8-8-05	33	24.9	6.5	36	71	35	<0.5	
5	Kafin Hausa	Kafin Hausa	9-8-05	39	26.1	6.6	125	89	40	<0.5	green box (automatic water level meter?)
6	Auyo	Main drainage canal from HVIP	9-8-05	72	25.6	7	179	89	70	<0.5	
7	Auyo	Northern main supply canal HVIP	9-8-05	46	26.8	6.5	36	54	40	<0.5	
8	Hadiyo Bridge	Hadejia	9-8-05	45	26.8	6.4	36	54	35	<0.5	old gauging station with lock (formerly operated by Jigawa State?)
9	Hadejia Bridge	Hadejia	9-8-05	47	27.3	6.4	89	71	45	<0.5	new (~June 2005) FMWR automatic gauge (green box)
10	Gashua Bridge	Yobe	9-8-05	23	29.7	6.4	18	36	40	<0.5	stage-board in good condition (maintained by NEAZDP)
11	Dapchi Bridge	Komadugu Gana	10-8-05	20	30.6	6.4	18	36	30	<0.5	stage-board in good condition (maintained by NEAZDP), stage level 2.62 m
12	Kari Bridge	Komadugu Gana	11-8-05	19	29.8	6.4	18	36	25	<0.5	old automatic recorder, no stage-board
13	Bunga/Geider Maiwa Bridge	Jama'are	12-8-05	24	29.9	6.4	18	36	20	<0.5	old painted stage-board on bridge (HNWCP), low water level
14	Chiako Bridge (Wudil-Kari road)	R. Kiyako tributary to Katagum River	12-8-05	26	32.4	6.4	18	36	30	<0.5	very wide, sandy and shallow
15	Birnin Kudu Bridge (Wudil-Kari road)	R. Dogwala tributary to Katagum River	12-8-05	25	32.5	6.4	9	18	30	<0.5	no stage-board
16	Tsaminyar Bridge (Wudil-Kari road)	Katagum River that tributes to Jama'are R.	12-8-05	40	31.1	6.4	18	36	25	<0.5	
17	Wudil Bridge (same as location 1)	Hadejia	12-8-05	44	29.9	6.4	18	36	60	<0.5	
18	Garon Malam/Chiromawa Bridge (Zaria - Kano Road)	Kano River	16-8-05	16	26	6.4	18	36	40	<0.5	just downstream of Tiga Dam
19	Bridge between Kura and Kano	Hadejia River	16-8-05	20	25.1	6.4	36	36	65	<0.5	just downstream of where Kano and Challawa rivers meet; KRIP
20	Gunguzu Reservoir	tributary to Challawa River	20-8-05	69	31.2	6.4	27	36	45	<0.5	
21	Spillway of Magaga Reservoir	tributary to Challawa River	20-8-05	32	28.7	6.5	36	36	40	<0.5	
22	Challawa Reservoir	Challawa River	20-8-05	28	30.3	6.4	36	36	55	<0.5	reservoir level ~518.6 m, reported release rate by HJRBDA 10 m^3/s
23	Source close to Challawa Release Gates	spring from Challawa Reservoir	20-8-05	41	28.6	6.4	18	36	45	<0.5	local people believe that the water is very pure
24	Challawa Bridge (K.Agur-Kano road)	Challawa River	20-8-05	28	31.9	6.4	27	36	40	<0.5	