CONCEPT PAPER

REOPTIMIZATION OF TIGA AND CHALLAWA GORGE DAMS TO RESTORE HUMAN LIVELIHOODS AND ECOSYSTEMS IN THE HADEJIA-JAMA'ARE-KYB-LAKE CHAD BASIN

A Component of the

Global Investigation of Techniques to Reoptimize Major Water Management Systems to Restore Ecosystems and Livelihoods

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Background on the Global Survey Project

The ultimate objective of this project is to restore natural ecological functions and environmental services (i.e., that support human livelihoods) to the downstream floodplains below the major dams of the world. There are today some 49,000 such dams operating in the world, the vast majority built since the Second World War, and two-thirds of them in developing countries. These dams were designed with a focus on providing a relatively narrow range of economic and social benefits. The *Global Dam Reoperation Project* will now assess the feasibility of reoptimizing the major irrigation, power and flood management systems to enable these dams to be reoptimized to restore a substantial measure of the formerly productive floodplains, wetlands, deltas and estuaries in ways that do not significantly reduce—and can often even enhance—their existing benefits.

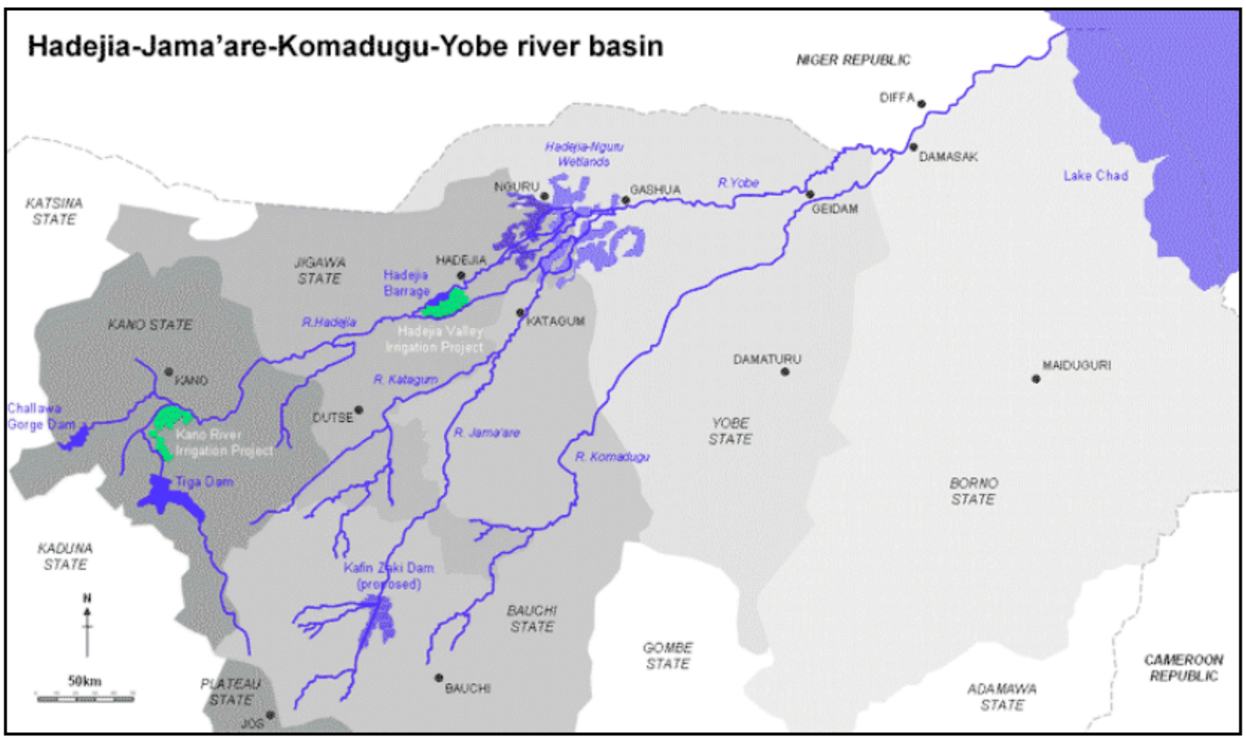
Riverine ecosystems and the myriad species they support are shaped by and dependent on the timing, magnitude, duration, and frequency of flow patterns. Alteration of natural flow patterns and fragmentation of habitat by water storage and diversion projects are the primary reasons that aquatic species are in sharp decline worldwide. The consequences for the downstream river basin can be profound. In most cases highly dynamic riverine systems are transformed by dams into static water delivery channels, reducing the diversity of habitat and species. Elimination of annual floods deprives riparian forest and wetlands of periodic inundations, effectively disconnecting the river from its productive floodplains. Native fisheries suffer in the face of exotic invaders, seasonal natural and cultivated food sources are lost, pastoral use of the floodplain becomes impossible, game species are displaced, groundwater levels decline, and recreational and aesthetic values of a living river basin disappear.

In recent years, increasing attention is being paid to the ecological benefits of reoperating dams to store and release water in a pattern that more closely resembles natural flow conditions with their seasonal variability. IUCN has been at the forefront of this work. Essentially, the aiming point is to operate the reservoirs more as a run-of-the-river facility and less as a storage facility. We can regard this work as defining the environmental water demands for the system. For instance, the Tiga and Challawa Gorge dams, the focus of this project component, have engaged in environmental flow release experiments in the past. However, relatively little attention has been paid heretofore to techniques enabling these dams to make such environmental flow releases a permanent operational feature without reallocating water from economic to environmental uses. This may be regarded as the environmental water supply side of the equation. This project is intended to fill that knowledge gap by illuminating the measures and techniques that can be widely applied to such water management systems to enable environmental flows to be restored pervasively around the world and the best prospects for the application of these techniques. We shall specifically examine techniques for optimizing the irrigation systems that these dams provide to enable a more natural flow pattern to be re-established into the Hadejia-Nguru wetlands and then in the Komadugu-Yobe River into Lake Chad.

With this work, the partnership expects to produce nothing short of a fundamental transformation in the way existing dams are operated as well as how new dams are sited, designed and managed, to allow rivers to once again function as dynamic biohydrologic systems rather than as water delivery channels. This will be done by demonstrating successful techniques and outcomes in regions of the world that have been intensively dammed, where the government officials and river basin commissions who own and operate the dams are interested in partnering with this project to investigate reoptimization potential, and where financial support for this work can be raised.

<u>The Ecohydrologic Setting: The Human Production Systems and Ecosystem Values in the Basin</u>

The basin is formed by the Hadejia and Kano rivers flowing in from the west and the Jama'are River flowing in from the south, to form the Hadejia-Nguru wetlands complex. Downstream is a highly obstructed channel to the Komadugu and Yobe rivers, which today contribute negligible flows to Lake Chad due to high consumptive use for irrigation, the natural infiltration to recharge the aquifer system, and the sediment and exotic weed barrier that has developed due to the flow depletions.



As IUCN has observed:

"The seasonal flooding of the *fadamas* and floodplains in the Hadejia-Nguru wetlands, which is crucial to the use of the area by people, fauna and birds, is thus part of a wider system. The use of groundwater by rural people and urban dwellers through tens of thousands of square kilometers of the States of northeast Nigeria, and in Niger too, is dependent upon the recharge of the Chad formation by [these] rivers. Indeed much of the productive agriculture practiced on the desiccated lake bed of Lake Chad, and perhaps Lake Chad too, is supported by the shallow groundwater of the Chad formation."

The Basin is situated in northeastern Nigeria (57%) and southeastern Niger (43%). It is typical of the southern Sahel, with a strongly seasonal rainfall regime that supports large numbers of people dependent upon seasonal agriculture and pastoralism in the floodplains and wetlands. Around 80% of the rainfall occurs in just three or four months, between June and September, supporting rain-fed agriculture and extensive grasslands for livestock grazing, with little or no flows occurring during the driest months. Once the rain ends, these resources dry up, and the farmers and pastoralists concentrate in the vast wetlands that have formed where the waters of the Hadejia and Jama'are rivers meet the ancient sand dunes, forming a confused pattern of drainage, with three distributary river channels nourishing a complex pattern of permanently and seasonally flooded lands.

The groundwater system is recharged mainly from seasonal flooding due to riverbank overtopping and to a lesser extent from concentration of rainfall in depressions. This recharge has been substantially reduced by the flow regulation due to Tiga and Challawa Gorge dams. The natural flow regime of the Komadugu-Yobe River is seasonal with high flows after the rainy season (June to September) and low or zero flows during the dry season. Virtually all of the rivers lose flow as they approach Lake Chad as a result of evaporation, transpiration and, principally, infiltration. There is no doubt that groundwater recharge comes mainly from the inundation of the fadamas and floodplain rather than from the river channels themselves.

The wetlands support extensive wet-season rice farming, flood-recession agriculture and dry-season irrigation (Hollis, et al. 1993). The extent of irrigation for wheat production has greatly increased since the early 1980s, partly due to the advent of small petrol-powered pumps, engendering conflicts between farmers and pastoralists and between small and larger farmers over access to land. The floodplain also supports large numbers of fishing people (most of whom also farm) and pastoralists (mostly Fulani) who graze large numbers of cattle. These wetlands are home to over one million people and over 10 million inhabitants of the basin are heavily dependent upon their productivity (IUCN Water Audit Inception Report). According to IUCN: "The economic value of production from the wetlands is very large, many times greater than that of all the irrigation schemes for which the inflowing rivers are dammed, diverted and their water used" (Hollis, et al, 1993). Thus, the wetlands are one of the most productive areas of northern Nigeria; they produce an agricultural surplus in most years, support a substantial population at relatively high levels of nutrition and income, and are of greatest importance to the local economy in times of drought.

Fishing is also a major activity during the flood season and when the flood recedes. It has, for example, been estimated that in the 1989/90 season, over 6,000 metric tons of fish were caught (Thomas, 1996).

The wetlands are also renowned for their wildfowl. In 1995, the wetlands hosted 259,000 water related bird species (Polet and Garba Boyi) with over 50,000 Palaeartic ducks having been observed. Indeed, parts of the wetlands have been designated as an internationally important Ramsar site (Polet and Thompson, 1996).

The IUCN Inception Report for the Water Audit lists the following water resources management problems in the basin:

- Water scarcity. Demands for surface water exceed supplies by at least a factor of two under the current pricing regime where water is essentially a free good.[1]

- Fragmented, inequitable and uncoordinated management of surface water uses, with ill-defined and often conflicting responsibilities among the 30 odd agencies at the local, river basin and federal levels. Limited knowledge about water availability and usage remains a major constraint on improved management.

- Invasion of aquatic weeds and associated silt block the Hadejia River flow into the Komadugu-Yobe River and Lake Chad, hindering fishing, fostering disease vectors and reducing biodiversity.

- Increasing population and vulnerable groups. Population is projected to rise from 15 million to over 25 million in the next 20 years. "This and migration in pursuit of livelihood by the pastoralists, fishermen and environmental refugees as a result of increased desertification, have intensified the competition for scarce land and water resources in the basin, resulting in frequent conflict."

- Severe ecosystem degradation in an already poverty-stricken environment.

- Underutilized development potential. Improvements in both agriculture and livestock production—the primary sectors of the economy—can be achieved by optimizing benefits from existing water infrastructure. For instance, only half of the one million irrigable hectares are actually irrigated and the current dams could—but do not now—generate hydropower.

- Inadequate operation and maintenance of existing water infrastructure.

- Lack of coordination between the two river basin authorities (i.e. HJRBDA and CBDA – see page 5).

- Poor flood management in the operation of the storage reservoirs causing unpredictable and destructive floods and permanent inundation of the Marma Channel.

- Irregular and low flows in the Komadugu-Yobe River resulting in the abandonment of small-scale irrigation schemes and over abstraction of groundwater.

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[1] Farmers are provided as much water as they demand regardless of crops or willingness to pay. The nominal charge for this water is 1000 Naira per year (about $ 7 USD). Less than half the farmers pay this assessment, and no penalties are levied against those who do not. Hence, there is no incentive to use water carefully, and, therefore, there is much waste (per. comm. with HJRBDA staff).

- Shrinking and splitting of Lake Chad. Even a little increase in inflows from the Komadugu-Yobe River would significantly improve the health of Lake Chad.

- Degradation in water quality due to industrial effluents.

Notably, reoptimization of the operations of the two large storage reservoirs in this basin could ameliorate every one of these problems, including inculcating better and more coordinated performance by the many management agencies in the basin. The proposed project would illuminate the technically and economically feasible options for improved operations. This analytical work would utilize the data that the Water Audit is collecting and embellish the Decision Support System that is being built to allow a comparative evaluation of a range of improved management scenarios.

Tiga and Challawa Gorge Dams—Current Operations and Reoptimization Potential

Tiga and Challawa Gorge dams control 80% of the flows into the Hadejia-Nguru wetlands. The Tiga and Challawa Gorge dams were built and are operated by the Hadejia-Jama'are River Basin Development Authority (HJRBDA), and planning for the lower part of the basin is conducted by the Chad Basin Development Authority (CBDA). The boundary between the two runs somewhat illogically down the middle of the wetlands, reflecting the former boundary between two states, rather than the hydrologic boundaries of this resource. There is no coherent, integrated development plan for the entire basin, nor is there much coordination between the agencies responsible for the dams and those for water supply. Additionally, communication among the six states (Jos, Kano, Jigawa, Bauchi, Yobe and Borno) in the basin, the Diffa province in Niger within the basin and the federal planning and management authorities has been lacking. Altogether, some thirty agencies of government at various levels share some degree of jurisdiction over water management in the basin.

Tiga Dam, built on the Kano tributary in the early 1970s, is by far the larger of the two dams. Its primary function is to store water for the Kano River Irrigation Project (KRIP) Scheme. The KRIP was one of the first large-scale irrigation schemes developed in northern Nigeria. At present, delivery infrastructure has been completed to permit 15,000 ha of irrigation to take place from this project. Another 7,000 ha is currently under construction to achieve the full build-out of 22,000 ha of irrigated lands. Notably, the current water demand for the KRIP is 60% higher than expected. In effect, the full amount of the planned irrigation allocation is being utilized on only 60% of the planned irrigation area. According to the IUCN Water Audit Inception Report (2005), "The higher demand is explained by changes in cropping patterns (rice instead of wheat) and excessive losses in the secondary and tertiary irrigation channels." Also, notably "14% of the total annual average yield of the reservoirs appears to flow to waste into the Marma channel and Nguru lakes, where it is also causing significant damage to the local environment."[2] Tiga Dam releases water into the irrigation canal all year round. Thus, the dam actually provides inter-annual storage to carry water over from years of abundance to years of scarcity. During the wet season, the irrigation deliveries are to provide supplemental irrigation for rice cultivation. Tiga Dam also operates as a flood control facility, and has spilled water for flood management

[2] According to the Inception Report, these excessive releases result in a perpetual and detrimental dry season flooding condition in the environs of the Marma channel and Nguru Lake which has caused extensive invasion of exotic weeds, loss of fadama rice cultivation, and loss of flood- recessional agriculture and pasturage.

purposes periodically. Below it, a barrage has been constructed to provide short-term storage of water to irrigate the Hadejia Valley Irrigation Project (HVIP) Phase I.

The Challawa Gorge Dam was completed on the Challawa tributary in 1992. It supplements water deliveries from Tiga dam to the Hadejia Valley Irrigation Project (1000 ha has been developed and 5,000 ha are under construction) and the City of Kano. Challawa Gorge Dam also operates as a flood control facility, and has spilled water for flood management purposes in 3 of the past 10 years of operation. Together, the Kano city water supply, the KRIP and the HVIP consume about half of the estimated long-term annual yield of the reservoirs (IUCN Water Audit Inception Report, 2005).

A contract to build another dam on the Jama'are River, the Kafin Zaki Dam, was granted in early 1993. Nine other dams have been constructed in the basin, but their storage is a small fraction of the Tiga and Challawa Gorge dams, which makes these the appropriate subjects for reoptimization investigations.

By constricting the flows, these irrigation dams reduce the extent of the inundation of the floodplain and wetlands during the wet season and increase it during the dry season. This has desiccated lands that were formerly wetted on a seasonal basis for recessional agriculture, and has waterlogged low lying lands which no longer experience their natural drying out cycle. In sum, the dams have transformed the river into a perennial river but with greatly reduced seasonal floods. Since the dams became operational, the maximum extent of flooding has declined from 300,000 ha in the 1960s to around 70,000 to 100,000 ha more recently (Center for Ecology and Hydrology, 2000). IUCN estimates that the effect of Tiga Dam and the KRIP Phase I Scheme has been to reduce the flood extent by between 200 and 450 km^3. The effects are particularly acute during the periods of extended drought in the basin. In some years, the flood has failed to arrive completely. As a result of the dams, there has not only been a reduction in the magnitude of the floods, but also a decline in their duration, a reduction in the area inundated, a decline in the groundwater tables and a general shortage of water in the lower part of the basin. Since the dam operators do not have inflow monitoring devices nor inflow forecasting tools for the reservoirs, they tend to create unexpected floods during years of good rains in order to save the dams to the detriment of the downstream communities. This situation illustrates the importance of implementing a flood warning system for the basin.

Simulations reported by IUCN show that if Tiga Dam were supplying the full 22,000 ha of irrigation to the KRIP Phase I Scheme, the loss in flood extent in the floodplain would almost always be greater than the irrigated area. In wet years, an area more than twice the irrigated area would fail to be flooded and groundwater recharge would be seriously depleted even in relatively wet years. This translates into a loss of fishery production of between 1,000 metric tons in dry years to 2,250 metric tons in wet years. Moreover, the effect of the dams is likely to be compounded by a spiral of degradations, as the decrease in productivity prompts an increase in fishing effort as fisherpeople try to maintain their incomes.

This change in flow patterns has created conditions which have caused a massive invasion of the exotic *Typhus* reed into the waterways, which has greatly reduced the areas that can be used for agriculture, and has caused massive siltation of the waterways, which results in permanent standing water and poor drainage. The reed invasion and siltation have choked the flow of water into the Yobe River and onward to Lake Chad, contributing to the drastic reduction and potential death of that aquatic system. So the transformation of the Hadejia Nguru is, in fact, a transboundary tragedy.

<u>The Scope and Workplan of the Dam Reoptimization Project and How It Will Build Upon and Complement the Work of the IUCN and Other Partner Projects in the Basin:</u>

Since 1985, this basin has been the focus of the Hadejia-Nguru Wetlands Conservation Project, conducted by IUCN with support from the Nigerian Conservation Foundation (NCF) and Birdlife International. In this current IUCN project, being conducted jointly with the Federal Ministry of Water Resources and NCF, the focus is the entire basin (i.e., Hadejia-Jama'are-Komadugu-Yobe Basin). In addition to other deliverables, this project is undertaking a Water Audit and creating a Decision Support System. The aim of the water audit is to strike a balance "between consumptive and instream uses in the basin that would enable decisions to be made to ensure the security of supply of the various diversions" (IUCN Water Audit Inception Report, 2005). Here the focus is not on quantifying the impact on irrigation of a decision to give priority to wetland, but rather on finding ways to maximize the broad societal benefits associated with multiple water management objectives.

The dam reoptimization investigation put forward in this proposal will build upon and complement that work. In effect, the Water Audit will provide a much needed diagnostic of the water management problems in the basin. The reservoir re-operation investigation will illuminate solutions to address at least a significant portion of the most pressing of these problems. Specifically, the aim of the dam reoptimization investigation is to illuminate how the operation of the irrigation schemes and their storage components (Tiga and Challawa Gorge dams) can increase the total water service benefits that can be achieved within that balance. The need for a complementary "effective and beneficial reservoir operating manual and guidelines" is explicitly recognized in the Inception Report for the Water Audit (2005). That can best be accomplished as a product of a simulation of operational alternatives designed to restore the functionality of the Hadejia-Nguru wetlands system (and perhaps the flow regime all the way to Lake Chad) while preserving the irrigation and water supply benefits from those reservoirs to the maximum extent possible. That is what the collaboration of the partnership will provide.

The reservoir reoptimization analysis will utilize and augment the following products of the water audit:

- All of the data sets and water use information being gathered by the Water Audit project. The reoptimization investigation will probably need to augment data on groundwater utilization and quality and the physical characteristics of the aquifers and on the use of water in rice cultivation in the basin.

- Information on the current operation (inflow and outflow rates) of Tiga and Challawa Gorge dams.

- The determination of the environmental river flow requirements of the basin. In addition to an idealized hydrograph for purposes of maximizing ecosystem functions and traditional human production systems in the basin, the partnership will also develop a range of restoration scenarios designed to achieve specified subsets of ecosystem and human livelihood benefits, as is appropriate to an optimization analysis that seeks to define ways to achieve the broadest range of benefits.

- The water management scenarios developed by the Water Audit. To these the partnership will add additional management techniques specifically designed to optimize reservoir reoptimizations. For instance, these will include conjunctive water management scenarios and improvements in water use in rice cultivation. The partners have developed a strong expertise in conducting focus group exercises and personal interviews that lead to the clear definition of interesting water management scenarios. This is a vital step in the planning process as some experience is needed to separate the potentially fruitful options from the probably fanciful ones in advance of deciding which scenarios to model in a DSS (Decision Support System). In addition, the narrative scenarios that typically emerge from the fact-finding efforts usually require some translation into algorithms that can be input into simulation models. The partners are also proficient at this task.

The partnership proposes to contribute to the development of the DSS for the Komadugu Yobe Basin (KYB) Project and to expand and use it to evaluate reoptimization scenarios for Tiga and Challawa Gorge dams, such as those described in the next section of this paper. The technical elements that the partners could contribute to the development of the DSS include:

  - Translating environmental flow prescriptions into algorithms that can be input to water management simulation models.

  - Defining reservoir operating rules for use in water management simulation models that are dynamic and flexible rather than static and rigid. Typically these involve attempts to define operating rules based on the current state of the system and recent patterns of operation.

  - Conducting the spatial analysis of catchment characteristics that are needed to simulate hydrologic processes.

  - Representing groundwater resources in the water management simulation model.

  - Developing model logic to represent the conjunctive management of surface water and groundwater in water management simulation models.

  - Representing policy initiatives, such as actions that change the economic incentives associated with patterns of water use, in the context of water management simulation models.

- Contributing technical input on the design and development of the analytical package which will improve its ability to consider reservoir reoptimization among the array of potential management strategies.

The Irrigation System Reoptimization Strategies That Will Be Investigated

Where downstream ecosystems and food production systems are adversely affected by a combination of flow depletion and alteration due to irrigation and municipal water storage dams, as is the case in the Hadejia-Nguru basin, restoration of these functions requires two things: (1) created additional water in the system to offset the consumptive use, and (2) additional storage so that that additional yield can be managed for environmental purposes. In the study area, we will investigate the potential to increase water supply for beneficial uses through three techniques: (a) reduction in physical losses in the irrigation system through reductions in evaporation, deep percolation to unusable groundwater sinks, and unrecovered irrigation tail water, and reductions in losses in the City of Kano water system due to leakages in the delivery system; (b) improved and sustainable utilization of the groundwater resource through its conjunctive management with the surface water storage system (explained below); and (c) by capturing flood control releases from the dams and managing this supply for groundwater recharge and environmental flows (also explained below).

These techniques are derived from fruitful interviews with the Tiga and Challawa Gorge dams operators, officials of the HJRBDA, officials in the Dams and Reservoir Department and the Irrigation and Drainage Department of the Federal Ministry of Water Resources, and consultations with colleagues at IUCN (KYB Project) and DFID (JWL project), and modeling work that the partners have performed in other basins, particularly in the Central Valley of California. These concepts are preliminary, but illustrate the types of advanced water management techniques that will be modeled and investigated in this project.

The underlying logic of these scenarios is that, to restore water-dependent ecosystems and human livelihoods downstream of the two large storage dams, the dams must be reoptimized, in coordination with the runoff from the entire basin, to release a flow pattern that more closely mimics the natural variability in flows that occurred before the dams were built. Since the Hadejia Barrage also provides a barrier and diversion of the flows entering the wetlands, it will also have to be reoptimized to restore a more natural flow pattern into the wetlands. Ideally, that flow pattern would be maintained in some attenuated form all the way to Lake Chad, the terminus of the basin. Of course, the aiming point for this type of optimization analysis is that the flow pattern would be improved without impairing the water supply benefits that the dams currently provide. Indeed, the scenario analysis would also include benefits enhancements such as installation of hydropower generators at the outlets of these dams and perhaps installation of hydrodynamic turbines in the irrigation canals themselves.

To restore a more natural flow pattern means operating these dams to release more water during the wet season, to recreate an annual artificial flood event, calibrated to the yearly variability in rainfall. It also means releasing less water into the downstream river system during the driest part of the year, again to emulate natural flow patterns. How can this be done while meeting water supply demands?

Two intriguing possibilities have emerged from preliminary consultations. Again, these are only examples of the types of strategies that appear to be worthy of further investigation:

1) Groundwater is already utilized to some extent in the basin, and there is even some concern about over-utilization in the Komadugu-Yobe area of the basin. There may be potential for groundwater use within the KRIP scheme and the HVIP scheme command areas. If groundwater could be pumped to substitute for some fraction of irrigation releases from the reservoirs, that stored water could be released instead to augment the peak flows during the wet season, thereby creating an artificial flood event. If groundwater could also be used instead of reservoir releases to recreate an annual low or no flow conditions, again emulating the natural pattern, the permanent flooding of the Marma channel (and other areas) could be eliminated. But how would that groundwater then be replenished so the usage pattern is sustainable over the long term? Where groundwater is used, or could be used, aquifer storage space can be created if the physical characteristics of the aquifer and the aquifer are appropriate. Both Tiga and Challawa Gorge dams also release water in some years for flood control purposes. If that water could instead be released to recharge the aquifers, the mass balance could be maintained in both the reservoir and the groundwater system. This is a classic conjunctive use or "aquifer storage and recovery" configuration. The added advantage of this scenario is that increased storage capacity and flexibility is likely to lead to a more reliable water supply for irrigators and municipal water systems. The main cost of this scenario would be well development and pumping costs (electricity or diesel fuel). Of course, retrofitting these dams with electrical generators, which we would also evaluate, might ameliorate this cost.

2) Tiga Dam is interesting and somewhat unusual in that it releases water for irrigation purposes all year round. It is operated to provide inter-annual storage rather than inter-seasonal storage. During the wet season, this water is used to supplement rainfall in rice cultivation. However, this currently results in significant overuse of water, collection in depressions in the basin, large evaporative losses, and losses in the secondary and tertiary canals. If some fraction of this wet season irrigation water could be conserved through better on-farm water management practices or reduction in conveyance losses, that saved water might be dedicated to the downstream river system instead, augmenting the flows otherwise available and, thus, creating the artificial flood event for which we are aiming. There are many cost effective ways to tighten up irrigation systems in just this way, many well demonstrated in the rice cultivation areas of California, where NHI has a depth of experience. Similarly, water can be saved by eliminating leakage from the City of Kano delivery system, or recovering these losses through groundwater extractions.

To be sure, these management improvements would carry a price tag. Groundwater pumping has an energy cost, and irrigation and municipal system improvements entail both capital and operating costs. But the benefits of a more productive Hadejia-Nguru wetland system and downstream floodplain may be far larger. In any event, the government's current plans for water resource development in this region will also require an investment of funds. The reoptimization investigation will, in effect, present an alternative investment strategy that will allow the government to make an informed choice as between the costs of benefits of the current plans versus the reoptimization alternative.

In investigating reoptimization strategies of this sort, we will also build on the 1993 IUCN report, "The Hadejia-Nguru Wetlands, Environment, Economy and Sustainable Development of a Sahelian Floodplain Wetland." In it, G.E. Hollis and J.R. Thompson report on simulations of the operations of Tiga and Challawa Gorge dams to generate a regulated natural flood regime into the wetlands using large reservoir releases. A series of scenarios were simulated which primarily addressed how these dams could be operated to achieve downstream wetland inundation, and which estimated the impact of these operations on other water management objectives in the system. This very interesting work revealed a number of findings pertinent to the proposed reoptimization investigation:

- Substantial flood releases may be possible from Tiga Dam using the old hydropower outlet together with two other pipes through the dam, the sluice on the irrigation canal and direct releases from Ruwan Kanya Reservoir, which is on the irrigation canal.

- There is a question whether the two ($50m^3$/sec) existing outlets from Challawa Gorge Dam have enough capacity to release an adequate flood discharge if operated alone. Whether this outlet could be operated in tandem with releases from Tiga Dam was not apparently tested.

- The design and construction contract for Kafin Zaki Dam apparently allows for a review of the capacity of the outlets for this dam "to incorporate the capacity for adequate artificial flood releases".

- A flood release from Tiga Dam in August of 400 million m^3 was found to be unsustainable while a release of 350 million m^3 was shown to be feasible.

- Such a flood release would not jeopardize the irrigation of 14,000 ha at KRIP since the irrigation water supplied was equal to historic demand, but deficiencies in supplies to the HVIP (at 8,000 ha) in drought years.

The report includes a cautionary note worth quoting in full:

> "Any scheme of flood releases from present and projected reservoirs can only be undertaken with a much improved monitoring network of instruments, greatly enhanced levels of training amongst responsible staff, and a very close and effective liaison between the river managers and those who actually use the rivers and their waters. It is essential that the timing of the releases is correct. Too much water, too early in the season and the planted seed will be drowned. Too little water, too late and the small rice plants will wither and die before the onset of the flood. A big reservoir release, when flood conditions already exist from heavy rainfall and large discharges in tributaries, could cause serious damage to bridges and the inundation of towns and villages. Similarly, it will be essential that the releases in the Hadejia River are carefully coordinated with those in the Jama'are River so as to derive maximum benefit in the wetlands and downstream of Gashua. Such coordination will require substantial studies of the hydrology of the rivers using daily data, greatly enhanced understanding of the mechanisms of flooding and groundwater recharge, and probably the development of a real time forecasting and control model for the river basin. So, whilst such a scheme of flood releases may be shown to be technically feasible and economically desirable, it is

> essential that perhaps a decade of planning and organization be undertaken before any such scheme is implemented."

The Value of this Work to Demonstrate Strategies for Climate Change Adaptations in the African Context

As in most regions, global climate change is likely to manifest its most profound effects in Africa at the interface between the lands and the waters—both freshwater and sea water—but even more so. The one prediction that climatologists make with confidence is that climate change will cause weather patterns, and hence, precipitation patterns, to become more extreme. Hydrologically, that means that the droughts will be more severe and last longer. It also means that the flood events will be more severe and last longer. That is bad news for Africa, the continent that is already most ravaged by droughts and floods, with often devastating consequences for the food production systems that are here, particularly, so intimately connected to natural river functions. Nowhere is this more graphically illustrated than in the Hadejia-Nguru basin which is especially prone to droughts and floods, and which is also a classic illustration of the reality that far more food is produced in Africa from floodplain agriculture and grazing, freshwater fisheries, and small scale irrigation dependent upon groundwater recharge, than from the commodity irrigation schemes or aquaculture.

It does not take predictive models to know that climate change adaptations are vital to avert human catastrophe on a massive scale in Africa. Therefore, it will be important to know how the reoptimization scenarios for environmental restoration will perform in a future of more intense droughts and floods in the Hadejia-Nguru basin. Stated another way, we want to know whether these scenarios also provide climate adaptation benefits.

We do not need to know precisely how climate change will affect the hydrology of the basin to perform this analysis. To evaluate the reoptimization scenarios, the conventional approach is to replay the historic runoff patterns to see how the system would have functioned had the reoptimization scenarios been in place during the period of record. After we have run this analysis, we will then run additional cases to see what the results would be assuming that the dry periods are X % more severe and last Y % longer, and assuming that the flood events are X% more severe and last Y% longer. This will allow us to see whether the objectives of the dam are better served under climate change scenarios with the reoptimization scenarios or not.

Almost surely, this analysis will show that the scenarios do perform better than current operations. This is because climate change will require greater capacity to store and channel water in the Hadejia-Nguru river system. That is to say, more storage to carry water over from times of relative abundance to times of relative scarcity for both water supply and environmental performance, and more storage to capture and attenuate large runoff events to prevent flood damage. New dams have severe drawbacks in terms of their adverse effects on aquatic ecosystems and floodplain livelihoods in Africa. Moreover, they are very expensive and take a long time to build—often decades. Therefore, making better use of existing dams to buffer the effects of droughts and floods is highly desirable.

We hypothesize (and this project will test whether) the Tiga and Challawa Gorge dams can do a better job of managing larger floods by utilizing the capacity of the downstream floodplain and wetland complex to accommodate (store and attenuate) controlled flood flows, provided that floodplain land uses are adapted to this purpose. We also hypoth-esize that our reoptimization concept will allow the two reservoirs to be maintained at higher average storage levels, which will assure a larger water supply going into a period of reduced runoff (a drought sequence). This is important because the storage levels at Tiga dam were reduced by 25% some years ago specifically to avoid potential flood damages downstream.

Remanaging land uses in floodplains to accommodate controlled flood events effectively utilizes the natural storage capacity of the floodplain in combination with the upstream reservoir to reduce the risks of catastrophic flooding, while also reconnecting the river to its floodplain and wetlands system, which is vital for ecosystem processes and for floodplain food production and other human livelihoods. To state the concept more precisely, changing land uses in the floodplain allows it to accommodate higher rates of releases of water from the reservoir when that becomes necessary to create flood retention capacity. That is turn allows the reservoir storage levels to be maintained at a higher level than would otherwise be safe and prudent. This reoptimization concept has many benefits. Higher storage levels means both more water supply and more reliable water supply in the face of global warming. It also reduces downstream flood risks. And it also substantially improves floodplain environments and their productivity.

Thus, an explicit objective of this reoptimization technical investigation is to demonstrate the efficacy of conjunctive water management and improved irrigation techniques as climate adaptive strategies for potential application elsewhere in Africa and at the global scale.

The Project Coordinators:

Hadejia-Jama'are-Komadugu-Yobe Basin Trust Fund: The idea of the Hadejia-Jama'are-Komadugu-Yobe Basin Trust Fund (HJKYBTF) was proposed by three donor-supported projects (i.e. DFID-JWL Project, IUCN-KYB Project and LCBC/GEF Project) operating in the basin, strongly supported by stakeholders, and finally consented to by the Executive Governors of the Komadugu Yobe Basin (KYB) states in Nigeria at their Summit of Leaders in June 2006. The Board of Trustees to the Trust Fund was then officially inaugurated in May 2007 and has since commenced operations. Among other things, the HJKYBTF is responsible for the implementation of the Catchment Management Plan developed for the basin by the KYB Project and the incorporation of any other IWRM-related issues and activities that the Trust Fund deems relevant. An initial contribution of about USD 12 Million has been provided by the six KYB states and the Federal Government of Nigeria to the Fund. The HJKYBTF solely sponsored the Technical Workshop to design this reoptimization concept and its associated systems in the KYB that was held in Kano, Nigeria in August 2007.

The Natural Heritage Institute: Founded in 1989, NHI has developed a reputation for creating innovative, dynamic, and broadly replicable solutions to environmental problems that benefit ecosystems and the human communities that rely on them worldwide. NHI specializes in addressing technically complex resource management challenges, with particular competence in the restoration of damaged aquatic ecosystems, including expertise in hydrology, freshwater ecology, environmental planning and economics, environmental engineering and legal and institutional design. NHI routinely advises high-level government decision makers and non-profit conservation organizations on innovative resource management solutions in both the domestic and international spheres.

International Union for the Conservation of Nature: IUCN-PACO: Established in 1948, IUCN now has a membership of more than 1,000 organizations, including some 81 States, 113 Governmental Organizations or Agencies of public law and 859 Non-Governmental Organizations, thus forming a unique worldwide partnership. Thirty-nine African States are represented in the Union, of which 12 are in West Africa. Its mission is to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable.

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