Upstream Dams and Downstream Water Allocation

The Case of the Hadejia'Jama'are Floodplain, Northern Nigeria

Edward B Barbier

Department of Economics and Finance, University of Wyoming

PO Box 3985, Laramie, WY 82071-3985

ebarbier@uwyo.edu tel: (307) 766 2178 fax: (307) 766 5090

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Introduction

The following paper is concerned with the allocation of water upstream and its impacts on economic activities downstream. First, the basic hydrological and economic issues of upstream water diversion are reviewed. Then a model of upstream water diversion with downstream impacts is constructed. The model is illustrated with the example of the Hadejia-Jama'are floodplain in Northern Nigeria, in which the downstream losses from dams and other barrages constructed upriver include agricultural production, fishing and fuelwood collection as well as the impacts on the recharge of shallow aquifers that are important for dry-season irrigation and water use by villages located outside of the floodplain.

The Hadejia-Jama'are case study illustrates that the economic costs of upstream water diversion can be substantial, particularly in a semi-arid environment where downstream uses of water are critical to the economic livelihoods to a large number of rural households. Unfortunately, in Northern Nigeria, the construction of dams and other water projects upstream have already affected irreversibly the hydrology of the Hadejia-Jama'are floodplain. Some of these impacts could be mitigated by the implementation of regulated flood regimes that would reduce some of the downstream economic losses with little impact on upstream water uses. As this case study demonstrates, it is imperative that such a management plan is implemented as soon as possible.

Hydrological, Ecological and Economic Issues of Upstream Water Diversion

Lower catchment rivers and ecosystems in a drainage basin receive their water discharge and nearly all their sediment from the upper watershed, and over long periods of time, adjust and adapt to these flows of water and sediment from the upper catchment (Wilcock 1993). In Africa, one of the most significant downstream riparian ecosystems in river basins are the seasonally inundated savanna or forested floodplains. These "wetland" ecosystems are relatively flat areas adjacent to rivers created by sedimentary deposits of meandering channels as well as periodic flooding. During seasonal flood events, water often leaves the main river channel and inundates a floodplain. Water velocity decreases across the floodplain owing to lower flows and increased friction from the land surface (Cech 2003). As this occurs, sediment rapidly falls out of the floodwater and is deposited. These alluvial deposits make for extremely fertile soils, which have been exploited for centuries in many regions of Africa by traditional "flood recession" agriculture. That is, as the floods abate and recede, crops are planted in the naturally irrigated soils.

Around half of Africa's total wetland area consists of floodplains, and they include famous, large-scale examples that cover several thousand square kilometers such as the Inner Niger Delta in Mali, the Okavango Delta in Botswana, the Sudd of the Upper Nile in Sudan and the Kafue Flats in Zambia (Lemley *et al.* 2000; Thompson and Polet 2000). There are also many smaller and less well-known floodplain systems that are locally important.

Africa's floodplains typically serve as critical habitat for birds, including wintering grounds for migratory species, and the availability of water in many floodplains during the dry season is an important resource for grazing wildlife. Millions of people across the continent are also dependent on the floodplains for their economic livelihoods. Production activities dependent directly on the floodplains include agriculture, fishing, grazing and wood and non-wood harvesting of riparian forest resources (Adams 1992; Scudder 1991). In many instances, the uses of these wetlands are integrated with those of surrounding semi-arid, or "drylands", and thus floodplains have an economic importance beyond the initial areas inundated (Scoones

1991). Hydrologists also maintain that floodplains in some semi-arid regions may also recharge groundwater resources in surrounding areas (DIYAM 1987; Thompson and Hollis 1995).

By influencing transfer of water and sediment downstream, economic activities and developments in upstream areas can drastically affect both the inundation area of a floodplain and its crucial ecological functions. This will in turn impact on the various economic activities that may be dependent on the floodplain. For example, diversion of upstream water supplies for irrigation, water supply, flood control and hydroelectricity generation will interrupt the continuous downstream transfer of water and sediment which would otherwise take place. The result is a change in channel flow regime and morphology, sediment transport rates, water quality and water temperatures, which will have dramatic consequences to the ecology of lowland river ecosystems and floodplains (Wilcock 1993). If the latter disruptions have a negative impact on downstream economic activities, such as irrigated agriculture, fishing and recreational activities, then there could be significant costs involved.

Thus, in the presence of significant environmental impacts, the net benefits of a development project or program cannot be appraised in terms of its direct benefits and costs alone. The forgone net benefits of disruption to the natural environment and degradation must also be included as part of the opportunity costs of the development investment.

Upstream Water Diversion

Upstream water diversion is clearly an example of a unidirectional economic externality. Water that is diverted upstream means less water downstream, and the result is that upstream activities benefit at the expense of downstream activities. Determining the optimal level of water diversion between upstream and downstream uses is therefore a critical issue. A simple production function model of a river basin can illustrate this important water allocation choice.

For example, consider a river basin in which there are two competing uses for water flowing through the basin: water diverted upstream for irrigated agriculture and water flowing downstream for natural floodplain agriculture. Thus floodplain agricultural production is entirely dependent on the stock of water available downstream and 'stored' in the naturally occurring floodplain. This downstream water supply, W, is freely available to the agricultural system, which uses a fixed proportion of it, kW.[1] Output per hectare in the agroecosystem, h_1, is therefore a function of the available water stock, W, and a vector of other inputs, z_1 (e.g. labor, purchased inputs, etc.). Assuming that the agricultural system produces for a market in response to a given market price, p^h, and faces a vector of given input prices, c, the discounted economic returns of present and future production in the agroecosystem can be represented as

$$\begin{gathered} V^1 = V^1(z_1, W, t;\ p^h, c, \delta) = \int_0^T (p^h h_1 - cz_1)\, e^{-\delta t}\ dt \\ h_1 = h_1(z_1, W), h_{1i} > 0, h_{1ii} < 0, i = z_1, W, \end{gathered} \tag{1}$$

where δ is the rate of discount and T is the time period over which the downstream agroecosystem is in operation.

However, the continuous diversion of water for upstream projects, such as irrigation or water supply, reduces the flow of water through the watershed and drainage basin, directly affecting the supply of water available downstream for the floodplain. This diversion can be represented by:

$$\begin{gathered} W(t) - W(0) = -\int_0^t d\ dt \\ \text{or}\ \ W = -d\,. \end{gathered} \tag{2}$$

Thus d represents the amount of water diverted each period by upstream projects, and hence the amount of water no longer available for the stock of downstream supply, W. If it is assumed that water in a river basin is being continuously diverted upstream for an irrigated agricultural system, then the discounted returns per hectare for this system, V^2, may take the following form

$$V^2 = V^2(z_2, d, t;\ p^h, c, \delta) = \int_0^T (p^h h_2 - cz_2)\, e^{-\delta t}\, dt \tag{3}$$

$$h_2 = h_2(z_2, d, \textstyle\int d\, dt) = h_2(z_2, d, W(0) - W(t)),\ h_{2i} > 0,\ h_{2ii} < 0,\ i = z_2, d, W(0) - W(t),$$

where agricultural yield, h_2, is presumed to be an increasing function of both current water diversion, d, cumulative diversion into the upstream irrigation network, $\int d\, dt$, and variable inputs, z_2. Output is sold at the given market price for irrigated crops, p^h, and cost of inputs is c. In this simple example, it is assumed that there is no user charge imposed on the agricultural system for the irrigation water supplied through the upstream water project.[2]

In this case, the economic externality problem arises because any farmer benefiting from the diverted irrigation from the upstream water project is unconcerned about any resulting impacts on downstream water availability. For example, it is clear from equation (3), that the economic agent would maximize discounted returns by choosing a rate of water diversion, d^i, in each period t, that would satisfy the following condition

$$\frac{\partial V^2}{\partial d} = p^h h_{2d}(d^i) = 0, \quad \forall t \tag{4}$$

i.e., from the standpoint of the upstream irrigation farmer, optimal diversion of water to the upstream irrigated agricultural system in every time period should occur until there are no more gains to be had from using additional water inputs.

In contrast, if there was a single river basin planning authority, this agency would be concerned with maximizing not only the returns to upstream irrigated agriculture, e.g. equation

(3), but also the returns to the downstream agroecosystem as well, e.g. equation (1). Denoting λ as the costate variable, or 'shadow price', of the downstream water supply, the current value Hamiltonian, *H*, and relevant first order conditions of concern to the river basin authority might be:

$$H = (p^h h_1 - cz_1) + (p^h h_2 - cz_2) - \lambda d$$

$$\frac{\partial H}{\partial d} = p^h h_{2d}(d^*) - \lambda = 0 \qquad (5)$$

$$-\frac{\partial H}{\partial W} = \lambda - \delta\lambda = p^h h_{2W(0)-W(t)} - p^h h_{1W} \text{ or } \frac{\lambda}{\lambda} + \frac{h_{1W}}{h_{2d}} - \frac{h_{2W(0)-W(t)}}{h_{2d}} = \delta. \ \forall t$$

In comparison with (4), the first order conditions in (5) show that the optimal rate of water diversion for the entire river basin occurs where the marginal benefit to upstream irrigated agriculture of diversion equals the shadow price, or value, of water supply to the downstream agroecosystem. By definition, λ(*t*) is the imputed value of the downstream water stock, *W*, in terms of the net returns to the agroecosystem in the lower catchment. As this shadow value is positive, and is likely to be increasing over time as *W* is depleted, then the optimal rate of diversion, d^*, for the entire watershed and drainage basin will be less than the rate, d^i, that an upstream farmer would decide on his or her own.[3]

Consequently, the *valuation* problem facing the river basin planner is to determine the contribution of the available downstream water to the returns to the lower catchment agricultural system, and how these returns might change over time as more water is diverted to the upstream project. As the following example indicates, overcoming this incentive problem and ensuring an optimal rate of diversion in a river basin system is particularly difficult if plans and development for upstream water diversion are already well advanced.

Case Study: Hadejia-Jama'are River Basin, Northern Nigeria

In Northeast Nigeria, an extensive floodplain has been created where the Hadejia and Jama'are Rivers converge to form the Komadugu Yobe River, which drains into Lake Chad (see Figure 1). Although referred to as wetlands, much of the Hadejia-Jama'are floodplain is dry for some or all of the year. Nevertheless, the floodplain provides essential income and nutrition benefits in the form of agriculture, grazing resources, non-timber forest products, fuelwood and fishing for local populations (Thomas and Adams 2000). The wetlands also serve wider regional economic purposes, such as providing dry-season grazing for semi-nomadic pastoralists, agricultural surpluses for Kano and Borno states, groundwater recharge of the Chad Formation aquifer and many shallow aquifers throughout the region, and "insurance" resources in times of drought (Hollis *et al.* 1993; Thompson and Hollis 1995). In addition, the wetlands are a unique migratory habitat for many wildfowl and wader species from Palaearctic regions, and contain a number of forestry reserves (Hollis *et al.* 1993; Thompson and Poulet 2000).

However, in recent decades the Hadejia-Jama'are floodplain has come under increasing pressure from drought and upstream water developments. The maximum extent of flooding has declined from between 250,000 to 300,000 ha in 1960s and 1970s to around 70,000 to 100,000 ha more recently (Thompson and Hollis 1995; Thompson and Polet 2000). Drought is a persistent, stochastic environmental problem facing all sub-Saharan arid and semi-arid zones, and the main cause of unexpected reductions in flooding in drought years. The main long-term threat to the flooplain is water diversion through large-scale water projects on the Hadejia and Jama’are Rivers. Upstream developments are affecting incoming water, either through dams altering the timing and size of flood flows or through diverting surface or groundwater for irrigation. These developments have been taking place without consideration of their impacts on the Hadejia-Jama'are floodplain or any subsequent loss of economic benefits that are currently provided by use of the floodplain.

The largest upstream irrigation scheme at present is the Kano River Irrigation Project (KRIP). Water supplies for the project are provided by Tiga Dam, the biggest dam in the basin, which was completed in 1974. Water is also released from this dam to supply Kano City. The second major irrigation scheme within the river basin, the Hadejia Valley Project (HVP), is under construction. The HVP is supplied by Challawa Gorge Dam on the Challawa River, upstream of Kano, which was finished in 1992. Challawa Gorge also provides water for Kano City water supply. A number of small dams and associated irrigation schemes have also been constructed or are planned for minor tributaries of the Hadejia River. In comparison, the Jama’are River is relatively uncontrolled with only one small dam across one of its tributaries. However, plans for a major dam on the Jama’are at Kafin Zaki have been in existence for many years, which would provide water for an irrigated area totaling 84 000 ha. Work on Kafin Zaki Dam has been started and then stopped a number of times, most recently in 1994, and its future is at present still unclear.

Against the benefits of these upstream water developments must be weighed the opportunity cost of the downstream floodplain losses. Economic valuation studies have focused on three types of floodplain benefits that are likely to be most affected by impacts on the floodplain:

- Flood-recession agriculture, fuelwood and fishing in the floodplain (Barbier *et al.* 1993).
- Groundwater recharge that supports dry season irrigated agricultural production (Acharya and Barbier 2000).

- Groundwater recharge of domestic water supply for household use (Acharya and Barbier 2002).

Impacts on flood-recession agriculture, fuelwood and fishing

A combined economic and hydrological analysis was recently conducted to simulate the impacts of these upstream projects on the flood extent that determines the downstream floodplain area (Barbier and Thompson 1998). The economic gains of the upstream water projects were then compared to the resulting economic losses to downstream agricultural, fuelwood and fishing benefits.

Table 2 indicates the scenarios that comprise the simulation. Since Scenarios 1 and 1a reflect the conditions without any of the large-scale water resource schemes in place within the river basin they are employed as baseline conditions against which Scenarios 2-6 are compared. Scenario 2 investigates the impacts of extending the Kano River Irrigation Project (KRIP) to its planned full extent of 22 000 ha without any downstream releases. In contrast, Scenario 3 simulates the impacts of limiting irrigation on this project to the existing 14 000 ha to allow a regulated flood from Tiga Dam in August to sustain inundation within the downstream Hadejia-Jama'are floodplain. Challawa Gorge is added in Scenario 4 and the simulated operating regime involves the year-round release of water for the downstream Hadejia Valley Project (HVP), but not for sustaining the Hadejia-Jama'are floodplain. Scenario 5 simulates the full development of the four water resource schemes without any releases for the downstream floodplain. In direct comparison, Scenario 6 shows full upstream development, but less upstream irrigation occurs in order to allow regulated water releases from the dams to sustain inundation of the downstream floodplain.

In Table 3, the impacts of Scenarios 2-6 upon peak flood extent downstream are evaluated as the difference between maximum inundation predicted under each of these scenarios and the peak flood extents of the two baseline scenarios. The gains in upstream irrigated area are also indicated for each scenario in Table 3. The estimated floodplain losses are indicated in Table 4 for each scenario compared to the baseline Scenarios 1 and 1a. Given the high productivity of the floodplain, the losses in economic benefits due to changes in flood extent for all scenarios are large, ranging from US$2.6-4.2 million to US$23.4-24.0 million.[4] As expected, there is a direct tradeoff between increasing irrigation upstream and impacts on the wetlands downstream. Scenario 3, which yields the lowest upstream irrigation gains, also has the least impact in terms of floodplain losses, whereas Scenario 5 has both the highest irrigation gains and floodplain losses. The results confirm that in all the scenarios simulated the additional value of production from large-scale irrigation schemes does not replace the lost production attributed to the wetlands downstream. Gains in irrigation values account for at most around 17% of the losses in floodplain benefits.

This combined hydrological-economic analysis would suggest that no new upstream developments should take place in addition to Tiga Dam. Moreover, a comparison of Scenario 3 to Scenario 2 in the analysis shows that it is economically worthwhile to reduce floodplain losses through releasing a substantial volume of water during the wet season, even though this would not allow Tiga Dam to supply the originally planned 27 000 ha on KRIP.

Although Scenario 3 is the preferred scenario, it is clearly unrealistic. As indicated above, Challawa Gorge was completed in 1992, and in recent years several small dams have been built on the Hadejia's tributaries while others are planned. Thus Scenario 4 most closely represents the current situation, and Scenario 5 is on the way to being implemented - although when the construction of Kafin Zaki Dam might occur is presently uncertain. As indicated in Table 4, full implementation of all the upstream dams and large-scale irrigation schemes would produce the greatest overall net losses, around US$20.2-20.9 million (in terms of net present value).

These results suggest that the expansion of the existing irrigation schemes within the river basin is effectively ‘uneconomic’. The construction of Kafin Zaki Dam and extensive large-scale formal irrigation schemes within the Jama’are Valley do not represent the most appropriate developments for this part of the basin. If Kafin Zaki Dam were to be constructed and formal irrigation within the basin limited to its current extent, the introduction of a regulated flooding regime (Scenario 6) would reduce the scale of this negative balance substantially, to around US$15.4-16.5 million. The overall combined value of production from irrigation and the floodplain would however still fall well below the levels experienced if the additional upstream schemes were not constructed.[5]

Such a regulated flooding regime could also produce additional economic benefits that are not captured in our analysis. Greater certainty over the timing and magnitude of the floods may enable farmers to adjust to the resulting reduction in the risks normally associated with floodplain farming. Enhanced dry season flows provided by the releases from Challawa Gorge and Kafin Zaki dams in Scenario 6 would also benefit farmers along the Hadejia and Jama’are Rivers while the floodplain’s fisheries may also experience beneficial impacts from the greater extent of inundation remaining throughout the dry season. The introduction of a regulated flooding regime for the existing schemes within the basin may be the only realistic hope of minimizing floodplain losses. Proposed large-scale schemes, such as Kafin Zaki, should ideally be avoided if further floodplain losses are to be prevented. If this is not possible the designs for water resource schemes should enable the release of regulated floods in order to, at least partly, mitigate the loss of floodplain benefits that would inevitably result.

Currently, as a result of such economic and hydrological analyses of the downstream impacts of upstream water developments in the Hadejia-Jama'are floodplain both the States in Northern Nigeria and the Federal Government have become interested in developing regulated flooding regimes for the existing upstream dams at Challawa Gorge and Tiga, and have been reconsidering the construction of Kafin Zaki Dam. If these revised plans are fully implemented, then this suggests that some outcome between Scenarios 3 and 4 in Table 4 is likely for the Hadejia-Jama'are River Basin.

Finally, it should be noted that floodplain farmers downstream from the dam developments on the Hadejia and Jama'are Rivers have proven to be highly adaptive to changes in flood patterns that have occurred so far. For example, Thomas and Adams (1999) suggest that since the mid-1970s there have been considerable agrarian changes downstream in response to the construction of the Tiga Dam and subsequent drought years. The authors argue that "while in the short term the socioeconomic impacts of dams and drought were strongly negative, over a longer period the environmental changes caused by the dam and drought were strongly negative, over a longer period the environmental changes caused by the dam and drought gave added impetus to the diversification and expansion of agriculture" (Thomas and Adams 1999, p. 154). Table 5 summarizes some of the adaptive responses to changing flood patterns and environmental conditions that have occurred in the agricultural systems in the Hadejia-Jama'are floodplain.

The most important adaptive responses include expansion of rainfed farming on areas that no longer flood, and even the expansion of flood recession farming through the introduction of cowpeas; expansion of irrigated dry season farming and mechanized rice production; and increased off-farm employment (see Table 5). However, there are some important negative aspects to these trends. The sustainability of irrigated wheat and mechanized rice production has been questioned, especially due to the problems of soil erosion, declining fertility and overuse of water (Kimmage 1991; Kimmage and Adams 1992). Moreover, the expansion and shifting of agricultural production on to new lands has led to increased conflicts among farmers and between agriculturalists and the migrating *Fulani* pastoralists in the region, who for hundreds of years have had traditional communal dry season grazing rights to pasture within the floodplain area (Thomas and Adams 1999). While permanent emigration in search of new employment opportunities may in the short run reduce pressure on local land and water resources, in the long term it may affect the provision of rural health and educational services and the available pool of local agricultural labor.

Overall, the adaptive agrarian changes in response to the decline of flooding pattern downstream of the dams built in the Hadejia-Jama'are River Basin may mitigate somewhat the floodplain losses estimated for the different scenarios reported in Table 4. However, there are two notes of caution. First, as pointed out by Thomas and Adams (1999, p. 159) it is optimistic to consider all of the agrarian adaptations to be responses solely to the construction of Tiga Dam and the loss of downstream flood recession agricultural benefits: "most of the positive features of agricultural change in the Hadejia-Jama'are floodplain (new forms of recession farming, irrigation, improved marketing, etc.) would be likely to have happened anyway, without the dam, as they have elsewhere throughout northern Nigeria." Second, some of the farming innovations that have occurred in the floodplain, such as the expansion of dry season irrigated crop production, are themselves threatened by the impact of upstream water diversion on the downstream wetland areas and their ability to recharge the shallow aquifers that are used for tubewell irrigation (Acharya and Barbier 2000; DIYAM 1987; Thompson and Hollis 1995). It is the latter impacts on dry season irrigated agriculture that we now turn to.

Impacts on dry season irrigated agricultural production

Several hydrological studies of the Hadejia-Jama'are River Basin suggest that the "standing water" of the inundated areas of the downstream floodplains appears to percolate through the sub-soil to recharge many of the shallow aquifers in the area (DIYAM 1987; Thompson and Goes 1997; Thompson and Hollis 1995). As noted above, these shallow aquifers are increasingly being accessed through tubewell irrigation to expand dry season vegetable and wheat production. If upstream water diversion is causing less flooding and standing water downstream, then the resulting reduction in groundwater recharge could have important implications for dry season irrigated agricultural production downstream.

Acharya and Barbier (2000) have conducted an economic analysis of the impact of a decline in groundwater levels on dry season vegetable and wheat irrigated agricultural production in the floodplain region. They surveyed a sample of 37 farms in the Madachi area, out of a total 309 dry season farmers on 6,600 ha of cropland irrigated through tubewell abstraction from shallow aquifers. Wheat, tomato, onions, spring onions, sweet potatoes and pepper are the main cash crops grown by the farmers, although okra and eggplant are more minor crops grown principally for home consumption.[6] On average, irrigated dry season agriculture in the Madachi area is worth $412.5 per ha, with a total estimated annual value of $2.72 million over the entire 6,600 ha.

Employing a production function approach, Acharya and Barbier value the groundwater recharge function of the floodplain as an environmental input into the dry season agricultural production in the Madachi area.[7] They model crop-water production relationships for both vegetable and wheat production, and based on this analysis, the authors are able to calculate the welfare changes to farmers in Madachi of a one-meter fall in groundwater levels from 6 to 7 meters in depth. The latter is the projected fall in mean water depth of the shallow aquifers in the area due to the declining flood extent and recharge function of the floodplain wetlands (Thompson and Goes 1997). The analysis was then extended to estimate the welfare impacts for all dry season irrigated farming on an estimated 19,000 ha throughout the floodplain.

The results of the analysis are summarized in Table 6. They suggest that a one meter change in groundwater recharge would reduce the welfare by $32.5 annually on average for vegetable farmers (7.6% of annual income) in Madachi and by $331 annually for farmers producing vegetables and wheat (77% of annual income). Total loss in annual income for all 134 vegetable farmers in Madachi is $4,360, and for the 175 wheat and vegetable farmers $57,890. The total loss for all 309 Madachi farmers of $62,250 amounts to around 2.3% of the annual economic value of irrigated dry season farming in Madachi.

In the entire downstream region of the Hadejia-Jama'are River Basin, the annual losses to vegetable farmers amount to $82,832. For wheat and vegetable farmers, the welfare loss is around $1.1 million. The total welfare impact of around $1.2 million annually is around 15.1% of the economic value of irrigated dry season agriculture in downstream areas.

Impacts on domestic water supply for household use

Any impacts on the groundwater recharge of shallow aquifers due to a decline in the Hadejia-Jama'are flood inundation area will also have a major impact on village water wells that supply domestic water to households throughout the region. Villagers prefer to use well water for drinking, cooking and cleaning. Other activities such as watering of animals, washing clothes and utensils and house building may use water obtained directly from the wetlands in addition to well water. All households procure water from wells in one of three ways: (i) they collect all their own well water, (ii) they purchase all their water from vendors who collect well water, or (iii) the households both collect and purchase their well water.

In order to estimate the value placed on groundwater either purchased or collected from village wells by households in the wetlands region, Acharya and Barbier (2001) have combined a hypothetical method of valuation, the contingent behavior method, with a household production model of observed behavior. Three villages in the Madachi region of the Hadejia-Jama'are floodplain and one village in the Sugum region were chosen for the economic valuation study, based on the hydrological evidence that the villages in these areas rely on groundwater recharged mainly by wetlands (Thompson and Goes 1997). The flooding in Madachi is caused by the floodwaters of the Hadejia River. The Sugum region is located in the eastern part of the wetlands and is influenced by the flooding of the Jama'are River.

The first step in the valuation approach was to derive and estimate the demand for water by the various types of households. To do this, a household production function model was constructed to determine the factors influencing a representative household's decision to choose its preferred method of water procurement – collect only, purchase only or both collect and purchase. The second step in the valuation procedure was to use the household water demand relationships to estimate the effect of a change in wetland flooding on the welfare of village households dependent on groundwater well supplies. As noted above, hydrological evidence suggests that reduced flooding in the wetlands will result in lower recharge rates and hence changes in groundwater levels in wells (Thompson and Hollis, 1995; Thompson and Goes, 1997). Changes in groundwater levels in turn affect collection time and the price of vended water, assuming all other household characteristics remain constant. The welfare impacts associated with these price changes were therefore estimated as changes in consumer surplus in the relevant household water demand equations.[8]

To value the change in the recharge function due to reduced flooding within the wetlands, it was hypothesized that a decrease of one meter in the level of water in village wells would result in an increased collecting time of 25% and an increase in the price of vended water of approximately one cent.[9] These assumptions are based on the evidence provided by the survey data on the relationship between collection time and well water levels and on the change in price indicated by vendors as likely to occur, in the event of a one meter decrease in water levels. Using the estimated demand equations, the welfare effects due to changes in both collection time and the price of vended water were calculated for the sample of households surveyed. These effects were then extrapolated to entire the population of the floodplain in order to calculate an aggregate welfare impact. The results are depicted in Table 7.[10]

The welfare estimates suggest the average welfare effects of a one-meter change in water levels is approximately $ 0.12 per household per day. This impact is equivalent to a daily loss of approximately 0.23% of monthly income for purchase only households, 0.4% of monthly income for collect only households and 0.14% of monthly income for collect & purchase households. The total value across all floodplain households of maintaining the current groundwater recharge function (i.e. avoiding a one-meter drop in well water levels) amounts to $13,029 per day. This translates into an annual value of $4.76 million for the groundwater recharge of village wells by the floodplain wetlands. Such estimated welfare losses indicate that the failure of the Hadejia-Jama'are wetlands to provide the existing daily level of recharge would result in a substantial economic loss for wetland populations presently deriving benefit from groundwater use for domestic consumption.

Conclusion

Upstream water investments and developments should not be based on the assumption that water is a "free" good. The correct economic approach to assessing dams and other water projects upstream that divert water is to consider the forgone net benefits of disruption to the natural environment and degradation downstream as part of the opportunity costs of the development investment. This is particularly important where substantial impacts on economic livelihoods will result from the hydrological and ecological impacts of upstream water diversion, as the case study of the Hadejia-Jama'are River Basin in Northern Nigeria illustrates.

As the case study demonstrates, there is a direct trade-off between increasing irrigation upstream and impacts on the floodplain downstream. Full implementation of all the upstream dams and large-scale irrigation schemes would produce the greatest overall net losses in net present value terms, around US$20.2-20.9 million (Table 4 Scenario 5). In addition, the reduction in mean peak flood extent associated with this scenario is predicted to cause a one-meter fall in groundwater levels in the shallow aquifers that are recharged by the standing water in the floodplain wetlands. This is likely to lead to annual losses of around $1.2 million in tubewell irrigated dry season agriculture and $4.76 million in domestic water consumption for rural households.

These substantial losses suggest that the expansion of the existing irrigation schemes within the river basin is effectively "uneconomic". The introduction of a regulated flooding regime would probably protect the groundwater recharge function of the downstream wetlands as well as reduce substantially the losses to floodplain recession agricutlure, forestry and fishing, to around $15.4-16.5 million (Table 4 Scenario 6). However, the latter losses could be reduced even further if the plans to construct Kafin Zaki Dam and to implement the Hadejia Valley Project fully are abandoned. The result would be an outcome between Scenarios 3 and 4 reported in Tables 2-4. The net downstream losses would therefore be in the region of $2.2 to $8.1 million. This may be the best outcome, given that Tiga Dam, Challawa Gorge and many small dams on the tributaries of the Hadejia River have already been constructed.

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Figure 1. The Hadejia-Jama'are River Basin, Northern Nigeria

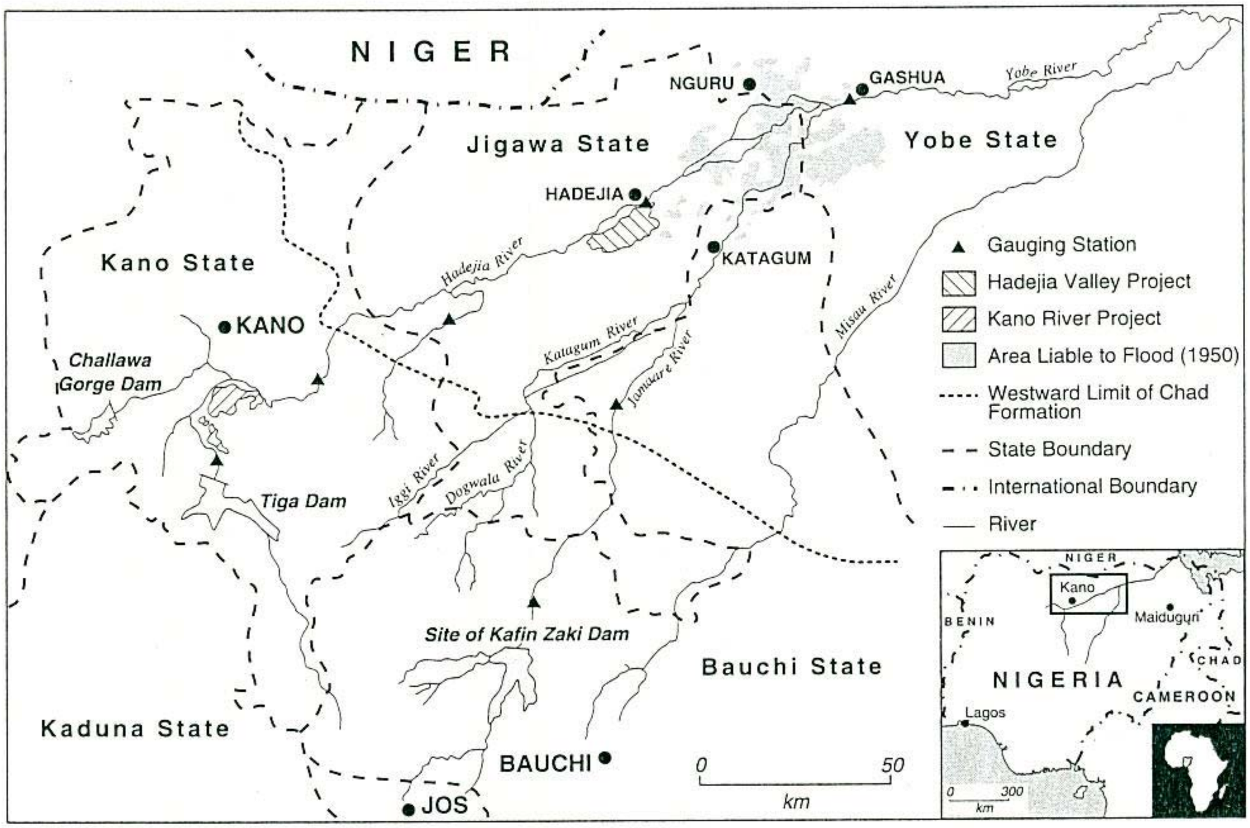

Figure 1. The Hadejia-Jama'are Basin.

Table 1. Comparison of Present Value of Net Economic Benefits: Kano River Irrigation Project (KRIP) and Hadejia-Jama'are Floodplain (HJF), Nigeria (US$ 1989/90 Prices)

	8 %, 50 years	8%, 30 years	12%, 50 years	12%, 30 years
Total (US$ '000) a/				
HJF	37,084	34,179	25,335	24,595
KRIP	593	546	403	391
Per Hectare (US$/ha) b/				
HJF	51	47	35	34
KRIP	31	29	21	20
Per Water Use (US$/m) c/				
HJF	14,548	13,409	9,939	9,648
KRIP	40	36	27	26

Notes: a/ Based on a total net benefits from agricultural, fuelwood and fish production attributed to the Hadejia-Jama'are floodplain (HJF), and total net project benefits of irrigated crop production from the Kano River Irrigation Project (KRIP).

b/ For HJF, weighted average of per hectare agricultural, fuelwood and fish production with weights determined by total cropland (230,000 ha) forest area (400,000 ha) and fishing area (100,000 ha) to total production area (730,000 ha). For KRIP, based on a total crop cultivated area of 19,107 ha in 1985/86.

c/ For HJF, based on an estimated annual average river flow into the floodplain of 2,549 $10^6 m^3$. For KRIP, based on an estimated annual water use by the project of 15,000 m^3/ha.

Source: Adapted from Barbier *et al.* (1993).

Table 2. Scenario for Upstream Projects in the Hadeja-Jama'are River Basin, Nigeria

Scenario (Time Period)	Dams	Regulated Releases ($10^6 m^3$)	Irrigation Schemes
1 (1974-1985)	Tiga	Naturalised Wudil flow (1974-1985)	No KRIP
1a (1974-1990)	Tiga	Naturalised Wudil flow (1974-1990)	No KRIP
2 (1964-1985)	Tiga	None	KRIP at 27,000 ha
3 (1964-1985)	Tiga	400 in August for sustaining floodplain	KRIP at 14,000 ha
4 (1964-1985)	Tiga	None	KRIP at 27,000 ha
	Challawa Gorge	348/yr for HVP	
	Small dams on Hadejia tributaries		
5 (1964-1985)	Tiga	None	KRIP at 27,000 ha
	Challawa Gorge	348/yr for HVP	
	Small dams on Hadejia tributaries		
	Kafin Zaki	None	84,000 ha
	HVP	None	12,500 ha
6 (1964-1985)	Tiga	350 in August	KRIP at 14,000 ha
	Challawa Gorge	248/yr and 100 in July	
	Small dams on Hadejia tributaries		
	Kafin Zaki	100 per month in Oct-Mar and 550 in August	None
	HVP	Barrage open in August	8,000 ha

Notes: KRIP = Kano River Irrigation Project
HVP = Hadejia Valley Project

Source: Barbier and Thompson (1998).

Table 3. Impact of Scenarios on Mean Peak Flood Extent and Total Irrigated Area

	Scenario 1 (km^2)	Scenario 1a (km^2)	Irrigated Area (km^2)
Scenario 2	-150.62	-211.20	270
Scenario 3	-95.25	-55.83	140
Scenario 4	-265.02	-325.60	270
Scenario 5	-870.49	-931.07	1 235
Scenario 6	-574.67	-635.25	220

Source: Barbier and Thompson (1998).

Table 4. Impact of Scenarios in Terms of Losses in Floodplain Benefits versus Gains in Irrigated Production, Net Present Value (US$ 1989/90 Prices)

		Scenario 1			Scenario 1a		
	Irrigation Value [1] a/	**Floodplain Loss [2] b/**	**Net Loss [2] - [1]**	**[1] as % of [2]**	**Floodplain Loss [3] b/**	**Net Loss [3] - [1]**	**[1] as % of [3]**
Scenario 2	682 983	-4 045 024	-3 362 041	16.88	-5 671 973	-4 988 990	12.04
Scenario 3	354 139	-2 558 051	-2 203 912	13.84	-4 184 999	-3 830 860	8.46
Scenario 4	682 963	-7 117 291	-6 434 328	9.60	-8 744 240	-8 061 277	7.81
Scenario 5	3 124 015	-23 377 302	-20 253 287	13.36	-24 004 251	-20 880 236	13.01
Scenario 6	556,505	-15 432 952	-14 876 447	3.61	-17 059 901	-16 503 396	3.26

Notes: a/ Based on the mean of the net present values of per ha production benefits for the Kano River Irrigation Project in Table 1, and applied to the gains in total irrigation area shown in Table 3.

b/ Based on the mean of the net present values of total benefits for the Hadejia-Jama'are floodplain in Table 1, averaged over the actual peak flood extent for the wetlands of 112,817 ha in 1989/90 and applied to the differences in mean peak flood extent shown in Table 3.

Source: Barbier and Thompson (1998).

Table 5. Agrarian Change Downstream of the Tiga Dam, Nigeria

Adaptive Response	Positive Aspects	Negative Aspects
Expansion of rainfed farming on areas that no longer flood	Increased rainfed area and yields at Zugobia. Relocated rainfed area at Dallah with higher yields.	Forest clearing, land use conflicts between Dallah and Gabaruwa, land use conflicts with Fulani pastoralists.
Expansion of flood recession farming	Introduction of drought-tolerant cow peas by migrants returning from Lake Chad to replace cassava.	Cassava would normally be preferred as it produces higher returns, uses less labor and is more pest resistant.
Expansion of dry season irrigated farming	Increased vegetable and wheat production through introduction of pumps, tubewells, credit and extension.	Forest clearing, increased erosion, crop and pest disease, agrochemical pollution. Conflicts with Fulani pastoralists.
Expansion of mechanized rice farming	In Tavurvur, increased yields and reduced labor costs.	Concentration of land ownership, reduced employment, agrochemical pollution. Dependence on government subsidies and special loans.
Increased off-farm employment	Increased income from salaried employment. Cash income safety net for drought years and crop failures.	Increased income inequality between wage earning and nonwage earning households. Increased rural-urban migration.

Source: Based on Thomas and Adams (1999).

Table 6. Welfare Impacts on Dry Season Farmers of a One-Meter Drop in Groundwater Levels, Hadejia-Jama'are River Basin, Nigeria

	Average welfare loss per farmer (US$/year)	**Total loss for all Madachi farmers (US$/year)**[a]	**Total loss for all dry season farmers (US$/year)**[b]
Vegetable Farmer	32.5	4,360	82,832
Wheat and Vegetable Farmers	330.8	57,890	1,099,905
All Farmers		62,250 (2.3%)[c]	1,182,737 (15.1%)[d]

Notes: [a] The Madachi farming area includes approximately 6,600 ha of irrigated dry season farming, comprising 134 vegetable farmers and 175 vegetable and wheat farmers.

[b] Based on an estimated total irrigated dry season farming area comprising 19,000 ha in the Hadejia-Jama'are floodplain area.

[c] Percentage of the annual net economic benefits of irrigated dry season agriculture in the Madachi area ($2.72 million).

[d] Percentage of the annual net economic benefits of irrigated dry season agriculture in the Hadejia-Jama'are floodplain area ($7.84 million)

Source: Acharya and Barbier (2000).

Table 7. Welfare Impacts on Households of a One-Meter Drop in Groundwater Levels, Hadejia-Jama'are River Basin, Nigeria

Household Type	Number of Affected Households in Wetlands	Welfare Loss per Household ($/day)	Welfare Loss for the Wetlands ($/day)
Purchase only	22,650	0.033	736
Collect only	57,013	0.137	7,833
Collect and purchase	28,302	0.226	6,410
All households	107,965	0.121	13,029

Source: Acharya and Barbier (2002).

Notes

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1. The assumption that there is no cost of using the supply of water available to the agricultural system is certainly realistic for a floodplain system dependent on the natural recession of flood water as a source of irrigation. In the case of irrigation provided by a human-made reservoir and channel network, the assumption of a freely available supply suggests that the fixed costs of the water reservoir and network were absorbed by an external agency (e.g. central or regional government), and there is no recurrent charge to the irrigated agricultural system for using water as an input. Obviously, this raises issues over the efficiency of water input use, and the possibility over time of excessive use relative to the supply of available water. Although an extremely important issue, particularly with regard to the supply of irrigated water (see Repetto 1986 for a discussion and examples),this problem is not an explicit focus of this paper. The problem could easily be incorporated into the model by examining how the amount of water abstracted for irrigation in each time period, $k(t)$, influences the rate of depletion of the total downstream water stock available to irrigation, $dW/dt = - k(t)W(t)$, and assuming a cost of abstraction $c_w \geq 0$.

2. In what follows, for simplicity, the fixed costs of establishing the upstream water project and irrigation will also be ignored. See also the previous note on how water abstraction costs could be included.

3. Although it is possible that the optimal rate of diversion, d^*,may lead to complete depletion of the stock of water available downstream, W, over the planning horizon $(0,T)$. It is also possible that d^* may also be zero as $t \rightarrow T$. The inclusion of cumulative diversion into the upstream irrigation network, $\int d\ dt = W(0) - W(t)$, as an argument in h_2 suggests that output from the upstream agricultural project does not necessarily have to fall to zero if $d^* = 0$. It is fairly easy to work out the conditions determining the optimal path of $d(t)$ as well as the rate of change, dd^*/dt, from the first order conditions. See Barbier (1994) and Dasgupta and Heal (1979) for further discussion.

4. Note that one reason for these high losses in floodplain benefits is that the total production area dependent on the wetlands is around 6.5 times greater than the actual area flooded. This critical feature of a semi-arid floodplain, its ability to "sustain" a production area much greater than the area flooded, is often underestimated and ignored. This in turn means that changes in flood extent have a greater multiplier impact in terms of losses in economic benefits in production areas within and adjacent to the floodplain, because of the high dependence of these areas on regular annual flooding. See Barbier and Thompson (1998) for more details.

5. Some of the upstream water developments are being used or have the potential to supply water to Kano City. Although these releases are included in the hydrological simulations, the economic analysis was unable to calculate the benefits to Kano City of these water supplies. However, the hydrological analysis shows that the proposed regulated water release from Tiga Dam to reduce downstream floodplain losses would not affect the ability of Tiga Dam to supply water to Kano. Although the potential exists for Challawa Gorge to supply additional water to Kano, it is unclear how much water could be used for this purposed. The resulting economic benefits are unlikely to be large enough to compensate for the substantial floodplain losses incurred by the Gorge and the additional upstream developments in the Hadejia Valley. Currently, there are no plans for Kafin Zaki Dam to be used to supply water to Kano. In addition, the economic analysis was unable to calculate other important floodplain benefits, such as the role of the wetlands in supporting pastoral grazing and in recharging groundwater both within the floodplain and in surrounding areas. Groundwater recharge by the floodplain may provide potable water supplies to populations within the middle and lower parts of the river basin, and supply tubewell irrigation for dry season farming downstream (Barbier *et al.*1993).

[6] Some farmers are also involved in mechanized rice production, but as this crop does not involved use of groundwater irrigation, it was excluded from the subsequent analysis.

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[7] See Barbier (1994 and 2001) for further discussion of the use of the production function approach in valuing environmental inputs, especially in a developing country context.

[8] The estimated demand equations were Marshallian, or ordinary, demand functions. Consumer surplus measures based on ordinary demand functions will be a reasonable estimate of a multi-price change on welfare if the resulting income effects are small. It was assumed that this condition was likely for the price change concerned with in the Northern Nigeria case study.

[9] The price of vended water in the surveyed villages ranged between 2.3 to 5.7 cents per 36 liters of water. The average amount of water collected either by vendors or households per trip is 36 liters, which is carried to houses in two 18-liter tins.

[10] To calculate the consumer surplus effects of a change in collection time, a shadow value of time spent collecting water was estimated, using an approximated based on the local agricultural wage rate. See Acharya and Barbier (2002) for details.