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Managed flood releases from reservoirs: issues and guidance

a submission to the World Commission on Dams

In this report, a **managed flood** is a controlled release of water from a reservoir to inundate a specific area of floodplain or river delta downstream to restore and maintain ecological processes and natural resources for dependent livelihoods undertaken in collaboration with stakeholders. This is distinct from planned releases to test flood gate operations or to optimise storage in multi-reservoir systems or from sudden, unplanned releases sometimes made from reservoirs to prevent dam failures without warning downstream communities.

This document focuses on developing countries but most issues are relevant worldwide.

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Executive summary

Dams and their associated reservoirs have brought enormous benefits to many parts of the world through the provision of water for domestic supply, irrigation, power generation and industrial processes. However, the consequential cessation of flooding downstream has led to degradation of wetland ecosystems. It is a key tenet of this document that this degradation can result in a decline in natural resources, rural-urban migration and a consequent rise in rural poverty. The release of managed floods from reservoirs to restore and maintain downstream wetland ecosystems and their dependent livelihoods is seen as a sustainable development option in such cases and fully in-line with the wise use of wetlands promoted by the Convention on Wetlands (Ramsar, 1971) and OECD (1996) development guidelines.

Large populations living on floodplains throughout the world and particularly in developing tropical countries rely heavily on natural resources. The local economy is often based on flood recession agriculture, fishing, animal husbandry and collecting wild resources such as timber, honey, fruit, thatching materials and medicines. Such communities often have limited alternative livelihood options and this makes them particularly vulnerable to changes in the condition of the natural resources on which they depend. These people require the maintenance of flooding for their livelihoods and often fail to benefit from dams. It is vitally important that these stakeholders participate fully in the process of deciding on development options.

Managed flood releases are not a panacea for downstream environmental impacts of dams. Many dams are not able to make flood releases or to pass sediment because of their design. Thermal stratification in the reservoir may result in poor water quality, thus limiting the potential for flood releases. Where the target floodplain is someway downstream of the dam, the contributing flows from tributaries must be forecast, if given levels of flooding are to be achieved. Infrastructure on the floodplain, such as irrigated land, roads, houses or factories may need to be protected by embankments.

Poorly managed floods may have direct consequences for health including drowning and changes in the abundance and distribution of disease vectors. In addition, there may be important indirect health consequences such as malnutrition, contaminated drinking water, injury, stress, communal violence and loss of well-being. Consequently, releases must be carefully managed to avoid negative impacts. Nevertheless, loss of floods may also lead to food shortages through loss of farm and and fisheries, and to social disorder, civil and ethnic conflict over resources, as in the case of the Senegal valley. In addition, many dams stop only small and average sized floods. When large floods do occur, the impacts can be significantly worse that prior to the dam, since the floodplain is likely to have been settled by people who considered they were safe from flooding.

Scientific studies may help to determine the flooding requirements of plants and animals. However, natural ecosystems are complex and simple rules do not exist because of the unique characteristics of each river catchment. Relationships between species numbers and flood extent are often smooth curves with no clear threshold below which the ecosystem fails. Consequently, the target area of flooding becomes a political or economic question. Furthermore, flooding may be managed to favour certain parts of the ecosystem that provide natural resources, whilst discouraging those that are useless or are pests. This helps to optimise flood releases towards supporting dependent livelihoods.

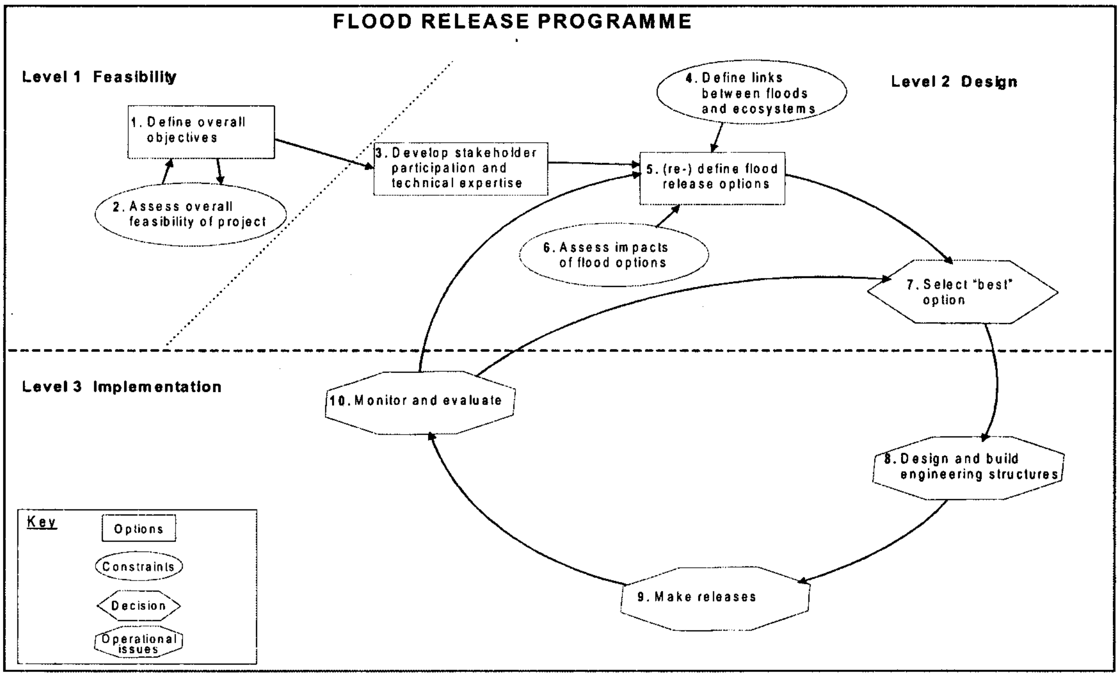
Successfully managed flood releases require co-ordination of the various institutions involved. In many cases, there are gaps or overlaps in responsibilities of institutions. Institutions often require capacity building, such as representation skills in community NGOs to convey local aspirations for the floodplain, or technical expertise in the operating authority to plan and implement appropriate and timely releases to achieve agreed levels of flooding.

Effective dissemination networks are required to inform floodplain inhabitants of the coming floods. In addition, legislation may need to be changed to allow flood releases to be made and to control resource over-exploitation following restoration.

Managed flood releases involve a trade-off with other potential uses of the water. Whether or not managed floods are appropriate - and if so what their size, frequency, duration and timing should be - requires an appropriate decision-making process that includes directly quantifiable monetary values and non-monetary measures of biodiversity and human welfare.

The guidelines contained in this report are distilled into 10 steps that need to be undertaken to achieve effective managed flood releases from reservoirs:

1. define objectives for flood releases
2. assess overall financial feasibility
3. develop stakeholder participation and technical expertise
4. define links between floods and the ecosystem
5. define flood release options
6. assess impacts of flood options
7. select the best flood option
8. design and build engineering structures
9. make releases
10. monitor, evaluate and adapt release programme



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in developing countries in the tropics, but many aspects of them are relevant world wide. They are appropriate to existing dams and the planning of new dams.

1.2 Target audience

The guidelines are intended for river basin development authorities, water resource, irrigation and energy departments and dam operators and any organisations involved with them or on their behalf in mitigating downstream impacts or planning managed floods. They are compatible with and reinforce other guidelines including the 1996 OECD *Guidelines for Aid Agencies for Improved Conservation and Sustainable Use of Tropical and Sub-Tropical Wetlands* and the 1999 Convention on Wetlands (Ramsar) *Guidelines for integrating wetland conservation and wise use into river basin management.*

1.3 Principles

These guidelines aim to highlight the potential benefits and practical problems of flood releases and to suggest methods for defining more precise release patterns that can be agreed by relevant local stakeholders. It is not possible to propose prescriptive national or international criteria for managed flood releases. The socio-economic circumstances, as well as the ecosystem and livelihood requirements below any particular dam will always be site specific and so managed flood releases should vary from one location to another.

The guidelines are based upon the following general principles.

- ***Purpose***: clear objectives for flood releases should be defined, in terms of desired benefits that are equitably distributed amongst stakeholders and should contribute to fostering sustainable livelihoods on and around the floodplain
- ***Process /method***: a transparent process should be employed to ensure participation and ownership of proposed managed flood options by all stakeholders
- ***Solution***: solution to the magnitude, frequency, duration and timing of any flood releases should be negotiated through agreed techniques of investigation
- ***Costs***: the monetary and non-monetary costs and benefits and their distribution amongst all stakeholders resulting from flood releases and lack of flood releases must be evaluated
- ***Implementation timescale***: the planning process should set timescales for the implementation of flood releases and expected results
- ***Monitoring, evaluation and adaptive management***: the results of flood releases should be monitored and procedures reviewed to assess compliance with objectives - where necessary the flood release programme should be adapted

1.4 Report structure

Chapter 2 provides a brief review of flooding as both a hazard and a benefit to human populations and summarises the impact of dams on flood flows. The concept of managed flood releases is introduced.

Chapter 3 summarises the importance of floods for natural ecosystems and people. It also examines how alteration of the flood hydrology by dams impacts on the natural resource base utilised by many human communities and the implications for livelihoods and health.

Chapter 4 contains an overview of issues that need to be considered when planning flood releases. The first part of the chapter covers engineering issues as well as issues of community participation and operational responsibility. The second part of the chapter presents a simple conceptual framework for making decisions about managed floods.

Chapter 5 deals with methods of decision-making. When contemplating and planning managed flood releases it is necessary to consider whether managed floods are a desirable and feasible option and, if so, to determine the magnitude, duration, frequency and timing of releases in order to maximise the benefits to be gained from the releases. This is a complex process requiring the integration of environmental, social and economic factors.

Chapter 6 covers issues pertaining to the implementation of managed flood releases. This includes: planning and co-ordination; development of reservoir operating rules; the design/redesign of hydraulic structures and/or environmental engineering to make flood releases possible and improve the benefits gained; pilot releases; flood warning and post flood monitoring and evaluation.

Chapter 7 draws together the lessons learned as the basis for guidelines required to achieve effective and safe managed flood releases from reservoirs. The guidelines are summarised as a set of ten steps.

2 The importance of floods

The ecological importance of floods is now widely recognised. However, for people, floods can represent either a hazard or an advantage, depending on their circumstances. In this chapter a brief review of the hydrology of floods is followed by an introduction to dams and their impacts on flooding regimes. Finally, the concept of managed floods is presented.

2.1 Floods – friend or foe?

Floods affect more people worldwide than any other natural hazard. In China alone in 1998 floods killed 3000 people, affected the well being of millions of others and caused $20 billion worth of damage. In 2000, large areas of Mozambique were inundated and an unknown number of people lost their lives. Consequently, the perception of many is that floods are a negative natural phenomenon that we should do our utmost to control. Engineering works, such as dams, are a common response to this threat and flood control is seen as a major secondary benefit of dams built for other purposes such as hydropower production.

In contrast to this negative view of floods, it is also recognised that floodwaters are essential for many ecosystems. As a result of periodic inundation, the floodplains of the many rivers including the Amazon, Zaire, Niger, Mekong and Zambezi support wetland ecosystems of exceptional productivity, which in turn support large human communities. Floods provide natural irrigation, fertilise floodplain soils, recharge aquifers, shape the landscape and maintain biodiversity.

Box 2.1.1 What is a flood?

The common definition of a flood is "the inundation of normally dry land". On many river systems, there is a sharp divide between a well-defined river channel and adjacent flat land (the floodplain). Flooding normally occurs when flow in the river exceeds the capacity of the channel and water spills onto the floodplain. However, on other rivers the channel and floodplain merge seamlessly and there is no distinct boundary. In such cases it is difficult to define a critical level above which a "flood" occurs. Because of this, hydrologists have defined a flood as "any significant increase in river flow". This project is concerned primarily with floodplain inundation, so the former definition is adopted.

Floods are neither inherently good nor bad. Floods are "good" if floodwaters provide natural irrigation, support fisheries and improve soil fertility. Floods are "bad" if people are drowned, communicable diseases are transmitted, or industrial and residential property and infrastructure or food resources are damaged or destroyed. In practice, very large, rare flood events will almost always be a hazard because of human occupation of floodplains. However, from an ecological perspective, they may still be important in terms of sediment transport and landscape processes.

Box 2.1.2 Flood assessment

Flood assessment can be divided into two elements: physical and socio-economic. The first element relates to the physical hydrology of the catchment and hydraulic properties of the river channel and its floodplain. These determine how often riparian land will be inundated, to what depth and for how long. The second element represents the sensitivity of the land to flooding in economic and social terms and relates to land use and social perception of flooding.

2.2 Flooding mechanisms and variability

A vital first step to analysing floods is to understand the flooding mechanism (Table 2.2.1). Flooding is often simply a result of river flow exceeding the channel capacity as a result of rainfall and/or snow/glacier melt in the catchment upstream. However, floods may also result from local rain falling directly on the floodplain, or runoff from local streams. On many floodplains processes work in sequence, with rainfall causing initial saturation of the land and local runoff causing initial flooding, whilst deep inundation occurs when the river overtops its banks, as in the Logone floodplain in northern Cameroon. However, causes vary between rivers, eg. parts of the Amazon floodplain become flooded as a result of the water table rising.

The size of a flood is determined largely by four factors:

- the drainage area of the river
- the amount of rainfall (or snowmelt)
- the proportion of precipitation that reaches the river (related to geology and soil type)
- the speed of runoff (related to catchment slope, land use and channel geometry).

Table 2.2.1 Types of flooding and mechanisms

Types of flooding	Mechanism
Direct local rainfall	Rain falling directly on the floodplain exceeding infiltration capacity of the soil
Local runoff	Small local streams bring water to the floodplain
Flow in river exceeding channel capacity	Heavy rainfall and/or snowmelt in the catchment upstream; major reservoir release; dam break upstream (natural such as ice dam break "Jokelhlaup" or man-made dam failure)
Groundwater rising	Rise in floodplain water table due to groundwater movement from valley sides
High tides (coast and estuaries)	High astronomical tide; storm surge; tsunami
Combinations of above	High tide combined with high river flow causing flooding in the estuary

Trees and other dense vegetation help to absorb water and encourage infiltration of water into the soil, this both reduces the runoff volume and increases the time taken for water to reach the river. Deforestation or overgrazing of grasslands can thus increase flood risk. For example, deforestation in the Himalayas has been linked with increased flooding downstream on the Ganges and Brahmaputra in Bangladesh, though this theory has been contested. Urban developments (with their large areas of roofs, roads etc) and soils that are frozen or compacted by cattle or agricultural machinery, tend to be impermeable, so a high proportion of the rainfall reaches the river, whereas the proportion of rainfall which becomes flood runoff tends to be lower on catchments with permeable soils and geology.

On small river systems, river flows fluctuate rapidly in direct response to rainfall, so many floods can potentially occur in any one year. On large river systems, the response to rainfall is slower, and many rivers have a distinct annual or biannual flood season. This is particularly pronounced in those parts of the world where the climate exhibits distinct rainy seasons, such as the Indian monsoon. This study is concerned with river systems where flooding is a regular annual or bi-annual event, as it is in these systems that ecological and social flood dependence has evolved.

On any river, the size of floods varies from year to year and the larger the flood the less often it occurs. Hydrologists have formalised this association through flood frequency analysis, which produces a flood frequency curve that defines the relationship between flood magnitude and probability of occurrence. Structures built on a river (e.g. bridges) or flood defence (e.g. embankments) are built to a design standard, such that they will withstand a certain size of flood, such as the "100-year flood" (i.e. that flood which will occur once, on average every 100 years). Dams tend to be built to much stricter standards, such as the "probable maximum flood". However, dams are not designed to store all floodwater during such a major event. They possess a "spillway" that can pass excess flow without damage to the dam.

2.3 Impacts of dams

Dams are designed to have an impact on the hydrological cycle, replacing natural high and low flows by an artificial regime. The impact on individual flood flows depends on both the storage capacity of the dam relative to the volume of flow and the way the dam is operated. During a small flood, the total volume of flow may be stored within the reservoir, thus no flood is experienced downstream of the dam. During average-sized floods, some floodwater may pass through the dam (once the reservoir storage is filled), but this takes some time, so that the flood downstream is reduced in magnitude and occurs later than it would do naturally (this impact is called flood attenuation). When the flood is large in comparison to storage capacity within the reservoir, there may be little impact on the flood, with the peak flow only slightly reduced and the timing slightly delayed. Thus, in general, reservoir impact reduces as flood magnitude increases.

Tarbela dam on the River Indus in Pakistan and the proposed Grand Falls dam on the River Tana in Kenya have relatively small storage in comparison to flood volume. They have little impact on floods with return periods greater than about 10 years. Thus large catastrophic floods will not be prevented or substantially reduced. In contrast however, many reservoirs are so large in relation to flood volume, that even the largest floods are stored and floods may never occur downstream (e.g. Lake Nasser behind the Aswan High Dam). The reservoir may have additional subtle effects on flood hydrology downstream. A flood experienced at a particular location, such as a floodplain, may result from the combination of flows from various tributaries upstream. If one tributary is dammed, and its floods attenuated, this will effect the relative timing of the various flows (i.e, they will be desynchronised), so that the flood hydrograph at the floodplain may be quite different.

By reducing floods, dams often diminish biodiversity, change natural resource systems and opportunities for flood-based livelihoods downstream, such as fishing, recession agriculture and livestock rearing, thus increasing rural poverty and causing rural-urban migration (chapter 3). In some cases the objective of the dam is to provide water or hydropower to major urban centres, and rural communities fail to benefit from either rural electrification or water supply. Their poverty often brings them in close contact with the natural environment such as disease vectors. The associated effects of the influx of construction workers, labour migration, loss of traditional assets and uncertainties often damage the social environment and this, in turn, affects human health. However, some rural communities clearly benefit from new employment in factories, on intensive irrigation schemes or reservoir fisheries, or from more readily available food.

Nevertheless, it should not be assumed that before dams were constructed, life on floodplains was without problems and that large populations lived in perfect harmony with the annual flooding. There has always been a high risk of contracting a range of diseases associated with floodplains, such as malaria, schistosomiasis and diarrhoea. However, the prevalence of these diseases has often been increased significantly by the development of intensive irrigation. Not all floodplain users have lived permanently in the wetland, many alternate between the floodplains and the more healthy uplands or drylands. Even so, the floodplains have supported high populations, as exemplified by the inner delta of the Niger in

Mali. The reduction of disease in west Africa over the past 30 years through intense health programmes and massive land pressure as a result of rising populations have led to significant demographic change with large populations moving into the floodplains to settle permanently.

2.4 The concept of managed floods

It is now widely accepted that there is a need for more integrated development of river basins that takes into account environmental concerns and makes more effective use of modern infrastructural advances. One option is to release water from reservoirs at certain times of the year to simulate key aspects of the natural flow regime. Reservoir compensation releases should include managed floods to inundate the floodplain and thus rehabilitate indigenous flood-based farming systems that support rural livelihoods, whilst retaining sufficient reserves for power generation and irrigation. The new paradigm contests that whilst large floods may always have some negative impacts, all floods play an important role in maintaining the structure, processes and resources of a river system.

Box 2.4.1 What are managed floods

Large releases may be made from reservoirs for a range of reasons, including the testing of flood-gate operations or achieving optimal storage within multi-reservoir systems. In this report, a **managed flood** is defined as a controlled release of water from a reservoir to inundate a specific area of floodplain or river delta downstream to restore and maintain ecolo gical processes and natural resources for dependent livelihoods undertaken in collaboration with stakeholders. This is distinct from sudden, unplanned releases sometimes made from reservoirs to prevent dam failures without warning downstream communities.

There are cases where sudden very large releases of water have been made from a reservoir in an emergency to prevent overtopping, and hence possible failure, of the dam. In some cases no warning was given and loss of life and property resulted downstream. This type of mis-management has, in some areas, become synonymous with artificial floods. It is important to stress that in this report we are concerned with "managed" floods. Stakeholders should be included in the decision to create floods, in the operation of the dam to ensure the appropriate timing and magnitude of the floods and informed of the flood occurring in good time.

Scudder (1980) was one of the first to suggest managed floods as a viable development strategy. Since then various experiments with managed floods have been made, primarily in Africa (Table 2.4.1.). The restoration of the floodplain ecosystem and traditional farming systems which can be achieved by managed floods releases has been demonstrated on the Waza-Logone floodplain in Cameroon through ecological and socio-economic surveys. Following an economic valuation of the products and functions of the Hadejia-Nguru wetlands in Nigeria, the Hadejia-Jamare River Basin Development Authority has experimented with dam releases to augment the annual flood. In the Senegal basin, the value of flood recession farming to rural livelihoods has been acknowledged and a programme of managed flood releases has been implemented. The size and timing of managed flood releases from the Pongolapoort dam on the Phongolo River in South Africa have been defined by a participatory process, involving local farmers, fishermen and other stakeholders.

In the past managed floods have rarely, been considered as an integral component at the design stage of dams. An exception is the Itezhi-tezhi reservoir on the Kafue River in which additional storage was set aside specifically for managed flood releases. However, releases have not been entirely successful because of institutional problems between conflicting users. The concept of managed floods is being considered for some new dams, such as that proposed for Grand Falls/Mutonga on the Tana river in Kenya. However, a satisfactory solution to the problem of passing sediment through dams has not yet been found.

Table 2.4.1 Some examples of environmental, social and economic consequences of managed flood releases

Country	Project	Consequences of flood releases
Senegal/ Mali/ Mauritania	Senegal valley irrigation, hydropower and navigation	Flood releases have been made for the past 10years from the Manantali reservoir to maintain flood recession agriculture in the Senegal valley. In addition, water has been released through channel embankments to restore the natural resources and biodiversity of the delta. Investigations are underway to assess how flood releases can be maintained when hydro power generators are installed in the dam.
Sri Lanka	Multiple water diversions, including the Mahaweli project.	The Mahaweli catchment has been managed for irrigated paddy for many centuries and a complex system of dams, embankments and canals has been developed. Some small scale flood releases have been tried to flush sediment and control disease vectors, but major flood releases may be incompatible with food production.
Kenya	Tana River Hydropower project	Managed flood releases have been considered in the design of a proposed new dam at Grand Falls, to maintain natural resources and flood recession agriculture on the floodplain downstream. However, a solution has not been found to flushing sediment through the dam.
Pakistan	Indus River, irrigation and hydropower	Multiple water diversions along the length of the Indus have led to drastic reduction of freshwater reaching the delta. As a result, floodplain forests along the lower Indus are dying and increased salinity is having a devastating effect on the delta ecosystem, and on the people who depend on it for their livelihoods. Flood flows at the end of the wet season would sustain the floodplain forests, mangroves and fisheries.
Nigeria	Hadejia-Jama'are Rivers – irrigation	These rivers have been dammed to provide water for intensive cereal irrigation. Economic valuation showed that water used by the Hadejia-Nguru floodplain wetlands was more productive than water used for irrigation. As a result, test flood releases have been made to restore the wetlands and their natural resources.
Republic of South Africa	Phongolo River – Irrigation	The Pongolapoort Dam caused loss of fisheries and recession agriculture on the floodplain downstream. Early attempts to restore the floodplain ecosystem failed as floods were released at the wrong time. More recent releases have been much more successful, as their timing was agreed by stakeholder committees through a participatory approach to flood management.
Zambia	Kafue floodplain	Flood releases have been made from the Itezhitezhi dam to maintain flood recession agriculture and biodiversity of the Kafue Flats. However, elevated water-levels at the downstream end of the Flats, resultig from the operation of the Kafue Gorge Dam have largely undermined anticipated benefits.
USA	Colorado river urban water supply and water diversion projects	A detailed scientific study was undertaken in 1996 on test flood releases from the Glen Canyon dam to restore sand beaches, used by animals, campers and river runners, and the scouring of vegetation and fine sediment deposited in backwater areas. This study demonstrated the importance of flood flows for beach building processes.
Cameroon	Logone floodplain	Construction of the Maga dam across the Logone floodplain to supply the SEMRY irrigation scheme led to loss of natural resources (grazing, arable land and fisheries) and biodiversity in the Waza National Park. In addition, embankments were built along the river to protect the scheme. Floodwater is now released through the dam and embankments to re-inundate the floodplain. Local communities, localgovernment, Park staff and SEMRY management played important roles in the re-inundation programme.

Criteria for a reservoir site that make it suitable for managed flood releases as a development option include:

- Reservoir capacity greater than the mean annual flood
- Significant areas of floodplain and wetlands downstream of the dam that would benefit from reinstatement of flooding.
- Stakeholders who request reinstatement of seasonal over-bank flooding.
- Farming/fishing systems downstream of the dam not irreversibly adapted to the no-flooding situation since dam construction.
- Institutional arrangements that exist, or can be established, for effective decision making and management of flood releases.
- Downstream ecosystems that have not adapted irreversibly to the no-flooding regime
- Limited vulnerable infrastructure developed on the floodplain after dam construction.
- Existing adequate low-level outlet facilities capable of making substantial releases.
- New dams with suitable low-level release facilities designed into the scheme
- Downstream benefits accruing from managed flood releases that exceed lost opportunity costs of using stored water for other purposes.

The aim of re-flooding is not necessarily to restore former conditions. In most cases this would not be possible, even if desirable, due to infrastructural changes and ecological and socio-economic adjustment to the altered hydrological regime. The aim is to have fully integrated river basin development (extending to coastal fisheries) that combines the best of traditional practices and modern techniques and maximises benefits (both monetary and non-monetary) for flood-dependent and reservoir dependent development (Figure 2.4.1).

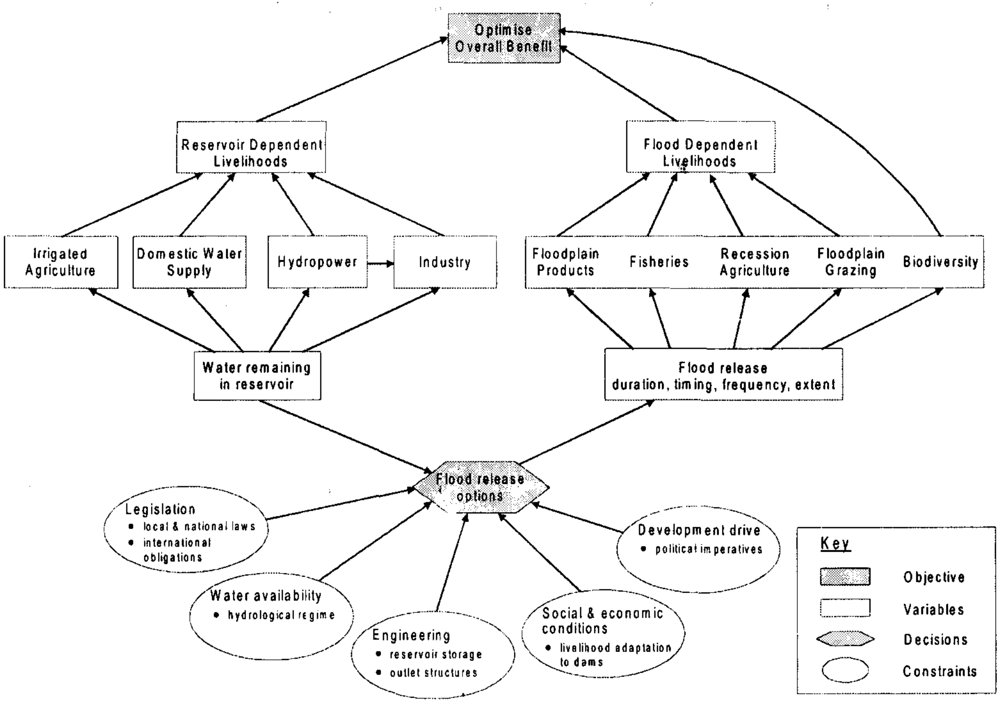


Figure 2.4.1 Flow chart showing the trade-off between using water for managed flood releases and for other purposes.

3 People, floods and dams

For most of the world's existing stock of large dams, environmental issues have played little part in their design and the specification of operating rules. Most dams have been constructed with the emphasis on maximising the economic use of water and with little or no understanding of the long-term consequences of alterations to flow volumes, flow patterns and water quality. Dams have environmental impacts, not just upstream where the river and surrounding valley is inundated, but also downstream, where the natural hydrological regimes of ecosystems may be substantially altered. Changes in ecological processes, arising as a consequence of the change in flow regime, can have profound social and economic repercussions for people dependent on the natural resources and ecosystem functions of floodplains and wetlands to sustain their livelihoods. For such communities, the biological resources of floodplains often provide the single most important contribution to their livelihoods and welfare in the form of food supplies, shelter, medicines, income, employment and cultural integrity. This chapter summarises the importance of floods for natural ecosystems and examines how alteration of the flood hydrology by dams impacts on the natural resource base utilised by many human communities and how this in turn impacts on livelihood strategies. The impacts on human health are also discussed.

3.1 Floods, dams and ecosystems

3.1.1 Importance of natural flood regimes for ecosystem integrity

The river ecosystem consists of all the components (both biotic and abiotic) of the environment linked to that river, including people, and not only the aquatic habitats associated with water in the channel. The river ecosystem extends from the headwaters to the sea and includes riparian areas; associated groundwater in the channel/banks and floodplains; wetlands; the estuary and any near shore environment that is dependent on freshwater inputs. Rivers are important natural corridors for the flows of energy, matter and species and are often key elements in the regulation and maintenance of landscape biodiversity. High flows are a dominant control of channel and floodplain morphology, influencing processes of sediment transport and erosion.

Box 3.1.1.1 Ecological concepts of rivers and floodplains .

1. The "river continuum concept" encompasses the linkages upstream and downstream from a river's source to the coastal zone, including any deltas or lagoon systems. This concept includes the gradual natural changes in river flows, water quality and species, that occur along the rivers length. Nutrients and sediment generated in the headwaters are recycled downstream driving plant growth and biotic productivity. One of the most obvious characteristics of the river continuum concept is the migration of fish from the sea to spawning grounds in the headwaters. River engineering projects, such as dams, break this continuum causing radical changes in flows, water quality and stopping the movement of species.

2. The "flood pulse" concept is based on the importance of lateral connectivity between rivers and their floodplains and sees the inundation of floodplains as the main driving force behind river life, not as a problem that needs eradicating. Rivers provide the floodplain with nutrients and sediment, whilst the floodplain provides a breeding ground for river species and improves water quality through settlement of sediment and absorption and re-cycling of nutrients and pollutants.

Natural river ecosystems are adapted to the natural hydrological regime and many components of those systems rely on floods for the exchange, not just of water, but also energy, nutrients, sediments and organisms. The spatial and temporal variation in water depth and flow patterns as well as the frequency and duration of inundation, at different locations on a floodplain are responsible for a diverse array of habitats and hence ecological diversity, all of which are maintained by flooding. It is flooding that makes rivers and floodplains amongst the most fertile, productive and diverse ecosystems in the world.

Coastal marine wetlands are often highly dependent on inputs of freshwater and associated nutrients and sediments from rivers. Coastal wetlands are ecologically and environmentally diverse because of the gradual and often fluctuating dynamic boundaries between salt, brackish and freshwaters. Salt water may penetrate considerable distances upstream, but boundary patterns vary with flow regimes and landscape forms. These patterns influence not only vegetation, but also animal behaviour, such as the degree to which marine species can range into the food-rich wetlands.

3.1.2 Impact of dams on natural ecosystems

Dams constitute obstacles for longitudinal exchanges along rivers. They not only alter the pattern of downstream flow (i.e. intensity, timing and frequency) they also change sediment and nutrient regimes and alter water temperature and chemistry. Flow regulation by dams disrupts the natural processes of downstream river systems. Reduction of flood peaks reduces the frequency, extent and duration of floodplain inundation. Reduction of channel-forming flows and truncated sediment transport often alters channel and floodplain morphology. Changes also occur in water quality. These changes and others directly and indirectly influence a myriad of factors that affect natural processes and so, ultimately, influence the ecological integrity of ecosystems, sometimes tens or even hundreds of kilometres downstream.

Box 3.1.2.1 Water quality impacts of reservoirs

Water retained in deep reservoirs has a tendency to become thermally stratified, with warm well-mixed water at the surface (the epilimnion) and cold, dense water at the bottom (i.e. the hypolimnion). In the hypolimnion, the process of decay of organic matter submerged when the dam was constructed may become anaerobic. Then carbon dioxide and hydrogen sulphide are released; pH decreases and the solution of iron and manganese occurs from the bottom sediments. These chemical and biological changes mean that the water discharged often from a reservoir has a very different chemical composition to that of in-flowing rivers. The quality of water released from a stratified reservoir is determined by the elevation of the outflow structure(s) relative to the different layers within the reservoir. Water released from near the surface is well-oxygenated, warm, nutrient-depleted water. In contrast, water released from near the bottom is cold, oxygen-depleted, nutrient-rich water that may be high in hydrogen sulphide, iron and/or manganese.

The environmental consequences of dam construction should not be considered in isolation, but must be approached within the context of the whole river ecosystem including the coastal zone. Impacts can be considered within a hierarchical framework of interconnected effects, within which first, second and third order impacts are identified (Table 3.1.2.1). Ecosystem functioning is guided by abiotic steering variables related to hydrology, water quality and sediment load. These can be used as primary indicators of ecosystem condition and changes to them are first-order impacts. Changes caused by first order impacts have implications for morphology and primary production (i.e. second order impacts) which in turn result in ecosystem changes at higher trophic levels (i.e. third order impacts). In general terms the complexity of interacting processes increases from first to third order impacts.

Overall, responses of aquatic ecosystems to dams are multiple, varied and complex. They depend on the dam structure and its operation and local sediment supplies, climate, and the attributes of the local biota. The impacts of a dam may occur a great distance from where it is built, if there are few tributaries joining. Despite the research that has been conducted to date, it is in many cases impossible to predict, even with site specific studies, what the precise impacts of a dam will be. Some occur rapidly, whilst others may not occur until many decades or centuries after dam closure.

Table 3.1.2.1 Impact of dams on downstream ecosystems (modified from Petts, 1984)

First order impacts	**immediate abiotic effects that occur simultaneously with dam closure and influence the transfer of energy, and material, into and within the downstream river and connected ecosystems**
1. Hydrology	• reduced flow because of increased evaporation from the reservoir and/or abstractions • reduced variability of flow except where operational procedures result in fluctuations that occur at non-natural rates (eg. pulse releases for hydropower production) • reduced magnitude, duration and frequency of flooding
2. Water quality	• thermal regulation • salinisation due to increased evaporation • alteration of dissolved oxygen and nitrogen content • alteration of pH • alteration of nutrient, hydrogen sulphide, manganese and iron concentrations (controlled largely by whether or not the reservoir is stratified and level of release)
3. Sediment load	• reduction in load because of sedimentation within the reservoir • changes to river turbidity
Second order impacts	**abiotic and biotic changes in upstream and downstream ecosystem structure and primary production, which result from the modification of first order impacts by local conditions and depend upon the characteristics of the river prior to dam closure (e.g. changes in channel and floodplain morphology, changes in plankton, macrophytes and periphyton). These changes may take place over many years.**
1. Geomorphological Changes to channels, Floodplains and deltas	• degradation where reduced sediment load results in increased erosion • aggradation where reduced flows result in increased sedimentation
2. Plankton	• populations increase where dams mitigate floods, regulate temperatures, reduce turbidity and reduce downstream effluent dilution
3. Attached algae	• populations increase where dams enhance low flows, reduce flood magnitude and frequency, reduce turbidities, regulate thermal regime and reduce substrate erosion
4. Aquatic macrophytes	• rooted plant populations may increase where dams reduce flooding and substrate erosion and enhance deposition of fine nutrient-rich sediment • floating plant populations may increase where dams reduce high discharges so that channels are not flushed
5. Riparian vegetation	• species dependent on flood pulses (eg. riparian forest trees) may be adversely affected as consequence of flood mitigation • reduction in silt deposition and nutrient replenishment on floodplains results in reduced soil fertility
Third order impacts	**long-term, biotic, changes resulting from the integrated effect of all the first and second order changes, including the impact on species close to the top of the food chain (e.g. changes in invertebrate communities and fish, birds and mammals). Complex interactions may take place over many years before a new "ecological equilibrium" is achieved.**
1. Invertebrates	• marked changes in macroinvertebrate distribution and abundance (often a decrease in diversity) occur as a consequence of changes in flow regime and physicochemical conditions (e.g. temperature, turbidity and dissolved oxygen).
2. Fish	• marked changes in fish populations occur as a consequence of blockage of migration routes and changes in flow regime, physicochemical conditions (eg. temperature, turbidity and dissolved oxygen), primary production and channel morphology.
3. Birds and mammals	• changes in bird and mammal populations arise as a consequence of chages in floodplain habitat and fragmentation of the river corridor

Box 3.1.2.2 Impact of dams on sediment transport

Reservoirs act as sediment traps, with many storing almost the entire sediment load supplied by the drainage basin. The reduction in sediment load in rivers downstream of dams impacts on channel, floodplain and coastal delta morphology. This reduction tends to cause scour of the channel downstream of the dam, but flow regulation that eliminates flood peaks and hence reduces sediment transport capacity, has an opposite effect. Typically, because transported material is no longer replaced by material arriving from upstream, increased erosion occurs for the first few kilometres or tens of kilometres below a dam. However, further downstream, increased sedimentation (aggradation) may occur because material mobilised below the dam and material entrained from tributaries cannot be moved through the channel system by the regulated flows. In addition, removal of fine material may leave coarser sediment that 'armours' the bed, protecting it from scour.

Sediment trapping can alter the character of floodplains. In some circumstances, the depletion of fine suspended solids reduces the rate of over-bank accretion so that new floodplains take longer to form and soils become infertile. In other circumstances, channel bank erosion results in loss of floodplains. However, in some places, the reduction in the frequency of flood flows and the provision of stable low flows may encourage vegetation encroachment which will tend to stabilise new deposits, trap further sediments and reduce floodplain erosion. Hence, depending on specific conditions, dams can either increase or decrease floodplain deposition/erosion.

3.2 Floods, dams and natural resources

3.2.1 Floods and natural resources

Natural resources are the components of the ecosystem used by people, such as fish, grasses, timber and fruit. Floodplain natural resource systems are defined by two inter-related characteristics:

- *flood-tolerance* – mechanisms evolved to tolerate the environmental stress associated with flooding, such as the physical disturbance of seeds and seedlings and the low oxygen content of waterlogged soils.
- *flood-dependence* – through this adaptation, the continued functioning of these systems depends on regular seasonal flooding.

While clearly there is a continuum between these two characteristics within all floodplain systems, the more regular the floods, the more these systems can be described as flood dependent, and the more the communities living in the floodplains have evolved livelihood strategies dependent on this regular flooding. Such systems are tolerant of less frequent, large flood events, and indeed may depend on them for the creation of new niche environments or for particular stages in growth cycles such as seedling establishment. In addition, many floodplain ecosystems can withstand long periods of aridity between floods.

Communities living in and around regularly inundated floodplains have adapted their patterns of land use to take advantage of these natural resource systems. This linkage goes back to the very earliest stages of social development, starting with hunter/gatherer communities and progressing through the major floodplain farming based systems of the Nile and the Tigris-Euphrates, the Indus in Pakistan and the Ganges in India and the Hwang Ho and Yangtze in China.

Floodplain ecosystems support human communities in a wide variety of ways (Figures 3.2.1.1 and 3.2.1.2). It is this range of activities, from opportunistic harvesting to active management, which characterises the use of floodplain resources.

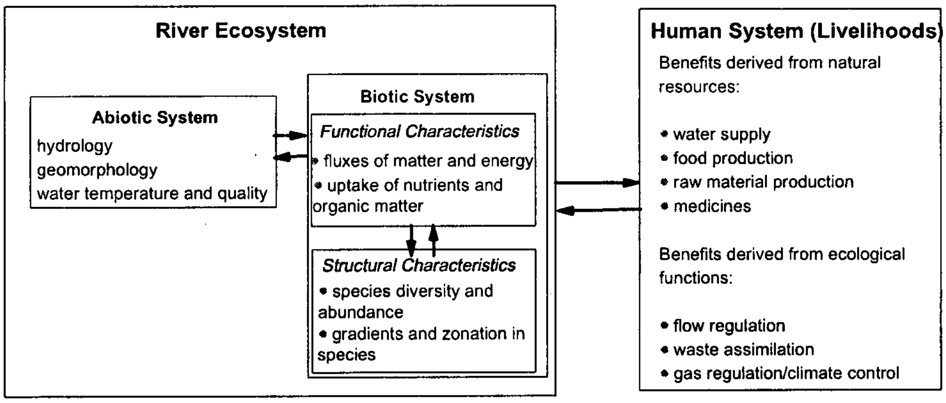
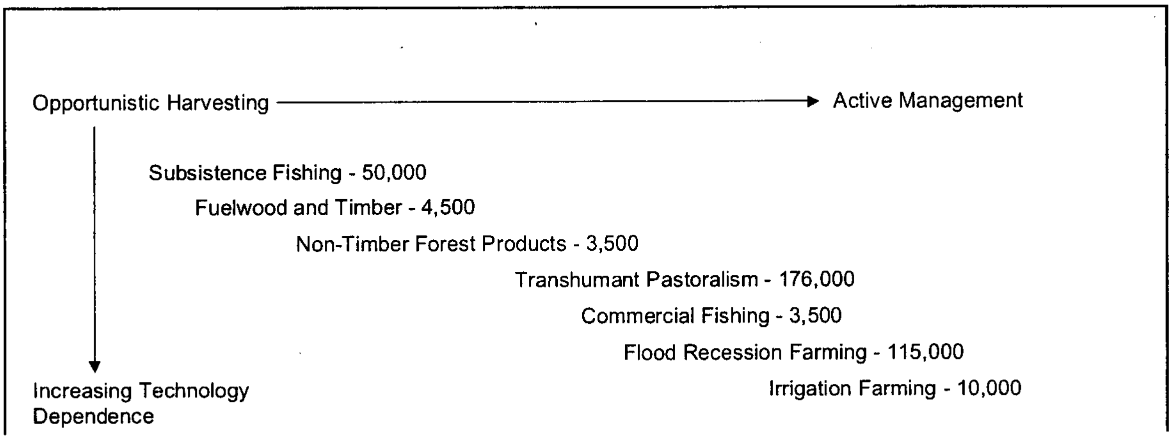


Figure 3.2.1.1 Influence of river ecosystems on human livelihoods (modified from Lorenz et al., 1997



Floodplain fisheries
Floodplain fisheries are often highly productive, with the main river channel providing mobility and habitat transference, migration routes and the floodplain spawning and nursery habitats.

The extent of dependence on seasonal flooding varies. Many fish species (often the economically important ones) exhibit strong relationships between population cycles and natural flooding events. This dependence can be linked to access to feeding and breeding habitat. In the Illinois River largemouth bass rely on annual spring floods to reach inundated terrestrial vegetation in order to breed. In the inner delta of the Niger River, fish migrations are triggered by and strongly tied to the flood volume, while prior to the construction of the dams, the now defunct coastal fisheries off the Nile Delta were highly dependent on the nutrient load of the floods.

However, it is not just the inherent ecological productivity that is important. The net productivity of fisheries is a function of primary productivity and catch effort. During flood recession, ponds and ox-bows are left within the floodplain, while the main channel drops to low season levels. Fish populations are concentrated during the dry season in smaller and smaller open water areas and are then easier to catch.

Riverine forests and forest products
As with all natural floodplain systems, riverine forests are both flood-dependent and flood-tolerant. While floodplain forests in semi-arid zones depend on minimum flooding frequencies and durations for groundwater recharge, and irregular major events to create new sites for seedling establishment, flood-tolerance still appears to be a major determinant of forest distribution. Most floodplain forest species will not flourish in areas inundated for excessive periods.

Box 3.2.2.1 Use of riverine forest plant species in the Tana River, Kenya

Use categories		**Number of species**
Food	Alcoholic Drinks	3
	Flavouring	2
	Food	10
Construction	Poles	16
	Canoes	12
	Furniture	4
	Thatch, traditional huts	2
Technology	String	11
	Traps	5
	Arrows, baskets, beehives, brooms, combs, drums, glue, mats, mortars, paddles, pestles, spoons, stirrers, tool handles, walking sticks	27
	Medicines/remedies	23
Commerce	Mats and baskets	2
Other	Firewood	9
	Ritual	4
	Beehive resting trees, flocculent, games, perfumes, poisons, toys	7

Forests and woodlands often show clear zonation, related to the effects of micro-topography on flood extent and period of inundation, and on changes in light conditions that reflect the vegetation position in relation to open water. The result of this is the creation of species rich forest/woodland complexes, which in turn supply a wide range of "minor products", which together can form a very high cumulative value to floodplain communities.

In arid and semiarid areas where forest growth is limited by water availability to riverine areas, the value of these forests is clear and highly significant. It is the only source for timber and non-timber products. However, even in humid areas, where forest growth is not restricted to floodplains, the particular species present on floodplains can provide a unique resource for local communities.

Comparative studies in Western Amazonia, looking at the uses of floodplain and dryland forests showed that the first conservation priority is the floodplain forests. Mature floodplain forests provide local construction materials and food, while the lower floodplain forests are important for medicinal plants, and the swamp forests produce the commercially valuable species.

While hunting is by no means restricted to floodplain forest, it is a major benefit to local communities, both for subsistence and as an income source. Among many communities it also has cultural and social significance. Indeed even in developed countries, the "minor products" of recreation and hunting are increasingly recognised as the most valuable benefits of floodplains and are the main justification for wetland conservation and regeneration in many parts of the world, including the USA and Europe.

Floodplain grazing systems

As with other floodplain communities, grassland environments are as diverse as the flooding systems on which they depend. Grasslands occur both in floodplain areas where there is inadequate water for forest growth, and in areas where there is too much water for forest growth.

There is a distinction between wet floodplains and dry floodplains. In dry floodplains there is a continuum from swamp grassland to dry hinterland grassland, with forest zones occurring in suitable wetter environments. In wet floodplains, where the climax vegetation of the hinterland is forest, grassland occupies areas too wet, or too frequently inundated for forest survival.

Box 3.2.2.2 Zones in floodplain grasslands of the Kafue Flats, Zambia

Dominant environmental condition	Main grass associations
Permanent Swamp	*Vossia cuspidata* *Echinocloa scabra + Cyperus papyrus* *Leersia hexandria + Echinocloa pyramidalis*
Deep Flooded Grassland Long Flood	*Oryza perennis + Echinocloa pyramidalis*
Deep Flooded Grassland Short Flood	*Leersia hexandra + Acroceras macrum + Paspalum commersonii*
Shallow Flooded Grassland Long Flood	*Setaria avettae + Vetiveria nigritania*
Shallow Flooded Grassland Short Flood	*Cynodon dactylon* *Setaria sphacelata + Themeda triandra*
Floodplain Margins	*Hyparrhenia rufa + Setaria sphacelata + Panicum coloratum*

While supporting large wildlife populations, managed floodplain grazing systems have developed under a variety of climatic regions, ranging from temperate water meadows to arid tropical floodplains and deltas, and again within these broad categories the different grassland zones provide different grazing resources.

Floodplain grazing systems mimic natural wildlife systems, with seasonal migrations from hinterland grazing during the rains to the floodplains during the dry season. The combined system can make available much larger areas of hinterland grazing, supporting considerably greater herd numbers than could be supported throughout the year on any one component.

In addition, the seasonal movement of livestock has the added benefit of reducing risks of overgrazing and habitat degradation – in both areas of hinterland grazing and floodplains. The other floodplain element that is particularly significant in arid and semiarid areas is the availability of highly nutritious browse in floodplain woodlands and riverine forests.

The human response to this seasonal movement requirement is transhumant or nomadic pastoralism. Strategies of environmental use embrace mobility, management of herd structure, and in some cases management of the environment. In arid and semi-arid areas cattle use the herbaceous vegetation almost exclusively, while sheep, goats and camels browse successively higher levels of trees and scrub vegetation. The use and access rights to these resources are complex and highly formalised, with dry season grazing areas generally defined and reserved by individuals or small groups and wet season grazing areas more likely to be common property or open access.

In more humid areas, pastoralism gives way to mixed systems, although the seasonal movement of livestock out of the floodplain remains characteristic.

Flood recession farming

In humid areas, floodplain agriculture is typified by rice cultivation, and this still continues under semi-natural conditions with the cultivation of deep water "floating rice" varieties in parts of Asia – particularly Bangladesh, Vietnam and Myanmar.

However, in most humid areas, water control structures are used to limit water depth and "swamp rice" is the main crop. Apart from rice, the majority of arable production in humid flood zones is based on avoiding floods, through planting on levees and artificial bunds and areas beyond the floodplain, or, in parts of the Amazon, on rafts.

In drier areas, and particularly where dryland cultivation is limited by rainfall, flood recession farming has developed as a naturally irrigated system. The amount of management varies, but rarely extends beyond simple water spreading using seasonally constructed bunds and ditches.

Box 3.2.2.3 Flood recession farming in the Senegal Valley, Senegal

In Senegal and Mauritania, despite low rainfall, in average years the area allows for two harvests, one dependent on summer rains on sandy upland soils and the other on post-summer floods on the alluvial plain. The general "walo" system of recession farming is then sub-divided. "Falo" on the steep riverbed slopes describes a system in which maize, beans, watermelons and potatoes are important. The "hollade" areas form the bulk of the floodplain and are used for millet, beans and watermelon, while the "fonde" on the high ground is rarely inundated, and is only occasionally used.

But this seasonal use for flood recession farming does not reduce the fisheries production of the floodplain, which provides over 70 kg of fresh fish per hectare.

At higher levels of management, recession farming can become part of a flood management intervention. In Bangladesh, farmers developed an agricultural system based on rice and mixed farming, that "accommodates" seasonal flooding. Attempts to control natural flood patterns to protect farmland and urban centres failed, and a new approach is being explored. This approach is based on "flood proofing", which *accepts* flooding and takes a flexible approach to protection based on the cost and risk of protection, rather than trying to protect everything.

Biodiversity and tourism
In addition to direct use of natural resources by local communities, indirect use through conservation and tourism is extremely important in many flood-dependent systems. Protected areas, such as national parks or Ramsar sites have been established throughout the world to conserve rare or endangered species, including the Waza National Park on the Logone floodplain in Cameroon, the Okavango delta in Botswana and the Indus delta mangrove forests of Pakistan. In these areas, tourism can provide an important source of income. Whereas in the past agriculture and wildlife conservation was often in conflict, through programmes such as CAMPFIRE in the Zambezi valley, local communities benefit from protection of habitats and species.

3.2.3 Impacts of dams on natural resource systems

Large dams are designed to trap a significant proportion of "normal" floods, while withstanding large floods by allowing excess water to pass directly through via the spillway (section 2.3). Dams modify the extent, frequency and duration of downstream floodplain inundation. They also trap much of the seasonal sediment load transported by the floods (Table 3.1.2.1). These changes impact on both the biotic and abiotic components of ecosystems (section 3.1.2) and hence the natural resource systems on which people depend. In the downstream floodplains, alteration of flood regimes forces a change in the natural systems to cope with drier, less fertile conditions, while often still leaving them vulnerable to major flood events. The impact on human use of floodplains is the same. The reduction of more frequent floods encourages patterns of land use that are adapted to reduced or non-flood conditions, without significantly decreasing exposure to major floods.

Box 3.2.3.1 Changes in access to floodplain resources in the Kafue Flats, Zambia

The Kafue Gorge dam is situated at the downstream (eastern) end of the Kafue Flats. The terrain limits the storage of the reservoir at this location and the Itezhitezhi dam has been constructed at the upstream (western) end of the Flats to provide the storage required to guarantee hydropower production. The natural resource use patterns of the Kafue Flats have been affected by the combined impacts of the downstream Kafue Gorge Dam and the upstream Itezhitezhi Dam.

Physical changes to the flows and floodplain
- The downstream reservoir and increased dry season releases have increased the permanent open water area from 300 km^2 to 1,500 km^2 or around a 20% loss of the original flood recession area.
- The wet season peak flows have decreased from around 1000 m^3/sec to 750 m^3/sec

Changes to systems of resource use
- The loss of traditional near channel flood recession garden systems.
- A decrease in grazing resources through a direct decrease in the area of the recession zone; a change in vegetation in the drier remaining floodplain zones to less valuable woody vegetation; and the knock-on effects of conversion of land to irrigation farming made possible by higher dry season flows.
- A decrease in the national parks wildlife grazing areas due to increased open water; compounded by increasing pressure from and conflict with cattle grazing.
- A change in fish species and catch composition, *Oreochromis andersonii* from 50% of catch in 1968 to 3% in 1983 and an increase in predator species *Clarius gariepinus, Marcusenius macrolepitus, Labeo maolybdinus* and *Hepsetus odeo.*
- An increase in fish catch effort due to larger areas of dry season open water.
- Decrease in families supported by fishing from 2,600 in 1977 to 1,150 in1984

The impact of any dam on downstream natural resource systems is site-specific, and depends to a large extent on the way the dam is operated. The physical impact of reduced flood flows and sediment transport depends on the selected construction and management option:

- reducing the area of normal regular seasonal inundation
- reducing the period of inundation
- increasing the area of permanent open water
- reducing the extent of the normal flood recession zone
- reducing the sediment deposition within the floodplain

Different natural resources systems are often constrained by topography and hydrology to a particular zone within the floodplain and further modified by human activities. The impact of a change in flood regime will therefore not be equally distributed across the range of resource systems, nor the cost met equally by the different users. As a starting point in evaluating the impact of flood management, the change in the area of each zone or natural habitat can be equated to the loss of productivity, taking into account contributing flows between the dam and the flood plain and from rainfall within the flood plain.

As an example, an overall decrease of 50% in the area of inundated floodplain grassland will result in a 50% decrease in floodplain grazing and the replacement with a dry-land system. A further problem is that a decrease in floodplain area will concentrate the remaining floodplain activities in a smaller zone, increasing land pressure and the potential for land degradation and conflict between different users.

The consequences for natural resource systems of reduced periods of inundation will also vary:

- Flood recession agriculture will not be affected if the period of inundation is adequate to bring soil moisture up to saturation.
- The extent and use of floodplain grazing areas will be fundamentally unchanged, although the quality of grazing may be affected by changes from floodplain species to less nutritious non-floodplain species.
- Fisheries would be most affected. Although the breeding pattern might be unaffected, the decrease in access to floodplain feeding resources would decrease gross production.
- Groundwater recharge will also to be reduced, and while this may have a number of implications away from the floodplain, it could have a direct impact on floodplain forests where mature species are dependent on shallow groundwater.

The impact of reduced sediment loads is immediate: the competence of the flowing water to carry sediment is increased and this can lead to bed degradation, channel movement and other physical changes in the drainage system. However, the impact on the floodplain will depend to a large extent on the distance between the dam structure and the floodplain.

- If the floodplain is immediately below the dam structure, there will be a drop in sediment load, leading to bed degradation within the floodplain, reduced flooding, increased channel mobility, reduced build-up of levee structures and reduced biological productivity as a result of loss of nutrients held to the sediment particles
- If the floodplain is distant from the dam structure the flow will re-stabilise through transport of secondary bed sediments into the floodplain. There is therefore likely to be little change in floodplain morphology. However, a significant change in fertility status is likely, as a result of the loss of nutrient rich fine sediments.

The impact of sediment trapping in upstream dams will vary according to position. In all cases there can be expected to be a decrease in biological productivity associated with a decrease in the fine to medium sediment load transported during flood events. The evaluation of this impact is difficult and the effects will not be immediate, residual fertility will decline gradually.

Thus overall, as with natural ecosystems, the impact of altered flood regimes caused by dam construction are multiple and complex and in many cases are difficult to predict. The way the dam is operated may significantly affect natural systems. A summary of possible impacts arising from different management options is presented in Box 3.2.3.2.

Box 3.2.3.2 Summary of impacts of dam construction and reservoir management options

Flood option	Impacts on use of natural resource systems
1. No dam	Existing multiple use patterns continue. Continued "normal" floods act to reduce the impact of larger and potentially catastrophic floods.
2. Operated to Maximise Storage for Irrigation, Water Supply or Hydropower	Loss of normal flooding pattern forces a change from floodplain to dry-land and river channel systems, with an associated loss of options for land use and livelihoods dependent on floodplain forests and forest products, floodplain fisheries, floodplain grazing and flood recession farming. Decreased value of interdependent hinterland grazing in arid and semi-arid areas. Increased risk of flood damage to incoming dry-land land use systems from continued exposure to the threat of large floods.
3. Operated to Release "Normal" Floods	Existing multiple land use patterns can be maintained and improved, as the management can moderate the inherent variability in "normal" floods. Increased reliability of floods can enhance production systems. Incorporation of communities into management structures and provision of advance flood warning can enhance community management capacity and increase the value derived from existing systems.
4. Operated to Release Limited "Normal" Floods	Existing multiple land use patterns can be maintained, although the total productivity will be reduced roughly in proportion to the loss of flooded area, and hence the flood recession zone. Fisheries productivity will be further reduced by the decrease in duration of flooding, and may also be damaged by a change in the timing of the first flood, which can act as a trigger to migratory behaviour or breeding. However, the increased ability to manage these limited floods may improve the reliability of flooding. This can mitigate for the decrease in gross productivity through removing the annual variability in production. Again the incorporation of communities into management structures can enhance community management capacity and increase the value of the reduced areas under production.
5. Increased Dry Season Discharge	Reduced flood recession zone and increased permanent open water area. Decreased total productivity of the floodplain in rough proportion to the loss of flood recession zone, while for fisheries an increased catch effort as remaining stock is more mobile.

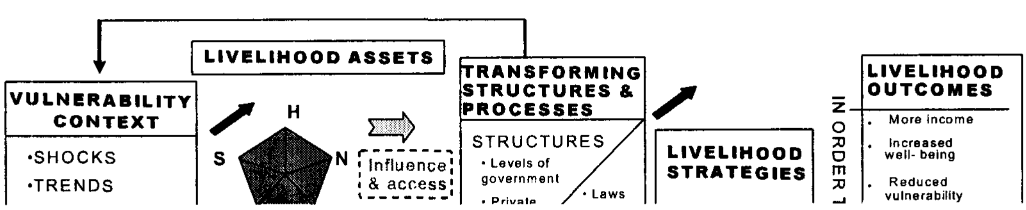
3.3 Floods, dams and livelihoods

3.3.1 Floodplain-dependent livelihoods

Floodplain natural resource systems (see Section 3.2.1) are defined by flood dependence, as are the floodplain livelihood systems based on them. Floodplain dwellers in developing countries depend on production systems such as recession agriculture and floodplain grazing, even though these livelihood strategies are combined at individual, household, community and floodplain level with other, non-natural resource-based, strategies. Cessation of floods through dam construction is therefore likely to have serious negative effects on downstream livelihoods. These effects were for a long time ignored or overshadowed by the more dramatic effects of displacement from reservoirs. Earlier reviews by dams specialists refer only to the benefits that downstream populations accrue in terms of increased access to hydropower, irrigation and potable water, with no consideration given to potential negative impacts. This inadequate appraisal of the downstream impacts of dams is reflected in Horowitz's (1991) description of the "millions of rural smallholders living downstream of high dams in the Third World" as "invisible victims of development".

The development of a livelihoods framework (Carney 1998, see also Scoones 1998) has presented an opportunity to view the impact of dams on downstream populations holistically; from the livelihood strategies that people pursue through their access to, and utilisation of capital assets (natural, social, financial, physical and human) in their attainment of a variety livelihood outcomes.

Box 3.3.1.1 DFID's Sustainable Livelihoods framework



Capital assets
The major immediate downstream impact of dams is undoubtedly on natural capital, or the natural resources viewed as an asset for building livelihoods. Dams have been identified as decreasing the area available for flood recessional agriculture, reducing soil fertility by reducing sediment transfer, and decreasing the quantity and quality of floodplain grazing. There are also impacts on fisheries through reduction in fishing grounds and nutrient inputs to fisheries and the subsequent disruption to fish breeding, on fuelwood availability and on "minor floodplain products" (see section 3.2.3).

The access to and utilisation of other capital assets by downstream populations are also affected directly and indirectly by dams. Social capital, the social resources upon which people draw when pursuing different livelihood strategies, can be eroded as access to resources becomes constricted, often resulting in the loss of kinship ties and social networks, and conflict between different user groups.

Livestock in traditional pastoral systems are used to create and embody social relations and changes in grazing patterns can therefore have a profound effect on social capital. Other forms of capital (financial, physical and human) are effected to varying degrees by upstream dam construction.

3.3.2.2 Declining social capital on the Tana River, Kenya (JICA, 1997)

Drought and recent changes in flood regime (as a result of dam construction) have had significant impacts in the Lower Tana River Valley in Kenya on social networks within and between communities living downstream. Environmental changes have led to the need for acceptance and reliance on state authority and services, which are, in turn, rendering clan and inheritance-based customary systems of regulated access to floodplain farmland and grazing resources increasingly redundant. Amongst the Pokomo (one of the principal ethnic groups in the Tana River District), traditional patterns of social cohesion, reinforced by age-group based communal work groups and by ceremonies and feasting at times of surplus are being eroded.

The impact of declining riverine pastures is also being felt between ethnic groups, with increasing pressure being placed on common pool resources shared by farmers and pastoralists. Despite agreements between groups, such as recognised access corridors for livestock to rivers for watering, disputes are becoming more commonplace, straining social relations which have traditionally been mutually beneficial, such as trading of milk for produce.

Livelihood strategies
By accessing and using the above capital assets, and in the context of institutions, people develop livelihood strategies, whether natural resource-based, non natural resource-based or migratory in nature. The impact of dams on these livelihood strategies, as on the assets on which these strategies are based, are largely detrimental. Natural resource based strategies have been profoundly altered away from flood recessional agriculture and livestock production towards more input-intensive, small irrigation.

Dwindling natural resource availability has also commonly brought about a forced diversification, often on unfavourable terms, of livelihood strategies. Petty trade, handicrafts and wage labour, are prevailing livelihood shifts. Farmers on the Tana river have had to diversify into activities such as casual labour, small-scale trading and charcoal burning, as well as long-term dependence on food aid. Similarly, the migration of one or more household members, or even whole communities, has been witnessed as a response to untenable livelihood conditions in downstream regions. The Pongolapoort dam in South Africa, for example, was partly responsible for high labour migration out of the Phongolo floodplain from the 1950s onwards.

Box 3.3.2.3 Changing livelihood strategies on the Atbara River, Sudan (Abdel Ati 1992)

The effects of drought and the damming of the River Atbara resulted in the dereliction of traditional irrigation methods, leading to the intensification of share-cropping arrangements between farmers and diesel pumps owners. Consequently, there has been a significant change in the type of agricultural inputs required, such as fuel and spare parts, and this has opened small producers to exploitation from urban-based investors.

Although agriculture still represents the major activity in the downstream area, the proportion of those engaged in it dropped from 92% to 81% between 1964 and 1989. Fishing and wood collection disappeared as livelihood strategies, but trade and handicrafts emerged as a basic occupation having previously been practised as secondary activities. In addition, a substantial increase in manual labour was experienced, indicating the decline of traditional occupations as well as the spread of landlessness resulting from the depletion of cultivable land.

Greatly increased out-migration was another result. The reduction in available agricultural land or its loss through sale, erosion or desert creep and the adoption of more capital intensive technology in agriculture meant that during the first 15 years after the construction of the dam, about 5% of the settled population left the area, and some villages completely disappeared, whilst others were severely depopulated.

Livelihood outcomes

The impact of dams on livelihood outcomes is evident through changes in income, environmental sustainability, well-being and vulnerability. It is generally asserted that dams have a negative impact on floodplain dwellers' incomes downstream. The decline in area cultivated and increases in real costs of production have reduced the return and thus income to farmers, leading to increased dependency on informal money lenders. In Thailand, the construction of the Pak Mool hydro-electric dam at the mouth of the Mool River has resulted in over 5000 fishing families in three districts losing nearly all their food and income sources, with a drop in earnings of more than tenfold, from approximately US$ 4,000 to US$ 350-400 per annum (Tangwisutijit, 1996).

Environmental sustainability as a livelihood outcome focuses attention on the ways in which changing livelihoods have effects on natural resources within and beyond the floodplain. Floodplain dwellers' over-exploitation of resources following changes in floods has been self-evident and unsurprising. In Sudan, a response to the decline of traditional irrigation has been a growing tendency for farmers to base agriculture on underground water as well as the use of *mataras* (deep wells) and emergency wells (Abdel Ati, 1992). The implications of this strategy on the longevity of the underground aquifer (clearly a key natural capital asset) remains to be seen. A depletion of livelihood options may result in migration as a result of dam construction. This strategy can often result in deforestation, overgrazing and erosion.

Vulnerability is evident both in a direct physical sense, where there is a risk that floodplain populations may adapt to the cessation of "normal" natural floods by building houses and establishing permanent cultivation in lower-lying areas, thus leaving themselves open to larger floods that are not controlled by the dam. Alternately, dam-induced shifts in livelihood strategies from, for example, flood recessional agriculture to various forms of irrigation using higher levels of inputs as in the Senegal Valley, can lead to 'material' vulnerability from economic trends and shocks such as changes in input prices due to world-market or local conditions. Well-being is an elusive criterion, and should by its nature be participatorily defined. The evident decline in social capital and disruption of culturally important seasonal cycles can be interpreted as a reduction in well-being amongst downstream populations.

3.4 Floods, dams and health

3.4.1 Health impacts of floods

Table 3.4.1.1 illustrates the main categories of health concerns associated with floods. The indirect consequences of natural or poorly managed floods can include malnutrition, contaminated drinking water, injury, stress, communal violence and loss of well-being. The direct consequences include drowning and changes in the abundance and distribution of disease vectors.

Acute events such as death by drowning may seem to have a high priority. However, the morbidity and death associated with communicable diseases such as diarrhoea, malaria and schistosomiasis are numerically far greater. These and other health impacts can be avoided by improved planning and communication between the principal proponents and the health sector. Plans that ignore health may simply transfer hidden costs to a health sector, which is often under-resourced and unable to cope with them. The economic consequences then include lost productivity, lost educational achievement, pain and suffering.

Table 3.4.1.1 Major health concerns associated with floods

Health categories	**Examples**	**Probable relative magnitude of problem**
Communicable diseases	Vector-borne diseases , gastro-intestinal diseases, zoonoses, geohelminths, respiratory infection	☹☹☹☹☹☹
Nutrition	Under-nutrition associated with loss of wild foods, choice of crop, loss of livestock, unequal entitlements within the household, or opportunity costs to women who walk long distances in search of fuel and water, food security	☹☹☹☹
Non-communicable diseases	Poisoning of drinking water supplies with minerals, pesticides or industrial chemicals	☹☹☹
Psychosocial disorders	Associated with loss of community cohesion, uncertainty, fear, abuse, social disruption, lack of empowerment. Manifestations include alcoholism, violent behaviour, theft, suicide, and depression.	☹☹☹
Injury	Drowning from unexpected floods, communal and domestic violence	☹☹
Well-being	Quality of life, associated with human and social capital	n/a

Communicable diseases

Communicable diseases differ from other health concerns. They are strongly associated with lack of infrastructure, poverty, crowding and exposure to natural environments (Table 3.4.1.2). The community can often develop partial and protective immunity to infection while they are under moderate challenge. This immunity can be disrupted by both extreme challenge and by removal of challenge. Restoration of a flood that has been lost may lead to renewed challenge and consequent epidemics of diseases like malaria and rift valley fever.

Table 3.4.1.2 Some categories of communicable disease and their association with ecosystem components

Sub-category	Association	Examples
Vector-borne disease	Mosquitoes, snails, tsetse flies, *Simulium* blackflies and copepods	Vivax and falciparum malaria, dengue, Japanese encephalitis, rift valley fever, bancroftian and brugian filariasis urinary and intestinal schistosomiasis (bilharzia), river blindness
Zoonoses	Birds, mammals, molluscs and fishes	Japanese encephalitis, trypanosomiasis, leptospirosis, brucellosis, opistochiasis
Gastro-intestinal diseases	Contaminated drinking water and food	Diarrhoea, dysentery, Shigella, Giardia, cholera
Geohelminths infections	Contaminated soils	Hookworm, roundworm
Respiratory infection	Stress, crowding, displacement	Pneumonia, TB

Vector-borne diseases

Malaria is by far the most important of the vector-borne diseases (Table 3.4.1.3). Some 1000 million people are at risk of this disease every year. The abundance of its vectors is likely to be greatly influenced by flood management decisions in most hot climates. The next most important group is probably schistosomiasis. The host snail is found on many floodplains and transmission depends on water contact such as fishing, bathing, farming, and washing. This is a chronic disease with relatively little apparent morbidity for many years but possible high morbidity rates in later life. Two mosquito-borne arboviruses are also important: rift valley fever and Japanese encephalitis. River blindness is focally important but more likely to be associated with rapid stream flows above the floodplain.

Table 3.4.1.3 Vectors, habitats and diseases associated with floods

Vector	Genera	Disease	Examples of habitat requirements in relation to flood
Mosquitoes	*Anopheles*	Malaria, filariasis	Hoofprints, stream pools, rock pools, ricefields, water with low organic content, flood waters
	Aedes	Rift Valley Fever	Flood fringes, recession lands, flood waters
	Culex	Japanese encephalitis, filariasis	Ricefields, lake fringes, semi-permanent swamp
	Mansonia	Filariasis	Permanent swamp
Snails	*Bulinus*	Urinary schistosomiasis	Unstable, semi-stagnant water, new inundation
	Biomphalaria	Intestinal schistosomiasis	Stable, slow flowing water (lower temperature tolerance)
Tsetse flies	*Glossina*	Sleeping sickness	Gallery forest, fringe woodlands
Blackflies	*Simulium*	River blindness	Fast moving water, rapids, spillways
Ticks		Arboviral and rickettsial infections	Tall grasslands with cattle herds

The importance of the other categories of health issues must not be overlooked. They are strongly linked with social impacts and with natural resource management. Malnutrition can be an indirect consequence of social and environmental impacts. In Bangladesh, malnutrition was judged to be a more severe consequence of uncontrolled floods than death by drowning.

3.4.2 Floodplains and agricultural pests

Floodplains are a source and target of agricultural pests and disease vectors. Upstream construction of dams and reduction of flooding is unlikely to significantly reduce the probability of pest attacks. Conversely, the introduction of controlled artificial flooding is unlikely to reintroduce pests that are not supported by the modified habitats and farming systems.

Floodplains and migratory pest habitats

While pests and pest damage within the floodplain environment are significant problems in the development of the floodplain, the role of the floodplain in supporting migratory pests is of much wider concern. Floodplains provide:

- a permanent habitat for pests, which under certain environmental conditions undergo major population explosions and migrate to other areas; and
- a seasonal habitat for migratory species which, again in response to an environmental trigger, move on to other areas.

Examples of both types of problem can be found in Africa. Plagues of red locusts have devastated sub-Saharan Africa at least three times in recent recorded history, with the last major outbreak ending in 1944. The identified sources, or "outbreak" areas, are major floodplain systems in Tanzania, Zambia, Malawi and Mozambique. These areas support permanent locust populations that under certain ecological conditions swarm, migrate and devastate vegetation areas up to 1500 times larger than the original outbreak area (Bahana, 2000).

Grain eating birds also pose a major threat to crop production. The most notorious of these is the *Quelea*, which under natural conditions feed on wild grass seed. When the rains come and the grass seed germinates, the birds are deprived of their preferred food and migrate. All species need to drink at least once a day, which determines their range and migration patterns. The Red-Billed *Quelea* is the most common species and is associated with permanent rivers, while the Red-Headed *Quelea* is associated with swamps (Allen, 1997). If wild grass seeds are not available – or other grains are more readily available , *Quelea* can rapidly become a major agricultural problem.

Preventative control strategies include the use of chemicals, trapping, firebombing and scaring and the modification of environmental factors. While poisoning can be fairly effective, the use of chemicals in flood plains threatens other components of the wetland systems.

Controlled grass burning, bush/forest clearing and water management could provide some benefits. And while increased flooding can reduce red locust populations, it will not solve the problem, as the eggs are laid in damp soil following flood recession or the beginning of the rains. Indeed the increased population density resulting from the decreased availability of habitat can itself trigger swarming behaviour.

- The changes in flood regime and land use that accompany upstream dam operation are unlikely on their own, to significantly reduce the pest challenge from migratory pests associated with floodplains. Changes in habitat associated with upstream dam operation may under some circumstances increase the probability of pest outbreaks.

4 Practicalities of managed flood releases

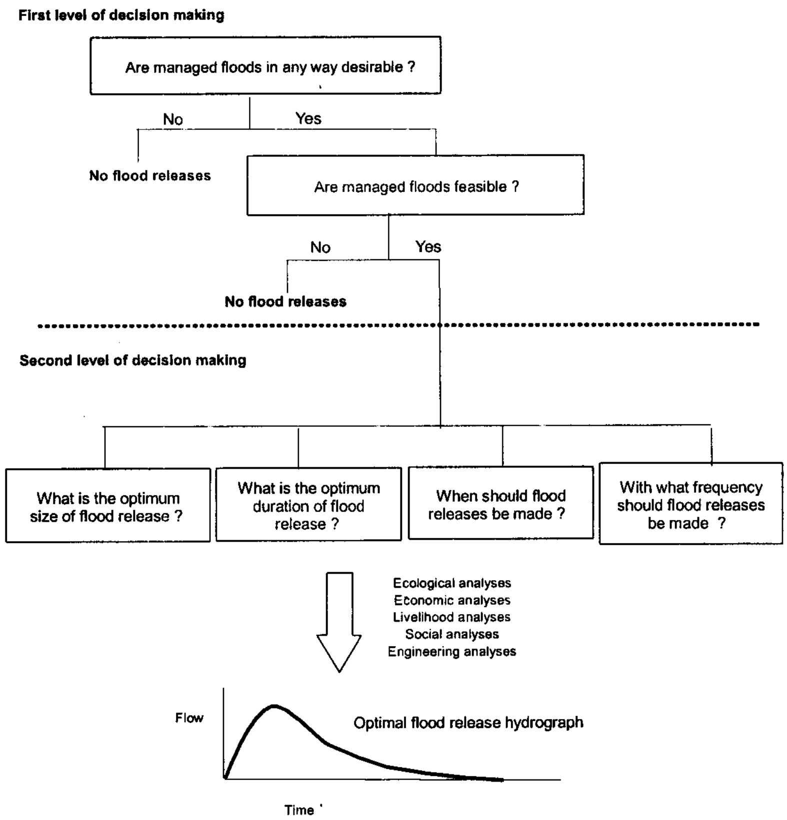
It is not possible, even if desirable, to reproduce the natural flooding regime downstream of a dam. The aim of managed floods is to find a compromise in the allocation of water between managed flood releases and retaining sufficient water within the reservoir to support activities for which the dam was originally built or, in the case of new dams, for which it is being built. It is likely to be uneconomic to create managed floods solely from reservoir releases, nor should it be necessary to do so. Optimal results would be achieved by releasing water from the reservoir to supplement periods of natural high runoff from the catchment area downstream of the dam. Consequently, releasing managed floods is not straight-forward. It requires technical expertise, a detailed understanding of the land-use and ecology of downstream ecosystems and close collaboration with the users of floodplain resources. The first part of this chapter briefly summarises some of the issues that need to be considered in the planning of managed flood releases. It covers engineering issues relevant to making flood releases as well as issues of community participation and operational responsibility. The second part of the chapter presents a simple conceptual framework for making decisions about managed flood releases.

4.1 Issues to be considered when planning flood releases

There is a wide range of issues that must be overcome in implementing an effective managed flood release programme. Some of these are detailed below.

- The dam may not be physically able to release sufficient water to create a flood due to its design
- Different parts of the ecosystem (e.g. invertebrates, fish, floodplain trees and grasses) and different species and life stages of the same organism may require different timing, depth and duration of flooding
- It is not possible to prescribe the magnitude of managed floods required to fulfil specific ecological requirements because in all cases this will to a large extent depend on the unique characteristics of the river catchment in question.
- Water stored in the reservoir may be of poor quality due to processes related to thermal stratification and unsuitable for flood releases
- It may be difficult to release sufficient sediment with the water to prevent severe erosion downstream of the dam
- Different floodplain stakeholders (including farmers, fishermen and herders) require floods at different times
- Where the target floodplain is a significant distance downstream of the dam, flow from the intervening catchment and tributaries need to be taken into account in achieving target levels of inundation
- Indirect impacts of floods, such as health issues, may be very significant
- Communities living in the floodplain need to be informed when a flood is about to be released
- Floodplain communities may have adjusted their livelihood strategies to cope with lack of flooding
- Dam operators may have rights to store certain volumes of water but not to release sufficient to create a flood downstream
- Land tenure and access may have changed which may negate the potential benefits of managed floods

managed flood releases outweigh the benefits. Consequently, the no flood option must be considered throughout.



then more detailed cost-benefit analysis should be undertaken at the second level of decision-making with this included as an option.

Box 4.2.1 Mahaweli – a river where managed flood releases are not appropriate

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 Mahaweli Ganga in particular has long been utilised and diverted for irrigation purposes. There is ample evidence that ancient Sinhala kings realised the significance of the Mahaweli and constructed diversions, extensive canal systems and tanks for irrigation of large areas of paddy. Rock inscriptions dating from the 1st century BC refer to irrigation canals originating from the Mahaweli. More recent structures are better documented – e.g. a 17 mile canal constructed from Minipe by King Aggabcdhi 1 (AD 571-604) and extended by subsequent kings to a length of 47 miles. 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. (Karunatilake 1988). As a result of these and other early activities, Sri Lanka has a significant number of both large and small reservoirs, or "tanks". Their total number is said to be greater than 16,000 – the bulk of them situated in the dry zone. The general trend was for each village to have at least one tank. Today only a fraction of these are still functioning, but they are nevertheless indicative of the old and extensive water diversion and use systems depending on 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% per annum, and flushing has been considered as a technical option. Results of quantitative assessment have shown flushing to be a viable option, with the possibility of stabilising the storage capacity at about 70% of original storage volume. Flushing has been carried out twice, with a three year interval. A third flushing event planned for 1999 was cancelled due to problems resulting downstream from the earlier flushing.

A substantial portion of the outflow from Rantembe reservoir moves along irrigation canals downstream. The flushing trials created problems of siltation in these canals. 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 can not be confined to the main river. Any managed flood release from upstream reservoirs can be expected to have a similar effect downstream. The costs of converting weirs so that they are capable of regulating flows, together with the extensive logistical and co-ordination problems associated with managing the releases have not been calculated, but are likely to prove prohibitive.

If the initial first level decision is that floods are desirable (even if only for a small sector of society) and flood releases from the dam are practicable, then more detailed analyses must be undertaken. The objectives of the second level of decision making are to: i) confirm that managed flooding is a beneficial option and ii) determine the optimum flood release strategy. This is necessarily a complex process. Approaches and methods for making these decisions are presented in chapter 5.

5. Methods to define optimum flood releases

This chapter is concerned with methods that can be used to determine whether managed flood releases are an appropriate and feasible option and, if so, to define their magnitude, duration, timing and frequency. Making these decisions requires information and the integration of environmental, social and economic factors. At present there are very few practical methods for linking the different aspects: there is certainly no prescribed "best approach". Consequently, in this chapter a range of possible approaches and decision-making tools are presented. It is envisaged that in any specific situation only some of the methods will be relevant. Those used will be determined in part by availability of data and in part by the preference of those tasked with making the decisions. Decision-making is an iterative process and should be refined as more information becomes available.

5.1 Defining human aspirations

5.1.1 Defining and including stakeholders

If managed floods are to be viable in the long term, it is vital to identify and involve in planning, all those who have a stake in its implementation, including electricity companies and their subscribers, District Administrators, Provincial Governors and local members of parliament. As discussed in Section 4.1.2, downstream affectees are only one category of stakeholders, but one that it is both important and difficult to involve. Assuming that policy-makers are willing to include downstream affectees in decision-making fora, the first step is to determine whose livelihoods are dependent on floods. This can be achieved by defining in physical terms the extent of pre-dam flooding and the maximum flood that could be created by a managed release; clearly anybody living or cultivating within this area could be considered a stakeholder. Beyond these, there are a number of other categories of affectees:

- Fisherfolk dependent upon downstream riverine fish stocks
- Individuals and groups who enter the floodplain area at particular times of year, or who depend upon particular resources, for example, transhumant pastoralists and those who are users of 'minor floodplain products'
- Artisans, trades-people and others whose livelihoods are closely linked to the various categories of natural resource users within the floodplain.

Identifying these categories of downstream stakeholders may initially be based on available quantitative and qualitative information, but is likely to require a more lengthy process of participatory assessment to determine the extent and nature of the 'social floodplain'. The benefits of carrying out such a process extend beyond the identification of affectees, as it should also identify important differences of livelihood strategy and interest within the affectee group. Such differences may be geographic, between those close to the dry-season flow and those at the edge of the floodplain, wealth-related, or related to resource access and livelihood strategies, which may in turn coincide with ethnic differences. The differential interests of men and women, and of different age groups may also be important.

In most cases, the number of people whose livelihoods are dependent upon downstream riverine resources will be far too high to be directly representable within decision-making fora. The next step is therefore to identify institutions that can represent the body of stakeholders. Traditional institutions may be an appropriate vehicle for such representation, but it is important to note that they may not represent the full spectrum of stakeholders. Traditional village councils, for example, may represent settled flood recession-based cultivators, but not transhumant pastoralists. Similarly, women and younger men may have less voice within traditional institutions. In addition, there is a question of whether or not traditional institutions (if generalisations are possible) are able to shift from reactive decision-making to longer-range planning, particularly if it involves major hypothetical issues. An alternate strategy, the introduction of new formal institutions, can also be blighted by being captured by the literate, the well connected or entrepreneurial whose interests may not represent either the majority or those less able to articulate their needs. Clearly, there is no single route to building effective, representational institutions, whether through broadening traditional or fostering new formal structures, but an approach should include the following elements:

- a participatory assessment which results in a clear understanding of the different stakeholders whose livelihoods are located in the downstream region
- a clear understanding of the number, type and nature of traditional institutions
- adequate time and resources to invest in capacity building
- the fostering of a political will to include affectee representatives in decision-making fora and the establishment of processes to link these groups/institutions to the fora.

Ideally, if representative institutions can be identified, strengthened or built, representatives of downstream affectees should be able to negotiate directly with representatives of other stakeholders. Such negotiations could certainly make use of some of the decision-making methodologies discussed in section 5.5 as ways of making the outcomes of various decisions visible and comprehensible to all. In practice, differentials of power, organisation and education are likely to mean that direct negotiations cannot be the sole means of making affectees' voices heard. Other parties, drawn from the ranks of government itself, research institutions or NGOs will need to assist, advise or in varying degrees act as proxies for affectees. In such cases, decision-making methodologies can still be used, but as analytical, rather than negotiating techniques. Those advising or representing affectees will need to understand firstly the aspirations of downstream affectees, and secondly the likely impact of different flood regimes on their livelihoods.

5.1.2 Understanding affectees' aspirations

The decision to make flood releases must be in response to anticipated benefits on the floodplain downstream to one or more stakeholders. The 'livelihood outcomes' depicted in the Sustainable Livelihoods framework is an excellent starting point for categorising possible stakeholder objectives of managed flood releases. These are;

- Increased income
- Enhanced environmental sustainability
- Improved food security
- Reduced (or not enhanced) vulnerability
- Increased well-being – which must be participatorily defined and may include intangibles like access to social networks and maintenance of culturally important seasonal cycles.

In understanding what these outcomes or aspirations mean in a particular floodplain situation, it will be important to understand the seasonal use of resources and the interdependence of floodplain and non-flood plain resources. This is necessarily linked to the earlier described assessment of categories of downstream stakeholders (ethnic, occupational, and wealth-, gender- and age-based). A further set of concepts that will be useful in defining aspirations or objectives is that of coping strategies and adaptive strategies. Floodplain dwellers have adapted over time to the risk of floods and used that risk positively in strategies of flood recessional agriculture and seasonal grazing. Given time, floodplain dwellers will adapt to a cessation or diminution of floods, although there is no certainty that their overall livelihoods will be enhanced (or worsened) by doing so.

In the shorter term, however, floodplain dwellers may adopt *coping strategies* in the face of cessation or diminution of floods. Such coping strategies may involve trade-offs between different livelihood outcomes. In particular the short-term need to protect income or food security may impact negatively on environmental sustainability (through compensatory overuse of other resources such as distant grazing) or on vulnerability (through new settlement patterns in the line of occasional high floods.

5.1.2.1 Participatory Rural Appraisal

Participatory Rural Appraisal (PRA) is an approach that may be used to obtain the views of communities affected by the release regime from a reservoir, as well as to lay the groundwork for their future participation in flood management. It is used to obtain information on resource use as well as socio-economic issues. As an approach, PRA tends to the qualitative rather than the quantitative and aims at understanding local people's knowledge, perceptions and practices, rather than collecting data for statistical analyses. It comprises a range of tools including village mapping, focus group discussion and individual household interviews . These techniques, applied sensitively in the context of an overall participatory ethos, enable people to analyse their own situations and develop strategies to address their needs, priorities and capabilities for the improvement of their livelihoods. PRA was used in the Waza-Logone floodplain, Cameroon to obtain information on the benefits of floods to local communities. They were very much in favour of managed flood releases as these had great benefits for natural resources (Kouakam, 1994).

In defining human aspirations, PRA will be a very useful tool, both in the sense of specific "PRA tools" such as participatory mapping (which can be used in conjunction with aerial photographs), seasonal calendars, and timelines, but more importantly in the sense of a genuine approach to participation: a well-resourced and measured attempt to understand the livelihood outcomes which are important to these stakeholders.

5.2 Defining natural resource and ecosystem flood requirements

Natural resources, the part of the ecosystem used directly by people, have evolved under natural flooding conditions, and their diversity reflects the physical variability in the floodplain and in the hydrological system (see section 3.2). In many instances the primary objective of managed flood releases will be the maintenance or rehabilitation of the natural resources utilised by people downstream of the dam. Hence dam releases should be designed to meet the requirements of those components of the ecosystem that are identified as important natural resources. For example, the flood release regime could be designed to optimise particular human activities (e.g. flood recession agriculture) or preserve particular species (e.g. fish or plants). In some situations society may place great value on "near natural" ecosystems and flood releases may be justified for ecological reasons alone. Of course managed flood releases may be required to fulfil multiple objectives. Whatever, the specific objectives of managed floods the ecological flow requirements will need to defined.

Box 5.2.1 Defining flow needs for the natural resources of the Senegal valley

The principal objective of flood releases from the Manantali Dam on the Senegal River is to support downstream recession agriculture. A review of the natural (pre-dam) flood regime and related recession agriculture indicated that recession cropping varied from 103, 100 ha in wet years to almost nothing in years with negligible flooding. An appraisal of labour requirements, indicated that the maximum that could be cultivated was about 110, 000 ha.

Flood release hydrographs were designed to enable cultivation of 50,000 ha, 75,000 ha and 100,000 ha depending on the river flow in any year. Hence, it was planned that flood releases would enable an increase in the area cultivated, particularly in a dry sequence of years when under natural flow conditions there would be very little flooding.

The health of wetland ecosystems and thus their ability to provide natural resources, depends on complex interactions between water, soil, plants, animals and nutrients. It may be easy to demonstrate that a substantial reduction in water leads to degradation of a wetland and loss of goods and services. However, there is no easy method to identify critical threshold levels of water requirements below which significant changes occur. Consequently, it is not straightforward to define how much flood water must be released from a reservoir to restore and maintain wetlands downstream. In practice, three or four feasible flow regimes are normally defined (by considering what releases can be made that minimise the impacts on other water uses) and the ecological and natural resource implications determined.

Various methods have been developed around the world to determine flow regimes for riverine ecosystems. The majority of applications have been for setting minimum flows to maintain in-stream ecology. Nevertheless, the methods can be used for defining flood flows. The methods can be divided into four types.

5.2.1 Hydrological indices

The most commonly applied methods for setting flow requirements are rules-of-thumb, based upon natural hydrological indices. For example, many reservoirs make small releases during dry periods based on a percentage of mean river flow or a low flow statistic, such as Q_{95} (ie. the flow exceeded for 95% of the time). For managed floods, releases could be related to the "normal" or the mean annual flood, eg. the objective could be to achieve a flood extent equal to 75% of the mean annual flood at least every other year. Releases can be varied from year to year to mimic the inherent variability in the natural hydrological system. The advantage of this method is that the calculation requires only hydrological data and not detailed species requirements. Its disadvantage is that there is no guarantee that the flooding requirements of specific species are met. Nevertheless, by reproducing elements of the natural flooding regime, it is hoped that the general requirements of ecosystem processes, such as sediment and nutrient transport and different species, which have evolved to respond to flooding, are automatically met. The main use of the method could be its application to sites where no ecological data are available or during feasibility studies on managed flood releases.

Box 5.2.1.1 Defining the flow needs of the Kafue Flats, Zambia

The broad alluvial plain of the Kafue Flats, located between the Itezhi-tezhi and Kafue Gorge reservoirs, is characterised by floodplain swamps and marshlands. The Kafue Flats are an area of special ecological importance with high biodiversity. Over 400 species of birds have been recorded (including the endangered wattle crane) and it is the only place in the world where Kafue lechwe (a semi-aquatic antelope) are found.

In an attempt to safeguard the ecology of the Flats, additional storage was built into the Itezhi-tezhi dam, to allow managed flood releases (known as a freshet) each year. The increased storage enables a release of at least 300 m^3s^{-1} throughout March (a total volume of 803 million m^3). The managed flood release was perceived as a drought mitigation measure to allow some flooding even in very dry years, without jeopardising hydropower production. It is believed that the value of 300m^3s^{-1} was chosen without detailed evaluation of the ecological impact for specific species, but making the *a-priori* assumption that in dry years some flooding was better than no flooding.

5.2.2 Desk-top hydro-ecological analysis

This method involves a desk study of available data from literature related both to river flows and water requirements of particular species and/or ecosystems. Refinements over simple hydrological indices are that reservoir releases may be made at specific times to target individual species, for example to stimulate fish migration. This method provides the opportunity to include a range of quantitative and qualitative biological information. In many cases this requires transferring results from a study site where data were collected, to the site of interest where the dam is sited. The scientific literature provides information on thresholds for sediment entrainment, which can be applied to ensure maintenance of channel geometry. However, most studies have taken place in temperate latitudes. Care must be exercised in using results derived from rivers in different climatic or biogeographical regions. Project reports often contain more local information, such as knowledge of fishermen on the relationship between flooded area or depth and fish reproduction. In many cases the information base will be restricted, and while flow information for the main channel will often be available, the flood extent will not have been monitored and there will be inadequate information on micro-topography to model the actual flood within the flood plain. It is therefore often necessary to rely on historic remote sensing to characterise vegetation zones and define flood extent, and to infer the relationship between flooding and habitat.

Box 5.2.2.1 Lower Indus delta flow needs

The Indus is one of the major river systems of Asia, and dominates the landscape and economy of Pakistan, providing water for the worlds largest irrigated area. The lower Indus supports large floodplain that provide timber products, especially pit-props for the mining industry. Where the river joins the sea an extensive delta has formed, stabilised by mangroves. These provide camel fodder and fuelwood and support an extensive fishery (with a foreign exchange earning of over US$100 million in 1997) and many rare species. Fresh groundwater within the delta supports communities of fisherfolk and camel herders.

Records from the nineteenth century suggest that freshwater flows to the lower Indus were around 150 million acre feet (MAF) per year (185,000 million m^3). Some flow occurred all year round, with higher flows starting in March, peaking in August, and declining in November. Since then construction of dams and barrages for irrigation has reduced the flows of water and sediment. During the period 1960-1971, freshwater inflows were only 35 MAF (43,000 million m^3) and the Indus Water Accord only provides 10 MAF (12,300 million 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 100 acres (40 ha) of mangrove forest requires 1 cusec (0.028 $m^3\ s^{-1}$) during July and August to remain healthy and support the associated fisheries. For the estimated 260,000 hectares of man groves a total volume of 27 MAF (33,300 million m^3) would be needed. A typical hydrograph shape would suggest a flow peak of 5000 $m^3\ s^{-1}$. The floodplain forests need to be inundated at least twice in five years to enable saplings to become established.

5.2.3 Multi-disciplinary expert panel

The key difference in this method is the involvement of a multi-disciplinary team of experts and the collection and analysis of some new field data. The Building-Block Method developed in South Africa and the Holistic/Expert Panel approach from Australia are examples. In this method, an expert panel makes judgements about the ecological consequences of various scenarios of magnitude and timing of flows. The panel is composed of a range of disciplines, including an ecologist, geomorphologist and hydrologist, and five major ecosystem components are often analysed: fish, trees, macrophytes, invertebrates and geomorphology. In tropical environments it is also important to include a vector ecologist. It is common place for panels to undertake field visits to view the river at different flows, during which basic measurements, such as flooded area, flow velocity and sediment concentrations can be made. Stakeholders, such as farmers and fishermen are not part of the panel itself, but the expert panel holds public meetings in the catchment.

5.3.1 Method of health impact assessment

The method of health impact assessment advocated consists of the following steps:

- Identifying vulnerable communities and health issues;
- Investigating health determinants;
- Reaching conclusions;
- Recommending measures for managing health risks and enhancements.

Examples of the health determinants requiring investigation

The table below indicates examples of health determinants. Some of these will be changed by the project. The change may be positive or negative in terms of their likely health outcomes. It is not always possible to associate a change in health determinants with a change in health outcome. Generally, the risk of a change in health requires several health determinants to act together. For example, numerous mosquitoes only increase the incidence of disease if people do not protect themselves from the bites, immunity is low and the health services fail to provide vector control, prompt diagnosis and treatment. Personal protection depends on poverty, housing design, knowledge, attitude and belief. In seasonal climates, vector-borne diseases often have seasonal changes in incidence. The managed flood may extend or reduce the transmission season.

Table 5.3.1.1 Examples of heath determinants and their classification

Risk factors	Sub-divisions	Example health determinants
Individual/family	Biological, behavioural and circumstances	Age, occupational activities, poverty
Environmental	Physical, social, economic	Mosquito breeding sites, communal violence, underemployment
Institutional	Health services, other services	Drug supply, water supply

Stakeholders

The stakeholders in a flood restoration project include a diverse range of different communities. Each community is vulnerable to different health issues because of individual/family characteristics, relationships with the environment and access to institutional support. The most vulnerable communities are likely to be single women, the elderly and children who have poorly defined land rights and live on the floodplain. They may be dependent on the flood and so benefit from its restoration. They may simultaneously experience negative health impacts because of loss of drinking water, exposure to insect vectors or through not receiving warnings of an imminent flood.

Boundaries

In common with other forms of impact assessment, health assessments must establish geographical and temporal boundaries. The geographical space is bounded laterally by the distance that people, livestock or vectors can move from non-flooded to floodplain lands and longitudinally by the downstream effect of the flood. Mosquitoes have a flight range of about 2-3kms while *Simulium* has a range of about 8kms. Migrant people can transfer parasites, such as schistosomes, between river basins. The temporal phases of flood plain management will include annual seasonal cycles and longer cycles. The flood itself is part of an annual cycle and the prevalence of some health risks will vary in sequence. There are longer cycles associated with the response of the human community to infection. For example, the clinical effects of schistosomiasis may take many years to appear. The opposite may also occur. For example, there may be an immune response so that clinical effects become less severe with time: the flood may cause an epidemic of malaria or Rift Valley Fever for a few years, but this may then diminish. The timing of the flood within the normal annual cycle could also be important. For example, the flood may provide mosquito-breeding sites but if it occurs during a cool season the mosquitoes may not flourish.

5.3.2 Management of health risks

The most important principle for managing health risks and promoting health gains associated with any development policy or programme is to use prospective health impact assessment. This facilitates an effective dialogue and negotiation with planners, health professions and affected communities at the planning stage. Health safeguards include, in decreasing importance:

- Changes to project plans and operations, including catchment management;
- Provision of infrastructure such as drinking water supply and sanitation;
- Improved management and maintenance;
- Timely provision of accessible health care including diagnosis and treatment;
- Special disease control operations;
- Individual protective measures;
- Redistribution of risk through insurance schemes.

Table 5.3.2.1 Examples of risk management measures

Zooprophylaxis	There is a possibility of using livestock as diversionary hosts to protect people from malaria
Alternate wetting and drying of floodplains or streams	Controls some mosquito species
Health centres	Ensuring that health centres are equipped and functional **before** releasing the flood
Water supply and sanitation	Helps to control diarrhoea, various intestinal parasites and schistosomiasis. Domestic water supplies such as wells should be protected from contamination by flood waters.
Vaccination	May be appropriate for certain arboviruses
Handling moribund animals	Control of Rift Valley Fever
Flushing	Floods can have a flushing effect on stagnant waters, removing pollutants such as human waste, unblocking drains or flushing away mosquito larvae.
Community control	Increasing empowerment and reducing uncertainty are postulated to be health enhancers in themselves.
Communication	Multiple communication routes are required to ensure that all stakeholders receive an early warning of flooding dates.

The most appropriate safeguards improve the project outcome as well as improving human health - the "win-win solution". Multiple barriers to exposure are likely to be more effective than single ones. In some cases, health can be safeguarded without additional project costs by simply improving communication between stakeholders. Projects that ignore health safeguards simply transfer hidden costs to the health sector and may lower productivity and educational achievement.

It is important to note that recommendations to change individual human behaviour are unrealistic. Health promotion/education is important but only relevant when specified in detail with clear indications of the resources required, who will provide them, and how often they will be repeated and evaluated. Accessible medical care is very important, but only as a last resort. Projects often provide too little medical care and too late. In the case of managed floods, a clear recommendation is that local health centres must be operational and stocked with drugs before the beginning of each flood season. This may require a special budget from the operators of the flood, as the health sector is usually under-resourced.

Community regulation of floods is postulated to improve health by reducing uncertainty and increasing empowerment. The early warning associated with a regulated flood should also enable various institutions that support health to provide a better service. For example, drugs and food supplies may be delivered at the most appropriate times as floods may often disrupt communication routes.

The timing of floods may affect the risk of epidemics. For example in areas of unstable malaria transmission, small changes at the beginning of the malaria season may determine whether an epidemic occurs.

Design characteristics

There have been attempts to identify the engineering design characteristics of dams and canals in order to prevent breeding of various vectors. See, for example, Table 4 (from Jobin 1999). Further work may be required to extend these results to managed floods.

Table 5.3.3.1 Design requirements to control vector breeding

Structure/process	Bilharzia snails	Malaria mosquitoes	River blindness blackflies
Canal velocity (m/s)	Varies with discharge from >.58 to >0.81	>0.1	<0.5 or >3.0
Drain drying, rapid drop	Adults 1-2 weeks	1 hour	1 hour
Drawdown (cm/hr)	4.1 for a slope of 5:1 1.4 for a slope of 10:1		

Both vectors and parasites are sensitive to temperature. For example, falciparum malaria has a low transmission threshold of about 16°C. Bilharzia snails reproduce at temperatures of 20-30°C. It has been suggested that the absence of bilharzia from the Indus system may be temperature related (Jobin, *pers. comm.*). The discharge of water from reservoirs can reduce the downstream temperature by up to 2°C (Institute of Hydrology, *pers. comm.*). This may be sufficient to promote snail breeding on the flood plains in conditions that are otherwise too hot. Pond and reservoir temperatures also fall with depth and so some snails survive by migrating to deeper waters.

The chemical characteristics of water can deter vector breeding. Snails do not like saline conditions. Malaria mosquitoes often have very specific requirements. For example, in Africa, they may be found breeding in new pools of water in hoof prints at the flood edge, but not in pools of water that are several months old. In general, malaria mosquitoes require water that is low in organic content. Blackflies require highly oxygenated water with low nutrient content.

Most vectors cannot withstand more than a short loss of their water habitat. However, some snails can aestivate (hibernate) in mud and some mosquitoes have drought resistant eggs. The aquatic stage lasts 1-3 weeks in mosquitoes and blackflies in warm climates. The adults live 1-2 weeks. Snails can live much longer and can remain infective with bilharzia for up to 6 months.

Blackfly larvae (*Simulium*) are found on dam spillways, rapids, drop structures, bridge supports, river rocks and weeds. There has been concern in the past over the discharge of reservoirs through spillways that are operated continuously for more than a week. This could occur during managed floods. However, it seems more likely that discharges will be made from deep water and so there is no problem.

5.4 Determining the impacts of flood options on livelihoods

In the consideration of managed flood options, the incorporation of downstream stakeholders in decision-making must be followed up by ex-ante appraisals of how these livelihoods may be affected. The Sustainable Livelihoods (SL) approach discussed earlier (Section 3.3.1.) provides a good framework for analysing the livelihood strategies that people pursue, the assets on which these are based, and the outcomes that result and thus is an appropriate tool for looking at the impact of various flood options (see DFID, 2000, especially Section 4).

5.4.1 Livelihood assets

The livelihoods approach is initially concerned with the asset status of different groups of people (who can comprise wealth strata, ethnic or occupational groups). It must be recognised that asset levels vary within and between households and communities, they change over time, and have different functions (supporting production and consumption, providing safety nets against vulnerability, etc.). In addition:

- assets may be complementary, with a range of assets usually required to achieve a given livelihood outcome.
- assets may be substitutable, with human capital, for example, sometimes compensating for a lack of financial capital.
- in addition, the extent to which an asset can be converted into others may be important and time bound. For example, small livestock may be easily sold at some times of the year but not at others due to low prices of lack of demand.

Access to assets does not necessarily mean control over them, nor to the benefits that they give. Ownership, access and the cost of access must therefore be considered separately.

Natural capital
Natural capital includes all natural resources used for livelihoods; water, agricultural land, grazing land, livestock, forests and fisheries. Of these, downstream land used for flood recession agriculture, grazing land and fisheries are most affected by dam construction. The availability and utilisation of these assets may be ascertained through a variety of participatory and non-participatory survey techniques. Detailed information on natural resource use (soil, water, flora, fauna) may require aerial photography, satellite imagery, maps, soil survey data and the like. Quality and management issues are more likely to be understood through participatory methods such as transect walks, mapping (e.g. current and past land use, water source, etc.), ranking of species (by abundance or importance), timelines (to describe historical changes in rainfall, river flows, soil fertility etc.) and seasonal calendars.

Participatory methods can also reveal issues of access. Property rights regimes and the rules of access to customary and communal lands (e.g. grazing lands) can be researched using stakeholder analysis, key informant interviews, focus groups and visual tools such as Venn diagrams. Privately owned natural assets (e.g. private land, housing plots, livestock etc.) and their distribution can be established from sample surveys.

Special attention must be paid to gender issues when investigating natural capital. Women and men tend to have differential access to natural assets, notably land, with varying degrees of dependence on different types. Investigative methods must therefore incorporate elements of gender analysis, and sensitivity to age, ethnicity, occupation and other social distinctions.

individuals, households and communities are utilising a variety of livelihood strategies, a sample survey may reveal disparities between individuals and groups, thus facilitating a greater understanding of who the 'winners' and 'losers' may be as a result of changing circumstance. In addition, larger population-based sample surveys should provide an indication of whether there has been in- or out-migration in the region. This, in turn, may be followed up by participatory assessments on reasons for these population movements.

5.4.3 Livelihood outcomes

Discussion of livelihood appraisal methods thus far has been largely static, and concerned with taking a snapshot of livelihood processes at a particular point in time. If livelihood appraisal is to be used ex-ante to plan flood regimes, either before dam construction or from an existing dam, analyses of different types of capital need to be linked to changes in flood regimes and to changes in each other. If the technical parameters of changes in flood regime are known, and if there is a good understanding of access to natural capital, likely changes in natural capital can be mapped, either by outside investigators or participatorily. The same will probably be the case for physical capital, at least in the sense of public infrastructure. Changes in access to the other three types of capital can also be hypothesised, although the definitions of the types of capital, and the hypothetical changes in them will be more difficult to grasp, either in a participatory exercise or for outside observers. There is an additional complicating factor that changes in social, human and financial capital will be determined at least as much by access to natural capital as directly by flood regime.

Given an inventory of likely changes in access to capital, and current livelihood strategies among different groups, [1] some projections of changes in livelihood strategy can be made, again either by outside investigators or participatorily (although it has to be said there are few precedents for conducting this sort of exercise in a participatory manner, and the ability of a participatory exercise at handling complex hypothetical questions needs to be carefully considered). These projections need to be considered against the outcome criteria of income, environmental sustainability, well-being and vulnerability. Measuring changes in income, as highlighted in the section on financial capital, can be sensitive. Survey questions may need to be proxied or indirect, aiming to construct a composite picture over time. Aggregate changes in household income in flood regimes over time (pre- and post-dam construction) are most effectively measured through sample surveys, due mainly to the area and population size. Group discussions can reveal information on family members who are working for a wage, the jobs they are doing and its permanence or seasonality. Less obvious sources of incomes, such as remittances, pensions, rental income etc. also need to be investigated.

Environmental sustainability as a livelihood outcome in the context of flood regimes, focuses attention on the ways in which changing livelihoods have effects on natural resources within and beyond the floodplain. These changes can be measured through a combination of techniques, including environmental impact assessments and more people-centred participatory appraisals. Balancing environmental and people-centred assessment methodologies keeps livelihoods at the centre, but with the main emphasis on the natural environment.

Well-being and vulnerability are less easily definable livelihood outcomes, indeed, it has been argued that it is important to allow people themselves to define the criteria against which livelihoods are judged. Within the context of development-induced displacement,

[1] The livelihoods framework as generally used includes another important set of concepts, structures and institutions. We are assuming here that changes in informal/local/traditional institutions due to changing flood regimes can be largely equated with changes in social capital. Formal structures and institutions will remain relatively constant over changes in flood regime, unless they are deliberately changed from outside to mitigate or manage those changes.

concepts of culturally specific spatial-temporal orders, and their disruption are used to explain "social disarticulation" or "social impoverishment" and the loss of community capacity to self-manage. Clearly, well-being in one sense includes the 'harder' income data previously discussed, as well as perceptions of vulnerability and sustainability, which can only be highlighted via participatory techniques.

Box 5.4.3.1 PRA in the Waza-Logone project, Cameroon

PRA methods were used in the Logone Floodplain, Northern Cameroon to investigate the socio-economic impacts of declining floods. PRA was chosen both because of the intrinsic arguments for participation in collecting complex information on interactions between society and the environment and because it was seen by project managers as low cost (a view many PRA advocates would dispute). It was also felt that conventional survey methods would fail to capture seasonal variations in an area inaccessible by road in the dry season.

PRA methods used included:

- participatory mapping: with men of land-use and environmental information, with women of activities and problems within the village
- timelines, which identified key dates in floodplain history, and illuminated the issue of conflicts between farmers, herders and fishers
- transect walks: outside the village to examine natural resource issues and inside the village to look at building materials and living conditions
- ranking, of problems and productive activities
- wealth ranking, which enabled sampling of households for interview, estimation of human and livestock numbers, and understanding of local notions of wealth
- semi-structured interviews
- Venn diagrams of relations between groups and institutions within and outside the village
- resource flow diagrams, 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 organisers were also able to set up simple environmental and socio-economic monitoring systems run by villagers themselves. (Kouokam 1994).

5.5 Making choices between flood options

The complexity of environmental management problems have given rise to the development of a number of decision-making tools. In most cases, these have evolved from the tools applied in conventional business settings. Decision making in a business context primarily involves concerns of a financial nature, allowing monetary valuations to be used as the numerical quantity in the assessment process. When decisions need to be made which concern the wider environment, society and the very ecological base on which we depend for our life support, it is clear that these cannot all be given a monetary value.

A number of useful decision making strategies that are appropriate for dam management have been developed, and some of these are outlined below.

5.5.1 Environmental valuation methods

Evaluating the various costs and benefits associated with the net gains of an upstream dam with managed releases requires employing *environmental valuation* (Box 5.5.1.1). This is particularly important for the downstream environmental impacts of dams and flooding regimes, as many of these involve changes in resources, livelihoods and human health that are non-marketed. However, if a new dam is being constructed, substantial upstream environmental impacts may also occur, such as reservoir flooding, relocation of human populations and alteration of river valleys. Economists currently employ a variety of environmental valuation techniques to assess non-marketed impacts (Table 5.5.3.1). The various techniques that have been used in the context of floodplain and riverine wetland valuation are described in more detail in Barbier et al. (1997).

Box 5.5.1.1 Environmental impacts and valuation

Since the impact of controlled flood releases is likely to have a significant effect on both local society and the surrounding environment, these must be taken into account when planning reservoir management. This can be addressed through a process of Environmental Valuation which allows relevant values to be incorporated into the decision-making process. Environmental values are usually identified through the assessment of scale (how much of something there is), and the application of an appropriate 'price'. Calculation of the 'price' of any environmental attribute can in some cases be directly assessed from the market (e.g. fish prices), or derived through the use of implicit substitutes, known as 'shadow prices'.

Other methods can be used to assess the other use, option and existence values, which make up 'total environmental value'. *Option values* refer to those values which are ascribed to environmental resources as a result of some expectation associated with their possible use in the future. This would include the *bequest value*, which results from individuals placing a high value on the conservation of the floodplain for future generations to use. Existence value may be identified by individuals who do not currently use a floodplain's resource directly, but nevertheless wish to see such resources preserved 'in their own right' for reasons of culture, heritage or biodiversity. These 'intrinsic' values are subjective valuations by individuals unrelated to either their own or others' use, whether current or future. While all of these dimensions of value may be difficult to measure, they must, as far as possible, be included to calculate the 'total environmental value' of any resource. Although they will to some extent be 'site specific', they do have an important role in the decision-making process, and where possible, should be included in any analysis.

Table 5.5.1.1 Evaluation methods and example values.

Upstream impacts

Environmental characteristic	Economic effect, cost or benefit identified (C/B)	Appropriate valuation technique	Some examples of economic impacts resulting from ecosystem changes
Soil erosion and reservoir sedimentation	Reduced storage capacity, decrease in power, lower water quality. (C)	Measures of productivity changes (eg. loss of power), preventive expenditures, market pricing	Watershed protection values found to be greater than timber productivity in British Columbia (Canadian Ministry of Environment, 1995)
Chemical changes in reservoir water quality	Loss of fishery production, change in treatment costs. (C)	Changes in productivity, market pricing and preventative expenditures	Water quality improvements in the Danube estimated to have floodplain benefits of $458/ha. p.a.(Gren, 1994)
Loss of productivity of flooded area	Loss for timber/non-timber products, grazing. (C)	Changes in productivity, market pricing.	Forestry in Indonesia valued at US$67/ha/p.a. (Ruitenbeek, 1992)
Changes in flow rates out of dam	Changes in energy/water output from dam – change in use value (C)	Changes in productivity, market pricing.	Economic benefits of controlled flood releases to maintain the Nadejia-Nguru Wetlands of Nigeria estimated to be $50-75/$m^3$ of water released.(Barbier et al.,1993)
Modification of aesthetic quality of river valley	Area becomes more or less attractive to humans. (C/B)	Contingent valuation, travel cost method, hedonic pricing.	Aesthetic values of a Thai national park estimated at 13 Million Bhat. (Grandstaff and Dixon 1986).

Downstream impacts

Environmental characteristic	Economic effect, cost or benefit identified (C/B)	Appropriate valuation technique	Some examples of economic impacts resulting from ecosystem changes
Silt removal from downstream flows	Clearer irrigation channels downstream (C/B), and loss of fertiliser functions of silt. (C)	Preventive expenditures, damage costs avoided.	Benefit of improved herding in Waza Logone Floodplain estimated at 30 million CFA p.a. Positive agricultural benefits also identified (IUCN 1994)
Chemical changes downstream water quality	Loss of fishery production, change in treatment costs. (C).	Changes in productivity, market pricing, and preventative expenditures	Positive values identified for nitrogen abatement functions of wetlands in Sweden (Bystrom, 1998)
Changes in water temperatures	Changes in crop yields such as rice, loss of fisheries etc. (C/B)	Changes in productivity, market pricing.	Impacts of changes in water temperatures on fisheries identified but not quantified (Meier and Munasinghe, 1994)
Reduction in natural floods	Reduction in recession agriculture, reduction in flood damage to infrastructure. Changes in use, option and intrinsic values. (C/B)	Avoidance of flood damage costs, changes in productivity, preventative expenditures, market pricing	Flood protection value of Boston wetlands estimated at US$17M.p.a. (McNeely, 1988) See also Hadejia-Jama'are River Basin case study, above.
Loss of access to resources	Livelihood impacts, loss of natural capital (C)	Productivity changes, market pricing, replacement costs, opportunity cost pricing.	Value of non-timber forest products and services for forest dwellers in Guyana assessed at US$357 per capita p.a. (Sullivan 1999)

Upstream and downstream impacts

Environmental characteristic	Economic effect, cost or benefit identified (C/B)	Appropriate valuation technique	Some examples of economic impacts resulting from ecosystem changes
Health impacts on humans and animals	Decrease in animal productivity, medical treatment for human conditions, increase in mortality rates.(C)	Health care and veterinary costs, loss of earnings, preventative expenditures.	Increased incidence of Malaria valued in terms of treatment costs etc. (Meier and Munasinghe, 1994)) Increased prevalence of Malaria, Schistosomiasis, and Rift Valley Fever found in Senegal valley after dam construction (Verhoef,1996).
Enforced resettlement	New infrastructure required, loss of production, social costs (C)	Relocation costs, market pricing.	Relocation costs associated with the Upper Kotmale Hydro Project estimated at $6,500 per household in Sri Lanka (JICA, 1987),
Impacts on fish migration and spawning	Changes in fish production (C/B)	Changes in productivity, market pricing.	Fishery benefits of delta mangroves valued at US$130/ha in Thailand (Christensen,1982); breeding ground value of estuarine ecosystem in Belize estimated in terms of increased fishery outputs (Lindberg and Enriquez, 1994).
Opportunities for recreation, tourism and related employment	Gains or losses in tourist activity (C/B)	Gains/losses in tourist revenue, contingent valuation, travel cost method, hedonic pricing.	Value of un-sedimented water for tourism revenue found to be greater than logging revenues in Thomson River in Australia (Read-Sturgess, 1994)
Wildlife and biodiversity	loss of habitats and species (C)	Contingent valuation, travel cost method, hedonic pricing.	Loss of cloud forest valued at US$37,517,314 (Echeverria et al.1995) Imputed value of capturable biodiversity benefits to Indonesia assessed at US$1500/$Km^2$ p.a. (Ruitenbeek, 1992)
Opening of new areas through access roads	Ecological disturbance, changes in production (C/B)	Contingent valuation, hedonic property values.	Loss of Spotted Owl habitats valued at US$56 per household in California (Loomis and Gonsalez-Caban, 1998)
Greenhouse gas emissions though inundation and loss of forest	Deforestation, long term climate impacts. (C/B)	Preventive and adaptive expenditures	Total net impact of CO_2 emissions from Kukule Hydro Project in Sri Lanka estimated at 999,000 tons. Valued at $15/ton abatement costs, this is equivalent to an externality value of about $15 million. (Meier and Munasinghe, 1994)
Impacts on cultural heritage sites	Cultural heritage sites lost through dam construction, loss of social capital. (C)	CVM, travel costs, citizens juries, relocation costs.	Cultural value of Warrumbungles National Park in Australia estimated to increase regional income by $323,400p.a. (Ulph and Reynolds, 1984)

Notes:

1. When prices are calculated on the basis of market prices, it may not fully reflect all the 'value' of the attribute being considered. The two main reasons for this are:
   a. Market prices reflect the purchase price of something, including any tax or subsidy incorporated in them. In some cases, the tax element within market prices may be very high (e.g. petroleum), and thus estimates of the value of such products based on market prices may be overstatements of the actual value of the good or service itself.
   b. From a theoretical viewpoint, market prices do not include the value of *consumer surplus* (the additional benefit gained from the consumption of a good which a consumer would be willing to purchase, at a price higher than the market price). This can mean that values obtained on this basis may be underestimates.
2. Because of the positive multiplier value associated with most developmental changes, the macroeconomic effects of changes in any economic system are almost always greater than the initial effect. For example, when estimating the value of infrastructure changes from dams, it is important to remember that while these changes may be estimated on the basis of revenues generated in engineering projects, saving of transport costs etc., the final impact is much greater, in the sense that it generates employment in that, and other, sectors. In projects in developing countries, this factor is even more complicated by the proportion of imports required by the project itself, since the value of imports is one of the things which may influence both the country's exchange rates, and the value of the multiplier itself. In the case of large projects in small countries, this can be an important consideration. It is important to remember that the multiplier effect of any of these changes is not included in this analysis, and not addressed by any of the valuation methodologies included here. (For more detail on macroeconmic issues, see Dornbusch and Fischer, 1994, pp.458-460.)

In estimating the impact of river modification projects, it is important to examine the contribution made by the project to the level of Gross National Product (GNP), as opposed to the Gross Domestic Product (GDP), as this will indicate the extent to which benefits are retained by the country in question, as opposed to being repatriated to other countries who may be the owners of the power company or commercial agri-business which provides motivation for the building of the dam in the first place. (See Todaro, 1994, P.436.)

5.5.2 Cost benefit analysis

Most planning and development decisions to build and operate a dam are based on an economic assessment of its benefits compared to its costs, although other factors such as environmental impact (see Section 5.5.3) are increasingly considered. The benefits generated by the dam due to the increase in 'upstream' water uses may include intensive irrigation, domestic supply or power generation. Traditionally, the assessment of costs was restricted to the capital costs of dam construction and the recurrent costs of maintaining canals and pipes. More recent assessments have examined the wider impacts of dams, in particular the potential loss in 'downstream' economic benefits that may result from reduced or diverted hydrological flows and restricted inundation of natural floodplains. In some cases this has led to the re-definition of operating rules to allow for managed flood releases to maintain downstream floodplain benefits.

To apply *cost-benefit analysis* – the economic assessment of costs and benefits to determine the gains and losses to society of a development option – to the problem of deciding between different flood release options for a dam requires the following steps:

- The different flooding regime scenarios need to be specified, including the resulting physical impacts associated with each regime in terms of changes in 'upstream' water uses (e.g., irrigation projects, hydropower, water supply, etc.), any necessary modifications to dam design, structure and operation, and the likely health, livelihood and resource implications of any changes in the 'downstream' hydrology and floodplain area.
- The various benefits and costs associated with each flood release regime need to be assessed and translated into monetary terms through the application of *economic valuation* methods.
- As the benefits and costs associated with each regime occur over time, yet the decision as to which flood regime to adopt must be taken today, this means that future benefits and costs must be 'discounted' into 'present values'.
- The resulting discounted benefits and costs for each flood release regime must be compared, and the regime with the highest *present value net benefits* (i.e. benefits less costs) should be preferred, provided that this value also exceeds the present value net benefits of the dam design *without any flood releases*

The first step is covered in the rest of these guidelines and therefore will not be discussed further here. However, it is highly recommended that the economist conducting the cost-benefit analysis (CBA) should be involved with the hydrologists, ecologists, socio-economists and other experts assessing the physical impacts of the various flood regimes in order to determine jointly the appropriate benefits and costs that need to be assessed.

Numerous guidelines have been written on the general economic methodology to be employed in a CBA, including adjusting the monetary values of benefits and costs to eliminate the influence of any market distortions, taxes or subsidies on these values, appropriate discounting procedures, and the overall economic rationale for the CBA approach (see, for example, Gittinger 1982; Perkins 1994; Ray 1984). The remainder of this section will discuss briefly the specific application of CBA to the problem of choosing a preferred flood regime option, and the particular problem of valuing non-marketed environmental impacts associated with various flooding regimes.

How cost-benefit analysis works

The rationale for assessing the economic impacts of dams, including the possibility of managed flood releases from them, is relatively straightforward.

For example, suppose that an upstream irrigation project is to be established on a river in a semi-arid river basin. If this project diverts water from an existing floodplain downstream, then any resulting loss in wetland benefits must be included as part of the overall costs of the project. Given direct benefits (e.g. water for irrigated agriculture), B^D, and direct costs (e.g. costs of constructing the dam, irrigation channels, etc.), C^D, then the direct present value net benefits, NB^D of the project are:

$$NB^D = B^D - C^D.$$

Box 5.5.2.1 Value of water for hydropower, irrigation and public supply

It is important to determine the value of water in a reservoir to be able to compare it with alternative uses such as managed flood releases. The value of water in its end use varies considerably and is dependent on a number of factors. The three principal end uses of water from reservoirs are: hydropower, irrigation and public water supply. The value of water in each of these uses and the factors on which it depends are discussed below.

Hydropower The value depends on the head across the turbines, and the cost of alternative sources of generation. The value of the water would normally lie within the range of US$ 10 to 20 per 1000 m^3 though in exceptional cases where the available head was high it could be as much as US$ 50. It should be noted however that the water is not consumptively used and may be available for other purposes. Specific examples are:

		US$ per 1000 m^3
Kariba	Zambezi	20
Roseires	Sudan	10

Irrigation The value of water depends on the method of irrigation, the type and value of the crops grown, and the crop water requirements, which in turn is influenced by climatic conditions. It also depends on whether the irrigation water provides the whole of the water to the crop or is merely supplementary at key times in the crop cycle, the latter case having a considerably higher value per unit than the former. In our experience the value of water used for irrigation purposes lies within the range of US$ 10 to 100 per 1000 m^3, although exceptionally, some intensive methods, such as drip irrigation, have achieved US$ 50 per 1000 m^3. Specific examples are:

		US$ per 1000 m^3
rice	Pakistan	20 (WCD, 2000)
cotton	Syria	40
wheat	temperate climate	50
cotton/groundnuts	Sudan c. 1980	70
intensive cropping	Morocco	120 to 350
drip irrigation	Israel	50

Public water supply Based on what customers pay for domestic and industrial water supply in different parts of the world the value of water in this end use can be regarded as lying within the range of US$ 250 to US$ 2000 per 1000 m^3. In this case a major part of the cost is involved in treating and distributing the water to the customer, so it does not reflect the value of the raw water at source. There are usually alternative sources of water available and this will set a limit in assessment of the opportunity cost of water used for this purpose. Specific examples of average charge for water are:

		US$ per 1000 m^3
Manila	Philippines	250
Beirut	Lebanon	300
	Thailand	330
Istanbul	Turkey (includes sewerage)	800
	Germany	1600
	Portugal	750

Note: These figures are marginal values and do not include the cost of infrastructure or external costs. Net present value is normally discounted over 30 years at 10% (though sometimes 12%)

However, by diverting water that would otherwise flow into downstream floodplain wetlands, the irrigation project may result in losses to floodplain agriculture and other primary production activities, reduced groundwater recharge and other external impacts. Given these reductions in the net production and environmental benefits, NB^{W}, of the wetlands, then the true present value net benefits of the development project (NB^{P}) are $NB^{D} - NB^{W}$. The development project can therefore only be acceptable if:

$$NB^{P} = NB^{D} - NB^{W} > 0.$$

If the for-gone wetland benefits are significant then the failure to assess the loss of wetland benefits will clearly lead to an over-estimation of NB^{P}. This is tantamount to assuming that there is no opportunity cost of diverting floodwater from the wetlands, which as we have noted throughout these guidelines is rarely the case. Moreover, the loss in wetland benefits, NB^{W}, may be so substantial that NB^{P} is in fact negative and the irrigation project is essentially 'uneconomic'.

Now supposing that the upstream irrigation project can be modified to allow for managed releases. This may increase the direct costs of the project and/or lower its upstream benefits, such that the present value direct net benefits of the project with releases, $NB^{D}¢$, are less than the net benefits without such releases, NB^{D}. However, the managed releases may lead to much greater preservation of downstream wetland benefits, so that

$$NB^{P}¢ = NB^{D}¢ - NB^{W}¢ > NB^{P} = NB^{D} - NB^{W}.$$

In other words, the net gains of the upstream irrigation project with managed releases is greater than if the project is built without such releases. Consequently, if the project is to proceed, then its design should be modified to include managed flood releases to conserve downstream wetland benefits.

Limitations of cost-benefit analysis
Economic values are not the only criterion on which to make decisions about dam construction and operation. It is also vital to consider the other political, social, historical or ecological issues. Political considerations may include the obligations of a state under international conventions such as the Biodiversity and Wetlands (Ramsar) Conventions. Consequently, species may therefore be protected without the need to show that this might have an economic benefit. Some states have agreements to ensure that certain quantities of water flow downstream to their neighbours along international rivers. Decisions on floodplain management may also be affected by national policies, such as the desire to make a country self sufficient in rice, which could be used as an argument for intensive irrigation of former wetlands, even where the traditional extensive farming methods may make more efficient use of water. Social considerations may include the decision to maintain traditional ways of life (thus effectively giving it a high value), which depend on wetland resources, such as fishing, flood recession agriculture and herding, and which govern the social fabric of a local society.

It is of course impossible at this point in time to accurately assess all of the issues relevant to dam development in monetary terms, so conventional and even extended cost benefit approaches fail to adequately serve as a basis for decision making. Evidence of this change in attitudes towards analytical methods is demonstrated by the fact that the World Bank and other development banks, which have traditionally looked favourably on dams and other major water projects, have shifted their policies to emphasise a more thorough examination of the full benefits and costs of these projects.

Box 5.5.2.2 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 a griculture, grazing resources, non-timber forest products, fuelwood and fishin g for local populations, and helps to recharge the regional aquifer serves as an essential groundwater source. However, in recent decades the floodplain has come under increasing pressure from the construction of the Ti ga and Challawa Gorge dams upstream. The maximum extent of floodin g has declined from 300,000 ha in the 1960s to around 70,000 to 100,000 ha more recentl y and 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 US$ 32 per 1000 m^3 of water (at 1989 prices). However, the returns per crops grown in the Kano River Project were at most only US$ 1.73 per 1000 m^3 and when the operational costs are included, the net benefits of the Pro ject are reduced to US$ 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 pro jects were then compared to the resultin g economic losses to downstream agricultural, fuelwood and fishing benefits. Given the hi gh productivity of the floodplain, the losses in economic benefits due to chan ges in flood extent for all scenarios are lar ge, ranging from US$2.6-4.2 million to US$23.4-24.0 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 lar ge-scale irrigation schemes would produce the greatest overall net losses, around US$20.2-20.9 million.

These results suggest that the expansion of the existin g irrigation schemes within the river basin is effectively 'uneconomic'. The introduction of a re gulated flooding regime would reduce the scale of this negative balance substantially, to around US$15.4-16.5 million. The overall combined value of production from irrigation and the floodplain would however still fall well below the levels experienced if the additional upstream schemes were not constructed.

5.5.3 Environmental impact assessment

Most countries of the world have recognised for many years the need to consider environmental impacts of development projects. This has led to widespread adoption in law of the need for Environmental Impact Assessment (EIA; Box 5.5.3.1). However, in many cases impacts are still considered as an inconvenience at the end of the development process, after a project has been designed. The solution is merely to ignore impacts or reduce them to some extent. EIA does not normally evaluate the impacts in terms that can be compared with the designed benefits of the project. Nevertheless, significant environmental impacts have led to major projects being cancelled or the design significantly changed. Ideally, environmental impacts should be an integral part of the development process, considered from the start when options for development are first considered, not as an after-thought when the project is near completion.

The current trend in EIA is to incorporate more social impacts, as measured by Social Impact Assessment techniques, and to move away from the 'do no harm' approach to the 'do good' approach (Goodland, 2000). Recognition has also been explicitly expressed that any environmental and social impact assessment should be made from the very inception of any project or plan, at the same time as other project design elements, rather than after it's design has been completed. In the case of flood release planning therefore, this suggests that both social and environmental impacts must be assessed and addressed from the beginning of the decision-making process, in a transparent and participatory way. While EIA is often an important statutory regulation within any process of development, there is often a lack of capacity in its implementation, or a lack of commitment on the part of the developers to subject themselves to the inevitably higher costs such assessments may incur. This has meant that while an EIA may be carried out, it may not be done efficiently and comprehensively, and indeed may be done in such a way as to provide more support to the developer than protection for the environment (Hirji and Ortolano, 1991).

Box 5.5.3.1 Environmental impact assessment (EIA)

EIA provides a framework for assessing the implications of development options. Impacts at all scales should be considered including the local, river basin, regional, national and international scales. This is particularly important where impacts may occur outside the catchment, or aquifer unit, or have an impact downstream beyond a regional or national boundary. In addition to the scale of the impacts, where possible the true cost to society of loss or degradation of aquatic ecosystems should be determined. EIAs must include impacts on human health, employment opportunities, customary rights (such as access to resources), the atmosphere and climate, ecosystems, natural resources, as well as any upstream-downstream effects.

Where the impact can not be determined with sufficient accuracy the precautionary principle should be adopted. Principle 15 of the Rio Declaration calls upon states to apply the precautionary principle stating that "where there are threats of serious or irreversible damage, lack of scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

EIAs are required on projects that exploit hydrological resources, extract non-renewable resources or might cause a substantial change of the renewable resource use or farming or fishing. The EIA process involves:

- Screening – to determine whether or not a thorough EIA is required;
- Scoping - to identify the most significant environmental issues;
- the assessment – which should involve local communities likely to be affected; .
- external review – to obtain an impartial judgement of the assessment if the project is implemented;
- monitoring (undertaken by the relevant authority).

Details of EIAs are available in many documents including OECD (1992).

5.5.4 Risk assessment

Risks associated with development projects include financial risks, health risks, safety risks and ecological risks. Since the 1980s, the need to make some assessment of these risks has become more explicit, and few major projects are undertaken today without some consideration being made of the potential risks involved. While some risks may be assessed statistically on the basis of frequency estimation, others may only be considered in qualitative terms. Some techniques have been developed to address the issue of risk, and these include hazard assessment, dose-response and stress-response methods, and safety and health risk assessments linking potential hazards to probabilities of their occurrence at any particular site. In the past, most risk assessments have focused on the risks borne by the donor agencies or developers, with very few assessments ever being made from the point of view of those most affected. The need to readdress this imbalance has been increasingly recognised following the Bhopal accident in 1984.

In the case of managed flood releases, there are a number of possible risks, but when a wide variety of variables are taken into account, the likelihood of many of these occurring is reduced. During the process of decision-making about flood releases, the possible risks which may occur need to be considered and evaluated both quantitatively and qualitatively, and from the viewpoint of a wide range of stakeholders. How these risks may be mitigated, and any costs associated with that, will be an important consideration in the final decision about the value of flood releases.

5.5.5 Multi-criteria analysis

Multi-Criteria Analysis (MCA) is a decision tool which takes the analytical process beyond the limits of cost benefit analysis, and is designed to cope with both qualitative and quantitative data, enabling decisions to be made on the basis of well-informed scientific principles and dynamic stakeholder participation. Compared with standard neo-classical techniques, these methods allow the analyst to take account of a wider variety of factors when reaching a decision and allow for alternative ethical and value systems to be taken into account.

For multi-criteria analysis to be a useful tool, it is important that the basic problem be structured correctly. This is likely to be the result of consultations with all of those involved, and is a dynamic process which may change with time. The identification of the criteria, the suggestion of the alternatives available, and the evaluation approach to be used, all need clarification before the problem can be solved. The problem itself can be structured as a model, and the most widely used approach places the criteria in an hierarchical format. Typical of this method of analysis is the Analytical Hierarchy approach, and the Multi-attribute Value Function approach[2], where criteria are either organised into an hierarchy, or else selected into a small set of important criteria with which the options are compared. This procedure is illustrated in Box 5.5.7.2.

5.5.6 Bayesian techniques

Bayesian networks (sometimes called belief networks or casual probabilistic networks) provide a method for representing relationships between variables even if the relationships involve uncertainty, unpredictability or imprecision. Links between variables can be established deterministically or probabilistically using available data or, if more appropriate, expert opinion. By adding decision variables (i.e. variables that can be controlled) and utility variables (i.e. variables that we want to optimise) to the relationships of a belief network, it is possible to form a decision-making tool.

Bayesian networks may be useful, in situations such as managing dam releases, because they enable the integration of physical and socio-economic variables within a single modelling framework. They also allow inclusion of expert knowledge on the same basis as more objectively derived data. Hence, the approach enables the creation of a model that may contain mathematical relationships as well as subjective elements corresponding to the experience of people who are an integral part of the system. Furthermore, the essentially graphical nature of the approach facilitates formal discussion of the system structure with people from a wide variety of backgrounds and so encourages interdisciplinary discussion and stakeholder participation (Batchelor and Cain, 1999).

5.5.7 Comparing decision-making methods

Since different decision-making frameworks are appropriate in different circumstances depending on the objectives of the study, it is not possible to recommend any "best" approach. Rather advantages and disadvantages are given which will aid selection in particular case studies.

[2] More information on these approaches are provided in the reference section .

Table 5.5.7.1 A comparison of decision making frameworks

Framework for decision-making	**Advantages**	**Disadvantages**
Environmental Impact Assessment	• Enshrined on law in many countries • Guidelines widely available • Value need not be assigned to impacts	• Often undertaken as an afterthought • Often poorly implemented • Costs of impacts not known • Ignores health and social impacts
Economic cost benefit analysis	• The use of money as a numeraire allows information about the various options to be easily assimilated into existing policy making structures. • Most stakeholders do have some understanding of the role of money estimates, and thus different scenarios can be relatively easily evaluated • The methodology is straightforward and can be conducted relatively easily.	• Monetary values are not easy to determine for many goods and services, especially those provided by the environment. • Such monetary values do not always represent the preferences of all of the relevant stakeholders • This method cannot take account of other types of values such as social, cultural, ethnic and ecological values.
Multi-criteria Analysis	• Allows the utilisation of both qualitative and quantitative data, thus enabling the incorporation of a broader range of variables. • Knowledge can be included both from informed experts and scientists, as well as local people and indigenous groups • Appropriate data can be collected in a participatory manner to ensure full representation of views. • Graphical representation of the data and links between different types of data, can make stakeholder involvement more feasible. • Alternative policy scenarios can be evaluated simply by changing the weights applied to the various criteria. This enables policy makers to have a better understanding of possible consequences of various decisions.	• Rigorous mathematical procedures underlie the method, and thus its implementation may require an input from experts, or the use of computer based software. • The use of weights can be seen as a disadvantage as this inevitably incorporates a subjective element. **Note:** this is not always considered a disadvantage. • The method requires a considerable amount of data to be collected to enable the incorporation of all of the various criteria. However, if this is collected in a participatory manner, it incorporates the various stakeholders in the decision-making process, and possibly results in an easier acceptance of the final decision
Bayesian Networks	• Graphical nature of the approach facilitates formal discussion of the system structure with a wide range of stakeholders from different backgrounds, encouraging interdisciplinary data analysis and stakeholder participation. • ability to specify relationships between variables in uncertain terms. • expert knowledge can be incorporated into the model on the same basis as more objectively derived data. This allows the creation of a model that may contain mathematical relationships as well as subjective elements corresponding to the experience of the people who are, in many cases, an integral part of the system being modelled. • data collection programmes can be designed to provide comprehensive data sets used to specify the conditional probability tables.	• The method needs to be applied carefully to appropriate situations, and is not applicable to every decision. • Some expertise is required to apply the method correctly, and its mathematical base requires appropriate use of suitable hardware and software. • Scale issues need to be carefully considered in the application of the method.

6 Implementing managed flood releases

This chapter deals with the establishment of mechanisms, procedures and methods for implementing a flood release programme. Prerequisites for the successful design and implementation of a flood release scheme are: good quality data, technical skills and community involvement. Data are essential firstly, to understand the links between flooding, ecological processes and natural resource use, and secondly, for evaluating the effectiveness of different release options and for optimising and implementing the flood release programme. Technical skills (where necessary strengthened through capacity building) are critically important for assessing alternative options, developing dialogues with different stakeholders and implementing the flood release programme. Community participation is essential, to ensure that all stakeholders understand and feel influential in the planning process and to make certain that flood releases make a positive contribution to meeting their needs and aspirations. The body responsible for managed flood releases should be clearly mandated to follow a process of community participation and given adequate and ring-fenced resources to do it.

6.1.1 Planning and managing flood releases

6.1.2 Forming a multi-disciplinary team

The mandate to make managed flood releases from reservoirs lies with the river basin development authority or other responsible public body, although operation of the dam may be the responsibility of the dam owner, which might be a private company. To plan, implement and monitor flood release requires a multi-disciplinary team. Permanent staff of the authority will manage the process, but the full range of specialist expertise required will not normally be available and consultants will need to be contracted in for certain aspects of the work. The team should include:

- Hydrologist
- Geomorphologist
- Aquatic ecologist
- Natural resources expert
- Anthropologist/social scientist
- Dam engineer
- Economist
- Health expert
- Legal expert

Box 6.1.1.1 Example outline Terms of Reference for the hydrologist

1. Organise, support and supervise the collection of data by a field team on river flows, rainfall, groundwater levels and floodplain inundation.
2. Determine the flooding mechanism of the floodplain
3. Estimate the natural flood frequency curve for the floodplain.
4. Calculate the relationship between flooded area and river flow.
5. Work with other team members to define the magnitude, frequency, duration and timing of floodplain inundation required.
6. Determine the storage/yield characteristics of the dam.
7. Calculate the release pattern required to achieve the desired inundation of the floodplain.

The work of the team should be monitored by a steering committee chaired by a senior member of the river basin development authority and composed of key stakeholders representatives.

Box 6.1.1.2 Example outline Terms of Reference for the aquatic ecologist

1. Organise, support and supervise the collection of data by a field team on ecological data, such as fish catches from the floodplain.
2. Review available information on life histories and habitat requirements of key species
3. Determine the relationship between species populations and area of the floodplain inundated
4. Work with other team members to define the magnitude, frequency, duration and timing of floodplain inundation required.

Box 6.1.1.3 Example outline Terms of Reference for the economist

1. Organise, support and supervise the collection by a survey team of economic data related to products, functions and attributes of the inundated floodplain.
2. Analyse the survey data to determine the monetary and non-monetary value of products, functions and attributes of the inundated floodplain (giving the results as US$ per unit volume of water)
3. Assess the economic performance of the intensive irrigation scheme or hydro-power plant supported by the dam (in terms of US$ per unit volume of water).
4. Compare the results of the value of water use in the floodplain with that in the intensive irrigation scheme/hydropower plant.

Box 6.1.1.4 Example outline Terms of Reference for the health specialist

1. Organise, support and supervise the collection of secondary data and community survey data related to health concerns associated with the floodplain.
2. Interview key informants including other members of the team in order to acquire additional evidence for the assessment.
3. Analyse the data to assess the changes in health determinants associated with the change in flood regime as they may affect each stakeholder community during each project stage.
4. Compare the health impacts of alternative flood regimes.
5. Recommend health safeguards and mitigation measures that can be incorporated in projects plans, operation and budgets.
6. Ensure local health sector involvement in planning

Boxes 6.1.1.1-4 provide example outline Terms of Reference for selected members of the team. These would need to be extended to cover all issues related to a particular study.

6.1.3 Information collection, organisation and dissemination

Good information is a key element in any development process. A data collection strategy should be developed and information collected on all aspects required to define the managed flood release requirements of a catchment, such as hydrology, vegetation, soils. Floodplain livelihoods, including recession agriculture, grazing, must be identified and recorded and health data assembled. Local communities should be involved in data collection, especially on local traditional knowledge. In addition, it is vital to establish a data management strategy and set up databases to hold all information. Research programmes should be established to address unanswered questions.

Summary information should be published in a form that is comprehensible to local communities and copies widely circulated. All information must be made freely available by establishing a records centre and publicising its existence.

6.1.4 Training, institution strengthening and awareness building

Training for effective planning and management

Technical expertise should be developed, though a training programme, in the relevant organisation. In particular, staff in the river basin development authorities who have a background in engineering or rural development may need to learn skills in ecology, geomorphology or stakeholder participation. However, training should not be limited to government institutions but should include private sector and NGOs. Training of staff in functions and values of floodplains is particularly important, as is the development of negotiation skills at all levels. Where possible training initiatives should be developed at the local level.

Strengthening institutions capacity

In many cases, NGO capacity will need to be strengthened to allow them to contribute effectively to decision making and project development. Where they do not exist, stakeholder groups must be established to permit input to policy development, planning and implementation. It is essential that adequate resources are found for agencies and other institutions for planning and managing flood releases. Collaborative management agreements between governments and local communities should be established.

Building awareness

One of the major obstacles to restoring and conserving wetland ecosystems and their dependent livelihoods is lack of appreciation of their functions and values and of the need for regular flooding. Awareness building should be undertaken of awareness to overcome this at all levels. This activity should span from school children to decision-makers and politicians through a clear communication strategy. To achieve this the various target audiences for different awareness raising activities need to be defined and communications material developed to support awareness raising activities.

6.1.5 Establishing institutional co-ordinating mechanisms

Managing flood releases from reservoirs should be a partnership between stakeholders, including government departments, river basin development authorities, private sector and local communities. Effective communication channels need to be established between these groups to ensure a participatory process. Three types of co-ordinating mechanisms are:

- Consultative forum, open to all – this may be particularly useful at the outset of a flood release project to gauge stakeholder views and to obtain their aspirations for the floodplain or delta.
- Steering committee, with key representatives of stakeholders – this group would take decisions on strategic directions of a flood release project
- Water committees, with affectees – these would be small groups of local community representatives, private sector and local government who would make recommendations on the timing and magnitude of floods in any year and would be responsible for reporting information back to their constituencies.

Box 6.1.4.1 Community based institutions in the Phongolo River

In the late 1960s the Pongolapoort dam was constructed on the Phongolo River in north-east South Africa near its borders with Swaziland and Mozambique. The reservoir was filled in 1970 with a view to irrigating 40,000 hectares of agricultural land for white settlers, with no provision for hydropower generation. No assessments were undertaken of impacts of the impoundment on the floodplain where 70,000 Tembe-Thonga people were dependent on recession agriculture, fishing and other wetland resources nor on the biodiversity of the Ndumu game reserve. In the event no settlers came to use the irrigation scheme. The dam changed the whole flooding regime of the river, which had significant negative impacts on agriculture and fisheries.

In 1978 a workshop was held on the Phongolo floodplain to review the future of irrigation and how to minimise the negative impacts on 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 Department of Water Affairs and the tribal authorities agreed to experiment with community participation. As a result, water committees were established, representing five user groups: fishermen, livestock keepers, women and healthworkers (both new primary health care workers and traditional herbalists and diviners). They were given the mandate to decide when flood waters should be released. These committees were very successful at implementing people's views and have led to management of the river basin to the benefit of the floodplain users. Indeed they have been so successful that attempts have been made to disband them by the KwaZulu government as they were seen as a threat to power.

Objective

The aim of the institutional co-ordination is to ensure that all the different parties that will have an interest in managed flood releases are properly involved and represented at each stage of the planning, implementation and operation of the project. This necessitates establishing a institutional framework within which responsibilities are clearly defined in an appropriate way. Table 6.1.4.1 identifies the different stages in the implementation of a typical project and the representation of the different parties.

Table 6.1.4.1 Representation of different stakeholders in managed flood releases

Function	Government	Operating authority	Public stakeholders
Planning		*	*
Financing		*	
Construction		*	
Reservoir filling			*
Managing releases			*

Legend
Shading denotes primary responsibility; * denotes participation

The parties involved have been grouped into the Government, the Operating authority and the Stakeholders. The Government is normally represented by a Ministry or Government Department. The Operating authority is the body that acts as the owner of the dam in terms of the operations. If the private sector is involved it may involve some delegation of authority from the public body to the operating entity which would also need to be taken into account. The public stakeholders are all those parties interested in the managed releases including farmers, fisherfolk, irrigation companies, electrical companies etc.

Ideally, the Government will be responding to the demands of the stakeholders in planning, building and operating a dam project and also seeking to optimise overall benefits to them when planning and implementing managed flood releases. The operating authority should be the vehicle through which the different interests are reconciled and an agreed water management policy is implemented. The opportunities to establish and strengthen these

- Organising the downstream users – it is likely in a flood plain where traditional users predominate that there will be a substantial number of small subsistence farmers. In order for their views to be taken into account there needs to be a form of collective organisation. This could be based on the village system or on groups of water users. The establishment of such groupings could well require some preparation, which should ideally be carried out during the planning and construction phases of the project.
- Reconciling the different user requirements – it is likely that releases for managed flood flows will be using water that could otherwise be allocated for other purposes, for example irrigation, hydropower and water supply. There therefore needs to be a forum for the different users to have their requirements presented and to hear the viewpoints of the operating authority. A system for reconciling the different needs and producing an agreed management plan for the reservoir and releases is essential. The outcome should be a water management strategy, which is clearly announced and communicated to the different users.
- Adjusting programmed releases to hydrological variations - the achievement of a desired flood hydrograph will normally be the result of reservoir releases supplementing natural flows. Skill is required to combine the two effectively to produce the desired flood levels for given durations. The operating authority will need the appropriate hydrological and hydraulic tools and trained staff to forecast and simulate flows along the target river reaches. There is scope for introducing the private sector into this by delegating certain functions performed by the operating authority to a private operator. In these circumstances the private operator would only be carrying out the releases in a technically optimal manner against the background of the agreed water management strategy.
- Monitoring the actual outcomes and adjusting as appropriate - the actual extent of flooding can be easily measured using satellite imagery and the impact on stakeholders and their views needs to be fed back into the development of the strategy for the following year.

6.1.6 Creating appropriate legislation

Many countries have legislation that influences the flow of water in a river, and the exploitation of related natural resources, such as fish, arable land and grazing land. For example, Pakistan has the Indus Accord that apportions water resources between its Provinces and hence impacts on the flow which reaches the Indus delta. Legislation also determines the amount of water that can be stored in a reservoir and how much can be released from it.

Some legislation acts against managed flood releases. For example, laws to drain wetlands or prevent flooding of agricultural land. By April 2000 120 states had signed the Convention on Wetlands (Ramsar, 1971) which encourages the wise use of wetlands and consultation on shared water systems. At the 6th Conference of the Parties of (Brisbane, Australia) member states agreed resolutions to review and amend, if necessary, legislation, institutions and practices to ensure the wise use of wetlands. Furthermore, at the 7 th COP (San José, Costa Rica) member states were asked to eliminate legal instruments and economic measures that act as barriers to wise use and to establish laws that support wise use.

In addition to statutory law, human activities are governed by customary law and religious norms and practices. These may cover access to and use of water and natural resources of wetlands.

An important part of the process of developing and implementing managed flood releases is to review and amend, where necessary, laws relating to the reservoir, floodplain and water courses. This will include rights to construct dams, divert, release or abstract from rivers, cut floodplain forest timber, trap fish or graze cattle. This is particularly vital where laws have are set at a single value, some benefits to the yield of a reservoir can be achieved by maintaining the same annual volume of compensation flow but introducing variable releases (Gustard *et al*, 1987).

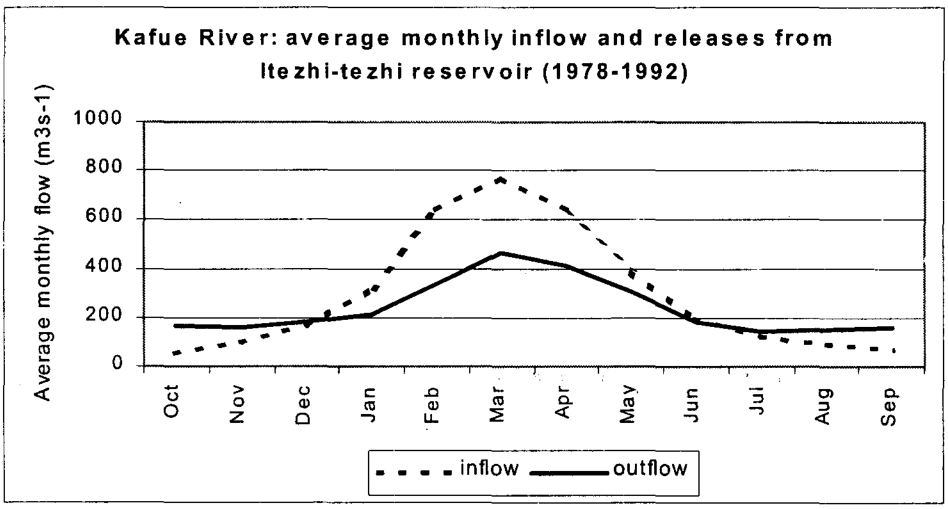
Box 6.2.4.1 Kafue Flats: the importance of low flows

The Kafue Flats are unusual in being directly downstream of one reservoir (Itezhi-tezhi) and directly upstream of another (Kafue Gorge). Their joint operation has affected flooding in the Kafue Flats considerably. Under natural conditions the Flats used to empty almost completely by the end of the dry season. Because of Kafue Gorge a larger permanently flooded area has been created. Releases from Itezhi-tezhi have meant almost no change in the maximum area flooded each year, but the annual minimum flooded area has increased from 300 km^2 to about 1500 km^2. At the downstream end of the Flats, the minimum water-level has been raised by about 3 m and the difference between maximum and minimum levels is now 1.2 m where under natural conditions it was in excess of 4 m. This has affected both the ecology and livelihoods of people utilising the natural resources of the Flats (Box 3.2.3.1).

The number of Lechwe (a rare species of aquatic antelope) dropped from in excess of 90,000 in the early 1970s to about 40,000 in 1998. Although some of the decline is attributable to poaching, many believe that the changed flood regime is also a factor. The decrease in the flood recession zone has also resulted in decreased grazing and the loss of traditional flood recession gardening systems. Furthermore, there was a decline in the number of fisherfolk utilising the Flats from 2634 in 1977 to 1157 in 1985. Although some of this decline is attributable to drought in the early 1980s, many believe that it is also due to the changed flood regime which has caused changes in fish species and increased the effort required to catch them.

Dry season releases from Itezhi-tezhi are greater than the flows that would occur naturally. Although the higher dry season flows may reduce hydraulic gradients and so may slow the drainage from the floodplain, it is unlikely that the higher dry season flows cause flooding directly, because the capacity of the river channel is larger than the releases made. The most likely reason for the greater dry season inundation is the elevated water levels at the downstream end of the Flats. The elevated levels occur because of backwater effects caused by water storage behind the Kafue Gorge dam. It is possible that the natural dry season recession could be simulated much more closely if the Gorge reservoir was drawn down further, earlier in the dry season.

This case highlights both the need for full understanding of the interaction between hydrological regime and ecological functioning/natural resources and the importance, where more than one dam exists of co-ordinating their operation.



The rule curves that optimise releases from the reservoir need to incorporate recommendations for flood releases. To ensure that the releases combine efficiently with the natural flooding regime, telemetered hydrometric networks may be used so that hydrometeorological data (e.g. rainfall or water-levels on tributaries) are available in real time to assist the dam operators (section 6.4). Hence, actual releases are governed partly by the volume of water stored in the reservoir, and partly by the external conditions in the upstream and downstream system.

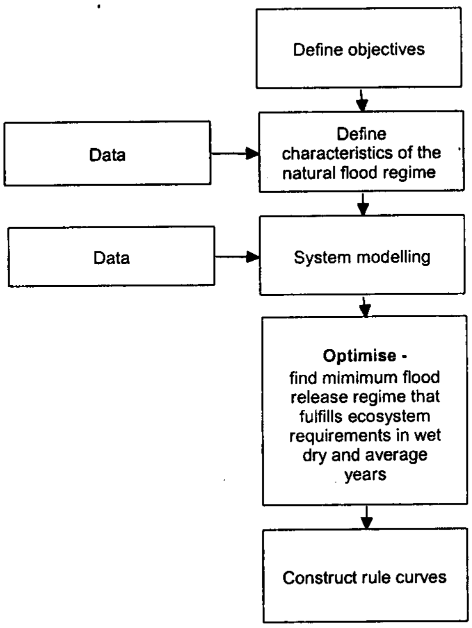


Figure 6.2.4.1 Flow chart illustrating development of optimum flood hydrographs

For all reservoirs, a flood rule curve that indicates, for any time of year, the level above which water in the reservoir cannot rise must be developed. This may call for occasional releases above those required for optimum ecological/livelihood requirements. Such releases provide against excessive spillway releases that might have undesired or even catastrophic consequences on the floodplain and so are a necessary forfeit dictated by safety considerations.

6.3 Designing/redesigning hydraulic structures

Although most dams are designed with low-level sluices, these are rarely of sufficient capacity to permit generation of managed floods. Effective managed flood releases require large capacity outlet facilities, and these should normally be placed such that releases can be made when the reservoir is above 30 or 40 % capacity. For economic reasons, it is unlikely that most operators would wish to make managed flood releases when reservoir storage is below this level. To some extent this criterion will depend upon the capacity of the reservoir relative to the mean annual flood, the time of year, and upon the variability of the annual inflows.

It may be difficult to design and install appropriate release facilities into some existing dams, where it may only be possible to make small managed flood releases using existing discharge facilities. Clearly, for new dams, appropriate low level outlet structures need to be included in the design where managed flood releases are to be made.

6.3.1 Outlet works

The capacity of the outlet works of a storage dam is normally considerably less than that of the spillway because their function is to provide a regulated flow whereas the function of the spillway is to pass excessive floods. The discharge from the outlet works is controlled by gates or valves, so that a high degree of flow management can be achieved.

Where the reservoir storage capacity is relatively small compared to the annual volume of runoff from the catchment, the outlet works assume greater importance. The extreme example of this type of dam is a river barrage in which a large number of gates are built in to a dam structure holding back a low head reservoir. The prime purpose of the dam is not to store water, but to provide control of water level in order to divert the flow into an irrigation canal or to provide depth of flow for navigation.

Box 6.3.1.1 Costs of installing flood gates

The estimated costs of including deep sluices in a new dam is of the order of US$ 2 million. It is now normal practice to include them in design for a number of reasons. Retrofitting such gates in an existing dam would be very expensive and the costs site specific. In some cases it would not be possible. The practical difficulties are formidable. The reservoir may need to be drawn down taking it out of service. It would be necessary to construct a coffer dam. In some cases it may risk damaging the integrity of the structure.

In some storage dams there is a special requirement to evacuate sediment from the reservoir, in which case there may be a facility to pass a large flow of water in the flood season from sluice outlets located at a low level in the dam. In such a case, the function of a high level spillway becomes less important.

For a water supply dam the outlet sometimes incorporates a tower in the reservoir enabling water to be drawn from different levels depending on the thermal, chemical and biological characteristics of stratified water zones. However, the capacity of such outlets would be too small to use for flood discharge.

6.3.2 Spillways

Spillways are designed to pass water through a dam that the reservoir is unable to store. This is achieved by passing it to the river downstream either directly over a length of the dam crest, or into a channel parallel to the dam, or by means of a high level outlet leading to a conduit or tunnel discharging to the river. The water is taken from the top, or near the top, of the reservoir. Spillways may be gated to allow full control of the discharge, or may be un-gated and act simply as an overflow facility. Sometimes the gated main spillway is supplemented for safety purposes by an un-gated emergency or fuse spillway. This facility is designed less robustly and may never be used, but helps to ensure the safety of the dam against extreme flood inflows.

In typical dam operation, river flows are stored in the reservoir and released through low level regulating outlets or turbines without any need for the spillway to operate. The spillway comes into use during floods or periods of sustained high runoff when the capacities of other release facilities are exceeded. The frequency of use will depend on the storage volume of the reservoir in relation to the annual runoff volume and the capacity of the outlet works.

The degree of control that can be exercised over the flow discharged by a spillway will depend on the type of structure. For a simple overflow arrangement the discharge will increase as the water level rises and it cannot be regulated. With a gated spillway the outflow can be varied to some extent with respect to reservoir head by operation of the gates.

6.3.3 Release options for existing dams

Where multiple structures occur, the choice of structure by which to release managed floods from an existing dam will also depend on whether it will be necessary to release water under conditions when the reservoir level has fallen below the minimum operating level for the gated spillway. In the case of a large reservoir it may be required to simulate the natural flood even when the reservoir is too low to allow the use of the spillway facility. Releases can then only be made through a low level outlet, which may not achieve the required flow. Table 6.3.3.1 presents a summary of release options for existing dams.

Table 6.3.3.1 Summary of release options for existing dams

Flow release facility	**Control of flow rate**	**Limitations**
Low level sluice outlet	*Yes*	Capacity normally too small for flood discharge. Where large capacity is provided (eg Roseires, Manantali) outlet must be designed for long term use in high velocity sediment-laden conditions
Hydropower turbines	Yes, subject to power demands	Some power stations have limitations on operation during major flood flows
Gated service spillway	*Yes*	As reservoir water level falls, discharge capacity reduces. If gates are at high level this limits use for passing a managed flood
Ungated overflow spillway (eg "morning glory" type or dam overflow type)	No	Cannot be used to pass a managed flood
Ungated emergency or auxiliary spillway	No	Cannot be used to pass a managed flood

6.3.4 Engineering facilities for new dams

For a new dam the first design choice would be for a large capacity low level outlet. The alternative would be for a spillway with sufficiently deep gates so that it can discharge over a satisfactorily large range of water levels. Table 6.3.4.1 presents a summary of engineering facilities for new dams.

The current gross storage volume of all the world's reservoirs is around 6,500 km^3 and some 12% of this volume has already been lost to sedimentation. The annual loss of this storage has been estimated at between 0.5 and 1.0%. New storage is still being created by dam construction but future projections show the total storage falling well short of matching the demand created by population growth.

Table 6.3.4.1 Summary of engineering facilities for new dams

Facility	Comment
Low level outlet capacity	Multiple outlets with sufficient capacity to pass managed flood discharges
Robustness of outlet design	Gates and linings to resist abrasion by high velocity flow containing increasingly coarse sediment as dam storage reduces with time
Monitoring equipment	Water levels/flows at downstream target areas and in tributaries to be communicated to flood management personnel.

Box 6.3.4.1 Releasing sediment from Tarbela Dam, Pakistan

The huge Tarbela Dam, completed in 1974 as a component of the Indus basin scheme, provides for both irrigation and hydropower. Of the 240,000 tonnes of sediment entering annually, 80% is trapped and unless action is taken the steadily reducing volume of the reservoir will mean that the facility has a severely diminished value by 2030. Studies have been undertaken recently of the technique of flushing sediment through the dam by lowering the reservoir level and releasing high flows for a sustained period. These studies have shown that it is possible to maintain a substantial long-term live storage with only a small annual reduction. 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 for extending the reservoir life it may be necessary to increase the capacity of the low-level flow release facilities at the dam.

The global figures mentioned above mask great regional differences in sedimentation caused by variations in erosion rates which are determined by such factors as climate, geology and population pressure. The preservation of reservoir storage by minimising sediment deposition is a high priority for many regions.

Where low level outlet works can be used to release a managed flood there is the powerful added advantage of discharging sediment from the reservoir at the same time. This has a double benefit: it both extends the life of the reservoir and revives the natural processes of sediment movement down the valley and deposition of fine sediments on the flood plain. However, to be effective in flushing sediment the reservoir level must be low enough to ensure that a scouring action occurs along the reservoir length. If the level is not low enough the scouring will occur only near the outlet. This level has implications for both water storage and power generation.

- It would be essential that effective communications links be established to all interested downstream stakeholders such that they are aware of imminent flood releases. No flood releases should be made until all interested parties downstream have been given time to move vulnerable livestock etc. to safety.

6.4.2 Pilot releases

Once a clear plan for the managed flood releases has been made and engineering structures have been constructed, pilot releases should be made. The results of the pilot releases must be closely monitored, as these will provide information on the effectiveness of each element of the release strategy and to test the various models and assumptions made in the design of the releases. This will include the following:

- quantity and quality of water released from different outlet structure settings
- relationship between flows released and inundation of the floodplain
- unintended impacts, such as flooding of infrastructure
- ecological response to floodplain inundation
- social response to flooding and to natural resource changes

Box 6.4.2.1 Controlled flooding experiments on the Colorado

In March and April 1996 pilot managed flood releases were made from Glen Canyon Dam to evaluate their feasibility for the restoration of sand beaches utilised by animals and also by river runners and campers and the scouring of vegetation and fine sediments deposited in backwater areas. Before the closure of the Glen Canyon Dam in 1963, melting snow in the upper Colorado River basin produced high flows that scoured large volumes of sediment from the river bottom. Later in the summer, receding floodwaters deposited this scoured sediment and also the sediment carried in from tributaries. This annual scour and fill process maintained large sand bars along the river banks, kept sand bars clear of vegetation and kept debris fans (i.e. deposits of cobbles and boulders that form at the mouths of tributaries) from constricting the river. Reduced frequency of flooding since flow regulation began has reduced the size of sand-bars and allowed vegetation to encroach on the channel. It has also allowed debris fans to build up and backwater areas used by native fish to fill in. The experiment included an 8-day period of 1,275 m^3s^{-1} high flow release preceded and followed by 3-day periods of steady release of 227 m^3s^{-1}. The high flow release (which approaches the maximum that can be released from the Glen Canyon Dam without spilling) was more than double the maximum release of 566 m^3s^{-1} allowed under a flow agreement of 1991 that aimed to protect the riparians from extreme daily fluctuations. However, it was only about half the average annual peak discharge that the system experienced under natural conditions (2645 m^3s^{-1}) and was considerably smaller in volume than the typical annual snowmelt hydrograph. Data obtained during the experiment confirms that the expected scour and re-deposition processes occurred. Most of the beach building processes occurred within the first 3 days of the high flow period.

6.5 Monitoring, evaluation and adaptive management

An essential part of any development project is to assess continually how well it is performing against agreed objectives. This then provides the opportunity to adapt the project to meet the objectives more effectively or, in extreme circumstances where necessary, to abandon it.

Evaluation can only be successful where good data are available. Consequently, monitoring should be an integral part of the development process. Monitoring should not only start from inception of the project but must continue long after its completion to determine whether the project meets the principle of sustainability.

Monitoring must cover all aspects of the project from physical and chemical aspects of the hydrology of the river, floodplain and reservoir, the ecological response to flood releases including biodiversity and natural resources and the implications for dependent livelihoods. This must include both the direct impacts on the target floodplain and the opportunity cost of not using the water for other purposes such as irrigation, water supply or hydropower. Only by monitoring the socio-economic aspects of people's lives is it possible to determine whether the project has contributed to poverty reduction.

Pilot flood releases (section 6.4.2) are particularly important as they permit the response of the ecosystem and local communities to flood releases to be tested.

The managing authority must take the results of monitoring very seriously and should take swift action to adapt the project or take remedial actions where necessary.

7. Ten steps to managed flood releases

In this section the information from chapters 1-6 is distilled into 10 steps which need to be undertaken to achieve effective managed flood releases from reservoirs to restore and maintain downstream ecosystems and their dependent livelihoods [4]. It should be noted that the order in which these steps are undertaken may be varied depending on circumstances in any particular dam, reservoir or downstream floodplain. In addition, the cycle should be repeated as improved knowledge becomes available. The 10 steps fall into three levels of action: *Level 1 decision-making* - assessment of the general appropriateness and feasibility of managed floods; *Level 2 decision-making* – defining the optimum magnitude, duration, frequency and timing of managed floods (given the economic, social and environmental trade-offs); *Level 3 implementation* – operationalising the chosen managed flood option.

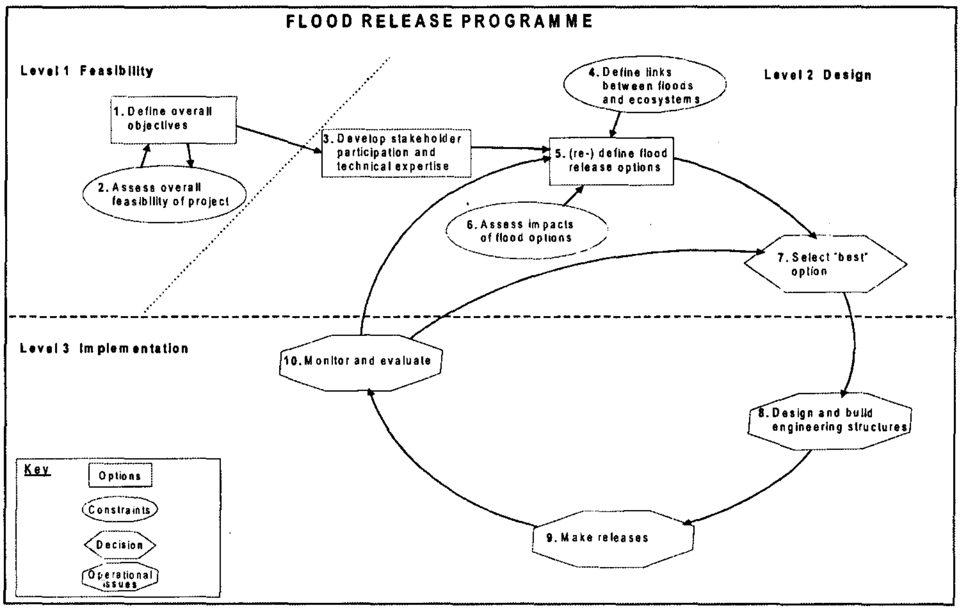


Figure 7.1 Framework for managed flood releases

Level 1 feasibility

Step 1. Define objectives for flood releases

As a first action, clear overall objectives for managed flood releases must be defined through a scoping study of the ecosystem, economy and social structure of the floodplain. It should be recognised that maintaining (in the case of new dams) or re-establishing (in the case of existing dams) the natural flooding regime may not be possible. The aim is to ensure that managed floods are compatible with the livelihood strategies of the floodplain communities. Objectives can include recession agriculture, fishing, animal husbandry or conservation of biodiversity. The sector(s) of society that will benefit from flood releases must be identified, together with any that may suffer. Objectives must to be defined in the context of the river basin management plan and national/regional policies and placed along side options for water use, including public water supply, irrigation and hydropower.

[4] Given the limitations on knowledge, particularly with regard to long term environmental change, a precautionary approach should be adopted.

Step 2. Assess overall feasibility
In parallel with defining objectives (Step 1), the technical and financial feasibility of managed floods must be defined. Three factors are particularly significant. 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 able to work operationally. Where several dams occur on the same river system, it may be necessary to co-ordinate operation of all dams to produce flood releases and hence for each to have suitable release structures, thereby making managed floods less feasible. 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, hydrogen sulphide, iron and manganese) at depth, which is inappropriate for release. In rivers with a high sediment load, sediment will need to be passed through the dam with the flood release, which may be very difficult and expensive. Third, the extent to which a dam controls flooding in target ecosystems, will depend on flow contributions from: the channel on which the dam is situated; tributaries downstream of the dam; local streams; rainfall and subsurface flows. If the dam has limited control on flooding then managed flood releases will have little impact. Changes to outlet structures that enable greater volumes of water to be released should be considered. In addition, broad financial factors must be considered including the costs of installing new release structures in the dam and the opportunity costs of releases (these will be considered in detail in Step 7).

Level 2 design
If after preliminary screening, it is considered that there could be significant benefits from managed flood releases and it is technically and financially feasible, the process can move to level 2 (steps 3-7).

Step 3. Develop full stakeholder participation and technical expertise
A key element in defining appropriate flood releases is to bring together the expectation of stakeholders for floodplain inundation. This should begin with identification of the various stakeholders. As well as dam operators/owners, local authorities, electricity companies, irrigated farmers etc. these will include downstream affectees, who should be regarded as a group subject to specific and heavy risk and needing a specific and innovative effort to involve. They will in turn include floodplain residents and other categories such as pastoralists and fisherfolk. Their current livelihood strategies, assets and aspirations can be mapped. Many of the techniques commonly included under the label of "Participatory Rural Appraisal" may be useful here, but what will be important is a genuine commitment to participation, with adequate time and resources. Where necessary the process should include building and strengthening stakeholder organisations, 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. Participation may be structured through the establishment of a Water Committee, which can help in deciding on the magnitude, frequency, duration and timing of floods and dissemination of the decision to local communities to inform them when the flood is coming.

An equally important action at an early stage is to initiate data collection to improve understanding of the physical, chemical, biological and socio-economic aspects of the reservoir and floodplain. An information centre should establish and its existence advertised and all reports and data should be made publicly available. In addition, technical skills in ecology, hydrology, engineering, health, economics, social anthropology and other should be strengthened within implementing organisations through training and awareness building to understand and use floodplains wisely.

Step 4. Define links between floods and the ecosystem
The relationships between the products, functions and attributes of floodplain and flooding (including sediment and water quality) should be defined in terms of frequency, duration, timing and discharge. In particular, the flooding necessary to maintain those parts of the ecosystem required to fulfil the agreed objectives (identified in step 1) needs to be quantified. For example, some wetlands may be more important for recession agriculture or fisheries. This will aid the definition of an optimum, targeted flood release. Although thresholds of flooding, below which a floodplain ecosystem ceases to function adequately, may exist, in most cases our understanding does not allow these to be easily identified. Available data often exhibit smooth or linear relationships between flood extent and ecological productivity without clear critical points. Consequently, asking the question "how much water does the ecosystem need?" is not appropriate. Instead, the question "how much water do we need to meet specific objectives?" (e.g. fish production targets) may be more relevant.

Step 5. Define flood release options
Taking into account potential objectives (step 1), outline technical and financial constraints (step 2) and ecosystem requirements (step 3) a small number (3-5) of flood releases options should be identified and quantified. Assessment should include, not only the magnitude, timing, frequency and duration of flood releases from the reservoir to produce a target flood extent on the floodplain, but also the impact on water reserves retained within the reservoir for other purposes. This step will almost certainly require a hydrological/hydraulic model of the floodplain, reservoir, main channel and catchment. Definition of flood release options will be an integrated activity encompassing Step 4 (the definition of links between floods and the ecosystem) and Step 6 (assessment of impacts of flood options). The no-flood option should always be included in the analyses. Appropriate flows during the non-flood season must also be addressed.

Step 6. Assess impacts of flood options
Since the final flooding regime will inevitably be a compromise between different objectives, it is important to assess the impacts of the various flooding options to be defined in step 5, both for the 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 defined. Impact assessment can take many forms but environment, health and law are key areas. In most countries a formal EIA will be a legal requirement. There should also be direct and participatory assessment of impacts on livelihoods, using a broad definition of assets to include social capital, and broad and criteria, defined through participation, to evaluate livelihood outcomes. Additionally, laws may need to be established to regulate natural resource use, as there may be an influx of people following restoration of floodplain ecosystem and its natural resources. The adequacy of current laws can be evaluated though a legal impact assessment. Restoration of floods may have positive or negative impacts on nutrition, drinking water quality, injury, stress, communal violence and general well-being. Thus a health impact assessment should be undertaken.

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 available for intensive irrigation, hydropower generation and/or water supply. These impacts must be quantified. In some cases, legislation (design to protect downstream communities) may prevent those responsible for the dam from making flood releases. In addition, they may have rights to use the water, which would require compensation.

Step 7. Select the best flood option
For each option, the monetary and non-monetary costs and benefits and their distribution amongst all stakeholders should be estimated. National or local economic benefits should not be the only criterion 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. A decision should then be made on the most appropriate option using a transparent method, which includes consultation with stakeholders. Multi-Criteria Analysis is one decision tool which takes the analytical process beyond the limits of cost benefit analysis, and is designed to cope with both qualitative and quantitative data, enabling decisions to be made on the basis of well-informed scientific principles and stakeholder participation.

Level 3 implementation

If after detailed assessment, it is considered that managed flood releases constitute an appropriate use of water in the reservoir, the process can move to level 3 (steps 8-10); implementation.

Step 8. Design and build engineering structures
The dam outlet structures will need to be designed and constructed (new dams) or may need to be adapted (existing dams) to allow flood releases to be made and sediment passed (where necessary and feasible). 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 houses, roads, factories) from flooding or to enhance/control inundation in selected areas. Further associated structures may also be required, such as fish ladders, or adaptation of the spillway to minimise disease vectors. Local health centres must be operational and stocked with drugs before the beginning of each flood season.

Step 9. Make releases
Where possible pilot flood releases of various sizes should be made over a period of 2-3 years to test the various models and assumptions made and thus to better determine the response of the ecosystem and of local communities. Further awareness development and capacity building exercises should be undertaken through demonstration of the impacts of the new flood regime. When the flood release programme has been optimised, full releases can be made.

Step 10. Monitor, evaluate and adapt release programme
Adequate ecological, socio-economic monitoring must be designed and established to assess the effectiveness of flood releases in relation to the stated objectives. This requires identification of appropriate indicators to assess if objectives are being attained. Since the time-scales for ecological, morphological and hence social change may be of the order of many decades, monitoring must be continued for long periods of time and adequate funding provided. The flood release programme should be modified as necessary, which may require use of an alternative option or the definition of new options.

Worked example

Box 7.1 contains an example of how each of the steps, 1-10, were undertaken in the case of the restoration, by managed floods, of the Waza-Logone floodplain in Cameroon. However, it should be noted that the steps were not undertaken in this order and no 10 step strategy was followed. Instead the activities in the Waza-Logone project have been re-organised to exemplify the 10 steps developed in this paper.

Box 7.1 Ten steps case study – the Logone floodplain Cameroon

The River Logone drains from the Adamoua plateau in central Cameroon. Before it joins the river Chari, floodwater from the river inundates annually a large floodplain, originally around 6000 km^2. This wetland has 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 6000 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 amongst the local Kotoko people who could earn US$ 2000 in four months. The Fulani name for the floodplain is yaérés, which means "dry season pasture", and 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 carr ying capacity has estimated at 1-2 cattle per ha, compared with 0.2 for surrounding savannah. Floating rice was the main arable crop, since it has low labour demands and fits well into the fishin g calendar. Yields were not high, but enough land was available to ensure self-sufficiency in rice.

Since 1979, the area inundated has reduced, partly by climatic factors, but primarily due to construction of a dam across the floodplain, which created Lake Ma ga to supply water to the Semry II irrigation project. (The dam is adjacent to the river (off-line) and thus does not stop all flow). Floodin g became insufficient in large areas to grow any floating rice and fish yields fell by 90%. The Semry rice scheme was not making full use of water stored in Lake Maga and the release water to rehabilitate the floodplain, whilst retaining enough to maintain rice production, was been identified as a development option. Hydrological, ecological and socio-economic studies suggested that managed flood releases could improved fisheries, agriculture and herding. Though much would depend on the available flood discharges and the response of local people and their environment (in terms of ve getation, fish etc) to renewed floodinn. A potential nenative effect is a larne influx of people who would over-exploit and thus degrade the rehabilitated resources of the floodplain.

The Waza-Logone Conservation Project, co-ordinated by IUCN, undertook a wide range of activities in the floodplain and surroundin area over 8 ears which hi hli hted man of the issues discussed in these uidelines. The results of these activities are used to exemplif the 10 steps to mana ed flood releases.

Step 1. Define overall objectives of flood releases
The ob ectives were to restore the biodiversit and the livelihoods of communities (who live from natural resources of the floodplain) through managed flood releases, whilst retaining sufficient water in the reservoir for intensive rice irri ation. These were defined throu h broad-level anal sis of the degradation of the floodplain ecosystem and of the efficiency of the SEMRY irrigation scheme.

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

Box 7.1 (contd)

Step 3. Develop stakeholder participation and technical expertise
A participatory process with established with relevant national and local authorities, floodplain communities (using Participatory Rural Appraisal) and SEMRY management. Local interest groups on, for example, fisheries, small scale rice farming were establish within local communities. The intention is to established 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 through involvement in the work of the project.

Step 4. Define links between floods and the ecosystem
Detailed studies of the interaction between vegetation and flooding were undertaken. These showed the change from annual to perennial grasses with inundation over a three year period. The surveys were continued as part of the pilot releases.

Step 5. Define flood release options
A hydrological model of the reservoir, floodplain, main river Logone and local tributaries was constructed and used to in conjunction with ecological and socio-economic models to define flooding options under dry, wet and very wet conditions

Step 6. Assess impacts of flood options
A preliminary Environmental Impact Assessment of all flood options was undertaken. Studies of water-related diseases led to water supply (wells), sanitation (latrines) and hygiene awareness programmes, which led to reduced diarrhoeal diseases. An assessment of the impact of re-flooding on the operation of SEMRY rice scheme was undertaken. Further studies of the health and environmental impacts of full floods options are planned.

Step 7. Select the best flood option
Economic analysis was undertaken of various flooding options. Re-flooding of 90% of the floodplain yielded annual values of: US$550,000 for fisheries, US$930,000 for herding and US$31,500 for recession agriculture. The net present value over 30 years was 15 000 million CFA (c. £13.6 million) assuming a discount rate of 4%.

Step 8. Design and build engineering structures
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.

Step 9. Make releases
Pilot flood releases were undertaken in 1994 and 1997 to determine the response of the ecosystem and of local communities. Further test releases from the dam are planned. Financing is being sought for the full flood release option.

Step 10. Monitor, evaluate and adapt release programme
For the pilot releases, hydrological, ecological, sociological and economic monitoring was established to assess the impacts of flood. Results were used to refine the models and flooding options. Monitoring is being continued.

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