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Use of decision support systems to improve dam planning and dam operation in Africa

Matthew McCartney
Jackie King

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Cover photo: Wikipedia: Katse Dam, Lesotho, opened 1996.

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Use of decision support systems to improve dam planning and dam operation in Africa.

Matthew McCartney

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This paper is an output of the CGIAR Challenge Program on Water and Food project "Improved planning of large dam operation: using decision support systems to optimize benefits, safeguard health and protect the environment".

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with contributions from

Michael Abebe, Seleshi Awulachew, Wondie Ayalew, Dereje Hailu, Solomon Kibret, Jonathan Lautze, Bruce Paxton, Yilma Seleshi, Solomon Seyoum and Benon Zaake

CGIAR Challenge Program on Water and Food
P.O. Box 2075
127 Sunil Mawatha,
Pelawatta, Battaramulla,
Sri Lanka

T +94 11 288 0143
F +94 11 278 4083
E cpwfsecretariat@cgiar.org

Learn more about CPWF at: **www.waterandfood.org**

Authors

Matthew McCartney	IWMI
Jackie King:	Southern Waters

Editing by Kingsley Kurukulasuriya
Design and layout by Thomas Meadley

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Acronyms

AfDB	African Development Bank
BBM	Building Block Methodology
CPWF	Challenge Program for Water and Food
DDP	Dams and Development Project
DRIFT	Downstream Response to Imposed Flow Transformations
DRM	Desktop Reserve Model
DSS	Decision Support System
DST	Decision Support Tool
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EEPCO	Ethiopian Electric Power Corporation
FAO	Food and Agricultural Organization of the United Nations
HIA	Health Impact Assessment
ICOLD	International Commission on Large Dams
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
MDG	Millennium Development Goals
NBI	Nile Basin Initiative
NEPAD	New Partnership for Africa's Development
NFS	Nile Forecasting System
RIBASIM	River Basin Simulation Model
RUBDA	Ruaha Basin Decision Aid
TVA	Tennessee Valley Authority
UNEP	United Nations Environment Programme
WCD	World Commission on Dams
WEAP	Water Evaluation and Planning
WHO	World Health Organization of the United Nations
WRPM	Water Resources Planning Model
ZESCO	Zambia Electricity Supply Corporation

Foreword

Current low levels of water storage in Africa correspond to high levels of poverty, a situation which is already exacerbated by the increasingly observed variability of water flows due to climate change. Despite this, the role of large dams for poverty alleviation and socioeconomic development remains controversial, which stems from the fact that although numerous positive benefits can be attributed to large dams, the potential benefits for local people are not necessarily accounted for in the design, and the associated costs can also be high. Too often in the past, the costs and the benefits – invariably for the poorest and voiceless - have been underestimated or ignored. The degradation of river ecosystems and loss of natural resources, caused by dams, have had devastating consequences for many rural communities whose livelihoods depend on them, and the potential benefits from dams to support livelihoods have rarely been met.

Today, the climate for decision making is changing. Development "at any cost" is no longer acceptable. Increasingly decision makers are being called upon to assess ranges of options and justify the choices they make. The demand for fair and transparent decision making involving the full range of stakeholders is increasing. This adds significantly to the complexity of decision-making processes but should lead to better, and hopefully, more acceptable decisions.

After a hiatus in dam investment, through the 1990s and the early part of this century, construction of large dams is increasing again. Many African governments are convinced that large dams can contribute to both attainment of the millennium development goals and broader economic development. As a result, numerous large dams are now being planned or are under construction.

Evaluating dam options and finding an appropriate balance between development needs and the need to safeguard the environment and existing livelihoods constitute a complex and difficult process. Modern decision support systems can usefully input to this process by guiding the analysis of complicated hydrological, environmental, social and economic factors associated with water allocation and assessing the impact of different, often conflicting, management options both in planning and operation of dams.

This publication highlights the constructive role that decision support systems can play in planning and operation of dams. It illustrates the importance of considering environmental and social issues in decision making so that positive benefits of large dams can be maximized and the negative impacts minimized.

Alain Vidal
Director, CGIAR Challenge Program on Water and Food

Executive summary

This publication is a contribution, by the Challenge Program for Water and Food (CPWF), to support global efforts for reducing poverty and promoting economic growth through improved management of water resources. It is intended to inform policy makers, water resource managers, and other interested stakeholders, about the contribution that Decision Support Systems (DSSs) can make to the planning and operation of large dams in Africa.

In Africa, large dams bring the challenges of sustainable development, and specifically integrated water resources management, to the fore. By storing water, and so increasing options for water management, large dams have brought broad social and economic benefits and have made significant contributions to national and regional development. However, history shows that dam construction can have profound social and economic repercussions for those, invariably poor people living close to, or downstream of, them. Such communities often have limited livelihood options and are thus particularly vulnerable to changes in the condition of the natural resources on which they depend. Too often in the past, the adverse impacts experienced by these communities have been largely ignored and, as a result, far too many people have had to "pay the price of development."

It is now widely acknowledged that a key goal of any large dam must be to ensure that it provides a development opportunity for all. This includes those communities living close to the dam who may be displaced or whose livelihoods may be disrupted. This requires that dams are planned and operated in a way different from the past, with much greater emphasis on local needs. This in turn requires that environmental and social factors are considered in much greater detail than was typically the case in the past.

Planning and operating large dams is extremely difficult. Complexity is manifest in uncertainty arising from climate variability and hence river flows, the intricacy of biophysical interactions within riverine ecosystems and, perhaps most significantly, in the number and kind of stakeholders involved. That is, stakeholders with different and often conflicting interests, values or rights; with incompatible forms of knowledge, social norms and attitudes; with unequal power and influence. Hence, the wise and sustainable utilization of the water stored in large reservoirs requires consideration of a number of complex and interrelated subjects, and poses intricate technical and political problems.

In recent years, a large number of DSSs have been developed to assist decision makers to improve planning and operation of dams. These can contribute to a wide range of management issues throughout the life cycle of a large dam by:

- Structuring decision making processes and making explicit environmental and social concerns.
- Integrating diverse sources of information from different scientific disciplines, and sometimes from nonscientific inputs.
- Supporting analyses and making clear the consequences (including trade-offs) of different options (e.g., through analyses of scenarios).
- Facilitating the involvement of different stakeholders in the decision making process so that all stakeholders participate from early in the process, thereby promoting increased cooperation and consensus building.

The recommendations made in this report relate to seven key issues pertaining to planning and operation of dams.

1. Enhance local community input to the decision making process.
2. Improve "follow-up" of Environmental Impact Assessments (EIAs) conducted for dams.

3. Improve consideration of downstream environmental and social impacts.
4. Consider possible health impacts and how these may be mitigated through dam operation.
5. Improve options assessment.
6. Improve mechanisms for benefit-sharing.
7. Improve water resource management in transboundary basins.

These issues were identified through research conducted in this project in the Nile Basin. They were confirmed as high priority issues at a workshop on dams and DSSs held in April 2008, attended by a number of water resource managers and planners from the region. Although far from exhaustive they address fundamental aspects related to the environmental and social sustainability of large dams.

The report draws heavily on case studies undertaken for the CPWF study. However, where points are better illustrated with examples taken from elsewhere in Africa, this has been done. Key messages are presented at the start of each chapter.

Key messages

- Construction of large dams in Africa is set to increase in the near future. The new dams have the potential to bring significant social and economic benefits. To maximize these benefits, mistakes associated with dam building in the past must be avoided. This requires better planning and management of dams.
- River ecosystems are complex interlinked systems supporting immense biodiversity all of which is directly or indirectly maintained by constantly changing river flow, including floods. If the natural flow regime is disturbed by a dam much of the biodiversity and many of the ecosystem services are placed at risk.
- River ecosystems are valuable to people. This value should not be underestimated. Dams are constructed to bring social and economic benefits, but they are also associated with social costs. It is essential that decision makers take into account not only the benefits but also the potential costs of dams and either avoid or mitigate them. Balancing the needs of different sectors of society is a key challenge facing dam developers.
- Both the nature of decisions and those making the decisions change at different stages in the planning cycle of a large dam. The information required at each stage varies but throughout the ecological and social implications should be given as much consideration as the engineering and economic aspects. DSSs can assist decision making at all stages of the project cycle.
- Faced with growing concerns over the sustainability of water use, many African countries are focusing increasingly on the development of integrated basin-wide approaches to water management. In this endeavor DSSs are useful tools to assist with the planning and operation of large dams. However, despite considerable expenditure in terms of human and financial capital, complex DSSs developed in the past have very often not been trusted and as a result they have rarely been used to assist decision making in the way envisaged. There are a number of constraints to the use of DSSs in Africa, which need to be overcome to ensure the advantages to be obtained from DSSs are fully realized.
- Throughout Africa there is an urgent need to enhance the benefits of dams whilst minimizing the negative impacts. Broadly, this requires better decision making processes that a) strengthen stakeholder involvement, b) improve EIAs, c) improve consideration of downstream environmental and social impacts, d) take better account of possible public health impacts, e) improve options assessment, f) improve mechanisms for benefit-sharing, and g) improve water resources management in transboundary basins.

1. Introduction

Key message

Construction of large dams in Africa is set to increase in the near future. The new dams have the potential to bring significant social and economic benefits. To maximize these benefits, negative impacts associated with dam building in the past must be avoided. This requires better planning and management of dams.

1.1 Study background

> **7 key issues**
>
> - Enhance local community input to the decision making process.
> - Improve "follow-up" of EIAs conducted for dams.
> - Improve consideration of downstream environmental and social impacts.
> - Consider possible health impacts and how these may be mitigated through dam operation.
> - Improve options assessment.
> - Improve mechanisms for benefit-sharing.
> - Improve water resource management in transboundary basins.

This report provides information to assist policy makers, water resource managers and other interested stakeholders in the planning and management of large dams in Africa. It provides an overview of key issues and describes how the benefits of dams can be enhanced, and the adverse impacts avoided or mitigated, by applying better decision making processes, specifically through the application of Decision Support Systems (DSSs).

The report illustrates the importance of environmental and social issues in planning and operation of dams. It discusses how these can be better incorporated in future decision making and the role that DSSs can play in improving the process. The report is a synthesis of findings and information gained through research conducted in the Nile Basin within CPWF Project 36: "Improved Planning of Large Dam Operation: Using Decision Support Systems to Optimize Livelihood Benefits, Safeguard Health and Protect the Environment."

The original intention of CPWF Project 36 was to identify the DSSs most appropriate for planning and managing the complexity of planning and operation of large dams. However, with hindsight this was an unrealistic objective. It is impractical because there are a huge number of DSSs and an even greater variety of situations in which they can be used. Consequently, any given DSS will be appropriate to assist decision making in certain situations but completely inappropriate in others. Instead, the report discusses generic issues and findings relating to the use of DSSs for planning and operation of dams. It illustrates how DSSs can assist with decision making related to large dams in Africa, through improved consideration of environmental and social issues and demonstrates the importance of successful participation of all stakeholders.

The report provides recommendations on the use of DSSs in seven key areas of decision making related to planning and operation of dams. These seven areas were identified as important through the research conducted. They were confirmed at a workshop of researchers and decision makers on dams and DSSs held in April 2008 and reaffirmed at a final project workshop held in September 2009.

1.2 Large dams in Africa

Through the provision of water for irrigation, hydropower and domestic supply, large dams have brought significant benefits to many millions of people. However, they remain controversial. This controversy arises from the fact that, too often in the past, the construction of dams has brought fewer benefits than envisaged and has resulted in significant social and environmental costs. Historically, large dam projects have often failed to pay sufficient attention to environmental impacts and those, invariably poor people adversely affected by their construction and operation. Those who have had to be resettled and those whose livelihoods have been affected by changes in river flow regimes have tended to pay the price of dam construction (Box 1.1).

Box 1.1. How dams can have adverse impacts on people

Although dams have brought benefits to many millions of people, their construction has not been without cost for many others. Globally, it is estimated that between 40 and 80 million people have been displaced as a consequence of the construction of large dams (WCD 2000a). Many of these people have not been adequately compensated. People living downstream may also be adversely affected as a consequence of changes in flow regimes caused by the way large dams are operated. In many developing countries, changes in flow, brought about by large dams, have resulted in the degradation of natural resources upon which many people rely.

For example, in some places dams, by reducing flooding, have significantly diminished the productivity of floodplain and estuarine fisheries as well as adversely impacting recession agriculture (Acreman *et al.* 2000). Dams may also cause negative public health impacts, for example, through the creation of breeding habitats for disease vectors, such as snails for schistosomiasis and Anopheles mosquitoes for malaria (Jobin 1999). People living upstream of dams may be 100% affected through loss of land to the reservoir. More people downstream may be slightly to severely affected by degradation of the river system.

An example of where a dam may have affected the livelihoods of people living downstream, Kafue Flats, Zambia. (Picture source, www.asla.org)

In Africa, relatively few large dams have been built and, after Asia, the continent has the lowest per capita storage of any continent (Figure 1.1). Although the need for economic development is urgent, many people continue to rely on natural resources and agriculture to sustain their livelihoods. Consequently, assessing all the implications of dams, both positive and negative, is of paramount importance both when planning new dams and when revising the design or operating rules of existing ones.

Currently the World Bank, the African Development Bank, the New Partnership for African Development (NEPAD) and other influential institutions are advocating increased development of hydraulic infrastructure on the African continent. The current position of the World Bank is that major water resource projects provide the basis for broad regional development, with "significant direct and indirect benefits for poor people" (World Bank 2004). As a result, many dams are being planned and it is likely that many will be built in the near future. There is no comprehensive list but Appendix 2 provides details of some of the new dams currently being built or planned in Africa.

1.3 Decision making

Against this background, the key challenge is to ensure that dams contribute to attempts to obtain reliable and sustainable sources of water, food and energy, whilst avoiding the mistakes of the past. This means placing greater emphasis on issues of equity and minimizing the negative environmental and social impacts.

Activities related to dam planning and management are usually motivated by the realization that there are either problems to solve or there are opportunities to improve the benefits derived from the water stored in reservoirs. However, in any given situation identifying the best course of action from amongst a large number of alternatives is extremely difficult and must take into account a wide range of factors and trade-offs. Planning and management of dams involve influencing and improving the interaction between the following three independent subsystems (Loucks and van Beek 2005):

- The natural river subsystem in which physical, chemical and biological processes occur.
- The socioeconomic subsystem which includes the human activities related to the use of the river subsystem.
- The administrative and institutional subsystem of administration, legislation and regulation, which encompasses the decision making process.

In such situations lack of planning and management invariably results in suboptimal benefits, increased tensions between different stakeholders (which in some case may lead to civil unrest) and, in worst case scenarios, complete project failure (e.g., when dams fail physically or reservoirs become completely silted).

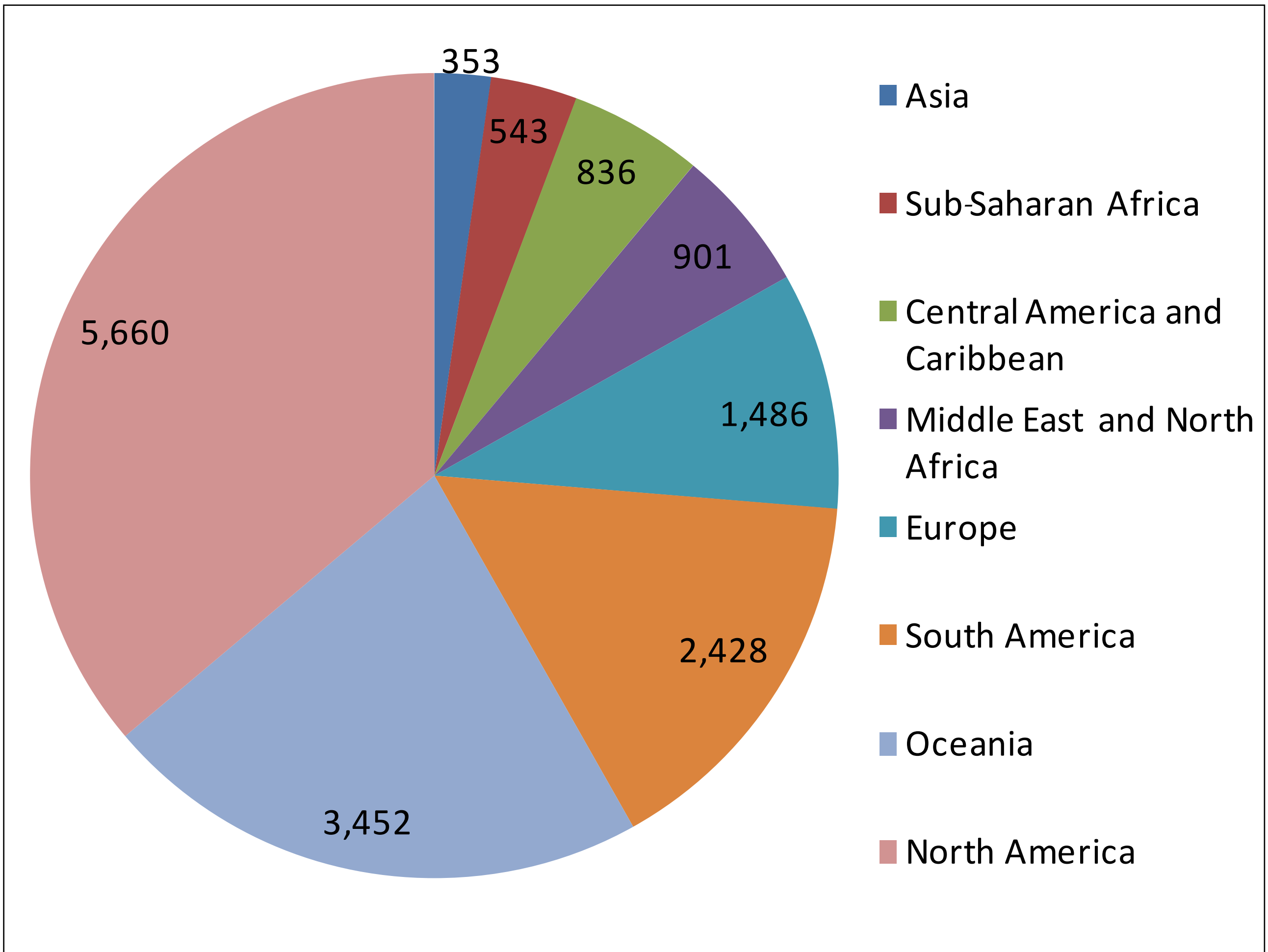


Figure 1.1. Per capita storage of water (m^3) by continent (White 2005).

To maximize the benefits to be obtained from them, planners and managers of dams need to take into account a range of interlinked biophysical, economic, political, organizational, social and environmental factors (Figure 1.2).

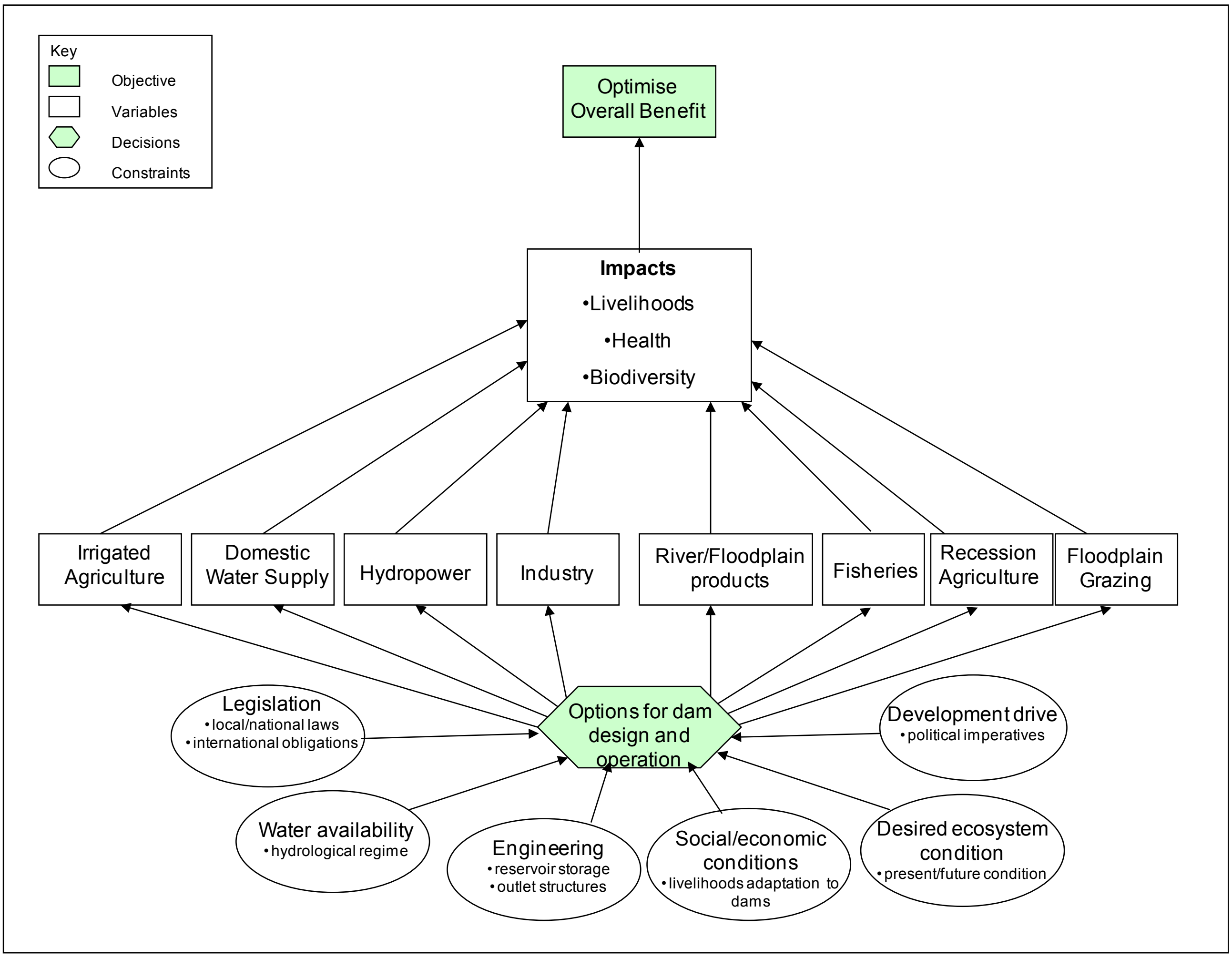


Figure 1.2. Complex web of interlinked issues and trade-offs that must be taken into account in planning design and operation of dams.

However, in any given situation the relationships between these different factors are often extremely complex and not well understood. Many complex issues must be considered and this makes informed decision making very difficult. In such situations, DSSs (Box 1.2) can improve the effectiveness of decision making processes by helping to identify and solve problems.

The environmental and social impacts of dams need to be considered in tandem because they are strongly linked; many social changes arise as a consequence of environmental changes, for example, through impacts on natural resources. A key reason why historically the intended outcomes of large dams have often not been fully realized is because environmental and social problems have rarely been given adequate consideration in project planning and implementation.

In recent years, public approval has become an important objective of decision making in relation to large dam planning and operation and, as a means to gain this approval, public participation has become an increasingly important element in decision making processes. However, the large number of stakeholders with differing and often conflicting views means that transparent and structured processes are needed to reach a common understanding of issues. Participatory multi-criteria analyses (Keefer *et al*. 2004; Hämäläinen 2004; Mustajoki *et al*. 2004) linked to DSSs provide ways to systematically structure and analyze complex problems and are being increasingly used.

Box 1.2. What Are Decision Support Systems (DSSs)?

Over the last 30-40 years, major advances have been made in the development and use of a wide range of tools to assist in the planning and management of complex water resource systems. DSSs are intended to provide all managers and political decision makers with assistance in making rational decisions based, as far as possible, on an objective assessment of issues. There is no common definition of a DSS. Many definitions refer specifically to computer software, models and systems, many of which have been developed. Examples include:

- HEC-ResSim developed to simulate reservoir systems.
- WEAP (Water Evaluation And Planning) model, developed to simulate water demand and supply.
- RIBASIM (River Basin Simulation Model), developed to simulate infrastructure operation and demand management.
- WRPM (Water Resources Planning Model), developed to simulate water allocation in catchments.

However, DSSs need not be computer-based. In fact a DSS can be anything that assists the decision making process. For example, guidelines and protocols that provide information on best practice as well as tools that facilitate dialogue between decision makers and water users are often considered to be forms of DSSs. Under this definition, in addition to computer models, commonly used forms of DSSs include life-cycle analysis, comprehensive options assessment, environmental impact assessment and strategic environmental assessment as well as approaches to estimate environmental flows and tools that mobilize stakeholders to participate in master planning of river basins.

1.4 Report structure

The rest of this report provides:

- A brief overview of the environmental and social impacts of large dams in Africa (Chapters 2 and 3).
- A conceptual framework and principles for the use of DSSs in the planning and implementation cycle of large dams (Chapter 4).
- An analysis of current challenges and opportunities in the use of DSSs for the planning and operation of large dams in Africa (Chapter 5).
- Recommendations on how to better incorporate environmental and social issues in planning and management of dams (specifically in relation to the seven issues identified) through the application of appropriate DSSs (Chapter 6).

2. The environmental impacts of dams

Key message:
River ecosystems are complex interlinked systems supporting immense biodiversity all of directly or indirectly maintained by constantly changing river flow, including floods. If the natural flow regime is disturbed by a dam much of the biodiversity and many of the ecosystem services are placed at risk.

2.1 River ecosystems

Rivers are central elements in most landscapes. They are important natural corridors for flows of energy, matter and species. Very often, they are key elements in the maintenance of biodiversity. Despite occupying a smaller area than land and oceans, freshwater habitats are home to a relatively high proportion of species. Almost half (42%) of all known fish species and a quarter of all mollusc species (25%) occur in freshwater (Darwall *et al*. 2005). These figures reflect not only the diversity of habitats that can support organisms within individual rivers but also the great diversity of river systems themselves. Rivers are also essential for many terrestrial species. Through the production of natural resources and provision of ecosystem services, rivers and the biodiversity they support, are essential for the livelihoods of many people (Chapter 3).

River ecosystems are complex, comprising all the physical, chemical and biological components of the environment linked to the river. A 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 dependent on freshwater inputs (Figure 2.1). Flow is one of the principal factors influencing the character of river ecosystems. The frequency of flow extremes (i.e., floods and droughts) exerts important controls on every physical, chemical and biological attribute of the river ecosystem.

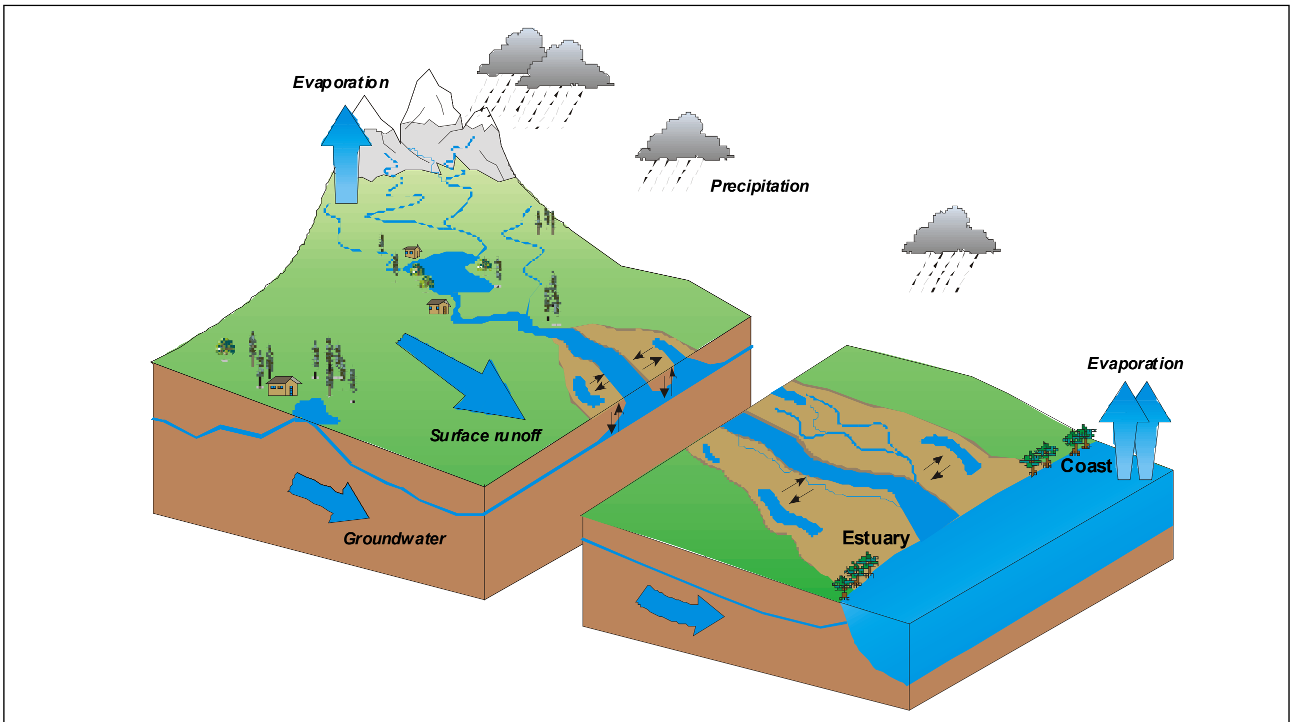


Figure 2.1. River ecosystems depend on lateral, longitudinal and vertical fluxes of water. Within a catchment all environments are dependent to a greater or lesser degree on connectivity with the active river channel. The ecological character of the river depends on the interactions with those environments.

Unregulated rivers are a continuum of linked surface water and groundwater flow paths. Channel shapes are determined by flooding. Floods also provide the floodplain with nutrients and sediment. In turn, the floodplain provides a breeding and feeding ground for many river species, including fish. Between big floods flow dynamics gradually and subtly reconfigure channel features.

Riverine plants and animals are adapted to the physical forces of water movement and constant change in the distribution of the resources that they require. Each species is most abundant where the resources that they need to sustain growth and reproduction are most abundant and/or most easily obtained. Some species can obtain all they require without much movement and so they will occur in a particular place along the river. Others must move long distances in search of resources. For many species changes in flow provide important cues in their life cycles. For example, many fish spawn at times that coincide with optimal flow and temperature conditions for their young to survive. Many coastal and marine ecosystems also depend on inputs of freshwater and associated nutrients and sediments from rivers.

Source: Wikipedia

Limpopo River in Mozambique

2.2 The impact of dams on river ecosystems

Dams constitute human-made obstacles. They fragment rivers, disrupting the flow of water and other fluxes. Although in many ways reservoirs are similar to lakes, the construction of a dam also results in phenomena (especially immediately after construction) that are unique and do not occur in natural lakes. However, the exact impact of a dam depends on site specific conditions, the type of dam and the way it is operated.

Dams create a hierarchy of interconnected effects in which first-, second- and third-order impacts occur (Figure 2.2). Changes in physical driving variables (i.e., hydrology, water quality and sediment) are first-order impacts. As well as changes to the river system these can also cause changes within other aquatic and terrestrial ecosystems, for example, as a consequence of reduced flooding and sediment transport to floodplains. Second-order impacts are those that arise from changes caused by first-order impacts (i.e., typically changes to river morphology and primary production). Third-order impacts are those that arise from changes caused by second-order impacts. Usually, the complexity of interacting processes increases from first- to third-order impacts and they are increasingly difficult to predict.

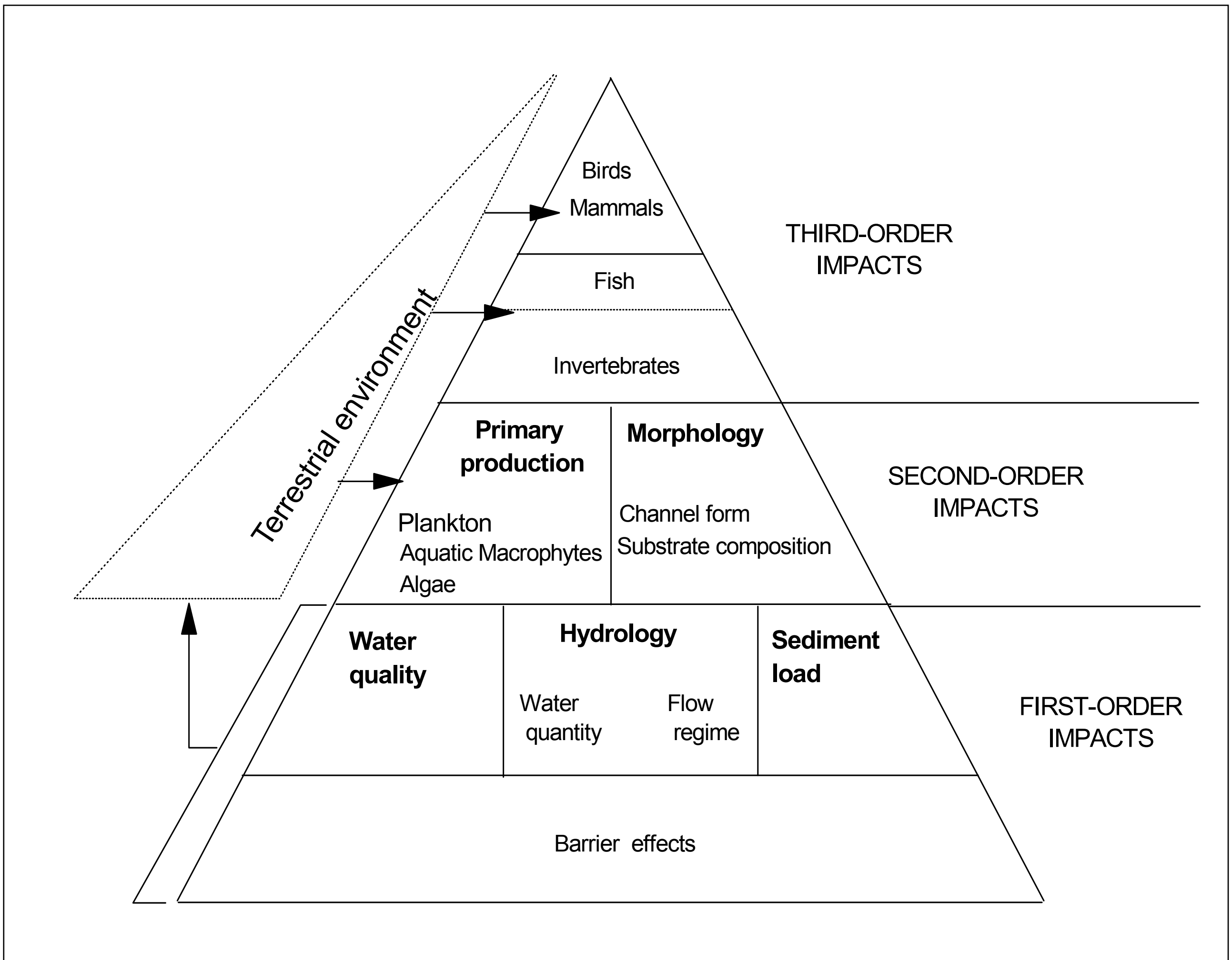


Figure 2.2. The impact of dams on river ecosystems (modified, from Petts 1984).

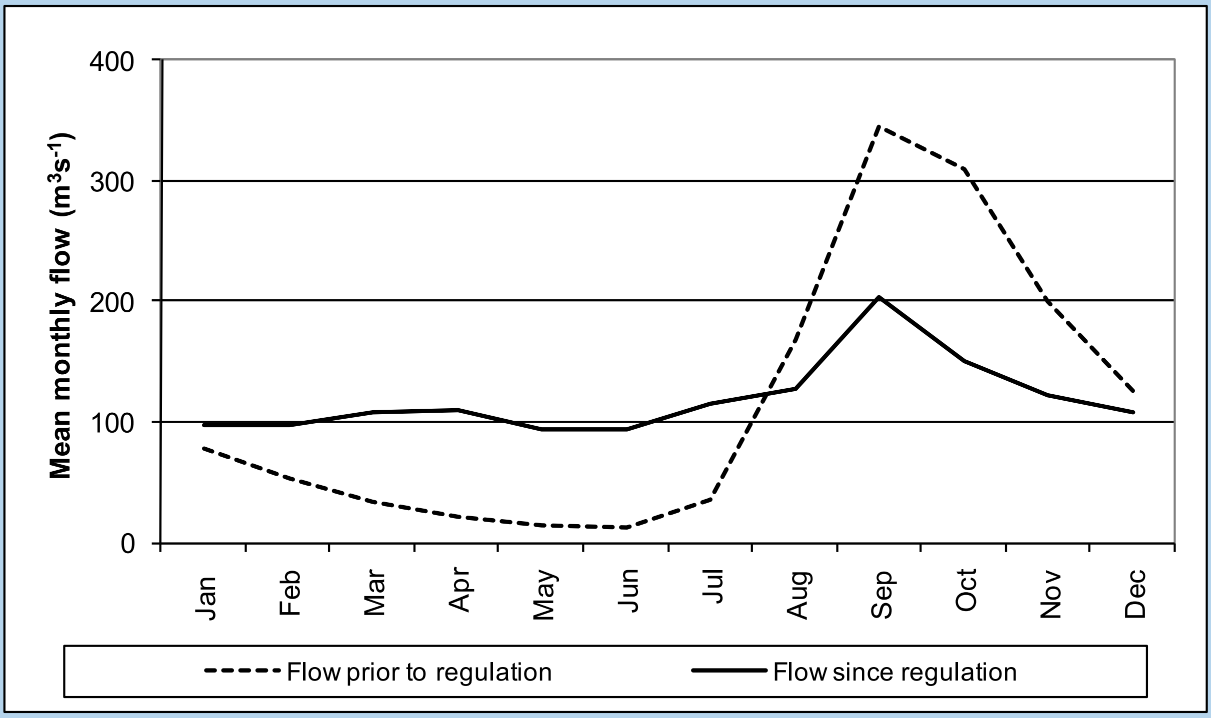
2.3 Impacts on flow

The effect of a dam on flows depends on both the storage capacity of the reservoir and the way the dam is operated. The most common attribute of dams is a decrease in flood peaks and an increase in low flows (Box 2.1). In some instances, operational procedures (e.g., for hydropower) can result in rapid flow fluctuations that occur at unnatural rates.

As well as altering the pattern of flow, dams also reduce the annual volume of flow. In all cases there is a temporary reduction, when the reservoir first fills. This may take several years if the reservoir storage greatly exceeds the mean annual runoff of a catchment. In many cases permanent reductions occur because the presence of reservoirs increases evaporation from a catchment. In addition, water abstraction for purposes such as irrigation and water supply commonly reduces the total flow further.

Box 2.1. Changes to flow regime downstream of the Chara Chara Dam on the upper Blue Nile.

Over the last decade flow in the headwaters of the Abay River (i.e., the Blue Nile) has been modified by operation of the Chara Chara Dam, located at the outlet of Lake Tana and built to regulate flow for hydropower generation. The graph shows how operation of the dam has affected mean monthly flows. Prior to construction of the dam only 12% of the flow from the lake occurred in the 5 months from February to June. Since the dam was built flow through the year is much less variable; now 43% of the flow occurs in these 5 months.



Regulation of flow in the upper Blue Nile, by the Chara Chara Dam (data provided by the Ethiopian Ministry of Water Resources)

2.4 Impacts on water quality

Water storage in reservoirs induces physical, chemical and biological changes all of which affect water quality. These changes mean that the water discharged from a reservoir often has a very different chemical composition to that flowing in. Typically, water released from near the surface will be well-oxygenated, warm, and nutrient-depleted. In contrast, water released from near the bottom is usually cold, oxygen-depleted, and nutrient-rich that is often high in hydrogen sulfide, iron and/or manganese. These differences in water quality can have significant impacts on downstream flora and fauna.

Eutrophication of reservoirs may occur as a consequence of large influxes of organic material and/or nutrients. In many cases these are the consequence of human activities in the catchment. Eutrophication can result in blooms of blue-green algae (Figure 2.3) which as well as being aesthetically unpleasant are, in some instances, toxic and can cause oxygen depletion at the bottom of the reservoir and increased pH and oxygen in the surface waters.

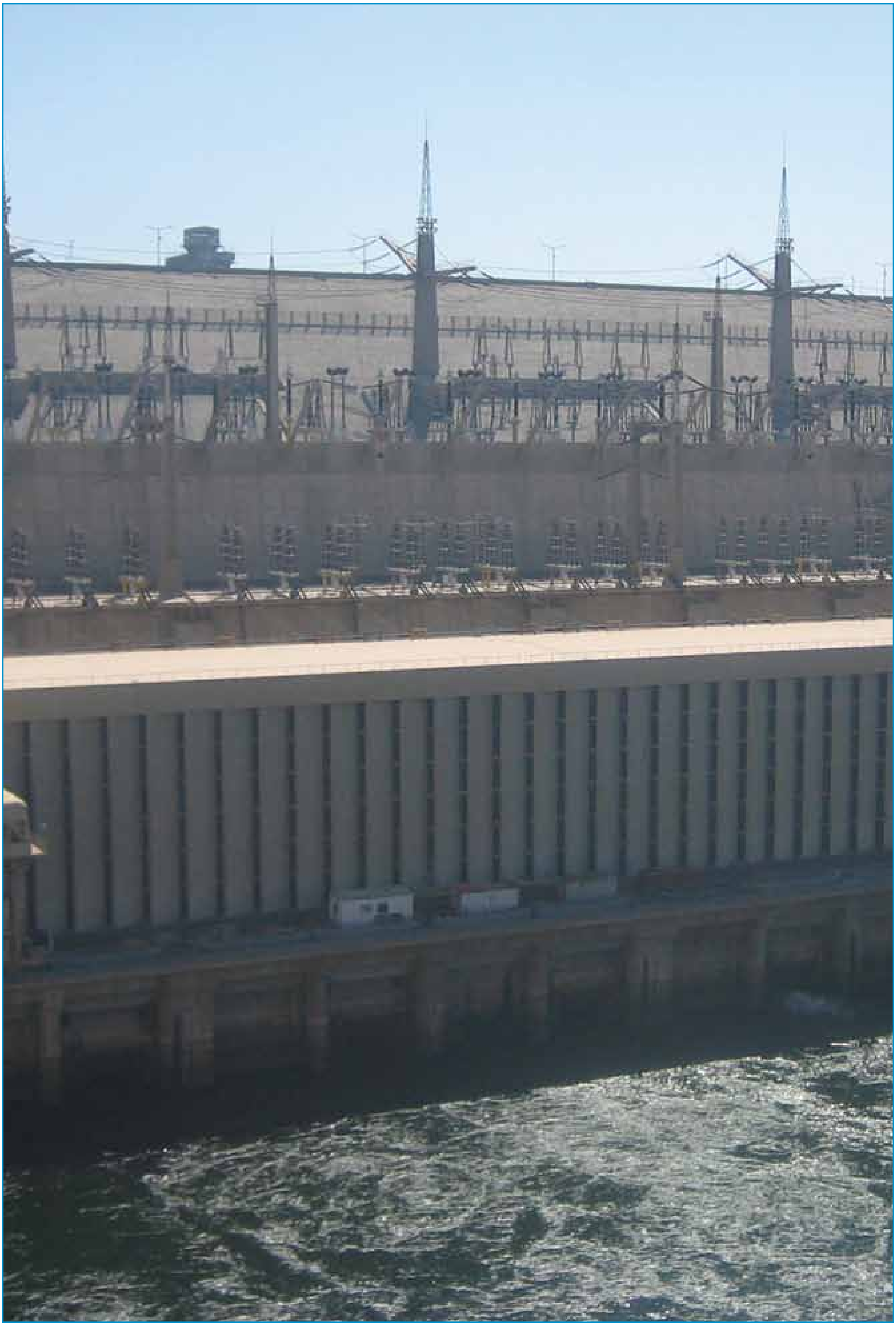
Source: Matthew McCartney

Figure 2.3. Algal bloom in the Hartebespoort Reservoir in South Africa.

2.5 Impacts on sediment

Reservoirs reduce flow velocity and so enhance sedimentation. Consequently, over time they fill with sediment. The rate at which a reservoir fills depends on characteristics of the catchment in which the dam is located, human land-use practices and the operation of the dam. The reduction in sediment in rivers downstream of dams can result in increased erosion of river banks and beds, loss of floodplains and degradation of coastal deltas. In some circumstances increased sedimentation (aggradation) occurs because material entering from tributaries cannot be moved by the regulated flows.

The Lower Nile River has been affected by the construction of two dams. The Aswan (1902) and the Aswan High (1970) dams were built to control the floodwaters of the Nile, to generate electricity and to provide year-round irrigation. These dams have significantly increased the amount of land available for agriculture and lengthened the agricultural year. Other changes, however, have been less favorable. The Aswan High Dam traps more than 98% of the sediment transported by the Nile, reducing the deposition of nutrient-rich silts onto downstream floodplains and the delta (Stanley and Warne 1998). Offshore fisheries that depended on nutrients from the Nile have drastically declined (Nixon 2004). The delta constitutes two-thirds of Egypt's arable land, but because it is being starved of fluvial sediments, it is steadily yielding to coastal erosion at a rate of around 5-8 m per year (Stanley and Warne 1998). In addition, reduced soil fertility means that farmers have to apply increasing amounts of fertilizer to replace the nutrient-rich sediments trapped in the reservoir.


Source: Wikipedia

High Aswan dam and its power station, Egypt

2.6 Impacts on organisms

Globally, degradation of freshwater habitats and the rate of species loss are now estimated to be five times greater in freshwater ecosystems than in terrestrial ecosystems (MEA 2005). At least 20% of the world's freshwater fish have become extinct, threatened or endangered in recent years (WCD 2000a). Although dams are not the only causes of these impacts, they are a major contributor. Dams impact flora and fauna by the following actions:

- Inundating terrestrial ecosystems, resulting in the loss of natural habitats and wildlife.
- Blocking the movement of migratory species up and down rivers.
- Changing river turbidity/sediment levels to which species/ecosystems are adapted.
- Trapping silt in reservoirs thereby depriving downstream deltas and estuaries of materials and nutrients that help make them productive ecosystems.
- Filtering out of woody debris, thereby removing habitats and a source of food.
- Fostering exotic species which tend to displace indigenous species.
- Reducing accessibility to the floodplain habitat for aquatic species that utilize the floodplain during periods of high flow.
- Modifying downstream habitat through modification of flow, sediment water temperature and quality regimes.
- Through provision of water, modifying other human activities, including agriculture, forestry, urbanization and fishing.

Dam-induced degradation of river ecosystems results in lower populations and sometimes even extinction of species both upstream and downstream of the dam. Dams alter habitats so that some species disappear and others, better suited to cope with the changed conditions, thrive. Upstream of dams the change of the river from a flowing to a still water system results in the loss of species that need flowing water (e.g., many species of fish) and the appearance of those that can exist in still water (e.g., phytoplankton). Downstream of dams, changes in flow, water quality and sediment regimes generally have an adverse effect on the majority of native species and can lead to infestation by less desirable species (see Appendix 1, *Water hyacinth*). Too much flow at certain times of year can be as bad as too little flow.

Many fish are adapted to utilize floodplains for feeding and reproduction. Reduced or mistimed flooding, often results in the decline or even disappearance of species that depend on floodplains. Reduced freshwater flows and nutrient inputs at the coast may have a negative impact on some marine species, particularly those that utilize estuaries as nursery areas (e.g., prawns). Changes also lead to complex alteration of riparian ecosystems, affecting terrestrial plants and animals (see Appendix 1, *Impact of the Kariba and Cabora Bassa dams*).

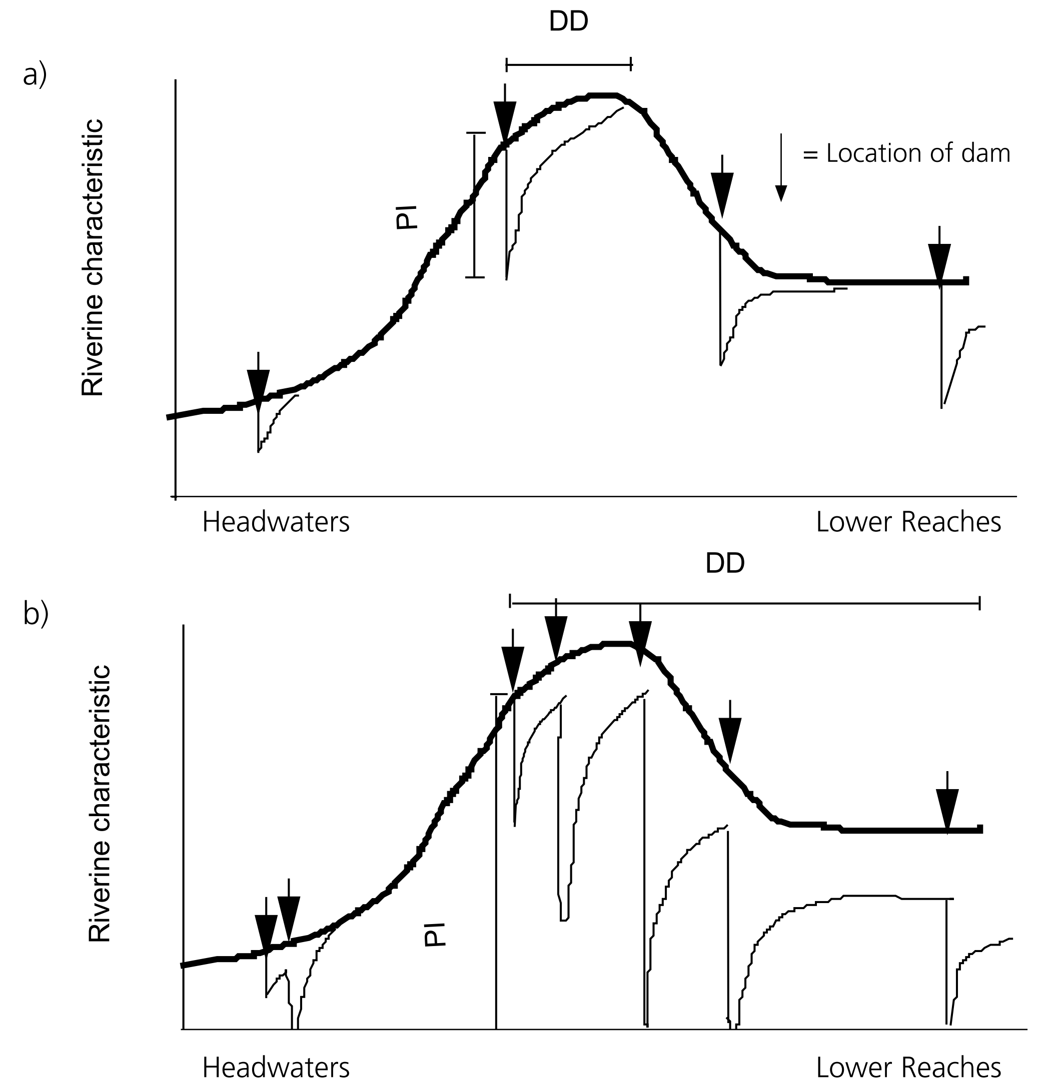
2.7 Cumulative impacts

Dams built in the same catchment, either in series (i.e., along the same river) or in parallel (i.e., on different tributaries) inevitably result in cumulative impacts. An individually insignificant impact may, when combined with others, produce a major change within a river ecosystem. In some circumstances, the total effect of cumulative impacts on a river ecosystem can be greater than the sum of each individual impact (Box 2.2). Cumulative impacts may be difficult to predict but should always be considered in planning and operation of dams.

Box 2.2 Cumulative impacts of dams (*source:* adapted from Bergkamp *et al*. 2000).

Dams result in changes in physical and chemical characteristics that, in turn, affect flora and fauna. The dynamic and self-correcting nature of rivers means that with increasing distance downstream, characteristics altered by the dam (e.g., flow, sediment load, dissolved oxygen, thermal heterogeneity, channel stability, presence/absence of a species) tend to return toward their natural level. Cumulative impacts can be visualized as occurring when any characteristic, altered as the consequence of one dam, fails to fully recover, before it is modified again as a consequence of a downstream dam or the operation of a dam on another tributary.

Two parameters can be used to measure the magnitude of impacts. These are: a) the discontinuity distance (DD) which refers to the longitudinal (i.e., downstream) shift and b) intensity (PI) which refers to the impact of regulation relative to its equivalent unregulated position. For any given riverine characteristic (i.e., biophysical attribute), cumulative impacts affect both DD and PI (see Figure below) In most cases, cumulative impacts result in an increase in both DD and PI. Although shown as approximating logarithmic functions the exact form of the response – distance to recovery - will be a function of a wide range of site-specific factors that include amongst other things the number and relative flow of tributaries that enter the river downstream of the dam.



The impact of dams on the hypothesized downstream pattern exhibited by a given river characteristic in situation a) with no cumulative impacts and b) with cumulative impacts (modified from Ward and Stanford 1995).

3. The social impacts of dams

Key message

River ecosystems are valuable to people. This value should not be underestimated. Dams are constructed to bring social and economic benefits, but they are also associated with social costs. It is essential that decision makers take into account not only the benefits but also the potential costs of dams and either avoid or mitigate them. Balancing the needs of different sectors of society is a key challenge facing dam developers.

3.1 River ecosystems and people

Throughout history rivers have played a key role in human development and many of the earliest civilizations (e.g., Nile, Tigris-Euphrates, Indus and Yangtze) depended on them. The seasonal advance and retreat of floodwaters shaped the belief systems, set the timing of planting and harvesting and replenished the nutrients in the soil for replanting the following year. These patterns of life remain largely unchanged for many communities around the world, particularly in the developing countries of Africa.

In addition to the role they play in supporting communities who live close to them, rivers also provide societies with a wide range of goods (provisioning services) and other services (regulatory and cultural services). Provisioning services can be thought of as products that are of societal use when extracted or diverted from the river system (Brismar 2002). These may include freshwater for domestic, industrial and agricultural use, fish, vegetation for food, medicines and construction, and much more. Other services can be thought of as processes of societal value that are naturally generated and maintained by the river system. These include the transportation and dilution of pollutants, water purification, soil wetting, fertilization of floodplains and deltas and erosion control of deltas (Brismar 2002).

For many communities inland fisheries are crucial to livelihoods, providing a ready source of protein and income for large numbers of people. In Africa, where many people cannot afford to practice aquaculture, the contribution of wild fisheries (2 million tonnes) to the livelihoods of people is much greater than that of cultured fisheries (283,409 tonnes) (Revenga and Cassar, no date). In some places fish are a vital source of protein, particularly during periods of the year when other food sources are scarce (Savy *et al*. 2006).

Not all natural processes in rivers are of direct benefit to human societies although indirectly they may maintain the ecosystem in ways that do bring benefits. For example, floods and droughts, whilst important ecologically, do not directly benefit people. Floods are some of the most damaging of all natural disasters; one-third of economic losses and half of all victims of natural disasters are flood-related (Douben 2006). Droughts can also be devastating, often increasing food insecurity in arid and semiarid areas (Houghton-Carr *et al*. 2002).

3.2 Dams and people

Dams have been an influential part of human development for thousands of years. However, it was only in the last century, and increasingly in the last 50 years, that technological advances have enabled the construction of large dams. In the period 1900 to 1949 less than 1,000 large dams were constructed every decade. Since 1950, there has been an upsurge in the construction of large dams with more than 5,000 being built each decade. The greatest proportion of large dams has been built in Asia (mostly China), North America and Europe. Currently, investment in large dams in Africa is increasing. Many are being built and many more are planned for the near future (Appendix 2).

Dams, by storing water when it is plentiful and making it available when it is not, provide a mechanism for mitigating some of the adverse impacts of flow variability. They enhance some river services and can facilitate the provision of completely new services (e.g., the production of electricity). However, as well as bringing benefits, dams also have costs, particularly for rural riverside communities. These costs result from the disruption of the ecosystem services that rivers naturally provide. Often, it is the poorest in society, lacking the political power and financial resources to mitigate impacts, who are the most adversely affected. These costs need to be factored into planning and management of dams so that, as far as possible, they can be mitigated.

3.3 The socioeconomic benefits of dams

Dams can contribute to the socioeconomic welfare of communities. Where designed and operated well, they ensure a reliable supply of water in dry times for domestic, agricultural and industrial use and, where they generate electricity, provide opportunities for the expansion of industry. By promoting economic growth, they can contribute to an increase in per capita income, and by using stored water to expand agricultural schemes they can contribute to increased food security (WCD 2000a). The broad linkages between infrastructural development (including dams), increased agricultural productivity and economic growth are well documented (Hanjra *et al*. 2009). The ability of dams to reduce flow variability means that water can be regulated, mitigating droughts and, to varying extents, controlling floods. Some examples of the principal benefits of dams are presented in Table 3.1.

Table 3.1. Examples of services and benefits generated by large dams in Africa.

Dams - Services and benefits	Socioeconomic significance to beneficiaries
Aswan High Dam, Egypt Irrigation: 3,361,000 ha Electricity: 2,100 MW (installed capacity); 9,750 GWh y^{-1} Flood protection Fisheries: 18,000 tons y^{-1}	• Economically the dam paid for itself within 2 years of construction. • Nearly all of Egypt's agriculture depends on irrigation in the Nile Valley. • The dam mitigated impacts of dangerous floods in 1964 and 1973 and the drought of 1983/84 that devastated East Africa. • Electricity generation in 1967 was 50% of Egypt's entire production. This reduced to 15% by 1998.
Katse, Lesotho Electricity: 182 MW (installed capacity at Muela); 454 GWh y^{-1} Employment: 8.4% of country's labor force employed by the Lesotho Highlands Water Project Tourism: 40-room hotel built at the dam	• Built in Lesotho to supply water to South Africa's major industrial and urban centers in Gauteng. • South Africa pays Lesotho \$35 million y^{-1} plus royalties. • Significant contribution to economic growth in Lesotho partly stimulated by the building of the Katse Dam. Estimated that per capita GDP (1994-2007) was elevated by 4.8% as a consequence of the scheme. • Growth in water and electricity use increased 23% and 5%, respectively, per annum.
Kariba, Zambia/Zimbabwe Electricity: 1,266 MW (installed capacity); 6,400 GWh y^{-1} Tourism: 485,000 visitors y^{-1} Reservoir fisheries: 23,250 tons y^{-1} Irrigation: 2,700 ha	• Supplying mainly the mining sector, urban populations and commercial farmers. • Twenty hotels (about 1,000 beds) established on the reservoir. • The fishery benefits mainly commercial *kapenta* (*Limnothrissa miodon*) fishing companies. • Jobs in irrigation schemes: 450 permanent and 3,000 casual.

Dams - Services and benefits	Socioeconomic significance to beneficiaries
Manantali, Mali Irrigation: 100,000 ha Electricity: 200 MW (installed capacity); 547 GWh y^{-1} Flood protection Navigation	• Built in Mali but managed by the Organization for the Development of the Senegal River (OMVS) to benefit Mali, Mauritania and Senegal. • Benefiting holders of irrigated land including rice, sugar cane and cotton. • Reverse migration of people who had left the region for the cities. • Electricity supplied to mines and urban centers with an estimated saving of energy expenditure in member states of 17%.
Gariep and Van der Kloof, South Africa Irrigation: 138 000-164 000 ha Electricity: 660 GWh y^{-1} (average: 1971 to 1998) Water supply: 151 $Mm^3 y^{-1}$ Tourism: 200,000 visitors y^{-1}	• Job units created or saved: 40,000 (regular and seasonal labor combined). • Electricity supply to the national grid. • Water supply to the industrial sector and cities through inter-basin transfers. • No. of people employed: 200 in 18 recreational facilities identified (with at least 1,000 beds).
Nalubaale-Kiira, Uganda Electricity: Installed capacity 380 MW	• Built on the White Nile at the outlet of Lake Victoria these two power stations supply electricity to Uganda and parts of Kenya. Supply 98% of Uganda's electricity.
Roseires, Sudan Irrigation: 1,305,000 ha Electricity: 280 MW installed capacity	• Built on the Blue Nile, the dam supplies water for irrigation including to Gezira, one of the largest irrigation schemes in the world. • The dam provides approximately 12% of the country's electricity including to the capital Khartoum.

There is no doubt that dams have enabled people to live in places where it would not otherwise be possible and, worldwide, have brought real benefits to many millions of people. However, dams are not a panacea. As with any human endeavor there are costs as well as benefits associated with dams.

3.4 Displacement and resettlement

Dams require the resettlement of people living or farming in the area that will be inundated by the reservoir. Globally, an estimated 60 million people have been displaced by dams (McCully 1996). Displacement is recognized as one of the most detrimental social impacts of dam building and it is also one of the most costly. In Africa, the legacy of displaced communities continues to haunt many large dams. For example, the Tonga people of Zambia/Zimbabwe, of whom 57,000 were displaced by construction of the Kariba Dam, continue to seek compensation for the loss of their land and livelihoods, 50 years after the dam was built (WCD 2000b).

The economic and social values of livelihood strategies followed by communities prior to displacement are often underestimated. Once a dam is built and people have been relocated, they may lose not only their land but also access to the resources that they once relied upon. For example, with the construction of the Katse Dam in Lesotho, displaced people lost access to potable water, wild vegetables and herbs (food and medicine), agricultural land, trees (firewood and construction material), stones and mud (construction material) (Metsi Consultants 2000). This loss of resources forces a greater reliance on cash incomes and breadwinners often have to seek wage-earning jobs.

In general, displaced people experience higher levels of landlessness, unemployment, indebtedness and hunger than before displacement. Funds for resettlement and rehabilitation are almost always inadequate. The larger the number of people displaced, the fewer are the chances that resettlement will be successful (Bartolome *et al*. 2000) (Box 3.1). A survey of communities affected by 44 dams in Africa, Asia, the Middle East and Central and South America, found that living standards were improved in only three cases and restored in only five cases (Scudder 2005).

Box 3.1. Displacement upstream of the Akosombo Dam, Ghana

(*source:* Tamakloe 1994).

Hydroelectricity generated by the Akosombo Dam – constructed on the Volta River in Ghana between 1961 and 1965 – was seen by Ghana's then Prime Minister, Kwame Nkrumah, as the key to growth of the newly independent country. The reservoir, Lake Volta, with an area of 8,500 km^2 comprises 4% of the total land area of Ghana. The newly created reservoir affected 80,000 people in 740 villages from nine ethnic groups. Prime Minister Nkrumah made a commitment that no-one's livelihood would be worse than before but, despite the best intentions, delays in the construction of the dam meant that the compensation devalued and property evaluations were inadequate. Furthermore, land for resettlement was not good for farming.

With a new government in 1966, institutional support for the resettlement declined. Many houses remained incomplete and increases in social density led to tensions between ethnic groups. Rainfall declined after the resettlement and temperatures rose in the agricultural areas resulting in the drying of perennial rivers, soil erosion and declining crop yields. As a result of these problems many of those relocated by the dam migrated out of the basin to local towns.

Source: Wikipedia

The Akosombo Dam on the Volta River, Ghana

3.5 Loss of Downstream Natural Resources and Livelihoods

Dams also have impacts on people living downstream. In some cases, the downstream impacts affect far more people than are displaced by the upstream flooding. However, in the past their plight has often been ignored.

In contrast to Europe where 90% of floodplains are intensively cultivated (Tockner and Stanford 2002) many African floodplains remain largely intact. Fishing, agriculture, grazing and gathering of wild plants often provide the livelihoods of the communities living close to these floodplains. For example, the floodplain resources of the Tana River in Kenya are vital for the Pokomo and Wardei people and traditional land-use practices of small-scale agriculture, pastoralism and fishing have maintained the ecological balance of the floodplain for thousands of years (Terer *et al.* 2004). By modifying flow regimes (Section 2.3) dams can impact the natural resources provided by floodplains and so can have very serious consequences for people (Box 3.2).

Box 3.2. Impact of upstream dams on the livelihoods of people living in and around the Hadeji-Nguru Wetlands.

In northeastern Nigeria, the Hadejia-Nguru Wetlands that form part of the Lake Chad Basin are located at the confluence of the Hadejia and Jama'are rivers and are home to about a million people. These wetlands are central to the economy of the region and, in common with many wetland areas in developing countries, the livelihoods of these communities surrounding the wetland are dominated by agriculture, pastoralism and fishing (Muslim 2008). Regulated by the Tioga and Challawa dams on the Hadejia River, irrigation schemes and drought have diminished the areal extent of these wetlands by at least two-thirds in the last 30-40 years (Thomas and Adams 1997; Muslim 2008). Siltation and invasion of the wetlands by Typha reeds, reduced fisheries, and excessive flooding and loss of life have resulted from poor management of flow releases (Muslim 2008). Barbier *et al.* (1997) showed that the estimated net value of the natural wetlands (US$34-51 ha^{-1}) was more than the net value of the benefits of diverting water for irrigation (US$20-30 ha^{-1}). Elsewhere in Africa, similar impacts on the livelihoods of downstream communities have been reported inter alia the Senegal River in Mali (Manatali Dam: Adams 2000a), the Volta River in Ghana (Akosombo Dam: Gyau-Boakye 2001), the Kafue River in Zambia (Ithezi-thezi Dam: Mumba and Thompson 2005).

Many dams reduce the magnitude of downstream flooding in dry to normal years. Often, this encourages people to move on to floodplains, to take advantage of the nutrient-rich soils or to gain easier access to waterways. However, their presence on the floodplain increases their vulnerability to larger floods. When sudden large inflows to a reservoir overwhelm storage space, emergency releases, often made with little or no warning, can have devastating impacts on floodplain communities, drowning people and destroying infrastructure. Increasingly it is now realized that to reduce the negative impact of floods, structural measures (which in addition to dams also include dykes and river straightening), are not adequate, simply because it is impossible to entirely eliminate flood risks. As an alternative, non-structural responses such as limiting human settlement in flood-prone areas (flood zoning), flood forecasting, evacuation, education and insurance, are increasingly being promoted.

3.6 Health impacts of dams

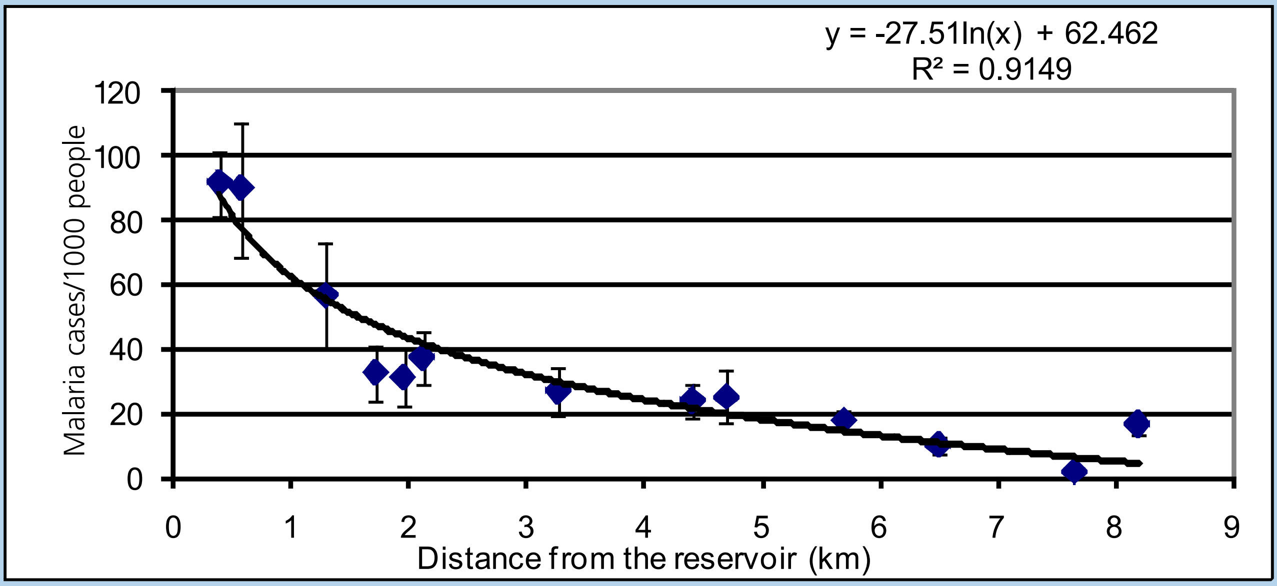
The burden of water-associated diseases in Africa is disproportionately high compared to other continents. The prevalence of water-associated vector-borne diseases (e.g., malaria, schistosomiasis, lymphatic filariasis) is influenced by hydrological changes that occur when water resources are developed and managed. By improving industrial and agricultural productivity dams contribute directly and indirectly to livelihoods and can have a positive impact on reducing poverty. This, in turn, can result in health benefits because people who are more food secure and have higher incomes tend to be healthier and can afford to spend more on health care. However, the construction of dams in Africa is often associated with adverse health impacts both in those communities living close to the reservoir and those living downstream.

Key among the potential negative effects of large dams and associated irrigation schemes is intensified transmission of malaria and schistosomiasis (i.e., bilharzia). This results from changes in environmental conditions that increase the abundance of disease vectors (e.g., mosquitoes and snails) (Keiser *et al.* 2005). Of these two, malaria has the highest burden of disease. In 2006, 247 million cases and approximately 900,000 deaths were reported, of which 91% occurred in Africa (WHO 2008). By providing breeding habitats for mosquitoes, reservoirs and irrigation systems increase malaria transmission (Box 3.3).

Schistosomiasis is also commonly linked to dam construction because changes in river ecology (resulting from changes in flow) often increase the habitat of the snail vectors. Other indirect effects on the health of a community can occur in the vicinity of a dam site, such as increased accidents from heavy vehicles, exposure to sexually transmitted diseases and psychological stress resulting from resettlement.

Box 3.3. Malaria transmission in the vicinity of the Koka Reservoir, Ethiopia
(*source:* Kibret *et al.* 2009).

To determine the impact of the Koka Reservoir in central Ethiopia on malaria transmission in its vicinity, time series of malaria cases (1994 to 2007) were obtained for 13 villages located at different distances from the reservoir. In addition, larval and adult mosquitoes were collected fortnightly between August 2006 and December 2007 in two villages close to the reservoir (~0.8 km) and another two villages farther away (>7 km) acting as controls. The study found substantially greater abundance of malaria vectors in communities close to the reservoir as a consequence of the breeding habitat created along the reservoir shore and, as a result, greater malaria transmission in communities located close to the reservoir.



Graph showing trend of declining malaria with distance from the reservoir, as a consequence of breeding habitat (puddles) created along the reservoir shore.

4. DSSs in the planning and operation of large dams

Key message

Both the nature of decisions and those making the decisions change at different stages in the planning cycle of a large dam. The information required at each stage varies but, throughout, the ecological and social implications should be given as much consideration as the engineering and economic aspects. DSSs can assist decision making at all stages of the project cycle.

4.1 DSSs and decision making

As human population increases and societies develop, water resources are increasingly under pressure with the result that the management of water has become an increasingly complex endeavor. Decision making is complicated not only by the natural variability of hydrological systems but also by the multiple, often conflicting, demands placed on water resources. DSSs are information systems that support decision makers to formulate alternatives and select options. A properly designed DSS will help decision makers by providing information in an understandable form at the appropriate time. The information provided by a DSS should assist decision makers to better understand their system, its problems and alternative ways to address them (Loucks and van Beek 2005).

The contribution made by DSSs to decision making processes varies considerably. A hierarchy of six broad approaches can be envisaged (Figure 4.1). In a completely unsupported process the decision maker makes the decision based solely on his/her knowledge and intuition. In a completely automated system a DSS will actually make the decision with no human input at the time the decision is made. For example, the emergency operation of spillway gates during a flood event may be predetermined and triggered simply when reservoir water levels reach a certain height. Although such systems are rare, they do exist. Between these two extremes the role of the DSSs can differ with relatively greater or smaller inputs to the decision making process.

<table>
<tr><th></th><th>Data provided by</th><th>Data analyzed by</th><th>Options generated by</th><th>Decision selection by</th><th>Decision implemented by</th><th>Approach to decision making</th></tr>
<tr><td>1</td><td colspan="5">Decision maker</td><td>Completely unsupported</td></tr>
<tr><td>2</td><td>Database/GIS</td><td colspan="4">Decision maker</td><td>Information Supported</td></tr>
<tr><td>3</td><td>Database/GIS</td><td>DSSs</td><td colspan="3">Decision maker</td><td>Systematic analysis</td></tr>
<tr><td>4</td><td>Database/GIS</td><td colspan="2">DSSs</td><td colspan="2">Decision maker</td><td>Systematic analysis of alternatives</td></tr>
<tr><td>5</td><td>Database/GIS</td><td colspan="3">DSSs</td><td>Decision maker</td><td>System with override</td></tr>
<tr><td>6</td><td>Database/GIS</td><td colspan="4">DSSs</td><td>Completely automated</td></tr>
</table>

Figure 4.1. Variable contribution of DSSs to decision making (adapted from O'Callaghan 1996).

4.2 Conceptual framework for decision making and large dams

Dams must be planned and operated in a way that takes into account the diversity of water uses both upstream and downstream of the dam. Consideration must be given to the full range of organizational, social and environmental factors as well as economic and technical issues. Different DSSs need to be used at different times and by different people. Broadly they can be used, throughout the life cycle of a dam, to:

- Structure decision making processes and make explicit environmental and social concerns.
- Integrate diverse sources of information from different scientific disciplines, and sometimes with nonscientific inputs.
- Support analyses and make clear the consequences (including trade-offs) of different options (e.g., through analyses of scenarios).
- Facilitate the involvement of different stakeholders in the decision making process so that all stakeholders participate from early in the process to promote increased cooperation and consensus building.

The types of decisions that need to be made throughout the planning and operation of dams vary. Broadly, two types of decision need to be made. The first types are those connected to strategic planning, including most importantly, before it is constructed, whether or not a dam should be built. The second types are those associated with day to day operation (i.e., management) of the dam to satisfy a range of competing requirements and stakeholders. An ideal conceptual framework for the decision making cycle for a large dam is shown in Figure 4.2. Currently, dam planning and operation rarely, if ever, conform exactly to this framework. It provides a notion of how planning and management might be conducted, though in reality decision making conducted within a context of multiple policy agendas will always be a somewhat "messy affair."

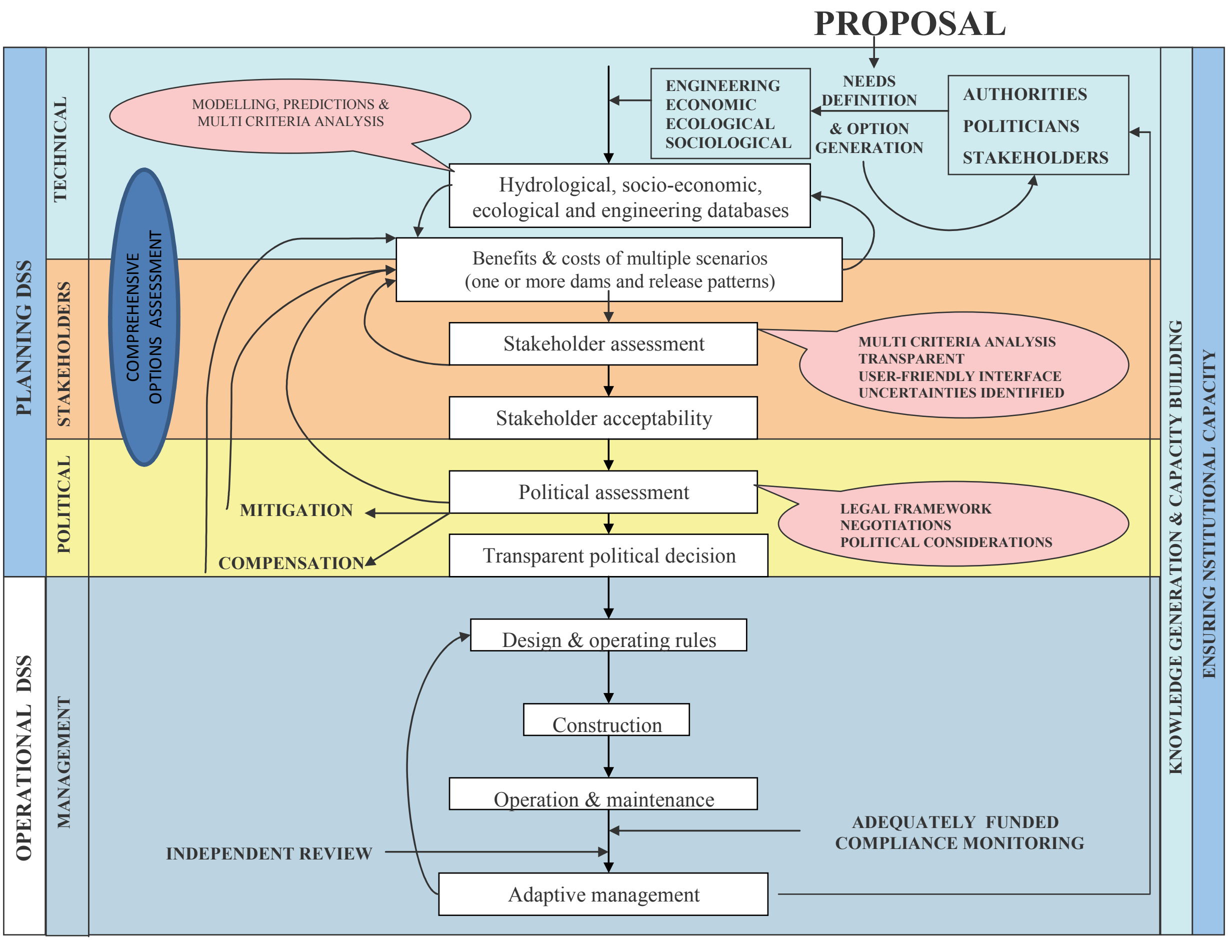


Figure 4.2. Conceptual framework for decision making in planning and operation of dams (McCartney 2006).

Two types of decision (i.e., for planning and operation) are shown in the left column. These generally conform to: a) the strategic assessment and project preparation and b) the project implementation and project operation phases of the project cycle (IHA 2009a), respectively. Table 4.1 provides an overview of the decision making processes to which DSSs can contribute at the different stages of the decision making cycle.

Table 4.1 Examples of processes to which DSSs can contribute at different stages of the decision making cycle.

Planning DSSs		**Operational DSSs**	
Strategic assessment	Project preparation	Project implementation	Project operation
• Water and energy needs assessment • Basin master plan • Strategic environmental assessment • Life cycle analyses of different options	• Comprehensive options assessment • Environmental and health impact assessment • Social impact assessment • Economic/financial viability assessment	• Dam design and plans for operation • Development of environmental, health and social management plans	• Dam operating rules and protocols • Implementation of environmental, health and social management plans

The framework conceptualizes the decision making process stepping through four major sets of activities: technical, stakeholder, political and management (second column on left). None of these four sets of activities is exclusive to the particular group which is used to designate it, but each is seen as the dominant "actor" at that particular stage in the project cycle. At each stage, the decision makers and their information requirements vary. For example, decisions about whether or not a dam should be built usually reside with politicians whilst decisions on day-to-day operation (requiring very different information) will be made by the dam operator.

4.3 Planning

The decision making process is initiated by a needs assessment. In relation to dams this relates primarily to likely future demands for water and/or energy services across a range of stakeholders. Following a needs assessment a range of options should be considered for fulfilling the demands. An options assessment comprises the collation and evaluation of all possible alternatives to meet the defined needs. In assessing options it is important that not only future demands but also the wider development objectives of a country or region are taken into account. Consequently, options assessments must also include assessment of the likely wider socioeconomic and environmental impacts, as well as issues of equity, poverty alleviation, etc.

In many instances, evaluation of options for the management of water resources will be best performed at the river basin level (e.g., through the development of a basin master plan). This should seek to balance competing uses of finite water resources and seek cross-linkages between different demands. Ideally, a range of stakeholders (including representatives of basin communities) should contribute to the development of basin master plans. In Africa, where many basins cross international borders, water resource option assessments should take into account the needs of all riparian countries. For dams, whether or not they are located in transboundary basins, options assessments will often result in multifunctional projects that should be more sustainable. Ideally, the options assessment should lead to the identification of a list of prioritized alternatives from which project proposals can be developed. The decision making process for a specific project is initiated by a proposal (top-right in Figure 4.2). This might be the construction of a new dam on a river (i.e., development) or changes to the operating rules of an existing dam to improve operation and reverse negative environmental and/or social impacts (i.e., rehabilitation). Responding to the proposal, the relevant authorities and all stakeholders (including all affected communities, both upstream and downstream, and those parties representing ecosystems) should be identified and their specific interests, issues and concerns ascertained.

At this point specific project-level options need to be reevaluated in detail and a "comprehensive options assessment" undertaken (UNEP 2007). All alternative plausible options, including the "no change" or the "no development" option, should be considered. Options will also include such things as optimization of capacity, different technical configurations, alternatives to mitigate environmental impacts and, in some instances, choices for rehabilitating ecosystem condition. This will inevitably be a largely technical exercise. However, all stakeholders including affected communities and end users need to be consulted widely, so that stakeholder concerns, in conjunction with the potential alternative options, guide the ensuing technical activities, which should be designed to provide information on the full range of costs and benefits of each option. Thus each option needs to be described in terms of technical, financial, institutional, environmental and social attributes and impacts. In accordance with the recommendations of the World Commission on Dams (WCD), the ecological and social aspects of the various options should be given as much consideration as the engineering and economic aspects.

All technical activities at this stage should be designed to provide the best possible understanding of the current status of the system and of all stakeholders, as well as the best possible predictions of the likely impacts of all the options. All options should be treated equally and, as far as possible, the full spectrum of costs as well as benefits linked to each (i.e., including the goods and services being provided by the ecosystem) should be evaluated. It is often difficult to make accurate projections of impacts. Use can be made of relatively complex projection techniques (e.g., the analysis of trends, modeling and multi-criteria analysis), but it should be recognized that complex techniques are not an end in themselves and the emphasis should be placed on experience, logic and common sense. All information should be stored in a comprehensive database.

Once evaluation of all options is completed, findings should be presented to all stakeholder groups in a way that is transparent, communicates all possible impacts and is explicit about uncertainties. Clearly, the way information is presented is crucial to ensuring the understanding of different stakeholder groups. Alternatives, that may be proposed by stakeholders, including suggestions for mitigating likely negative impacts, should be given full consideration and evaluated in the same way as all other options, with all findings reported back to stakeholders. As outlined here, this consultative process may be protracted. Although it should be time-bound (it cannot go on indefinitely), sufficient time must be given to do it properly. Ultimately, it may be impossible to reach consensus on a preferred option, but it is imperative that each stakeholder group feels that it has been listened to, with due consideration to its views. At the end of the process the relative degree of acceptability (or unacceptability) of each option for each stakeholder group should be determined.

The information pertaining to different options then moves to the political arena, where a political assessment should be completed. In support of the political process, a range of data should be available for each option. This should include quantitative and qualitative information on: a) the engineering aspects; b) the predicted changes in the river ecosystem; c) the predicted social impacts; d) the economic impacts, for beneficiaries, as well as the mitigation and compensation costs for those likely to be adversely affected; and e) the input from stakeholders on levels of acceptability. Each option should be assessed in terms of the country's legal framework and current political realities, and may involve negotiations with interested parties, perhaps leading to the requirement for additional or "compromise" options to be considered. Finally, all options should be ranked. Those completely unacceptable, for example because they do not conform to national legislation should be excluded. As far as possible the remaining options should be ranked on merit based on criteria that relate to both the initial needs as well as likely economic, social and environmental impacts. The final choice should be a transparent, well-motivated political decision, detailing which option has been decided upon and the reasons why it has been selected.

4.4 Operation

Once planning is completed, activities move into the arena of operation. The option that has been politically negotiated and chosen should guide the final design (and in the case of a new dam, construction) of the proposed development or rehabilitation project. Detailed consideration needs to be given to, as far as possible, avoiding and mitigating adverse impacts. For a new dam, this should include further consideration of design features (e.g., dam alignment, exact dam height, release structures, monitoring structures for inflows and outflows) as well as operating rules that meet all project objectives, including the minimizing of the negative impacts. Once the dam is operational, adequate, appropriately funded monitoring should be conducted to ensure both: a) compliance with operation and mitigation measures prescribed in the planning process, and b) evaluation of measures to ensure they are achieving the objectives intended. Monitoring should include both biophysical aspects of the scheme (e.g., to ascertain that flows released downstream are as intended and are effective in maintaining desired features of the river ecosystem) as well as socioeconomic aspects (e.g., to ascertain that intended benefits are being delivered). Monitoring is of extreme importance for mitigation and compensation programs because costs estimated on earlier predictions need to be verified, and the effectiveness of compensation and benefit-sharing mechanisms ascertained. To this end, all monitoring programs need to be well designed to ensure they provide information required for operational decision making. They should be well-structured, parsimonious (focusing on a few well-selected variables), and the results and methods subject to independent evaluation and auditing.

The final component of the process is adaptive management, which promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood (National Research Council 2004). For adaptive management to be successful, a prerequisite is a well- established monitoring network to collect the information necessary to deduce incremental changes and enable testing of the viability and effectiveness of decisions made. Adaptive management is often difficult for large organizations, as these tend to be prescriptive with rigid rules. A culture needs to be developed that facilitates response to findings from monitoring programs and assimilation of feedback received from different stakeholders, as otherwise recommendations may be made to no effect. Throughout the process, knowledge generation and capacity-building should occur, as should the development of institutional capacity to react (i.e., right-hand columns in Figure 4.2).

Source: Helen Houghton-Carr

Releases from Cabora Bassa Dam, Mozambique

Source: Panoramio

Vanderkloof Dam, South Africa

5. Decision support systems in Africa

Key message

Faced with growing concerns over the sustainability of water use, many African countries are focusing increasingly on the development of integrated basin-wide approaches to water management. In this endeavor DSSs are useful tools to assist with the planning and operation of large dams. However, despite considerable expenditure in terms of human and financial capital, complex DSSs developed in the past have very often not been trusted and as a result they have rarely been used to assist decision making in the way envisaged. There are a number of constraints to the use of DSSs in Africa. These need to be overcome to ensure the advantages to be obtained from DSSs are fully realized.

5.1 Use of DSSs for planning and operation of dams

Planning and operation of dams require the consideration of many interlinked variables in complex systems. To assist in this task, numerous computer-based DSSs have been developed. Broadly, these can be characterized into two types: simulation models and optimization models (Box 5.1). In the past, they have most often been developed by hydrologists and engineers, focusing primarily on the physical aspects of the system. Usually, they are based on simple engineering principles for dam operation, such as keeping reservoirs full for water supply or empty for flood control.

Box 5.1. Simulation and optimization models (*source:* McCartney 2007).

Simulation models

These replicate the physical behavior of a dam system by using mathematical equations to reproduce the key characteristics of the system on a computer. Simulation models provide the response of the system to specified inputs under given conditions. They therefore enable different alternatives to be investigated. Simulation models for the operation of dams have been applied for many years. Many models are customized for a particular dam or river basin. However, more recently, the trend has been to develop general models that can be applied to any basin or reservoir system. For example, HEC-ResSim has been designed and developed by the Hydrologic Engineering Center of the US Army Corps of Engineers specifically to perform Reservoir System Simulation for one dam or more.

Optimization models

Simulation models are useful for examining the long-term reliability of operating systems, but they are not well suited to determining the best or optimum strategies. Instead optimization models are used to systematically derive optimal solutions under specified objectives and constraints. The application of optimization techniques in reservoir studies has a long history and there are a large number of relatively complex mathematical techniques available.

A number of DSSs have been developed for use in Africa. These include the Nile Basin Decision Support Tool (DST) developed to simulate the water resource implication of alternative resource development options in the Nile Basin (Appendix 1, p50). There are also the Water Resources Planning Model, developed to assess water allocation in catchments in South Africa and a DSS developed for water resource planning in the Volta Basin (Appendix 1, p50). In the case of the High Aswan Dam, in Egypt, several different DSSs are used for planning and operation of the dam (Appendix 1, p51). However, there are many others (see Appendix 3, *Examples of DSSs used for dam planning and operation in Africa*).

5.2 Constraints to the development and use of DSSs in Africa

There are several constraints to the development of DSSs, many of which are common the world over, but are particularly prevalent in Africa. These constraints arise for technical reasons and because of limitations in human, financial and institutional capacity. They include:

- The lack of fundamental biophysical data (e.g., on river flows and ecological attributes of the river ecosystem).
- Limited understanding of the complex ecological and social consequences of dam construction and river regulation.
- The lack of qualified professionals (e.g., in water resources, agriculture, hydrology, ecology, public health, conflict resolution, socioeconomics, etc.) to develop, manage and use DSSs.
- The abundance of transboundary basins, which adds an extra layer of complexity and significantly increases the development time of basin-wide DSSs because of the need to gain agreement and coordinate the activities of all riparian countries (see Section 6.7).

Despite the recognition of the importance of well-managed water resources, the acquisition of hydrological data is not normally a high priority, and often attempts to collect other physical, chemical and biological data are even more limited. In recent years many monitoring networks in Africa have been deteriorating due to lack of investment and trained personnel. Consequently, data are rarely of sufficient quality to assist planning and decision making at a local level. Furthermore, although many of the broad impacts of river regulation are now understood, the specific ecological and social impacts of dams remain extremely difficult to predict.

Although many computer-based DSSs have been developed, there are several concerns over their use for decision making in Africa. These concerns include:

- The lack of capacity to develop and use these systems. Often they are developed by experts from outside the continent, so little of the experience and expertise remains within the region.
- The lack of ownership, and hence interest in applying DSSs, developed by others.
- Poor communication between model developers and users compounded by the lack of adequate training for users and, very often, insufficient documentation and support services.
- No consideration of the wide range of stakeholders that should be involved in the decision making process, including those without technical knowledge.
- No allowance for subjective and value-dominated human components in the decision making process.

In the past, water resources planning and management were left primarily to technical professionals. This is no longer the case. The need to satisfy societal requirements has expanded beyond the objective of simply water supply and, increasingly, a diversity of concerned parties demand input into the decision making process. Usually, only a small fraction of them is represented by technical professionals. For this reason, there is a need to provide information in user-friendly" ways that empower people to be involved in the process. However, very often this is not an issue considered in the development of DSSs, and they are rarely adept at outputting information to be applicable to a range of stakeholders.

Typically the most adverse social impacts are manifest in projects where the affected communities are least able to participate in the planning process (WCD 2000a). In cases where people are not involved apparent secrecy leads to distrust, rumors and speculation both about dam objectives and impacts (see Appendix 1, *Failure to include local communities in decision making processes*). In extreme cases this can result in civil unrest.

In a review of computer-based DSSs used for water resource planning, Prasad (2004) concluded that "....while much progress has been made in relation to assessing hydrological and ecological effects of different water management alternatives, attempts to address socioeconomic effects have been insufficient." He emphasized the need for greater use of socioeconomic indicators to: a) clarify socioeconomic goals and objectives, b) assist in the evaluation of trade-offs arising from different operating systems, and c) facilitate stakeholder involvement in decision making through negotiation.

These constraints undermine the effectiveness of DSSs, people and institutions and constitute a major challenge throughout much of the continent. Hence, although the need to move beyond determining immediate physical targets (e.g., volumes of water for irrigation or units of power) to consider far-reaching impacts on ecosystems and livelihoods is now broadly recognized, it is not widely applied. Many of the DSSs developed in the past have ended up neither providing the information really required nor being fully accepted by planners and managers. Often, very sophisticated models are developed, but they are rarely trusted and, very often, they are not used as envisaged to assist in decision making.

5.3 The way forward

Overcoming these constraints, so that DSSs can be more successfully used, requires changes that affect decision making throughout water resources planning. Across much of sub-Saharan Africa this is now widely recognized. Increasingly, governments are developing policies and strategies that promote Integrated Water Resources Management (IWRM). In comparison to the past, this approach focuses more on environmental and social impacts and brings issues of equity to the fore. However, there is a long way to go from the development of such policies to their successful implementation.

The following are suggestions to enhance the application of DSSs to planning and operation of dams, and hence to contribute to IWRM, in Africa:

- Invest in data collection, capacity-building and research. Good information and analyses are essential for effective planning and operation of large dams. Currently, throughout most of Africa, insufficient knowledge and analytical capacity are critical impediments to identification and holistic planning of large dams. Data collection and monitoring systems need to be significantly enhanced, and much more research is needed into the interlinkages between the environmental and social impacts of dams.

- DSSs need to be usable and developed collaboratively. For DSSs to be used users must be confident in the outputs, which must provide readily understood information, address the range of stakeholder concerns and provide them in a timely fashion. Hence, the capacity to use DSSs and interpret the information they provide must be built locally and sustained over time. Simple transfer of technology and/or knowledge from elsewhere is generally inappropriate. Those who use DSSs must be involved in all aspects of their design, development and implementation.

- DSSs need to based on participatory inputs from a range of stakeholders. It is essential that DSSs are developed within a fully participatory environment in which all stakeholders can contribute and which take into account their views and expectations. By facilitating communication between different stakeholders DSSs can improve relationships and make decision making processes more rational and more easily justified, defended and understood.

- Examples of effective and innovative DSSs need to be better shared. There is need to enhance the sharing of innovative approaches and practical experience in the use of DSSs in Africa. Examples of implementation, including assessment of outcomes and the value of any DSSs to the decision making process, are required to improve practices and make implementation more effective. Currently, beyond a few project reports, there is almost no critical evaluation of the application of the wide range of DSSs used for planning and operation of large dams in Africa. Country-specific experience should be documented and published. Communication of the information to planners, managers and practitioners should be improved.

More detailed recommendations on the contribution DSSs can make to aspects of decision making that are important in the planning and operation of dams in Africa are given in the following chapter.

Source: www.archithings.com

Tekeze hydropower project, Ethiopia

6. Recommendations

Key message
Throughout Africa there is an urgent need to enhance the benefits of dams whilst minimizing the negative impacts. Broadly, this requires better decision making processes that a) strengthen stakeholder involvement, b) improve EIAs, c) improve consideration of downstream environmental and social impacts, d) take better account of possible public health impacts, e) improve options assessment, f) improve mechanisms for benefit-sharing, and g) improve water resources management in transboundary basins.

This chapter discusses each of the seven issues identified through the research project and confirmed at the workshops conducted in May 2008 and September 2009.

6.1 Enhancing stakeholder input to the decision making process

Stakeholder participation is key to improving decision making and governance in the planning and operation of dams. For decisions to be sustainable it is important that local people feel involved and that their points of view are acknowledged and, where possible, acted on. This requires empowering all stakeholders to be involved in the decision making process from the outset. Many government policies acknowledge the need for participation and some experience has been gained in Africa. For example, in Senegal, the water requirements of different stakeholders utilizing different natural resources were identified, and this informed modeling efforts to determine dam release regimes on the Senegal River (Duvail and Hamerlynck 2003). In South Africa, attempts to involve stakeholders in planning flood releases from the Pongolopoort Dam have been only partially successful (McCartney *et al*. 2003). In both cases local stakeholders were only involved after the dams had been built and the adverse impacts had occurred.

The recognition that decisions are more sustainable if stakeholders are actively involved in the decision making process has increasingly led to DSSs being designed with their participation and involvement. In the Great Ruaha River in Tanzania, attempts have been made to involve stakeholders directly in the development of a computer simulation model for water resource planning (see Appendix 1, *RUBDA*) and simultaneously, an innovative, noncomputerized DSS was developed to involve local communities (see Appendix 1, *The River Basin Game*). Such processes help increase the acceptability of decisions made. Even when people disagree with the decision made they are more likely to be accepted if they had been consulted and actively involved in the decision making process.

If carefully designed and implemented DSSs can contribute to:

- The open sharing of information and improve the transparency of decision making processes for all stakeholders.
- Making the decision making process cooperative rather than adversarial.
- The empowerment of weaker stakeholders by providing them with information that relates directly to the concerns that they themselves identify.

To achieve these objectives it is necessary that DSSs address, to the extent possible, the concerns of all stakeholders. In reality many of these concerns will not be directly related to the dam but may be influenced in a tangential manner. DSSs can often highlight the linkages and in particular identify the social implications of biophysical changes arising from dam construction and operation. To empower stakeholders in negotiating processes DSSs need to provide and present information that is understandable to a range of stakeholders, including nontechnical people.

6.2 Improving follow-up to EIAs conducted for dams

Currently, environmental impact assessments (EIAs), in various forms, are the primary tool for examining the environmental and social consequences, both beneficial and adverse, of large dams. They are widely viewed as safeguards to ensure that environmental damage is minimized and adverse social impacts are avoided. However, to be effective EIAs require competent and comprehensive follow-up, which involves the implementation of measures taken to mitigate the adverse environmental and social impacts of a project, plus monitoring to determine their effectiveness. Without some form of systematic follow-up to decision making, EIAs simply become a mechanism to secure a development permit, rather than a meaningful exercise in environmental management (see Appendix 1, *EIA follow-up of the Koga Dam*). This is a recognized problem both in the developing and the developed world; implementation of EIA recommendations is often not done well.

Successful implementation of EIA recommendations requires that both policies and institutions are in place to enable adequate follow-up. It also requires that project managers have the tools necessary to facilitate the effective monitoring of impacts and to predict the potential consequences of changes arising from construction and operation of dams. DSSs can also help with determining possible differences in outcomes and impacts arising from different scenarios of development or different modes of operation of a dam (see Appendix 1, *Adaptive management at the Itzehi-tezhi Dam, Zambia*).

DSSs can help improve follow-up mechanisms by, amongst other things, providing dam operators with tools to assist in the archiving, analyses and interpretation of data collected in monitoring networks established through EIAs. The intention is to provide insights into how the system (including social components) is being impacted by a dam and to facilitate informed decision making to enable adjustments to be made in the way it is operated. DSSs can also be used to harmonize data collection and to highlight gaps in monitoring networks, thereby facilitating improved data collection. Finally, again by providing insights into system functioning, they can be used to assist in the development of longer-term management plans. Thus DSSs are essential for adaptive management.

6.3 Improving consideration of downstream environmental and social impacts

By their modification of flow-related ecological processes dams can reduce the opportunities for people whose livelihoods are dependent on riverine ecosystems (chapter 3). Environmental flows are the flows released from a reservoir (or in the absence of a dam simply left in the river) in order to maintain valued features of the ecosystem, including those elements that support livelihoods. In recent years, a large number of methods for estimating environmental flow requirements have been developed. The most rigorous are based on very detailed studies that require considerable data and input from experts across a range of disciplines. However, a number of simpler approaches that require fewer data and fewer expert inputs have also been developed. Of course, the simpler methods (usually based on hydrological indices) produce less robust results in which less confidence can be placed. However, such methods are useful for initial planning in areas where data are scarce and/or preliminary results are required quickly (see Appendix 1, *Use of the Desktop Reserve Model (DRM)*).

Although, a full analysis, based on detailed environmental and social understanding of river ecosystems is preferable, application of such methods can be of use in the early stages of planning as long as model limitations are recognized and precautions are put in place to work within data limitations. When water resource decisions have to be made, with or without scientific input, they provide a useful initial estimate that can create awareness and provide at least a basis for discussion between dam proponents/operators and other stakeholders.

DSSs can make important contributions to many aspects of estimating downstream environmental flows. For the simpler approaches the best are those, such as the DRM, that compute both high and low flow requirements based on naturalized flow series. The more complex approaches will often utilize a range of DSSs to investigate intricate ecological processes and requirements (e.g., habitat requirements for specific fish species) as well as the social and economic implications of different possible flow regimes.

The broad impacts of modification of the flow regime are now well understood. However, all dams are unique and often there is often great uncertainty of specific impacts and, in particular, the likely socioeconomic implications of change. DSSs are being increasingly combined with expert judgment to gain insights into flow-ecosystem links and in turn the links to livelihoods (see Appendix 1, *Application of DRIFT*).

Environmental flows are essential for the sustainable and equitable development of aquatic resources. The countries of sub-Saharan Africa would benefit significantly from programs to build capacity in environmental flow assessment. As a starting point, these should be developed using the expert opinion of national ecologists, hydrologists, social scientists and others who have detailed knowledge and experience of the region's rivers, with guidance from experts in the process of environmental flow assessment. Such programs should include research to better understand flow-ecology-livelihood links as well as how to proceed with limited knowledge and improve relevant DSSs. Even if the initial results are uncertain, attempting environmental flow assessment, utilizing teams of appropriately guided experts, would facilitate holistic approaches and assist interactions between different disciplines. This would be a useful first step in the development of national and regional expertise in environmental flow assessment.

6.4 Considering possible health impacts and the role of dam operation in mitigation

In Africa there are particularly strong links between diseases and the construction of infrastructure, including dams. However, the public health impacts arising from the construction and operation of dams are often poorly understood and often overlooked during planning and operation of dams. Public-health agencies are often not involved or only marginally involved. As a result, adverse disease impacts are often passed to health authorities to deal with, rather than being more fundamentally incorporated into the planning process. Inadequate consideration of public-health impacts can seriously reduce the envisioned benefits of large dams and, in some circumstances, may undermine their sustainability (Section 3.6).

An innovative approach to disease control that has not been widely explored in Africa is the use of dam management as a form of environmental control, for example, reducing malaria by managing reservoir water levels to reduce mosquito breeding habitat. Research conducted in Ethiopia has shown that at least under certain circumstances, manipulation of water levels has the potential to reduce breeding habitat by drying out puddles around reservoir shores (see Appendix 1, *Use of reservoir operation as a tool for malaria control*).

DSSs can contribute significantly to both improved understanding of the complex links between disease vectors and reservoirs and also better management of likely health impacts. Many models have been developed that simulate the mechanisms underlying disease vector dynamics and their relations to the environment. Although much research still needs to be undertaken, these models enable a better understanding of the mechanisms underlying disease transmission both generally and also in specific geographic environments. As such, they provide a starting point for predicting the likely impacts prior to dam construction and the impacts that may arise from specific interventions to reduce transmission.

By quantifying the likely health impacts, DSSs can contribute to Health Impact Assessments (HIAs), which are similar to EIAs but focus on health (WHO 1999). They provide a systematic approach for screening, assessing, appraising and formulating management plans to address key public health issues associated with development projects, including dams. However, HIAs are generally under utilized as tools for health protection. Practical approaches to HIAs have been advocated by the World Health Organization and the Asian Development Bank. However, while most African countries have a framework for EIAs few possess adequate capacity for HIAs. A policy shift is required to build capacity and ensure that institutions promote integrated Environmental Health Impact Assessments rather than EIA (Amerasinghe and Boelee 2004).

DSSs can also be used to assess the non-health implications and trade-offs associated with alternatives for disease control. For example, modifying dam operating rules to reduce vector habitats will invariably alter water availability for other uses (e.g., hydropower production and/or irrigation) with consequent economic implications (see Appendix 1, *Integrating malaria controls*). DSSs can be used to compare the costs incurred through dam management with other options (e.g., increased distribution of bed nets and/or clinics to treat diseases). However, it is important to remember that economic factors should not be the only consideration. All public health interventions have limitations and often integrated approaches that utilize many different measures have the biggest impact on disease transmission (Mutero *et al*. 2004).

6.5 Improve options assessment

A comprehensive options assessment of dams and their alternatives was highlighted by the WCD as being critical for sustainable development (WCD 2000a). The aspiration of the WCD was that, in any given situation, development needs would be matched to the most appropriate development options. Hence, before a dam is built a "needs assessment" should be conducted and a dam (or dams) must be identified as the most feasible/beneficial option. Clearly, a comprehensive assessment requires a detailed evaluation of the implications (both positive and negative) of different options for fulfilling needs.

There remains a gap between aspiration and reality when it comes to implementing processes for options assessment. It is widely recognized that these assessments need to be conducted early in the process, before decisions on the type of investment are made. Currently, many options assessments begin only at the project level, and at this level, the technology to be used, has in many cases, already been determined. Needs assessment, conducted at the national and regional level, is viewed by many as a prerequisite to a comprehensive options assessment (UNEP 2003). Increasingly, basin wide options assessments are also being conducted with the objective of informing basin-wide water resource management plans (King and Brown 2009).

DSSs can contribute to options assessment both by assisting in the identification of needs (across a range of scales) and by providing information on the likely consequences of a range of approaches to satisfy the identified needs. At the national level DSSs can also provide information to assist with the establishment of goals, policies and procedures that facilitate proper options assessment. Where dams are being considered DSSs can contribute to the options assessment by investigating their impact both individually and cumulatively within a catchment (see Appendix 1, *Investigating the cumulative effect of dams on the water levels in Lake Tana*).

At basin or project level, a range of DSSs can be used to identify the costs and benefits (and to whom) of all possible options and for early screening of those that are infeasible. Economic tools can indicate which options are financially viable and highlight trade-offs between different needs. However, it is imperative that decisions are not guided by financial concerns alone. In all cases non-monetary benefits also need to be considered and some form of multi-criteria analyses is essential. Optimization models can contribute to identifying best possible options, but it is essential to factor in constraints to protect essential ecosystem services and people's livelihoods.

Of course a prerequisite for informed decision making is a good understanding of how existing river flow regimes benefit and support the livelihoods of riparian communities and how changing flows will affect these benefits. To get a sufficient understanding requires a holistic evaluation that integrates inputs from a range of different disciplines, all of which may use a number of DSSs. Of course, it is essential that biophysical information is produced in such a way that it is possible to predict both likely ecological impacts and, in turn, the likely social implications (positive and negative). Such understanding can only be obtained if local communities are actively involved throughout the process (see Section 6.1).

6.6 Improving mechanisms for compensation and benefit-sharing

The primary beneficiaries of dams often live far away from where the dams are located. Those who live closer to the dam either upstream or downstream, are the most likely to be adversely affected. Too often, in project planning and implementation, the national interest has been the primary consideration and local concerns are neglected.

Ensuring equitable outcomes from development requires that measures are developed to sufficiently offset any negative impacts. As the WCD noted, the construction of a dam should be a development opportunity for all (WCD 2000a). This means ensuring stable improved livelihoods of all affected people. However, in the past the focus has generally been on immediate compensation and relocation and, even when this has been done well, little thought has been given to how livelihoods are best enhanced and supported in the long term. A key component, almost never considered, is how to retain stable social structures, particularly in displaced communities.

One way to address adverse impacts is to go beyond simple compensation and to share some of the benefits generated by a dam with the communities directly affected. A number of benefit-sharing mechanisms have been developed. These enable communities to gain directly from the dam. Benefit-sharing mechanisms can be either non-monetary or monetary. The former are generally included in compensation policies and include mechanisms for community development, for example, access to irrigated land, guaranteed employment generated by the project or improved access to services (e.g., schools and clinics). Monetary benefit-sharing is based on the premise that dams may generate a significant economic return that can be shared with project-affected communities either directly (i.e., revenue-sharing) or indirectly (i.e., development funds, equity-sharing, taxes paid to local authorities, preferential electricity or water fees). Increasingly, novel approaches to benefit-sharing, including those that promote local development (e.g., dam proponents providing solar panels for rural electrification), are being considered and in some instances (though rarely in Africa) implemented (UNEP 2007).

Benefit-sharing mechanisms are clearly stipulated in the legislation of some countries. For example, article 43 of the Constitution of Ethiopia (revised in 1995) defines the rights of all Ethiopians to participate in national development and to be consulted with respect to policies and projects affecting their community. It further states (article 44) that all people who are displaced or whose livelihoods are adversely affected as a consequence of State Programs have the right to commensurate monetary or alternative means of compensation. Hence, project plans must include "attractive" compensation and incentives to the affected population. This is usually interpreted to mean a package that improves or at least restores the social and economic base of those affected. Although these principles have been formalized within the country's civil code the effectiveness of on the ground implementation is not always as good as it might be (see Appendix 1, *Compensation and benefit-sharing*)

In some places, dam proponents have negotiated partnership agreements directly with concerned communities on the basis of a wide variety of mechanisms. For example, Hydro-Québec in Canada routinely negotiates business agreements with local communities for all new hydropower projects. However, such arrangements are rare in Africa.

DSSs can contribute to detailed evaluation of compensation needs (usually based on losses that are likely to be incurred) and the appropriateness of proposed benefits across a wide range of affected people with a range of livelihood strategies (i.e., an assessment of who is likely to be adversely affected by construction and operation of dams and what they will lose). For upstream communities this will most often consist of loss of assets due to inundation, whilst for downstream communities impacts on natural resources are the most common. As far as possible this evaluation should include an assessment of non-monetary as well as monetary impacts arising from the scheme.

To design adequate benefit-sharing mechanisms it is essential to have both an understanding of local conditions and good data. In the past, even where social baselines have been established data on living standards linked to livelihoods are often missing. As a result, it is impossible to determine whether living standards have been restored or improved in the great majority of projects. This is a serious omission which hinders the implementation of remedial measures and ultimately undermines evaluations of the extent to which projects are a success. Post-project evaluation of the success/failure of compensation and benefit-sharing mechanisms is rare.

Clearly, participation of the affected people, including the capacity to negotiate, is essential in designing and implementing compensation and benefit-sharing systems (Section 6.1). Having a transparent system, in which parties are empowered to negotiate helps ensure a more equitable distribution of benefits as well as accountability of those agencies entrusted with benefit redistribution. The record indicates that in those cases in which compensation packages were negotiated with project-affected communities, in conjunction with other stakeholders, the process has resulted in better outcomes. Even when, for whatever reason, the negotiated form of compensation proves not to be the most appropriate or effective option, project-affected people tend to feel more satisfied, as a result of the negotiation process.

6.7 Improving water resources management in transboundary basins

Africa is a continent with a large number of rivers that cross international borders, the so- called "transboundary" rivers. With the exception of island states, every African country has territory in at least one transboundary river basin. Furthermore, transboundary basins cover 62% of Africa's total land area and virtually every one greater than 50,000 km^2 crosses at least one national border (Giordano and Lautze 2009). The planning and operation of large dams in these river basins, already difficult, are further complicated by the fact that the water resources are shared between nations.

When a dam is built on a river that flows entirely within the borders of a single country, the costs and benefits associated with the construction of the dam are borne by individuals and groups within that country alone. However, when a dam is built in a transboundary basin a different calculus must be considered. In the absence of a well- defined water-sharing agreement, construction of dams in upstream riparian states can lead to tensions and even conflict between countries if downstream states feel that these dams are depriving them of water to which they are entitled or for which they have a need. In many instances control of water by upstream states is viewed as an issue of national security by downstream nations.

Several papers (Salman 2001; Bandyopadhyay 2002; Wolf *et al.* 2003a, b) acknowledge the importance and implications of dam construction in international watersheds. Bandyopadhyay (2002) explains that dam construction in international basins "constitutes an area fraught with tension and friction among co-riparian nations." The World Commission on Dams (2000a) notes how conflicts over transboundary rivers are "often caused by proposals to store or divert water by constructing dams." Another report identifies dam construction as "the most important cause of water related conflicts" because "...it is only with dams that states can significantly re-direct, store, and otherwise alter the course of rivers to the extent that would cause changes of conflict-invoking proportions in neighboring states" (Curtin 2000).

While transboundary basins present challenges, they also present opportunities. Collective decision making allows for achievement of benefits over and above those which would normally be available to individual countries. Although countries may not benefit equally from pure maximization of collective benefits, increasingly there are ways to offset this by viewing water in a broader context. Indeed, recent thought in the international water movement has called for a shift from sharing water to sharing water's benefits and considering these benefits in a broader context of regional collaboration and economic development (Sadoff and Grey 2002).

Within Africa there are numerous instances of states cooperating to build and operate dams on their shared rivers (e.g., Orange, Senegal and Zambesi basins). Maximizing the benefits of water resources is increasingly recognized to require basin-wide water management. In international basins, this calls for a transboundary decision making framework typically manifested through an international agreement. In recent years, there has been a significant increase in transboundary water agreements in Africa that have focused on the development of equitable use of shared water resources and led to the formation of institutions to manage international rivers (Giordano and Lautze 2009). Nonetheless, the majority of Africa's transboundary basins currently have no basin-level agreement in place.

DSSs can contribute in various ways to confidence-building between nations, the development of international water agreements and improved management of water resources in transboundary basins. They can do this by providing a mutually acceptable platform for information management and analyses of water resource interventions within the basin. In an appropriate political and institutional environment, the beneficial functions that DSSs can provide for transboundary basins are typically:

- A knowledge base from which riparian countries can draw and to which they can contribute information relevant to the sustainable development of water resources.
- A common basis for policy and strategic analyses, facilitating dialogue/ negotiations between riparian states.
- A platform for communication, facilitating the joint identification of development strategies and the coordination of responses to emergencies such as floods and droughts.
- A platform for identifying potential cooperative projects (including large dams) and the tangible benefits, impacts and trade-offs that would accrue to each state from such projects.
- A tool for the integrated management of infrastructure (including large dams) throughout the basin with the objective of maximizing benefits and minimizing costs for all the riparian countries.

Clearly, in transboundary basins the process of development and the manner of application are critical if a DSS is to be useful, with the results accepted as credible and objective by all the riparian states. To increase credibility, it is also important that DSSs developed for use in transboundary basins support the IWRM principles of stakeholder and community involvement. Ideally, they should be able to respond to non-state as well as state actors requests for information in addressing transboundary issues. Furthermore, the knowledge gained through application of DSSs should be made publicly available (Lee and Scurrah 2009). Hence as much effort needs to go into the establishment of appropriate institutional arrangements as goes into the technical aspects of the DSS development and use, if not more (see Appendix 1, *Development of DSSs in the Nile Basin*).

Decisions pertaining to planning and operation of large dams made by individual states within transboundary basins are rarely equitable nor, when viewed from the perspective of the entire basin, as effective or efficient as they could be. The challenges in developing DSSs that will be accepted by all the riparian states are manifold. However, when they can be implemented within an appropriate institutional framework, they have an important role to play in building confidence, enhancing cooperation and maximizing the multiple benefits that can be generated within a basin.

Source: Panoramia

Wilaya de Béjaia, Algeria

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Source: Panoramia

Heyshope Dam, South Africa

Appendix 1. Case studies and additional information relating to this R4D Paper

Water hyacinth (source: Joffe and Cooke 1997)
From Chapter 2, Section 2.6

An example of the infestation by less desirable species is that of water hyacinth. The Niger Delta, in Nigeria, a vast and ecologically complex floodplain, is one of the world's largest wetlands. The freshwater swamp forests are among the most extensive in Africa. The delta is home to more than 6 million people, most of whose livelihoods depend on fishing, subsistence agriculture and the selling of wetland products. The delta ecosystem is maintained through a dynamic equilibrium between flooding, erosion and sediment deposition. However, construction of dams along the Niger River has disrupted the hydrological balance, significantly modifying water flow regimes and sediment deposition. The spread of water hyacinth (*Eichhornia crassipes*), in part resulting from reduced flushing, is a major problem. The weed spread 800 km in just 7 years. The negative effects on fishing, navigation, irrigation, fish ponds and human health (i.e., because it provides a habitat for mosquitoes), are estimated to have affected 5 million people.

Source: Wikipedia

Impact of the Kariba and Cabora Bassa dams on the ecology of the downstream Zambezi floodplain (various sources summarized in McCartney and Acreman 2000).
From Chapter 2, Section 2.6

Impoundment of the Zambezi with the creation of Lake Kariba and, further downstream, Cabora Bassa, illustrates the complex consequences that dam construction may have on downstream ecosystems. Following closure of the Kariba Dam some 2.3 km^2 of land were lost from 10% of the total bank-length of the Zambezi between Lake Kariba and the Zimbabwe/Mozambique border. Erosion is attributed to the release of silt-free water, the maintenance of unnatural flow-levels, sudden flow fluctuations, and out-of-season flooding. The maintenance of relatively high, but in-channel, water levels for long periods has encouraged upper-bank erosion as a result of wave action.

The construction of the Kariba Dam has had a significant impact on the ecology of the floodplain located 130 km downstream of the dam. Under natural conditions, the active migration of the Zambezi River produced a broad floodplain containing a series of residual pools. Prior to construction of the dam, the floodplain was in most years inundated to a depth of up to 5 m, and flooding persisted for 3 months or more; silts and nutrients were supplied and stagnant pools flushed. At the same time, large herbivores were driven off so that aided by waterborne seed dispersal the vegetation could recover from the intense grazing pressure to which it was subjected during the dry season. Thus, the productivity of the floodplain was replenished each year.

Now, river regulation has reduced the ecological dynamism of the floodplain and removed the instability that was previously a key factor in the ecosystem, resulting in reduced productivity. Flood control during the wet season has induced a response in the vegetation's composition to one favoring drier conditions; the species composition of the grass sward has declined, with an increase in unpalatable herbs and grasses. Floodplain pools have become infested with emergent rooted aquatics and water fern. The elimination of flooding has allowed grazing to continue for longer periods than formerly, and some herbivores (e.g., water buck) have moved from their wet-season dispersal areas to spend virtually all year on the floodplain. Consequently, the recovery period of the floodplain is markedly reduced and the habitat placed under additional stress. Overgrazing has resulted in habitat reduction and is believed to be the cause of reduced populations of various natural species including hippopotamus, Nile crocodile and various waterfowl.

Downstream of Cabora Bassa, flow regulation has allowed intrusion of salt water in coastal areas, reduced silt loads and destroyed large areas of mangrove along the coastal floodplain. Reduced flooding in the delta area has dried out the rich alluvial soils, many of which have become alkaline or saline with invading savanna vegetation.

Source: www.webshots.com

Examples of DSSs used in Africa

From Chapter 5, Section 5.1

Nile Basin DST

In the Nile Basin, a number of DSSs have been developed to assess and weigh the benefits and impacts of water development and management strategies. These include the Nile Basin DST which is a planning model for the whole of the Nile Basin, developed under the auspices of the FAO. It includes a river and reservoir simulation and management module comprising five components: a) river network configuration, b) river hydrology, c) existing and planned hydropower facilities, d) water use, and e) reservoir operating rules. The model simulates the movement of water through river reaches and reservoirs and can be used to simulate the impacts of alternative water resource development options (Georgakakos 2006). Interestingly, although the Nile Basin DST exists, it suffers from many of the limitations to DSSs outlined is Section 5.2 and also does not address ecological and social impacts of dam development. As a result, it has not been widely applied in the basin. Currently, the Nile Basin Initiative (NBI) is developing a new DSS as part of the Water Resources Planning and Management (WRPM) Project of the Shared Vision Initiative (NBI 2006). Since it is being developed in the region the WRPM DSSs hold much greater potential for adoption by countries in the basin (see Appendix 1*, Development of DSSs in the Nile Basin*).

Water Resources Planning Model (WRPM)

Developed in South Africa this simulation model is used for assessing water allocation within catchments. The model simulates surface water and groundwater as well as interbasin transfers. The impact of dams on the water yield of the catchment is accounted for. The model is designed to be used by a range of users with different requirements and can be configured to output information in different user-friendly ways (Mwaka 2006).

Volta DSS

A DSS has been developed to assist with the management of transboundary water resources in the Volta Basin. The DSS comprises a hydrological modeled coupled with the Water Evaluation And Planning (WEAP) model. The DSS has been used to simulate the impacts of upstream development of small reservoirs and climate change scenarios on inflows to Lake Volta and hydropower production in Ghana. The DSS is currently being utilized by the Volta Basin Authority to assist with basin planning (de Condappa *et al.* 2009).

Source: Wikipedia

Akosombo Dam, Ghana

DSSs used in the operation of the High Aswan Dam

From Chapter 5, Section 5.1

The High Aswan Dam is crucial for the well being of nearly all the 63 million people who live in Egypt. Of the country's population of 63 million 97% (in 2000) live on 5% of land in the small strip along the Nile River and in the Delta. Nearly the entire agricultural area of 3.4 million ha is irrigated with water supplied from the reservoir which stores 162 Bm^3 of water (two times the mean annual flow at Aswan).

Source: Wikipedia

To assist with dam operation a suite of DSSs is utilized. These include:

- Nile Forecasting System (NFS): software developed to predict long-term inflow into the reservoir based on upstream rainfall and climate, which can be used with climate change models.
- DSSs for sedimentation: used to evaluate the effects of various inflow scenarios on sedimentation in the reservoir and produce time-series of maps.
- RIBASIM: software for river-basin simulation used to generate inflow estimates, route discharge and simulate abstractions from upstream reservoirs. The software is also used to model the river downstream of Aswan to value potential water surpluses and deficits.
- DSS for the High Aswan Dam: given a certain inflow is used to simulate different operational strategies for the dam to assess implications for power production and downstream flows.
- SOBEK: hydrodynamic model used to simulate water levels along the Nile downstream of the dam to generate flood extension maps and assess the morphological effects of larger floods.

These DSSs provide the dam operators with a broad range of information with which to plan both immediate releases and long-term strategies for managing the dam.

Failure to include local communities in decision making processes
(*source:* McCartney *et al*. 2009a).
From Chapter 5, Section 5.2

The Chara Chara weir was built at the outlet of Lake Tana, Ethiopia in 2001. The operation of the dam affects the livelihoods of people living both upstream close to the shores of the lake and downstream close to the river. Upstream, increased drawdown of the lake has caused decline in fisheries, problems with shipping and destruction of papyrus reed beds used by local people for boat building. Downstream, the regulated flow has benefited some people by providing water for dry-season irrigation, but diversion to a hydropower station has caused the drying up of the Tis Issat waterfalls, a renowned symbol of Ethiopia's natural heritage and a major tourist attraction. Local people complain that they have gained nothing from the construction of the power station (not even electricity) and have had their livelihoods adversely affected by the drying up of the waterfall.

To date decisions pertaining to both the construction of the weir and its operation have been made in isolation by the government and the Ethiopian Electricity Power Corporation (EEPCO - a parastatal that manages the power stations and the day-to-day operation of the Chara Chara weir) without any form of public consultation. This form of decision making has led to widespread dissatisfaction, fueled controversies and resulted in rumors and speculation about the function of the weir and the resultant impacts. Many local communities are unhappy with changes in water levels of the lake caused by the dam operation, which they believe are leading to environmental degradation and adversely impacting their livelihoods. However, the mechanisms do not exist for them to communicate their concerns and they do not feel empowered to raise them with government or EEPCO.

Source: Matthew McCartney

People use the shoreline of Lake Tana for a variety of livelihood activities

RUBDA – an example of DSS development with stakeholder participation
(*source:* Cour *et al.* 2005).
From Chapter 6, Section 6.1

The Ruaha Basin Decision Aid (RUBDA) is a DSS developed for the management of water resources in the Great Ruaha River catchment in Tanzania, which contains two major hydropower dams, called Mtera and Kidatu. Its aim is to support users, such as the Basin Water Office and District Councils in making water allocation decisions. It provides a means of determining the likely hydrological and socioeconomic consequences of allocation alternatives. It was recognized early in the project that if it was to be used by those for whom it was intended, the DSSs would need to live up to their expectations and objectives. Consequently, considerable effort went into determining user information needs and requirements, through numerous interviews, workshops and seminars. Early versions of the DSSs were presented to stakeholders, including likely future users, and their feedback was used to modify it to make it more user-friendly and flexible enough to meet a range of different expectations. The model was designed to be flexible so that a range of possible alternatives, including upgrading both rain-fed and irrigated agricultural systems within the basin, could be assessed. Indicators of performance were defined through workshops and cover a range of water resources, and economic and social criteria that stakeholders, with extensive knowledge of local conditions, felt could adequately reflect water resource, economic and social implications at different locations within the catchment.

Source: Wikipedia

Great Ruaha River

The River Basin Game – a tool to facilitate stakeholder participation in decision making
(*source*: Lankford *et al.* 2004).
From Chapter 6, Section 6.1

The River Basin Game is a dialogue tool for decision makers and water users that was been tested in Tanzania and South Africa in workshops involving both high-level decision makers and community representatives. It comprises a physical representation of the catchment in the form of a large wooden board. In contains the river flows between the upper and downstream catchments and has on it several intakes into irrigation systems of varying sizes. Glass marbles that 'flow' down the channel represent the water. Participants make decisions about water abstraction and allocation between different irrigation schemes and can see the impact of wet and dry years. The game has been found to promote mutual understanding of different people's levels of access to water and allows participants to actively react to different alternatives. Experience shows that, by the end of the game, participants have a good understanding of system dynamics and common property pitfalls. The game also enables them to identify which water management issues are most critical and what solutions might be considered. The game is socially inclusive in that it enables a range of stakeholders to contribute ideas for water management solutions and make suggestions about institutional arrangements.

Source: Matthew McCartney

The River Basin Game being played by local people during a workshop in Tanzania

EIA follow-up of the Koga Dam

(*source:* Abebe *et al.* 2008).
From Chapter 6, Section 6.2

An EIA was conducted for the Koga Dam recently constructed on the Koga River, one of the major inflows to Lake Tana, in Ethiopia. The dam was built to supply water to a 7,000 ha irrigation scheme. An investigation of the EIA follow-up found that although there were some weaknesses (most notably in the evaluation of downstream impacts) overall, the EIA had been reasonably well conducted. However, the follow-up was weak with only two out of 20 proposed environmental mitigation activities being undertaken adequately. Poor implementation was found to have arisen for a variety of reasons. Key limitations were:

- Lack of monitoring which meant that managers were unable to make informed decisions.
- Lack of relevant expertise in the project management team.
- A weak regulatory and institutional framework.
- Lack of public participation and the absence of a strong civil society to ensure that EIA recommendations were implemented.

Source: Matthew McCartney

Koga Dam, under construction, 2007

Adaptive management at the Itzehi-tezhi Dam, Zambia

(*source:* McCartney *et al.* n.d.; Schelle and Pittock 2008).
From Chapter 6, Section 6.2

The Kafue Flats is an area of floodplain wetlands, covering about 6,500 km^2, along the Kafue River, a tributary of the Zambezi. Comprising the meandering river and a complex of lagoons, ox-box lakes, abandoned river channels, marshes, levees and floodplain grassland the Flats constitute one of the most biologically diverse ecosystems in Zambia. Traditionally, the natural resources of the Flats have been utilized in a wide variety of ways, for both commercial and subsistence purposes. It is estimated that more than 100,000 people are in some way dependent on the Flats. Cattle grazing is a major activity and up to 290,000 head of cattle (10 to 20% of the national herd) utilize the Flats during the dry season. Some flood recession agriculture is practiced (maize, groundnut and cassava), but yields are low and this has never been widespread as a land use. Baskets and mats are woven from reeds and papyrus at a subsistence level. Hunting, although illegal, provides an important source of protein for local people. The Flats support one of Zambia's most productive artisanal fisheries, supplying not only the floodplain communities, but also urban centers such as Kafue town and Lusaka. There is some commercial farming on the Flats, primarily sugar and winter wheat. The largest producer of sugarcane is the Nkamabala Estate, which presently cultivates 13,400 ha and abstracts water from the Kafue throughout the year for irrigation.

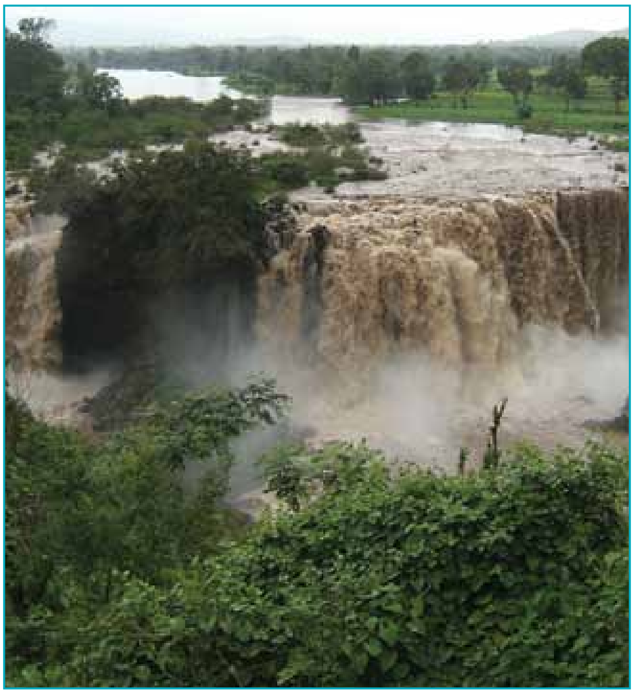
Through the Flats, flow in the Kafue River is largely controlled by the operation of the Itezhi-tezhi Dam, which was constructed in 1977, on the western side of the Flats to regulate flows for hydropower production. It was the first major dam in Africa designed and constructed with additional storage (ca. 15% extra) specifically for the purpose of releasing managed floods – an extremely progressive concept at the time. Apart from maintaining a minimum flow of 40 m^3s^{-1}, to preserve riverine (in-stream) habitat and service other uses (including commercial irrigation), the dam operator (ZESCO) was also required to release a daily minimum flow of 300 m^3s^{-1} over 4 weeks in March each year. This was to simulate the natural flooding regime. Despite these environmental flows the ecological condition of the Flats has declined over the years with consequent adverse impacts, particularly for fisheries and cattle grazing.

Although the Itezhi-tezhi Dam has contributed to negative impacts on the Flats there is little evidence of how much damage is a consequence of the dam and how much can be attributed to other causes. Nevertheless a Strategic EIA conducted in 2002/2003 identified water management in the Flats as a key priority. A computer model developed specifically to simulate the hydrodynamic behavior of the Flats was used to evaluate flooding patterns for different release options. On the basis of results obtained the operating rules of the dam were modified to allow more flexibility and better mimic the natural flooding regime. The strategy developed allows for a more gradual rise and recession, and hence a longer-duration flood than had occurred in the past. The new operating rules also allow for flood releases of different magnitudes and timing depending on the extent and pattern of rainfall each year. The system is underpinned by a newly designed and rehabilitated hydrometeorological monitoring network that provides real-time data exchange on a daily basis. This enables forecasts of inflows into the Itezhi-tezhi Reservoir, thereby enabling the dam operators to make much more informed decisions. Overall, the system has provided a mechanism for improving the operating regime that should provide ecological and hence livelihood benefits, without adversely affecting electricity production. However, to date there has been no evaluation on whether the new operating regime is effective.

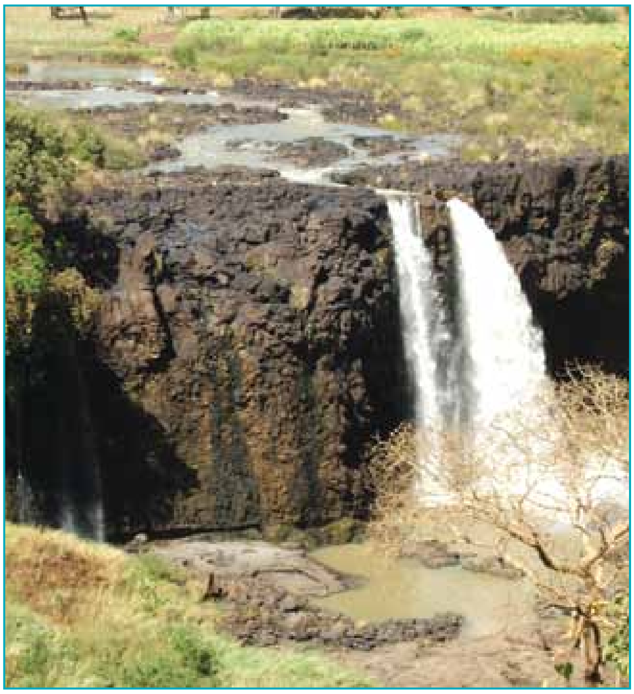
Use of the Desktop Reserve Model (DRM) to estimate flows over the Tis Issat Falls
(*source:* McCartney *et al*. 2009b).
From Chapter 6, Section 6.3

The DRM is a computer DSS intended to provide a preliminary, low confidence estimate of environmental flow requirements in situations when a rapid appraisal is required and data availability is limited. The model is underpinned by the concept of the Building Block Method (BBM), which is based on the premise that, under natural conditions, different flows play different roles in the ecological functioning of a river (King *et al*. 2000). Hence, to preserve different aspects of the ecology of a river, it is necessary to retain different elements of the variability of natural flow and include both high and low flows.

In Ethiopia, the DRM has been used to provide a preliminary estimate of flows over the Tis Issat Falls downstream of the Chara Chara Weir, located on the outlet of Lake Tana. The model provides a low confidence estimate of the flow needed to maintain the basic ecological condition of the river reach incorporating the Falls. The results indicate an average annual flow allocation of 862 Mm^3 equivalent to 22% of the natural mean annual flow (4,107 Mm^3). Currently, allocation of this flow is not attained, because water is diverted upstream of the Falls for electricity production at the Tis Abbay power station. In several months average flows are less than 70% of the DRM estimated requirement, which may be an underestimate. Although no ecological surveys have been conducted it is likely that in the long-term the reduction in flows will have severe ecological and social consequences.



Source: Wikipedia



Source: Matthew McCartney

Impact of flow regulation and upstream diversion on flow over the Tis Issat Falls, Blue Nile, Ethiopia

Much more detailed studies, including ecological surveys, are necessary to provide estimates which can be accepted with more confidence. The DRM results must be treated with extreme caution and are not adequate for detailed planning. However, they do indicate that present flows are, almost certainly, a long-way below the minimum required to maintain even the basic ecological functioning of the river reach that contains the Falls.

More information on environmental flows can be found at the website of the Global Environmental Flows Network. (http://www.eflownet.org/index.cfm?linkcategoryid=1&siteid=1&FuseAction=main)

Application of DRIFT: A scenario-based holistic approach to environmental flow assessment
(*source:* King *et al*. 2003)
From Chapter 6, Section 6.3

Downstream Response to Imposed Flow Transformation (DRIFT) is a holistic approach to advising on environmental flows. It comprises a structured process for combining data and knowledge from a range of experts including hydrologists, ecologists, geomorphologists, chemists, botanists, sociologists, anthropologists, economists and public-health experts. Each specialist chooses his or her own specific methods and tools to predict how specified changes in flow would impact on the component of interest to him or her. Unlike many methods it is nonprescriptive; no river condition is specified, but instead the impacts of a range of scenarios are deduced and all results (including uncertainties) presented in a transparent manner. For each scenario the following are ascertained:

- Biophysical consequences for the river ecosystem.
- Socioeconomic consequences for subsistence users (i.e., impact of changing resources and health profiles).
- Benefits derived from the modified flow regime.

DRIFT consists of four modules. The first, the biophysical module describes the river ecosystem and how it would change with flow changes. The second, the socioeconomic module identifies subsistence users at risk from flow manipulations and quantifies their links with the river. The third module comprises scenarios of potential future flows and the impacts of these on both the river ecosystem and the riparian population. The fourth module outlines possible mitigation measures and their costs.

The approach has been applied in Lesotho, South Africa, Sudan, Tanzania, and Zimbabwe, and the Okavango Basin and the Zambezi Delta and various applications have been used as good practice case studies by the IUCN and UNEP and the World Bank. The approach provides decision makers with information that is often overlooked or inadequately considered in water resources development. The quantified results of the scenarios can be used to make informed decisions about the implications of different options. The scenarios also provide a range of indicators that can be used in monitoring programs to assist adaptive management.

Source: Wikipedia

Subsistence fishing and floodplain, Lukanga Swamp, Kafue River, Zambia

Use of reservoir operation as a tool for malaria control

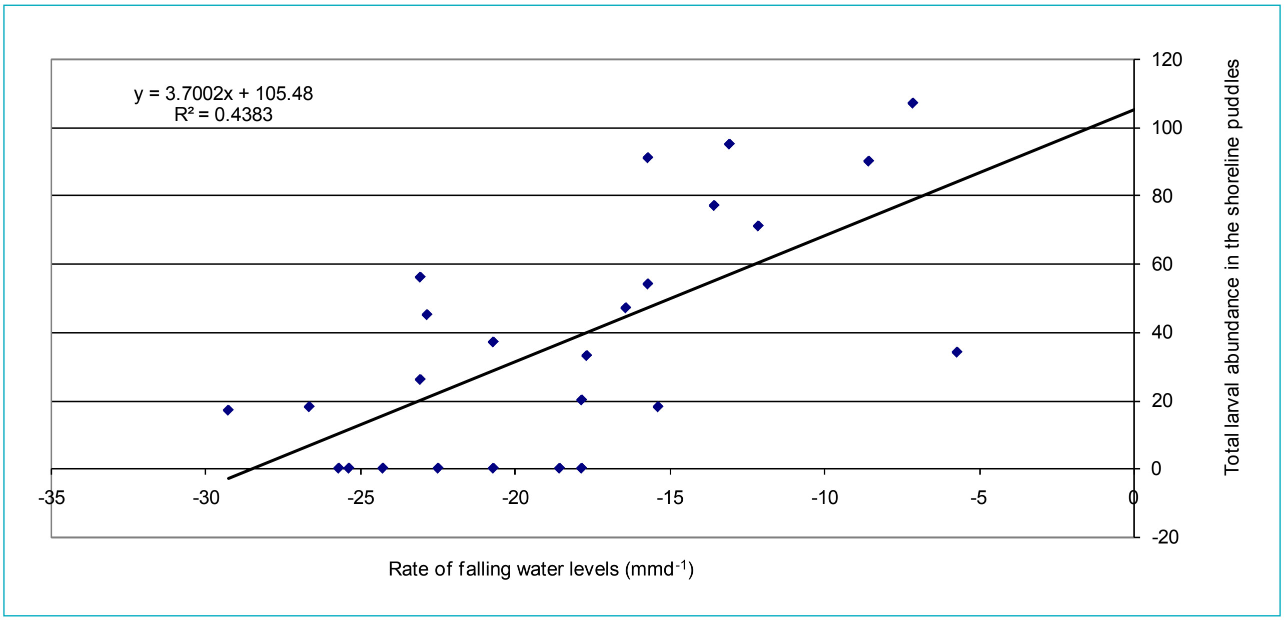
(*source:* Kibret *et al.* 2009).
From Chapter 6, Section 6.4

Writing in 1947, the Tennessee Valley Authority (TVA) in the USA stated:

> Whenever a stream is impounded for navigation, power, recreation, flood control, or any other purpose in a malarious or potentially malarious region, the resulting lake may create a public health hazard to the people in the vicinity unless appropriate measures for malaria prevention and control are carried out. For this reason, provisions for the control of malaria should be incorporated into the basic design, construction, and operation of any impoundment in such a region. Adequate planning in the initial stages of the project will also result in increased effectiveness and economy.

Subsequently, the TVA incorporated a range of water management measures around reservoirs designed to reduce malaria transmission in adjacent communities (TVA 1947). These measures, which include the manipulation of water levels to modify mosquito breeding habitat are still used today, not to reduce malaria, but to control nuisance mosquitoes. Incorporation of malaria control parameters into water management has also been attempted in India and Zambia in the past. However, such measures have never been widely used and, with a few exceptions, are hardly applied today.

Recent studies conducted in Ethiopia have confirmed that manipulation of reservoir water levels has the potential to reduce mosquito breeding habitat along the shore of the Koka Reservoir. Broadly, more rapid drawdown at the end of the wet season and beginning of the dry season has resulted in desiccation of shoreline puddles thus preventing the production of mosquito larvae. Although more research is required to determine the impact on disease transmission this supports the hypothesis that dam operation could contribute to malaria control.



Graph showing the relationship between total larvae abundance in shoreline puddles and the rate of falling reservoir water levels.

Integrating malaria controls into multipurpose reservoir management
(*source:* Reis *et al*. 2009)
From Chapter 6, Section 6.4

Increased rates of malaria have been found near the Koka Reservoir in Ethiopia, and drawdown rates have been shown to affect mosquito breeding habitats (see Appendix 1, *Use of reservoir operation as a tool for malaria control*). A study was conducted to determine how changing drawdown rates would impact the multipurpose objectives of the reservoir. Malaria reduction measures (i.e., drawing the water levels down during the malaria transmission season from mid-September to mid-November) were added to the existing objectives of the dam. Daily inflows were used to simulate outflows and reservoir levels from 1980 to 2006 using the HEC-ResSim3.1 software. Management of the dam to control malaria was evaluated in terms of impact on its primary purposes: hydropower generation, sugarcane irrigation, flood reduction and maintenance of downstream environmental flows. Without compromising downstream environmental flows or flood protection, lowering the reservoir at rates recommended to minimize breeding habitats was found to reduce both hydropower generation (on average 2%) and the volume available for irrigation (up to 20%). One way to mitigate the storage reduction would be to integrate the Koka Reservoir operation with that of others in the national electricity grid (i.e., drawdown of the Koka Reservoir to avoid malaria whilst keeping other reservoirs full and then using the water stored in those at a later date).

Source: Matthew McCartney

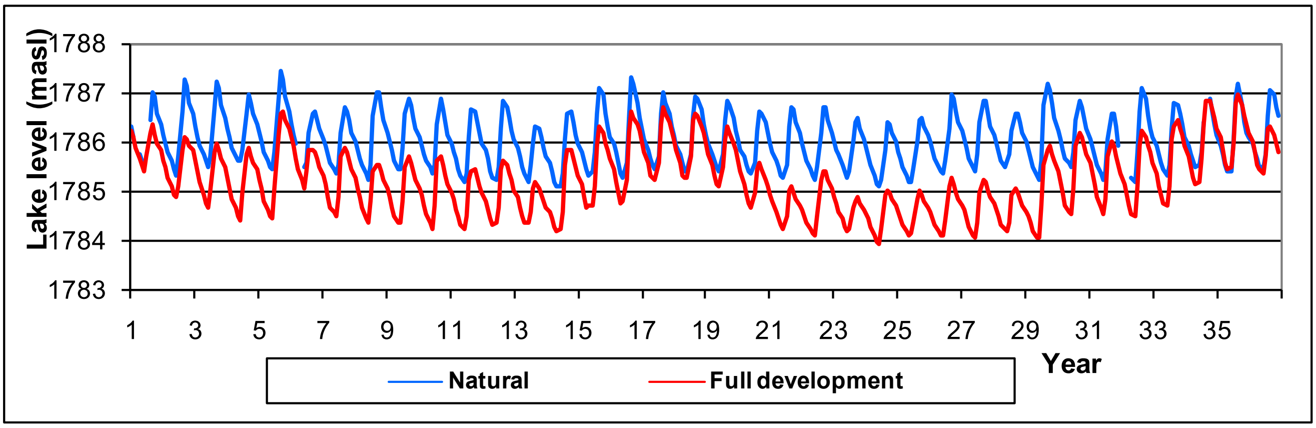
Shoreline of the Koka reservoir

Investigating the cumulative effect of dams on the water levels in Lake Tana

(*source:* Alemayehu *et al.* 2009)
From Chapter 6, Section 6.5

Lake Tana and its environs are valuable for many people, including the communities who live around the lakeshore, those living on islands and those living close to the Blue Nile River, which flows from it. The lake is an important source of water for domestic supply, irrigation and hydropower production, fisheries, grazing and water for livestock, as well as reeds for boat construction. It is also important for water transport and as a tourist destination. Plans for future development include the transfer of water from the lake to the Beles River for power production and the development of a number of irrigation schemes on the five main tributaries flowing into the lake (MOWR 2008).

A study was conducted to determine the likely impact of a number of development alternatives on the water levels and surface area of the lake. Application of the Water Evaluation And Planning (WEAP) model showed that, with full development of all currently envisaged schemes (i.e., irrigation schemes and hydropower), the mean water level will drop by 0.44 m and the average surface area will decrease by 30 km^2 and up to 81 km^2 in some dry seasons. There will be prolonged periods of several years during which water levels will be much lower than they would be naturally. If downstream environmental flow requirements are maintained the mean lake water level will reduce by a further 0.37 m and the area will reduce by an additional 26 km^2. Without careful management these changes are likely to have severe ecological and social consequences including desiccation of the wetlands surrounding the lake, reduced fisheries, loss of reeds currently utilized for boat building, increased agriculture on the exposed lake bed and increased periods when shipping on the lake (which is vital for the livelihoods of many of the 15,000 people living around the lakeshore and on islands) is not possible.



Comparison of natural and simulated lake water levels over 37 years, assuming all possible infrastructural development is implemented.

The information gained from the DSSs provides insights into the trade-offs associated with different levels of development and possible trade-offs between different ecosystems (i.e., in this case the lake and the downstream river reaches). Ultimately, as in most cases, it is a difficult political decision to determine which development options are acceptable, but as this example demonstrates, DSSs can provide a credible scientific basis to underpin the decisions to be made.

Compensation and benefit-sharing in the Koga irrigation scheme, Ethiopia

(*source:* Gebre *et al*. 2007)
From Chapter 6, Section 6.6

The Koga irrigation scheme anticipates intensifying agricultural production and productivity among smallholder farmers in the Koga River Valley, thereby reducing poverty and enhancing food security. The project includes the construction of a 21.5 m high dam that will inundate an area of 18.6 km^2 of which 360 ha are cultivated, 5 ha are homesteads and the remainder is communal grazing for approximately 42,000 head of cattle. Approximately 602 households will be displaced by the project: 373 from the area of the reservoir and the remainder from the site of the dam and as a result of the construction of infrastructure (e.g., roads, night reservoirs and canals) in the irrigation command area. Another 4,473 households will lose assets as a consequence of the scheme.

Arrangements for resettlement and compensation were developed to comply with both the Constitution and civic code of Ethiopia as well as the African Development Bank's Operational Directive on Involuntary Resettlement (AfDB 2003). A resettlement committee that comprised representatives of the local communities, government and the project management unit was established. All farmers who lost land as a consequence of the scheme were to be compensated with plots in the irrigation scheme. The majority of displaced households were to be resettled in "host" villages located close to the irrigation scheme. A small number of households were moved to the outskirts of the nearby town of Merawi. Cash compensation was paid for loss of assets including buildings, infrastructure, crops and trees. Those farmers who, because of the timing of construction, had to be moved in the early phases of the project development were given monetary compensation for lost harvests for up to 3 years. It was anticipated that they would be cultivating in the irrigation scheme after these 3 years. Improved social services, including a clinic, a school and a flour mill as well as better water supply were promised.

A recent review found that there were many problems with the implementation of the compensation and benefit-sharing scheme. Many people felt that there was inadequate communication and the way that compensation was determined was unclear. Many claimed there were irregularities in the inventory and many felt that their assets (trees, etc.) had been undervalued. Because of delays in the project start-up the 3 years were nearly over, but no land in the scheme had been allocated and yet no additional compensation was forthcoming for those farmers who had lost land at the start. Furthermore, because, over the 3 years, food prices had increased substantially these farmers felt they had not received adequate compensation for their lost harvests. None of the promised improved social services had materialized.

However, by far the biggest concern raised was in relation to the social upheaval that was anticipated by many who were to be relocated. The review identified considerable mistrust and animosity between the host communities and those who would be relocated. A commonly expressed view, within the host communities, was that the displaced people should not be moved to "their" villages and should not be allocated land within the irrigation scheme. Many felt that the people being displaced had received adequate compensation for lost assets and they did not deserve land in the scheme, particularly as they themselves would have smaller plots of land in the irrigation scheme than they currently farmed and would not receive compensation for the difference. The view was most succinctly stated in one interview:

> "...we do not feel comfortable sharing land and co-existing with people we have never known before. It is hard for us to trust and get along with outsiders..."

Physical threats had been made and, not surprisingly, people who were supposed to move to the host villages expressed grave concern about the reception they would receive and if they would be able to settle.

Overall, the review highlighted many of the complexities and difficulties associated with implementing compensation and benefit-sharing packages. It concluded that there had been insufficient public consultation and irregularities in the handling of compensation, which in conjunction with delays in construction, had led to considerable disgruntlement. Rumors and speculation about the project and whether or not it would bring tangible benefits were widespread. The result was that the project was viewed with distrust by many local people, including those communities who were the intended primary beneficiaries.

Source: www.zef.de

Koga irrigation scheme, Ethiopia

Application of DRIFT to evaluate compensation in the Lesotho Highlands Water Project (LHWP)
(*source:* King and Brown 2009)
From Chapter 6, Section 6.6

The LHWP is a multi-billion dollar water transfer and hydropower project implemented by the Governments of Lesotho and South Africa, and is one of the world's largest water resource developments. It is envisaged to eventually comprise seven major dams on the headwaters of the Senqu River in Lesotho, which becomes the Orange River as it passes into South Africa. The LHWP was conceived and negotiated in the mid-1900s before the upsurge in concern about the downstream impacts of water resource developments on rivers and people's livelihoods. But by completion of the first dam, Katse, on the Malibamatso River in 1998, global concerns over environmental degradation had grown to the point that international pressure forced a reconsideration of the downstream impacts of the LHWP dams. This was done in an EFA that adopted a scenario-based approach named DRIFT (Downstream Response to Imposed Flow Transformation) (King *et al.* 2003; Brown and Joubert 2003). It is believed to be the first documented study to quantify not only the biophysical consequences of various development scenarios, but also the social and resource-economic consequences. River goods were identified and valued, as was compensation for riparian people for loss of river resources, and the health implications for people and livestock were described (Metsi Consultants 2000, 2002).

The study resulted in assessment of, and compensation for, downstream environmental degradation and social losses associated with reduced flows being accepted as legitimate project costs. Payments were limited to villagers living in the proximal reaches downstream of the LHWP Phase 1 structures. This distance varied but was in the region of 60 km downstream of the structures and included approximately 7,000 households. Compensation was to be paid in two tranches, one immediately and one after 10 years. The total compensation was calculated as the 2003 value of predicted resource losses over the life of the project (50 years), at an appropriate discount rate and adjusted for inflation from the start date of the project. The first tranche payments totaling about US$ 3 million were made in 2004. The payments were vested in local legal entities or community trusts (LHDA 2005).

The study illustrated several important things:

- Compensation costs are often trivial in comparison to the potential economic gains from the industrial use of the water, with the latter overwhelming all other issues if only economics are considered. This highlights the need for ecological and social considerations to be addressed at the same time, with equal weight, and in the same formal process as the economic ones.

- Flows for ecosystem maintenance need not greatly affect the economic rate of return (ERR) of water resource developments, and it can be economically defensible to increase the environmental water allocation for ecological or social reasons (Brown and Watson 2007). Failing to deal with ecosystem costs does not make them go away; it simply distorts the ERR calculations to the extent that the true costs of the project to the community are not taken into account (Watson 2008).

- The cost of a flow assessment is low in comparison with the related engineering and other water resource studies. In LHWP Phase 1, the costs, including the flow assessment and compensation to subsistence users, were about 0.5% of project costs. Downstream compensation costs for river degradation were about one-fifth of those upstream of the dam for inundation (Brown and Watson 2007).

Development of DSSs in the Nile Basin

From Chapter 6, Section 6.7

Within the Nile Basin cooperative management of water resources could bring significant benefits for all the riparian nations. Collaborative management of river flows could help mitigate the impacts of floods and droughts and reduce downstream siltation of reservoirs and irrigation schemes. Opportunities for coordinated hydropower and agricultural production with some shared infrastructure (including large dams) are widespread.

The DSS of the Nile Basin is being developed by the NBI with the cooperation of all the riparian states. The objective of the DSS is to enhance the analytical capacity to support the development, management and protection of the Nile water resources by providing a common, basin-wide platform for communication, information management and analyses. To facilitate common acceptance and to enhance cooperation between the riparian states a process of developing DSS has been initiated based around several core principles:

Response to perceived needs: The development of the DSS is based on a comprehensive needs assessment conducted at regional/subregional and national levels. The DSS has been designed and is being constructed specifically to address these identified needs. This should enhance both ownership and sustainability of the system.

Joint ownership: The DSS will be jointly owned by all the riparian states. To enhance ownership a number of steps have been initiated:

- Decision-maker participation in the project overview. This participation is facilitated through the project steering committee, which comprises representatives from all the riparian countries.
- User participation in the design and technical development. This participation is effected through user involvement in DSS development teams, working groups and task forces. Again representatives from all the riparian countries are involved.
- Adjustment to user needs by development of a modular open-ended system that can be upgraded and adjusted according to user needs and their development over time.

Transparency: All assumptions, methodologies and technical aspects have to be agreed upon and must be readily accessible to users and decision makers. Transparency is ensured by involving users and decision makers in the development process.

Sustainability: This relates to institutional, financial and technical aspects of the DSS. To ensure institutional sustainability the DSS will be located in permanent institutions with water resource management responsibilities in each of the riparian countries. Financial sustainability will be ensured through the establishment of appropriate financing mechanisms, most likely based on government commitments, hopefully guaranteed by the perceived usefulness of the DSS in supporting high-priority decision making. The technical sustainability relates to aspects such as training of appropriate personnel and maintenance of relevant databases. Mechanisms to ensure technical sustainability are being developed.

Phased implementation: The phasing of implementation activities is acknowledged to have a critical impact on the success of the project. On the one hand, there is a need for a gradual, participatory development of the DSS in parallel with training and mobilization of government commitment. On the other, there is need to demonstrate the usefulness of the DSS at the earliest possible opportunity to maintain interest and momentum. A phased strategy that aims to balance these two requirements is being implemented.

Appendix 2. Examples of large dams planned or being built in Africa (*source*: IHA 2009b; IRN 2006; others)

Name	Country	River	Primary purpose	Anticipated completion
Koudiat Acerdoune	Algeria	Isser/Sebaaou	Water supply/ irrigation	n/a
Bougous	Algeria	Bougous	Water supply/ irrigation	n/a
Douera	Algeria	Ben Amar	Irrigation	n/a
Tabellout	Algeria	Djendjen	Water supply	n/a
Dyodyonga	Benin/Niger	Mekrou	Hydropower (26 MW)	Undetermined
Adjarala	Benin/Togo	Mono	Hydropower (96 MW)	Undetermined
Lom Pangar	Cameroon	Lom (tributary of Sanaga)	Hydropower (56 MW)	2010
Memve Ele	Cameroon	Ntem	Hydropower (202 MW)	Undetermined
Nachtigal	Cameroon	Sanaga	Hydropower (300 MW)	Undetermined
Grand Inga	Democratic Republic of Congo	Congo	Hydropower (3,500 MW)	Undetermined
Gilgel Gibe III	Ethiopia	Omo	Hydropower (1,870 MW)	2012
Karadobi	Ethiopia	Abay (Blue Nile)	Hydropower (1,600 MW)	Undetermined
Mendaya	Ethiopia	Abay (Blue Nile)	Hydropower (1,620 MW)	Undetermined
Border	Ethiopia	Abay (Blue Nile)	Hydropower (1,400 MW)	Undetermined
Mabil	Ethiopia	Abay (Blue Nile)	Hydropower (1,400 MW)	Undetermined
Anger	Ethiopia	Anger	Irrigation	Undetermined
Nekemte	Ethiopia	Anger	Irrigation	Undetermined
Arjo	Ethiopia	Didessa	Irrigation	Undetermined
Lower Didessa	Ethiopia	Didessa	Irrigation	Undetermined
Danguar	Ethiopia	Beles	Irrigation	Undetermined
Baro 1 and 2	Ethiopia	Baro - Akobo	Hydropower (916 MW)	Undetermined

Name	Country	River	Primary purpose	Anticipated completion
Tekeze	Ethiopia	Tekeze	Hydropower (300 MW)	2010
Tendaho	Ethiopia	Awash	Irrigation	2010
Kesem	Ethiopia	Awash	Irrigation	2010
Sambangalou	Gambia	Gambia	Hydropower (45 MW)	Undetermined
Bui	Ghana	Black Volta	Hydropower (157 MW - 310 MW)	Undetermined
Hemang	Ghana	Pra	Hydropower (93 MW)	Undetermined
Sondu-Miriu	Kenya	Sondu	Hydropower (60 MW)	Undetermined
Ewaso Ngiro	Kenya	Mara	Hydropower	Undetermined
Mutonga/Grand Falls	Kenya	Tana	Hydropower, irrigation and water supply	Undetermined
Mashi	Lesotho	Senqu	Inter-basin transfer to South Africa	Undetermined
Metalong	Lesotho	Phuthiastsana	Water supply	Undetermined
Talo	Mali	Bani	Irrigation	Undetermined
Martil	Morocco	Martil	Water supply/ irrigation	n/a
Taskourt	Morocco	Al Mal	Irrigation/water supply	2012
Zerrar	Morocco	Ksob	Water supply/ irrigation	n/a
Tasmallout	Morocco	Ansegmir	Irrigation/water supply	n/a
Mphanda Nkuwa	Mozambique	Zambezi	Hydropower (1,300 MW)	Undetermined
Epupa	Namibia	Kunene	Hydropower	Undetermined
Popa Falls	Namibia	Okavango	Hydropower (30 MW)	Undetermined
Kandadji	Niger	Niger	Hydropower	Undetermined
Mambila	Nigeria	Benue	Hydropower (3,900 MW)	Undetermined
Zungeru	Nigeria	Kaduna	Hydropower (950 MW)	Undetermined

Name	Country	River	Primary purpose	Anticipated completion
Imboulou	Republic of Congo	Lefini	Hydropower (120 MW)	2009
Sounda Gorge	Republic of Congo	Kouilou	Hydropower (1,000 MW)	Undetermined
Bumbuna	Sierra Leone	Seli (Rokel)	Hydropower	n/a
Boegoeberg	South Africa/ Namibia	Orange	Irrigation	Undetermined
De Hoop	South Africa	Steelpoort	Mine supply, irrigation and environmental flows	2011
Skuifraam	South Africa	Berg	Water supply	Undetermined
Thukela	South Africa	Thukela	Interbasin transfer (to Vaal River)	Undetermined
Merowe	Sudan	Nile	Hydropower (2,500 MW)	2010
Kajbar	Sudan	Nile	Hydropower (300 MW)	Undetermined
Setit	Sudan	Atbara	Irrigation	Undetermined
Sherek	Sudan	Nile	Hydropower (400 MW)	Undetermined
Bedden	Sudan	White Nile		
Rusumo Falls	Tanzania/Rwanda	Kagera	Hydropower (60 MW)	Undetermined
Rumakali	Tanzania	Rumakali	Hydropower (222 MW)	2024
Ruhudji	Tanzania		Hydropower (36 MW)	2012
Moula	Tunisia	Bou Terfess	Water supply	n/a
Kebir	Tunisia	n/a	Water supply	n/a
Bujagali	Uganda	White Nile	Hydropower (200 MW)	Undetermined
Kamdini	Uganda	White Nile	Hydropower	Undetermined
Murchison	Uganda	White Nile	Hydropower	Undetermined
Batoka Gorge	Zambia	Zambezi	Hydropower (1, 600 MW)	Undetermined
Gwayi Shangani	Zimbabwe	Zambezi	Water Supply	Undetermined
Tokwe-Mukorsi	Zimbabwe	Tokwe	Irrigation	Undetermined
Bubi-Lupane	Zimbabwe	Bubi	Hydropower	Undetermined

Appendix 3. Examples of DSSs used for dam planning and operation in Africa

DSSs	Description
Lake Victoria Decision Support Tool (LVDST)	Database, utility tools (i.e., to process and prepare data) and control models have been combined to support long- range planning and short-range operation of the Lake Victoria Reservoir and hydropower units. Allows short-term hydropower production to be optimized within constraints imposed by long-range planning decisions (Georgakakos 2006).
The High Aswan DSS	Specifically for the High Aswan Dam, this DSS provides decision support for the Egyptian Ministry of Water and Irrigation. It comprises various decision/optimization models relating to reservoir releases for irrigation, energy generation and flood protection (Georgakakos 2006).
NileSim	Simulation model of the water resources of the entire Nile Basin. Developed primarily as a learning tool to explain complex river behavior and management to nontechnical persons. Enables scenarios to examine the effects of policy options and changes caused by manipulating dams and regulating river use (Levy and Baecher 2006).
River Basin Simulation Model (RIBASIM)	This water balance simulation model enables evaluation of measures related to infrastructural, operational and demand management. It generates water distribution patterns and provides a basis for detailed water-quality and sedimentation analyses in river reaches and reservoirs. It has been used to simulate water flows in the whole of the Nile Basin as part of the Lake Nasser Flood and Drought Control project that aimed to evaluate risk and mitigation measures for different flood- and drought-control scenarios (Delft Hydraulics 2006).
Ruaha Basin Decision Aid (RUBDA)	A water resource simulation model developed to assess the impact of development scenarios in the Great Ruaha River Catchment in Tanzania. This model was designed with the involvement of key stakeholders in the basin intended to help assess, among other things, the hydrological and socioeconomic impacts of different allocation decisions (Cour *et al.* 2005).
Water Resources Planning Model (WRPM)	Developed in South Africa, this simulation model is used for assessing water allocation within catchments. The model simulates surface water and groundwater as well as interbasin transfers. The impact of dams on catchment water yield is accounted for. The model is designed to be used by a range of users with different requirements and can be configured to provide output of different information (Mwaka 2006).
Agrohydrological modeling system (ACRU)	Developed in South Africa, this is a multipurpose simulation model that has been used to simulate land use/management influences on water resources, sediment yield and selected water-quality constituents, dam water budgets and operating rules, irrigation water demand and supply, and crop yields. It includes modules for dam operating rules which have been applied in South Africa (Schulze and Smithers 2004).

DSSs	Description
GLOWA Volta DSSs for the Volta Basin	A scientific information system developed as part of the GLOWA Volta project to integrate knowledge and provide decision support for the planning, management and use of water resources in the Volta Basin. The nucleus of the DSSs is a water optimization model, which represents the decision rules and constraints of water users, the physical water resources system as well as production functions and technology sets (Glowa Volta 2006).
DSSs for Komati Water Resources Planning	The Komati Basin Water Authority (KOBWA) manages water resource development in the Komati River Basin which is shared by South Africa, Mozambique and Swaziland. KOBWA uses a suite of three DSSs to plan and manage dams in the catchment. These are DSSs for water allocation (yield*)*, water curtailment (rationing) and river hydraulic application (Dlamini 2006).
DSSs for the Senegal River Delta	The hydrodynamic model, MIKE-11, has been used in conjunction with a digital elevation model, to assess hydraulic functioning of different release regimes on the Senegal River Delta and the consequent implications for the ecology and hence livelihoods of local people (Duvail and Hamerlynck 2003).
The Nile Decision Support Tool (Nile DST)	This tool was developed as part of the FAO Nile Basin Water Resources project to objectively assess the benefits and trade-offs associated with various water-development and -sharing strategies. It comprises six main components: databases, river simulation and management, agricultural planning, hydrologic modeling, remote sensing and user-model interface (Georgakakos 2003, 2006).
Kafue DSS	A hydrodynamic model (KAFRIBA-Kafue River Basin) has been developed to improve the operation of dams located upstream and downstream of the Kafue Flats (wetland system) on the Kafue River, Zambia. Used in conjunction with improved forecasting of flows into the upstream reservoir, the DSS enables the dam operator (Zambia Electricity Supply Company) to make decisions on releases in a systematic way that balances hydropower requirements with other water uses and protection of the ecology (and hence livelihood benefits) of the Kafue Flats (DHV Consultants 2004).
DamIFR	Developed and applied in South Africa to derive dam operating rules that satisfy environmental flow requirements, the model is intended to compliment traditional reservoir yield models. It can be used to simulate several linked reservoirs and computes the proportion of daily environmental flow needed to release during periods of low reservoir storage when there is competition from other users (Hughes and Ziervogel 1998).
Global Water Availability Assessment (GWAVA) model	This model provides a global/regional- or catchment-scale approach to modeling hydrology and assessing availability of water resources. It provides assessments of the availability of water on a spatial basis (GIS), in terms of indices of water supply vs. water demand. It enables impacts of climate and population change to be investigated and can also be used to look at land-use change impacts and development of hydropower schemes. It has been used to simulate regional water resources across eastern and southern Africa as well as more specifically in Swaziland and the Okavango Delta (Tate *et al*. 2002).

DSSs	Description
TALSIM 2.0	This reservoir simulation model was developed by the Technical University of Darmstadt, Germany. This model has been used to simulate operation of the Kidatu and Mtera dams on the Great Ruaha River, Tanzania (Yawson *et al.* 2003).
Downstream Response to Imposed Flow Transformations (DRIFT)	Used in the Lesotho Highlands Dam project, to assess the impact of different present and future flow release regimes on the river ecology and, via relationships determined between ecology and social benefits, the livelihoods of riverine communities (King *et al.* 2003). DRIFT has also been used in Sudan, the Lower Mekong, the Okavango Basin, the Zambezi Delta and Zimbabwe.
Water Evaluation And Planning (WEAP) model	A simulation model developed to evaluate planning and management issues associated with water resource development. WEAP can be applied to both municipal and agricultural systems and can address a wide range of issues including sectoral demand analyses, water conservation, water rights and allocation priorities, streamflow simulation, reservoir operation, ecosystem requirements and project cost-benefit analyses (Stockholm Environment Institute 2007). The model has been applied to assess scenarios of water resource development in the Olifants Catchment in South Africa (McCartney and Arranz 2009), and for the Pangani Catchment in Tanzania (King pers. comm.).
Desktop Reserve model	Developed in South Africa, this is a hydrological model for estimating environmental flow requirements in situations where a rapid appraisal is required and availability of data is limited (Hughes and Hannart 2003). The model is built on the concepts of the Building Block Methodolgy (King *et al.* 2000) and provides estimates of both low- and high-flow requirements. It has been used extensively in South Africa to provide initial estimates of the ecological Reserve.

Glossary

Artisanal
Refers to small-holder fisher-folk who catch for livelihoods as opposed to large-scale commercial fisheries.

Decision maker
Anyone with the responsibility for making decisions. In relation to this report, the outcome is a choice pertaining to the planning or operation of large dams.

Decision Support System (DSS)
Any tool that facilitates decision making processes and supports more rational decisions.

Ecosystem
A dynamic complex of plant, animal and microorganism communities and their nonliving environment interacting as a functional unit.

Ecosystem services
The benefits people obtain from ecosystems. These include provisioning services, such as food and water; regulating services, such as flood and disease control; cultural services, such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling that maintain the conditions for life on earth. The concept "ecosystem goods and services" is synonymous with ecosystem services.

Environmental flow
Environmental flows constitute the water that is left in a river, or released into it (e.g., from a reservoir), in order to maintain valued features of the ecosystem.

Environmental Impact Assessment (EIA)
An assessment of the possible impact – positive or negative – that a proposed project may have on the environment, together consisting of the natural, social and economic aspects. The process of identifying, predicting, evaluating and mitigating the biophysical, social and other relevant effects of development proposals prior to major decisions being taken and commitments made.

Informed decision making
Making rational decisions based on knowledge of the possible consequences as opposed to arbitrary decisions based solely on intuition.

Integrated Water Resources Management (IWRM)
A process which promotes the coordinated development of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Large dam
Defined as dams higher than 15 m from base to crest, or with storage capacity exceeding 3 million m^3 for heights between 5 and 15 m (ICOLD 2003).

Policy maker
A person with the power to influence or determine policies and practices at the international, national, regional or local level.

Social impacts
As with any infrastructure, large dams have a wide range of direct and indirect social consequences both positive and negative. These impacts include those on livelihoods and people's health and spiritual and cultural impacts.

Stakeholder
Any person, group or organization having a direct or indirect stake (i.e., whose interests may be affected) in the construction and/or operation of a large dam.

Water resource managers
The people responsible for solving water-related problems or meeting special water related needs.

Source: dailynews.co.tz

Nyumba ya mungu, Tanzania

R4D Series

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Paul J. Block, 2008.

R4D 02 Use of decision support systems to improve dam planning and dam operation in Africa.
Matthew McCartney and Jackie King, 2011.

About CPWF

The Challenge Program on Water and Food was launched in 2002 as a reform initiative of the CGIAR, the Consultative Group on International Agricultural Research. CPWF aims to increase the resilience of social and ecological systems through better water management for food production (crops, fisheries and livestock). CPWF does this through an innovative research and development approach that brings together a broad range of scientists, development specialists, policy makers and communities to address the challenges of food security, poverty and water scarcity. CPWF is currently working in six river basins globally: Andes, Ganges, Limpopo, Mekong, Nile and Volta.

About this R4D Paper

After a hiatus in dam investment, through the 1990s and the early part of this century, construction of large dams is increasing again. Modern decision support systems can usefully input to this process by guiding the analysis of complicated hydrological, environmental, social and economic factors associated with water allocation and assessing the impact of different, often conflicting, management options both in planning and operation of dams. This publication highlights the constructive role that decision support systems can play in planning and operation of dams. It illustrates the importance of considering environmental and social issues in decision making so that positive benefits of large dams can be maximized and the negative impacts minimized.

Mailing address:

CGIAR Challenge Program on Water and Food

P.O. Box 2075

127 Sunil Mawatha,

Pelawatta, Battaramulla,

Sri Lanka

Tel +94 11 288 0143

Fax +94 11 278 4083

Email: cpwfsecretariat@cgiar.org

www.waterandfood.org

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