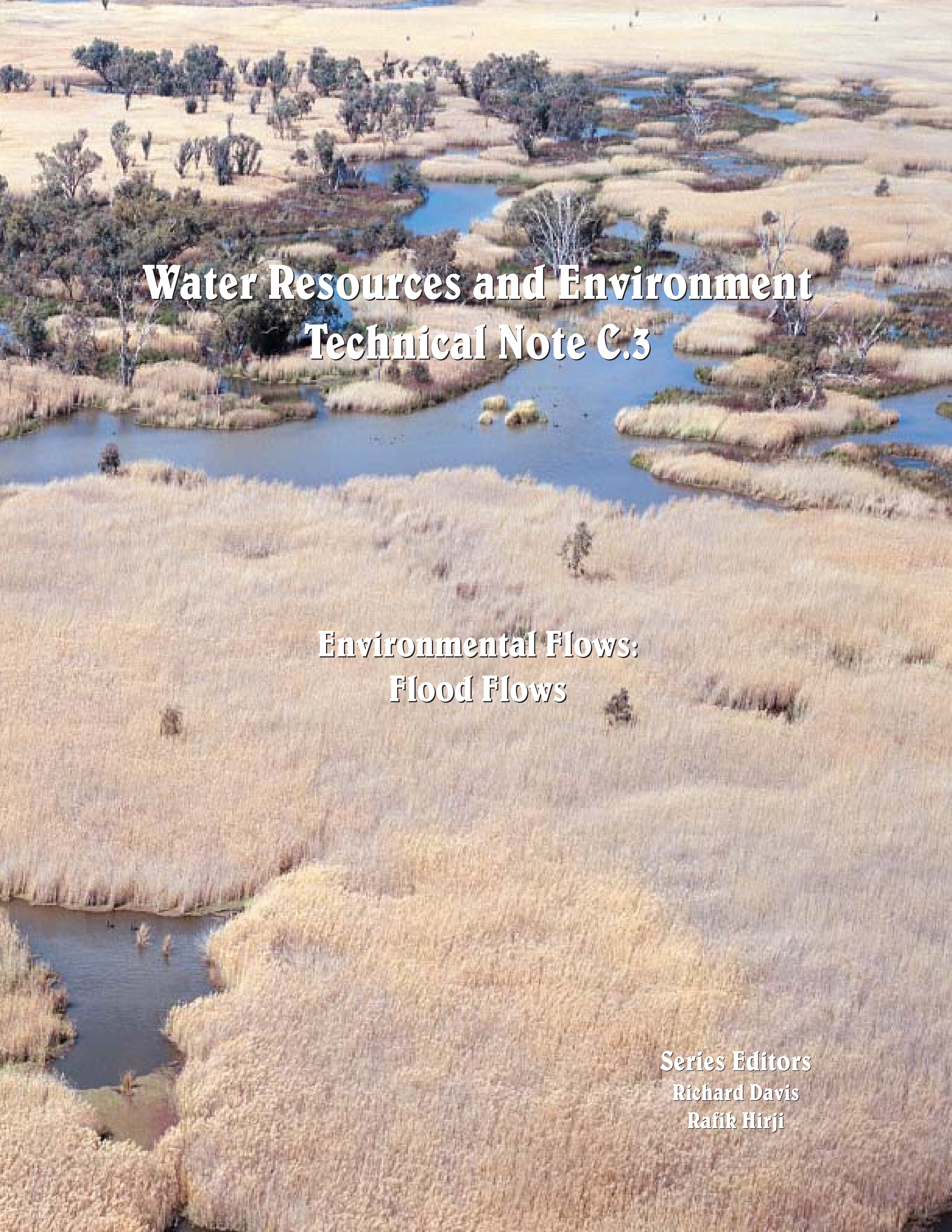

Water Resources and Environment Technical Note C.3

Environmental Flows: Flood Flows

Series Editors
Richard Davis
Rafik Hirji

WATER RESOURCES AND ENVIRONMENT

TECHNICAL NOTE C.3

Environmental Flows: Flood Flows

SERIES EDITORS
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FOREWORD

The environmentally sustainable development and management of water resources is a critical and complex issue for both rich and poor countries. It is technically challenging and often entails difficult trade-offs among social, economic, and political considerations. Typically, the environment is treated as a marginal issue when it is actually key to sustainable water management.

According to the World Bank's recently approved Water Resources Sector Strategy, "the environment is a special 'water-using sector' in that most environmental concerns are a central part of overall water resources management, and not just a part of a distinct water-using sector" (World Bank 2003: 28). Being integral to overall water resources management, the environment is "voiceless" when other water using sectors have distinct voices. As a consequence, representatives of these other water using sectors need to be fully aware of the importance of environmental aspects of water resources management for the development of their sectoral interests.

For us in the World Bank, water resources management–including the development of surface and groundwater resources for urban, rural, agriculture, energy, mining, and industrial uses, as well as the protection of surface and groundwater sources, pollution control, watershed management, control of water weeds, and restoration of degraded ecosystems such as lakes and wetlands–is an important element of our lending, supporting one of the essential building blocks for sustaining livelihoods and for social and economic development in general. Prior to 1993, environmental considerations of such investments were addressed reactively and primarily through the Bank's safeguard policies. The 1993 Water Resources Management Policy Paper broadened the development focus to include the protection and management of water resources in an environmentally sustainable, socially acceptable, and economically efficient manner as an emerging priority in Bank lending. Many lessons have been learned, and these have contributed to changing attitudes and practices in World Bank operations.

Water resources management is also a critical development issue because of its many links to poverty reduction, including health, agricultural productivity, industrial and energy development, and sustainable growth in downstream communities. But strategies to reduce poverty should not lead to further degradation of water resources or ecological services. Finding a balance between these objectives is an important aspect of the Bank's interest in sustainable development. The 2001 Environment Strategy underscores the linkages among water resources management, environmental sustainability, and poverty, and shows how the 2003 Water Resources Sector Strategy's call for using water as a vehicle for increasing growth and reducing poverty can be carried out in a socially and environmentally responsible manner.

Over the past few decades, many nations have been subjected to the ravages of either droughts or floods. Unsustainable land and water use practices have contributed to the degradation of the water resources base and are undermining the primary investments in water supply, energy and irrigation infrastructure, often also contributing to loss of biodiversity. In response, new policy and institutional reforms are being developed to ensure responsible and sustainable practices are put in place, and new predictive and forecasting techniques are being developed that can help to reduce the impacts and manage the consequences of such events. The Environment and Water Resources Sector Strategies make it clear that water must be treated as a resource that spans multiple uses in a river basin, particularly to maintain sufficient flows of sufficient quality at the appropriate times to offset upstream abstraction and pollution and sustain the downstream social, ecological, and hydrological functions of watersheds and wetlands.

With the support of the Government of the Netherlands, the Environment Department has prepared an initial series of Water Resources and Environment Technical Notes to improve the knowledge base about applying environmental management principles to water resources management. The Technical Note series supports the implementation of the World Bank 1993 Water Resources Management Policy, 2001 Environment Strategy, and 2003 Water Resources Sector Strategy, as well as the implementation of the Bank's safeguard policies. The Notes are also consistent with the Millennium Development Goal objectives related to environmental sustainability of water resources.

The Notes are intended for use by those without specific training in water resources management such as technical specialists, policymakers and managers working on water sector related investments within the Bank; practitioners from bilateral, multilateral, and nongovernmental organizations; and public and private sector specialists interested in environmentally sustainable water resources management. These people may have been trained as environmental, municipal, water resources, irrigation, power, or mining engineers; or as economists; lawyers, sociologists, natural resources specialists, urban planners, environmental planners, or ecologists.

The Notes are in eight categories: environmental issues and lessons; institutional and regulatory issues; environmental flow assessment; water quality management; irrigation and drainage; water conservation (demand management); waterbody management; and selected topics. The series may be expanded in the future to include other relevant categories or topics. Not all topics will be of interest to all specialists. Some will find the review of past environmental practices in the water sector useful for learning and improving their performance; others may find their suggestions for further, more detailed information to be valuable; while still others will find them useful as a reference on emerging topics such as environmental flow assessment, environmental regulations for private water utilities, inter-basin water transfers and climate variability and climate change. The latter topics are likely to be of increasing importance as the World Bank implements its environment and water resources sector strategies and supports the next generation of water resources and environmental policy and institutional reforms.

Kristalina Georgieva
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INTRODUCTION

Large dams provide benefits to many people around the world by providing water for hydropower generation, irrigation, and water supply. However, without proper provisions being made, these dams can also cause considerable damage to upstream and downstream ecosystems. In a few cases, the operating rules for these dams allow for releases to maintain instream ecosystems. However, almost exclusively, these flows remain within the river channel. It is rare for high flows to be released to inundate floodplain and deltaic ecosystems. Yet, when flooded periodically, these floodplain ecosystems supply important products (arable land, fisheries, grazing land), functions (groundwater recharge, nutrient cycling) and attributes (biodiversity). For many centuries, floodplain ecosystems have provided economic, social, and environmental security for rural communities. Floods are also very important for fish migration and sediment transport. In some cases, managed floods have been proposed–and in a few places, implemented–as part of a dam mitigation strategy to restore and conserve wetland ecosystems, which help sustain traditional livelihoods. Such releases involve a tradeoff, since less water will remain in the reservoir for its primary design purposes, such as hydropower, irrigation, or public supply (Figure 1).

In this Note, a managed flood is defined as a controlled release of water from a reservoir to inundate a specific area of downstream floodplain or river delta to restore and maintain ecological processes and natural resources for dependent livelihoods. Such releases are undertaken in collaboration with stakeholders. This is distinct from planned releases to test floodgate operations or to optimize storage in multi-reservoir systems, and from unplanned releases made to prevent dam failures.

Managed floods are not a panacea for downstream environmental problems caused by dams. However, they may be appropriate where downstream wetland and riparian ecosystems support livelihoods–particularly where alternative livelihood strategies are limited–or where important biodiversity and bioproductivity need to be maintained.

Technical Notes C.1 to C.4 deal with environmental flows. Although changes in flow will affect water quality–for example, by increasing or decreasing turbidity–the focus in these Notes is primarily on the direct effects of flow on the ecological functioning of rivers and the management of water quantity. Note C.1 introduces concepts and methods for determining environmental flow requirements for rivers. Note C.2 reviews some important case histories. This Note describes the reinstatement of flood releases from reservoirs for floodplain inundation. It assesses the general appropriateness and feasibility of introducing managed floods; considers the design of appropriate flood flows, including the optimum magnitude, duration, frequency and timing of managed floods (given the economic, social, and environmental feedbacks and tradeoffs); and discusses implementing the chosen managed flood option. It concludes with a case study–the Waza-Logone floodplain in Cameroon–that illustrates many of the desirable features described earlier. Note C.4 addresses the downstream social issues arising from changes in flows.

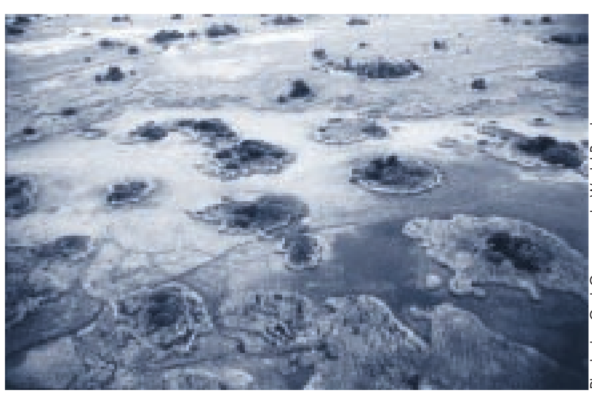
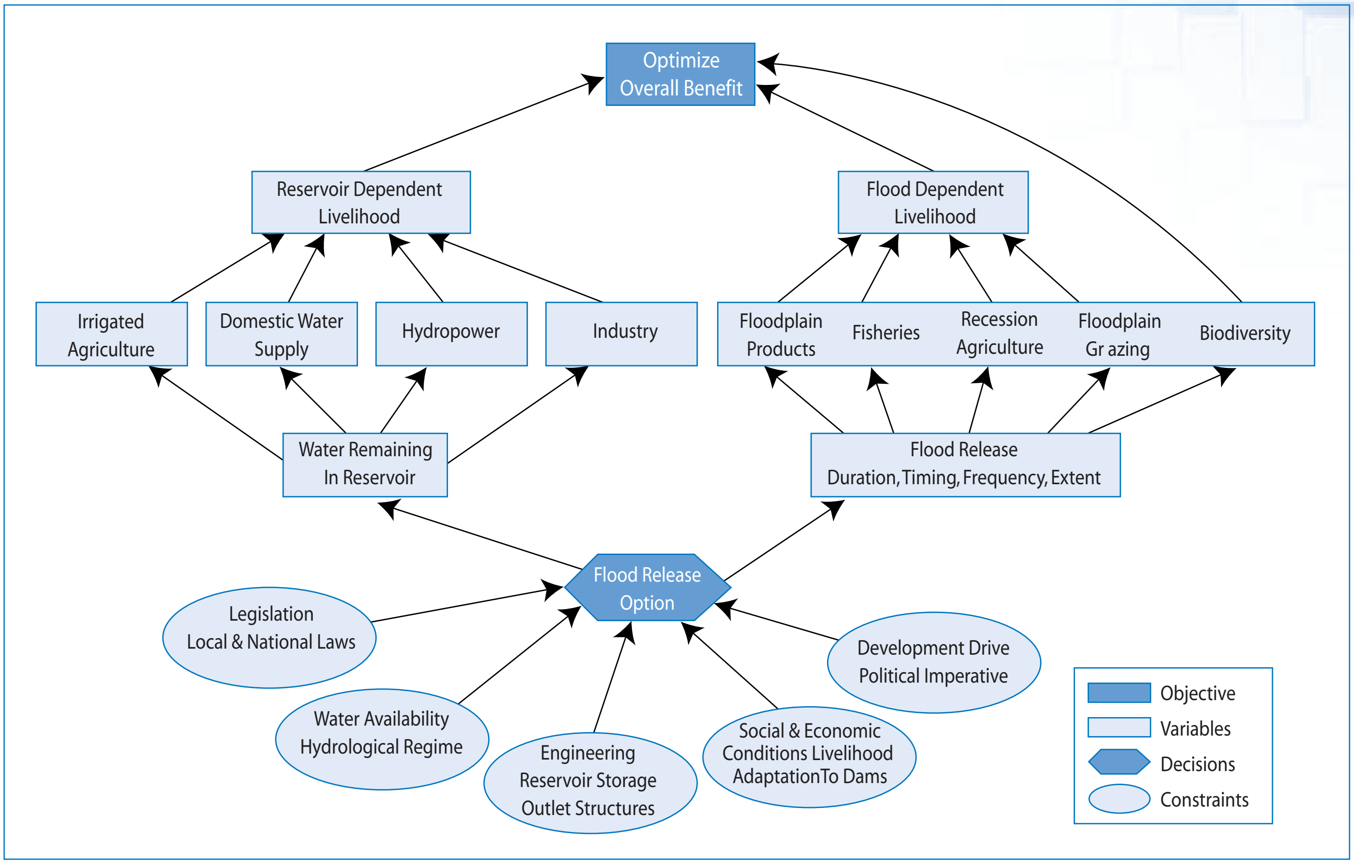


Photo by Curt Carnemark, World Bank

Okavango Swamp, Botswana

Figure 1.
Flow chart showing the trade-off between using water for managed flood releases and for reservoir-based activities.



ESTABLISHING THE APPROPRIATENESS OF MANAGED FLOODS

OBJECTIVES FOR FLOOD RELEASES

Flows to replenish floodplains and associated ecosystems are one of the component environmental flows described in Technical Note C.1. As with all environmental flows, clear objectives for managed flood releases must be defined through a study of the ecosystem, economy, and social structure of the floodplain to ensure that managed floods are compatible with the livelihood strategies of the floodplain communities. Consequently, consultation with local people is a critical element of flood releases.

Objectives can include flood recession agriculture, fishing, animal husbandry, groundwater recharge, or conservation of biodiversity and bioproductivity (Box 1). The study must identify both those people who will benefit from flood releases, and those who may suffer. For existing dams, adaptations to the altered hydrological regime may mean that release of managed floods will not provide significant benefits. Objectives must be defined–in the context of any river basin management plan and national/regional policies–and assessed alongside other options for water use, including public water supply, irrigation, navigation, and hydropower.

ENSURING TECHNICAL FEASIBILITY

Three factors are particularly significant for ensuring the technical and financial feasibility of man-

Box 1.
The Senegal valley: a suitable situation for managed flood releases

As part of the development of the Senegal River basin, the Organisation pour la Mise en Valeur du Fleuve Senegal (OMVS) constructed two dams. At the river's mouth, the Diama dam inhibits saltwater intrusion into the river to allow its use for irrigation and to regulate water levels for navigation. In the headwaters, the Manantali dam was built to generate hydroelectric power and to provide flows for navigation and irrigation in the middle valley of the Senegal River. Prior to dam construction, which began in 1986, natural inundation covered up to 250,000 hectares of the floodplain of the middle Senegal valley, and supported up to 125,000 hectares of flood recession agriculture (including maize, beans, watermelon, potatoes, and millet), grazing, forests (which provide fuelwood and construction timber), fisheries, and wildlife habitat. The estimated economic value of the floodplain was: recession agriculture, $56-136 per hectare; fishing, $140 per hectare; and grazing, $70 per hectare. It was feared that cessation of floods through operation of the Manantali dam would have a devastating effect on mid-valley livelihoods.

By 1991, the reservoir had filled and the spillway was tested, but the turbines had not been installed. In subsequent years, OMVS conducted managed flood releases to inundate 100,000 hectares of land that provided a cultivation area of 50,000 hectares. This required around 7.5 billion m^3 of water, yielding a value of about $2 per 1,000 m^3 for agriculture, fishing, and grazing. The World Bank has agreed to help finance the installation of turbines at Manatali in 2001, provided that the principle of managed floods is recognized by OMVS as a possible long-term option. The Governments of Mali, Senegal, and Mauritania have now signed a Water Charter that includes the release of the annual flood when sufficient water is available (normally 9 years out of 10).

aged floods. First, the engineering characteristics of the dam and reservoir must be adequate. Reservoir storage capacity must be sufficient, the outlet structures must be large enough to permit major releases, and they must be able to work operationally. For many existing dams, outlet structures may be too small, thereby making floods that adequately inundate the floodplain less feasible. Where several dams occur up/downstream of each other, it may be necessary to coordinate operation of all dams to produce flood releases. In such cases, each dam must have suitable release structures.

Second, the environmental characteristics of the reservoir and its catchment must be appropriate. Thermal stratification in many reservoirs leads to poor water quality–low oxygen, high concentrations of hydrogen sulphide, iron, and manganese–at depth, which is inappropriate for release (see Note G.2). In rivers with a high sediment load during floods, sediment will need to be passed through the dam with the flood release, which may be very difficult and expensive, although some solutions have been developed.

Third, the extent to which a dam controls flooding in target ecosystems will also depend on flow contributions from tributaries downstream of the dam; local streams entering the floodplain; rainfall; and subsurface flows. If the dam has limited control over flooding, then managed flood releases will have little impact unless the releases can be timed to augment high flows from other tributaries.

In addition, broad financial factors must be considered, including the costs of installing new release structures in the dam, the opportunity costs of water releases, and the benefits to downstream livelihoods (Box 2).

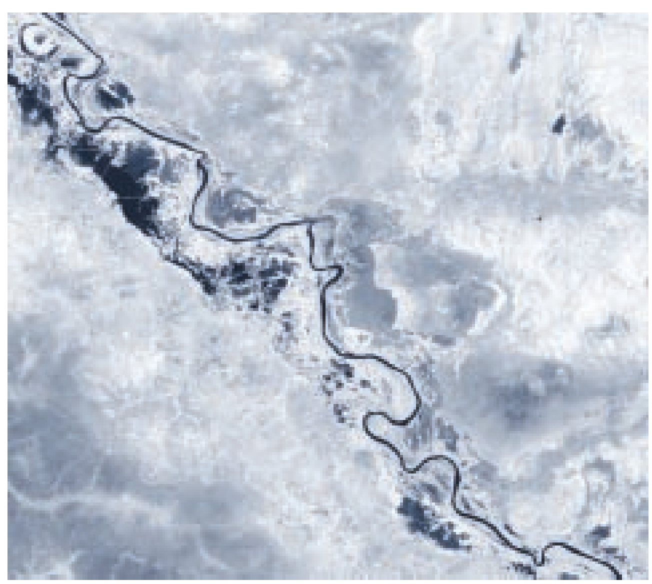


Photo by ORSTOM, Senegal

Satellite image, Senegal River below Manatali Dam

BOX 2.
MAHAWELI: A RIVER WHERE FLOOD RELEASES ARE NOT APPLICABLE

The Mahaweli Scheme is a comprehensive multipurpose water resource development designed to harness the hydroelectric and irrigation potential of the Mahaweli Ganga, Sri Lanka's largest and most important river. The river has been utilized and diverted for irrigation purposes since at least the 1st century BC. King Parakrama Badhu 1 (AD 1153-1186) is said to have constructed or restored 165 dams, 3,910 canals, 163 major tanks and 2,376 minor tanks, making extensive use of the water resources of the Mahaweli Ganga. Today only a fraction of these constructions are still functioning, but they are nevertheless indicative of the old and extensive water diversion and use systems in the Mahaweli Ganga. The current Accelerated Mahaweli Development Programme (AMDP) includes the development of 320,000 acres of new irrigated land.

Due to their complexity, large and integrated water-use structures such as seen in the Mahaweli basin may not be suitable candidates for managed flood releases. The experience gained from sediment flushing trials conducted in Rantembe reservoir by the Mahaweli Authority and Ceylon Electricity Board and Irrigation Department is indicative of some of the problems that could be expected if controlled flood releases were to be used in managing the Mahaweli system.

Rantembe reservoir is silting fast, at about 6 percent per annum, and flushing has been considered as a technical option. Flushing of sediment has been carried out twice with a three-year interval. A substantial portion of the outflow from Rantembe reservoir moves along irrigation canals downstream. A third flushing event planned for 1999 was canceled due to problems resulting downstream from siltation in these canals from the earlier flushings. Both old and new weirs for diversion of water into these irrigation systems were constructed without any regulatory facilities. As a result, sediment-laden water cannot be confined to the main river. Any managed flood release from upstream reservoirs can be expected to have a similar effect downstream. The cost of converting weirs to regulate flows, together with the extensive logistical and coordination problems associated with managing the releases, have not been calculated, but are likely to be prohibitive.

DESIGNING FLOOD RELEASES

If preliminary screening determines that there could be significant benefits from managed flood releases, and it is technically and financially feasible, then possible flood releases need to be designed.

STAKEHOLDER AND TECHNICAL PARTICIPATION

A key element in defining appropriate flood releases is to incorporate the expectations of stakeholders for floodplain inundation. This should begin with identification of the various stakeholders, such as dam operators/owners, local authorities, electricity companies, farmers, and—most importantly—downstream farmers and communities. Downstream communities—floodplain farmers and residents, including pastoralists and fisherfolk—should be regarded as subject to significant risk. Getting them involved requires a specific and innovative effort. Their current livelihood strategies, assets, and aspirations should be mapped to establish the population at risk.

Many of the techniques commonly included under the label of "Participatory Rural Appraisal" (such as village mapping and ranking exercises) may be useful here, but what is important is a genuine commitment to participation, with adequate time and resources (Box 3). Where necessary, the process should include building and strengthening stakeholder organizations, such as local NGOs, to enable them to participate fully. The aim is to ensure that managed floods are compatible with the livelihood strategies of the floodplain communities. If local social structures allow, participation can be structured through the establishment of a Water Committee (Box 4), which can help in deciding on the magnitude, frequency, duration, and timing of floods, as well as in informing local communities when the flood is coming.

At an early stage, an equally important action is to initiate data collection to improve understanding of the physical, chemical, biological, and socioeco-

Box 3.
Participatory Rural Appraisal in the Waza-Logone project, Cameroon

Participatory Rural Appraisal (PRA) methods were used in the Logone Floodplain in Northern Cameroon to investigate the socioeconomic impacts of declining floods. PRA was chosen because of the difficulties of collecting complex information on interactions between society and the environment in a participatory way. It was also felt that conventional survey methods would fail to capture seasonal variations in an area that was inaccessible by road in the dry season.

Several PRA methods were used, including:

- *Participatory mapping* was used with both men and women to gather information on land-use, the floodplain environment and the operation of the village
- *Timelines* identified key dates in floodplain history; these illuminated the issue of conflicts among farmers, herders, and fishers
- *Transect walks* were used outside the village to examine natural resource issues, and inside the village to look at building materials and living conditions
- *Ranking* was used for problems and productive activities
- *Wealth ranking* enabled sampling of households for interview, estimation of human and livestock numbers, and understanding of local notions of wealth
- *Semi-structured interviews*
- *Venn diagrams* described relations between groups and institutions within and outside the village
- *Resource flow diagrams* were used on common property issues, trade, and service delivery
- *Feedback* to villagers

Despite a relatively short time-scale and constraints such as the lack of an educated woman on the team, the experience generated a great deal of quantitative and qualitative information. The organizers were also able to set up simple environmental and socioeconomic monitoring systems that could be run by villagers.

Box 4.
Community-based institutions in the Phongolo River

In the late 1960s, the Pongolapoort dam was constructed on the Phongolo River in northeast South Africa near its borders with Swaziland and Mozambique. The reservoir was filled in 1970. It was intended to irrigate 40,000 hectares of agricultural land for white settlers, with no provision for hydropower generation. There were no assessments of the impacts of the impoundment on the downstream floodplain, where 70,000 Tembe-Thonga people were dependent on recession agriculture, fishing, and other wetland resources, or on the biodiversity of the Ndumu game reserve. When constructed, the dam changed the whole flooding regime of the river, which had significant negative impacts on agriculture and fisheries. In addition, few settlers used the irrigation scheme.

In 1978, a workshop was held on the Phongolo floodplain to review the future of irrigation and to minimize the negative impacts on the floodplain. This led to a plan for controlled releases to rehabilitate the indigenous agricultural system and the wildlife. However, initial releases of water from the dam were made at the wrong time of the year, and crops were either washed away or rotted. In 1987, the South African Department of Water Affairs and Forestry and the local authorities agreed to experiment with community participation. As a result, water committees were established, representing various user groups, including fisherfolk, livestock keepers, women, and healthworkers (both new primary health care workers and traditional herbalists and diviners). They were given the mandate to decide when floodwaters should be released. These committees successfully implemented people's views, which in turn led to river basin management that benefited the floodplain users.

nomic aspects of the reservoir (see Note G.2) and floodplain and wetlands (see Note G.3). All reports and data should be made publicly available; establishing a local information center is an excellent way to do this. In addition, implementing organizations need training and awareness building to understand and use floodplains wisely. This requires strengthened technical skills in ecology, hydrology, engineering, health, economics, social anthropology, and law.

LINKS BETWEEN FLOODS AND THE ECOSYSTEM

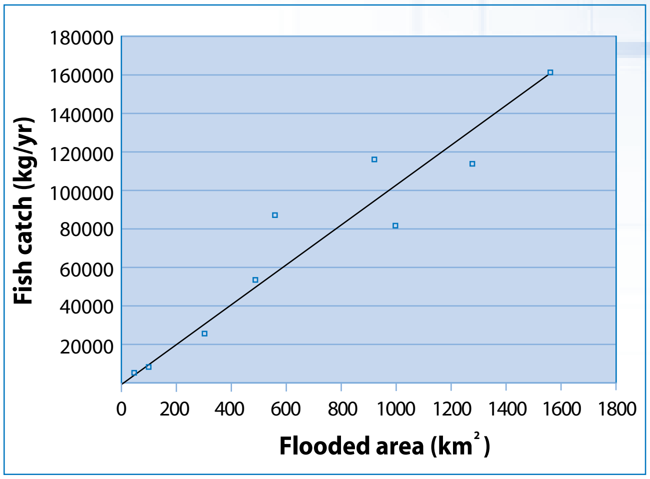
Indicators such as the frequency, duration, timing, and discharge of floods can be used to identify linkages between the products, functions, and attributes of the floodplain and flooding and its social implications. In particular, the flooding necessary to maintain those parts of the ecosystem required to fulfill the agreed objectives needs to be quantified. For example, some wetlands may be important for recession agriculture or fisheries. This will aid the definition of an optimum, targeted flood release. Thresholds of flooding, below which a floodplain ecosystem ceases to function adequately, may exist, but in most cases they cannot be easily identified.

Instead, available data often exhibit smooth or linear relationships between flood extent and ecological productivity (Figure 2) without clear critical points. Consequently, considering how much water the ecosystem needs is not appropriate; instead, the more relevant question is how much water is needed to meet specific objectives, such as fish production targets.

For example, the Indus River dominates the landscape and economy of Pakistan, providing water for the world's largest irrigated area. The lower Indus supports a large floodplain that provides timber products, especially pit-props for the mining industry. Where the river joins the sea, an extensive delta has formed, stabilized by mangroves. These provide camel fodder and fuelwood; support an extensive fishery, which earned $100 million in foreign exchange in 1997; and provide habitat for many rare species. Fresh groundwater within the delta supports fishing communities and camel herders.

Records from the 19th century suggest that freshwater flows to the lower Indus were around 185 billion m^3 per year. Some flow occurred all year round, with higher flows starting in March, peaking in August, and declining in November. Since then, construction of numerous dams and barrages for irrigation has reduced the flows of water and

FIGURE 2.
RELATIONSHIP BETWEEN FLOODED AREA AND FISH CATCH



Source: Welcomme, R.L., 1976.

sediment down the Indus. During the period 1960-71, freshwater inflows were only 43 billion m^3, and the Indus Water Accord only provides 12.3 billion m^3 per year. This occurs mainly in the period June-August, with little or no flow in other months. Ecological studies by the Sindh Forest Department estimated that each 40 ha of mangrove forest requires 0.028 $m^3\ sec^{-1}$ during July and August to remain healthy and to support the associated fisheries. For the estimated 260,000 hectares of mangroves, a total volume of 33.3 billion m^3 would be needed. A typical flood hydrograph shape would suggest a flow peak of 5,000 $m^3\ sec^{-1}$. The floodplain forests need to be inundated at least twice in 5 years to enable saplings to become established.

DEFINING FLOOD RELEASE OPTIONS

Typically, a small number (3-5) of flood-release options will be identified and quantified, taking into account the objectives, technical and financial constraints, and ecosystem requirements. Assessments should include descriptions of the magnitude, timing, frequency, and duration of flood releases from a reservoir to produce a target flood extent on a floodplain, as well as the impact on water reserves retained within the reservoir for other purposes. The overall aim is to optimize benefits from reservoir-based and flood-based livelihoods (Figure 1). This step will almost certainly require a hydrological/

hydraulic model of the floodplain, reservoir, main channel, and catchment (Box 5). The "no-flood" option should always be included in the analysis.

Appropriate flows during the non-flood season must also be addressed. For example, the Kafue Flats floodplain in Zambia is unusual in being directly downstream of one reservoir (Itezhi-tezhi) and directly upstream of another (Kafue Gorge). The joint operation of the dams significantly affects flooding in the flats. Under natural conditions, the flats used to empty almost completely by the end of the dry season, creating a large recession zone that was important for agriculture, fishing, grazing, and biodiversity (especially providing habitat for the rare lechwe antelope). Managed flood releases from Itezhi-tezhi have meant little change in the maximum area flooded each year. However, dry season releases from Itezhi-tezhi for hydropower generation are greater than the flows that would occur naturally. This increase, combined with storage in Kafue Gorge reservoir, has created a larger permanently flooded area. The annual minimum flooded area has increased from 300 km^2 to about 1,500 km^2. The decrease in difference between dry and wet season inundation has reduced the flood recession zone and also resulted in the loss of grazing, traditional flood recession gardening systems, and a decline in fisheries.

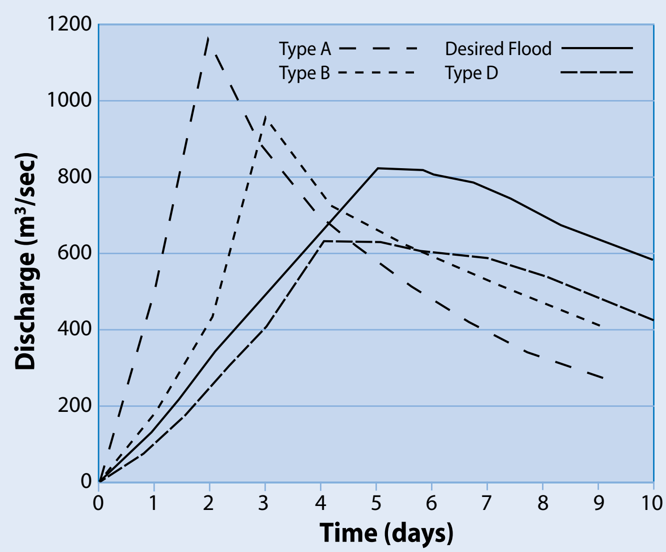
This highlights both the need for full understanding of the interaction between the entire hydrological regime and the ecological functioning of the floodplain and, where more than one dam exists, the importance of coordinating their operation to ensure that flows–including periods of no flow–achieve the objectives agreed between the parties.

BOX 5.
FLOOD RELEASE OPTIONS FOR THE TANA RIVER, KENYA

The Tana River is the largest river in Kenya. It rises in the highlands of the Aberdares and Mt. Kenya, and then flows for more than 250 km over the flat, dry coastal plain to the Indian Ocean. The Tana has an extensive floodplain and delta, which support the livelihoods of over half a million people through agriculture, fishing, livestock rearing, and horticulture. To satisfy the increasing electricity demand within Kenya, planning is under way to dam the Tana upstream of the floodplain at Mutonga (and Grand Falls) to supplement a cascade of five existing upstream dams.

Recognizing the local and national value of the floodplain and delta, planners and developers have agreed that floods should continue. Consequently, the feasibility study designed a dam that will store enough water to produce a flood downstream through short-term high-flow releases, as well as produce the necessary electricity. Furthermore, recognizing that silt is as important as water for the maintenance of the productivity of the floodplain, the dam designers will try to release silt together with the flood water, although this is technically very difficult and may not be feasible. A major challenge is to release the correct amount of water, such that when it combines with rainfall and tributary inflows between the reservoir and the floodplain, the desired level of floodplain inundation is achieved.

Using data from historical and recent floods, a modeling study is currently underway to address these limitations. The figure shows three possible flood release hydrographs (A, B & D – broken lines) that vary in volume. Depending on the hydrological conditions in the rest of the catchment, these can all produce the desired flood downstream (solid line). To ensure the optimum release, regional rainfall, soil moisture, and flows from tributaries must all be monitored. Despite this complexity, it is anticipated that the final design will result in a dam that meets the demand for electricity and respects the needs of its floodplain and dependent livelihoods downstream.



IMPACTS OF FLOOD OPTIONS

Since a final flooding regime will inevitably be a compromise between different objectives, it is important to assess the impacts of the various flooding options, both for floodplain-dependent livelihoods and for reservoir-dependent livelihoods. A range of impact assessments must therefore be initiated at an early stage, so that scoping of issues and collection of data can begin and possible measures to mitigate negative impacts can be defined. In most countries, a formal EIA is a legal requirement. Impact assessment can take many forms, but environment, health, and law are key areas. There should also be direct and participatory assessment of impacts on livelihoods, using a broad definition of assets, including social capital. The criteria to evaluate livelihood outcomes should also be defined with stakeholder participation.

Additionally, laws may need to be established to regulate natural resource use, as there may be an influx of people into restored floodplain ecosystems. The adequacy of current laws can be evaluated though a legal impact assessment. Managed floods may have positive or negative impacts on nutrition, drinking water quality, injury, stress, communal violence, and communicable diseases such as malaria, schistosomiasis, and arboviruses. Thus, the health impacts of flood options should also be considered as part of the assessment.

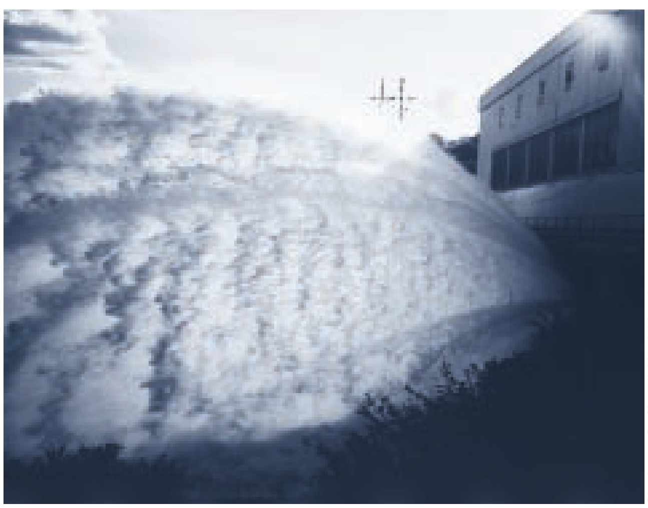


Photo by Rafik Hirji, World Bank

Nyumba ya Mungu Dam, Tanzania

The assessment must equally include the impacts on the reservoir and its dependent activities. Releasing water to create a managed flood will normally mean less water for intensive irrigation, hydropower generation and/or water supply. These impacts must be quantified. In some cases, legislation designed to protect downstream communities may prevent those responsible for the dam from making managed flood releases. In addition, downstream communities may have rights to use the water, which would require compensation.

SELECTING THE BEST FLOOD OPTION

For each option, the monetary and non-monetary costs and benefits and their distribution among all stakeholders should be estimated (Box 6). National or local economic benefits should not be the only criteria on which to make decisions about managed floods. It is also vital to consider other political, social, historical, and ecological issues, particularly the rights and welfare of those affected. In many cases, the link between flooding and livelihoods will be imprecise and understood in only a qualitative way. A decision should then be made on the most appropriate option, using a transparent method in which stakeholders participate and understand the results.

BOX 6.
VALUATION IN THE HADEJIA-JAMA'ARE RIVER BASIN, NORTHERN NIGERIA

In Northern Nigeria, an extensive floodplain exists where the Hadejia and Jama'are Rivers converge. 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. In addition, it helps to recharge the regional aquifer and serves as an essential groundwater source. The maximum extent of flooding has declined from 300,000 ha in the 1960s to around 70,000 to 100,000 ha more recently, following the construction of the Tiga and Challawa Gorge dams upstream. There are plans for a new dam at Kafin Zaki.

Economic analysis of the Kano River Project (a major irrigation scheme benefiting from the upstream dams) and the floodplain showed that the net economic benefits of the floodplain (agriculture, fishing, fuelwood) were at least \$32 per 1000 m^3 of water (at 1989 prices). However, the returns from crops grown in the Kano River Project were at most only \$1.73 per 1000 m^3. When the operational costs are included, the net benefits of the project are reduced to \$0.04 per 1000 m^3.

A combined economic and hydrological analysis was conducted to simulate the impacts of these upstream projects on the flood extent that determines the downstream floodplain area. The economic gains of the upstream water projects were then compared to the resulting economic losses to downstream agricultural, fuelwood, and fishing benefits. 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 \$2.6 million to \$24 million. As expected, 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, around \$20 million.
These results suggest that the expansion of the existing irrigation schemes within the river basin is uneconomic. The introduction of a regulated flooding regime would reduce the scale of this negative balance substantially, to around \$15 to \$16 million. However, the overall combined value of production from irrigation and the floodplain would still fall well below the levels experienced if the additional upstream schemes were not constructed.

IMPLEMENTATION

DESIGNING ENGINEERING STRUCTURES

The dam outlet structures will need to be designed and constructed (for new dams) or may need to be adapted (for existing dams) to allow necessary and feasible flood releases and sediment delivery. The position of outlets will need to take into account any thermal and associated chemical stratification in the reservoir. Embankments may need to be constructed on the floodplain to protect infrastructure–such as houses, roads, and factories–from flooding or to enhance, control, or reduce inundation in selected areas. However, infrastructure is still likely to be affected by large natural flood events, irrespective of any managed flood releases.

Some infrastructure may also be needed to maximize the benefits from the controlled releases. For example, to make the most of the flooding that does occur in the Hadejia-Jama'are River Basin (Box 6), a series of small embankments have been built by farmers to control the level of water in different parts of the floodplain. Water movement is controlled by small, hand-operated sluice gates. Early in the flooding season, mesh "gates" are installed, which allow water in but keep out fish that would eat the young growing plants. Once the plants are established, the mesh is removed to allow fish to spawn and fry to grow in the flooded areas. As the flood subsides, wooden boards may be put in if flooding needs to be prolonged.

Further associated structures may also be required, such as fish ladders, sluice gates, or adaptation of the spillway to minimize disease vectors. Local health centers may need to be stocked with drugs before the beginning of each flood season.

RELEASING THE WATER

Where possible, pilot flood releases of various sizes can be made over a period of 2–3 years to determine the response of the ecosystem and of local communities. If project funds permit, it is best to install real-time monitoring of both precipitation and river flows, and link these data to flood forecasting models. This helps define the appropriate release to create the required inundation, thus optimizing water resources allocation between reservoir-dependent livelihoods and flood-dependent livelihoods. In many cases, it will be possible to create the desired floodplain inundation by adding water from a reservoir to a natural small flood rather than trying to create the entire flood from managed reservoir releases.

Floodplain residents need advance warning about planned flood releases to enable them to move livestock and other vulnerable assets to safe areas. Ideally, the coordination mechanisms established during the planning phases to elicit stakeholder views can be used to disseminate flood warnings. In addition, radio broadcasts, posters, and other media may be required to reach all floodplain communities. Further awareness development and capacity building exercises can be used to demonstrate the impacts of the new flood regime. When the flood release notification program is completed, full releases can be made.

In many cases, it will be necessary to liberate sediment from the reservoir as part of the flood releases to maintain the structure of downstream rivers and deltas and the fertility of floodplains. This will also help to prolong the life of the reservoir by sustaining its storage capacity (Box 7). However, the technique will be of limited value with hydropower dams, because it is not possible to pass high silt loads through hydropower turbines.

MONITOR, EVALUATE, AND ADAPT RELEASE PROGRAM

Adequate ecological and socioeconomic monitoring will help to assess the effectiveness of flood releases in relation to the objectives. It is preferable to decide at an early stage on the indicators of whether the objectives are being attained or not. Monitoring should be designed to differentiate between the changes to social and environmental conditions caused by flood releases from those arising from other factors. Since the time-scales for ecological and social change may be many decades, monitoring should be continued for long periods with adequate funding. The flood release program can be modified once the effectiveness of the releases becomes apparent.

BOX 7.
RELEASING SEDIMENT FROM TARBELA DAM, PAKISTAN

Pakistan's Tarbela Dam, completed in 1974 as a component of the Indus basin scheme, provides for both irrigation and hydropower. Of the 240,000 tons of sediment entering the reservoir annually, 80 percent is trapped. Unless action is taken, the steadily declining volume of the reservoir will mean that the facility has a severely diminished value by 2030. A technique to flush the sediment through the dam by lowering the reservoir level and releasing high flows for a sustained period has been tested recently. These studies have shown that it is possible to maintain a substantial long-term live storage with only a small annual reduction in stored water. The process works effectively when a low reservoir level is maintained and the period of flushing is several weeks. The live-storage volume at Tarbela would eventually settle at about half its original value. To use this flushing technique to extend the reservoir's life, it may be necessary to increase the capacity of the low-level flow release facilities at the dam.

A PRACTICAL EXAMPLE — THE WAZA-LOGONE FLOODPLAIN

The Waza-Logone floodplain in Cameroon is ecologically and socially suited to flood releases. In this example, flood releases from an existing dam were negotiated in a way that satisfied downstream communities dependent on floodplains, as well as those groups who used the stored water for irrigation.

The Logone River drains from the Adamoua plateau in central Cameroon. Before it joins the Chari River, flood water from the river inundates annually a large floodplain, originally around 6,000 km^2. This wetland has a high biodiversity with large herds of giraffe, elephant, lions, and various ungulates. Part of the floodplain is designated as the Waza National Park, which attracts around 6,000 tourists per year.

In the flood season, the entire floodplain becomes a vast fish nursery. Up to the 1960s, fishing was the primary economic activity among the local Kotoko people, who could earn $2,000 in four months. The Fulani name for the floodplain is yaérés, which means "dry season pasture." Annually, some 300,000 cattle and 10,000 sheep and goats grazed on the floodplains. Pastures become accessible when surrounding savanna grasses withered and their protein content was depleted. The carrying capacity has been estimated at 1–2 cattle per ha, compared with 0.2 for surrounding savannah. Floating rice was the main arable crop of the floodplain, since it has low labour demands and fits well into the fishing calendar. Yields were not high, but enough land was available to ensure self-sufficiency in rice.

The area inundated has been reduced since 1979. This is partly due to climatic factors, but primarily due to construction of a dam across the floodplain, which created Lake Maga. The lake supplies the SEMRY II irrigation project, where rice is grown. (The dam is adjacent to the river and thus does not stop all flow). There is insufficient flooding to grow floating rice in large areas of the floodplain, and fish yields fell by 90 percent.

The SEMRY rice scheme was not making full use of water stored in Lake Maga. Using the water to rehabilitate the floodplain, while retaining enough to maintain rice production, was a development option. Hydrological, ecological, and socioeconomic studies suggested that such managed flood releases could improve fisheries, agriculture, and herding, though much would depend on the available flood discharges and the response of local people and their environment to renewed flooding. However, re-establishing these flood flows could attract a large influx of people, who would over-exploit the area and thus degrade the rehabilitated resources of the floodplain.

The Waza-Logone Conservation Project, coordinated by IUCN, undertook a wide range of activities in the floodplain and surrounding area over 8 years that highlighted many of the issues discussed in these Notes. The results of these activities are used to exemplify the design and implementation of managed flood releases.

PRELIMINARY STEPS

The objectives were to restore biodiversity and the livelihoods of communities–who depend on natural resources of the floodplain–through managed flood releases, while retaining sufficient water in the reservoir for intensive rice irrigation. These objectives were defined through analyses of the degradation of the floodplain ecosystem and of the efficiency of the SEMRY irrigation scheme.

Technical studies were undertaken to assess the capacity of the outlet structures of the dam, the channels leading from it, and the river embankments. Because the reservoir is shallow, thermal and chemical stratification was not a problem. In addition, the reservoir is "off-line" and does not control the entire flow of the river, so sediment release was not an issue. Natural inundation of the floodplain resulted from a series of three processes: (1) rain falling directly onto the floodplain; (2) runoff from local streams entering the floodplain; and (3) flows in the Logone River exceeding the capacity of its channel.

DESIGNING FLOOD RELEASES

The project developed a participatory process that involved relevant national and local authorities, floodplain communities (using Participatory Rural Appraisal), and SEMRY management. Local interest groups—concerned with, for example, fisheries and small-scale rice farming—were established within local communities. The next step was to establish a water committee with local community representatives, the SEMRY rice scheme managers, Waza National Park staff, and local authorities. Technical expertise was developed in local institutions by involving their staff in the project.

The project team conducted detailed studies of the interaction between vegetation and flooding. These showed that there was a change from annual to perennial grasses with inundation over a three-year period. The surveys were continued as part of the pilot releases.

A hydrological model of the reservoir, floodplain, main river, and local tributaries was constructed and used in conjunction with ecological and socio-economic models to define flooding options under dry, wet, and very wet conditions.

A preliminary Environmental Impact Assessment of all flood options was undertaken. Studies of water-related diseases focused attention on water supply (wells), sanitation (latrines), and hygiene awareness programs, which led to reduced diarrheal diseases. The team also assessed the impact of re-flooding on the operation of the SEMRY rice scheme. Further studies of the health and environmental impacts of the full-flood option are planned.

The team also conducted an economic analysis of various flooding options. Re-flooding of 90 percent of the floodplain yielded annual values of $550,000 for fisheries, $930,000 for herding, $31,500 for recession agriculture, and $60,000 for tourism. The net present value over 30 years was 15,000 million CFA (about $20 million), assuming a discount rate of 4 percent.

IMPLEMENTING THE CHOSEN FLOWS

Changes to the embankments along the main river and channels feeding the floodplain with water were planned and implemented in collaboration with local communities. Modifications to the outlet structures of the dam were not required. No embankments were necessary to protect the SEMRY rice scheme from flooding.

Pilot flood releases were conducted in 1994 and 1997 to determine the response of the ecosystem and of local communities. Further test releases from the dam are planned. Hydrological, ecological, sociological, and economic monitoring was established for the pilot releases to assess the impacts of flooding and the results were used to refine the models and flooding options.

CONCLUSION

Most river systems throughout the world will have some element of their ecosystem–such as fish species that breed on the floodplain or vegetation that requires periodic watering–that has evolved to benefit from floods. In some cases, the species or landscapes (particularly those that are rare or endangered) may be worth conserving for their own sake. In many other cases, local communities will have developed livelihoods that depend on these floods. These dependencies include subsistence agriculture in developing countries and sport fishing in developed countries. In principle, therefore, most reservoirs have a potential for managed flood releases.

The appropriateness of managed flood releases will depend on the relative merits of using water for flood releases compared to storing it in the reservoir for irrigation, public/industrial supply, or hydropower. This decision can only be made on a case-by-base basis.

FURTHER INFORMATION

The following reports provide background information on managed flood releases:

Acreman, M.C. 2000. *Managed flood releases from reservoirs; issues and guidance*. World Commission on Dams Thematic Review 11.1 Dams Ecosystem functions and environmental restoration. World Commission on Dams. Down-loadable from www.dams.org or on CD from Earthscan, London, www.earthscan.co.uk

Acreman, M.C., and G.E. Hollis. 1996. *Water management and wetlands in sub-Saharan Africa*. Gland, Switzerland and Cambridge, UK: IUCN.

Petts, G.E. 1984 *Impounded rivers*. Chichester, UK : John Wiley & Sons.

Articles on the subject include:

Junk, W.J., P.B. Bayley, and R.E.Sparks. 1989. “The flood pulse concept in river floodplain systems.” In: Dodge, D.P., ed. *Proceedings of the International Large Rivers Symposium*. Honey Harbour, Ontario, September 1986. Canadian Journal of Fisheries and Aquatic Science, special publication, 106: 110–127.

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Welcomme, R.L. 1976. “Some general and theoretical considerations on fish yields of African rivers.” *Journal of Fisheries Biology*, 8: 351–364.