EFFECTS OF RIVER REGULATION ON AQUATIC MACROPHYTE GROWTH AND FLOODS IN THE HADEJIA-NGURU WETLANDS AND FLOW IN THE YOBE RIVER, NORTHERN NIGERIA; IMPLICATIONS FOR FUTURE WATER MANAGEMENT

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ABSTRACT

The Hadejia River is a tributary of the Yobe River in semi-arid northern Nigeria and is regulated by two major dams. The other main tributary is uncontrolled. Comparison of the discharge data for the controlled and uncontrolled rivers shows an average decrease of 33\% in annual flow in the upstream part of the Hadejia River. The total annual flow and the peak flow in the Hadejia River further downstream, just above the Hadejia-Nguru Wetlands (HNW), however, did not show a significant reduction in discharge. This is related to a relatively small river flow reduction at lower flows in the upstream part of the Hadejia River and the fact that the formal large upstream water users are not (yet) working at full capacity. The major impact of the dams on the downstream part of the river is the change in regime from ephemeral to perennial. The introduced dry season flows created favourable circumstances for the development of aquatic macrophyte blockages in the HNW. Owing to these blockages, the Hadejia River stopped contributing to the flow in the Yobe River for much of the year. Furthermore, after the completion of the dams, the timing of the floods in the HNW became less predictable.

Suggestions for improvement of water management are made. These comprise engineering structures, including a flow diversion structure to regulate flows in the HNW, implementation of environmentally acceptable river flow strategies and water allocation management. Copyright © 2002 John Wiley & Sons, Ltd.

KEY WORDS: floods; Nigeria; regulated rivers; Typha domingensis reeds; wetlands

INTRODUCTION

In many semi-arid areas, increasing pressure is being put on water resources as a result of agricultural development and an increasing population along with the demands of industry. There is also an increasing awareness of the potential environmental impacts of river regulation on the environment (WCD, 2000). This paper examines the effects of river flow regulation on the Yobe River Basin in Nigeria and highlights the importance of considering how changes in flow regime can: alter in-stream vegetation growth; lead to less reliable timing of floods; and lead to wastage of water.

THE STUDY AREA

Catchment characteristics

The Yobe River Basin is situated in the Sudan-Sahel zone of northern Nigeria (Figure 1). The catchment area is 84138 km\textsuperscript{2} (WRECA, 1972). Most of the flow (\(\sim\) 80\% in the Hadejia River system, a tributary of the Yobe River) is controlled by the upstream Tiga Dam (completed in 1974) and Challawa Dam (completed in 1992; Figure 1 and Table I). The Jama’are River is presently uncontrolled, but plans...
Figure 1. The Yobe River Basin
exist to build a dam at Kafin Zaki (Figure 1). The Komadugu Gana River, another tributary of the Yobe River, effectively dries out downstream of Dapchi, where it forms a wide floodplain. 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 (Marmar 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). Presently, the Yobe River ends in a series of smaller pools in the northern part of the Lake Chad area. Historically, the river contributed approximately 1% of the total annual inflow into the lake (MacDonald, 1993). 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–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 1000 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 year$^{-1}$ between 1961–1990 for the northeastern arid zone of Nigeria (i.e. the middle and lower part of the basin). More recently (1994–1998), the annual trend for Nguru (middle part of the basin) rainfall has reversed (Figure 2(a)).

The dams at Tiga and Challawa supply water to two large, partly finished, formal irrigation schemes; namely the Kano River Irrigation Project (KRIP, 13400 ha) and Hadejia Valley Irrigation Project (HVIP, 2075 ha). The dams also contribute to Kano City Water Supply (KCWS). Table I provides an overview of the above mentioned river control structures and the large formal water users. 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 floodplains 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 the some parts of the Yobe River. Furthermore, the floodplains serve as a fishing area in the wet season 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 Bdlia, 1998). Another important function of floods in the HNW, for local farmers and village wells, is groundwater recharge (Goes, 1999).

<table>
<thead>
<tr>
<th>Year</th>
<th>Project</th>
<th>Major attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>Tiga Dam</td>
<td>Storage capacity: 1989 × 10^6 m$^3$</td>
</tr>
<tr>
<td>1974</td>
<td>KRIP</td>
<td>Developed area (1998): 13 400 ha</td>
</tr>
<tr>
<td>1974 (?)</td>
<td>KCWS</td>
<td>First water intake: below Tiga Dam</td>
</tr>
<tr>
<td>1992</td>
<td>Challawa Dam</td>
<td>Storage capacity: 972 × 10^6 m$^3$</td>
</tr>
<tr>
<td>1992</td>
<td>Hadejia Barrage</td>
<td>Storage capacity: 11.4 × 10^6 m$^3$</td>
</tr>
<tr>
<td>1992</td>
<td>HVIP</td>
<td>Developed area (1998): 2075 ha</td>
</tr>
<tr>
<td>1999</td>
<td>Lowering of spillway Tiga Dam</td>
<td>Storage capacity reduced to 1429 × 10^6 m$^3$</td>
</tr>
<tr>
<td>1999</td>
<td>KCWS</td>
<td>Second water intake: below Challawa Dam</td>
</tr>
</tbody>
</table>

This paper presents the changes in regime of the Hadejia River as a result of the construction of the dams and its consequences for the water uses along the Hadejia and Yobe Rivers. Furthermore, the management of the surface water resources in the basin is discussed.

**Hydrometric network in the catchment**

The former Kano State 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 because of a reduction in available resources. In the late 1980s, the monitoring of the hydrometric network had ceased almost completely. Published (WRECA, 1970, 1972, 1974; FMWR, undated) and previously...
unpublished river flow data collected by the former Kano State are presented, using upgraded rating curves, by Diyam Consultants (1996). 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 six key stations in the basin are: for the Hadejia River system, Wudil and Hadejia; for the Jama’are River, Bunga and Katagum; and for the Yobe River, Gashua and Yau (Figure 1). Hadejia, Bunga and Gashua are the only stations in the basin with long-term (1964–1998) records. The recent (1994–1998) data for Bunga are, until high discharge gaugings are carried out and the rating curve is updated, less reliable. Table II presents, for the six key stations, an overview of the mean annual flow and peak discharge before (1964–1973) and after (1979–1989) the construction of the Tiga Dam.
Table II. Mean annual river flow and peak discharge at six sites in the basin before and after the completion of Tiga Dam

<table>
<thead>
<tr>
<th>River</th>
<th>Site</th>
<th>Catchment area (km²)</th>
<th>Pre-Tiga Dam construction</th>
<th>Post-Tiga Dam construction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean annual flow (10⁶ m³)</td>
<td>Mean annual rainfall (mm)</td>
<td>Mean peak discharge (m³ s⁻¹)</td>
</tr>
<tr>
<td></td>
<td>Katagum</td>
<td>15 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yau</td>
<td>84 138</td>
<td>423</td>
<td>5</td>
</tr>
</tbody>
</table>

a Wudil: using weighted rainfall from Bauchi, Kaduna and Kano; Bunga: using weighted rainfall from Bauchi, Jos and Kano (Afremedev Consultancy Services, 1999).
b Excluding 1987.
RESULTS

Changes in flow regime

Peak flow. The Tiga Dam and the frequency of prolonged droughts reduced the average peak flow in the upstream part of the Hadejia River at Wudil (Figure 1) by 64% between 1964–1973 and 1979–1989 (Figure 2(b)). While in the uncontrolled Jama’are River at Bunga, the average peak showed a reduction, as a result of droughts only, of 27% between these two periods (Table II). This 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, 1987).

Figure 2(c) shows that, at a high annual runoff for Wudil, relatively little water arrives at Hadejia. Thompson (1995) showed that the relative flow reduction increases significantly when the 10-day discharge at Wudil is above $87 - 145 \, \text{m}^3 \, \text{s}^{-1}$. The causes for the river flow reduction at relatively high flows require further study, but the reduction is most likely attributed to floodplain inundation and the presence of at least four (Kafin Hausa River which is shown on Figure 1 and smaller channels near Majia, Tsaiwawa and Harbo) non-returning channels with an elevated river bed where they connect to the main Hadejia River. The decrease of peak flows at Wudil reduced the inflow in the non-returning channels and the floods. As a result shallow groundwater recharge probably decreased.

The average peak flow at Hadejia was reduced by 34% from $99 \, \text{m}^3 \, \text{s}^{-1}$ (1964–1973) to $65 \, \text{m}^3 \, \text{s}^{-1}$ (1979–1989), which is the same order of magnitude as the peak flow reduction at Bunga (27%) on the uncontrolled Jama’are River (Table II). It can thus be inferred that this trend is primarily because of the climatic change present. In the 1990s, the Hadejia peak flow has the same order of magnitude as in the 1960s (Figure 2(b)). Therefore, the peak flow at Hadejia has not been significantly reduced (1979–1998) as a result of the construction of the flow regulation structures upstream. This is because of the relatively small river flow reduction between Wudil and Hadejia at lower flows at Wudil.

Annual flow. The annual runoff in the upstream part of the Hadejia River at Wudil (Figure 1) was reduced as a result of an increased water usage (mainly KCWS and KRIP) and evaporation losses from Tiga Reservoir. This caused a reduction of the annual discharge at Wudil (Table II). Another cause of the reduced annual runoff, following the completion of Tiga Dam (1974), was a number of droughts in the 1970s and mid-1980s. The cumulative mass curve of annual flows at Wudil and Bunga (Bunga is an upstream site on the neighbouring uncontrolled Jama’are River, Figure 1) shows a consistent gradient from 1964 to 1973, the pre-Tiga Dam period (Figure 3(a)). This gradient remained the same through the drought period of 1972 and 1973. Thus, it is assumed that subsequent droughts would have resulted in a similar flow reduction at Bunga and Wudil in a situation with no dams. However, after the completion and filling-up of Tiga Reservoir (1979–1989) the gradient of the cumulative mass curve dropped from 0.95 to 0.64 as a result of a reduction of annual river flow at Wudil by 33%. The flow reduction during the filling-up period of the reservoir (1974–1976) was around 58%.

The gradient of the cumulative mass curve of annual flows at Bunga and Hadejia, downstream of Wudil just above the HNW (Figure 1), did not change significantly between the pre- and post-Tiga Dam periods (Figure 3(b)). An upgrade of recent Bunga River flow data is needed (see above) before the impact of Challawa Dam (1992) on the annual river flow at Hadejia can be determined with the cumulative mass curve. However, a major impact is unlikely since the recent (1994–1997) annual Hadejia discharge has the same order of magnitude as in the 1960s (Figure 2(d)). This is because of the relatively small river flow reduction between Wudil and Hadejia at lower flows at Wudil and the fact that the formal large upstream water users are not (yet) working at full capacity.

Dry season flow. As a result of the dry season releases from Tiga Dam, which are made to supply water to the three large formal users upstream of Hadejia (i.e. KRIP, KCWS and HVIP), an alteration of the Hadejia River regime from ephemeral to perennial occurred. Between 1963 and 1973, only 2% of the mean annual runoff passed Wudil from November to May. After the Tiga Dam was built (1979–1989) this percentage increased to 21%.

At Hadejia, dry season river flows increased from 4% of the annual flow (1964–1973) in the uncontrolled river to 16% (1977–1991) after Tiga Dam was built and 32% (1993–1997) after the
Figure 3. (a) Cumulative annual river flow relation between Bunga (Jama’are River) and Wudil (Hadejia River): 1964–1989 (excluding 1987). (b) Cumulative annual river flow relation between Bunga (Jama’are River) and Hadejia (Hadejia River): 1964–1990 (excluding 1987)

completion of the Challawa Dam (Figure 2(d)). Figure 4 shows the increased dry season flows by presenting two hydrographs with similar annual flows: one for a hydrological year during the pre-dams period and another for a year during the post-dams period.

Effects of changes in flow regime

Aquatic macrophyte development and flow reduction. Owing to excessive aquatic macrophyte growth (mainly *Typha domingensis*) and silt blockages in the Old Hadejia River (Figure 1) virtually no water (less than 1%) from the Hadejia River system has been contributing to the Yobe River since at least the early 1990s (Thompson, 1995; Goes and Zabudum, 1996, 1998). In the Hadejia Barrage, *Typha* started to grow shortly after the completion in 1992. It was observed that the *Typha* grows in zones of the barrage with
shallow (less than 1–1.5 m deep) and fluctuating water (E. Kazaure, pers. comm.). *T. domingensis* and other reeds did not invade the channels of the uncontrolled ephemeral Jama’are River. The reeds can not 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. Similar experiences have been reported on *Typha* reeds in the Sudd Wetlands in southern Sudan (Sutcliffe and Parks, 1996). According to the authors, large areas on the fringe of a permanent swamp had been invaded with *T. domingensis*, and it was deduced that this species was favoured by the extension of shallow permanent flooding which followed a rise in inflows. According to Howard (1996), the following circumstances are favourable for the development of the reed: (1) the absence of fast flowing water; (2) continually moist soil; and (3) relatively nutrient rich water. This means that the diversion of wet season river flows to dry season releases from the dams and possibly nutrient rich drainage water from the irrigated areas (unfortunately there is no data on surface water quality) created favourable circumstances for the reeds to develop in the Hadejia River system. The main blockages developed in the southern channel in the HNW (Old Hadejia River), which used to contribute to the Yobe River, and less in the other main channel (Marma Channel), which flows into Nguru Lake, because the gradient of the first 30 km of the Old Hadejia River (0.12 m km$^{-1}$; Chifana Consultants, 1983) is lower than the gradient of the Hadejia River system flowing towards Nguru (0.18 m km$^{-1}$; Diyam Consultants, unpubl.) and because of a series of fish traps which were present in the Old Hadejia River. The fish traps, which trap sediment and may cause ponding and slow the water, are observed in the Old Hadejia River on aerial photographs from 1968–1969 and are not seen on the photos in the channel flowing towards Nguru Lake and in the Burum Gana River (Diyam Consultants, 1996).

As a result of the blockages in the Old Hadejia River, the Yobe River now completely depends on the Jama’are River for its water. Diyam Consultants (1996) estimated that the mean annual contribution from the Hadejia River to the Yobe River prior to the regulation was 20% of the average annual flow at Gashua. However, the estimated contribution was zero in dry years. Although the Jama’are River provides the bulk of the water to the Yobe River, the additional water from the Hadejia River may, especially in below average peak flow years, be crucial to raise the peak flows to a level above which the river spills into the flood plains and/or to provide additional water in the river for small-scale farmer managed irrigation.

![Figure 4. Daily hydrograph at Hadejia for a pre-dams year (1969/1970: annual flow 877 × 10⁶ m³) and a post-dams year (1994/1995: annual flow 872 × 10⁶ m³)](image-url)
Less reliable timing of floods. Only one value is available for the flood extent in the HNW for the pre-dams period; 1692 km² in 1969 (Table III). 1969 was a wet year with above average annual discharges at Bunga (Diyam Consultants, 1996) and Hadejia (Figure 2(d)). In 1974, the flood extent in the HNW was 1369 km². For the period 1990–1993, a flood extent between 387 and 910 km² was observed. For the last 4 years (1994–1998), the flood extent was between 967 and 1806 km². So despite a decrease in wet season river flows at Hadejia, relatively large flood extents are still possible in wet years. This is explained by the fact that the Hadejia River stopped contributing to the Yobe River because of the blockages.

Rice farmers in the HNW prefer the floods to arrive from 1 to 4 weeks after the onset of the rains. This period is needed for young plants to grow strong enough to withstand the flooding and grazing by fish which come with the floods (Hadejia et al., 1994). For the period 1984–1998, the date of the onset of the rainfall in the HNW varied between 17 June and 30 August, the average date was 12 July with a standard deviation of 17 days (Goes and Zabudum, 1998). It can thus be concluded that, in an average year, it would be advantageous for rice farmers if the floods arrive in late July or early August. Taking into account a travel time of 2 weeks for the water to flow from the dams to Hadejia and 1 week from Hadejia to Likori (Goes and Zabudum, 1996), in a mean year flood releases from the dams should start in early-July. Contrary to what would be expected, after the completion of the dams the timing of the floods in the HNW became less predictable (Figure 5). Even dry season flooding occurred in the HNW in February–March 1996 and December 1997–February 1998. Based on a field survey, it was estimated that the dry season floods of 1997–1998 destroyed between 30 and 60% of the flood recession farms along the Marma Channel between Likori and Tukwikwi (about 10 km before Nguru Lake; Figure 1) (Goes and Zabudum, 1998). Presently (1998–2000), as a result of the increasing dry season flow, the lowest floodplains along the Marma Channel (e.g. Maikintari just downstream of Likori, Figure 1) remain flooded all year round. Therefore, at the moment these floodplains can no longer be used for flood rice farming, flood recession agriculture and/or dry season grazing.

Water wastage during the dry season. Dry season flows in the HNW during the second half of the dry season (January–May) are wasteful because there are not many demands during this period. Small-scale irrigation in the HNW is mainly practised during the first part of the dry season (mean maximum Nguru temperature between 11 November and 10 February: 32.1°C) and not during the hottest part of the dry

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Flood extent (km²)</th>
<th>Method and source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upstream of Gashua</td>
<td>Had./Katag. to Gashua (HNW)</td>
</tr>
<tr>
<td>1969</td>
<td>October</td>
<td>2350</td>
<td>1692*</td>
</tr>
<tr>
<td>1974</td>
<td>September</td>
<td>2004</td>
<td>1369</td>
</tr>
<tr>
<td></td>
<td>October</td>
<td>1846</td>
<td>1325</td>
</tr>
<tr>
<td>1986</td>
<td>November</td>
<td>1186</td>
<td>Landsat TM (Sule, 1993 in: Hollis et al., 1993)</td>
</tr>
<tr>
<td>1987</td>
<td>September</td>
<td>700</td>
<td>Field &amp; aerial surv. (Benthem, 1988 in: Hollis et al., 1993)</td>
</tr>
<tr>
<td>1990</td>
<td>September</td>
<td>910</td>
<td>Landsat TM (Sule, 1994 in: Hollis et al., 1993)</td>
</tr>
<tr>
<td>1991</td>
<td>September</td>
<td>893</td>
<td>Aerial survey (HNWCP)</td>
</tr>
<tr>
<td>1992</td>
<td>October</td>
<td>545</td>
<td>Aerial survey (HNWCP)</td>
</tr>
<tr>
<td>1993</td>
<td>October</td>
<td>387</td>
<td>Aerial survey (HNWCP)</td>
</tr>
<tr>
<td>1994</td>
<td>October</td>
<td>1728</td>
<td>Aerial survey (HNWCP)</td>
</tr>
<tr>
<td>1995</td>
<td>October</td>
<td>967</td>
<td>Aerial survey (IUCN-HNWCP)</td>
</tr>
<tr>
<td>1996</td>
<td>Oct./Nov.</td>
<td>1567</td>
<td>Aerial survey (IUCN-HNWCP)</td>
</tr>
<tr>
<td>1997</td>
<td>October</td>
<td>1107</td>
<td>Aerial survey (IUCN-HNWCP)</td>
</tr>
</tbody>
</table>

* Estimated on basis of total flood extent in 1969 and percentage of total flood in HNW in October 1974.
Figure 5. Periods during which the Hadejia discharge exceeded 19 m$^3$ s$^{-1}$ (threshold value above which over bank flow starts; Goes and Zabudum, 1996)

season (mean maximum Nguru temperature between 11 February and 10 June: 38.5°C; Kowal and Knabe, 1972). One of the main reasons for the fact that the discharge in the Hadejia River is maintained at higher than optimal levels during the second half of the dry season is to ensure that the pits of KCWS downstream of Tiga Dam are adequately filled (Diyam Consultants, 1996). The excessive dry season releases are likely to increase further because the new (1999) water intake to KCWS downstream of Challawa Dam is operated with similar flow regulation principles.

**DISCUSSION**

*Water management in the regulated Yobe River Basin*

Uncoordinated surface water uses. Uncoordinated developments throughout the basin because of increasing demands for water are leading to an inequitable water distribution and environmental damage. The expansion of the HVIP from 2075 to 6109 ha, for example, with an increase in water requirements from 75 to 220 $10^6$ m$^3$ year$^{-1}$, was approved in 1998.

Table IV presents the water resources and both current and potential water requirements for the Hadejia, Jama’are and Yobe River systems. The total surface water resources are the flows at the upstream end of each river reach. It is important to note that current water requirements of some of the formal large upstream users are not utilized fully. This creates false expectations among other, predominantly downstream, users when the excess water is temporarily available (IUCN-HNWCP, 1999). A good example is KCWS, which is unable to abstract its present requirements ($202 \times 10^6$ m$^3$ year$^{-1}$) because of the fact that the intake works are just partly operative. The second water intake for KCWS has just been constructed (1999) and it is, therefore, likely that the magnitude of water abstraction will increase towards their current water requirements.

The water requirements within the Hadejia River system have clearly reached a ceiling beyond which further expansion of the requirements of one use will deprive other uses of water. The demands need to
Table IV. Annual surface water resources and requirements in the Yobe River Basin (excluding the Komadugu River, source: IUCN-HNWCP, 1999)

<table>
<thead>
<tr>
<th>River system</th>
<th>Available surface water resources range (mean)</th>
<th>Mean river flow reduction</th>
<th>Present water requirements</th>
<th>Potential water requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(10^6 m^3 year^-1)</td>
<td>(10^6 m^3 year^-1)</td>
<td>Formal (10^6 m^3 year^-1)</td>
<td>Informal (10^6 m^3 year^-1)</td>
</tr>
<tr>
<td>Hadejia</td>
<td>536-2567 (1739)</td>
<td>798^a</td>
<td>894^d</td>
<td>765</td>
</tr>
<tr>
<td>Jama’are</td>
<td>518-4577 (2194)</td>
<td>919^b</td>
<td>0</td>
<td>1620</td>
</tr>
<tr>
<td>Yobe</td>
<td>381-2551 (mean 1201)</td>
<td>855^c</td>
<td>58</td>
<td>246</td>
</tr>
</tbody>
</table>

Formal schemes = evaporation from reservoirs and water uses by large irrigation projects and Kano City.
Informal = all other uses (e.g. flood and small scale agriculture, water supply for smaller towns and villages), these uses partly depend on natural river flow reductions.

^a Wudil to Nguru.
^b Foggo to Gashua.
^c Gashua to Yau.
^d A total of 144 x 10^6 m^3 year^-1 extra in 2002 when the approved (in 1998) expansion of HVP is planned to be completed.
be controlled, given the fact that the potential water requirements are 2.6 times larger than the mean available surface water resources (IUCN-HNWCP, 1999).

The average annual surface water resources within the Jama’are and Yobe river systems are currently able to satisfy the current water requirements which are placed upon them. This may change in the near future because the potential water requirements for the Jama’are River system are 1.8 times the available water resources in an average year. This can be largely attributed to the reservoir behind the proposed Kafin Zaki Dam, the proposed large formal irrigation projects in the Jama’are Valley and the planned expansion of the area used for small-scale irrigation upstream of Katagum (IUCN-HNWCP, 1999). To aid management of water resources and flow strategies, resumption of hydrological monitoring and upgrading of the gauging station network is also needed.

**Recommended major engineering structures.** The following engineering measures are recommended to improve the water management in the basin (IUCN-HNWCP, 1999):

1. The installation of the proposed (Diyam Consultants, 1996) flow proportioning structure at Likori in the HNW. The structure will distribute water between the two rivers that feed the uses in the wetlands (Marmi Channel and Burum Gana River) and the river which contributes to the Yobe River (Old Hadejia River). Diyam’s proposal includes the construction of a canal (3–5 km) from Likori to the Old Hadejia River. The proposal is conceived as the best option for conveying water from the Hadejia River to the Yobe River because it can be controlled in such a way that there are no disastrous impacts on uses along the Marmi Channel and Burum Gana River. Other advantages of the proposed site are: good accessibility; the flow in the three channels is controlled at one location; and the first 10–15 km of the Old Hadejia River, which has the largest siltation and aquatic macrophyte growth, is by-passed. There would still be a need for aquatic macrophyte clearance and dredging at some locations in the remaining part of the Old Hadejia River. Otherwise, water allocated to people along the Yobe River may inundate areas along the Old Hadejia River, which is a section where flood and recession cultivation is not practised. Furthermore, aquatic macrophyte clearance and dredging is necessary as well at some locations in the Burum Gana River and Marmi Channel. This can be facilitated by managing the structure and the dams in such a way that no water will flow into the channels during several months of the year. This will help to control the invasion of *Typha* because its growth is hampered by a dry soil.

2. The intake works for KCWS need to be improved by, for example, lowering the intake to the river bed in combination with a weir. When the measure is executed, the dry season releases can be reduced so less water will be wasted.

3. The installation of a valve at the second outlet structure of Tiga Dam. Although Tiga Reservoir has twice the inflow of Challawa Reservoir, the maximum capacity of the main outlet at Tiga Dam (25–35 m$^3$ s$^{-1}$) is just a third of the maximum capacity of the two outlets of Challawa Dam (86 m$^3$ s$^{-1}$). Furthermore, the main task of the working outlet at Tiga Dam is to supply the KRIP. The installation of a valve at the second outlet is, therefore, necessary to enable Tiga Dam to contribute to peak wet season releases for flood farmers and to serve as a back-up in case the other outlet is out of order.

**CONCLUSIONS**

The average annual flow in the upstream part of the Hadejia River reduced by 33% after the completion of Tiga Dam (1979–1989). Furthermore, the peak flow is reduced and the river regime has changed from ephemeral to perennial. The impact of these reductions is probably limited in the upstream section of the river because of 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 (1979–1997) as a result of the construction of the control structures. This is because of the
relatively low river flow reductions upstream at 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. This may be done by: enhancing the number of river flow monitoring sites along the section; monitoring the discharge into non-returning channels; long-term groundwater level monitoring; and the mapping of the maximum flood extent.

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; (2) lead to dry season floods that are disadvantageous for farmers and herders; and (3) waste water.

Owing to the flow management related problems in the regulated Yobe River Basin, three engineering projects and the implementation of environmentally acceptable flow regimes are necessary. The newly recommended engineering structure in the HNW can apportion water between the HNW and the Yobe River, the improvement of the intake works for Kano City Supply enables the reduction of dry season flows and the installation of a second valve on the Tiga Dam can improve flood releases. Two changes in flow regime are recommended. (1) During the second half of the dry season (February–May) releases from the dams should be limited only to the three large formal water uses. That water can be saved for, for example, the restoration of a part of the historic contribution from the Hadejia to the Yobe River. Furthermore, this will facilitate the clearance of aquatic macrophyte and silt blockages. (2) The timing of the floods should become more predictable so farmers can plan the land preparation and planting of seeds accordingly. In an average year, early July is the appropriate time for the start of the wet season flood releases from the dams.

The potential water requirements in the basin exceed the water availability in a mean year. Therefore, a proper basin-wide demand control policy has become essential. Policy makers have to decide on quantities of water to be allocated to the large formal users in the upstream part of the basin. The consequences of the allocation on the amount of water remaining for uses downstream has to form a part of the decision making process. There is also an urgent need for an institutional organization that manages the water resources on a basin-wide scale.

ACKNOWLEDGEMENTS

The paper is based on the author’s work experience as a hydrologist at the Hadejia-Nguru Wetlands Conservation Project. The Hadejia-Nguru Wetlands Conservation Project is a field project of IUCN—The World Conservation Union (Switzerland). Core funding for the third phase of the project (April 1995–March 1998) was provided by the Commission of the European Union. Bridging funds (April 1998–present) have been provided by the Department for International Development (UK), the Royal Society for the Protection of Birds (UK) and the Yobe State Government (Nigeria). Michael van der Valk and two anonymous reviewers made numerous valuable comments on an earlier version of this paper. Michael also drew the map. This study would not have been possible without the kind assistance from the people and organizations mentioned above.

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