ASSESSING ENVIRONMENTAL FLOW REQUIREMENTS FOR THE MARROMEU COMPLEX OF THE ZAMBEZI DELTA:

APPLICATION OF THE DRIFT MODEL (DOWNSTREAM RESPONSE TO IMPOSED FLOW TRANSFORMATIONS)

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1. Introduction

1.1 The Marromeu Complex of the Zambezi Delta

The Zambezi Delta is a broad, flat alluvial plain along the coast of central Mozambique. The delta is triangular in shape, covering an area of approximately 1.2 million hectares that stretches 120 km from its inland apex (near the confluence of the Zambezi and Shire Rivers) to the main Zambezi River mouth and 200 km along the Indian Ocean coastline from the Cuacua River outlet near Quelimane south to the Zuni River outlet. The large port city of Beira is located about 200 km to the south. The Delta is bordered to the north by the Morrumbala escarpment that serves as a divide between the Zambezi and Shire River catchments, and to the west by the Cheringoma escarpment that separates the Zambezi and Pungue River catchments. The entire Lower Zambezi basin in Mozambique covers an area of approximately 225,000 km^2 from Cahora Bassa Reservoir to the Zambezi Delta (more than 27% of the total land area of Mozambique) and supports more than 3.8 million people (25% of the total population of Mozambique) (Figure 1.1).

The 11,000 km^2 Marromeu Complex includes the southbank of the Zambezi Delta and adjacent uplands. The complex includes the Marromeu Special Reserve (*Reserva especial de Marromeu*), four surrounding hunting concessions (*Coutadas* 10, 11, 12, and 14), coastal mangrove zone, commercial sugar production fields, lowland subsistence agriculture and grazing lands, the Salone depression (a river corridor that connects the Marromeu Complex to the Zambezi River), and the Cheringoma escarpment (Figure 1.2).

At the heart of the Marromeu Complex are the 1500 km^2 Marromeu Special Reserve and surrounding hunting concessions (8252 km^2) that extend from the edge of the buffalo reserve into the adjacent Cheringoma highlands. These productive grasslands support diverse wildlife, including Cape buffalo (historically the largest population in Africa), African elephant, Lichtenstein's hartebeest, sable antelope, eland, zebra, hippopotamus, waterbuck, and reedbuck. Carnivores include lion, leopard, wild dog, and spotted hyena (Dutton *et al.* 2001). The complex supports the highest density of water birds in Mozambique, with large nesting colonies of great white and pinkbacked pelicans, yellowbilled and African openbill storks, glossy ibis, and whitebreasted cormorants (Bento and Beilfuss 1999). Tremendous numbers of spurwinged geese and other waterfowl feed on the floodplain. The wetland is home to 120 breeding pairs of endangered wattled cranes and provides critical refuge for up to 30% of their global population during times of extreme drought in southern Africa (Bento 2002). Other bird species of international concern include grey crowned cranes, saddlebill storks, woolynecked storks, goliath herons, African skimmers, redwing pratincoles, and Caspian terns. Humpback and minke whales occur offshore, along with bottlenosed, roughtoothed, and humpback dolphins.

The Marromeu Complex is vital for the national economy of Mozambique and provides subsistence for hundreds of thousands of rural villagers. The extensive coastal mangroves and estuaries nourish the prawn fishery on the Sofala bank, one of Mozambique's most important sources of export revenue (Turpie *et al.* 1999). The floodplain swamps provide important spawning grounds for riverine and oceanic fishes, and support an important freshwater fishery during years of good flooding. The wet grasslands provide critical dry-season grazing lands for livestock. The rich delta soils support the largest sugar plantation in Mozambique and productive flood-recession agriculture along drainage ways. The savannas and woodlands provide fuelwood, building materials, wild fruits, honey, and medicinal plants to local communities (Beilfuss *et al.* 2002). The complex also offers exclusive ecotourism and trophy hunting opportunities through the hunting concessions (Dutton *et al.* 2001).

1.2 History of water resources development in the Zambezi Delta

The Zambezi Delta lies at the downstream terminus of the great Zambezi River system and bears the cumulative effects of engineering and agricultural projects over a 1,357,000-km^2 catchment that extends over portions of eight developing countries. These development works are indelibly intertwined with the history of the delta and its peoples.

Over the millennia, the delta was nourished by the annual spread of Zambezi floodwaters. The fertile floodplains provided recession agriculture, hunting, fishing, and abundant natural resources for its scattered inhabitants. The delta's vast, seasonally flooded grasslands supported diverse and abundant wildlife populations (Tinley 1969). The healthy floodplain provided spawning grounds for riverine and anadromous fishes and critical dry-season grazing lands for livestock and wildlife (Loxton Hunting and Associates *et al.* 1975). Extensive coastal mangroves and estuaries supported a productive prawn fishery (da Silva 1986).

The rise of commercial agricultural schemes in the delta in the late 1800s began the century-long process of severing the link between the Zambezi River and its delta. In 1893, the first embankments were constructed in the delta. Low dikes were constructed to protect the sugar fields at Mopeia, cutting off the upper delta distributary channels that delivered Zambezi floodwaters to the north bank floodplains. Over the next thirty years, similar embankments were constructed at Marromeu and Luabo. After widespread flooding in 1926 damaged the sugar plantations, the flood protection dikes were raised to the maximum level of the flood (Bolton 1983). During the remaining century, this level was exceeded only five times—in 1939, 1940, 1952, 1958 and 1978. In the 1930s, a railway line between Marromeu and Sena (80 km upstream on the mainstem Zambezi) was constructed to link with the existing line from Sena to the coastal port of Beira (Bolton 1983). The railway (and parallel road system) was designed without proper hydrographic surveys and obstructed the passage of water into the upper distributaries between Chupanga and Marromeu (Tinley 1994). Water movement in this region was further restricted by the construction of a direct railway line between Marromeu and Inhamitanga (located midway along the Sena-Beira railway line on the Cheringoma escarpment southwest of the delta) during the 1970s. The cumulative impact of these road and dike works was a dramatic reduction in the movement of floodwaters between the Zambezi River and Delta.

In December 1958, Kariba Dam, the first major dam on the Zambezi River, began impounding water and further altered flooding patterns in the delta (Tinley 1975). Previous smaller projects, including a run-of-river hydroelectric generator at Victoria Falls, had a negligible effect on the hydrology of the Zambezi River. Kariba Dam, however, controlled more than 40% of the total runoff of the Zambezi River and was operated to generate steady hydropower production by storing peak floods and releasing a constant outflow of water (Reeve and Edmonds 1966). During the 1960s and 1970s, a major tributary of the middle Zambezi, the Kafue River, was dammed first at Kafue Gorge and then at Itezhitezhi Gorge, further stabilizing the Zambezi River flow regime downstream of Kariba (Balasubrahmanyam and Abou-Zeid 1982, Turner 1984).

Following the construction of Kariba Dam, Portuguese colonial interests in the development potential of the lower Zambezi Valley resulted in the establishment of the *Missao de Fomento e Povaoamento do Zambezi* (MFPZ). The MFPZ aimed to undertake the systematic investigation of Zambezi basin resources in Mozambique, to organize plans for their exploitation and development, and to prepare designs for the projects that would be selected (Hidrotécnica Portuguesa 1958, 1961, 1965). From 1966-1974, the majority of MFPZ reports and investigations in the Zambezi concerned hydropower development in the Cahora Bassa Gorge. In December 1974 these plans culminated in the construction of Cahora Bassa Dam.

With the closing of Cahora Bassa Dam, the natural flood cycles of the lower Zambezi River became a phenomenon of the past. Inundation of the delta, when it occurs, is now dependent on regional rainfall-runoff within the lower Zambezi Basin or on erratically timed water releases to protect the dam wall during years of exceptional upper basin floods (Beilfuss and Davies 1999). The cumulative impact of these developments is a significant adverse shift in the magnitude, timing, duration, extent, and frequency of flooding events in the delta

The dam was constructed as part of a comprehensive plan for multi-purpose development of the Lower Zambezi system including the delta, under the auspices of the Zambezi Valley Planning Authority. The principle elements of the plan were (a) construction of Cahora Bassa Dam and other mainstream dams for hydropower generation, flood control, and river navigation; (b) establishment of a navigable channel along the river for transhipment to a deepwater port at Chinde; (c) establishment of large irrigated agriculture schemes in the tributary basins and main alluvial plain; and (d) development of mining and industrial projects (Hidrotécnica Portuguesa 1965). Bolton (1983) and Isaacman and Sneddon (2000) noted that a remarkable feature of the development planning for the Lower Zambezi was the almost total disregard for the indigenous population and their established patterns of water use. Even flood control, which promised some relief from the large floods that periodically devastated households and crops in the low lying areas of the delta, disrupted the land use practices adopted by local communities to harness the flood waters for economic gain (Liesegang and Chidiamassamba 1997). Furthermore, hydropower sales were committed to South Africa (and, to a lesser extent, Zimbabwe) with minimal electrical infrastructure development in the lower Zambezi Valley itself (Middlemas 1975).

At present, the management of Cahora Bassa Dam, as with that of the Kariba and Kafue Dams further upstream, remains focused on maximizing hydropower production relative to other potential Zambezi River uses. Powerlines to South Africa and Zimbabwe, which were sabotaged during the war, have been rehabilitated, and Cahora Bassa Dam now operates at full capacity[1]. Furthermore, additional plans are underway for the Cahora Bassa North Bank Power Station, and for a new hydroelectric dam downstream of Cahora Bassa at Mepanda Uncua Gorge. A narrow window of opportunity remains to implement a new vision for the management of Zambezi waters for the Zambezi Delta and the people of Mozambique.

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[1] The high voltage DC powerlines from Cahora Bassa Dam to South Africa were cut by the RENAMO opposition forces in June 1980, effectively shutting down all power production from the dam after only 11 months of full production. More than 2000 pylons were damaged, and many of these sites were landmined to thwart rehabilitation efforts (Hidroeléctrica de Cahora Bassa 2000). Power production was not fully restored until August 1998. Thus, during the first 24 years of Cahora Bassa operation the only power produced (about 15 MW, or 0.7% of the 2075 MW potential output) was for the *Hidroeléctrica de Cahora Bassa* facilities at Songo.

1.3 Integrating water resources management with the Marromeu Complex Management Planning Process

For the past decade the Museum of Natural History-Mozambique (*Museu de História Natural*), Zambezi Valley Planning Authority (*Gabinete do Plano de Desenvolvimento da Região do Zambeze*), in consultation with the International Crane Foundation-USA, have taken a leadership role in raising awareness about the local, regional, and global significance of the Marromeu Complex and promoting its conservation for the benefit of people and wildlife. They have worked in close collaboration with Mozambican scientists, community members, major stakeholders, NGOs, and government decision-makers towards consensus on the need for a holistic management plan for the delta to resolve competing visions for how the resources of the Marromeu Complex should be used, including wildlife hunting, ecotourism, sugar production, timbering, fisheries, grazing, and subsistence agriculture. They conducted extensive research on the hydrology, vegetation, and wildlife of the Zambezi Delta, and demonstrated the importance of restoring seasonal flood flows in the Zambezi River to sustain ecological processes and subsistence production systems in the delta without sacrificing the national development aims of Mozambique (e.g., Beilfuss 2001, in prep a, in prep b; Beilfuss and Bento 1997, in prep; Beilfuss *et al*. 2000, 2002, in prep.; Bento and Beilfuss 2000; Bento 2002). To disseminate these findings, they organized a series of face-to-face meetings, including three international workshops, to raise awareness among local stakeholders and national decision-makers about the need for integrated management of the lower Zambezi Valley and Delta (Beilfuss 1997, Davies 1998). They met with former President of Mozambique, Joaquim Chissano, key members of Parliament, and the Governors of Tete, Sofala, and Zambezia Provinces in the Zambezi Valley. This work also was featured in the BBC *Earth Reports* documentary series that aired at the World Water Forum in Japan. This extensive dialogue has resulted in the political will and commitment necessary to implement a unique vision for the future of the Zambezi Delta.

In October 2003, the Government of Mozambique declared the Marromeu Complex of the Zambezi Delta as the first *Wetland of International Importance* in Mozambique under the Ramsar Convention (Beilfuss and Bento 2003). The Ramsar Convention is the world’s foremost international agreement for the protection and wise use of wetlands, and requires national commitment to the sustainable management of designated wetland sites. The designation of the Marromeu Complex as a *Wetland of International Importance* was honored as a “Gift to the Earth” by the World Wildlife Fund, their highest accolade for globally significant conservation achievement. In addition to designating the site, the Government of Mozambique stipulated that an integrated management plan must be developed to ensure the sustainable development of the Marromeu Complex in accordance with the spirit of the Ramsar Convention. In December 2003 the Museum of Natural History was approached by the Zambezi Valley Planning Authority and the Ministry for Coordination of Environmental Affairs (*Ministério para a Coordenção da Acção Ambiental*) to coordinate the first integrated management plan for the newly designated Ramsar site.

The Museum of Natural History, under the auspices of the Zambezi Valley Planning Authority and the Ministry for Coordination of Environmental Affairs, is currently coordinating the creation of a comprehensive management plan for the Marromeu Complex through a transparent, inclusive process that involves all communities, stakeholders, and decision-makers concerned with the Zambezi Delta region. The planning process has been endorsed by the Ministry for Coordination of Environmental Affairs (MICOA), the Ministry of Tourism (MITUR), Ministry of

Agriculture and Rural Development (MADER), Ministry of Public Works and Housing (MOPH), Ministry of Fisheries (MP), Ministry of Science and Technology (MST), and Zambezi Valley Planning Authority (GPZ). The project is providing a unique opportunity to address and reverse decades of ecological degradation in the Marromeu Complex caused by large upstream dams, disenfranchisement of local communities, uncontrolled wildlife hunting, rapid expansion of sugar production, and other factors.

A key step in the management planning process is an assessment of the Environmental Flow Requirements for managing inflows from the Zambezi River to the Marromeu Complex of the Zambezi Delta, to halt or reverse adverse socio-economic and ecological changes that have resulted from river regulation. This report provides the detailed analysis of this assessment.

1.4 Aims of the project

The main aims of the project are to use available data and expert opinion to:

- Establish the relationship between hydrological conditions (past, present, and future) and different water-related users and concerns in the Marromeu Complex
- Identify potential conflicts/tradeoffs among users/concerns in the Marromeu Complex with respect to flow requirements.
- Explore the potential for the improvement in the condition of the Marromeu Complex through incorporation of environmental flow releases into Cahora Bassa Dam, chiefly in terms of:
    - reduction in dry season lowflows;
    - provision of a regular annual flood; and,
    - possible regulation of large floods (1:5 year return period or larger).
- Identify key knowledge gaps and data requirements that would need to be addressed prior to any formal Environmental Flow Assessment (EFA) for the Zambezi River and Delta.

1.5 The use of expert opinion

Specialists were recruited to provide expert opinion on hydrology, hydropower, hydraulics, vegetation dynamics, invasive species, large mammals, waterbirds, small-scale and commercial large-scale agriculture, freshwater fisheries, coastal and marine fisheries, livestock, economic use of natural resources, religious and cultural use of natural resources, human settlement patterns, public health, water supply, water quality, and navigation for this study. Each specialist was quick to note that there is a dearth of quantitative data for the delta on which to base analyses and predictions. For a few of these disciplines, available data were truly insufficient to complete the data analysis. For most disciplines, however, a mix of quantitative and qualitative evidence of changes in the delta, partly as a result of hydrological manipulations, has been reported in various studies, interviews and discussions. In cases where data were not available to support certain predictions, specialists in this study were specifically required to rely on their experience to provide the required inputs. Readers are thus requested to look beyond the detail at the overall picture that emerges from this study. We have clearly stated the data, opinions and assumptions on which the inputs are based, and the limitations to which they are subjected.

1.6 Report overview

This report provides the following information:

(1) An overview of the process and study team employed to assess Environmental Flow Requirements for the Marromeu Complex using the DRIFT (Downstream Response to Imposed Flow Transformations) methodology

(2) A description of the hydrological change levels used for the DRIFT assessment and modelling of trade-offs between hydropower generation and annual flood releases for meeting hydrological change levels

(3) A description of the hydraulic (mass transfer) model used to assess the movement of waters from the Zambezi River to the delta

(4) The complete set of eleven specialist studies submitted for the DRIFT assessment: (i) Agriculture; (ii) Estuarine ecology and coastal fisheries; (iii) Freshwater fisheries; (iv) Livestock; (v) Large mammals; (vi) Waterbirds; (vii) Floodplain Vegetation; (viii) Natural resource utilization; (ix) Water quality; (x) Groundwater; (xi) Navigation.

(5) Output from the DRIFT model, including assessment of trade-offs between water users in the delta, the implications of different flow scenarios on hydropower generation, and discussion.

(6) Numerical model input and output for assessing changes in dry season low flows, the annual flood, and the 1:5 year return period flood.

(7) An attached CD containing the complete *Proceedings of the Workshop on the Sustainable Water Management for the Zambezi Delta, held 5-6 September 2005 at the Museum of Natural History-Mozambique,* including presentations, remarks, minutes of discussion, invitations, participants, media coverage, and other background information.

1.7 Acknowledgements

We are grateful to the Liz Claiborne and Art Ortenberg Foundation for providing the core funding for this project. Additional funding, in-kind, and administrative support was provided by the International Crane Foundation and the Carr Foundation. We thank Prof. Dr. Patrocinio da Silva of the Zambezi Valley Planning Authority and Mr. Carlos Bento of the Museum of Natural History in Mozambique, who are leading the management planning process for the Marromeu Complex Ramsar Site through their respective institutions. We also thank the Ministry for the Coordination of Environmental Affairs (MICOA), Ministry of Agricultural and Rural Development (MADER), Ministry of Fisheries (MP), and Ministry of Tourism (MITUR) for their institutional support for the management planning process. Special thanks to Dr. Jackie King and Dr. Ted Scudder for helping conceptualize the application of the DRIFT model to the Zambezi River basin, and to Dr. Robert Douthwaite for extensive comments on an earlier draft of this report.

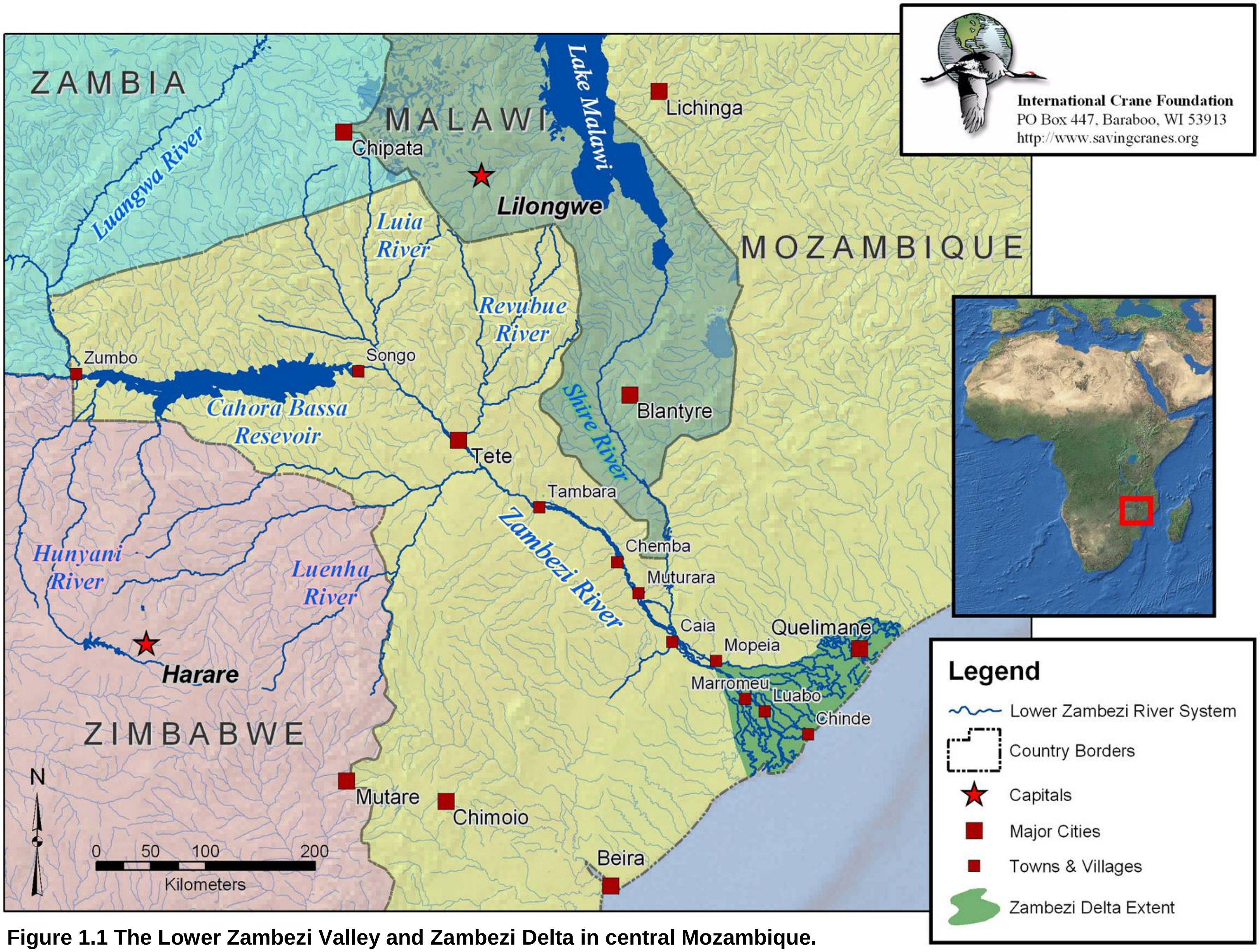
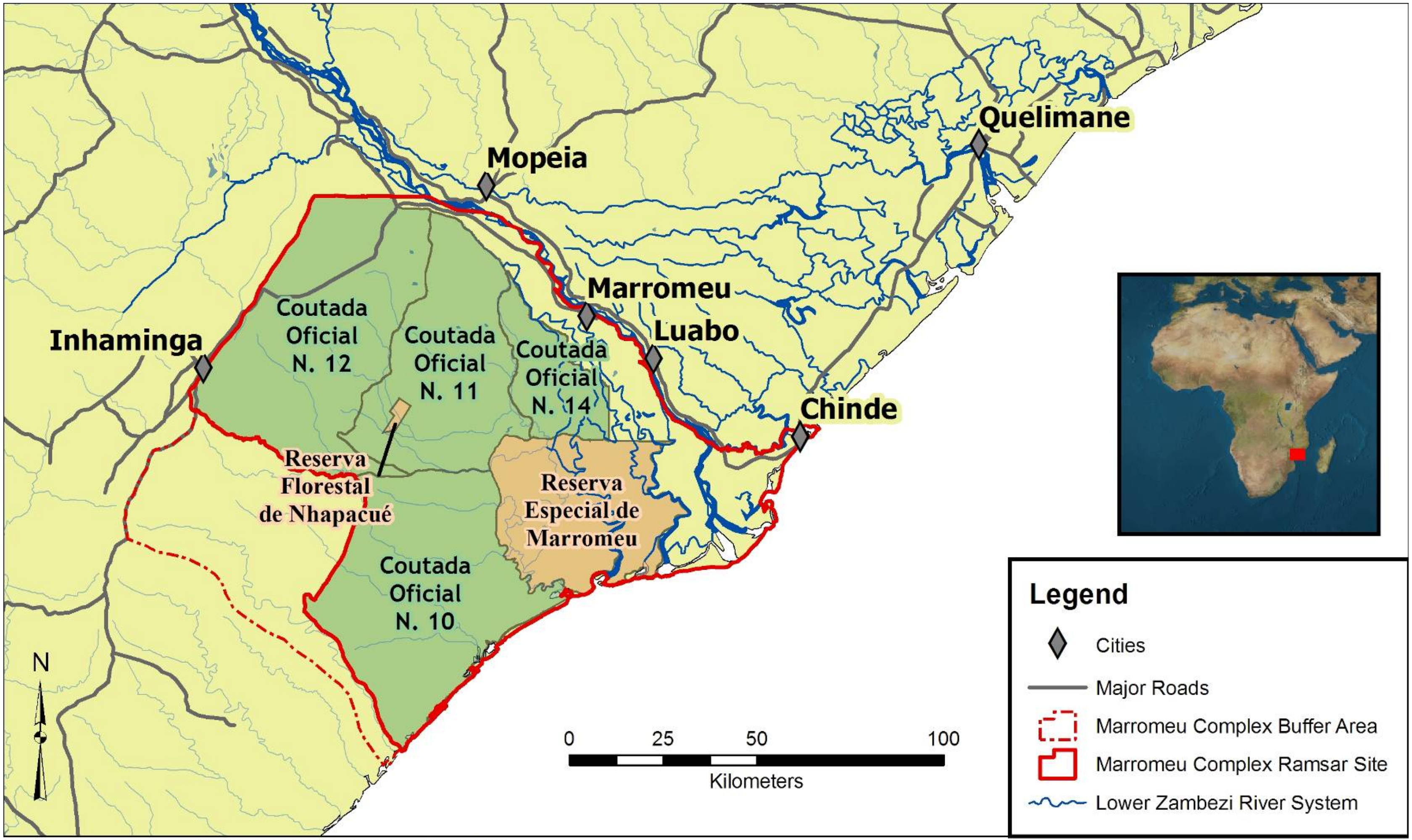


Figure 1.1 The Lower Zambezi Valley and Zambezi Delta in central Mozambique.



Map by Dorn Moore, International Crane Foundation May 2006

Figure 1.2. The Marromeu Complex Ramsar Site.

2. The Process and Study Team

2.1 The environmental flow process used

A modification of a process called DRIFT (Downstream Response to Imposed Flow Transformations; King *et al.* 2003) was used to evaluate different water management scenarios for the Zambezi Delta.

DRIFT (King *et al*. 2003; Brown and Joubert 2003; Brown *et al*. 2005) is a structured process for combining data and knowledge from various disciplines to produce flow-related scenarios for water managers to consider.

Its central rationale is that different parts of the flow regime elicit different responses from a river ecosystem. Thus, removal of one part of the flow regime will affect the ecosystem differently than removal of another part. Furthermore, it is assumed that:

- It is possible to identify and isolate these different parts of the flow regime within a long-term hydrological data set of daily flows;
- It is possible to describe in isolation the probable biophysical consequences of partial or whole removal of any one of these parts;
- The parts of the flow regime and their linked consequences can be re-combined in various ways, to describe the river condition of any flow regime of interest (the biophysical part of the scenario).

DRIFT has been applied, in various guises, in Lesotho, Zimbabwe and South Africa. This present study focuses on the Marromeu Complex as part of the management planning process for the Ramsar Site, although any changes in the hydrological regime will affect the whole of the Zambezi Delta.

Three key hydrological categories were selected for evaluation. These were deemed to be those historically most affected by water resources development, and for which changes in water management were expected to result in significant consequences for the ecosystem/users of the delta (see Section 3 for more detail).

- Dry season lowflows;
- The ‘annual’ flood;
- 1:5 year return flood.

The flow changes that were evaluated for these categories encompass a mixture of (see Section 3):

- Changes in magnitude.
- Changes in duration.
- Changes in timing (i.e., month of occurrence).

The main users/concerns in the delta that have been affected by the flow changes were identified and (in the absence of quantitative data on each of these) specialists (see Section 2.2) were approached to provide opinion on the consequences for these on various measures aimed at restoring flows towards those recorded pre-dam. The main users/concerns that were identified were:

- Flow-related small-scale agriculture
- Commercial large-scale irrigation supply
- Estuarine ecology
- Coastal fisheries
- Freshwater fisheries

- Livestock
- Large mammals
- Waterbirds
- Floodplain vegetation of biodiversity interest
- Invasive, undesired vegetation
- Natural resource utilization
- Water quality
- Groundwater recharge (water supply)
- In-channel navigation
- Public health
- Human settlement patterns

Specialists were contracted to assess each of these users/concerns. The specialists for public health and human settlement patterns were unable to complete the full DRIFT analysis (described below) prior to the workshop or completion of the final report. The information supplied by the specialists was entered into a DRIFT database (Brown and Joubert 2003), which comprised a matrix of consequences, for a range of possible flow changes in the three flow categories.

The database was used to evaluate:

- Conflicting uses/concerns, i.e. potential tradeoffs, in the delta;
- A range of permutations to create new flow regime scenarios, together with their consequences for different users in the delta and the implications for hydropower generation.

The outputs of the DRIFT database were:

- Presented to the specialists in a workshop situation for evaluation, and re-calibration, where necessary;
- Used in a workshop format involving MICAO, DNA, ARA-Zambezi and other government and non-government representatives to explore:
    - potential conflicts/tradeoffs among users in the delta area with respect to flow requirements;
    - the potential for the improvement in the condition of the delta through incorporation of environmental flow releases into Cahora Bassa Dam.

The background information from the specialists that was used to populate the database, the output of DRIFT, and the key knowledge gaps and data requirements identified are all presented in this report.

2.2 Basic assumptions

The following basic assumptions were applied to the DRIFT analysis:

- The study focused on Marromeu Complex (south bank) of the Zambezi Delta.
- Present day conditions were used as a starting point, and change was expressed as a percentage move towards or away from a pre-defined target condition.
- Specialists assumed a 30-year horizon for their predictions.
- Each flow change was considered in isolation, i.e., it was assumed that the remainder of the flow regime remained at present day levels.
- For the flood flows it was assumed the same magnitude would occur each year[2].

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[2] This will not actually be the case, as the magnitude of flows at the delta will depend on downstream contributions, i.e., vary as a function of climate each year. However, the complications introduced by having to consider varying annual magnitudes were outside the scope of this study.

2.3 Scoring system used

Into the foreseeable future, predictions of river change will be based on limited knowledge. Most river scientists, particularly when using sparse data, are thus reluctant to quantify predictions: it is relatively easy to predict the nature and direction of ecosystem change, but more difficult to predict its timing and intensity. To calculate the implications of loss of resources to subsistence and other users/concerns in order to facilitate discussion and tradeoffs, it is nevertheless necessary to quantify these predictions as accurately as possible.

In this study, we used DRIFT 'severity ratings', with a slight variation from the way they are normally used (e.g., King *et al.* 2003). Here, the specialists representing each of the users provided a rating on a six-point scale that spans no change to 100% change (Table 2.1). This scale already accommodates uncertainty, as each rating encompasses a range. Greater uncertainty was expressed through providing a range of severity ratings (i.e. a range of ranges) for any one predicted change (after King *et al.* 2003). The ratings imply that a gain of 5 equates to full achievement of target(s) whilst a loss of 5 equates to a total loss of a use.

In DRIFT these severity ratings are converted to integrity ratings through the addition of a plus or minus sign to denote a move towards (+ve) or away from (-ve) the defined target conditions.

Table 2.1 Severity ratings for predictions of change and conversion to percentage target attainment or breakdown.

Severity rating	Equivalent gain	Equivalent loss
0	no change	no change
1	0-19% move towards target	0-19% move away from target
2	20-39% move towards target	20-39% move away from target
3	40-59% move towards target	40-59% move away from target
4	60-70% move towards target	60-70% move away from target
5	80-100% move towards target	80-100% move away from target

2.4 The study team

Study team members, their roles on the project and their affiliations are provided in Table 2.2.

Table 2.2 Study team members, their roles on the project and their affiliations.

Name	Role(s)	Affiliation
R. Beilfuss	Coordination Hydrology Hydropower Water supply Water quality In-channel navigation	International Crane Foundation, USA and Carr Foundation, USA
C. Bento	Coordination Waterbirds	Museum of Natural History, Mozambique
S. Bila	Large mammals	Faculty of Veterinarian Science, University of Eduardo Mondlane, Mozambique
R. Brito	Agriculture	Faculty of Agronomy, University of Eduardo Mondlane, Mozambique
C. Brown	Facilitation Database design	Southern Waters Ecological Research and Consulting, South Africa
E. Chonguiça	Natural resource utilization	IUCN-The World Conservation Union - Mozambique Programme Office
P. da Silva	Livestock	Zambezi Delta unit, Zambezi Valley Planning Authority
P. Funston	Large mammals	Tshwane University of Technology, South Africa
D. Purkey	Mass transfer model	Natural Heritage Institute, USA
R. Silva	Estuarine ecology and coastal fisheries	Institute for Fisheries Research, Ministry of Fisheries, Mozambique
J. Timberlake	Floodplain vegetation	Flora Zambesiaca, RBG Kew, United Kingdom
D. Tweddle	Freshwater fisheries	South African Institute for Aquatic Biodiversity, South Africa

2.5 The Terms of Reference for specialists

2.5.1 Provide a list of up to four key sub-components that you will use to describe flow-related change in your discipline.

For example, sub-components for the vegetation analysis might include mangroves; riparian forests, and permanent papyrus swamps

2.5.2 For each of the chosen subcomponents, describe the following to the extent possible:

- status prior to river regulation;
- present-day status;
- the desired target condition for that sub-component.

Please try to be as quantitative as possible with your descriptions.

2.5.3 Evaluate and rank each of the hydrological flow categories in terms of their impact on each of your sub-components.

Please add motivations/explanations where necessary.

2.5.4 Compile a list of your data requirements from other disciplines.

In order to provide consequences for your discipline, it is expected that you may first have to obtain information on habitat or other changes from other specialists on the team. For instance, before you can describe the *consequences of a reinstating the 1:5 year flood flows for buffalo, you may have to consider the EFFECT of the resultant flow on the following:*

- *depth and wetted area on the floodplain (from hydraulics);*
- *carrying capacity (from botanist).*

Note: You must not decide on the consequences for another discipline represented in the team, as this may lead to conflicting information in the database.

2.5.5 Considering a 30-year horizon (i.e., 60 years after closure of the dam), evaluate the likely changes in each of your sub-components assuming no-change in the present operating rules of Cahora Bassa Dam.

This task is designed to determine whether or not the status of particular sub-component has reached equilibrium in the 30 years since closure of Cahora Bassa Dam, or whether the change is ongoing. For each sub-component provide the following information on data sheets provided:

- *Whether given no change in the operation of Cahora Bassa Dam there will be in an increase or decrease in abundance or concentration of the sub-component.*
- *An estimate of the* ***severity*** *of the predicted increase or decrease (if any) in terms of a range between 1 and 5 (Table 2.2).*
- *Whether the change represents a move towards or away from the target condition described in Section 5.2.*

A written motivation and explanation for the consequences you have predicted.

2.5.6 Using the datasheet provided, evaluate the consequences for each sub-component of the change levels for each of the hydrological flow categories.

For each consequence, provide the following information on data sheets provided:

- *Whether the change will result in an increase or decrease in abundance or concentration of the sub-component.*
- *Whether the change represents a move towards or away from the target condition.*
- *An estimate of the extent* ***severity*** *of the predicted change (if any) in terms of a range between 1 and 5 (Table 5.1).*

A written motivation and explanation for the consequences you have predicted.

2.5.7 Respond to the question: ‘Do you think slight variability in the magnitude of the Annual Flood will be beneficial or detrimental to your subcomponents?’

Please motivate your answer.

2.5.8 Respond to the question: ‘Do you think that, in a 30-year horizon, a “pre-regulation condition” in the delta could be achieved if the flow conditions prior to river regulation were reinstated, i.e., do you think the current condition is reversible?’

Please motivate your answer.

2.5.9 Provide a report written in MS Word in the required format.

Do not supply detailed background information/literature reviews, rather use the time available to deliberate and motivate the consequences of flow change.

2.5.10 Liaise with Project Coordinator and Facilitator as they populated the DRIFT database.

2.5.11 Attend a two-day workshop in Maputo with the rest of the team to evaluate (and adjust if necessary) the overall results of the DRIFT evaluation, and to present the outcomes to government agencies and Marromeu Complex stakeholders.

2.6 Schedule of activities

14-16 November 2004:	Conceptualization meeting in Citrusdal, South Africa
22-23 June 2005:	Planning meeting in Cape Town, South Africa
24 June 2005:	ToRs finalized and submitted to specialists
1–31 July 2005:	Specialist studies conducted
1–31 August 2005:	Report review and database population and analysis
3-5 September 2005:	Specialists review DRIFT results in Maputo
5-6 September 2005:	Specialist Workshop in Maputo
10 October 2005:	Reworked specialist reports submitted
11-31 October 2005:	Revised report review and database analysis

3. Background – Hydrology and Hydropower

3.1 Introduction

A range of hydrological changes levels were selected to evaluate the three flow categories (dry season low flows, the annual flood, and the 1:5 year return period flood) in terms of pre-dam (reference) conditions, present day conditions, and potential conditions corresponding to different environmental flow releases. This paper describes the approximate hydrological conditions corresponding to each of these reference states and change levels. Pre-dam conditions refer to hydrological conditions observed prior to significant regulation of the Zambezi (i.e., prior to Kariba Dam, the first major regulatory structure on the Zambezi River). Present day conditions refer to the period since construction of Cahora Bassa Dam.

Each of the hydrological change levels and reference states is described in terms of flow characteristics at the apex of the Zambezi Delta. These flows thus comprise a combination of prescribed flow releases from Cahora Bassa Dam plus unregulated flow contribution from downstream tributaries including most notably the Luia, Revuboe, Luenha, and Shire Rivers. Flow releases from Cahora Bassa Dam may comprise a mix of turbine discharge and sluice gate spillage. Tributary inflows estimates are based on average annual discharges observed during pre-dam (28-year) and most recent (28-year) periods of hydrological record.

Flows in the Zambezi Delta, in turn, are affected by discharge into major Zambezi Delta distributary channels (most notably the Cuacua and Salone depression) and lateral movement into floodplain systems, before dividing among the three major distributary forks near the Indian Ocean. Flows near the coast are also affected by tidal levels. Chapter 4 addresses the hydraulic movement of water from the mainstem Zambezi to these distributary channels and downstream floodplains.

The author notes that all of the hydrological descriptions provided below are approximations based on best scientific judgement, given the lack of hydrological data to accurately describe the system. Critical data gaps include the absence of river discharge gauging downstream of Tete (inflows from the Shire River, Luenha River, and many smaller tributaries and baseflows are not recorded), the absence of river gauging data to estimate the proportion of Zambezi flows that drain through distributary channels such as the Cuacua (north bank) and Salone depression (south bank), the absence of a stage-discharge rating curve to link flows in the Zambezi River to corresponding water levels in the river channel (the more recent stage-discharge rating curve measurements were undertaken at Marromeu c. 1960), and the absence of recent channel-floodplain cross-sectional data for any point in the Zambezi Delta. It is our hope that future hydrological monitoring and subsequent analysis will improve our ability to describe the characteristics of different hydrological scenarios in the delta, especially in conjunction with observed flow releases.

For a detailed review of sources and reliability of the hydrological data used in this analysis, see Beilfuss 2001.

3.2 Description of change levels for dry season low flow

For dry season lowflows, three alternatives for magnitude, two alternatives for duration, and two alternatives for timing were assessed, resulting in five change levels over and above pre-dam and present-day conditions.

3.2.1 Pre-dam (reference) conditions

Prior to regulation, Zambezi floodwaters receded during an eight to nine month period following peak flooding in February/March, reaching a minimum in November (Figure 3.1). For the 28-year period prior to Zambezi River regulation, the mean date of occurrence of minimum flow was November 14, with a standard deviation of only 12 days. Average monthly discharges were 1125 m^3/s in September, 736 m^3/s in October, 620 m^3/s in November, and 1440 m^3/s in December. From mid-September through early December, the Zambezi River became a sluggish, braided system of rivulets and sandbars. Tidal influence occurred more than 80 km inland from the Indian Ocean coast.

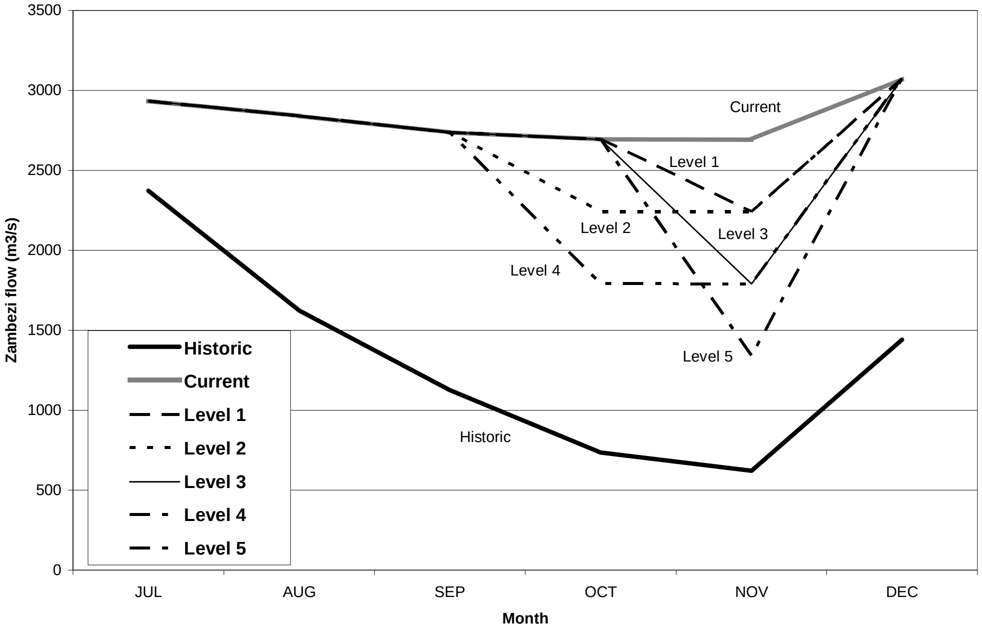


Figure 3.1 Estimated mean monthly dry season low flows for pre-dam (historic), present-day (current), and change levels 1-5.

3.2.2 Present day condition

Zambezi River discharge near the Zambezi Delta is now (2005) approximately 2690 m^3/s in October (365% of pre-dam flows) and November (435% of reference flows). 4-5 turbines are typically in operation, discharging a constant flow of about 2250 m^3/s throughout the year, including the dry season months of October and November. Downstream tributaries contribute about 440 m^3/s in October and November, on average. This steady dry season discharge is nearly 60% of bankful discharge (4500 m^3/s). Deeper channel areas are inundated and most sandbars are consolidated and vegetated.

3.2.3 Change level 1

Zambezi River discharge near the Zambezi Delta is reduced to approximately 2240 m^3/s (17% reduction from present day) during the month of November. This is

360% of pre-dam flow conditions. One turbine is taken off-line and Cahora Bassa discharge is reduced by 450 m^3/s to 1800 m^3/s for the entire month, augmented by downstream tributaries that contribute about 440 m^3/s on average.

3.2.4 Change level 2

Zambezi River discharge near the Zambezi Delta is reduced to approximately 2240 m^3/s during the **two-month period** of October and November (17% reduction from present day). This is 300% and 360%, respectively, of reference (pre-dam) flow conditions. One turbine is taken off-line and Cahora Bassa discharge is reduced by 450 m^3/s to 1800 m^3/s for this entire period, augmented by downstream tributaries contributing about 440 m^3/s in October and November, on average.

3.2.5 Change level 3

Zambezi River discharge near the Zambezi Delta is reduced to approximately 1790 m^3/s (34% reduction from present day) during the month of November. This is 290% of pre-dam flow conditions. Two turbines are taken off-line and Cahora Bassa discharge is reduced by 900 m^3/s to 1350 m^3/s for the entire month, augmented by downstream tributaries contributing about 440 m^3/s on average.

3.2.6 Change level 4

Zambezi River discharge near the Zambezi Delta is reduced to approximately 1790 m^3/s (34% reduction from present day) during the **two-month period** of October and November. This is 240% and 290%, respectively, of pre-dam flow conditions. Two turbines are taken off-line and Cahora Bassa discharge is reduced by 900 m^3/s to 1350 m^3/s for this entire period, augmented by downstream tributaries contributing about 440 m^3/s in October and November, on average.

3.2.7 Change level 5

Zambezi River discharge near the Zambezi Delta is reduced to approximately 1340 m^3/s (51% reduction from present day) during the month of November. This is 215% of pre-dam flow conditions. Three turbines are taken off-line and Cahora Bassa discharge is reduced by 1350 m^3/s to 900 m^3/s for the entire month, augmented by downstream tributaries contributing about 440 m^3/s on average.

Note: Further reductions in Zambezi dry season flow (by further reducing the number of turbines in operation) were determined to be politically unacceptable at present due to lost hydropower generation, as a consequence, pre-regulation dry season flow levels are not proposed as an attainable change level.

3.3 Description of change levels for wet season annual flows

For the annual wet season flood release, three alternatives for magnitude, three alternatives for duration, and two alternatives for timing were assessed, resulting in 18 change levels over and above pre-dam and present-day conditions.

3.3.1 Pre-dam (reference) condition

For the 28-year period prior to Zambezi River regulation (a wet period relative to the full historical record), the mean annual peak flood discharge in the delta region was approximately 9800 m^3/s. The annual flood cycle generally began with the onset of the rainy season in late November or December, with rapidly rising flood levels through January. Peak flooding typically occurred in February and March. The general timing of the maximum annual flood discharge was fairly predictable, occurring in almost all years between mid-February and mid-March, with a mean date of March 1 and standard deviation of 21 days. The mean annual discharge occurred in 19 of 28 years, with an average duration of 13 days (about half of one month). The maximum duration of flooding above this level was 66 days (more than two months). Mean monthly discharges were 1440 m^3/s in December, 3886 m^3/s in January, 6496 m^3/s in February, 7436 m^3/s in March, 5849 m^3/s in April, 4509 m^3/s in May, 3418 m^3/s in June (Figure 3.2). That maximum annual two-month mean discharge was 6989 m^3/s during February and March.

Bankful discharge occurs at approximately 4500 m^3/s. These flows result in shallow inundation of channel islands and floodplain areas within the upper diked perimeter and low lying floodplain areas towards the coast, but no significant discharge of floodwaters into the Cuacua channel or the delta interior. During the 28-year period prior to Zambezi regulation, flows exceeded 4500 m^3/s in every year of record. The mean duration of flow exceeding 4500 m^3/s was 93 days (more than 3 months), with a maximum of 155 days above 4500 m^3/s in 1956 and a minimum of 2 days above 4500 m^3/s in 1949. Flows exceeded 4500 m^3/s (the approximate bankful discharge) in every year of record.

Flows of 7000 m^3/s result in total inundation of channel islands and floodplain areas within the upper diked perimeter, and widespread flooding along Cuacua channel of the delta northbank. Low-lying floodplain areas towards the coast (where the river is not diked) are deeply inundated. Some floodwaters reach the Marromeu buffalo reserve and other areas of the delta interior, resulting in shallow inundation with depth determined by local rainfall runoff. For the 28-year period prior to Zambezi River regulation, flows exceeded 7000 m^3/s in 24 (86%) of years. The mean duration of flow exceeding 7000 m^3/s was 37 days, with a maximum of 101 days above 7000 m^3/s in 1956.

Flows of 10,000 m^3/s (approximately the mean annual flood prior to Zambezi regulation) result in extensive flooding of the delta northbank and total inundation of channel islands and floodplain areas within the upper diked perimeter and along coastal distributary floodplains. The southbank dikes are not overtopped, but floodwaters drain through the upper distributary channels into the Marromeu buffalo reserve and other interior areas. For the 28 year period prior to Zambezi River regulation, flows exceeded 10,000 m^3/s during 15 (54%) of years. The mean duration of flow exceeding 10,000 m^3/s was 12 days, with a maximum of 65 days above 10 000 m^3/s in 1958.

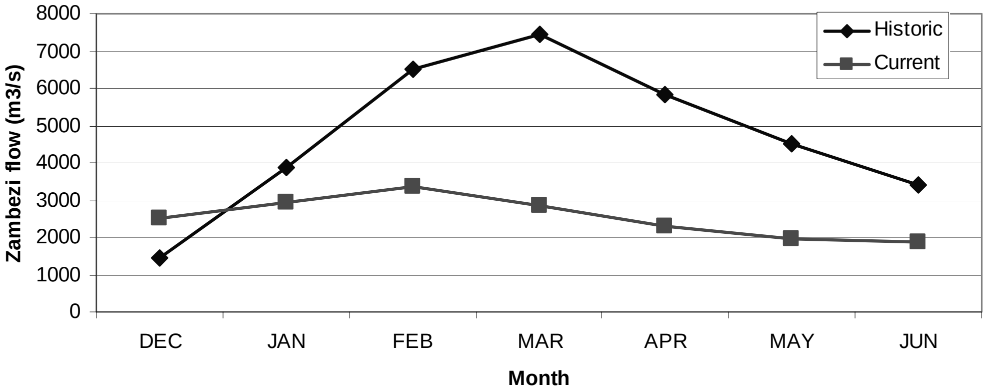


Figure 3.2 Estimated mean monthly wet season flows for pre-dam (historic) and present-day (current).

3.3.2 Present day condition

The magnitude, timing, duration, and frequency of flooding events in the delta region at present differ significantly from the pre-regulation state. There is no longer a clearly discernable period of high flows and low flows (Figure 3.2). Over the 28-year period of Cahora Bassa Dam operation, the mean annual maximum flood discharge has been approximately 3800 m^3/s (39% of the pre-regulation maximum).

The timing of the maximum annual flood discharge has become highly unpredictable, controlled by the reservoir design flood rule curve, which stipulates maximum allowable reservoir water levels at the end of each calendar month. The mean date of the maximum annual discharge (February 10) is only 18 days earlier than under pre-regulation conditions. However, the standard deviation is 40 days and flood releases from Cahora Bassa Dam may occur in any month -- annual downstream peaks (factoring in unregulated tributary contributions) have occurred at the end of the dry season in October and November in the past

The historical (pre-regulation) mean annual discharge of 9800 m^3/s has occurred in only 3 of the past 28 years. Floods exceeded this discharge for 42 days in 1978, 3 days in 1989, and 20 days in 2001 (all corresponding to “emergency” flood releases from Cahora Bassa Dam). Mean monthly discharges are 2490 m^3/s in December (73% higher than the unregulated mean discharge), 2940 m^3/s in January (24% lower), 3369 m^3/s in February (48% lower), 2868 m^3/s in March (61% lower), 2314 m^3/s in April (61% lower), 1945 m^3/s in May (57% lower), and 1886 m^3/s in June (45% lower). That maximum annual two-month mean discharge is 3119 m^3/s during February and March.

During the 28-year period of Cahora Bassa operation, flows have exceeded bankful discharge (approximately 4500 m^3/s) during only 16 of the past 28 years. The mean duration of flow exceeding 4500 m^3/s has been 26 days (less than 1 month), with a maximum of 166 days above 4500 m^3/s in 1978 and 124 days in 2001. Over the same period, flows have exceeded 7000 m^3/s in only 10 of 28 years, with a mean duration of 10 days.

3.3.3 Change level 1

Bankful discharge (4500 m^3/s) occurs continuously during the last half of December for 15 days. To achieve this discharge, Cahora Bassa Dam would need to discharge 3680 m^3/s (1430 m^3/s as spillage), based on an expected average tributary contribution of 820 m^3/s during this period. Flows before and after this period would be 3070 m^3/s and 3720 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 820 m^3/s in early December and 1470 m^3/s in early January, with no spillage except during exceptionally wet years. Actual turbine output may be reduced during very dry years.

3.3.4 Change level 2

Bankful discharge (4500 m^3/s) occurs continuously during the entire month of December. To achieve this discharge, Cahora Bassa Dam would need to discharge 3680 m^3/s (1430 m^3/s as spillage), based on an expected average tributary contribution of 820 m^3/s during this period. Flows before and after this period would be 2690 m^3/s and 3720 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 440 m^3/s in late November and 1470 m^3/s in early January, with no spillage except during exceptionally wet years. Actual turbine output may be reduced during very dry years.

3.3.5 Change level 3

Bankful discharge (4500 m^3/s) occurs continuously during the last half of February for 15 days. To achieve this discharge, Cahora Bassa Dam would need to discharge 2550 m^3/s (300 m^3/s as spillage), based on an expected average tributary contribution of 1950 m^3/s during this period. Flows before and after this period would be 4200 m^3/s and 3870 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 1950 m^3/s in early February and 1620 m^3/s in early March, with no spillage except during exceptionally wet years.

3.3.6 Change level 4

Bankful discharge (4500 m^3/s) occurs continuously during the entire month of February. To achieve this discharge, Cahora Bassa Dam would need to discharge 2550 m^3/s (300 m3/s as spillage), based on an expected average tributary contribution of 1730 m3/s during this period. Flows before and after this period would be 3720 m^3/s and 3870 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 1470 m^3/s in late January and 1620 m^3/s in early March, with no spillage except during exceptionally wet years.

3.3.7 Change level 5

Bankful discharge (4500 m^3/s) occurs continuously during the entire **two-month period** of December and January. To achieve this discharge, Cahora Bassa Dam would need to discharge 3355 m^3/s (1105 m^3/s as spillage) during December and January based on the average of expected tributary contributions for December (820 m^3/s) and January (1470 m^3/s). Flows before and after this period would be 2690 m^3/s and 4200 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 440 m^3/s in late November and 1950 m^3/s in early February, with no spillage except during exceptionally wet years.

3.3.8 Change level 6

Bankful discharge (4500 m^3/s) occurs continuously during the entire **two-month period** of February and March. To achieve this discharge, Cahora Bassa Dam would need to discharge 2715 m^3/s (465 m^3/s as spillage) during February and March based on the average of expected tributary contributions for February (1950 m^3/s) and March (1620 m^3/s). Flows before and after this period would be 3720 m^3/s and 3490 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 1470 m^3/s in late January and 1240 m^3/s in early April, with no spillage except during exceptionally wet years.

3.3.9 Change level 7

Moderate inundation (7000 m^3/s) occurs continuously during the last half of December for 15 days. To achieve this discharge, Cahora Bassa Dam would need to discharge 6180 m^3/s (3930 m^3/s as spillage), based on an expected average tributary contribution of 820 m^3/s during this period. Flows before and after this period would be 3070 m^3/s and 3720 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 820 m^3/s in early December and 1470 m^3/s in early January, with no spillage except during exceptionally wet years. Actual turbine output may be reduced during very dry years.

3.3.10 Change level 8

Moderate floodplain inundation (7000 m^3/s) occurs continuously during the entire month of December. To achieve this discharge, Cahora Bassa Dam would need to discharge 6180 m^3/s (3930 m^3/s as spillage), based on an expected average tributary contribution of 820 m^3/s during this period. Flows before and after this period would be 2690 m^3/s and 3720 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 440 m^3/s in late November and 1470 m^3/s in early January, with no spillage except during exceptionally wet years. Actual turbine output may be reduced during very dry years.

3.3.11 Change level 9

Moderate inundation of the floodplain (7000 m^3/s) occurs continuously during the last half of February for 15 days. To achieve this discharge, Cahora Bassa Dam would need to discharge 5050 m^3/s (2800 m^3/s as spillage), based on an expected average tributary contribution of 1950 m^3/s during this period. Flows before and after this period would be 4200 m^3/s and 3870 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 1950 m^3/s in early February and 1620 m^3/s in early March, with no spillage except during exceptionally wet years.

3.3.12 Change level 10

Moderate inundation of the floodplain (7000 m^3/s) occurs continuously during the entire month of February. To achieve this discharge, Cahora Bassa Dam would need to discharge 5050 m^3/s (2800 m^3/s as spillage), based on an expected average tributary contribution of 1950 m^3/s during this period. Flows before and after this period would be 3720 m^3/s and 3870 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 1470 m^3/s in late January and 1620 m^3/s in early March, with no spillage except during exceptionally wet years.

3.3.13 Change level 11

Moderate inundation (7000 m^3/s) occurs continuously during the entire **two-month period** of December and January. To achieve this discharge, Cahora Bassa Dam would need to discharge 5855 m^3/s (3605 m^3/s as spillage) during December and January based on the average of expected tributary contributions for December (820 m^3/s) and January (1470 m^3/s). Flows before and after this period would be 2690 m^3/s and 4200 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 440 m^3/s in late November and 1950 m^3/s in early February, with no spillage except during exceptionally wet years.

3.3.14 Change level 12

Moderate inundation of the floodplain (7000 m^3/s) occurs continuously during the entire **two-month period** of February and March. To achieve this discharge, Cahora Bassa Dam would need to discharge 5215 m^3/s (2965 m^3/s as spillage) during February and March based on the average of expected tributary contributions for February (1950 m^3/s) and March (1620 m^3/s). Flows before and after this period would be 3720 m^3/s and 3490 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 1470 m^3/s in late January and 1240 m^3/s in early April, with no spillage except during exceptionally wet years.

3.3.15 Change level 13

Extensive inundation of the floodplain (10,000 m^3/s) occurs continuously during the last half of December for 15 days. To achieve this discharge, Cahora Bassa Dam would need to discharge 9180 m^3/s (6930 m^3/s as spillage), based on an expected average tributary contribution of 820 m^3/s during this period. Flows before and after this period would be 3070 m^3/s and 3720 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 820 m^3/s in early December and 1470 m^3/s in early January, with no spillage except during exceptionally wet years. Actual turbine output may be reduced during very dry years.

3.3.16 Change level 14

Extensive inundation of the floodplain (10,000 m^3/s) occurs continuously during the entire month of December. To achieve this discharge, Cahora Bassa Dam would need to discharge 9180 m^3/s (6930 m^3/s as spillage), based on an expected average tributary contribution of 820 m^3/s during this period. Flows before and after this period would be 2690 m^3/s and 3720 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 440 m^3/s in late November and 1470 m^3/s in early January, with no spillage except during exceptionally wet years. Actual turbine output may be reduced during very dry years.

3.3.17 Change level 15

Extensive inundation of the floodplain (10,000 m^3/s) occurs continuously during the last half of February for 15 days. To achieve this discharge, Cahora Bassa Dam would need to discharge 8050 m^3/s (5800 m^3/s as spillage), based on an expected average tributary contribution of 1950 m^3/s during this period. Flows before and after this period would be 4200 m^3/s and 3870 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 1950 m^3/s in early February and 1620 m^3/s in early March, with no spillage except during exceptionally wet years.

3.3.18 Change level 16

Extensive inundation of the floodplain (10,000 m^3/s) occurs continuously during the entire month of February. To achieve this discharge, Cahora Bassa Dam would need to discharge 8050 m^3/s (5800 m^3/s as spillage), based on an expected average tributary contribution of 1950 m^3/s during this period. Flows before and after this period would be 3720 m^3/s and 3870 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 1470 m^3/s in late January and 1620 m^3/s in early March, with no spillage except during exceptionally wet years.

3.3.19 Change level 17

Extensive inundation of the floodplain (10,000 m^3/s) occurs continuously during the entire **two-month period** of December and January. To achieve this discharge, Cahora Bassa Dam would need to discharge 8855 m^3/s (6605 m^3/s as spillage) during December and January based on the average of expected tributary contributions for December (820 m^3/s) and January (1470 m^3/s). Flows before and after this period would be 2690 m^3/s and 4200 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 440 m^3/s in late November and 1950 m^3/s in early February, with no spillage except during exceptionally wet years.

3.3.20 Change level 18

Extensive inundation of the floodplain (10,000 m^3/s) occurs continuously during the entire **two-month period** of February and March. To achieve this discharge, Cahora Bassa Dam would need to discharge 8215 m^3/s (5965 m^3/s as spillage) during February and March based on the average of expected tributary contributions for February (1950 m^3/s) and March (1620 m^3/s). Flows before and after this period would be 3720 m^3/s and 3490 m^3/s on average, respectively, based on regular turbine output of 2250 m^3/s and tributary inflows of 1470 m^3/s in late January and 1240 m^3/s in early April, with no spillage except during exceptionally wet years.

Note: Flood releases during December are timed to coincide with the early stages of flood rise, and enable increased storage capacity in Cahora Bassa Dam for the remaining flood season. Therefore, flood releases scheduled for December will serve to reduce the magnitude and frequency of major (emergency) flood discharges during subsequent peak flooding months. Flood releases during February, timed to the historical period of peak flooding, would have only a minor effect on the magnitude and frequency of emergency flood discharge.

3.4 Description of change levels for 1:5 flooding event

For the 1:5 year flood, one change level was considered, *viz*. reinstating the 1:5 year flood.

3.4.1 Pre-dam (reference) condition

During the 28-year period prior to Zambezi River regulation, the historical one in five year probability flooding event was approximately 13,000 m^3/s in magnitude. These large floods result in widespread deep inundation over most of the Zambezi Delta, especially during years of above-average local rainfall (which are highly correlated to large regional flooding events). Since 1930 eight floods have exceeded this magnitude, including the recent 2001 flood (estimated maximum discharge of 13,500

m^3/s), which serves to illustrate delta flooding patterns for the purposes of the present study.

The following observations were recorded during and following the 2001 flood:

- The floodplain fishery was highly productive, with hundreds if not thousands of people involved in catching, drying, transporting, and selling fish from the floodplains. In addition to local fish sales, a secondary market was established selling dry fish up to Malawi. Locals noted that it was the best fish harvest in more than 20 years.
- Floodwaters discharged through the Salone depression upstream of Marromeu into the central floodplains (the Marromeu Buffalo Reserve). The reserve also was inundated by floodwaters spilling overbank downstream of the region confined by dykes.
- Cape buffalo in the central floodplains were stranded on small islands of high ground. Many adults starved and calves drowned during the high water period. There appeared to be little or no movement from the floodplain to high ground on the escarpment.
- Sediments deposition was extensive on the Zambezi floodplains, destroying farm fields and reducing crops during the 2001 dry season but, according to local farmers, creating very favourable growing conditions for the 2002 dry season.
- Palms and acacias invading the upper floodplain were inundated for a prolonged period of time. Established adult palms and acacias appeared to have survived this period of inundation; seedlings and young plants may have been reduced but pre-flood data on the distribution of individual plants is not available.
- Thousands of people fled to high ground during the floods. Many people refused to leave their homes on the Zambezi banks and sandbar islands during the early stages of flood rise, but were later evacuated during the period of rapid flood rise. Many evacuees resisted evacuation, arguing that such large flood peaks no longer occurred because of Cahora Bassa.
- Expected outbreaks of cholera or other disease at resettlement camps were not reported.
- Local roads were severely damaged.
- The rebuilt dykes around Marromeu protecting the Sena Sugar fields did not overtop, but the dilapidated dykes around Luabo overtopped.

The 2001 flood resulted from a maximum discharge of 9032 m^3/s from Cahora Bassa Dam combined with downstream tributaries contributing more than 4100 m^3/s. Maximum inflows to Cahora Bassa Dam during the 2001 flood peaking at 13,797, a discharge that, if passed downstream, would have generated a delta flood of nearly 18,000 m^3/s. In fact, if Kariba Dam had not attenuated the flood peak, maximum flood discharges may have exceeded 19,000 m^3/s. Floods of this magnitude occurred only twice in the 28-year record prior to river regulation. Such floods are considered to be catastrophic by the delta population and are permanently fixed in the collective cultural memory of the delta (Beilfuss 2001).

It is important to note that large flooding events in the delta now are heavily influenced by reservoir operation. In addition to attenuating (capturing) the unregulated 1:5 and 1:10 year floods, the dams alter the hydrological characteristics of larger flood events that cannot be fully controlled due to insufficient storage capacity. During 2001, dam managers stored Zambezi River inflows to Cahora Bassa Dam throughout the flood cycle until reaching reservoir storage capacity in late February. Releases were then stepped up as water gates were opened over a series of days. When maximum inflows to the reservoir occurred on February 22, corresponding outflow was only 4739 m^3/s. As the reservoir filled, discharges were quickly stepped up over a two-week period until reaching the peak discharge on March 7. Thus floods attenuated by Cahora Bassa Dam are characterized by a more rapid rise and recession than unregulated river floods. This has adverse implications for downstream people and ecosystems, which have very little time to adjust to incremental increases in discharge. This was particularly extreme during the 1978 flood, when discharges increased over a two-week period to more than 14,700 m^3/s and resulted in extensive property damage and loss of life downstream. Coordinated management between Kariba and Cahora Bassa Dams has significantly improved since that time.

3.5 Modeling trade-offs between hydropower generation and annual flood releases for meeting hydrological change levels

To examine the availability of water for prescribed flood releases from Cahora Bassa Dam to create the DRIFT Annual Flood Change Levels described above, we adapted the HEC-5 model, *Simulation of flood control and conservation systems*, to model the Zambezi River system. The HEC-5 computer model was developed by the Hydrological Engineering Center of the U.S. Army Corps of Engineering. HEC-5 is a multi-purpose, multi-reservoir routing program that enables the modeling of complex river-reservoir systems in considerable detail, using a simple water balance approach. Model design, parameters, assumptions, and sensitivity testing are described in detail in Beilfuss (2001) and Li-EDF-KP Joint Venture Consultants (2001):

3.5.1 Goals

Hydrological models were developed to address three project goals:

- Assess the likelihood that each Annual Flood Change Level (described above) can be achieved, based on water availability in the catchment and requirements for hydropower generation (measured as outflow target reliability relative to conventional dam operation).
- Assess the affect of each Annual Flood Change Level on firm power generation.
- Assess the affect of each Annual Flood Change Level on total annual energy production.

3.5.2 Cahora Bassa parameters

The total installed capacity of the Cahora Bassa Power Station is 2075 MW. The generating head depends on the relative water levels in the reservoir and tailrace sections. Reservoir levels are based on fixed elevation-storage-area-outlet capacity relationships. Tailrace levels are based on specific stage-discharge relations. Firm power is estimated as 1370 MW continuous, based on a 95% reliability criterion used in the estimating Cahora Bassa outflows for the Mepanda Uncua Dam design studies.

Cahora Bassa outflows are governed by these hydropower generation requirements and a Design Flood Rule Curve, whereby the reservoir water levels are drawn down prior to each rainy season to provide additional capacity for safely storing and passing the design flood. Spillway discharges are based on all eight gates fully opened, with the crest gate operating for reservoir elevations above 327.0 m. Minimum water releases for social or environmental purposes are not stipulated for the baseline Cahora Bassa Dam model, but are modeled explicitly as different prescribed flooding scenarios. Water diversions by downstream communities are considered to be insignificant relative to total Zambezi flows, and are not modeled explicitly.

3.5.3 Simulation models

Water availability for prescribed flood releases from Cahora Bassa Dam depends on runoff from the entire Zambezi catchment upstream. Two models were developed to assess inflows and the potential for target flood releases, based on historical long-term inflow data, as described below. Note that we did not address climate change in these preliminary simulation models. Although predictions over the past five years have consistently indicated there is significant risk of reduced run-off in the river basin (R. Douthwaite, pers. comm..), we decided that it was most useful at this stage to run the models using existing data sets already accepted and in use by the water management authorities (HCB, DNA, ARA-Zambeze)

Inflow Model 1

Inflows to Cahora Bassa Reservoir were simulated using natural runoff from the entire Zambezi River catchment (Figure 3.3), using measured and reconstituted monthly flows for the period 1907-1998. The model routes the following inflows into Cahora Bassa reservoir:

- Runoff from the Upper Zambezi catchment and part of the Middle Zambezi catchment routed through Kariba reservoir;
- Runoff from the Kafue River catchment routed through Itezhitezhi and Kafue Gorge reservoirs and the Kafue Flats and into the Zambezi River below Kariba Dam; and
- Runoff from part of the Middle Zambezi catchment below Kariba Dam (most notably the Luangwa River) routed and into the Zambezi River above Cahora Bassa Reservoir.

The data set is the same as data used by Li-EDF-KP Joint Venture Consultants (2001). The model runs will be repeated after additional data is provided by the Zambezi River Authority to update this flow series through 2005.

Inflow Model 1 enables the following analysis:

- Assessment of firm power generation and total energy production that could have occurred over the period of record for different target outflows;
- Assessment of the full range of climatic conditions in the Zambezi basin as occurred over the past century, which may be considered representative of the expected range of future Zambezi catchment flows (unless there is a significant shift in run-off related to climate change, see note above); and
- Assessment of the effects of different Kariba and Itezhitezhi-Kafue Gorge Dam operation rules on outflow potential and hydropower generation from Cahora Bassa Dam, including opportunities for conjunctive management of upstream dams.

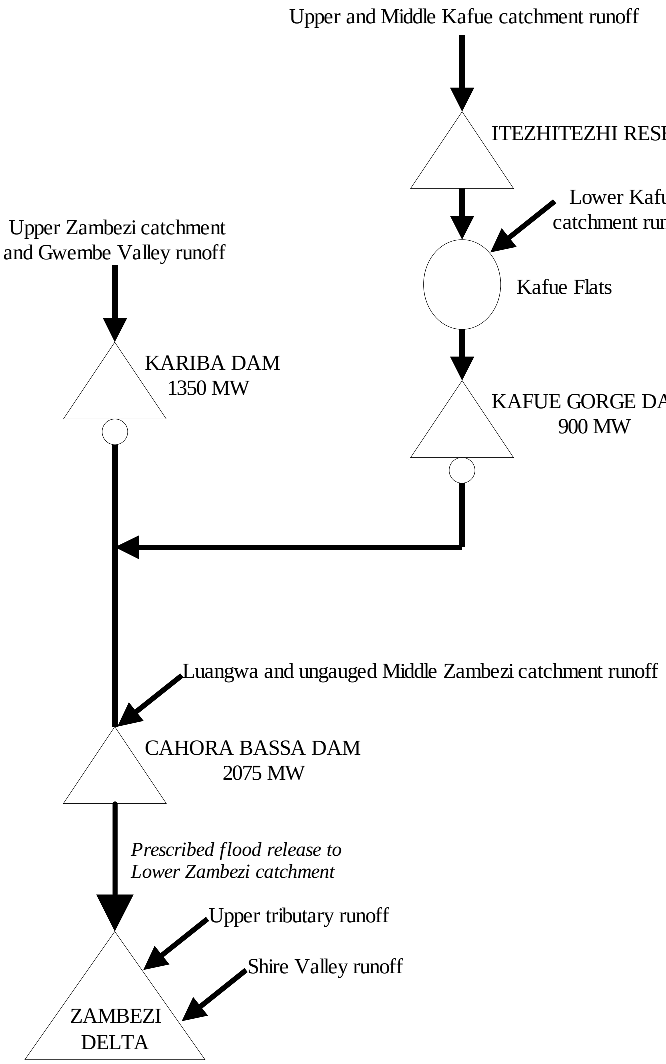


Figure 3.3 Schematic diagram of Inflow Model 1 for the Zambezi River catchment, using 1907-1998 daily flow data.

Inflow Model 2

Inflows to Cahora Bassa Reservoir were simulated using actual daily inflows to Cahora Bassa Dam for the period since the dam was in operation, 1974-2004 (Figure 3.4). We did not simulate operation of upstream dams as in Model 1, but rather used the measured regulated outflows as occurred over this period. These data were provided by the Direcçao Naçional de Aguas (DNA) and Hidroeléctrica de Cabora Bassa (HCB).

This model enables the following analysis:

- Assessment of firm power generation and total energy production that could have occurred over the period since Cahora Bassa Dam was constructed, if the dam had been able to operate a full capacity;
- Assessment of the range of different target outflows that could have occurred

(target outflow reliability) over the period since Cahora Bassa Dam was constructed, especially noting that this period includes substantially reduced Zambezi runoff (caused by the prolonged southern Africa drought from 1980-95) relative to the full historic record of Model 1; and

Assessment of the affects of actual Kariba and Itezhitezhi-Kafue Gorge Dam operation on outflow potential and hydropower generation from Cahora Bassa Dam, assuming that upstream dams operate independently.

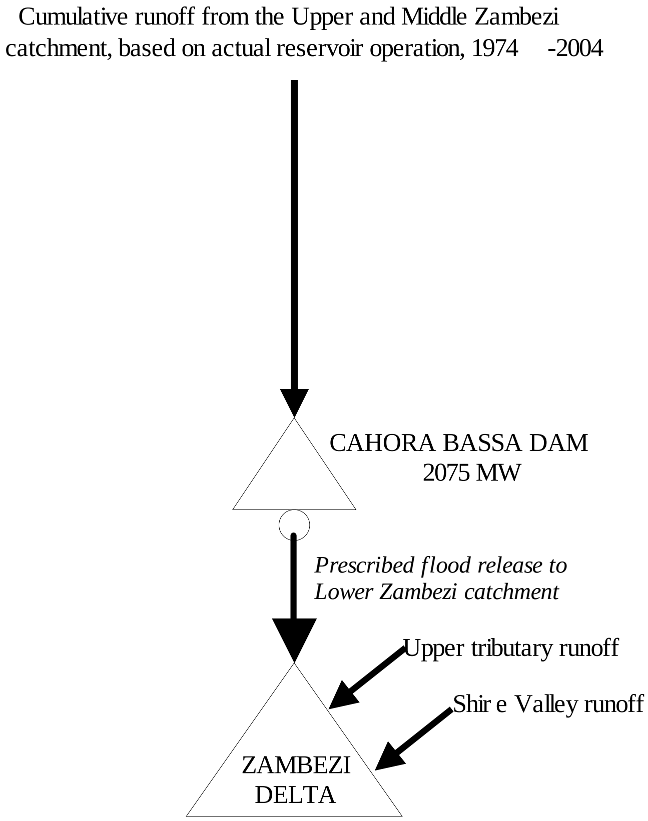


Figure 3.4 Schematic diagram of Inflow Model 2 for the Zambezi River catchment, using 1974-2004 daily flow data.

3.5.4 Model scenarios

Target outflows correspond to the different DRIFT Annual Flood Change Levels (target outflows) described above. Both models were designed to force the release of target outflows from Cahora Bassa Dam each year as long as sufficient water is available in the reservoir above the dead storage level. Outflows are a combination of turbine discharges (with hydropower generation) and sluice gate spillage.

The previous modeling study by Beilfuss (2001, in prep a) examined target outflows designed to mimic historical (pre-regulation) mean monthly flooding patterns and the potential to generate short-duration, high volume flood releases on a monthly or semi-monthly basis. Modeled historical outflows corresponded to mean annual flows for the four peak flooding months (January-April), the first three (January-March) and second three (February-April) peak flooding months, and the two peak flooding months of February and March. Short-duration, high volume outflows of 3000 m^3/s, 4000 m^3/s and 5000 m^3/s were modeled for January. For February and March, outflows of 3000 m^3/s, 4000 m^3/s, 5000 m^3/s, 6000 m^3/s, 7000 m^3/s, and 8000 m^3/s were modeled. To allow for reduced flood releases when reservoir levels reach a critical lower threshold (i.e., corresponding to drought periods. Beilfuss (2001, in prep a) modeled three additional scenarios as *desired outflows*. The model curtails releases when reservoir levels fall below the reservoir buffer level (designated in the model as 316 m, or 10 m below the Full Supply Level).

Results from this previous study suggested that the full suite of Annual Flood Change Levels could be modeled within the limits of water availability in the catchment and requirements for hydropower generation. We therefore modeled each of the 18 target outflows designated for the DRIFT model, plus the baseline case (no target outflow), for Inflow Model 1 and 2 (Table 3.1).

Target outflows from Cahora Bassa Dam were calculated as the difference between the required flows in the Zambezi Delta (corresponding to each Annual Flood Change Level) and tributary contribution below Cahora Bassa Dam. Estimated downstream tributary contribution was calculated as the sum of inflows from the Luia, Revuboe, Luenha, and Shire Rivers, which contribute more than 90% of lower Zambezi runoff. Revuboe and Shire River flows were calculated from river gauging data, Luia River flows were modeled from Revuboe River flows, and Luenha River flows were estimated from a rainfall-runoff model.

Table 3.1 Cahora Bassa discharges simulated to achieve each of the DRIFT Annual Flood Change Levels in the Zambezi Delta, based on the specified timing and duration of target flows and downstream tributary contribution.

Change Level	**Zambezi Delta flow (m^3/s)**	**CB Discharge (m^3/s)**	**Timing**	**Duration**	**Downstream tributary inflow (m^3/s)**
Baseline	Not specified	Not specified	Not specified	Not specified	Varies
1	4500	3700	Dec	2 weeks	800
2	4500	3700	Dec	4 weeks	800
3	4500	2750	Feb	2 weeks	1750
4	4500	2750	Feb	4 weeks	1750
5	4500	3375	Dec+Jan	8 weeks	1125
6	4500	2825	Feb+Mar	8 weeks	1675
7	7000	6200	Dec	2 weeks	800
8	7000	6200	Dec	4 weeks	800
9	7000	5250	Feb	2 weeks	1750
10	7000	5250	Feb	4 weeks	1750
11	7000	5875	Dec+Jan	8 weeks	1125
12	7000	5325	Feb+Mar	8 weeks	1675
13	10,000	9200	Dec	2 weeks	800
14	10,000	9200	Dec	4 weeks	800
15	10,000	8250	Feb	2 weeks	1750
16	10,000	8250	Feb	4 weeks	1750
17	10,000	8875	Dec+Jan	8 weeks	1125
18	10,000	8325	Feb+Mar	8 weeks	1675

3.5.5 Model results and discussion

Tables 3.2 and 3.3 show results for the Inflow Model 1 and 2, respectively. For each Annual Flood Change Level, we generated firm power output for each month (Inflow Model 1) or day (Inflow Model 2), and calculated firm power reliability as the percentage of months or days, respectively, out of the total that firm power requirements are met or exceeded. We calculated total power output as the mean of the annual total power generated for each inflow series. Target outflow reliability is calculated as the percentage of years in which outflows met or exceeded the specified flood release conditions, through a combination of turbine and sluice gate discharges. The percentage of years that these outflow levels occur under baseline conditions (with no target outflows) is also given for each case study. For example, for Model 1 with the current firm power level of 1370 MW, a continuous release of 5250 m^3/s during two weeks in February (Annual Flood Change Level 9) is possible in 86 years out of the 91-year time series (95.4% reliability). Under present operating procedures (baseline) this same outflow level would have occurred in only 3 out of the 91-year time series (3.3%). Firm power output corresponding to this Annual Flood Change Level is 95.8% (above the typical 95% threshold for maintaining present firm power contracts). Average power production is 14064 GWH/annum, a 2.3% reduction compared to the baseline case.

Table 3.2 Target outflow reliability, baseline outflow reliability, firm power reliability, total annual energy production, and energy production as a percentage of baseline production for different Annual Flood Change Levels using simulated monthly inflows from the Zambezi River catchment over the period 1907-1998 (Inflow Model 1). See text for definition of terms.

Change Level	Target outflow reliability (%)	Baseline outflow reliability (%)	Firm power reliability (%)	Energy production (GWH/annum)	Energy as % of baseline
Baseline	--	--	98.4	14,393	100.0
1	95.6	85.7	97.3	14,333	99.6
2	94.5	58.2	96.7	14,273	99.2
3	97.8	7.7	97.3	14,407	>100.0
4	97.8	7.7	97.1	14,357	99.7
5	92.3	42.9	94.2	14,083	97.8
6	95.6	2.2	95.1	14,355	99.7
7	94.5	29.7	96.2	14,186	98.6
8	89.0	2.2	92.9	13,722	95.3
9	94.5	3.3	95.8	14,064	97.7
10	91.2	3.3	92.5	13,637	94.7
11	72.5	4.4	89.7	13,112	91.1
12	78.0	1.1	83.9	12,963	90.1
13	89.0	5.5	93.3	13,801	95.9
14	78.0	0.0	90.9	13,067	90.8
15	90.1	2.2	92.2	13,612	94.6
16	83.5	1.1	90.0	12,993	90.3
17	24.2	0.0	87.0	12,575	87.4
18	25.3	0.0	68.0	12,018	83.5

For both inflow models, there is an inverse relationship between hydropower production and the magnitude and duration of flooding, as expected. Flow release targets in February can be met more reliably than in December, with slightly high firm power and energy production levels. However, both models reflect tremendous potential for meeting a range of target outflows without a substantial reduction in hydropower production.

Table 3.3 Target outflow reliability, baseline outflow reliability, firm power reliability, total annual energy production, and energy production as a percentage of baseline production for different Annual Flood Change Levels using actual daily inflows to Cahora Bassa Dam over the period of dam operation, 1974-2004 (Inflow Model 2). See text for definition of terms.

Change Level	Target outflow reliability (%)	Baseline outflow reliability (%)	Firm power reliability (%)	Energy production (GWH/annum)	Energy as % of baseline
Baseline	--	--	92.0	13,028	100.0
1	82.8	44.8	89.7	12,892	99.0
2	75.8	20.7	88.5	12,739	97.8
3	93.1	13.8	88.5	12,959	99.5
4	93.1	6.9	88.2	12,895	99.0
5	69.0	10.3	85.9	12,624	96.9
6	58.6	3.4	81.9	12,733	97.7
7	75.9	3.4	87.4	12,584	96.6
8	62.1	0.0	83.0	12,080	92.7
9	86.2	6.9	85.6	12,556	96.4
10	79.3	3.4	82.2	12,173	93.4
11	37.9	0.0	73.6	11,671	89.3
12	48.3	3.4	58.0	11,230	86.2
13	65.5	0.0	85.1	12,189	93.6
14	41.4	0.0	77.0	11,636	89.3
15	79.3	3.4	82.2	12,153	93.3
16	44.8	0.0	67.0	11,267	86.5
17	24.1	0.0	72.1	11,391	87.4
18	27.6	0.0	48.3	10,585	81.2

Over the 91-year historic flow series (Inflow Model 1), ten of the 18 Annual Flood Change Levels can be achieved with less than 5% reduction in annual energy production. Current firm power production (1370 MW) can be maintained at the 95% or higher reliability level for Annual Flood Change Levels 1-4, 6-7, and 9, covering a range of small and medium-size annual flood releases including an 8-week continuous discharge of 4500 m^3/s in February-March. Of particular note are Change Levels 3 and 4 (2-week and 4-week flows of 4500 m^3/s in the Zambezi Delta), which can be achieved in nearly all years (97.8% reliability) with almost no appreciable reduction in firm power reliability (<1.3%) or power production (<0.3%). During this same period, conventional outflows from Cahora Bassa Dam produce this level of flooding in only 7.7% of all years. Large annual floods of 10,000 m^3/s in the delta, extremely rare under conventional river regulation, can be reliably generated for two-weeks in December and February with <7% power reduction and firm power levels of 93.3% and 92.2%, respectively. In all scenarios, target outflow reliability substantially exceed baseline outflow reliability.

The 91-year record captures the range of climatic fluctuations over the past century, including the extended drought during the 1980s and early 1990s. Extension of the data series to include the most recent inflows (1999-2004) will incorporate the latest period of higher runoff into the model, with the expected increase in target outflow reliability, firm power reliability, and total energy production corresponding to each Annual Flood Change Level.

The effects of different Kariba and Itezhitezhi-Kafue Gorge Dam operation rules on outflow potential and hydropower generation from Cahora Bassa Dam was investigated in Beilfuss (2001). Target outflows from Cahora Bassa can be achieved with higher reliability and a smaller reduction in hydropower generation if outflows are coordinated with Kariba Dam management. Furthermore, hydropower generation for the Southern Africa Power Pool offers opportunities for coordinated management of energy sources to meet regional power demands without the need to maximize production at individual generating facilities.

During the more recent period of inflows (1974-2004) used for Inflow Model 2, Cahora Bassa Reserve levels decreased to dead storage level at the present 1370 MW firm power commitment level and output was significantly curtailed. In the baseline case, firm power reliability was only 92.0%, and average energy production over this period (13,028 GWh/yr) was 9.5% lower than energy production over the 91-year data series (Model 1). Clearly, the current level of firm power production could not have been sustained, even if Cahora Bassa had been operating at full capacity, during this period.

Despite the lower energy potential of this period resulting from reduced runoff from the Zambezi catchment, a surprising array of reliable outflows could have been generated with minimal reduction in hydropower. Annual Flood Change Levels 1, 3, and 4 could have been generated with <1% hydropower reduction, and eight scenarios covering small and medium annual floods were possible with <5% reduction. Change Levels 3 and 4 could have been achieved in 27 of 29 years (93.1% reliability) with almost no reduction in power production (<0.5%).

Modeling results are particularly noteworthy given the operation of Kariba Dam (which controls 63% of Zambezi runoff into Cahora Bassa Dam) over this time period. Kariba released only a constant turbine discharge, with no sluice gate flood releases, over a 20-year period from 1981-2000. The results highlight the importance of inflows from the Luangwa and other unregulated rivers in the Middle Zambezi catchment (22% of Zambezi runoff) for meeting outflow targets from Cahora Bassa Dam.

Future development of Cahora Bassa North Bank or downstream Mepanda Uncua Dam may affect the availability of water for prescribed flood releases from Cahora Bassa Dam. The impact of these structures must be further investigated once final design criteria are approved. Regardless of future river development, however, Cahora Bassa will remain the most important structure for meeting environmental flow targets in the lower Zambezi system.

The Design Flood Rule Curve currently in use by Hidroeléctrica de Cabora Bassa (HCB) was used to govern maximum allowable water levels in the reservoir. Previous model sensitivity tests revealed that the choice of flood rule curve has a very significant effect on power generation at Cahora Bassa Dam. For example, a Flat Rule Curve with a constant end-of-month water level of 326 m results in significantly higher levels of firm power reliability and total power generation than the current Design Flood Rule Curve. This relationship holds across the range of possible firm power target levels. Li-EDF-KP Joint Venture Consultants (2001) proposed that construction of additional spillway capacity at Cahora Bassa should coincide with the construction of any future downstream run-of-river dams such as Mepanda Uncua.

A hydrological monitoring network, flood warning system, and flood awareness program are essential for the implementation of prescribed flow releases in the Lower Zambezi catchment. At a minimum, improved river gauging and accurate stage-discharge curves are needed for the mainstem Zambezi River downstream of Tete (most notably at Caia and Marromeu, and on the Lower Shire River). The requirements for an effective flood warning system were first described by Rendel

Palmer and Tritton Consultants (1979) following catastrophic flood releases without warning from Cahora Bassa Dam in 1978. The flood warning system employed during the 2001 floods in the Lower Zambezi catchment, as well as improved communication with Kariba Dam operators, reflect significant improvements in the flood warning system. Further, a flood awareness program would be necessary for local inhabitants along the length of the lower Zambezi system to enable them to best utilize flood releases for economic and social gain, and without personal harm.

3.5.6 Conclusions

Hydrological modeling studies provide several important insights about the potential for achieving environmental flow targets in the Zambezi Delta.

1. As noted from previous research, efforts to recreate the historical flood hydrograph for the lower Zambezi system by designing flood releases to match historical mean monthly flows over a 4-month, 3-month, or even 2-month period are not possible without substantial reductions in hydropower output. Similarly, Annual Flood Change Levels of large magnitude and long duration cannot be generated without substantial reductions in hydropower generation.
2. Some immediate improvement in the Zambezi Delta flow regime could be made with no impact on hydropower production. Over the long-term record, a two-week release in February to generate flows of 4500 m^3/s in the Zambezi Delta (Change Level 3) could be achieved in 97.8% of all years, but would occur in only 7.7% of years if current dam operation practices continue. This outflow would be achieved with 97.3% firm power reliability and no reduction in hydropower generation.
3. Many Annual Flood Change Levels can be reliably achieved with minimal reductions in power generation. All of the small Annual Flood Change Levels (4500 m^3/s) and several of the medium Annual Flood Change Levels (7000 m^3/s) can be achieved within the constraints of firm power commitments. Several of the large Annual Flood Change Levels (10,000 m^3/s) can be achieved with only modest reductions in hydropower (<7%). Previous modeling research further suggests that firm power reliability and total energy generation for a given Annual Flood Change Level can be substantially improved by establishing minimum reservoir elevation thresholds for releasing water.
4. In all cases, management for targeted outflows results in significantly more reliable flood generation in the Zambezi Delta compared to conventional reservoir operation.
5. Flood Change Levels could be attained with less impact on hydropower generation through improved allocation of waters throughout the Zambezi basin, especially coordinated management with Kariba Dam outflows and power generation. However, there is substantial opportunity for generating Annual Flood Change Levels even with current level of regulated inflows to Cahora Bassa Dam, as evidenced by Model 2 results.

4. Background - Zambezi Delta Mass Transfer Model

4.1 Introduction

The exercise described in this report sought to explore the implications of different flow regimes at the apex of the Zambezi Delta on a range of resource users in the Delta system. For many of these resources, the flow regime at the apex of the Delta was not the primary consideration for assessing the condition; rather the primary determinant is the manner in which this inflow distributes itself across the system. Understanding these patterns of water flow and distribution across the Delta requires the use of an analytical tool to translate a given flow rate at the apex of the Delta into conditions across the Delta over time. The Zambezi Delta Mass Transfer (ZDMT) Model was developed to provide this information.

The ZDMT Model lies on a continuum of modeling approaches that range from simple statistical or anecdotal models up to complex fully distributed physical process models. Figure 4.1 places the ZDMT Model, which is a lumped parameter quasi-physical model, on this continuum

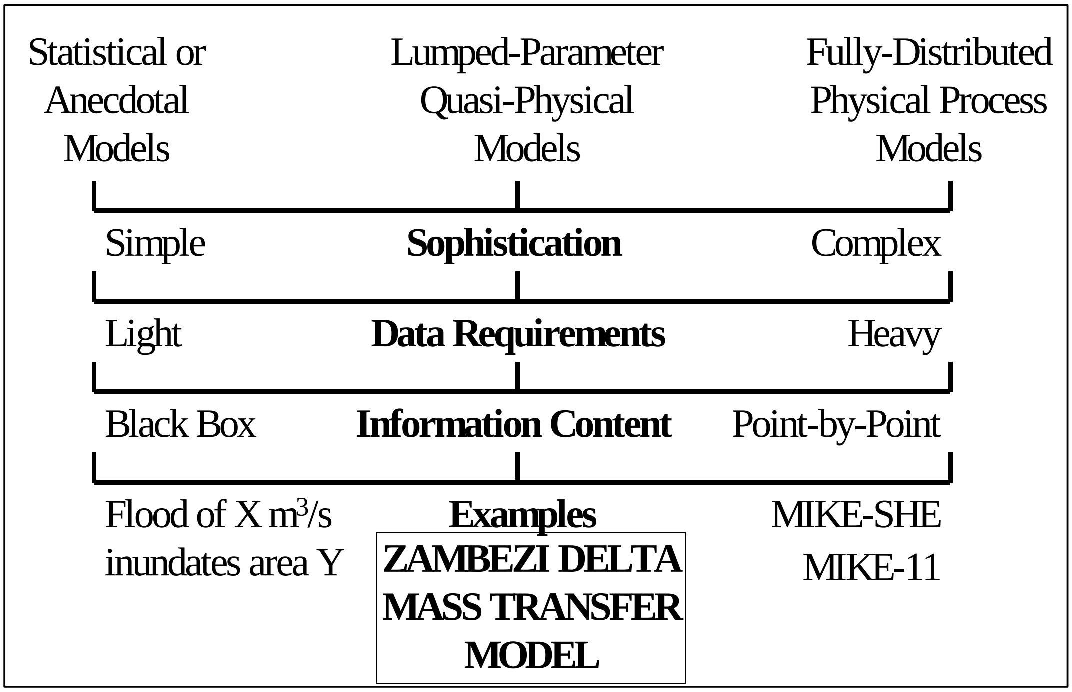


Figure 4.1 Continuum of Delta modeling approaches.

This intermediate approach was adopted because data on the hydraulic configuration and hydrologic condition of the Zambezi Delta is somewhat limited. A lumped-parameter model that utilizes the information that is available can generate results that are useful in the short-term, and provide a framework that can be refined and improved as more information on the system becomes available. As such, the goals of the ZDMT Model development effort were to:

- Develop a model that translates Delta inflow into estimates of water flow and distribution within the Delta.
- Provide model output to the DRIFT specialists for use in their analysis.
- Assess the data gaps that exist in terms of refining a model of water flow and distribution within the Delta.

The output from the model was been provided to the resource specialist to assist in the final preparation of ratings associated with various change levels (see Appendix A).

4.2 Technical Approach

The ZDMT Model works on the principle of mass conservation as it partitions the flow of water arriving at the apex of the Delta along potential flow paths that pass through a series of computational units. The basic structure of the partitioning pathways is shown in Figure 4.2, which also serves as the interface for the ZDMT Model. Based on the assumed DRIFT change level, water arrives at the large arrow in the upper left-hand corner of the figure. From this point the ZDMT Model directs water along one of several pathways as it moves through the Delta towards the Indian Ocean in the lower right-hand corner of the figure.

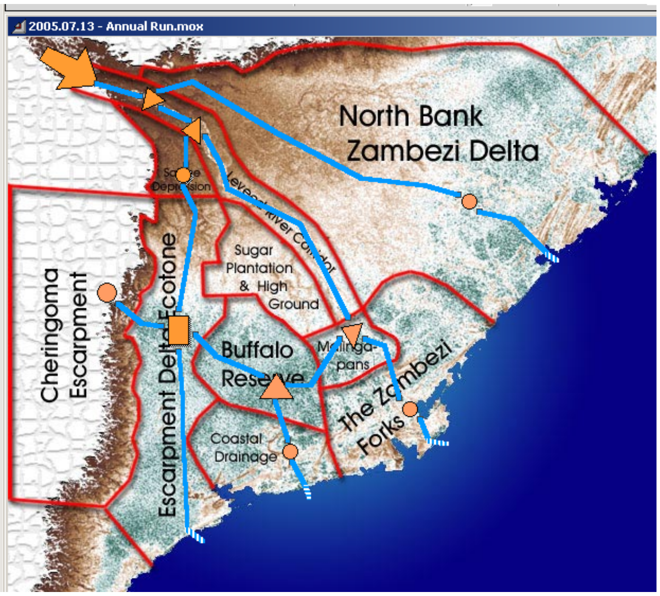


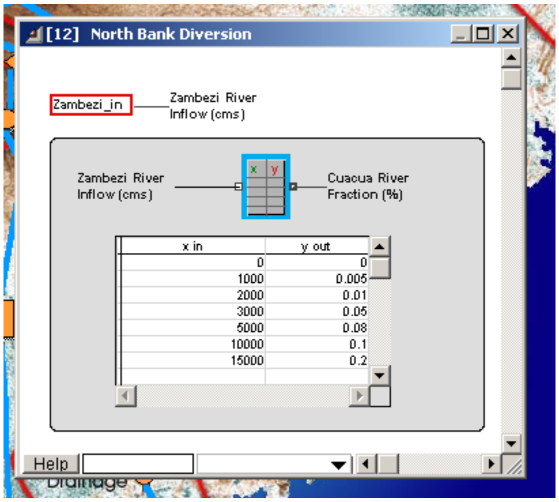
Figure 4.2 ZDMT model structure and interface.

The partitioning and redirecting of water arriving at the Apex of the Delta is accomplished by using simple hydraulic representations of the flow connections between the various computational units. These hydraulic representations are intended to mimic the presence of side channels, flow impeding structures such as culverts or trellises, and the micro-topology that directs shallow overland flow on the Delta floodplain. The information in Table 4.1 describes how each computational area is related to those upstream and downstream in the simulated flow path.

Table 4.1 Hydraulic/Hydrologic characterizations in the ZDMT model.

Routing Point	Inflows	Outflows	Outflow Control	Internal Hydrology
Delta Apex	• Cahora Bassa releases • Zambezi tributary flows	• Mainstem Zambezi River	• none	no
Cuacua Divergence	• Mainstem Zambezi River	• North Bank Zambezi Delta • Mainstem Zambezi River	• Discharge- divergence relationship • none	no
Salone Divergence	• Mainstem Zambezi River	• Salone Depression • Mainstem Zambezi River	• Culvert equation • none	no
Salone Depression	• Salone Divergence	• Escarpment Delta Ecotone	• Culvert equation	no
Escarpment Delta Ecotone	• Salone Depression • Cheringoma Runoff	• Buffalo Reserve • Indian Ocean	• Broad crested weir equation • none	yes
Malingapans	• Mainstem Zambezi River	• Buffalo Reserve • Zambezi Forks (India Ocean)	• Broad crested weir equation • none	yes
Buffalo Reserve	• Escarpment Delta Ecotone • Malingapans	• Coastal Drainage (Indian Ocean)	• Broad crested weir equation	yes

Figures 4.3-4.5 depict how the various hydraulic controls are represented in the ZDMT Model. A mass transfer based on a discharge-divergence relationship partitions a defined percentage of the flow in a river to a divergence channel. In the case of mass transfer between the mainstem Zambezi River and the Cuacua River divergence channel, the percentage increases as the flow in the mainstem Zambezi increase (Figure 4.3). A mass transfer based on a culvert equation relies on simple hydraulic expression that related the standing head upstream of a culvert to the discharge though the culvert. This type of expression is appropriate for flows into and out of the Salone Depression as these are controlled by culverts through levees, roads, and railway lines (Figure 4.4). A mass transfer based on a broad crested weir equation relies on a simple hydraulic expression that relates the standing head upstream of a long weir to the flow over the weir. This type of expression is appropriate when there is a long, continuous feature of micro-topography that separates an upstream computational unit from on located downstream along a Delta flow path (Figure 4.5). All this relationships are quasi-physical simplifications of the very complicated flow paths which water follows as it moves across the Delta from the Apex to the Indian Ocean (Figure 4.6).



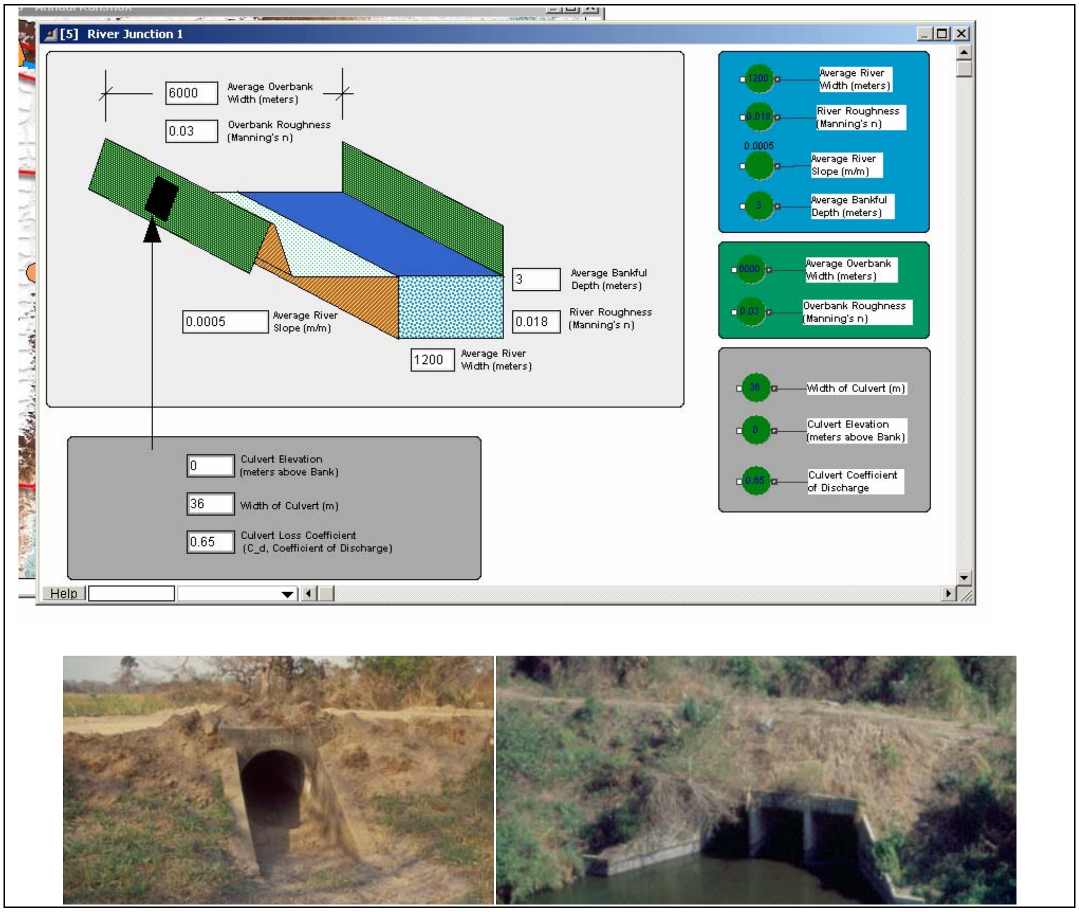
[12] North Bank Diversion

Zambezi_in — Zambezi River Inflow (cms)

Zambezi River Inflow (cms) — Cuacua River Fraction (%)

x in	y out
0	0
1000	0.005
2000	0.01
3000	0.05
5000	0.08
10000	0.1
15000	0.2

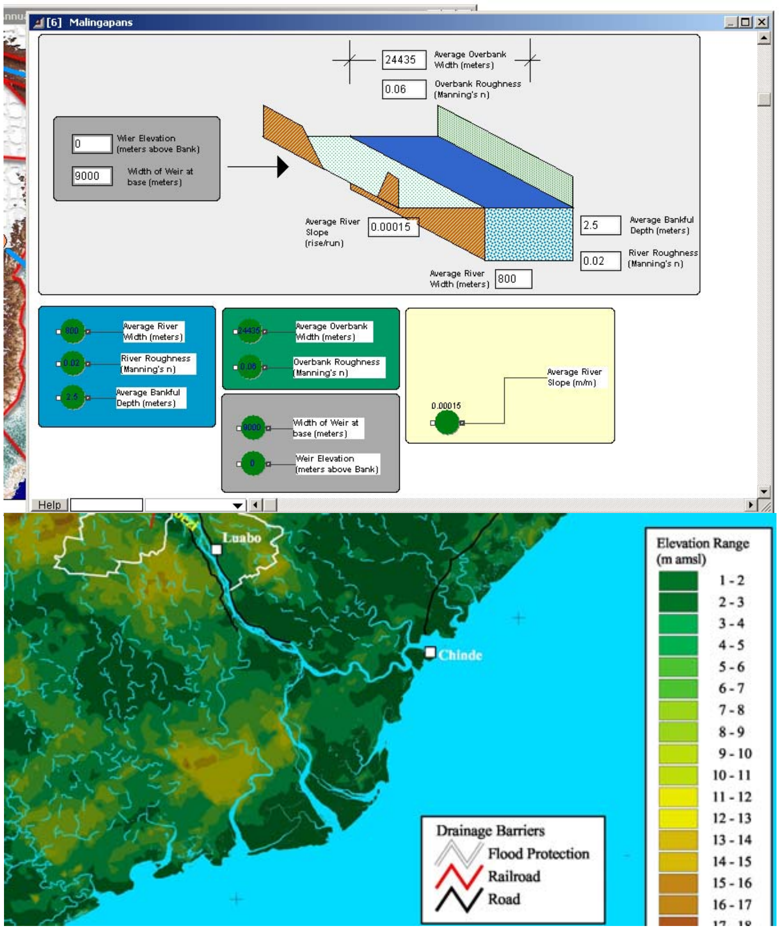
Figure 4.3 Discharge-divergence relationship between the mainstem Zambezi River and the Cuacua River.



[5] River Junction 1

Average Overbank Width (meters): 6000
Overbank Roughness (Manning's n): 0.03
Average Bankful Depth (meters): 3
River Roughness (Manning's n): 0.018
Average River Slope (m/m): 0.0005
Average River Width (meters): 1200
Culvert Elevation (meters above Bank): 0
Width of Culvert (m): 36
Culvert Loss Coefficient (C_d, Coefficient of Discharge): 0.65

Figure 4.4 Culvert equation relationship between the mainstem Zambezi River and the Salone Depression (photos by R. Beilfuss).



Average Overbank Width (meters): 24435
Overbank Roughness (Manning's n): 0.06
Wier Elevation (meters above Bank): 0
Width of Weir at base (meters): 9000
Average River Slope (rise/run): 0.00015
Average Bankful Depth (meters): 2.5
River Roughness (Manning's n): 0.02
Average River Width (meters): 800

Average River Width (meters): 800
River Roughness (Manning's n): 0.02
Average Bankful Depth (meters): 2.5
Average Overbank Width (meters): 24435
Overbank Roughness (Manning's n): 0.06
Width of Weir at base (meters): 9000
Weir Elevation (meters above Bank): 0
Average River Slope (m/m): 0.00015

Figure 4.5 Broad Crested Weir Relationship (e.g. between Malingapans and the Buffalo Reserve).

Figure 4.6 Complex flow paths in the Zambezi River Delta (photos by R. Beilfuss)

Figures 4.4 and 4.5 also depict the stylised relationship between channel flow and flow on the floodplain. The parameters used to describe the rectangular channel determine the flow rate at which water will overflow the main channel. At flow rates above this bank full level, the parameters used to describe the flat and rectangular floodplain contribute to the determination of the depth of inundation on the floodplain.

Where Table 4.1 refers to internal hydrology, it refers to the presence or absence of a routine to account for the contribution of local rainfall to floodplain inundation in a computational unit. This routine uses a simple soil moisture accounting approach to allow water on the floodplain to infiltrate and to potentially be depleted through evapotranspiration and sub-surface drainage up to soil saturation, at which point floodplain inundation is initiated. This routine is also used to estimate the surface water runoff entering the Escarpment Delta Ecotone from the adjacent Cheringoma Plateau.

Additional salient technical details of the ZDMT Model are provided in the following list.

- Developed in the EXTEND programming environment.
- Weekly time-step.
- One-year simulation using average inflows recorded since the construction of Cahora Bassa Dam.
- “Calibrated” to anecdotal model of 2001 flood event.
- DRIFT change levels imposed on average inflows.

While the model can be manipulated and run in the EXTEND Player environment, it cannot be modified outside of the EXTEND programming environment.

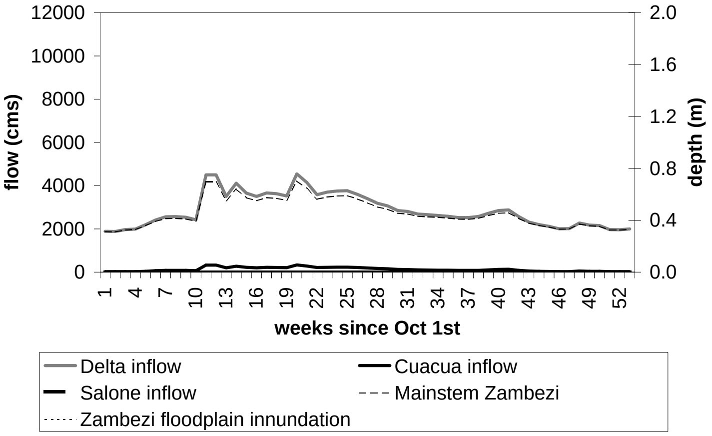
4.3 Results

Figures 4.7 through 4.12 depict the flow at various points along the Mainstem Zambezi River as if moves past the Cuacua and Salone Divergences. Recall the flow to the Cuacua and on through the North Bank Zambezi Delta are regulated via a discharge-divergence relationship. Flow into the Salone Depression is controlled by a culvert equation. In the ZDMT Model, the equations used to describe mass transfer through the culverts create a sever flow impediment, limiting flow to the Salone Depression, even under the largest and must sustained high flow events. The figures also reflect the fact that the parameters describing the main channel of the Zambezi River are set such that all flow up to 4500 cm/s is contained within the main channel. Floodplain inundation within the Mainstem Zambezi River system occurs only at higher flow rates and the simulated level of inundation is fairly linear with respect to the flow rate.

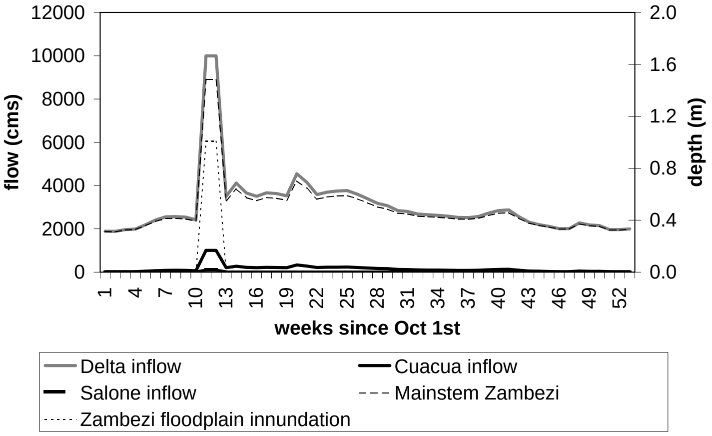
More interesting is the simulated level of inundation at other parts of the Delta. These results are shown in Figures 4.13-4.18 (inundation in the Buffalo Reserve is expressed in terms of area). Here the interaction between flooding associated with high flow on the Zambezi River and the impact of rainfall induced local flooding creates a non-linear response. As the duration of high flows increases, there is also a non-linear response in terms of inundation, particularly when the high flows coincide with the period of heavy rainfall during the months of December and January. The level of inundation in the Buffalo Reserve under different change levels is summarized in Figure 4.19.

Figure 4.20 depicts the levels of outflow from the Escarpment Ecotone to the Indian Ocean under the different change levels. This pathway seems to be heavily influenced by the timing and duration of high flow events on the Zambezi River without a great deal of non-linear variability in terms of the magnitude, timing, and duration of high flow events.

Change Level 1



Change Level 13



Change Level 7

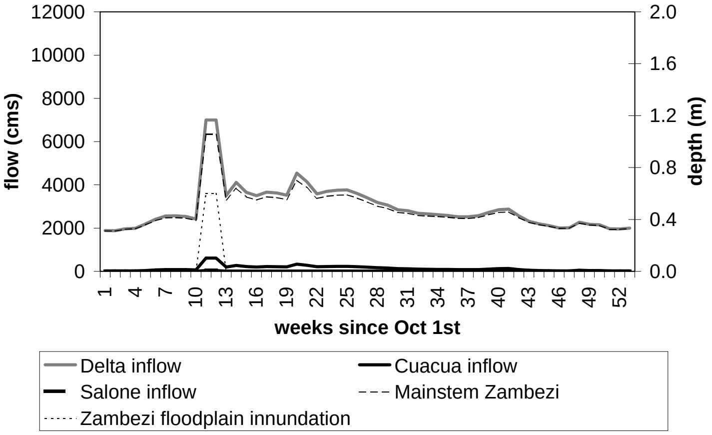


Figure 4.7 Flows in the Delta, 2-week high flow event, mid-December.

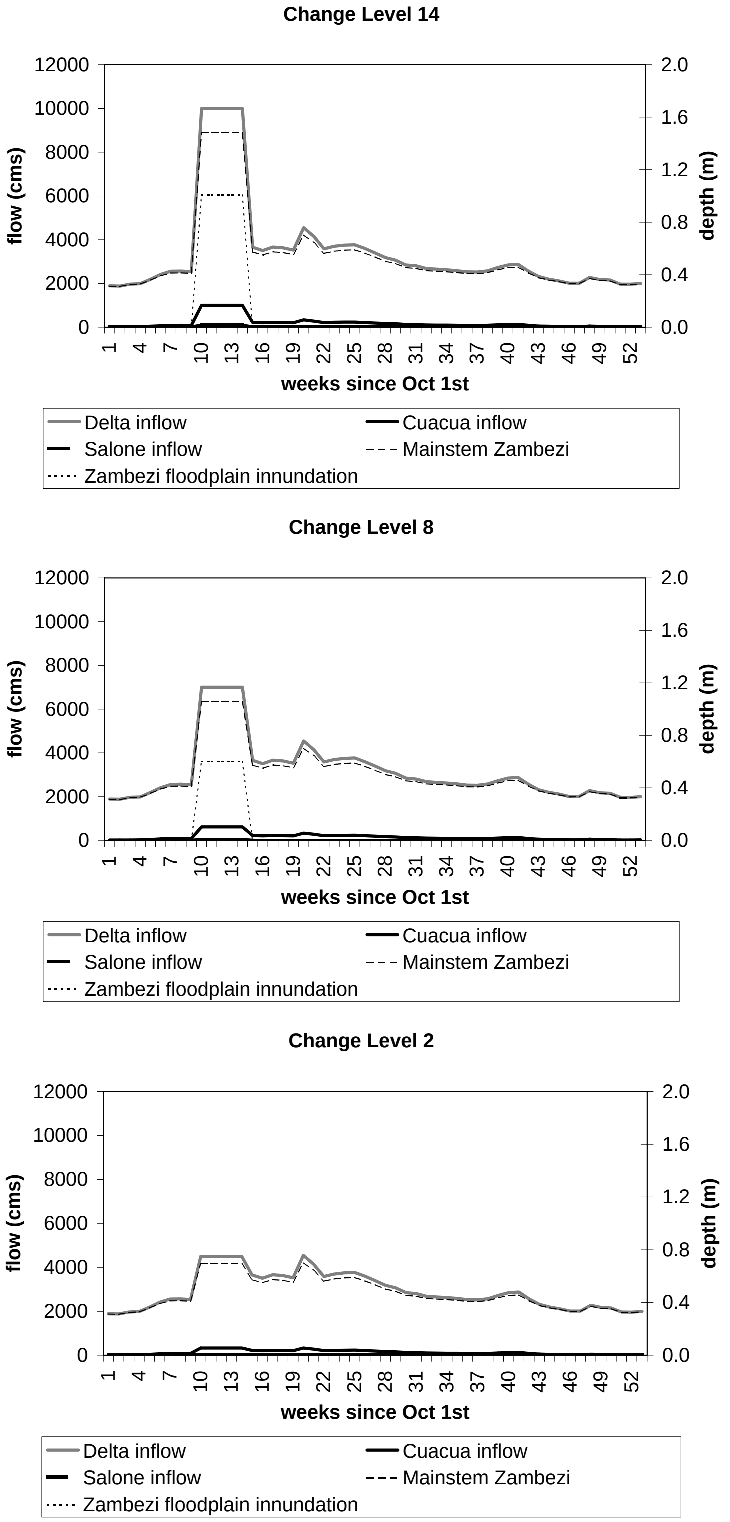
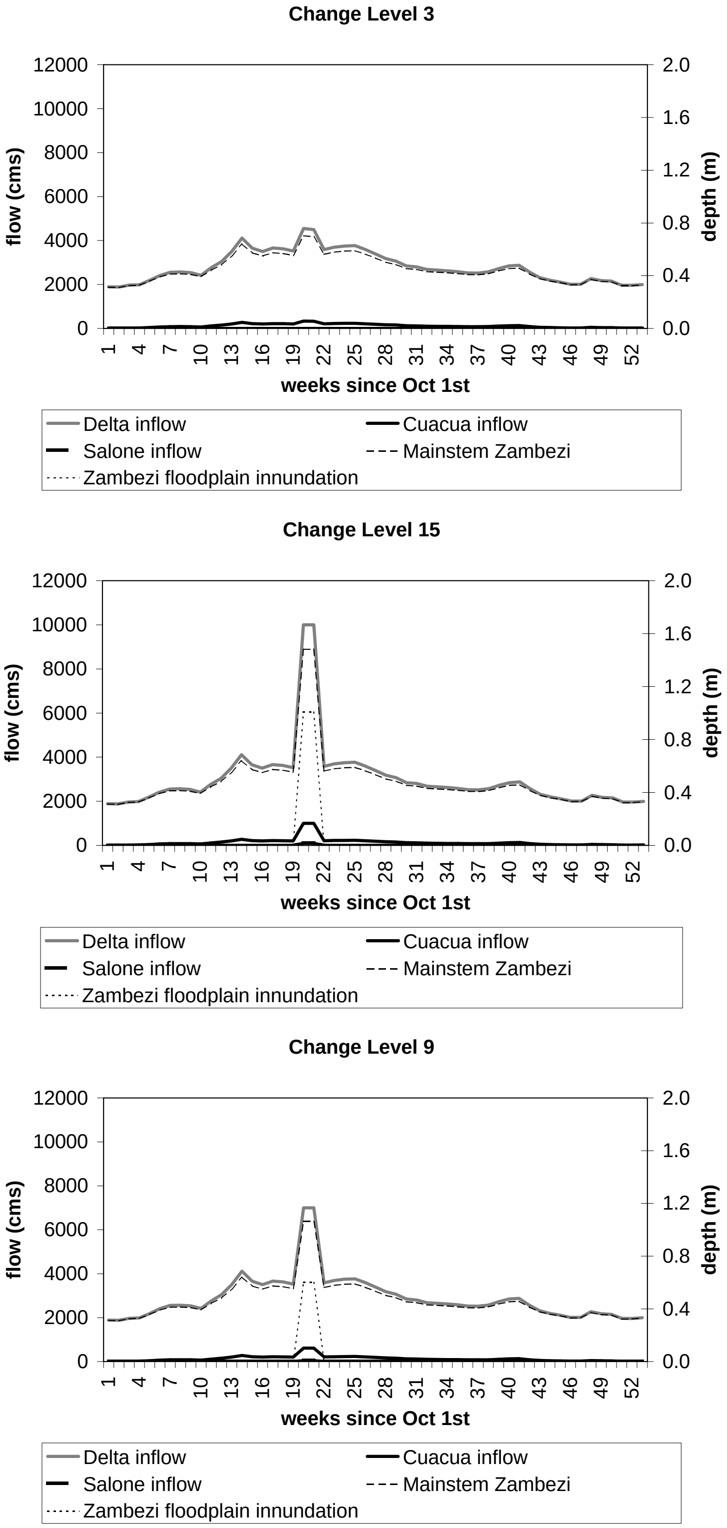


Figure 4.8 Flows in the Delta, 4-week high flow event, December.

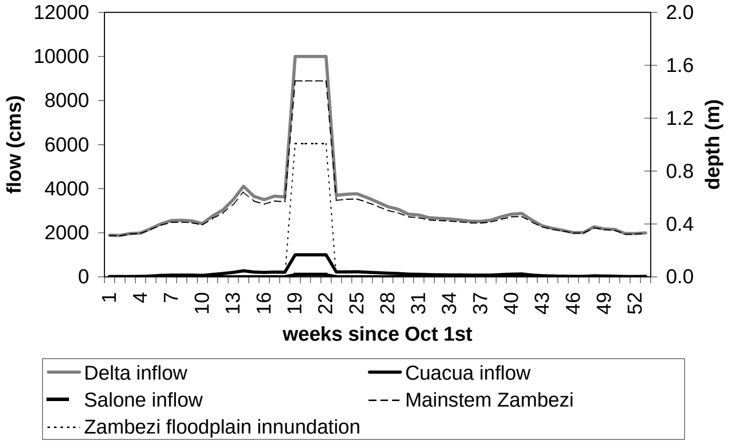

Change Level 3

Change Level 15

Change Level 9

Figure 4.9 Flows in the Delta, 2-week high flow event, mid-February.

Change Level 16



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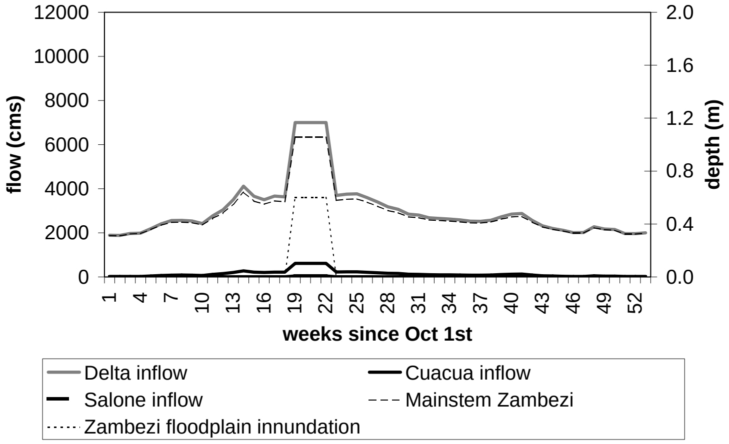


Change Level 4

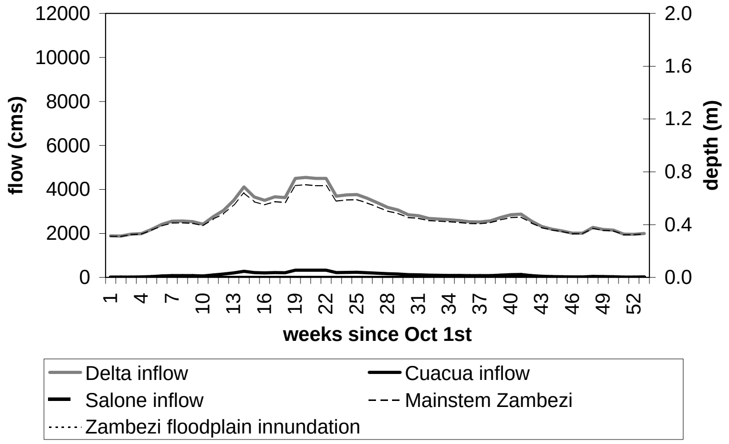
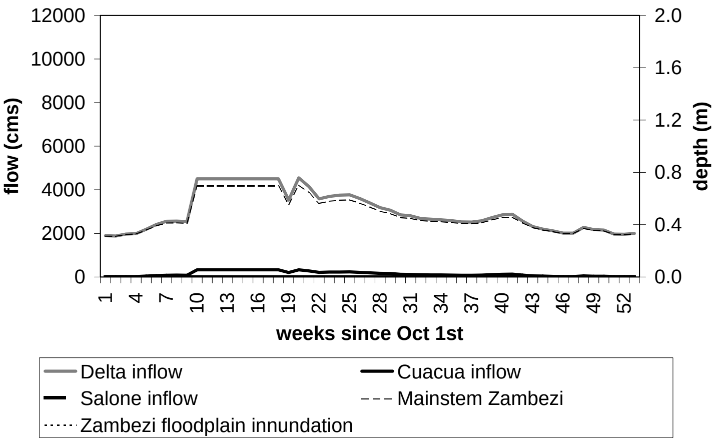
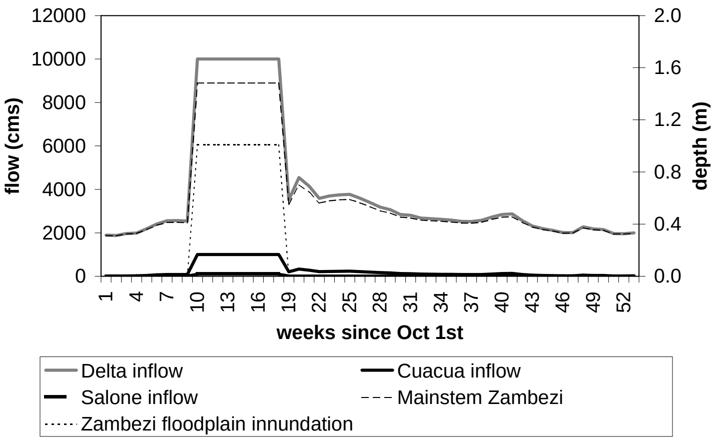


Figure 4.10 Flows in the Delta, 4-week high flow event, February.

Change Level 5



Change Level 17



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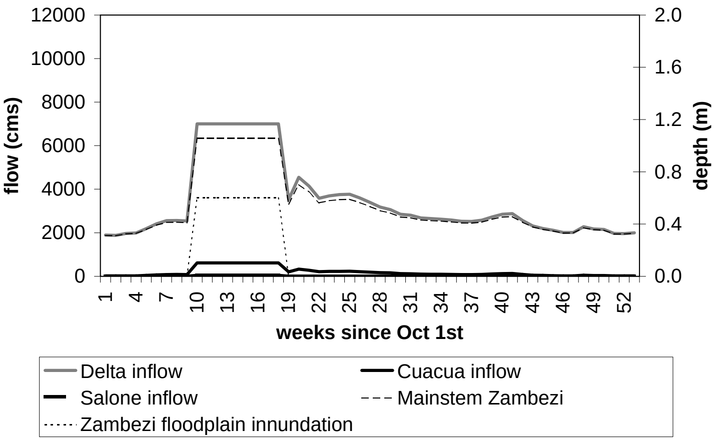
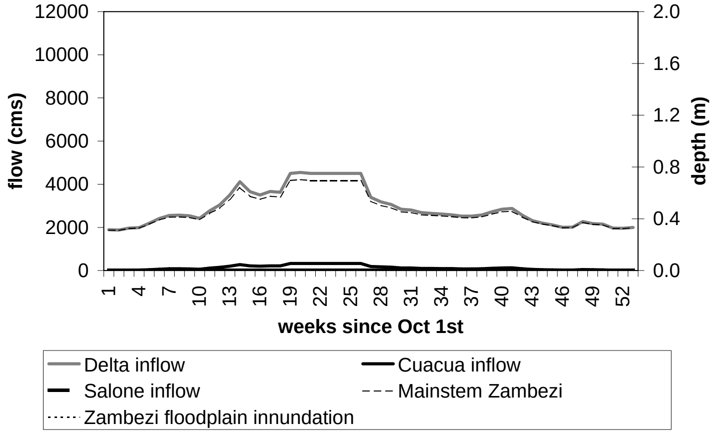
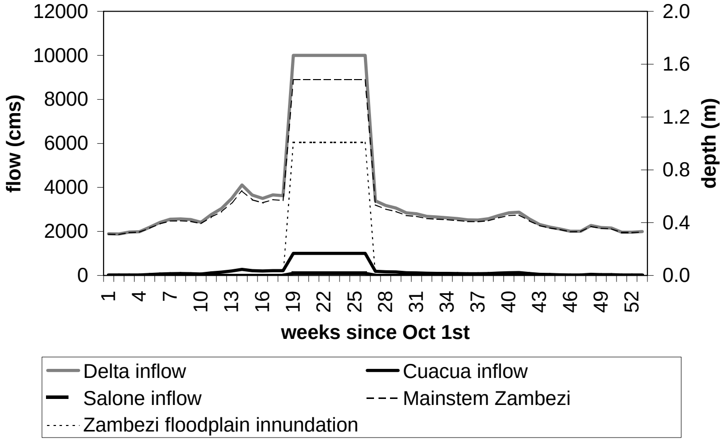


Figure 4.11 Flows in the Delta, 8-week high flow event, December-January.

Change Level 6



Change Level 18



Change Level 12

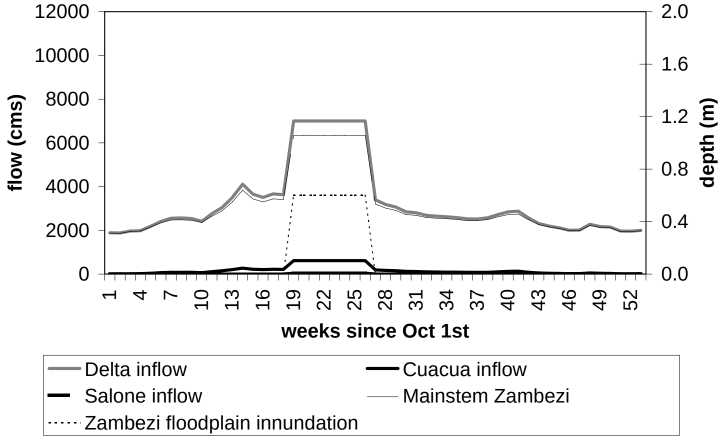
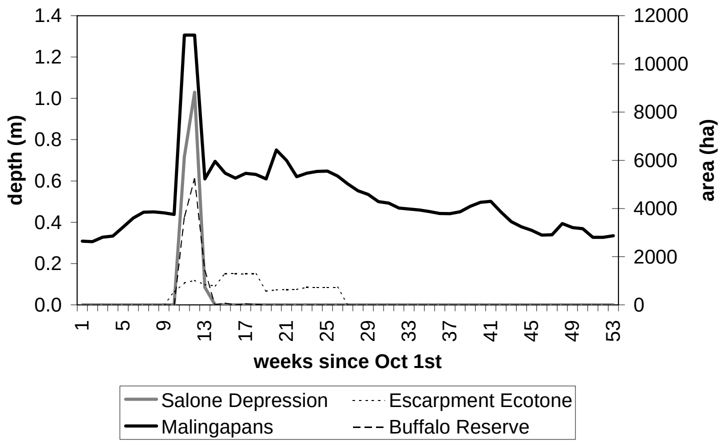
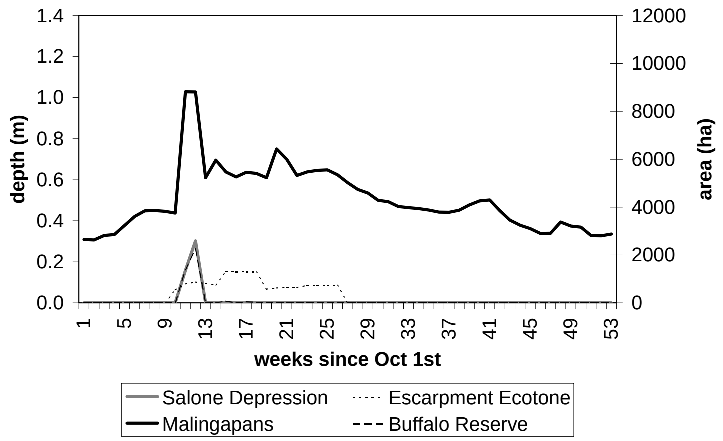


Figure 4.12 Flows in the Delta, 8-week high flow event, February-March.

Inundation, Change Level 13



Inundation, Change Level 7



Inundation, Change Level 1

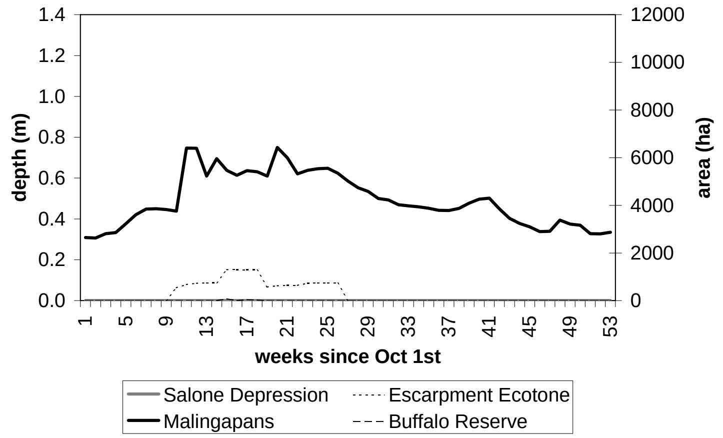
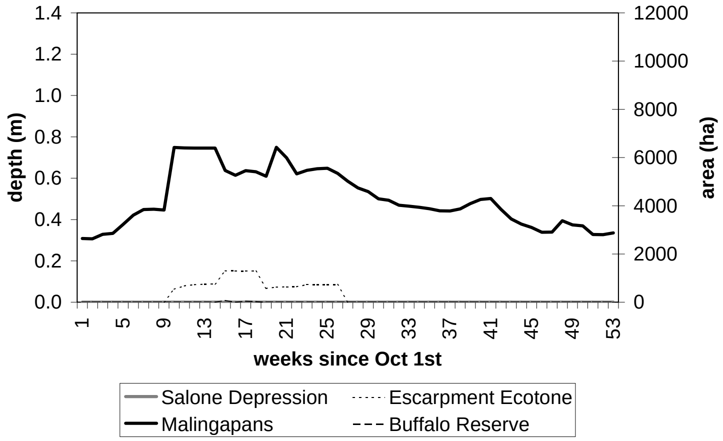
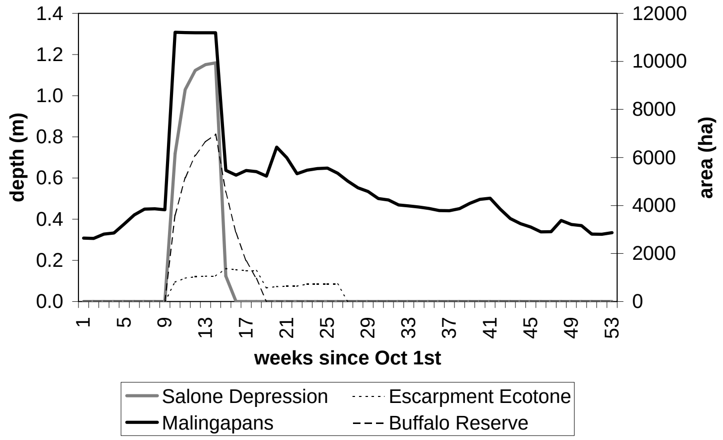


Figure 4.13 Inundation in Delta, 2-week high flow event, mid- December.

Inundation, Change Level 2



Inundation, Change Level 14



Inundation, Change Level 8

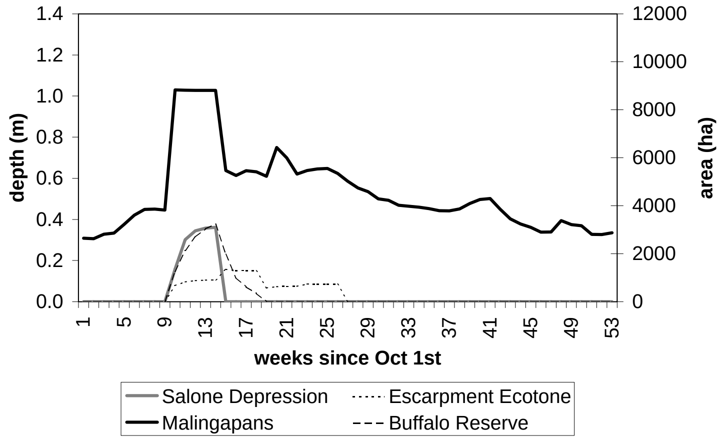


Figure 4.14 Inundation in Delta, 4-week high flow event, December.

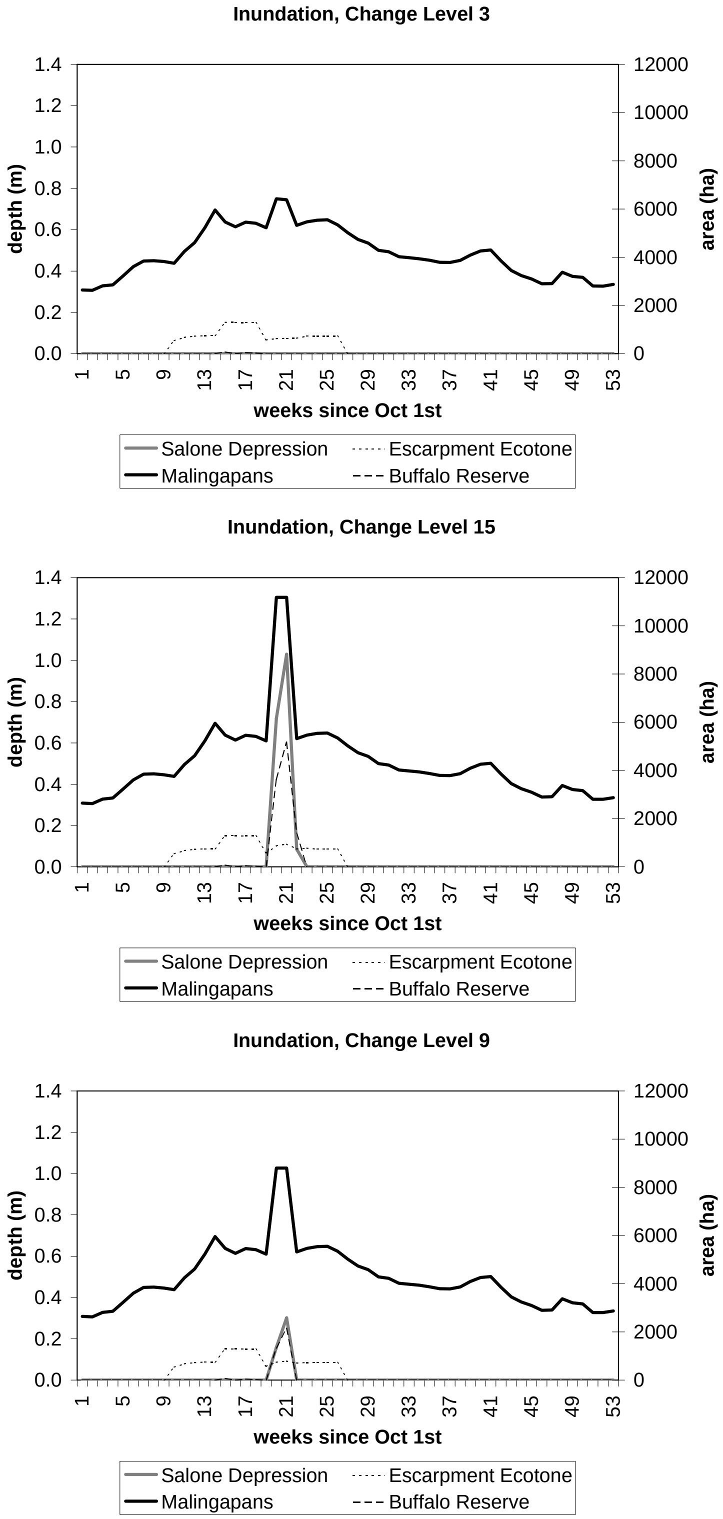


Figure 4.15 Inundation in Delta, 2-week high flow event, mid-February.

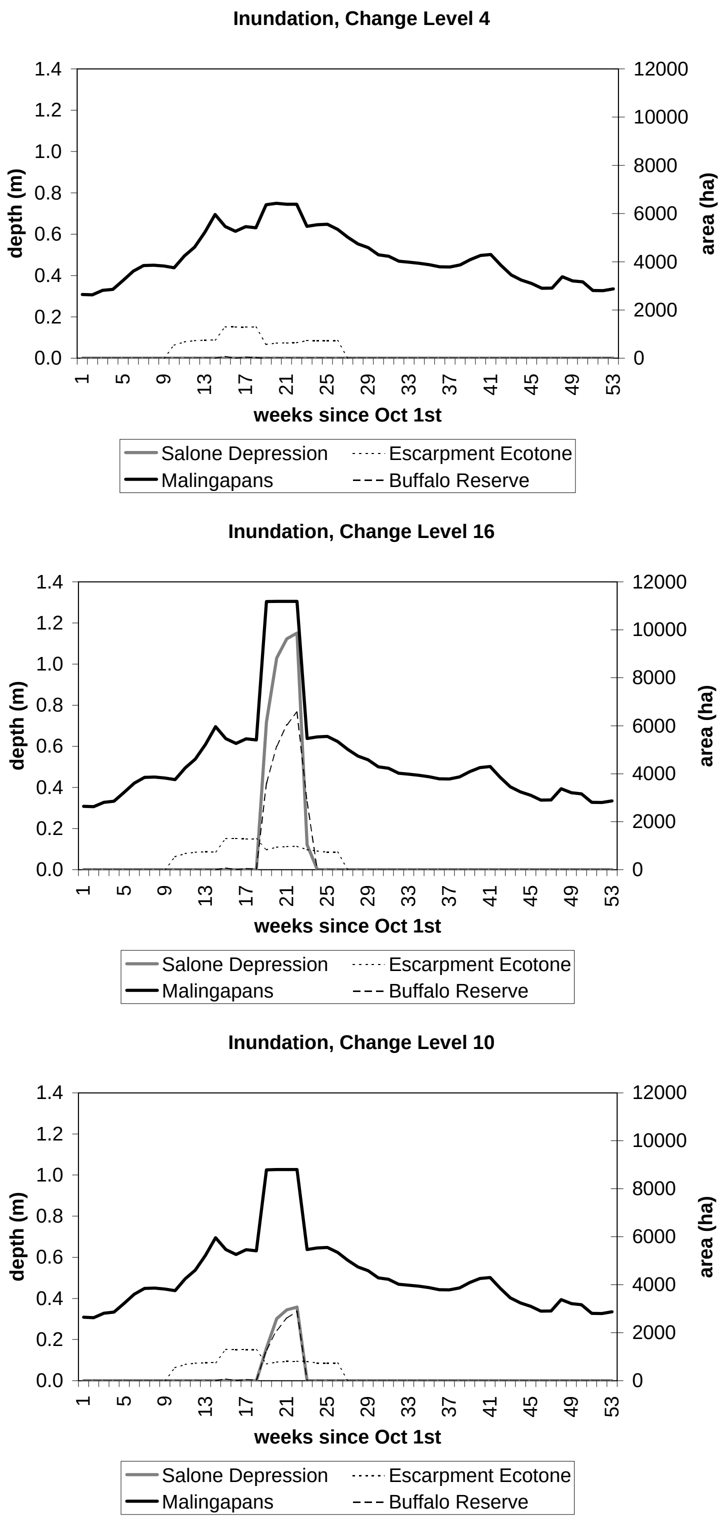
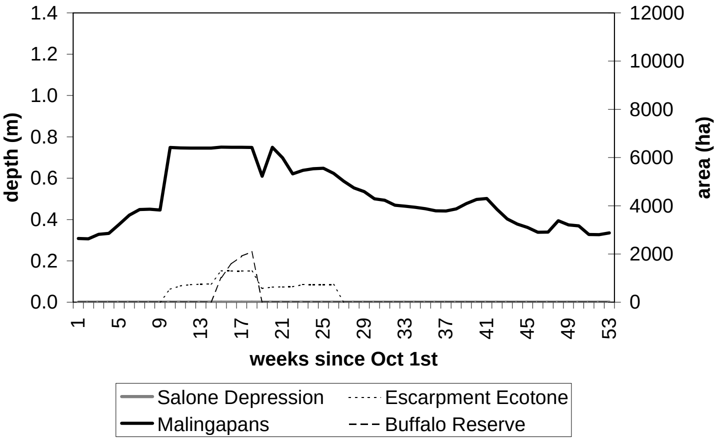
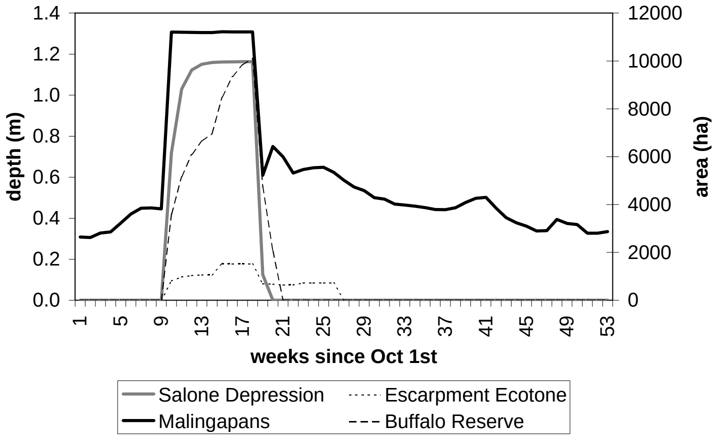


Figure 4.16 Inundation in Delta, 4-week high flow event, February.

Inundation, Change Level 5



Inundation, Change Level 17



Inundation, Change Level 11

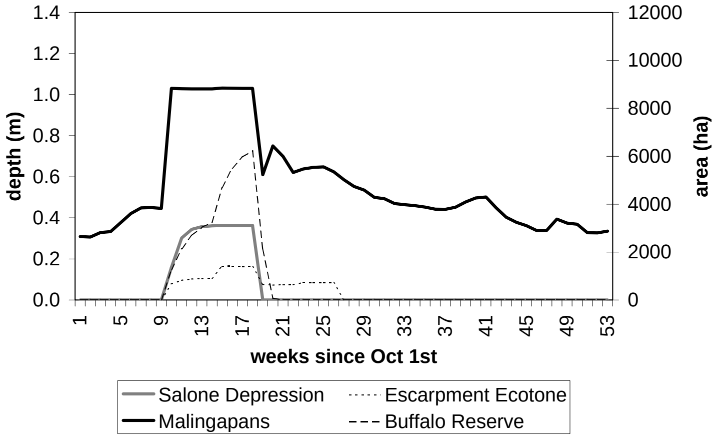
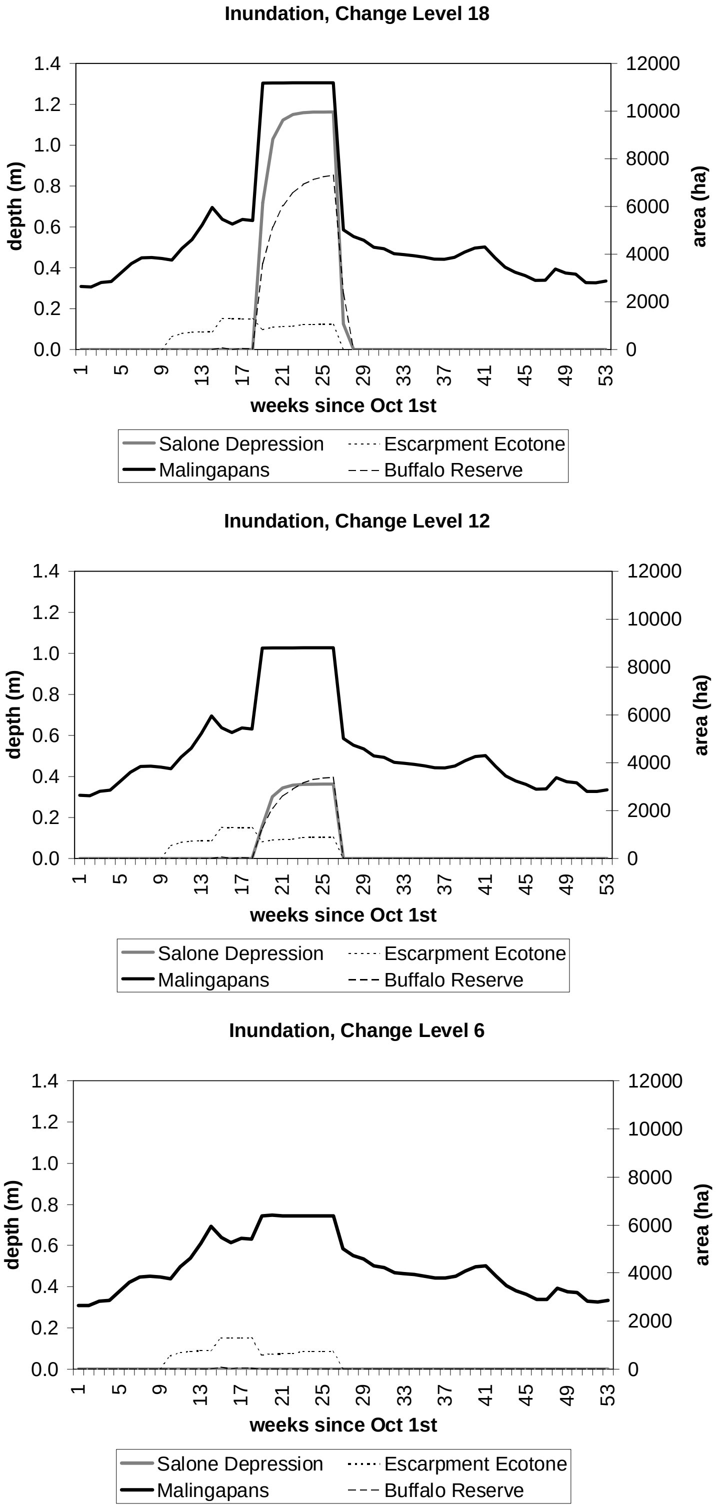


Figure 4.17 Inundation in Delta, 8-week high flow event, December-January.



Inundation, Change Level 18

Inundation, Change Level 12

Inundation, Change Level 6

Figure 4.18 Inundation in Delta, 8-week high flow event, February-March.

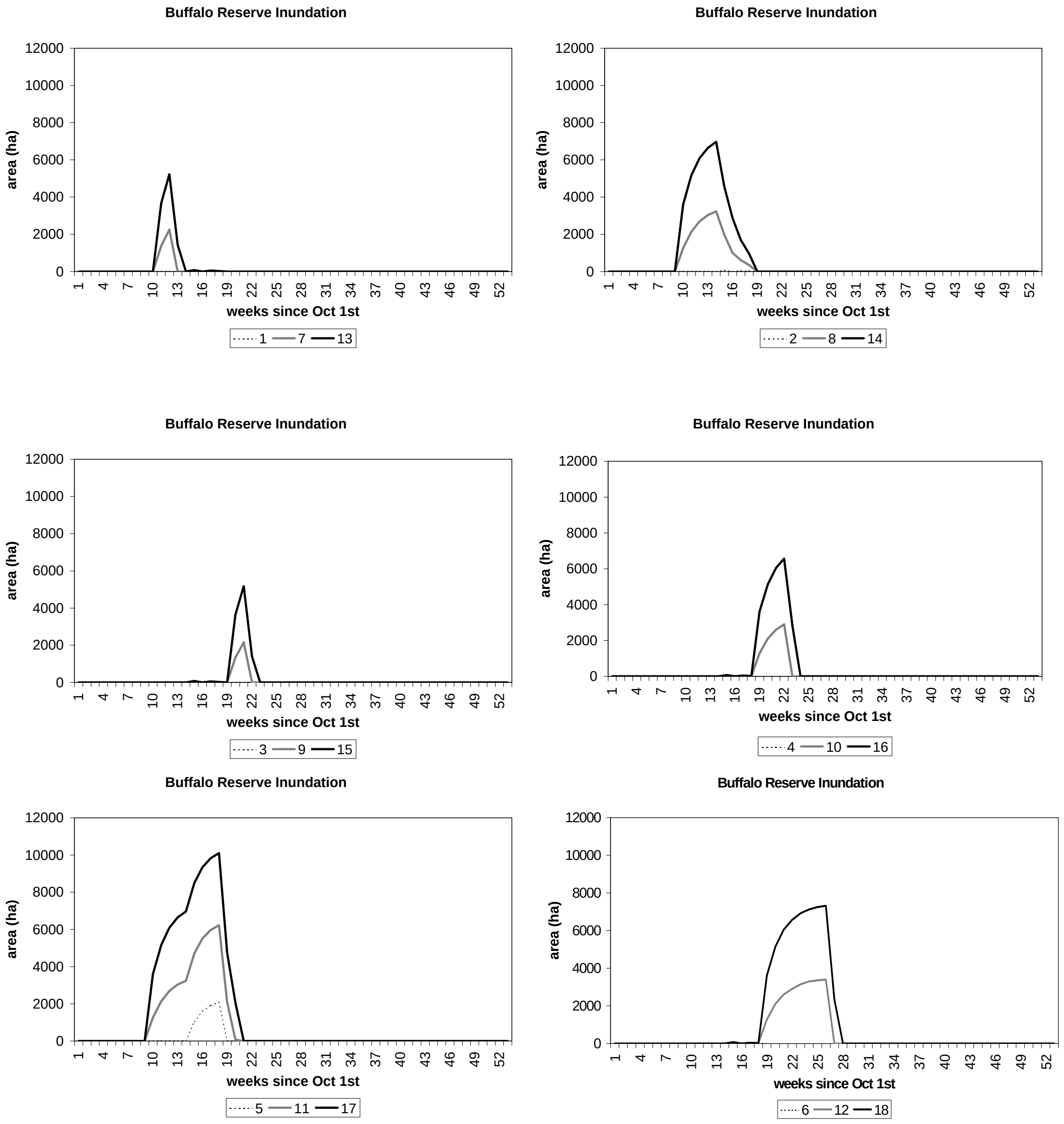


Figure 4.19 Buffalo Reserve inundation for high flow change levels.

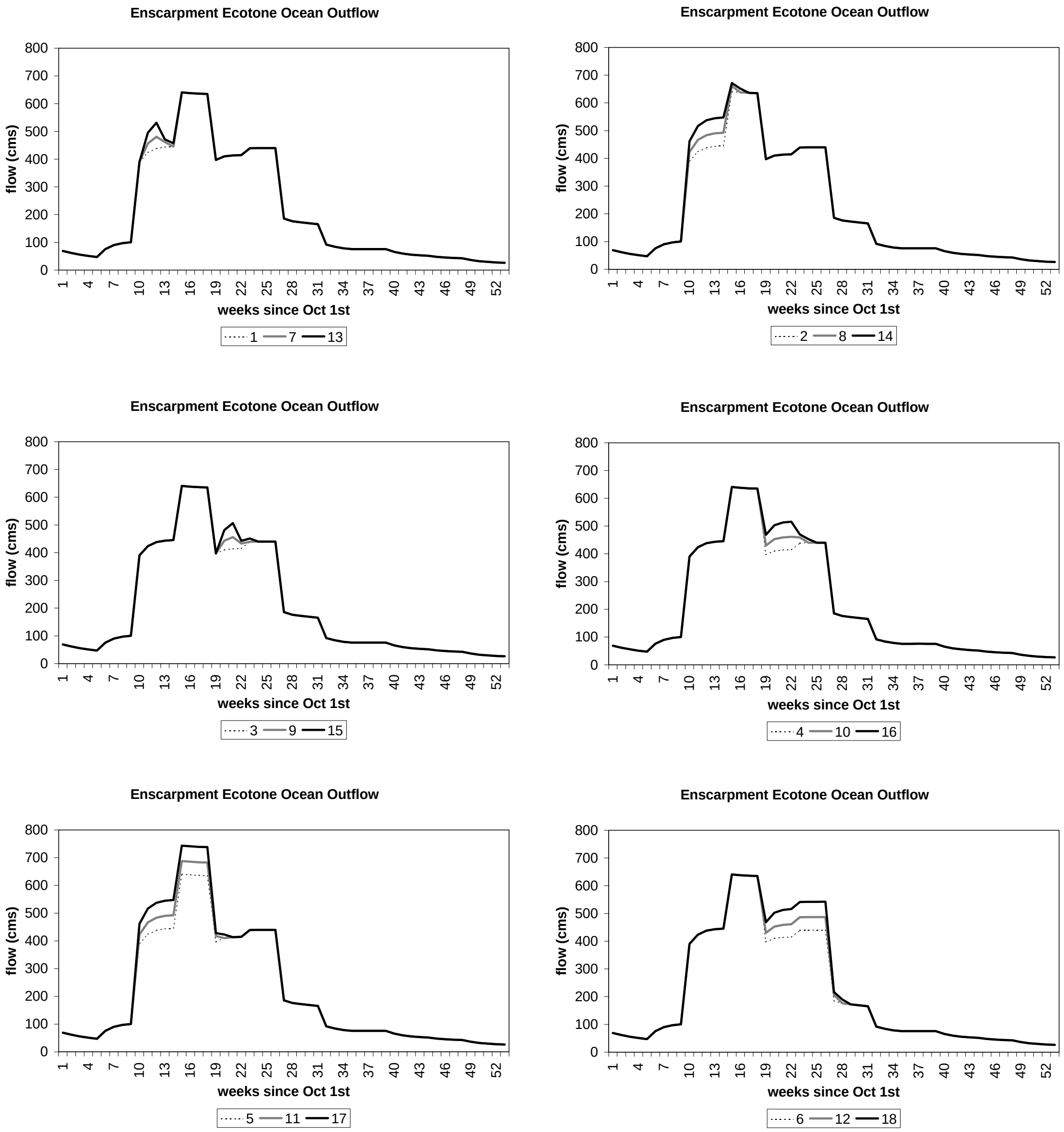


Figure 4.20 Outflow from escarpment ecotone to the Indian Ocean for high flow change levels.

4.4 Conclusions

The output of the ZDMT Model can serve to support the evaluation of various DRIFT change levels by the resource specialists. The model output should be considered, however, to be representative and not definitive. It is, as has been clearly stated, based on a number of simplifying assumptions that derive from gaps in the data available during the model development process.

Nonetheless, as the model is refined and improved it will be possible for the DRIFT analysis to be updated. This will allow for more refined analysis of potential tradeoffs associated with attempts to balance hydropower production at Cahora Bassa Dam with the range of other resource uses carried out in the Delta. The model provides a strong foundation for developing a powerful decision-support tool for the Lower Zambezi River system.

5. Specialist Study – Agriculture

5.1 Introduction

This section addresses the anticipated effects of the hypothetical flow manipulations on the agricultural sector.

5.2 Selection of key sub-components

The subcomponents that best describe the possible changes in the management of the river flow in the agricultural sector are:
- Irrigated Commercial Agriculture (ICA);
- Rainfed Agriculture for Food Crops (RAFC);
- Rainfed Agriculture for Cash Crops (RACC);
- Natural Flooded Rice (NFR).

5.2.1 Irrigated Commercial Agriculture (ICA)

The largest water user in this sector is sugar cane, but other smaller users (vegetables, fruit trees, rice and other cash crops like tobacco and cotton) could also be affected by flow manipulations. The methodology followed was to express the irrigation needs for these cash crops in terms of quantities (mm/month). Thereafter, these were transformed in terms of water flow required in m^3/seg/ha per month of crop growth. In cases where the area occupied by the crop is known this could then be converted to m^3/seg of water flow required from the river. These allowed evaluation of several growth scenarios in the irrigated agriculture and expression of these in terms of water abstracted from the river in m^3/seg per month.

The methodology for the computation of irrigation is the internationally recognized method that is referenced in several FAO publications and other irrigation reference books.

5.2.2 Rainfed Agriculture for Food Crops (RAFC)

Rainfed Agriculture for Food Crops is included here for the case of the small-scale agricultural sector that produces mainly for consumption (maize, beans, cowpea, sweet potato and other crops). All of these crops have rainfall as the main source of water but might also benefit from recession, riverbank agriculture or small-scale irrigation. Small scale irrigation refers irrigation using treadle pumps, controlled flooded irrigation, or other techniques for water control and management that requires small investments in the sector, resulting in a reduction of the risks of crop failure associated with rainfed agriculture and, to a less degree, with recession and river bank agriculture.

The methodology followed was:
1. Estimate the crop production levels (yields; based on monthly rainfall data) that will be obtained if rainfall is the only source of water (rainfed agriculture) and the corresponding amount of water used by the crop in mm/month;
2. Estimate the yields that will be expected if recession agriculture or river bank agriculture are used and the corresponding amount of water that will be used monthly by the crops.
3. Estimate the amount of water that would be used (in mm/month) if irrigation were applied.

5.2.3 Rainfed Agriculture for Cash Crops (RACC)

Rainfed Agriculture for Cash Crops refers to the small-scale agricultural sector producing mainly for the market (commercial agriculture), which includes crops like cotton, tobacco, sugarcane, sunflower and others. All of these crops have rainfall as the only source of water, but also might benefit from recession, riverbank agriculture or small-scale irrigation.

The methodology followed was:
1. Estimate the crop production levels (yields; based on monthly rainfall data) that will be obtained if rainfall is the only source of water (rainfed agriculture) and the corresponding amount of water used by the crop in mm/month;
2. Estimate the yields that will be expected if recession agriculture or river bank agriculture are used and the corresponding amount of water that will be used monthly by the crops.
3. Estimate the amount of water that would be used (in mm/month) if irrigation were applied.

5.2.4 Natural Flooded Rice (NFR)

Natural Flooded Rice covers the special case of flooded rice in the small-scale agricultural sector, where flooding occurs under natural conditions in lowland areas. This system was assessed separately as it requires special conditions in terms of water depths and conditions during the growing season. Again, water use was estimated as water used by the crop in mm/month.

With these different scenarios associated with water consumption (water use) for the small-scale agricultural sector, it is possible to transform into water flow (m^3/seg) and corresponding yields once the areas are known.

5.3 Description of status prior to river regulation

5.3.1 Irrigated Commercial Agriculture

Although commercial agricultural development under the Sena Sugar Estates was first introduced in the Zambezi Delta region more than a century ago, water extraction for irrigated commercial agriculture prior to river regulation was negligible relative to Zambezi River flows. Irrigation withdrawals were piped directly from the Zambezi River to sugar production fields in the adjacent floodplain. Large dykes, set at the elevation of highest known flood level, were constructed for protection of infrastructure against floods, but also prevented floodwaters from irrigated the fields.

5.3.2 Rainfed Agriculture for Food Crops

Prior to the river regulation, the Marromeu Complex supported a population of about 18 000 people, growing crops mainly for food consumption with an average cropped area of 1.50 ha/family. These crops were almost entirely dependent on rainfall for irrigation.

5.3.3 Rainfed Agriculture for Cash Crops

Prior to the river regulation, cash crops (other than sugar production) were negligible in the Zambezi Delta region.

5.3.4 Natural Flooded Rice

The total extent of Natural Flooded Rice along the lower Zambezi River prior to river regulation is poorly known. Most families located along the river produced a rice crop on flood-prone, fertile lowland soils in addition to rainfed crops on upland sites. This combination of crops provided some measure of food security: in years of local drought upland crops failed but natural flooding sustained a rice crop; in years of excessive floods the rice crop was washed out but upland crops were available.

5.4 Description of the current trajectory in condition

5.4.1 Irrigated Commercial Agriculture

The potential development of this sector is dependent on water availability during peak water demand that occurs at the end of the dry season. We assumed that land is not limiting since there are large areas available for irrigation development (the total extent of sugar production fields is currently less than occurred prior to the civil war). Currently, Marromeu supports about 12,000 ha of irrigated agriculture, with sugar cane as the main crop (10,000 ha) and about 2000 ha other cash crops. The target situation is difficult to define but, under present conditions with the sugar mill operating at full potential, we would expect development up to 20,000 ha of irrigated sugarcane. We expect an increase of irrigated land on the order of 6.0 %/year, which would reflect healthy economic development for the rural sector with a growth rate similar to the figures observed during recent years.

5.4.2 Rainfed Agriculture for Food Crops

Currently, the District of Marromeu has a population of around 36,000 people, which suggests approximately 6,000 families (6 people/family) are cultivating an average area of 1.5 ha/family. The main food crops grown in the area are maize, rice, sorghum, millet, cassava, groundnuts, sweet potato, and different types of beans.

5.4.3 Rainfed Agriculture for Cash Crops

Almost all the subsistence crops in the Zambezi Delta are rainfed. Of the 6,000 families cultivating an average area of 1.5 ha/family, only 0.5% practices irrigated agriculture. The main cash crops grown in the area are cotton, with an average area of 0.80 ha per farm and, sugar cane with an average area of 3.80 ha per farm.

5.4.4 Natural Flooded Rice

The present situation is that around 50.0 % of the families grow an average area of 0.80 ha with rice.

5.5 Description of desired target condition

5.5.1 Irrigated Commercial Agriculture

The target situation, in terms of maximizing agricultural development in the Marromeu Complex relative to other uses or concerns, would be to have irrigated land on the order of 70,000 ha by the year 2035, with a peak requirement on the order of 100 m^3/s during October. Figure 5.1 shows the variation of the water requirements for 10,000 ha of irrigated land during the year and the present available river flow during the dry season and the natural river flow during the same period.

70 000 ha gives a peak water requirement on the order of 100 m^3/s, in comparison to the natural river flow of 2600 m^3/s and the present dry-season minimum flow of 800 m^3/s in October and November.

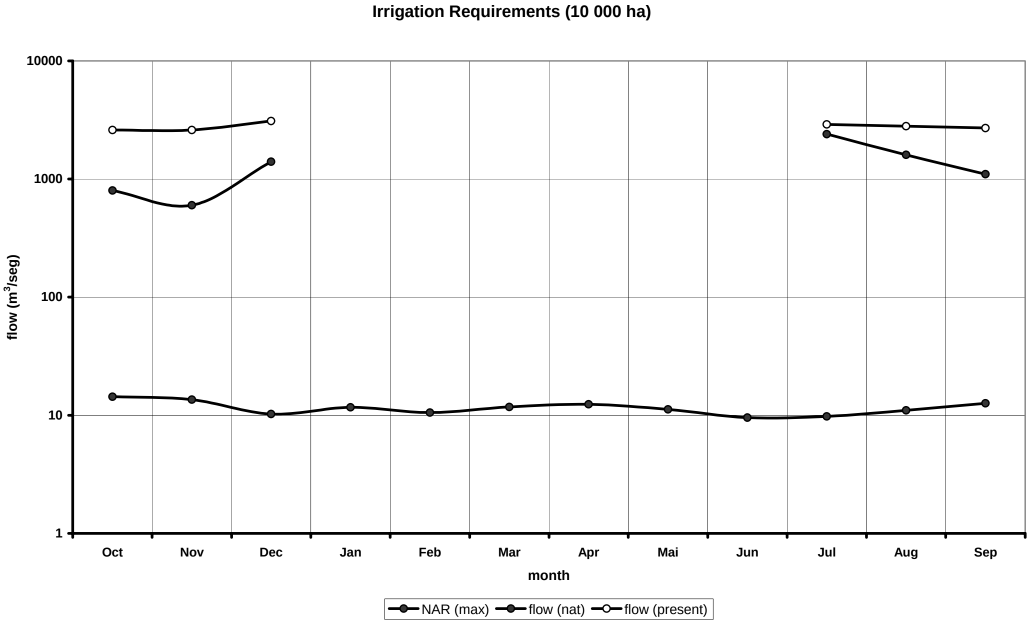


Figure 5.1 Flow requirements for 10,000 ha of irrigation in Marromeu, expressed in m^3/s.

So if we only take into consideration the irrigation development in Marromeu, the present river flows would not cause any problems to its future expansion. But we should also consider the development of the sector in the basin and it that case the picture might become different depending on the development initiatives upstream of Marromeu. In summary it can be stated that river flow during the end of the dry season and beginning of the wet season (August to November) determines the area that can be fully developed for irrigation. Furthermore, when computing the equivalent flow needed for irrigation, we did not take into consideration the irrigation efficiency. We are speaking of a net irrigation requirement without considering the losses that are intrinsic to the irrigation method.

5.5.2 Rainfed Agriculture for Food Crops

The target situation for this subcomponent is to increase the area grown per family to a value of 2.0 ha/family, with a population growth of 2.3 % a year. That would mean in 30 years a population of 70,000 people, equivalent to 12,000 families, resulting in a cropped area of 24,000 ha which is still expected to be available at the time. Here it is assumed that there will be an improvement in agriculture productivity with the introduction of animal traction and other best agriculture practices. It is also expected some improvement in terms of water use, somehow related to recession agriculture, river bank agriculture, and a certain degree of small scale irrigation.

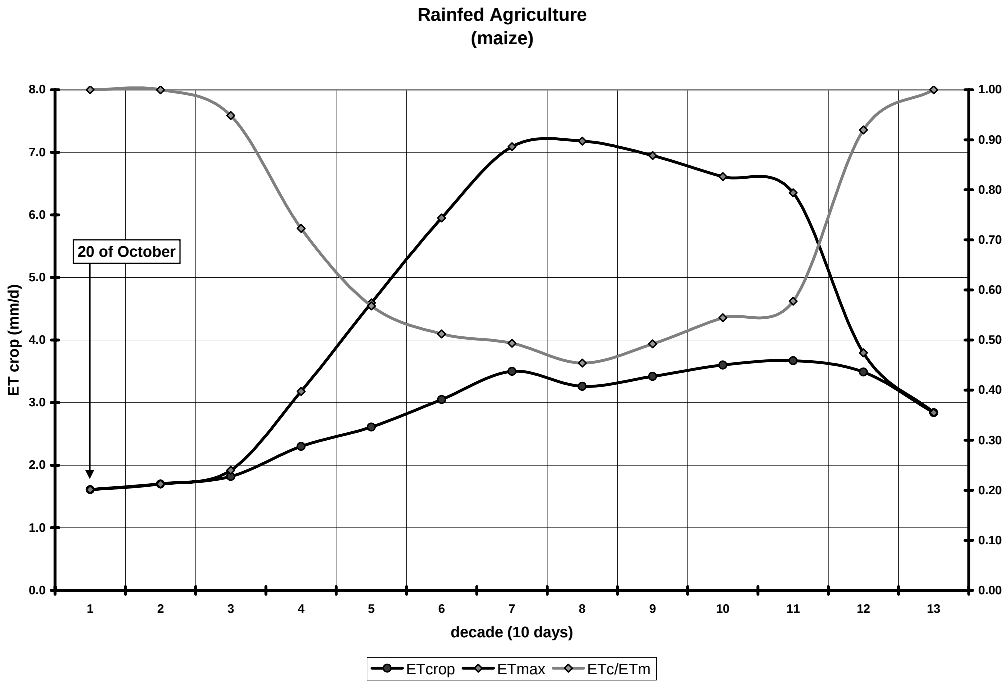


Figure 5.2 Irrigation requirements for Maize in Marromeu, expressed in mm/d.

Figure 5.2 shows the water requirements for maize in the case of rainfed agriculture (ETcrop) and, in the case there is supplementary irrigation (ETmax). As shown, the peak irrigation requirement occurs when the ratio (ETcrop/ETmax) is lower, close to 0.50, during the months of January and February. For an area of 24,000 ha it would mean in terms of supplementary irrigation on the order of 12 m^3/s that should be taken from the river. The value is not critical once the present river flow during this period is much higher and could easily accommodate the irrigation requirements. As above, when computing the equivalent flow needed for the supplementary irrigation, we did not take into consideration the irrigation efficiency.

5.5.3 Rainfed Agriculture for Cash Crops

The target situation for this subcomponent is to improve the leaving standard of the population with an area of 4.0 ha/family, and a population growth of 2.3 % a year. That would mean in 30 years a population equivalent to 12,000 families, resulting in a cropped area of 48,000 ha. It is also assumed that a certain improvement in agriculture techniques are expected with the introduction of animal traction and mechanization as well improved agricultural practices and a certain degree of small-scale irrigation. If we translate these areas into irrigation requirements, they would suggest a corresponding flow of 70 m^3/s during the critical period that goes from August to November.

As above, the river flow during the end of the dry season and beginning of the wet season (August to November) will determine the area that can be fully developed for small-scale irrigation. Again, we did not take into consideration the irrigation efficiency.

5.5.4 Natural Flooded Rice

The target situation for this subcomponent is to increase the areas to 1.60 ha/family and keeping the same percentage, reaching a total area of 9600 ha in Marromeu. It is assumed here also that there is a certain level of mechanization, improved technology, and water management at the small scale.

5.6 Evaluation and ranking the hydrological flow categories

The above subcomponents (irrigated agriculture, rainfed agriculture and natural flooded rice) are assessed according to the following flow regimes:

- ***Dry season lowflows***. The most affected sector is the irrigated agriculture where possible expansion (increase in cropped areas), will be determined mainly by the dry season low flow during the water peak demand that occurs usually in the dry period. In this case it is possible to establish a clear relation between river flow and irrigated area for different crops. To a less extent, small-scale agriculture will also be affected, taking into consideration that part of the small-scale sector will be using small-scale irrigation during the dry season for some important cash crops.
- ***Floods (annual flood)***. The annual flood will be mainly used to grow crops during the wet season which includes rice (flooded), maize, beans and others important food and cash crops. Here we are speaking mainly of the rainfed agriculture for the small-scale sector that might benefit from these floods (flood recession agriculture, river bank agriculture, natural flood agriculture, and small scale irrigation). In this case it will be possible to correlate the flooded area with crop yields.
- ***Floods (with a 5 year return period)***. These will be the same case as the annual floods but with different affected areas. The same relations are possible to establish (flooded area and yields).

The scenarios were based on a background picture of the present status and possible future growth/development. In the irrigation sector, the scenario used was to let this sector grow during the next 30 years with the present economical growth rate for this sector and see what it would mean in terms of water use. Available land and water is not and will not be a limitation in Marromeu in the near future.

For the rainfed agricultural sector we are looking at the small-scale farmers with the growth of the sector based on the present population and the expected population growth for the next 30 years. We also assumed an improvement on the present standard of living (poverty reduction). Based on the population number, it is possible to extrapolate the figures in terms of areas and water management scenarios as discussed before.

For the different flow categories, dry season low flow (DSLF), annual natural floods (NF_a), and floods with 1 to 5 years returning period ($NF_{1:5}$), the impacts are ranked in terms of importance from 1 (highest) to 3 (lowest). The results are presented in Table 5.1.

Dry season lowflows will affect more intensively the irrigated agriculture (ICA), which is determined by the peak water requirement that occurs usually by the end of the dry season, and the corresponding available flows in the river. If there is a change in the river flow during this period, the potential area under irrigation will be affected. The rainfed agriculture (RAFC, RACC), and the natural flooded rice (NFR) are dependent only on the rainfall and on the flooded areas that are not related to the dry season lowflows.

The annual natural floods will affect more intensely the potential growing agricultural area for all the three cases of rainfed agriculture (RAFC, RACC and NFR) where the yields are mainly determined by the water available from the rainfall during the wet season and, by the water available in the soil from the annual floods which are controlled and used using small scale interventions. The NFR is more dependent on the floods due to the required depth of water. The irrigated commercial agriculture (ICA) is in less extent determined by the natural floods. The only influence might be that, depending on the intensity of the floods and the level of the protections dykes, same areas will be flooded, affecting negatively the production in the sector. Most of the irrigated land will be protected from these annual floods.

The 1:5 year return flood will affect to a larger degree the areas grown and cropped because it will affect larger areas when compared to the yearly natural floods. Some of the impacts might be positive once they can result in increased cropped areas. But in some cases the impacts might be negative flooding and damaging areas where crops more sensitive to waterlog are grown. It is expected that these areas won’t be protected from the floods like in the irrigated agriculture. The irrigated commercial agriculture is also more intensely affected by these floods when compared to the annual floods, due to a higher intensity of the floods affecting crops that are sensitive to waterlog.

Table 5.1 Ranking of the agriculture sub-components against the types of hydrological change.

Flow category		**Rank per sub-component**			
		ICA	RAFC	RACC	NFR
Low flows	DSLF	3	1	1	1
Floods	Annual flood	1	2	2	3
	1:5 year flood	2	3	3	3

3 = most important
1 = least important.

5.7 DRIFT consequences

See Appendix A

5.8 Discussion

In this section, the changes that might occur in a 30-year horizon if, there are no changes in the present operating rules of Cahora Bassa Dam are evaluated.

Irrigated Commercial Agriculture. In this case, the development of irrigation is dependent on the river flow during the critical period and on the economic growth of the country. It is assumed that there will be an increase in irrigated area if the present operating rules are maintained, and that the area is only potentially limited by the total amount of water flow available during the dry season (from the April to October) that, in the present situation, is not close to being a limiting factor. An area of 10 000 ha of sugarcane requires a volume of irrigation in the order of 32 000 000 m^3 in April (equivalent to 12.4 m^3/s) and of 24 000 000 m^3 in November (equivalent to 9.2 m^3/s). Presently we are speaking of a reduction to a river flow in the order of 1 340 m^3/s in November, meaning that if there is a reduction in the river flow during the months of October and November, the changes will not affect the growth rate of the irrigated area because the amount of water available in the critical period is still much more than needed for areas that we have now and will have in the future, even if there is a substantial investment in the sector.

Rainfed Agricultural for Food Crops and for Cash Crops, and Natural Flooded Rice. For these types of agricultural, mainly based on the rainfall patterns and on the resulting flooded areas during the wet season, it is expected that no significant changes will occur from changing the pattern of the flow in the river during the months of October and November. There might be only a small influence in the case of rainfed agricultural for cash crops (RACC) that could benefit from small scale irrigation during the critical period but still the amount of water that might be used is still a long way from reaching its potential. The growth that is foreseen for these three sectors if the present operating rules of Cahora Bassa Dam are maintained is based on the population growth (2.3 % growth rate), poverty reduction and rural development policies for small-scale agriculture that showed a 6.0 % growing rate in the later years.

6. Specialist Study – Estuarine Ecology and Coastal Fisheries

6.1 Introduction

In the process of designing an environmental management plan for the “Complexo de Marromeu”, a part of the Zambezi river delta recognized as a Wetland of International Importance under the Ramsar Convention, an exercise was performed to assess the changes in the ecosystem under a set of scenarios of different river flow regimes. This exercise was run on a modelling tool called DRIFT.

The scenarios proposed were four levels of flow during the wet season (December to February), all higher than the average of the last 30 years, and five levels of flow reduction during the dry season (October-November). All these scenarios assumed water releases from the Cahora Bassa dam, about 500 km upstream from the Zambezi delta. The components of the ecosystem selected for this exercise were the shallow-water shrimp fisheries in the estuarine part of the delta and in the Sofala Bank, including the expanse of coastal waters off the delta; the estuarine bottom fishes; the mangrove crab; and the primary productivity in the coastal waters.

The reasons for the selection of these components of the ecosystem are that they all are relatively easy to monitor and have a strong dependency on the river outflow.

6.2 Selection of key sub-components

The selected sub-components are:

1. Shallow-water shrimp fisheries
2. Estuarine bottom fish
3. Mangrove crab
4. Primary productivity in coastal waters

6.2.1 Shallow-water shrimp fisheries

Shallow-water penaeid shrimps in the Sofala bank support important fisheries, of which an industrial fishery with a long history of catch and effort data, starting just after Cahora Bassa dam closure, in 1974 (Ulltang *et al*. 1980; Palha de Sousa *et al*. 1995). Artisanal fishers also catch the same species all along the Sofala Bank, but the assessment of their catches has only recently started (Balói *et al*. 1998). The combined information from the two fisheries may provide a good basis to assess possible impacts of changes in the Zambezi flow regime.

It has been scientifically established that the industrial shrimp catch in the Sofala Bank has a direct relationship with the Zambezi outflow and that catches might increase by approximately 20% with increased flows of the Zambezi (Jorge da Silva 1986; Gammelsrød 1992; Hoguane 2000). This percentage indicates that shrimp abundance depends on other factors, besides fresh-water outflow, probably the most important of which may be the reduction of effort that has been proposed since the 1980’s (Cadima & Silva 1989).

The shallow-water penaeid shrimp species have a development period in estuarine waters and it is generally accepted (although not yet proven) that shrimp migration from the estuaries to the coastal waters depends on fresh-water flooding of the estuaries. This might be a physiological response from the growing animals, that would not tolerate a low salinity, or it may result from the mechanical effect of flooding washing the shrimp out of the estuary (de Freitas 1980).

The migration of the young white shrimp from the estuaries to the coastal waters, called recruitment to the fishery, occurs yearly in the Sofala Bank between October and March, with a peak in December-January (sometimes February, Ulltang *et al* 1985). These young shrimp are the ones that support the fishery during the fishing season and, therefore, a higher flow than the present one during the recruitment period will enhance the catches during a full year.

Since the relationship between shrimp catch and the Zambezi outflow is a direct one, shrimp yield can be expected to increase with increased flows of the Zambezi, provided that the floods do not reduce significantly the estuarine substrates, where the young shrimp develop.

6.2.2 Estuarine bottom fish

Coastal and estuarine bottom fish, of which the catfish can be considered an indicator species, is sold dried in the region and its abundance can be assessed by following this trade. These fish are predators of shrimp and, therefore, their abundance may also be considered an index of shrimp abundance. It may be assumed that the abundance of bottom fish is directly proportional to the availability of suitable substrate, thus on the extent of the flooded area in the estuaries. Therefore, the scenarios proposed with increased flows would most probably increase the yield of these species. No information on the amount of change in the abundance of these fish was found in the literature and thus no reliable figures can be used in the DRIFT application.

6.2.3 Mangrove crab

The mangrove crab in an abundant species in the Zambezi delta and it is assumed that its abundance depends on the extent and health of the mangrove forest, thus on a suitable flood regime (Piatek 1981). Its trade depends on commercial opportunities, thus its abundance may be difficult to measure by fisheries methods, but is relatively easy to measure by biological surveying methods. It is believed that this species is relatively independent from the components of the ecosystem discussed above and, as such, may be considered an independent indicator of mangrove health, and of the effect of different flood regimes. Since the mangrove forests are usually subject to heavy exploitation, it is difficult to forecast the influence of different river flow regimes, whose effects may not be felt at short term, in these exploited system, without proper management measures. For this reason, it is not appropriate to assign figures for this species in the DRIFT application.

6.2.4 Primary productivity in coastal waters

Phytoplankton is the basis of the aquatic food-web and its abundance in coastal waters is easily assessed by satellite imagery. In the Sofala Bank, the Zambezi outflow is pushed northward along the coast and, therefore, the extent of the enriched coastal water depends on a steady flow regime, but also depends on the strength and position of the offshore Mozambique current, which is led by the direction and strength of inshore-flowing winds (Gammelsrød and Hoguane 1995). Primary productivity may also benefit from regular flooding by depositing organic matter over a larger and more remote extent of the floodplain, although primary productivity might be hampered by siltation brought by extensive floods.

It can thus be expected that a long flood season during the hot season (October-March) can enhance production along the whole Sofala Bank during that season, provided that the flow is not too strong as to deposit excessive amounts of sediment in the estuarine system.

6.3 Description of status prior to river regulation

Shallow-water shrimp fisheries:	There was no fishery prior to regulation.
Estuarine bottom fish:	Unknown.
Mangrove crab:	Unknown.
Primary productivity in coastal waters:	Unknown.

6.4 Description of the current trajectory in condition

Shallow-water shrimp fisheries:	Catch of around 10,000 tons per annum.
Estuarine bottom fish:	Unknown, but relatively easy to monitor.
Mangrove crab:	Unknown, but relatively easy to monitor.
Primary productivity in coastal waters:	Unknown, but relatively easy to monitor by satellite imagery.

6.5 Description of desired target condition

Shallow-water shrimp fisheries:	The desired target condition for that sub-component – increased catch to 12-14,000 tons.
Estuarine bottom fish:	The desired target condition for that sub-component – increased abundance, assumed to be proportional to mangrove flooded area.
Mangrove crab:	The desired target condition for that sub-component – increased abundance, assumed to be proportional to mangrove flooded area.
Primary productivity in coastal waters:	The desired target condition for that sub-component – increased area of high productivity, assumed to be proportional to flood conditions.

6.6 Evaluation and ranking the hydrological flow categories

Table 6.1 is a ranking of the three hydrological flow categories used in this study in terms of their impact on each of the sub-components. The reasoning supporting the rankings is discussed in more detail below.

Table 6.1 Evaluation of coastal and estuarine fisheries sub-components against the types of hydrological change.

Flow category		**Rank per sub-component**			
		Shallow-water shrimp fisheries	Estuarine bottom fish	Mangrove crab	Primary productivity in coastal waters
Dry season lowflows	DSLF	1	1	1	1
Floods	Annual flood	3	3	3	3
	1:5 year natural discharge	2	2	2	2

3 = most important
1 = least important.

Any *reasonable* increase in the present Zambezi flood regime will be beneficial to the estuarine and coastal ecosystem - by "*reasonable"* meaning, avoiding extreme floods—the net benefits of which are less clear. For the shallow-water shrimps, it is expected that increasing flood during the recruitment season (October to March) will be most beneficial. For the bottom fish and mangrove crab, it is expected that any increment in the amount of healthy substrate – flooded channels or mangrove forests – will increase their production. Concerning primary productivity, an increased flow in moderate amounts will probably increase phytoplankton in the coastal waters of the Sofala Bank, depending on other independent factors, such as the strength of the Mozambique Current and air temperature, among others.

Extreme floods, such as the "1:5-year flood", may increase production in the short term, but may be detrimental if there is significant damage to the substrates, and may decrease primary productivity due to excessive siltation. There may also be damage to the fishing fleets or severely hamper fishing operations (besides other social effects).

Any decrease in flow during the dry season is expected to lower the productivity of the coastal ecosystem. However, if this decrease is compensated by higher flow during the wet season, the result will be beneficial to the system.

6.6.1 Shallow-water shrimp fisheries

Dry season lowflows – probably no impact on present level, except if they are attached to high flows during the wet season.

Annual flood – expected to have a high impact, probably the best being the 2-month December-January high flows, which can provide a 20% increase in shrimp yield; the other options may increase the catches up to 20% of present level.

1:5 year natural discharge – these extensive floods may, or may not, increase present catch levels, according to duration and timing, but may also hamper the fishery operations, thereby decreasing catches.

6.6.2 Estuarine bottom fish

Dry season lowflows – will probably decrease catches, due to less available habitat, but to a low extent—although under very low flow conditions the increased concentration of fishes in river pools would make fish stocks easier to harvest.

Annual flood – expected to have a high impact, proportional to the period and area flooded.

1:5 year natural discharge – these extensive floods may increase present catch levels after the flood has receded, unless there is damage to the habitat.

6.6.3 Mangrove crab

Dry season lowflows – will probably decrease catches, due to less available habitat, but to a low extent.

Annual flood – increased flows in the wet season – expected to have a high impact, proportional to the period and area flooded.

1:5 year natural discharge – these extensive floods may increase present catch levels after the flood has receded, except if there is damage to the habitat.

6.6.4 Primary productivity in coastal waters

Dry season lowflows – will probably have low impact compared with present levels.

Annual flood - increased flows in the wet season are expected to have a high impact, proportional to the period of high flows (5-15%); short-period high flows are expected to have a low impact.

1:5 year natural discharge – expected to have a high impact in all of the coastal waters of the Sofala Bank, around and north of the delta, provided that other factors are in tune (position of oceanic water, air temperature) – increased productivity estimated at 0-20%.

6.7 DRIFT consequences

See Appendix A.

6.8 Discussion

This discussion addresses the question:

“Do you think that, in a 30-year horizon, a “pre-regulation condition” in the delta could be achieved if the flow conditions prior to river regulation were reinstated, i.e., do you think the current condition is reversible?

The regulation of the Zambezi has a 50-year history, with Cahora Bassa contributing in the last 30 years and, judging from the behaviour of the industrial shrimp fishery, it appears as if the ecosystem has adapted to the new regime. Hydropower is a national and regional priority and requires a regulated regime, therefore preventing a complete reversal of the present situation. A slow (30-year) reversion from the present regime will encompass a year-to-year change in the estuarine and coastal conditions, which may be detrimental to the system. During this regulation history, many changes, both climatic and in the use of the basin, have occurred, which will prevent a reversion to an earlier situation. It may, therefore, be neither possible nor desirable to target a complete reversion to a pre-regulation regime.

7. Specialist Study – Freshwater Fisheries

7.1 Introduction

This section addresses the anticipated effects on the freshwater fisheries in the delta of the flow changes described in Section 3. Coastal, estuarine and mangrove fisheries are dealt with separately in Section 6.

7.1.1 Fishes of the Delta

There have been remarkably few studies of the fishes of the Lower Zambezi River. Until recently, the only major survey of the Lower Zambezi region was that carried out by Wilhelm Peters in 1844-45 (Peters 1868), although brief reports on the fishes were made by Guy (1964) and Davies *et al.* (1975). The most detailed study of fish in the Lower Zambezi system is that by Tweddle and Willoughby (1979), which was conducted in the Lower Shire River in Malawi, an area of similar habitat to the floodplains of the Zambezi delta. A total of 61 species was recorded in that paper, later increased to 63 (Tweddle, unpublished data).

In 1999, Bills (2000) undertook the first systematic survey of Zambezi Delta in the 20th century. This survey was confined to the cool, low flow period in July, and Bills considered that this was not the ideal time for such a survey as fish were not breeding and not active. Bills recorded 65 species, of which 43 were freshwater species, seven marine/estuarine and the remainder marine/estuarine species that also penetrate into freshwater. Bills (pers. comm.) stated that the marine/estuarine species are restricted to within about 5 km of the coast and unlikely to be greatly influenced by changes in the operating regime of the Cahora Bassa Dam. Review of fishes impacted by changes in the dam operating regime can thus be restricted to freshwater species.

7.1.2 Estimation of fisheries yields in the Zambezi Delta

The Zambezi Delta provides a considerable amount of valuable fish protein to the estimated 350,000 people living in the area, although there are only very limited data on the extent of the fishery and the annual yield. SWECO (1982, quoted in Turpie *et al*. 1999) have estimated yields at *c*.10,000 tonnes per annum, however, anecdotal evidence from similar fisheries elsewhere (e.g. Barotse floodplain, Lower Shire marshes) suggests that is an underestimation, which considerably underrates importance of the fisheries of the Lower Zambezi Delta. For instance, the Lower Shire River, a tributary of the Lower Zambezi with associated floodplains of 65,000 ha in Malawi, historically produced sustainable annual yields of 5-7,000 tonnes (Tweddle *et al*. 1995a). A combination of lower water levels, invasion of water hyacinth (which choked fishing grounds) and increasing fishing pressure using unsustainable fishing methods (e.g., mosquito-meshed nets) led to a drastic decline in yields in the 1990s (Tweddle *et al*. 1995a; Chimatiro 2004) to less than 2,000 tonnes annually between 1994 and 2001, the last year for which data are available (Malawi Fisheries Department catch statistics), although Chimatiro (2004) considered these data to be underestimates. The estimated flooded area in the Zambezi Delta is eight times that of the Lower Shire marshes (at *c.* 500,000 ha, Turpie *et al*. 1999[3]).

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[3] Turpie *et al.* (1999) estimated an original 1 275 000 ha of wetland in the delta, divided into palm savanna, floodplain grass, wet grass, reeds and papyrus, channel and mangroves. The estimate above is based on floodplain grass only and is thus conservative.

For an area of this size, with a less dense human population and thus less risk of stock depletion through overfishing, a yield of several times the estimate of SWECO (1982) might be anticipated, even if some of the areas are remote from population centres.

Catch statistics for floodplain subsistence fisheries tend to underestimate the actual catches for a number of reasons.

1. Catch statistic recording systems tend to work best in stable fisheries, such as those in the sea and in lakes, where fishermen are organised, and land and sell their fish catch at recognised markets. In these situations, catches are recorded from a sample of fishermen at the landing and total catches are estimated using raising factors based typically on the number of vessels or the number of gears known to be active in the fishery (e.g., Bazigos 1972; Walker, 1974-1976, Tweddle *et al*. 1995b). In floodplain fisheries, however, there are numerous problems with implementing such systems, chief among which are the mobility of fishermen and the extremes in marsh area, which make consistent recording difficult even for the most highly trained and motivated staff (Tweddle *et al*. 1995a).

2. Frame surveys to assess numbers of craft and gears are not always done efficiently, and can result in raising factors that are too low, thereby underestimating catches. Many fishermen also do not use boats/canoes or share boats/canoes (Chimatiro 2004), resulting in disparities between catches for individual vessels.

3. Many fish are caught during the drawdown period for subsistence use by the families living on the floodplain, and (along with other informal catches) are typically excluded from standard catch recording systems (Tweddle *et al*. 2004). On the Barotse floodplain in Zambia, for instance, catches by children fishing with hooks outweighed those landed for sale at markets (Tweddle *et al*. 2004).

7.2 Selection of key sub-components

The selected fisheries sub-components are:

1. The sharptooth catfish, *Clarias gariepinus* (the blunttooth catfish, *Clarias ngamensis,* will be similarly affected).
2. The Mozambique tilapia, *Oreochromis mossambicus.*
3. The Manyame labeo, *Labeo altivelis.*
4. The tigerfish, *Hydrocynus vittatus*.

Bills (2000) found that *C. gariepinus*, and *O. mossambicus*, were common in the delta and important in the fisheries but that *L. altivelis* was dominant in fresh fish sales in markets. The tigerfish, *Hydrocynus vittatus*, was also an important component of the fish in the markets. This can be compared with the Lower Shire tributary, where Willoughby and Tweddle (1978) found that three species, *C. gariepinus*, *C. ngamensis*, and *O. mossambicus* made up 90% of the commercial catches.

While the ecology of each of these species is strongly influenced by the flood regime, their habits are very different.

7.2.1 The sharptooth catfish, *Clarias gariepinus*

The two *Clarias* species occur extensively over the floodplain as well as in the main river, although of the two, *C. ngamensis* is more closely associated with vegetation. Large adults tend to remain in the deeper river channels while juveniles prefer shallow vegetated areas. The species do not make extensive migrations (Willoughby and Tweddle 1978) and are believed to move from the river channels into the nearest freshly flooded areas to breed at the beginning of the rains. An exception to this is found in the Okavango Delta, where *C. gariepinus* exhibit pack-hunting behaviour as shoals move upstream, but this is in advance of the breeding season (Merron 1993). Both species lay large numbers of small eggs (fecundity up to over 160,000 eggs; Willoughby and Tweddle 1978) in flooding marginal vegetation.

7.2.2 The Mozambique tilapia, *Oreochromis mossambicus*

Oreochromis mossambicus is also found throughout the river and floodplains but has a very different reproductive strategy. It lays only a few hundred large eggs that are protected until long after hatching by maternal mouth brooding. The male guards a territory around a large saucer-shaped nest.

7.2.3 The Manyame labeo, *Labeo altivelis*

Labeo altivelis undergoes spawning migrations upstream and this makes it very vulnerable to over-exploitation (Jackson 1961; Skelton *et al*. 1991). The species is riverine and does not commonly appear on the floodplains (Tweddle and Willoughby 1979; Bills 2000).

7.2.4 The tigerfish, *Hydrocynus vittatus*

Hydrocynus vittatus is an active predator in the main river channels that spawns in December/January on a sandy substrate in the vicinity of aquatic vegetation along flooded riverbanks (Steyn *et al*. 1996; Skelton 2001). It is reported to make breeding migrations both up and downstream to suitable spawning habitat. Fecundity is extremely high, with up to 780,000 ova recorded in fish of 70 cm fork length (FL).

7.3 Description of status prior to river regulation

7.3.1 *Clarias gariepinus*

Under the natural flooding regime of the Lower Zambezi River, C. gariepinus would have been abundant on the floodplains, as currently found in the Lower Shire River. The peak breeding period for the species is at the beginning of the rains in December, coinciding with the first rains and rising water levels. Breeding continues on a smaller scale until March. The peak flood months for the Lower Zambezi were February-April, providing extensive flooded areas in which *Clarias* juveniles from the December/January spawning would have thrived. The extent of flooded areas would have been extensive and long lasting with annual inundation. The larger the flooded area the better the chance of sufficient numbers surviving to adulthood to breed and maintain high stock levels.

Experience from the Lower Shire River suggests that the species would have comprised about 50% of the catch. Depending on the area of flooding, the potential sustainable catch was very high. If, for instance, the area flooded was 500,000 ha (floodplain grass area estimated by Turpie *et al*. (1999)) and productivity of the Lower

Zambezi floodplains was similar to that of the Lower Shire River marshes[4], a direct comparison with the Lower Shire fishery suggests a yield of 25,000 tonnes.

7.3.2 Oreochromis mossambicus

Under the natural flooding regime, *O. mossambicus* would have been abundant on the floodplains, as found in the Lower Shire tributary of the Lower Zambezi. Catches of fishes in breeding condition were highest before the rains in November after a gradual increase in adults in breeding condition from August. Very low catches in December may be a result of adult males remaining on their nests while the females were in cover in vegetation while mouth brooding their fry. Both sexes were thus difficult to catch because they were not moving around then (Willoughby and Tweddle 1978). Spawning continued into the flood period, with some females found in breeding condition until March/April. The lull in spawning during the dry cold season may be related to the low water temperatures at that time, with water temperatures below 20°C inhibiting spawning (Willoughby and Tweddle 1978). Chimatiro (2004) found January to be the peak spawning month in a later study. The peak flood months for the Lower Zambezi were February-April, providing extensive flooded areas in which the *Oreochromis* juveniles would have thrived. The extent of flooded areas would have been extensive and long-lasting with annual inundation. The larger the flooded area the better the chance of sufficient numbers surviving to adulthood to breed and maintain high stock levels.

Experience from the Lower Shire suggests that the species would have comprised about 20% of the fishermen’s catches. Depending on the area of flooding, the potential sustainable catch was high.

7.3.3 *Labeo altivelis*

Labeo altivelis is primarily a riverine fish, found only rarely on floodplains. It spawns at the beginning of the rains, almost certainly in rising waters along the flooding vegetated banks of rivers. It makes large migrations upstream to spawn, which makes it very vulnerable to capture in smaller rivers than the Zambezi. The species has a total spawning strategy (i.e. all eggs released at once and not in batches over a period of time) and thus it may be vulnerable to severe recruitment failure if the flood level drops too quickly, leaving eggs high and dry or smothered in silt, as is believed to have happened to *Labeo mesops* in Lake Malawi in the 1960s resulting in fishery collapse (Skelton *et al.* 1991). Because the species is not floodplain dependent, the stocks were influenced only by river level changes and fishing in the main river channels, which is a difficult undertaking.

7.3.4 Hydrocynus vittatus

Hydrocynus vittatus is primarily a riverine fish, found only rarely on floodplains, as it is an active predator that prefers well-oxygenated water. It is reported to make breeding migrations both up and downstream to suitable spawning habitat at the beginning of the rains, December/January, on a sandy substrate in the vicinity of aquatic vegetation along flooded riverbanks (Steyn *et al*. 1996; Skelton 2001). The condition of the fish is strongly influenced by the flood regime. On the Barotse Floodplain, tigerfish were observed to be very lean in May at peak flood level as a result of the highly dispersed prey species, whereas at low flow they were in peak condition because of the ready availability of prey species forced off the floodplain by

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[4] As a lot of the water supplying the Lower Shire comes from Lake Malawi and has higher conductivity, the Lower Shire marshes may be slightly more productive.

falling water levels and thus concentrated in a much smaller area (personal observations). The tigerfish is a very important species, both in the subsistence fisheries and in recreational fishing. In other parts of the Zambezi River system, successful tourist fishing camps have been set up with the tigerfish as the main quarry. The tigerfish is therefore probably the most valuable fish species from an economic point of view and could be the subject of recreational fisheries tourism development in the Lower Zambezi.

7.4 Description of the current trajectory in condition

After 30 years of operation of Cahora Bassa, it can be assumed that the situation with regard to freshwater fish, diversity, distribution and abundance has stabilised and that few further changes might be expected if the situation remains unchanged for a further 30 years. Fish have relatively short life spans and thus there have been numerous generations since the dam was completed. The occasional flood from either flood releases from the dam or from the tributaries entering the river downstream of the dam will boost populations of those species that utilise the floodplains while drier years will cause falls in population. The fluctuations in fish numbers from these causes will be greater than any effects of the dam if there is no change in the Cahora Bassa operating rules.

There is, however, the possibility that some cut-off channels will silt up and be lost as fish habitat if not scoured out by an occasional flood. Other channels may, however be opened up by localised flooding. Over a 30-year time span, overall effect is likely to be minimal, but on a longer time scale it is feasible that there might be a measurable reduction in fish habitat.

7.4.1 Clarias gariepinus

Bills (2000) reported the frequent capture of smaller specimens in floodplain lagoons and backwater channels. A few large specimens were caught in the main channel but it did not appear to be common. Bills (2000) reported that local people caught the species in a wide variety of fishing gears. The erratic nature of current flood releases from Cahora Bassa does not suit the breeding cycle of *Clarias*. Floods may be released too late for spawning, as reported for the Phongolo River (Stallard *et al*. 1986), or they may be too erratic and/or of too short a duration, interfering with egg development or stranding recently hatched juveniles. The other non-impounded tributaries flowing into the delta will result in some suitable spawning sites to mitigate the loss of spawning potential in the main Zambezi River, but the extent of this mitigation cannot be determined. The failure of the floods to fill the floodplains and maintain connectivity between aquatic systems in the delta will result in a loss of nursery and growing habitat. It is not possible to estimate the actual yield at present because of the absence of catch data and lack of information on area of floodplain and inter-connectivity of water bodies to allow fish to retreat back from the floodplains into main channels during the drying phase.

7.4.2 *Oreochromis mossambicus*

Oreochromis mossambicus is one of the most abundant species in the delta and is found in a wide variety of habitats (Bills 2000). Its abundance is almost certainly directly linked to floodplain area, as it will occupy all available habitat. With the reduced areas under flooding with the present regime, therefore, the potential yield is proportionately lower than in the past, as evidenced in the Kafue Flats, for example.

7.4.3 *Labeo altivelis*

Labeo altivelis continues to be common in the main river channels and is an important component of the fishery. The lack of inundation of floodplains is not of major importance for this species, although drainage from the floodplain may alter food availability and water quality (such as dissolved oxygen) in the river channel.

The erratic flood releases from Cahora Bassa Dam are detrimental to the success of this species as they are not synchronised with the species' natural reproductive cycle. The natural flooding regimes of other tributaries may be utilised by *L. altivelis* and thus mitigate for the erratic Cahora Bassa releases.

7.4.4 *Hydrocynus vittatus*

Hydrocynus vittatus continues to be common in the main river channels and is an important component of the fishery. The lack of inundation of floodplains is not of major importance for this species, but it is for its small prey species. The erratic flood releases from Cahora Bassa Dam are detrimental to the success of this species as they are not synchronised with the species' natural reproductive cycle. The natural flooding regimes of other tributaries may be utilised by *Hydrocynus vittatus* and thus mitigate for the erratic Cahora Bassa releases.

7.5 Description of desired target condition

7.5.1 *Clarias gariepinus*

The pre-regulation conditions of regular flood cycle synchronised with the reproductive cycle of the species are highly desirable for *C. gariepinus*. The minimum requirement is for the flood releases to mimic the natural cycle in timing if not in volume. Rises and falls of water level should not be too rapid and the flood needs to be of sufficient volume and duration to (a) allow the juveniles to take advantage of naturally productive flooded areas for feeding and growth, and (b) allow them to return to deeper channels as the flood recedes. It is difficult to quantify the benefits, but they will be directly proportional to the extent of flooding if the flood is properly synchronised with the natural cycle.

7.5.2 *Oreochromis mossambicus*

The pre-regulation conditions, with a regular flood cycle, are favourable for *O. mossambicus*, though not to the same extent as for *C. gariepinus*. The minimum requirement is for the flood releases to mimic the natural cycle and for flooding to take place to release nutrients from the soil/vegetation for growth. Rises and falls of water level should not be too rapid and the flood needs to be of sufficient volume and duration to (a) allow the juveniles to take advantage of naturally productive flooded areas for feeding and growth, and (b) allow them to return to deeper channels as the flood recedes. It is difficult to quantify the benefits, but they will be directly proportional to the extent of flooding. A dry period to allow burning of the floodplain grassland may benefit fisheries as the Biological Oxygen Demand is then reduced when the floodplain is next inundated, increasing primary productivity.

7.5.3 *Labeo altivelis*

The pre-regulation condition, with a regular flood cycle, is desirable for *L. altivelis*, but it is not essential for inundation of the floodplains to occur. The minimum requirement is for the flood releases to mimic the natural cycle to allow successful spawning and hatching of the fry. Rises and falls of water level should not be too rapid. It is impossible at this stage to quantify the benefits but successful spawning in the main river should lead to improved stocks and thus catches.

7.5.4 *Hydrocynus vittatus*

The pre-regulation conditions, with a regular flood cycle are desirable for *Hydrocynus vittatues*, but it is not essential for flooding to occur. The minimum requirement is for the flood releases to mimic the natural cycle to allow successful spawning and hatching of the fry. Rises and falls of water level should not be too rapid. It is impossible at this stage to quantify the benefits but successful spawning in the main river should lead to improved stocks and allow the development of valuable recreational fishery tourism.

7.6 Evaluation and ranking of the hydrological flow categories

Table 6.1 is a ranking of the three hydrological flow categories used in this study in terms of their impact on each of the vegetation sub-components. For all four sub-components (species), the need for an annual flood is given the highest ranking. A large flood every five years is beneficial in that it scours out channels and results in good recruitment and thus higher stocks for up to two years, while the dry season low flow levels are not of major importance to the stocks and fisheries. The relative importance of the various aspects of flow change is discussed in more detail below.

Table 7.1 Ranking of the freshwater fisheries sub-components against the hydrological change flow categories.

Flow category		Rank per sub-component			
		Clarius gariepinus	*Oreochromis mossambicus*	*Labeo altivelis*	*Hydrocynus vittatus*
Low flows	DSLF	1	1	1	1
Floods	Annual flood	3	3	3	3
	1:5 year flood	2	2	2	2

3 = most important
1 = least important.

7.6.1 Duration and timing of flooding

No information is available on the relationships between flooding and catch for the Zambezi Delta fishery, however, available information on similar fisheries can provide some insight into the expected relationships.

Welcomme (1975) showed strong positive correlation between catches from floodplains on the Kafue River floodplain, the Niger Central Delta, and the Lower Shire floodplains and flood levels in the previous year, and indicated that good floods lead to high recruitment. Tweddle *et al*. (1995a), however, showed a positive relationship between river level and catch in the same year for the Lower Shire. This suggests two possibilities:

- either there was an intensification of the fishing effort since the analysis of Welcomme (1975), resulting in exploitation of the juvenile fishes, which form a major component of the catch with fewer fish surviving to contribute to catches in subsequent years, or;
- there is an annual influx of fish, in proportion to the extent of flooding, as a result of migrations upstream from the Zambezi River to breed.

Regardless of the explanation, the relationships clearly show the benefits to the fisheries of good floods.

Welcomme (1995) conducted a review of floodplain fisheries, both in Africa and elsewhere and came to a number of conclusions relevant to the present study. He emphasised the importance of maintaining aquatic connectivity, stating that the integrity of the channel-floodplain system, in so far as it affects fish and fisheries, is mainly a function of the lateral and longitudinal connectivity, both within the aquatic system and between the aquatic system and its basin. The major direct impact on fisheries of interfering with the connectivity is through migration. Many elements of the fauna migrate both longitudinally and laterally within the system for breeding, feeding or refuge. Interruptions in the migratory pathways result in the elimination of such mobile elements of the fish assemblages. The diversity of the fish community depends on an equal diversity in habitat. Welcomme (1995) further points out that productivity of lower order rivers originates in deposition or washing in of nutrients, silt and allochthonous material from headwaters.

In the Zambezi Delta, connectivity has considerably reduced as a result of interruption to the flood regime by Cahora Bassa Dam. This is illustrated by Beilfuss (2001), who presented topographic maps of the delta historically and under current conditions, showing numerous obstructed waterways that were formerly open.

In addition to the need to maintain connectivity, Welcomme and Hagborg (1977) pointed out that minimum water levels determine the habitat potentially available for fish production. Viable stocks must remain to reproduce to restock the floodplain each year. For low water refuges to be viable they must retain sufficient stocks of reproductively active fish during drawdown.

Welcomme (1995) stated that it appeared that fish assemblages in flood rivers are almost uniquely regulated by the morphology and hydrology of the system in which they live. Discussing relationships between flood and catch, Welcomme pointed out that the rapidity with which even heavily exploited assemblages and species respond to improvements in flooding indicates the extreme resilience of such systems provided the integrity of the system is maintained. Improvements in the flood regime by manipulation of flow through Cahora Bassa Dam can thus be expected to result in rapid improvement of fish stocks.

Other studies have showed that maximum lake and impoundment yields closely approximate maximum yields from river floodplains maintained at a constant level. However, with the effect of the flood pulse, the same levels are produced on active floodplains in one half to one third the time, freeing the floodplain for further production during its dry phase (Bailey, 1991, cited in Welcomme, 1995). This emphasises the need to mimic the natural flood cycle. An example of intense fish production in the Lower Zambezi system was Bangula Lagoon in the Lower Shire marshes (until it became choked by water hyacinth in the 1980s). This lagoon dries in the dry season and is heavily utilised by cattle, resulting in very high nutrient loads on refilling and thus a highly productive fishery (Shepherd *et al*. 1976).

Fisheries in unregulated rivers, e.g. the Barotse floodplain on the Upper Zambezi River, have four major components, a low water fishery in the main channel and residual waters on the floodplain, a fishery for migrating fish in the main channel and channels leading on to floodplain during rising flood, a fishery on floodplain during the flood, and a fishery for fish moving off the floodplain during the receding water period.

Control of rivers through damming disrupts fishery components. In South Africa, the Pongholo River has a similar fish fauna to the Lower Zambezi and this river was the subject of a considerable amount of research centred on the fisheries of the floodplain and the operation of the Phongolopoort Dam constructed above the floodplain (e.g. Coke and Pott 1970; Heeg and Breen 1982; Merron *et al*. 1985; Stallard *et al*. 1986; Weldrick 1996).

Heeg and Breen (1982) emphasised the need for floods of sufficient duration to allow for the transfer of energy-rich allochthonous organic material to aquatic components, while Merron *et al*. (1985) described how the 1984 flood caused by Cyclone Demoina resulted in large-scale fish recruitment. Stallard *et al.* (1986) pointed out that flood release through the dam in February/March was too late in the fishes' breeding season for them to take advantage of flood release. This observation is very relevant to the present study, where different time frames are considered for flood release from Cahora Bassa.

The recommendations resulting from all the Phongolo River studies was that the water releases through the dam should be as close to the natural flood regime as possible.

The study by Chimatiro (2004) on the Lower Shire also points to the need to provide flood pulses mimicking the natural regime. Chimatiro modelled the relationships between fish biology and hydrodynamic factors and statistically demonstrated that the flood pulse was the driving force behind major biological cycles of the fish. He also found that the most important measure for increasing yield is the retention of the maximum possible water level during the dry season.

7.6.2 Variability in magnitude of annual flood

Under a natural regime, variations in flood levels have a major impact on fish catches in subsequent years (Welcomme 1975; Tweddle *et al*. 1995). High floods are directly related to good catches, because the extra flooded area results in better juvenile survival and growth of floodplain loving species such as *Clarias gariepinus*. This suggests that creating smaller floods in some years will be detrimental to the first two subcomponents.

On the other hand, floodplain fisheries benefit enormously from the flooding/drying cycle. Active floodplains produce the same amount of fish in one half to one third the time of permanently flooded areas, freeing the floodplain for further production during its dry phase (Bailey 1991, cited in Welcomme 1995). This emphasises the need to reproduce the natural flood cycle. Lagoons that shrink greatly in area in the dry season and are heavily utilised by cattle result in very high nutrient loads on refilling and thus highly productive fisheries (Shepherd *et al*. 1976). Under such circumstances, it may be beneficial to provide a greater flood than normal every few years as this will release accumulated nutrients from the rarely inundated land for the benefit of the aquatic ecosystem.

In conclusion, slight variability in the magnitude of the annual flood will probably have minimal impact when considered over a period of a few years, but the fishermen dependent on fish catches for their livelihoods/subsistence will experience less consistent catches than if the flood was always of the same magnitude.

7.7 DRIFT consequences

See Appendix A.

7.8 Discussion

This discussion addresses the question:
"Do you think that, in a 30-year horizon, a "pre-regulation condition" in the delta could be achieved if the flow conditions prior to river regulation were reinstated, i.e., do you think the current condition is reversible?

Under the changes in flow regimes considered in this exercise, it is unlikely that full inter-connectivity will be restored (R. Beilfuss, pers. comm.) and thus the fish stocks are unlikely to reach a pre-regulation condition in a 30-year horizon. The situation could, however, change, if for example a major cyclone in the Zambezi Delta area, such as that which struck the Phongolo river system in 1984 (Merron *et al*. 1985), resulted in extensive flash flooding and thus the scouring of the closed channels. Reinstatement of flow conditions prior to river regulation would then allow the channels to be regularly scoured and kept open.

The extent of connectivity actually required to allow the fish stocks to fully utilise the floodplain depends partly on fishing intensity and partly on whether the isolated waters dry up and thus eliminate the fish stock. The key issue is the distribution of fish brood stock throughout the system needed to provide recruitment to flooded areas each year.

Inter-connectivity will affect the four sub-components differently. Provided refuge areas are available throughout the year in the cut-off channels, *C. gariepinus* and *O. mossambicus* should not be seriously impacted as they will spawn in the nearest available suitable spawning areas. *Labeo altivelis* and *Hydrocynus vittatus*, on the other hand, prefer flowing rivers and they make spawning migrations along the main river channels. Populations of these species will therefore be much lower in cut-off channels than they are in the main, flowing river channels. Thus it can be inferred that *C. gariepinus* and *O. mossambicus* would be at pre-dam levels but the other two will not unless a major climatic event results in scouring of the previously accessible areas.

The freshwater fish fauna of the Zambezi Delta is adapted to the natural flood regime. Spawning of the majority of species is synchronised with the flood cycle. The fauna can be broadly divided into mainstream species and floodplain species. For the purpose of this assessment of impacts of changes in the Cahora Bassa operating regime, three species were chosen that are very important in the fisheries. The fourth is a species that is considered, because of its active open-water predatory habits, to have a major impact on the ecology, particularly behaviour, of the rest of the fish fauna, i.e. the tigerfish, *H. vittatus*. Two of the species considered, *C. gariepinus* and *O. mossambicus*, utilise the full range of habitats available in the delta, while *H. vittatus* and *L. altivelis* are primarily mainstream fishes.

Although this report deals primarily with these four species, the majority of the other 70+ species in the delta area are also important, both ecologically and in the fisheries. Many smaller species such as *Barbus* spp. (~10 species) are the first to colonise new habitats as they become available through flooding and are regarded as pioneering species well adapted to the flood cycle.

Operating Cahora Bassa dam to mimic the natural flood cycle will have a beneficial impact on the fish population, whatever the scale of flood that is eventually agreed. The larger the flood, the better the conditions for the fauna.

To provide optimum conditions for fish breeding, recruitment and growth, the river level should ideally be allowed to rise from December through to February, without sudden rises and falls. Rapid changes in level have serious adverse effects on spawning success as eggs and fry are either left high and dry or are suddenly placed in deeper water at greater risk of exposure to predation.

The reproductive pattern of *C. gariepinus* is here described as it illustrates the habitat requirements and thus the flow regime needed. This species moves laterally from the river channel into newly flooding areas to spawn, possibly stimulated by chemical cues as dry land becomes submerged or rainfall drains off the land. Large congregations of spawning catfish can often be seen and heard in the shallows, such as just behind the reed-lined banks of the rivers as the banks are overtopped. For several weeks afterwards the young growing fry can be caught in flooded vegetation in very shallow water on the floodplains.

Oreochromis mossambicus breeds over a longer period both before and after flooding starts. The length of the breeding season may be temperature dependent with reduced activity in the colder months. This species is a maternal mouth-brooder, with territorial males that construct saucer-shaped nests in the bottom sediments. The mouth-brooding female guards the eggs in cover and after release the fry stay in cover in the shallows, gradually moving deeper as they grow. They make extensive use of the floodplain and abundance is directly related to the flooded area. The juveniles do not emerge from cover into the main river until they have attained a length of about 20 cm, by which time they are less vulnerable to predation by tigerfish.

The two predominantly riverine species, *L. altivelis* and *H. vittatus* both breed early in the rains with the first floods and, as for *C. gariepinus*, the cue is believed to be chemical as a result of run-off from the land coupled with rising water levels.

The scale of flooding will have a direct influence on the size of the fish stock for *C. gariepinus*, *O. mossambicus* and all the other floodplain species. The higher the level and the longer the period of flooding, the greater will be the positive benefits for the fish stocks and thus for the catches in the fishery. Flooding should ideally start in December, as the stimuli for breeding in three of the four species occur normally in December or January and the fish are in breeding condition then. A further benefit of early flooding is the extended period of warm water temperatures on the flooded plains, which will result in better growth for a longer period of time for the juvenile fishes before the cooler winter months.

8. Specialist Study – Livestock

8.1 Introduction

Much of the lower Zambezi Valley is well suited for livestock production, and livestock grazing activity is closely linked to Zambezi flood patterns. Livestock were typically herded along the river banks, where they found the best pasture and water supply. The availability of good quality pasture in the late dry season was especially important, and depended on prolonged flooding during the wet season. In the 1970s, the Zambezi Delta supported more than 50,000 head of cattle, the majority associated with the Sena Sugar Estates at Marromeu, which was the largest supplier of cattle to Beira. Other important areas for cattle production included Chinde, Mopeia, and Caia.

During the prolonged civil war in Mozambique, livestock in the delta (especially cattle and goats) were decimated. Today, there are less than 5000 head of cattle remaining in the delta (2000 at Chinde, 2000 at Marromeu, 500 at Mopeia, and 500 at Caia). Livestock restocking programs are currently underway in the delta, but most households own only chickens and ducks. The economic value of the loss of livestock has not been calculated, but was likely severe for many households, particularly during the height of the civil war and the regional drought when food security was low.

During the past decade, livestock numbers have been increasing and farmers are very interested in re-establishing the herds that existed prior to the war. There are large concentrations of cattle in Zambezia Province. Inaccessibility, poor market facilities, and diseases severely limit livestock production.

As livestock numbers grow, the return of regular annual Zambezi River floods will become increasingly important for maintaining good quality pasture. The carrying capacity of the pasture is now considered to be low in the delta region, especially on the alluvial terraces of the Zambezi, because of the lack of flooding. It is also interesting to note that many people now avoid grazing their animals along the river because the owners are afraid that crocodiles will catch and eat their livestock. The areas most affected include Luabo, Mopeia, and Chinde. Cattle production at Marromeu occurs inside the dykes protecting the Sena Sugar Estates, and is less influenced by Zambezi flooding patterns.

8.2 Selection of key sub-components

Only one sub-component was considered for livestock:

1. Cattle

8.3 Description status prior to river regulation

In the 1970s, the Zambezi Delta supported more than 50,000 head of cattle, the majority associated with the Sena Sugar Estates at Marromeu, which was the largest supplier of cattle to Beira. Other important areas for cattle production included Chinde, Mopeia, and Caia.

8.4 Description of the current trajectory in condition

Over the next 30 years, assuming no-change in the present operating rules of Cahora Bassa Dam, livestock will become limited by the availability of dry season pasture (carrying capacity of the delta).

8.5 Description of desired target condition

The goal is to restore historical numbers of livestock to the delta (approximately 50,000 head of cattle).

8.6 Evaluation and ranking the hydrological flow categories

Table 8.1 is a ranking of the three hydrological flow categories used in this study in terms of their impact on each of the sub-components. The reasoning supporting the rankings is discussed in more detail below.

Table 8.1 Ranking of the livestock sub-component against the hydrological change flow categories.

Flow category		**Rank per sub-component**			
		Livestock			
Low flows	DSLF	1			
Floods	Annual flood	3			
	1:5 year flood	2			

3 = most important
1 = least important.

Dry Season Low Flows do not have a significant effect on livestock.

Restoration of annual floods will benefit livestock by providing better foraging conditions at the end of the dry season. Small annual floods that do not inundate the floodplains and riparian areas will not provide significant benefit. Medium to larger floods that inundate the riparian areas and floodplains will provide benefit. The floods will the quality of foraging grasses, especially at the end of the dry season, and will provide more watering areas on the floodplain. The overall benefits of floods for livestock will increase with the depth and duration of flooding. The timing of the flooding (December or January) is not critical. Slight variability in the magnitude of the annual flood might is unlikely to affect livestock in the long-term. The relationship between ticks, tick-borne diseases and flooding requires further investigation (e.g., Kafue Flats).

Large floods such as 2001 may benefit the carrying capacity of the delta pasture, but also could result in death of livestock during the flooding events, so the overall benefit is not significant if there are regular annual floods occurring.

8.7 DRIFT consequences

See Appendix A.

8.8 Discussion

This discussion addresses the question:

"Do you think that, in a 30-year horizon, a "pre-regulation condition" in the delta could be achieved if the flow conditions prior to river regulation were reinstated, i.e., do you think the current condition is reversible?

If natural hydrological conditions of the delta are restored, it is possible to restore the historical carrying capacity of pasture for livestock (livestock numbers will depend mainly on restocking).

9. Specialist Study – Large mammals

9.1 Introduction

This section addresses the anticipated effects on the distribution and abundance of large mammals of the flow changes described in Section 3.

The Marromeu Buffalo Reserve and official hunting blocks (*Coutadas*) in the Zambezi River's Delta are recognized internationally as unique areas for their diversity and biomass of wildlife (Timberlake 2000a). However, this area was at the epicenter of a civil war from 1980 until a peace accord was signed in 1992. The abundant wildlife in the area was the principal source of animal protein used to sustain warring factions involved in the conflict, while ivory and rhino horn became the bounty for war weapons exchange (Dutton *et al.* 2001). The war resulted in a catastrophic decline of between 70% and 90% of most ungulate species in this area. Similar trends were observed in the nearby Gorongosa National Park (Dutton *et al.* 2001).

It is also highly probable however that modified hydrological flow regimes, due to the construction of three large dams in the Zambezi River catchments, also precipitated a process towards declining ungulate numbers in the Marromeu Delta, and that may be hampering the recovery of ungulate populations. Prior to the construction of Kariba Dam peak floods spread over a mosaic of vegetation communities in the 12,000 km^2 (1,200,000 ha) Zambezi Delta, one of the largest wetland systems in southern Africa. Floodplain grasslands were inundated with floodwaters for up to nine months of the year, and many areas were saturated throughout the dry season (Beilfuss 2001, in prep b). Kariba, and later Kafue, and then Cahora Bassa dams have fundamentally altered the very large flood plain in the Zambezi Delta. With the great reduction in flooding, dry season forage has been lost for both livestock and wildlife (see Section 8).

Today nearly 90% of the Zambezi catchment is regulated and the natural flood cycles of the lower Zambezi River are now a phenomenon of the past. Flooding in the delta is now dependent upon local rainfall-runoff within the lower Zambezi catchments, or unplanned (possibly catastrophic) water releases from the upstream dams (e.g. 2001 floods). These hydrological changes are further exacerbated by the construction of dikes along the lower Zambezi for agriculture, trains and road networks that prevent medium-sized floods from inundating the south bank floodplains (Beilfuss 2001).

The Marromeu Delta system (6,880 km^2 = 688,000 ha) consists of the Buffalo Reserve (established in 1950's) and 4 surrounding hunting blocks established in the 1960's (*Coutadas* 10, 11, 12, 14; see Figure 9.1). Situated on the south bank these consist of floodplain grasslands, deepwater swamps, and mangrove forests (Beilfuss *et al.* 2000, Beilfuss 2001). In the late 1960's the Marromeu floodplains contained one of the highest populations of buffalo in Africa (Anderson *et al.* 1990). Much of the lower Zambezi valley is well suited for livestock production, and livestock grazing was closely linked to Zambezi flood patterns. Livestock were typically herded along the riverbanks, where they found the best pasture and water supply. The availability of good quality pasture in the late dry season was especially important, and depended on prolonged flooding during the wet season (Loxton Hunting and Associates *et al.* 1975 cited in Beilfuss 2001).

Migratory and local movements of wild ungulates in the delta were opportunistic responses to the availability of different vegetation communities allowing ungulates to meet their year-round life requirements through rotational grazing in response to natural flood cycles (Tinley 1977). Herbivory is an integral part of the succession dynamics of floodplain systems, exerting selective pressure on the delta grassland composition. Many herbivores have co-evolved with plants, acting as dispersers and influencing plant regeneration patterns. Coarse grass (bulk) feeders, especially buffalo and elephant, graze down rank pastures and enhance grazing conditions for the medium- to short-grass feeders such as waterbuck and zebra. Shorter grassland is more suitable for a wide range of wetland birds, whose diversity and abundance is increased by ungulate grazing. The mulch of grass flattened by large herds of buffalo and elephant also enables greater penetration of rain and results in better primary production of floodplain grasses. The conversion of plants to dung speeds nutrient recycling and increases floodplain productivity. Following the ebb line is a zone of changing width of moist soil (depending on micro relief at each water level), supporting a green flush of vegetation that gradually dries out on its upper margins. Grazing herds follow the green zone and vacate browning lands. During these annual migrations, herbivores provide opportunities for plant regeneration by removing large quantities of emergent vegetation and trampling seed into soils, while browsers remove woody growth at the floodplain periphery (Tinley 1977).

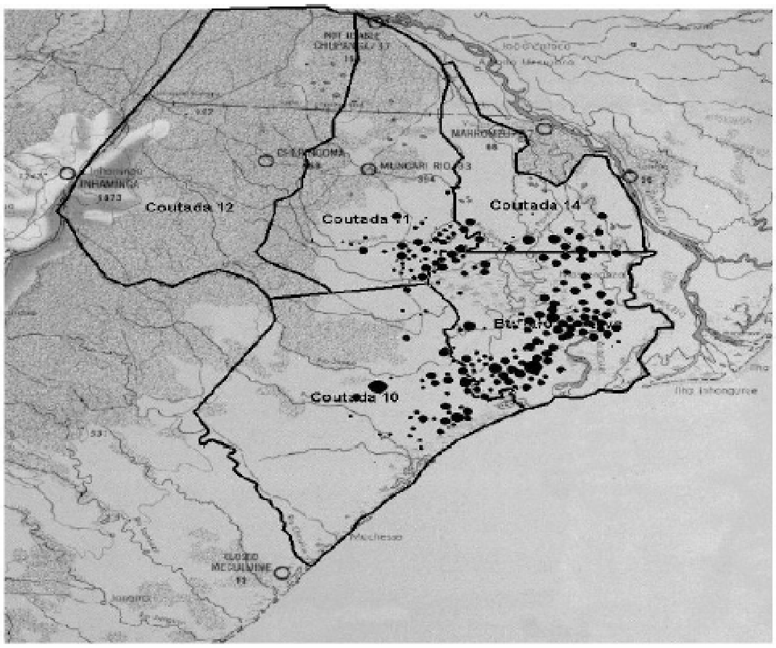

Figure 9.1 Map showing the Marromeu buffalo reserve and the four hunting blocks (*Coutadas*) on the southern bank of the Zambezi Delta (from Dutton *et al.* 2001).

Primarily from the reduction in flooding, relatively drought-tolerant grassland species have displaced flood-tolerant species in the broad alluvial floodplain, and saline grassland species have displaced freshwater species on the coastal plain. Of critical importance for large herbivores is the tussock grass habitat, reduced by 23% over the last 40 years, a major source of food in the wet season grazing areas for buffalo, zebra and waterbuck migrating from the more deeply inundated floodplains (Beilfuss 2001, Beilfuss *et al.* in prep).

Soft-leaved grasses and sedges in the swamps, preferentially grazed on by buffalo and waterbuck, have been reduced by 6% over the last 20 years (Beilfuss 2001, Beilfuss *et al.* in prep). Woody vegetation and thickets have invaded grasslands, and drought resistant grassland species have replaced stressed wetland species of higher nutrient content. Similar patterns have been shown for the Kafue Flats and middle Zambezi floodplains following river regulation (Kamweneshe *et al.* 2002). Buffalo are highly susceptible to starvation and high mortality when pastures dry out early, which is exacerbated when uncontrolled fires sweep across the delta. Hippo and waterbuck are also vulnerable to poor forage conditions in floodplains (Dutton *et al.* 2001). This also allows easy of access to the game by local hunters "*poachers*," a major problem in the Marromeu Buffalo Reserve and surrounding hunting blocks (Tony Wicker, *pers. comm.*)[5] and intrusion by poachers throughout the year is facilitated by the drier the floodplain. Furthermore, as a result of the constant scouring flow without a sediment load, the bed of the lower Zambezi River has incised down up to 3 m, thus further reducing flood spillage onto the floodplain.

The total area of perennially wet grassland, permanent deepwater swamp, and coastal mangrove is now about 2600 km^2 (260,000 ha), or 22% of the total delta area. There has been an 18% reduction in permanently flooded areas since 1960, and a 12% reduction in perennially wet grassland. The average duration of inundation in the hydromorphic vertisols along the western edge of the floodplain has decreased from 4-6 months per year in the past to 2-3 months per year today. These changes suggest that moisture conditions have become limiting in many areas of the floodplain. During the dry season most of the delta grasslands burn nowadays and deciduous *Acacia* savanna covers much of the higher delta plain (Beilfuss 2001; Beilfuss *et al.* in prep).

Although methodologies and equipment used over the past 40 years have not been consistent, the fluctuations in population numbers, individual species and their spatial distribution provides a reasonable impression of the impact of both the altered flooding regime and the effect of uncontrolled meat hunting operations (mainly buffalo both as a source of protein for the sugar companies and for soldiers during the civil war; Dutton *et al.* 2001). It is estimated that between 1976 and 1979, 12,000 buffalo were culled for meat production (Anderson *et al.* 1990). This was probably a sustainable harvest as wildlife populations remained strong (Tello 1986). However, civil war and anarchy ended sustainable management of this area in 1980. Anderson *et al.* (1990) place the cause for major reduction of wildlife on uncontrolled hunting with military weapons during the protracted civil war. Also over a period of only 7 years – 5 at the end of the civil war and the first 2 years following the ceasefire in 1990 – wildlife populations were decimated by illegal commercial meat hunting (Anderson *et al.* 1990; Cumming *et al.* 1994; Dutton *et al.* 2001; see Figure 9.2).

The reduction in ungulate wildlife has not been restricted to buffalo*.* A geographic race of Burchell's Zebra *(Equus chapmani)* and hippo also are on the brink of extinction (see Figures 9.2 and 9.3). *Coutada* (hunting block) operators in the delta now complain that the foraging quality of the delta grasses has decreased. Similarly in Mana Pools, between Kariba and Cahora Bassa dams, the frequency of perennial grasses declined with lack of Zambezi flooding (Dunham 1989 cited in Beilfuss 2001). The virtual elimination of hippos has probably contributed to the drying out of abandoned alluvial channels and loss of open water areas, the wallowing activities of hippo being vital in maintaining open water conditions in the many small ponds and distributary channels of the delta (Tinley 1977). These changes have been exacerbated by drier conditions across the delta from reduced flooding.

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[5] Tony Wicker, Nyati Safaris Limitada, Mozambique, P.O. Box 617, Krugersdorp, 1740, South Africa.

Likewise, the reduction in wildlife grazing pressure has also contributed to the increased extent of wildfires during the dry season. In the 1960's and 1970's intense grazing by wildlife created a mosaic pattern of grazed and ungrazed grasses (Tinley 1977; Tello and Dutton 1979), creating natural firebreaks. With the reduction in wildlife populations, vast expanses of ungrazed floodplain have created highly combustible vegetation at the end of the dry season. Wildlife also has unlimited access to the delta floodplain throughout the year, since there are no floods to drive them to the upland margin.

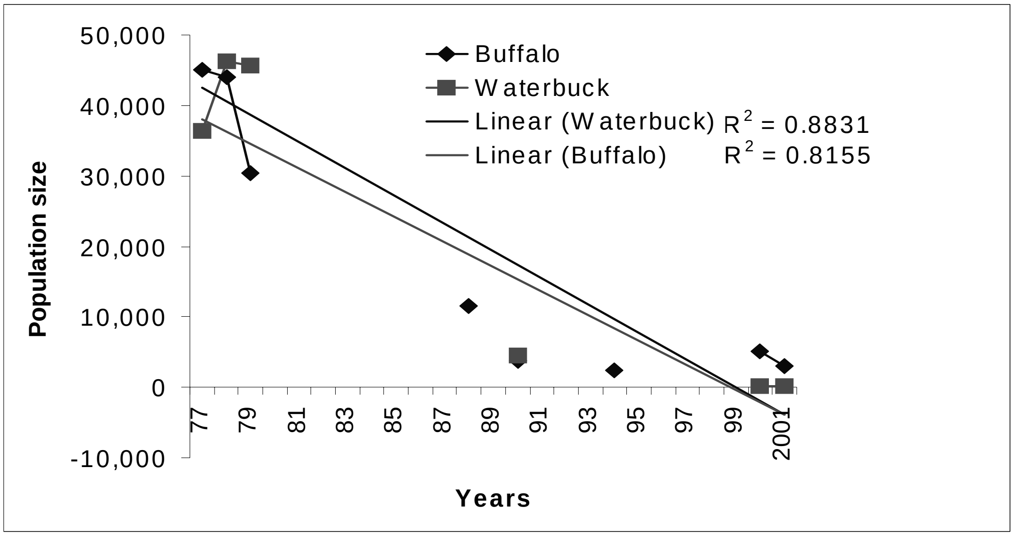

Figure 9.2 Population trends of the major high density (buffalo and waterbuck) wildlife species in the Marromeu Delta following the closure of Cahora Bassa dam.

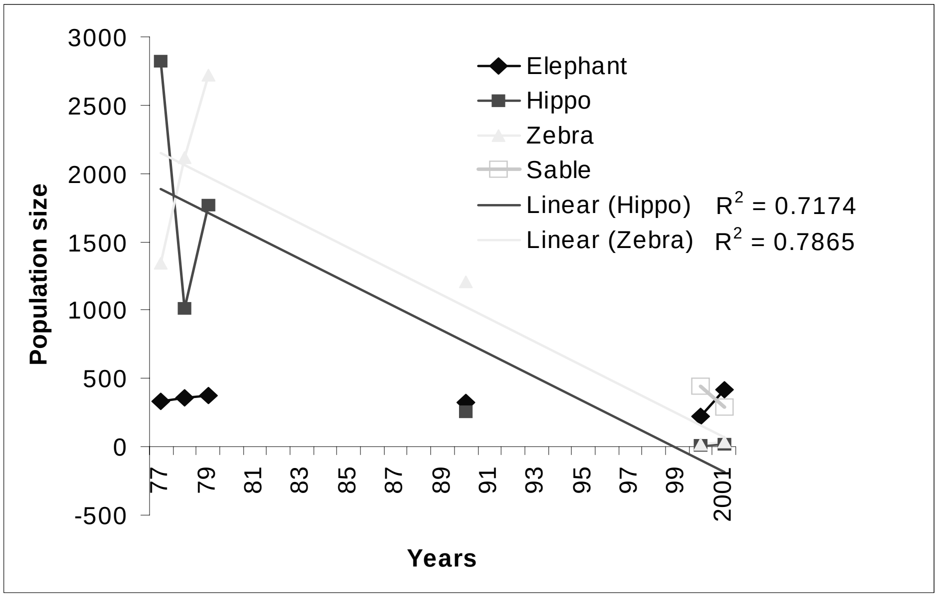

Figure 9.3. Population trends of the more important lower density wildlife species on the Marromeu Delta after closure of the Cahora Bassa Dam.

The floodplain grasslands are now highly susceptible to overgrazing because they are no longer rested during the flood season each year. The decreased grazing pressure from reduced wildlife numbers has, however, likely prevented further degradation of the floodplain grasslands. As wildlife populations slowly recover in the delta, unless the hydrological conditions in the delta improve, careful management will be required to prevent the widespread degradation of the floodplain grasslands due to overgrazing (Beilfuss *et al.* 2000; 2001).

There is widespread opinion among *Coutada* operators and wildlife biologists that the delta can no longer support the large herbivore concentrations it supported prior to the 1980's (R. Beilfuss *pers. comm.*), implying impacts primarily from reduced flooding, while some operators (T. Wicker, *pers. comm*.) believe that continued poaching into the 21st century is the main cause. Many studies (SWECO 1982, Anderson *et al.* 1990, Beilfuss 2001, and Li-EDF-KP Joint Venture Consultants 2001) recommend the consideration of artificial flooding. The question needs answering, why is the population of buffalo in the Marromeu Complex stagnant at around 4 000 – 6 000 individuals, along with apparently stagnant numbers of other ungulates? What percentage of the failure to increase exponentially by buffalo is from continued poaching by a disenfranchised and impoverished community of about 20,000 people surrounding the area, versus the change in habitat from the loss of flooding? This needs careful investigation followed up by mitigation.

If one considers the buffalo population trends specifically it would seem that in 1977 the population was comprised of about 45,000 individuals. With the initiation of an official cropping program for dried meat the population, it was reduced substantially by 1979 to about 30,000 individuals (Tello and Dutton 1979). This controlled cropping was abandoned during the civil war, but rampant uncontrolled hunting had reduced the population to about 12,000 individuals by 1988, which continued unabated into the 1990's and resulted in the population being reduced to about 3,000 individuals by 1994 (Cumming *et al.* 1994). The population has subsequently remained relatively constant around that figure (Dutton *et al.* 2001). The buffalo herds that survived the war years are now concentrated in the lowest, wettest part of the reserve. The emergency flood release in April 2001 resulted in over 40% mortality of the mainly buffalo calf population. Natural floods pre-Cahora Bassa may have impacted in a similar way on the buffalo population estimated then at >40 000, although under natural conditions the herds may have known when and where to move as the floods rose. Regardless, there would not have been as severe an impact as on the present low population, resulting in the substantial decline from 5125 in 2000 to 3056 in 2001.

While the major declines up until 1990 would seem to have been driven by excessive human exploitation of the species, it is unclear whether the low current levels are due to ecological changes in the Zambezi Delta due to reduced flooding, or continued excessive human utilization. This is equally the case for the other ungulate and mega-herbivore species depicted in Figures 9.2 and 9.3.

The once productive Zambezi Delta is now facing serious socio–ecological problems that will require multidisciplinary management strategies approach to resolve through a partnership between the provincial government and private enterprise.

9.2 Selection of key sub-components

When considering which key sub-components to select the feeding type and relative body-size of the respective herbivorous large mammals that are known to exist in the Zambezi Delta were reviewed. Clearly there are more than four species of interest, and while some could possibly be clumped, it was decided to focus on four individual or key species. In making this selection it was decided that although they are no doubt important and included initially, the relatively low and stable numbers of elephants counted against them being included in the analysis. White rhino are now extinct in the delta. Amongst the ungulates species that were considered included: sable antelope due to their commercial value and relatively large population size, eland (hunting value), duikers, impala (populations decimated by the flood), kudu, Lichtenstein’s hartebeest, nyala, oribi and reedbuck (both of which favour moist grassland). In an attempt to include the key species the following sub-components were chosen.

1. Bulk-grazing ungulates - buffalo
2. Tall moist-grass grazers - waterbuck
3. Short-grass megaherbivores – hippo
4. Medium- to short-grass ungulates –zebra.

9.2.1 Buffalo: Bulk-grazing ungulate

The Zambezi Delta was once famous for supporting the largest population of buffalo in Africa. However, the civil war depleted their numbers to critically low numbers, from which they do not seem to be recovering. This is possibly due to the altered landscape through reduced flooding, and persistent excessive utilization. Buffalo are almost unique in their bulk grazing nature amongst the antelope ungulates, and also due to their importance in the ecosystem are dealt with as an individual sub-component here.

9.2.2 Waterbuck: Tall moist-grass grazer

Waterbuck are regarded as a key species for the analysis due to their former large population size, and their requirement for moist grassland or proximity of suitable grazing to water. The population of waterbuck in the delta has shown similarly precipitous declines to the buffalo population, and is thus of similar interest.

9.2.3 Hippo: Short-grass mega-herbivore

Hippos are an important component of any wetland/floodplain system and are currently nearing extinction in the Zambezi Delta. Substantive habitat restoration will be required to re-instate their populations to former levels. Being a short-grass bulk grazer they are also very important architects of short grass grazing meadows that are favoured by other short grass grazing ungulates such as zebra (which are also at very low numbers in the Zambezi Delta).

9.2.4 Zebra: Medium to short-grass grazer

A specific subspecies of zebra was historically well represented in the Zambezi Delta but as with buffalo is fast approaching extinction. Zebra are relatively more tolerant of dry grass environments than the other species selected and their near extinction in the area is suggestive of severe over-utilization, and less so of an altered water flow pattern.

9.3 Description of status prior to river regulation

Much of the knowledge about the status of the various mammal sub-components is contained in the introduction and selection of sub-components described above. Here the status prior to river regulation, current trajectory and desired target condition of the major wildlife species are depicted in Table 9.1. A description or explanation thereof follows

Table 9.1 Status prior to river regulation, present-day status, and the desired target condition for the various wildlife populations in the Zambezi delta.

Species	**Status prior to river regulation**			**Present-day status**		**Current trajectory**	**Desired target condition**
	1977*	**1978***	**1979***	**2000**	**2001**		
Buffalo	45,000	43,992	30,394	5125	3056	Low stable	20,000
Waterbuck	36,380	46,227	45,653	131	168	Low stable	15,000
Hippo	2820	1010	1770	12	17	Near extinction	2000
Zebra	1340	2120	2720	15	34	Near extinction	1500

Buffalo seem to be stable but at relatively low numbers. An increased flooding regime and reduced floodplain burning would probably create better habitat for the buffalo, but at this stage it seems as if illegal meat hunting could be having as much effect as habitat on curtailing population growth. The extent of legal trophy hunting while fairly high for a population that should be allowed to grow may in fact not be affecting the buffalo population dynamics very adversely as the trophy hunting should only be directed towards adult bulls. It is likely therefore that the remaining bulls in the breeding herds are sufficient in number to cover the receptive cows. A healthy safari hunting industry may also be beneficial in that their activities may help to curb illegal hunting, which is usually indiscriminate of the sex or age of the animals hunted.

Waterbuck were at similarly high numbers to buffalo in the late 1970's, but have plummeted to even lower numbers and are showing little sign of recovery. Whereas buffalo are highly mobile species not necessarily associated with water, waterbuck are always found near water and it is thus expected that a drying of the Zambezi Delta coupled with excessive utilization has been highly detrimental to this species.

Hippos are also important architects of wetlands, but are very susceptible to poaching and habitat alteration. The conditions that favour hippos need to be recreated, and the utilization and illegal hunting of the species must be curtailed until reasonable numbers have been re-established.

The zebra population in the Zambezi Delta seems to be at critically low numbers. Without detailed knowledge regarding the reasons for this meat poaching could be a major factor restricting or even decimating these populations. With a re-instated flood regime one wonders whether poaching access might become more restricted. However, this is possibly unlikely without effective and committed anti-poaching policing and regulation.

In summary therefore it would seem that flooding on its own is not the solution to the crumbling wildlife populations of the Zambezi Delta, and that to be effective it would have to be coupled with sustainable or conservative trophy harvesting and effective protection of the important breeding segments of each population.

9.4 Description of the current trajectory in condition

Sub-component 1 – Buffalo

The buffalo population is probably at present being utilized to such an extent that it cannot grow. With effective conservation measures and conservative hunting quotas the population probably has the potential to grow to about < 10,000 individuals given current ecological conditions. Substantial flooding and reduced burning would seem to be required before the population can recover to former densities.

Sub-component 2 – Waterbuck

The waterbuck population being so closely linked to moist grassland would probably remain relatively stagnant at current low flow levels.

Sub-component 3 – Hippo

Hippo, already on the brink of extinction, are likely to disappear completely from the ecosystem due to poaching. With effective conservation, however, their population would probably start to show slow growth (± 5%/year) until they became constrained by suitable water (day resting) and grazing habitat.

Sub-component 4 – Zebra

Zebra seem to be on the brink of extinction, but would probably recover to a population of several hundred given effective conservation and reduced floodplain burning.

9.5 Description of desired target condition

See Table 9.1.

9.6 Evaluation and ranking the hydrological flow categories

Table 9.2 gives a rank to the hydrological flow categories in terms of their impact on each of the sub-components.

Table 9.2 Ranking of the large mammal sub-components against the hydrological change flow categories.

Flow category		**Rank per sub-component**			
		Buffalo	Waterbuck	Hippo	Zebra
Low flows	DSLF	2	2	2	2
Floods	Annual flood	3	3	3	3
	1:5 year flood	1	1	1	1

3 = most important
1 = least important.

For each sub-component it is estimated that the most important hydrological component would be a re-instated annual flood, although this might possibly be less important for sub-component 4 (zebra) which generally favour drier grasslands. Zebra would thus probably do best in relatively dry open floodplain environments, but would be negatively affected by too much burning and excessive utilization, whereas buffalo, waterbuck and hippo would probably be favoured by increased flooding. In pre-dam times the waterbuck population far exceeded that of any of the typical antelope ungulates and zebra, and for this reason it is felt that re-instated flooding would also be best for this sub-component.

9.7 DRIFT consequences

See Appendix A.

9.8 Discussion

A similar situation of reduced down-stream flooding in Waza Logone floodplain, Cameroon resulted in severe declines of several species of ungulates. However, once flooding was reinstated there were major positive impacts on wildlife populations within Waza National Park (Figure 9.4), which relies on the floodplain as a dry season grazing area. This clearly demonstrates the value of artificial flooding (Loth 2004). The artificial flooding also helped take pressure by elephants off *Acacia seyal* woodlands in Waza during the dry season by helping restore higher quality perennial grasses and water holes on the floodplain. However, crop raiding by elephants to the south after artificial flooding did not decrease, the area raided fluctuating between 8000 and 12,000 ha (de Longh *et al.* 2004).

Based upon the positive results from pilot artificial flooding, a number of scenarios were developed to expand flooding of the Waza Logone floodplain without negatively impacting the SEMRY rice schemes.

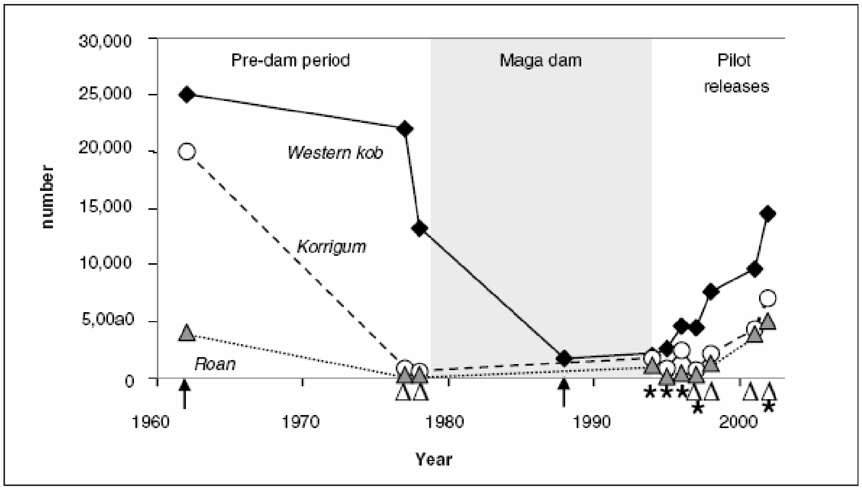

Figure 9.4 Increase in populations of western kob, korrigium and roan antelopes as a result of artificial floods from the Maga Dam on the Waza Logone floodplain, Cameroon.

10. Specialist Study – Waterbirds

10.1 Introduction

This section addresses the anticipated effects on the distribution and abundance of waterbirds of the flow changes described in Section 3.

The Zambezi Delta waterbird population is abundant and diverse. Some species are resident, others are migratory (intra-African, Palaearctic, and some nomadic). Several species are rare, and a few of these are regionally or globally threatened. All waterbirds in the Zambezi Delta are dependent on the floodplain ecosystem and its associated water regime (including the particular magnitude, timing, duration, and/or extent of surface waters) at some time of the year. Many species spend almost their entire life cycles in close association with the floodplain—feeding, roosting, loafing, nesting, and provisioning their chicks on the floodplain. Some waterbird species depend on specific floodplain conditions to secure their nests and chicks from predation, trampling, or fire, or to provide safe roosts. Many species require the rank growth of various wetland sedges and grasses for nesting materials or cover. Different species of waterbirds feed on a range of wetland food sources to meet their nutritional requirements for reproduction and migration, including underground rhizomes (tubers), seeds, and shoots of various aquatic and emergent plant species and animal protein such as snails, frogs, fish, and insects (and their larvae). The seasonal availability and abundance of these food items are determined in part by the hydrological flow regime. Hence, there are many important connections between waterbirds and the water conditions on the floodplain.

The importance of these connections are considered in this section.

10.2 Selection of key sub-components

The selected waterbird sub-components are:

1 Wattled Crane, *Grus carunculatus*.
2 Spurwinged Goose, *Plectropterus gambensis*.
3 Goliath Heron, *Ardea goliath*.
4 African Skimmer, *Rynchops flavirostris*.

10.2.1 Wattled Crane

The wattled crane is a Vulnerable species (BirdLife International 2000), resident in sub-Saharan Africa and among the most floodplain-dependent waterbirds in Africa. Wattled cranes feed predominately on tubers of *Eleocharis spp.* and *Cyperus spp* sedges and water lillies, which are rich in carbohydrates. Tuber productivity is closely related to the seasonal inundation of the floodplain, with carbohydrate reserves stored underground during the long dry season to stimulate new shoot growth at the onset of the next flood season. Experience from Asia, Australia, and elsewhere in Africa suggests that tuber productivity declines when hydrological conditions are altered, including failed flooding and/or permanent inundation (Beilfuss 2000). Wattled cranes are stimulated to breed by the onset of the annual flood. Eggs are laid, often near the time of peak inundation, on a giant platform nest constructed of rank grasses and sedges and surrounded by water to protect against predators and fire. Wattled crane pairs rear only one chick per brood, which is fed on the burst of plant and animal protein associated with the recession of floodplain waters during the dry season. Wattled crane ecology is covered extensively in Meine and Archibald (1996), and specifically for the Zambezi Delta in Bento (2002) and Bento *et al.* (in press). Douthwaite (1974) described wattled crane breeding biology in relation to hydrological changes in the Kafue Flats.

10.2.2 Spurwinged Goose

The spurwinged goose is also a wetland-dependent species, with similar habitat requirements as the Wattled Crane Based on his waterbird research in the Kafue Flats, Douthwaite (1987) wrote "in seasonal occurrence, distribution and diet it was similar to the Wattled Crane although Spur-wing were usually found in wetter areas… the two species also differed in the chronology of breeding and wing-molt." Although spurwinged geese feed on underground tubers, they have a more diverse diet that includes agricultural grains, fruits, grass shoots and seeds, and aquatic vegetation. The spurwinged goose depends on wetlands for nesting and roosting, but may rear 6-14 chicks per brood and is significantly less vulnerable to predation and drought. Thus, the spurwinged goose is a good example of a species that is affected by hydrological changes but to a somewhat lesser degree than the Wattled Crane. The biological attributes of the spurwinged goose are most recently detailed in Hockey *et al.* (2005); no research has been conducted on the species in the Zambezi Delta region.

10.2.3 Goliath Heron

The massive goliath heron is a highly wetland-dependent species that is rarely found away from water. It inhabits shallow water of rivers and lakes, marshes, tidal estuaries, reefs, and occasionally mangrove swamps, and is most common on the shores of large lakes. Goliath herons are territorial, solitary feeders, with a diet that is almost exclusively comprised of fish although frogs and other amphibians are occasionally taken. Goliath herons tend to feed on the largest fish prey available, often ignoring smaller fish. They build a large nest of sticks and reed stalks, usually on the ground or beside dense, flattened reeds, sedges, or papyrus, and feed their young with regurgitated fish. The significant dependence of Goliath Herons on large fish prey makes them vulnerable to negative changes in the hydrological regime of the floodplain that reduce fish availability – especially the loss of annual floods (see Tweddle, this volume). Goliath heron ecology is described in detail in Hancock and Kushlan (1984). No research has been conducted on the species in the Zambezi delta region.

10.2.4 African Skimmer

Unlike the wattled crane, spurwinged goose and goliath heron, which require flooding events to meet their lifecycle requirements, the African skimmer depends on low flow events. African skimmers require seasonal low flow conditions that expose river sandbars, where they build their nests. Breeding occurs during the dry season period of July to October when flood waters recede. Eggs are incubated for 21 days, and nestlings remain on the sandbars for an additional 5-6 weeks until fledging. If a flooding event occurs anytime during this period, nests, eggs, or chicks will be washed away. As a result, African skimmers – an endangered species in South Africa -- have all but disappeared from regulated rivers in Africa due to increase dry season flows associated with year-round for hydropower production, irregular surges of water for diurnal peaking-power, and/or late dry season releases to increase reservoir storage capacity. Coppinger *et al.* (1988) describe the distribution and breeding ecology of African Skimmers in the Upper and Middle Zambezi River, no research has been conducted on the species in the Zambezi Delta region.

10.3 Description of status prior to river regulation

No waterbird censuses were conducted in the Zambezi Delta region prior to river regulation. Best guess estimates of the historic numbers, based on observations in other floodplain systems and anecdotal accounts from observers involved in mammal surveys during that period, are as follows:

Wattled crane:	Common in floodplain areas supporting stands of Eleocharis spp. Sedges (perhaps >1000 individuals)
Spurwinged Goose:	Abundant across the floodplain (perhaps >10,000 individuals)
Goliath Heron:	Common in lakes and channels on the floodplain
African Skimmer:	Common on Zambezi sandbanks

Among the four sub-components considered here, the status of the Wattled Crane is probably the best, although still poorly, understood. Historical accounts indicate that the species was previously more abundant and widespread than today (see Bento 2002). The historic estimate of >1000 individuals is based on the assumed carrying capacity of the delta for the species under natural hydrological conditions, in comparison with other wetland systems in southern Africa that support large numbers of wattled cranes. Wattled cranes in the delta are exclusively associated with sedges of the genus *Eleocharis*, the tubers of which provide the adult cranes' main food supply. The main *Eleocharis* areas in the delta, and those supporting the highest density of wattled cranes, occur below the adjacent Cheringoma escarpment, where unregulated streams flow onto the floodplain. These wetlands experience some seasonal inundation in all years - conditions essential for the production of underground tubers - and high soil penetrability to enable the cranes to extract tubers. *Eleocharis* tuber production and soil penetrability is extremely low in the remaining vast areas of the delta that no longer receive regular annual flooding due to regulation of the Zambezi River. Significant differences in crane density between the *Eleocharis* beds of the Cheringoma and Zambezi floodplains suggest that the carrying capacity of the delta for cranes has been reduced (Bento *et al.* in press).

In 1990, an estimated 2570 wattled cranes (more than 30% of the global population) were observed in the delta (Goodman 1992). This was likely an occasional flock from elsewhere in southern Africa, however, as repeat aerial surveys from 1995-2002 suggest much smaller numbers. Bento *et al.* (in press) suggest that the prolonged regional drought in the late 1980s to early 1990s resulted in failed floods, low tuber productivity, and relatively impermeable soils across the region

10.4 Description of the current trajectory in condition

Data from six years of successive waterbird counts in the Zambezi Delta (1995-2000), suggest that the numbers of wattled crane, spurwinged goose, and goliath heron are stable at relatively low numbers compared to historical levels, although numbers tend to fluctuate from year to year and clear trends are difficult to determine. The status of the African skimmer, which apparently migrates great distances up and down the Zambezi and its tributaries, is unknown.

Estimates of present numbers in the delta region are provided below for the four sub-components.

Wattled crane:	Uncommon, restricted distribution <350 individuals.
Spurwinged Goose:	Common, more restricted distribution >6000 individuals.
Goliath Heron:	Uncommon <100 individuals.
African Skimmer:	Rare or occasional

Annual surveys during 1995-2002 suggest a core population of about 120 breeding pairs of wattled cranes remaining in the Zambezi Delta region, with another 100 or so birds in juvenile and non-breeding floater flocks. Bento (2002) modelled the wattled crane breeding population in the delta assuming no further changes in Zambezi River flow patterns, and found that the population will remain stable at current levels or slightly increase over the next 30 years. During the past 30 years, the population decreased to current lower numbers, likely as a result of a degradation of the hydrological conditions (resulting in reduced food availability) in the delta. Notwithstanding the low numbers, the population as it stands at present appears to be self-sustaining. Indeed, there is a possibility of a slight increase in numbers, which means that, over the next 30 years the population could export a few birds (although far fewer than in pre-regulation times) to neighbouring wetlands.

Spurwinged goose numbers are likewise expected to remain stable or slightly increasing under the current water regime, in the absence of hunting or other pressures.

Goliath heron numbers are likely also stable, corresponding to the current stable but reduced fish stocks on the delta floodplain (see Tweddle, this volume).

The future of African skimmers is less optimistic. If the Zambezi River continues to be managed under present day operation rules, the African Skimmer will disappear permanently in the Zambezi Delta long before the 30-year horizon is reached, as it has from other regulated rivers in Africa (the species is now considered to be extinct in South Africa) (Barnes 2000). Prescribed annual flood events may aid with the creation of sandbars, but dry season flows must be substantially reduced to enable access to open sandbars for nesting.

10.5 Description of desired target condition

Wattled crane:	>400 individuals
Spurwinged Goose:	10,000 individuals
Goliath Heron:	>200 individuals
African Skimmer:	>100 individuals

10.6 Evaluation and ranking the hydrological flow categories

Table 10.1 is a ranking of the three hydrological flow categories used in this study in terms of their impact on each of the water bird sub-components. The reasoning supporting the rankings is discussed in more detail below.

Wattled cranes, spurwinged geese, and goliath herons are most affected by changes in food availability and nesting suitability associated with changes in the annual flood. For wattled cranes, larger floods, like the 1:5 return flood, are also important as they inundate more extensive breeding grounds and provide relief from floodplain fires (Bento 2002), thereby increasing the chances of survival for chicks. Similarly goliath herons would be expected to benefit from the large fish stocks associated with 1:5 year flood events. African skimmers are entirely dependent on reduced and sustained dry season low flows.

Table 10.1 Ranking of the waterbird sub-components against the hydrological change flow categories.

Flow category		**Rank per sub-component**			
		Wattled crane	Spurwinged goose	Goliath heron	African skimmer
Low flows	DSLF	1	1	1	3
Floods	Annual flood	3	3	3	2
	1:5 year flood	2	2	2	1

3 = most important
1 = least important.

10.7 DRIFT consequences

See Appendix A.

10.8 Discussion

This discussion addresses the question:

"Do you think that, in a 30-year horizon, a "pre-regulation condition" in the delta could be achieved if the flow conditions prior to river regulation were reinstated, i.e., do you think the current condition is reversible.

Conditions are reversible for all the species if a more natural hydrological regime could be reinstated. Spurwinged geese, with their high fecundity and more generalized diet, would be expected to recover most rapidly. Goliath herons, which produce 2-4 chicks per year, also would be expected to recover fairly quickly, especially given the anticipated rapid response of fish stocks to improved hydrological conditions (Tweddle, this volume). The recovery of wattled cranes, given their very low fecundity and particular food requirements, is expected to be slow although wattled cranes did show a marked increase in breeding productivity following the large 2001 floods. The prognosis for the African skimmer, however, is not good. Although an improved dry season low flow regime could in theory aid in the recovery of the species, the duration of low flows required by the species (roughly 2.5 months) is unlikely to occur with current hydropower demands on the Zambezi River. In the long-term, African skimmers are likely to persist only on the few remaining unregulated rivers in the region.

11. Specialist Study – Floodplain Vegetation

11.1 Introduction

This section addresses the anticipated effects on the distribution of vegetation and on the status of vascular plant species of the flow changes described in Section 3. It looks both at distribution patterns of vegetation types as well as their status relative to a target condition (i.e. whether they disappear or become greatly diminished, or greatly increase). Two components of vegetation are covered here - one is vegetation types that we wish to encourage for biodiversity conservation reasons, the other is vegetation types that are considered negative and detrimental to overall biodiversity conservation.

11.1.1 Key assumptions

The following three key assumptions were applied:

1. All wetland systems are dynamic, and a key conservation concern is to ensure that this dynamism and mobility is retained. The danger in conservation is sometimes to "fossilize" a system, to freeze a situation in time and try and retain it. Pete Smith, a leading expert on the Okavango River system, called this the "glasshouse syndrome" (P.A. Smith. pers. comm. 1998).

2. There is nothing inherently "wrong" with change in distribution of vegetation types across the wetland landscape. As part of this, inevitably there will be some change in status, i.e. some habitats or vegetation types will become more common, others more scarce. The point is to try and determine when reduced (or increased) extent becomes unacceptable, when it results in the absolute loss of biodiversity or an ecological simplification of the system. This is something that is both very difficult to determine, and also value-laden. Perhaps that point can be taken as when: (a) there is an actual loss of overall biodiversity (i.e. of numbers of species); (b) there is loss to the system of restricted distribution species such that there is a decline in their global or regional status, or (c) there is loss of ecological goods and services.

3. The objective of the overall DRIFT assessment is to elucidate the consequences of flow change for both biodiversity conservation *per sê*, and for plant species as a human resource. In this section (Vegetation), however, the first aspect is given precedence as the second will be addressed under Natural Resource Utilisation (Section 12).

11.1.2 Factors affecting vegetation changes on the Zambezi Delta

There are nine main factors that have affected changes in vegetation in and around the Zambezi Delta over the last 100 years. The list indicates that flooding regimes and overall hydrology are not the only factors influencing change on the delta, although they are perhaps the most significant that have changed over the last 45 years.

1. Increased dry season base-flows owing to power generation from upstream dams.
2. Reduced flooding (both in incidence and extent) after the construction of Kariba and Cahora Bassa dams.

3. Construction of bunds across distributary channels (especially on the south bank) in the 1920s to control flooding.
4. Construction of sugar estates and concomitant changes in land drainage in the 1920s and onward.
5. Introduction of cattle and peripheral "terrestrial" human settlements (compared to previous primarily river-fringing settlement) following on from development of the sugar estates.
6. Introduction of aquatic water weeds and their subsequent spread.
7. The reduction in large herbivore grazers (elephant, buffalo, zebra, hippo) soon after the establishment of sugar plantations through meat-hunting, and again at the end of the civil war in the early 1990s. Conversely, it could be said that the great increase in large herbivore numbers during the 1970-1980s was the significant factor.
8. The activities of the logging industry on the Cheringoma plateau, especially in the 1950-1960s, and perhaps again now, which included tree felling, local clearance and road construction.
9. Changes in the timing and frequency of burning regime of the grasslands, with the increased frequency of fire being arguably to more important of the two.

11.2 Selection of key sub-components

As mentioned earlier, there are two vegetation components (each with their own sub-components), which are addressed separately here. The rationale behind choosing these, as opposed to other vegetation types, is four-fold:

a) To identify vegetation types that are fairly clearly defined and relatively limited in extent, so that any changes in distribution or status are more readily measured;
b) To provide a cross-section of vegetation types that also covers some of the most important non-plant biological conservation targets;
c) To cover vegetation types of particular biodiversity conservation concern, not just those of utilitarian value;
d) To cover vegetation types that are considered invasive and hence detrimental to biodiversity conservation goals.

For the Vegetation Component of vegetation types of biodiversity interest, the selected sub-components are:

1. Mangrove woodlands/forests (excluding saline grasslands),
2. Riparian forest (the narrow fringing forests along smaller distributor channels),
3. Papyrus-dominated permanent swamps.

While for the Vegetation Component of invasive, undesired vegetation types, the selected sub-components are:

4. Palm and Acacia savannas on the deltoid plain,
5. Invasive aquatic plants.

11.2.1 Mangrove Forests

Mangroves are fairly clearly defined on satellite imagery. They were stated to cover 1030 km^2 in 2000 with a -2% change in extent since 1960 (Beilfuss 2001; Beilfuss *et al.* in prep), "Mangrove forests on coastal estuary"), while Timberlake (2000b, as "D1 Mangrove forests") gives an extent of 1014 km^2 or 8% of the delta, based on 1996 satellite imagery and a delta area of 12,786 km^2. Mangrove forest comprises a number of different specialized mangrove species, with different individual ecological requirements. *Avicennia marina* is perhaps the most common and is often the first one to colonize new mudbanks. On the landward side, it is suggested (Beilfuss *et al*. in prep) that hypersalinity may lead to die-back of mangroves, being replaced by salt flats with grasses such as *Sporobolus* and the succulent herb *Salicornia*. Whether hypersalinity or some other edaphic factor (e.g. inadequate soil moisture through the year) is involved is not clear. However, through-flow of water from the Zambezi River is likely to have a significant effect on its distribution as it would modify salinity status. Mangrove forests also have economic significance both for timber and the ecological services they provide in reducing coastal erosion and as fish spawning grounds.

There is some contention with mangrove forests. Davies *et al*. (2000) say there have been significant detrimental changes in extent since the closure of Kariba and Cahora Bassa Dams, yet Beilfuss *et al*. (in prep) suggest minimal overall change in extent across the Delta as a whole, although significant changes in distribution have occurred. The latter view is taken here pending further confirmatory evidence.

11.2.2 Riparian Forest

This type is not described separately by Timberlake (2000a) and termed "*Barringtonia* evergreen swamp forest on closed waterways" by Beilfuss 2001, and is very limited in extent. It is basically a freshwater swamp formation, and forms a narrow fringe (1-5 trees deep) along freshwater (or occasionally brackish) distributary channels, mostly closer to the sea. Beilfuss *et al.* (in prep) gives the extent as 80 km^2 in 2000, with a 14% increase since 1960. However, the small scale of the map used in that paper precluded its depiction. The forests are characterized by species such as *Barringtonia racemosa* as well as *Phoenix reclinata* and other trees. Fruit-bearing trees are particularly common, thus making the type of importance to primates and frugivorous birds, as well as providing shelter for elephant, buffalo and various antelope. It can be considered a "key resource", following the Scoones and Graham (1994) analysis of livestock grazing systems. It is believed to have a particularly high biodiversity, and contains a number of species of restricted distribution. As a result its biodiversity conservation value is also very high.

11.2.3 Papyrus-dominated Permanent Swamp

This is a moderately and unambiguously clear formation on satellite imagery, where it shows as deep red patches. It is also present in small patches in and around permanent pools and backwaters, but at a scale not possible to depict separately on most maps from the large extent of wetland grassland. Timberlake (2000a, as C4 Papyrus swamp) gives an extent of 746 km^2 or 5.8% of the total delta area. Beilfuss *et al.* (in prep), as "Papyrus swamps on floodplain waterways and lagoons," gives 840 km^2 with an-8% change from 1960. Although species-poor in terms of plants, this vegetation type is the 'end-point' of the wetland ecosystem, short of open water with floating macrophytes. It is productive, and important in terms of ecological goods and services (water and sediment filtration) as well as papyrus providing an important raw material for rural populations. The largest single expanse is found on the middle reaches of the Rio Cuacua, some 50 km upstream of Quelimane.

11.2.4 Palm and Acacia Savannas

This group of vegetation types is not well-defined, and open to varying interpretation as to its distribution and extent; it is really a section (or part) of a continuum. However, it is expected that this sub-component would show the largest impact from changed flood/hydrological regime, as it has shown the maximum change in area following the closure of the major dams upstream. The sub-component comprises three units of Beilfuss (2001), namely: "*Borassus* palm savanna"; "*Hyphaene* palm savanna", and; "*Acacia* woodland and savanna on floodplain vertisols". The nearest equivalent in Timberlake (2000b) is "B1 *Borassus* and *Hyphaene* palm savanna (South bank)" and "B2 *Acacia* savanna with *Hyphaene* (North bank)". According to Beilfuss (2001), the combined types have an extent of 1390 km^2 in 2000, a 15% increase compared to 1960, while Timberlake (2000b) gives an area of 5535 km^2 or 43.3% of the Delta[6]. *Hyphaene* palm is used for making an alcoholic beverage as well as for construction material, while there has been a certain amount of interest in the local exploitation of *Borassus* palm for timber. The encroachment of *Acacia* and *Hyphaene* is considered by many to have been occurring at an accelerated level since the closure of Kariba and Cahora Bassa dams, and this encroachment is considered one of the largest threats to the Delta wetland ecosystem. Certainly, the "terrestrialisation" of wetland grassland is not readily reversible (trees act as 'pumps' to any build up of soil moisture, and once established trees are difficult to kill, even if regeneration does not occur). It forms part of the sclerosis of the landscape or "fossilization", and detracts from the landscape mobility required by wetland vegetation.

11.2.5 Invasive Aquatic Plants

This vegetation type comprises floating aquatic plants that cover open water in lagoons. Many of the species (*Eichhornia crassipes*, *Pistia stratiotes*, *Azolla filiculoides*, *Salvinia molesta*) are introductions from other continents. These species reproduce rapidly and can cover the entire water surface, not only cutting out light for other aquatic organisms, but also greatly increasing the biological oxygen demand when they die such that waters can become almost anaerobic. Beilfuss *et al.* (in prep) refers to this type as "15. Aquatic macrophytes on floodplain swamps and lagoons", but do not give a specific extent, incorporating it under papyrus swamps (840 km^2) as most patches are relatively small. Timberlake (2000b) refers to invasive aquatics under "C5. Open water with floating aquatics", which was not mapped. The sub-component evaluated here is not vegetation on open water, but just those floating-leaved species that are invasive. Anecdotal evidence, and evidence from other wetland systems in the Zambezi Basin, suggests that the extent of invasive plants is increasing. This is probably due to (a) a build up of nutrients owing to lagoons not being annually 'flushed out', and (b) the lack of removal of plants during large flood events since dam construction.

11.3 Description of status prior to river regulation

It is important to point out that a description of the status prior to river regulation is extremely difficult to provide, and in many cases requires extrapolation to a time for which there are few if any records.

1. Mangrove woodlands/forests: Probably similar to what it is now.
2. Riparian Forest: Unknown status. No reason to think it was different from present.
3. Papyrus Swamp: Probably of slightly greater extent owing to regularly flooded backwaters.
4. Palm and *Acacia* Savanna: Probably of lesser extent than now. Order of magnitude unknown and guesstimated at 15-20% less than at present.
5. Invasive Aquatic Plants: Of significantly lesser extent than now. Order of magnitude unknown and guesstimated at 60-80% less than at present.

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[6] Obviously a more liberal interpretation than Beilfuss (2001).

11.4 Description of the current trajectory in condition

1. Mangrove woodlands/forests: Figures given in Section 11.2.1 above. Evidence of dieback on landward side in some areas, but compensated for by establishment on new mudflats.
2. Riparian Forest: Tentative figures given in Section 11.2.2. Not clear if this type is under any threat, either from changed hydrology or from regular bush fires "sharpening" the margins.
3. Papyrus Swamp: Tentative figures given in Section 11.2.3. Patches still widespread. One large extent on Rio Cuacua, which, it is suggested, has shown signs of reduction.
4. Palm and Acacia Savanna: Tentative figures given in Section 11.2.4. Definite evidence of increasing density/recruitment of Hyphaene and Acacia plants.
5. Invasive Aquatic Plants: Of unknown extent, but a significant portion of open water lagoons. Evidence of increasing coverage.

11.5 Description of desired target condition

As mentioned in Section 11.4.1, the ‘Target Condition’ as described here represents the target status for biodiversity conservation. Other, and possibly conflicting, targets for exploitation of plant products by local people are addressed in Section 12. It must also be borne in mind that the biodiversity "goal" might well be a great state of flux, rather than a uniform status or narrow range of variation and fairly static distribution patterns.

1. Mangrove Forest: Similar extent and distribution to that at present. Presence of range of mangrove species on all available saline mudflats. Mobility of distribution and species composition (i.e. natural succession still operational). Death /dieback of similar order to establishment on new mud flats.
2. Riparian Forest: Similar extent to that at present, or slight increase. Range of species diversity and structure (physiognomy) retained; good age structure without increasing senility.
3. Papyrus Swamp: Similar extent to that at present. Perhaps more small patches in wetland grassland. No loss of extent in main area on Rio Cuacua. Vegetation successions still operational.
4. Palm and Acacia Savanna: Reduced extent of savannas, especially Acacia savanna. Even-aged structure not skewed towards regeneration/young growth. No sign of increasing density of woody species where already present, or of increasing extent.
5. Invasive Aquatic Plants: Greatly reduced extent, or complete loss.

11.6 Evaluation and ranking the hydrological flow categories

Table 11.1a&b provides a ranking of the three hydrological flow categories used in this study in terms of their impact on each of the vegetation sub-components. The relative importance of the various aspects of flow change is discussed in more detail below.

Table 11.1a Ranking of the sub-components for vegetation types of biodiversity interest against the hydrological change flow categories.

Flow category		Rank per sub-component			
		Mangrove	Riparian	Papyrus	
Low flows	DSLF	3	2	1	
Floods	Annual flood	2	3	3	
	1:5 year flood	1	1	2	

3 = most important
1 = least important.

Table 11.1b Ranking of the sub-components for invasive, undesired vegetation types against the hydrological change flow categories.

Flow category		Rank per sub-component			
		Palm/acacia savanna	Invasive aquatics		
Low flows	DSLF	1	1		
Floods	Annual flood	3	2		
	1:5 year flood	2	3		

3 = most important
1 = least important.

11.6.1 Duration and timing of flooding

The duration of flooding is perhaps the most important hydrological feature for the vegetation. For instance, for woody plants, a two-week duration flood will have far less impact than inundation for two months. Timing of the flood is not as important, although if the aim is to stop regeneration of woody plants (i.e., terrestrialisation), flooding is most effective if it occurs in the growing or regeneration season, from around September to February.

Riparian woodland is not much affected by differences in dry season base flow, or annual flooding below a certain (at this stage unknown) level. Once that "land saturation" point is reached, groundwater levels from incident rainfall and runoff from the Cheringoma Plateau would probably be enough to keep water seeping on the surface for most of the year, and maintain these forests in a healthy state.

Research on the Tana River in Kenya demonstrates the importance of large floods for initiating succession in riparian forest. Subsequent floods are important for the tree seedlings to become established before their roots can reach groundwater levels.

Mangrove forests need to have strong fluctuations in flow, as these ensure that mud flats are continually made available for invasion. High dry season base flows tend to "fossilize" this environment, stopping regeneration. Mangroves are seral, which means that they are not fixed in locality. As mudflats become consolidated, however, other woody or herbaceous plants can invade them.

Papyrus swamps need a certain level of inflow over the year to prevent desiccation of the swamp. Flushing flows are also required in order to reduce the rate at which papyrus becomes consolidated and is taken over by dryland vegetation. Papyrus, being seral, has a tendency to promote a build up of soil that becomes the habitat for less swampy plants.

Invasive aquatics are best controlled by 'flushing out', both the floating plants themselves being washed out to sea in a good flood, and through reduction in the build-up of nutrient levels in backwaters and lagoons. A large 1:5-year flood can be as effective as smaller annual floods.

11.6.2 Variability in magnitude of annual flood

Year to year variability in magnitude of flooding would probably not result in any major changes, positive or negative, to any of the five vegetation sub-components (excl. aquatic invasives). The vegetation types do not have a known threshold beyond which composition or seral direction changes. It is, however, quite possible that there is some such limit for seasonal inundation for the Palm and Acacia Savanna. This is likely to occur when anaerobic conditions in the subsoil (below *c.* 50 cm depth) persist for longer than woody plant roots can survive with minimal oxygen, i.e. the roots suffocate. At this point, woody roots start to die, giving competitive advantage to the more shallow-rooted grasses and herbs. It is likely that this flooding level is quite substantial, not "slight". Once again, changes in the duration of the flood, rather that its magnitude, would be the principal feature driving change. However, it is recognised that a large magnitude of flood could compensate for shorter duration owing to "ponding" or lack of land drainage.

For control of invasive aquatic plants, flushing out of nutrients is desired, as these plants reproduce most rapidly when nutrient levels are high. It is not known what the threshold for this is, but it may well be around 7000 m^3/sec.

11.6.3 Effects of flow changes on individual plant species

So far, it is only the effects on vegetation communities that have been addressed. What is the effect of changes in hydrology, especially flood regime, on individual species?

There has been a reported build-up of aquatic weeds, mostly free-floating species such as *Azolla* and *Eichhornia*, probably due primarily to build-up of nutrients in the waters in which they occur. A strong annual flood would "wash away" many of these nutrients and prevent their build up, hence there would be far less habitat for invasive plants. A good cleansing annual flood would be what is required to keep aquatic weeds under control.

There are very few endemic plant species in the Zambezi Delta. It is now not clear whether the screw pine, *Pandanus livingstonianus*, is in fact that species (see Timberlake 2000b), or one more widespread. The small herb *Vahlia capensis* subsp. *macrantha* is confined to sandbanks (Timberlake 2000b), hence reduced flood occurrences and high dry season base flows will reduce its available habitat. However, it is doubtful whether it is really that threatened. Some of the ground orchids are dependent on open wetland grassland to maintain their populations. But their populations are unlikely to be greatly threatened by even a 50% change in extent of wetland grassland.

The most threatened species are probably those found in the fringing riparian woodlands, followed by some of the herbaceous species confined to various sub-habitats of the moist/dry forests of the surrounding Cheringoma plateau area.

As with many of the vegetation types, what is required for conservation is an active mosaic of habitats, some more stable, but others in a continual state of flux. It is this variation in both time and space that leads to the high plant species and vegetation diversity, and hence animal diversity (both vertebrate and invertebrate) of the area.

11.7 DRIFT consequences

See Appendix A.

11.8 Discussion

This discussion addresses the question:
“Do you think that, in a 30-year horizon, a “pre-regulation condition” in the delta could be achieved if the flow conditions prior to river regulation were reinstated, i.e., do you think the current condition is reversible?

The extent of papyrus and wetland vegetation types would probably respond fairly quickly to a reinstatement of ‘pre-dam’ water quantity, duration and timing of flooding, and as long as water quality is maintained (i.e. it does not become eutrophic). Papyrus and many other wetland species are not long-lived, indeed they are quite facultative, as befits their "opportunistic" ecological niche. It is thus likely that a pre-regulation condition could be achieved in the 30-year horizon.

Woody plants have longer life spans, and often live longer than the 30 years postulated in the question. Over the 30-year period, significant changes could take place to woody communities, but these communities would not yet be "fully restored". Pre-dam conditions might take 80-100 years or so to achieve.

The Palm and Acacia Savanna is perhaps the most important type to address here as it is apparently encroaching into permanent wetland grassland. The key period in establishment of woody plants is the first one or two seasons. Once a woody plant has overcome its first dry season, and starts rising above the grasses, it is much more difficult to get rid of as its roots are established, and it can withstand regular burning, competition from grasses or herbivory. Hence a series of dry years in a wetland grassland or dambo can allow encroachment of woody plants from the margins. This process could possibly be halted by reinstating more natural food conditions, but is much harder to reverse. Thus, even if pre-regulation hydrological conditions were restored, it may take a few tree generations (which for *Acacia* might only be 100 years) to return to a pre-regulation vegetation distribution pattern for the Delta savanna vegetation.

Mangrove and Riparian Forest would respond fairly rapidly to changes in hydrology, but their physiognomic structure and age structure would take longer to restore. And part of the high biodiversity of riparian forest is due to its physical 3-dimensional structure.

12. Specialist Study – Natural Resource Utilization

12.1 Introduction

This section addresses the anticipated effects on the utilization of vegetation resources in the delta of the flow changes described in Section 3. Other important natural resources are considered under agriculture, freshwater fisheries, and coastal fisheries.

The responses provided here were guided by those provided for the same resources in the floodplain vegetation analysis (Section 11). The main difference between the assessments provided for the two is that palm savanna increase is an 'ecological' move <u>away from</u> target but 'resource use' move <u>towards</u> target. The expected response is however confounded by the fact the resource (palm savanna) is really not limiting in the delta. Indeed, none of the resources considered here are limiting, as all are abundant relative to current harvest rates.

The literature and other background to the vegetation types considered here are provided in Section 11.

12.2 Selection of key sub-components

The principle resources that are harvested for human use in the delta were determined by the IUCN Zambezi Basin Wetlands Conservation and Resource Utilisation Project (E. Chonguiça pers. comm.).

The selected sub-components were defined based on these target resources:

1. Mangrove forest.
2. Riparian trees.
3. Reed and papyrus swamp.
4. Palms.

The use of grasslands for thatch is considered an abundant natural resource locally that is not limited by water availability.

12.2.1 Mangrove forest

Mangroves are an important source of timber for rot-resistant housing construction, and also used for firewood by coastal communities.

12.2.2 Riparian trees

Hardwood trees are used for construction and fuelwood; local communities harvest riparian fruit trees.

12.2.3 Reed and papyrus swamp

Reeds are important for thatch and construction; papyrus is also used as a writing material.

12.2.4 Palm savanna

Hyphaene palm is used for making an alcoholic beverage as well as for construction material, while there has been a certain amount of interest in the local exploitation of Borassus palm for timber.

12.3 Description of status prior to river regulation

Mangrove Forest: Probably similar to what it is now (2005), or perhaps a slightly greater extent. Beilfuss (2001) shows a 7% decrease in mangrove forest (loss of 8000 hectares) and 7% increase (gain of 3000 hectares) of pioneer mangrove and saline mudflats since 1960.

Riparian Trees: Probably similar to what it is now (2005). Beilfuss (2001) shows no change in extent (3000 ha.) between 1960 and 2000.

Reed and Papyrus Swamp: Probably of slightly greater extent owing to regularly flooded backwaters. Beilfuss (2001) shows an 8% reduction in papyrus swamp since 1960. There has been a 5% increase in saline grasslands, including reed swamp (not differentiated) since 1960. The change in the extent of reed swamp alone is unknown.

Palm Savanna: Probably of less extent than now. Order of magnitude unknown, perhaps 15-20% less. Beilfuss (2001) shows a 19% increase (14,000 hectares) in Hyphaene palm savanna since 1960. There was slight decrease (-1000 hectares) in Borassus palm savanna, but this is attributed to invasion by Acacia savanna (which increased by 24% from 1960-2000).

12.4 Description of the current trajectory in condition

Mangrove Forest: Evidence of die-back on landward side in some areas, but compensated for by establishment on new mudflats.

Riparian Trees: Not clear if this type is under any threat, either from changed hydrology or from regular bush fires at the margins.

Reed and Papyrus Swamp: Patches still widespread. One large extent on Rio Cuacua, which, it is suggested, has shown signs of reduction.

Palm Savanna: Clear evidence of increasing density/recruitment of Hyphaene and Acacia plants.

In the absence of changes in Cahora Bassa management, the changes in delta vegetation and corresponding reduction in resource availability are expected to continue. Based on observed changes since 1960, some decrease in area extent of papyrus (away from natural state; and reduction in resource availability), and perhaps also a modest decrease in mangrove over time (away from natural state and reduction in resource availability) is expected. An increase in extent of palm savanna (away from natural state but increase in resource availability) is expected but here is no evidence to support an increase or decrease in riparian forest.

12.5 Description of desired target condition

Mangrove Forest:	Similar extent and distribution to that at present, or slight increase. Presence of range of mangrove species on all available saline mudflats. Mobility of distribution and species composition (i.e. natural succession still operational). Death /dieback of similar order to establishment on new mud flats.
Riparian Trees:	Similar extent to that at present, or slight increase. Range of species diversity and structure (physiognomy) retained; good age structure without increasing senility.
Reed and Papyrus Swamp:	Increased extent relative to the present. Perhaps more small patches in wetland grassland. No loss of extent in main area on Rio Cuacua. Vegetation succession still operational.
Palm Savanna:	Maintain or slightly increase the extent of palm savanna. Note that this is counter to the ecological target condition for palm savanna (desired decrease).

12.6 Evaluation and ranking the hydrological flow categories

Table 12.1 is a ranking of the three hydrological flow categories used in this study in terms of their impact on each of the vegetation sub-components. The reasoning supporting the rankings is discussed in more detail below.

Table 12.1 Ranking of the natural resource utilization sub-components against the hydrological change flow categories.

Flow category		**Rank per sub-component**			
		Mangrove forest	Riparian trees	Reeds and papyrus	Palms
Low flows	DSLF	3	2	1	1
Floods	Annual flood	2	1	3	2
	1:5 year flood	1	2	2	3

3 = most important
1 = least important.

12.7 DRIFT consequences

See Appendix A.

12.8 Discussion

This discussion addresses the question:
“Do you think that, in a 30-year horizon, a “pre-regulation condition” in the delta could be achieved if the flow conditions prior to river regulation were reinstated, i.e., do you think the current condition is reversible?

As described in Section 11, the extent of papyrus and wetland vegetation types will probably change fairly rapidly given the necessary changes in water quantity, duration and timing of flooding, and as long as water quality is maintained (i.e. it does not become eutrophic). Papyrus and many other wetland species are not long-lived; indeed they are quite facultative, as befits their "opportunistic" ecological niche. Woody plants have longer life spans, often longer than the 30 years postulated in the question. Over a 30-year period significant changes could take place to woody communities, but these communities would not yet be "fully restored". That might take 80-100 years or so.

However, perhaps the most important type to address here is the Palm Savanna that is apparently encroaching into permanent wetland grassland. From a resource use standpoint, this is a positive development, but it is also a movement away from the natural state. The key period in establishment of woody plants is the first one or two seasons. Once a woody plant has overcome its first dry season, and starts rising above the grasses, it is much more difficult to get rid of. Roots are established, and it can withstand regular burning, competition from grasses, herbivory, etc. Hence a series of dry years in a wetland grassland or dambo can allow encroachment of woody plants from the margins, a process which although it might stop with a return of "better" flood conditions, is much harder to reverse. I would imagine that even if pre-regulation hydrological conditions were restored, it may take a few tree generations (which with *Acacia* might only be 100 years) to return to a pre-regulation vegetation distribution pattern for the Delta savanna vegetation.

Mangrove and Riparian Forest would respond fairly rapidly to changes in hydrology, but of course their physiognomic structure and age structure would take longer to restore, and part of the high biodiversity of riparian forest is due to its physical 3-dimensional structure.

13. Specialist Study – Water Quality

13.1 Introduction

There are no reliable data for the Zambezi Delta region to describe water quality conditions prior to dam construction or under current conditions. Colleagues at the National Directorate of Waters have proposed to undertake a more complete analysis of water quality in the future, however, for the present analysis four key water quality sub-components were selected based on regional studies and extensive interviews with local residents:

13.2 Selection of key sub-components

The four sub-components selected for this water quality assessment are:

1. Sediment
2. Polluted effluent discharge
3. Nutrient eutrophication of water bodies
4. Salinity intrusion.

13.3 Description of status prior to river regulation

13.3.1 Sediment

The sediment load of the Zambezi River is significantly reduced relative to pre-regulation conditions, due to sediment trapping in the reservoirs (Bolton 1983). Cahora Bassa Dam, in particular, captures the major source of sediments to the Zambezi River, runoff from the Luangwa River in Zambia. Although detailed scientific studies of Zambezi sediment loads are lacking, numerous geomorphologic and associated ecological changes have been attributed to the lack of sediments by Davies *et al.* (1975), Guy (1981), SWECO (1982), Davies *et al.* (2000), Beilfuss (2001), and others, including:

- degradation of the coastal shelf (and corresponding die-off of mangrove vegetation);
- highly eroded riverbanks through down cutting of the mainstem Zambezi River. For example, former water intake pipes for Sena Sugar factory at Luabo are now more than five meters above the mean annual Zambezi River water level and must all be replaced. The roots of old trees are also exposed on banks;
- lateral stabilization of channels and consolidation of sandbars into vegetation islands;
- decrease in micronutrient availability associated with sediment transport.

13.3.2 Polluted effluent discharge

There is a likely decrease in water quality in the delta associated with effluent discharge from Sena Sugar factory at Marromeu. The extent of impact downstream from Marromeu is uncertain, but several local inhabitants from Marromeu to the coast have complained about reduced water quality and negative health effects since the factory began re-operation a few years ago (pers. com.). Molasses produced from sugar waste is also spread on local roads, from where it runs off into local stream channels and eventually the Zambezi River during the rainy season. These effluents likely also increase Biological Oxygen Demand (BOD) in the Zambezi River, which can negatively affect the aquatic ecosystem. These impacts may be attenuated in part by the relatively high dry season flows maintained by river regulation. Near Marromeu, air pollution produced by the sugar factory and from the burning of cane fields results in high particulate matter that may contaminate local water bodies. Several people also complained of other contaminants such as oil in the water (pers. com.).

13.3.3 Nutrient eutrophication of water bodies

Use of fertilizers for sugar production may be resulting in the eutrophication of floodplain waterbodies, especially abandoned channels, oxbow meanders, and shallow marshes (H. Silva pers. com.). These problems are exacerbated by the lack of annual flushing from Zambezi flood flows. At Malingapans, people complain that the Micelo branch of the Zambezi River is now choked with reeds and other weeds because of reduced flushing flows and nutrient-rich runoff (pers. com.). These weeds have greatly reduced the potential for boat transportation upstream, thereby isolating the community from Marromeu.

13.3.4 Salinity intrusion

Loxton Hunting and Associates *et al.* (1975) and SWECO (1982) expressed early concerns about changes in salinity associated with Zambezi River impoundment. Salinity intrusion is now widely reported from Malingapans to the coastal communities. Farmers at Malingapans, for example, note that Zambezi River water used for irrigation of rice crops is brackish and has resulted in the salinization of the floodplain, reducing crop yields (pers. obs). The historic influence of tides in the Zambezi River mainstem channels extended to Malingapans and further upstream during the dry season, and presumably turbine discharges during the dry season have reduced tidal influence upstream during the dry season. However, the control of regular annual flooding has affected the important function of flushing accumulated salts from the floodplains, leading to soil salinization. Halophytic vegetation has also replaced freshwater vegetation in the coastal region.

13.4 Description of the current trajectory in condition

Over the next 30-years (i.e., 60 years after closure of the dam) if current dam, operation practices continue, we expect a continued reduction in sediment transport and deposition, and a further exacerbation of problems associated with salinity intrusion and nutrient eutrophication in the Zambezi Delta region. Changes in water quality related to polluted effluent will depend much more on other factors (especially wastewater treatment methods) than on environmental flows.

13.5 Description of desired target condition

The desired condition for water quality would be a return to water quality conditions from 30 years ago, i.e., pre-Cahora Bassa Dam. These historical water quality conditions were not quantified by scientific research for the Zambezi Delta region, but could be approximated based on in-situ bio-physical conditions and comparison with other floodplain systems in the region.

13.6 Evaluation and ranking the hydrological flow categories

Table 13.1 is a ranking of the three hydrological flow categories used in this study in terms of their impact on river navigation. The relative importance of the various aspects of flow change is discussed in more detail below.

Table 13.1 Ranking of the water quality sub-components against the hydrological change flow categories.

Flow category		Rank per sub-component			
		Sediment	Effluent	Eutrophication	Salinization
Low flows	DSLF	1	3	1	1
Floods	Annual flood	2	2	2	2
	1:5 year flood	3	1	3	3

3 = most important
1 = least important.

Large flows are necessary to improve sediment transport and deposition, and flush floodplain water bodies and saline soils. Each of these sub-components would be expected to show increasing improvement with increasing magnitude of flows. The high dry season flows generated by dry season turbine outflow may serve to dilute polluted effluent, but Zambezi flow in the dry season under each of the DSLF scenarios is large relative to the volume of discharged effluent, and dry season flow reductions are assumed to have a negligible effect on water quality. Further research is necessary to verify these assumptions and provide a more complete assessment of water quality in the delta.

13.6.1 Variability in magnitude of annual flood

Slight variability in the magnitude of the annual flood is unlikely to significantly affect these sub-components, although, as noted above, some would show a higher degree of improvement during years with larger annual floods.

13.7 DRIFT consequences

See Appendix A.

13.8 Discussion

This discussion addresses the question:
"Do you think that, in a 30-year horizon, a "pre-regulation condition" in the delta could be achieved if the flow conditions prior to river regulation were reinstated, i.e., do you think the current condition is reversible?

Sediment transport and deposition is not reversible because the majority of sediments are trapped behind Cahora Bassa Dam. Only moderate improvements can be made as a function of downstream channel scour. Eutrophication of floodplain water bodies and soil salinization should be reversible with regular flushing flows. Improvements in water quality can be readily achieved by reducing the discharge of polluted effluent in the delta.

14. Specialist Study – Groundwater

14.1 Introduction

This section addresses the anticipated effects on groundwater recharge for domestic water supply of the flow changes described in Section 3. The focus here is on domestic water supply. Water supply for irrigation purposes is covered under agriculture (for subsistence, small-scale, and commercial; see Section 4) and navigation is covered in Section 15.

14.2 Selection of key sub-components

Only one sub-component was considered for groundwater:

1. Recharge of floodplain soils and water bodies.

14.3 Description of status prior to river regulation

There are no pre-regulation data on water table, but regular annual floods of much higher magnitude and longer duration than at present would have maintained in the past a significantly higher water table in the floodplain most years (Loxton Hunting and Associates *et al.* 1975; Beilfuss 2001). Local farmers contend that they had greater access to surface water in channels and lakes in the past and required only very shallow boreholes (pers. com).

14.4 Description of the current trajectory in condition

The effect of river regulation on floodplain groundwater levels has been described elsewhere for Africa (e.g., Sutcliffe and Parks 1989). The water table, especially in the upper delta (such as Salone depression) is many meters (local officials suggest anywhere from 7-14 meters) below the soil surface (pers. comm.). Access to water is now only through deep boreholes. People claim they have high mortality from crocodiles because they cannot get adequate water from floodplain in most years and now depend on the mainstem Zambezi River for water supply for bathing, cooking, drinking (pers. com.).

Over the next 30-years (i.e., 60 years after closure of the dam), in the absence of regular annual flooding or less frequent but regular large flooding events, the groundwater table will continue to decline, fed only by rainfall. With no action, in 30 years, it is expected that the water table will have further declined but not as rapidly as occurred over first 30 years.

14.5 Description of desired target condition

Water table increases such that shallow (hand dug) boreholes can be used for water supply and floodplain water bodies provide adequate water as an alternative to Zambezi River water (historical pre-dam conditions are taken as the target condition).

14.6 Evaluation and ranking the hydrological flow categories

Table 14.1 is a ranking of the three hydrological flow categories used in this study in terms of their impact on groundwater recharge. The relative importance of the various aspects of flow change is discussed in more detail below.

Table 14.1 Ranking of the groundwater sub-component against the hydrological change flow categories.

Flow category		Rank per sub-component			
		Recharge			
Low flows	DSLF	1			
Floods	Annual flood	3			
	1:5 year flood	2			

3 = most important
1 = least important.

14.6.1 Duration and timing of flooding

The key historical (pre-impoundment) hydrological data used for evaluation of target condition were as follows (from Beilfuss 2001):

- 1-day maximum: 11,500 m3/s.
- 2-week maximum: 10,000 m3/s.
- 4-week maximum: 8500 m3/s.
- 8-week maximum: 7500 m3/s.

- Jan mean monthly: 3900 m3/s.
- Feb mean monthly: 6500 m3/s.
- Mar mean monthly: 7400 m3/s.
- Apr mean monthly: 5900 m3/s.
- May mean monthly: 4500 m3/s.

- 2-week average duration flood: 10,000 m3/s.
- 4-week average duration flood: 7400 m3/s.
- 8-week average duration flood: 5800 m3/s.

- Average no. days above 4500 m3/s: 93.
- Average no. days above 7000 m3/s: 37.
- Average no. days above 10,000 m3/s: 13.

- The natural 1:5 year flood peak *c.* 13,000 m3/s.

Past flooding events occurred with gradual rise, crest, and fall, but artificial flooding events characterized by rapid rise and recession. Volume of recharge must be considered over entire flooding season, even if prescribed flood volumes greatly exceed historical volumes during specific periods.

14.6.2 Variations in the magnitude of the annual flood

Slight variability in the magnitude of the annual flood will not significantly affect long-term groundwater recharge or associated water supply, although it certainly will affect recharge on a yearly (case-by-case) basis depending on magnitudes.

14.7 DRIFT consequences

See Appendix A.

14.8 Discussion

This discussion addresses the question:
"Do you think that, in a 30-year horizon, a "pre-regulation condition" in the delta could be achieved if the flow conditions prior to river regulation were reinstated, i.e., do you think the current condition is reversible"

A "pre-regulation condition" for groundwater recharge in the delta could be achieved over a 30-year horizon, if the flow conditions prior to river regulation were reinstated, i.e., the current condition is reversible. However, this assumes that other structure limits to flow (especially embankments) are modified to facilitate better flow movement over time.

It is worth considering that extreme floods are not fully controlled by Cahora Bassa Dam, but are attenuated and generally reduced in magnitude, so significant improvement would be expected in terms of the magnitude and duration of floodplain inundation for groundwater recharge during flooding years if they were reinstated.

15. Specialist Study – In-channel Navigation

15.1 Introduction

This section addresses the anticipated effects on barge navigation in the lower Zambezi River, as affected by the changes in the Zambezi flow regime described in Section 3. Also important are Zambezi River flows for the ferry crossing at Caia. The exact hydrological needs for these two forms of navigation change from year to year depending on geomorphologic changes at the specific navigation sites resulting from previous year's flooding and associated scouring events. These two navigation needs are therefore lumped together for this general assessment of environmental flows.

15.2 Selection of key sub-components

Only one sub-component was considered for in-channel navigation:

1. River navigation.

15.3 Description of status prior to river regulation

Dry season flows were much lower than at present, limiting navigation potential and resulting in need for expensive dredging (e.g., SOGREAH 1981; Bolton 1983). Therefore dam operation has substantially improved navigation potential by maintaining high baseflows during the dry season (present day flows are almost an order of magnitude higher than historical dry season minimum flows).

15.4 Description of the current trajectory in condition

Flows are currently ideal--navigation is limited by economic development, but high dry season flows from Cahora Bassa help maintain barge traffic in channel throughout dry season. The Ministry of Public Works and Housing requested that Cahora Bassa Dam operators release dry season spillage in addition to turbine discharge (releasing through one sluice gate throughout dry season) to improve navigation especially at the Caia ferry crossing. This is currently being done, with discharge also through 4 turbines.

Over the next 30-years (i.e., 60 years after closure of the dam), current (or increased) levels of navigation will depend on maintaining high dry season flows and reducing large flooding events. Regular operation of the dam, as has occurred over the past 30 years, is generally conducive to navigation relative to more natural conditions. Increased turbine generation during the dry season would reduce the need for spillage (non-turbine releases) for navigation.

15.5 Description of desired target condition

The current state of river flows, with allocated spillage releases during the dry season, is highly desirable for navigation

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15.6 Evaluation and ranking the hydrological flow categories

Table 15.1 is a ranking of the three hydrological flow categories used in this study in terms of their impact on river navigation. The relative importance of the various aspects of flow change is discussed in more detail below.

Table 15.1 Ranking of the river navigation sub-component against the hydrological change flow categories.

Flow category		Rank per sub-component			
		River navigation			
Low flows	DSLF	3			
Floods	Annual flood	2			
	1:5 year flood	1			

3 = most important
1 = least important.

Reductions in DSLF will impact negatively on navigation. River navigation is unlikely to be affected by smaller annual floods, including discharges of 4500 m^3/s. River navigation is halted during large flooding events, such as floods of 7000-10,000 m^3/s. Annual floods may also indirectly reduce the potential for navigation by reallocating water releases from dry season to flood season. River navigation is also not possible during extreme events (such as 1:5 year natural flood), but these are less frequent than annual floods and therefore less important.

15.6.1 Variability in magnitude of annual flood

Slight variability in the magnitude of the annual flood might affect short-term navigation patterns, but will not have a net affect on navigation in the long-term.

15.7 DRIFT consequences

See Appendix A.

15.8 Discussion

This discussion addresses the question:
“Do you think that, in a 30-year horizon, a “pre-regulation condition” in the delta could be achieved if the flow conditions prior to river regulation were reinstated, i.e., do you think the current condition is reversible?

From a navigation perspective, it is not desirable to return to pre-regulation conditions. Navigation benefits from dam operation that increases dry season flows and decreases flood flows.

16. DRIFT Outputs

16.1 Introduction

Details of the flow requirements for different users or concerns (hereafter referred to as “users”) in the delta are given in the preceding sections of this report. This section summarises those requirements with the aim of:

- comparing the requirements within and between users with respect to the different flow changes assessed (see Sections 2 and 3);
- constructing the relationships between flow and various combinations of users in the Zambezi Delta, in order to elucidate the flow requirements for the Delta;
- evaluating the flow changes against modelled hydropower losses and/or gains to:
    - provide an indication of the possible tradeoffs between Delta users and hydropower generation;
    - evaluate these against the specialist’s assessments as to whether or not past changes to the delta are realistically reversible;
- summarising the various outputs to provide a recommended way forward.

16.1.1 Delta users included in this assignment

The users for the Delta considered in this assignment include:

- Irrigated commercial agriculture
- Small scale agriculture (subsistence and cash crop)
- Estuarine and coastal fisheries (esp. prawns)
- Freshwater fisheries
- Livestock
- Large mammals
- Water birds
- Floodplain vegetation of biodiversity interest
- Invasive, undesired vegetation
- Natural resource utilisation
- Water quality
- Groundwater (as a proxy for domestic water supply)
- In-channel navigation.

Clearly, the list above is not exhaustive and it represents a bias towards socio-economic activities. Much of the focus is on activities and interests that either represent possible livelihood options for residents or have relevance for their health and well-being. The exception to this is the water birds and floodplain vegetation of biodiversity interest, which can be viewed as rough proxies for ecosystem condition. Other ecological ‘users’ could include wider biodiversity considerations, rare and endangered species and ecosystem functioning. Similarly some socio-economic uses, such as the collections of medicinal plants and alternative forms of protein (such as reptiles, amphibians and rodents) have not been addressed.

16.1.2 Summary of hydrological change levels assessed

Details of the hydrological change levels are provided in Section 3. In summary, the three flow categories for which flow changes were considered were:

- dry season lowflows (present day, plus 5 change levels);
- the ‘annual’ flood (present day, plus 18 change levels);

- 1:5 year return flood (present day, plus 1 change level).

The flow changes encompass a mixture of:
- changes in magnitude;
- changes in duration;
- changes in timing.

The following basic assumptions were applied:
- the study focused on the southern bank of the Zambezi Delta.
- PRESENT DAY conditions were used as a starting point, and change was expressed as a percentage move towards or away from a pre-defined target condition.
- specialists assumed a 30-year horizon for their predictions.
- each flow change was considered in isolation, i.e., it was assumed that the remainder of the flow regime remained at PRESENT DAY levels.
- for the flood flows it was assumed the same magnitude would occur each year[7].

16.2 Assessment of the tradeoffs between Zambezi Delta users

Comparison of the ratings returned for the flow changes each of the users provides a clear indication of whether a particular flow change was perceived as beneficial, i.e., result in a positive move towards the target condition, or detrimental, i.e., result in a negative move away from the target condition for that user. This provides a practical method of checking whether or not conflicts are likely to exist with respect to the flow requirements of different users in the delta. The ratings from each of the users for each of the flow changes evaluated are provided and discussed below.

16.2.1 Dry season lowflows

Figure 16.1 indicates the ratings returned for each of the users for the five possible changes (all reductions) considered for the dry season lowflows.

The results indicate clearly that the majority of users perceive reductions in the dry season lowflows as negative. The reasons for this are elucidated in each of relevant the specialist sections (Sections 5-15). The exceptions to this are those users concerned with biodiversity, as the reduced low flows would provide some much needed variability in the system. Of all the sub-components considered, the fate of the African Skimmer is probably most linked to reduced low flows in the delta, as extended low dry season flows are required for it to complete its breeding successfully.

Thus, there are some minor conflicts between users in the delta with respect to dry season lowflows; however, the majority opinion among the users assessed in this study is that reduction in lowflows is either neutral or more detrimental than beneficial.

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[7] This will not actually be the case, as the magnitude of flows at the delta will depend on downstream contributions, i.e., vary as a function of climate each year.

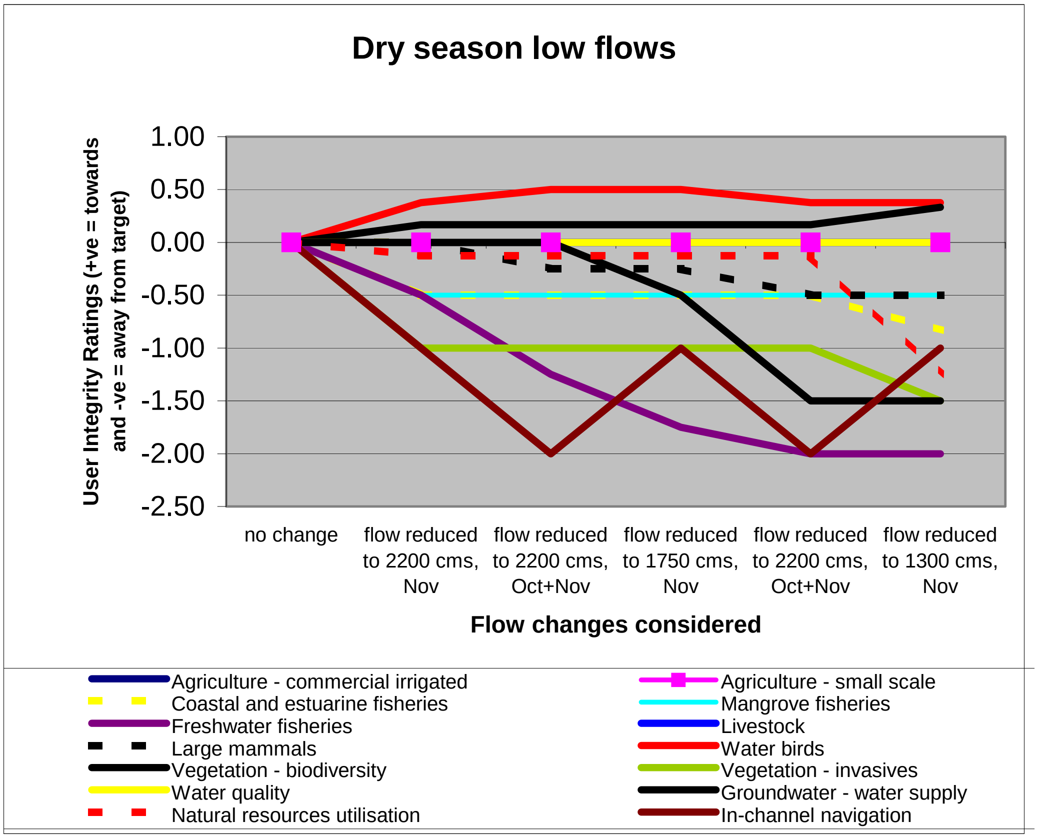

Figure 16.1 Ratings returned for each of the users for the five possible changes considered for the dry season lowflows.

16.2.2 Annual flood

Figure 16.2 indicates the ratings returned for each of the users for the eighteen possible changes (various levels of increases in either December/January or February/March) considered for the annual flood.

The results indicate clearly that the majority of users perceive some form of reinstatement of the annual flood to be beneficial. The reasons for this are elucidated in each of relevant the specialist sections (Sections 5-15). The exceptions to this are those users concerned with in-channel navigation and commercial agriculture, as the flood levels could negatively affect those activities. In this regard it is worth considering that flooding does still occur periodically in the delta (i.e., with Cahora Bassa Dam in place), but that the timing of these flood events are highly erratic. Flood releases from Cahora Bassa Dam may occur in any month, and annual downstream peaks (factoring in unregulated tributary contributions) have occurred in October and November (see Section 3). Thus, presumably, the perceived negative affects of the floods on in-channel navigation and commercial agriculture could be better managed if the occurrence of the floods was more predictable.

The timing of the annual flood has particular relevance for hydropower generation at Cahora Bassa Dam. Flood releases during December are timed to coincide with the early stages of flood rise, and enable increased storage capacity in Cahora Bassa

Dam for the remaining flood season. Therefore, flood releases scheduled for December will serve to reduce the magnitude and frequency of major (emergency) flood discharges during subsequent peak flooding months. Flood releases during February, timed to the historical period of peak flooding, would have only a minor effect on the magnitude and frequency of emergency flood discharge. February releases may also significantly prejudice hydropower generation in dry years.

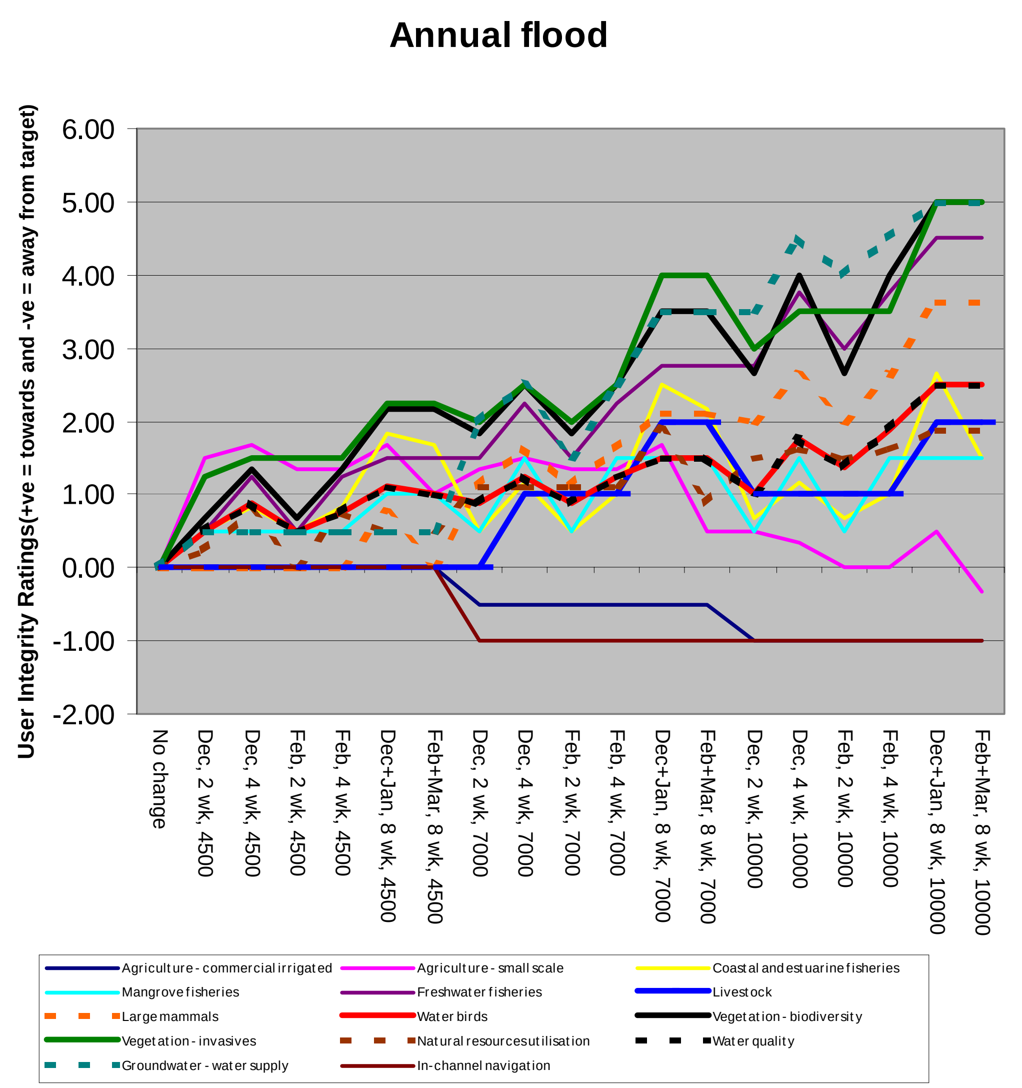

Figure 16.2 Ratings returned for each of the users for the eighteen possible changes considered for the annual flood.

Since the timing of the annual flood has important implications for hydropower generation, it is useful to consider whether the users in the delta have some preference for floods in February or in December. Figure 16.3 provides an indication of the combined ratings for all users who expressed a preference of reinstatement of the annual flood, and indicates that, an average the users do not show a strong preference for a February flood over a December flood. Rather, the perceived (combined) beneficial effects of the floods increase with increased magnitude and increased duration.

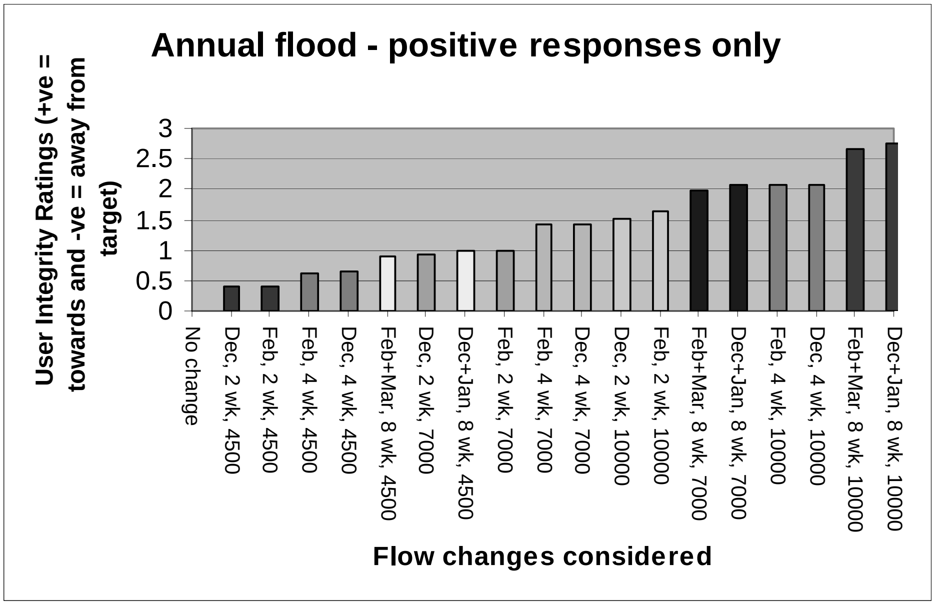

Figure 16.3 Combined ratings for users who expressed a preference of reinstatement of the annual flood for the eighteen possible changes considered[8].

Thus, there are some minor conflicts between users in the delta with respect to reinstatement of the annual flood; however, the majority opinion among the users assessed in this study is that restoration of annual flooding is beneficial. Most importantly, these annual flood releases from Cahora Bassa offer a measure of predictability that creates opportunities for significantly higher socio-economic benefits than the current, erratic discharge patterns.

16.2.3 The 1:5 year flood

Figure 16.4 indicates the ratings returned for each of the users for the reinstatement of the 1:5 year return period flood.

The results indicate that the majority of users perceive some form of reinstatement of the 1:5 year flood to be beneficial. The reasons for this are elucidated in each of relevant the specialist sections (Sections 5-15). As was the case for the annual flood, the exceptions to this are those users concerned with in-channel navigation and agriculture, as the flood levels could negatively affect those activities.

Many of the perceived benefits of reinstating the 1:5 year flood were evaluated on the changes that have occurred in the ecosystem following the 2000 floods, e.g., increased fish catches (see Sections 6 and 7). Many of these benefits would, however, also be provided by a managed annual flood in December, which would have much lower negative social effects.

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[8] The colours denote floods of the same magnitude and duration.

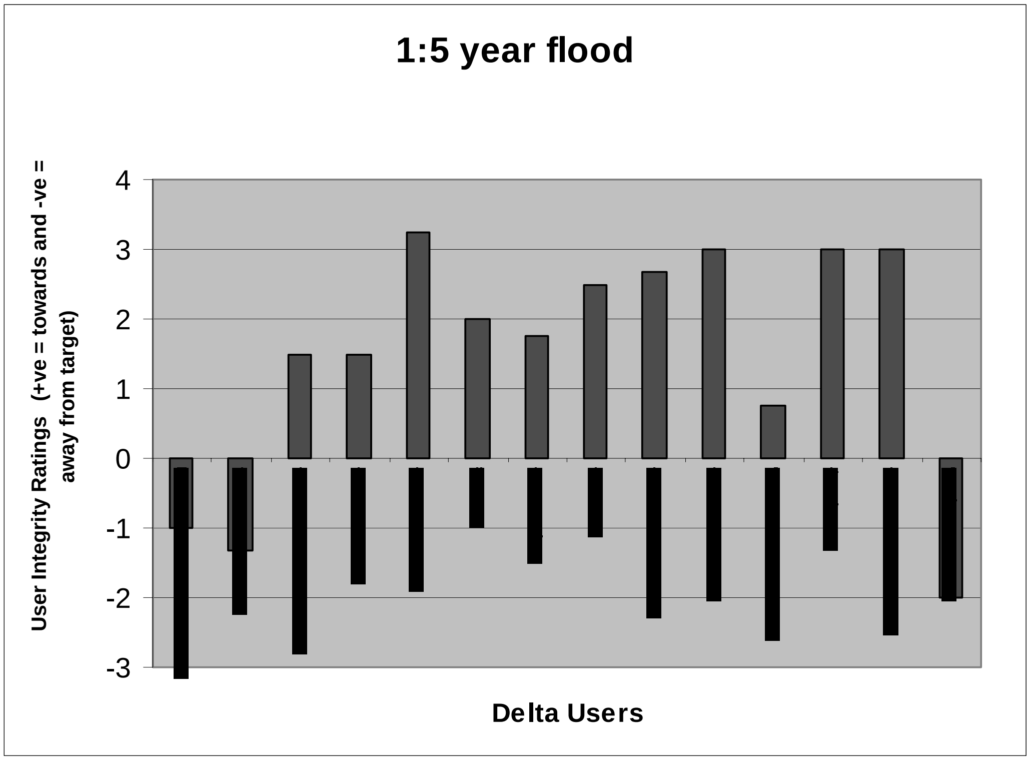

Figure 16.4 Ratings returned for each of the users for the reinstatement of the 1:5 year flood.

16.3 Implications of flow change in the Zambezi Delta

The DRIFT software combines the scores returned by the users with the consequences for hydropower generation of supplying the various flow changes that were assessed (Brown and Joubert 2003). This allows for the creation of a range of permutations comprising ‘new’ flow regime scenarios, together with their consequences for different users in the delta and the implications for hydropower generation. These are created in the DRIFT SOLVER routine, using the Solver tool in Excel, which provides the necessary (“branch and bound”) algorithm (Microsoft, 1985 -1997). An integer linear program (e.g., Winston 1994) optimises the distribution of a given total volume of water among the different change levels of flow classes in a way that results in the lowest aggregate impact on the riverine ecosystem according to the Integrity Ratings. It does this by summing the ratings given for all the sub-components, taking into account all the negative or positive signs, to produce combinations of high and low flows that return the highest possible ‘Percentage Move Towards Target’ for that volume (Brown and Joubert 2003).

This information is then depicted using DRIFT-CATEGORY, the purpose of which is to display the relationship between the hydropower lost in the provision of the flows and the percentage move towards or away from the target conditions described by each of the users.

A DRIFT CATEGORY plot was created for the combined ratings of the 14 user groups assessed (Figure 16.5), with the requirements of each user given equal importance. The following applies to all DRIFT CATEGORY plots.

- The plot depicts the combined ratings for all users at the level of the whole delta, relative to the current state of the system, and the hydropower values provided are the **hydropower losses** (in GWH/a[9]) linked to the provision of each scenario.
- The combined scores are expressed a DRIFT Integrity ratings, and indicate a move towards target conditions (+ve) or away from target conditions (-ve).
- PRESENT CONDITION = Overall Integrity Score of zero (0).
- Each of the red squares in Figure 15.5 represents an entire flow regime made up of a combination of:
  - One of six levels of change in the dry season lowflows (present day plus five changes);
  - One of 19 levels of change in the annual flood (present day plus 18 changes);
  - One of two levels of change in the 1:5 year flood (present day and historic).
  - The remainder of the flow regime at present day levels.

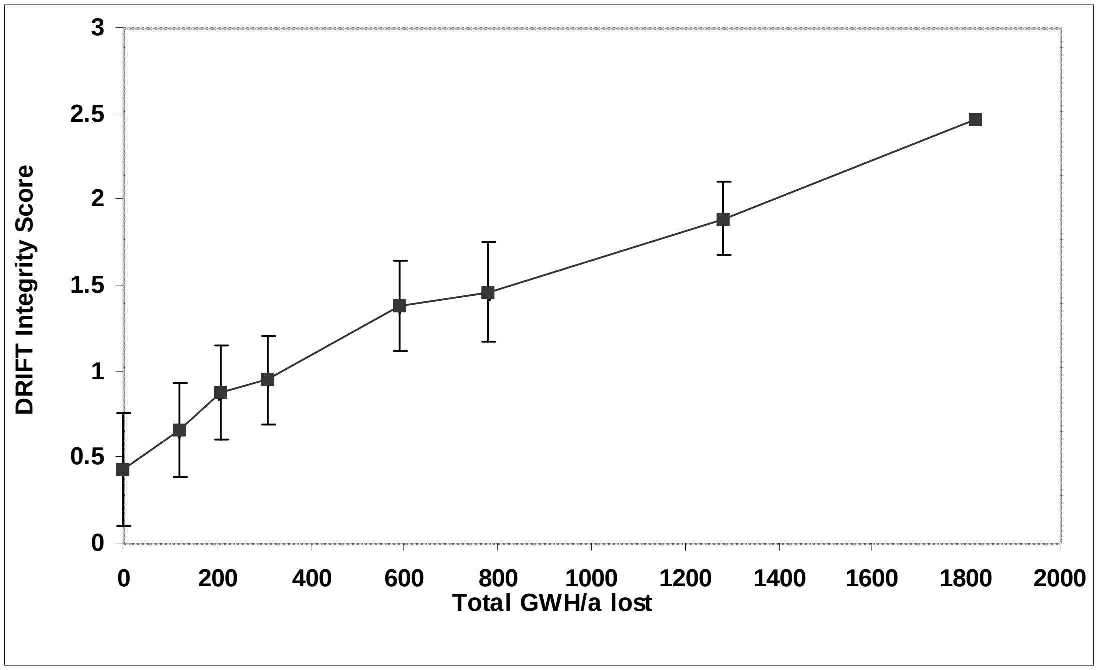

Figure 16.5 DRIFT CATEGORY plot for combined ratings of the 14 user groups assessed.

In every case, the optimisation programme in DRIFT SOLVER selected present day levels for dry season lowflows and for the 1:5 year flood. Thus, the only changes selected (and those deemed more important) were changes to the annual flood.

As mentioned in Section 16.2.2, the timing of the annual flood did not emerge as being as important as the magnitude and duration of the flood. This is illustrated by the change levels that were selected by DRIFT SOLVER (Figure 16.5) in order of most beneficial to least beneficial for the combined delta users (Table 16.1).

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[9] Gigawatts per Hour annum (see Section 3).

Table 16.1 Annual flood change levels selected by DRIFT SOLVER in order of most beneficial to least beneficial for the combined delta users.

Most to least 'beneficial'[10]	% GWH/a lost	DRIFT 'Integrity score'	Loose translation of percentage	Annual flood
1	0%	0.43	*c.* 8% towards target	Dec; 2 weeks; 4500 m3/s
2	2%	0.65	*c.* 12% towards target	Feb; 2 weeks; 4500 m3/s
3	3%	0.80	*c.* 15% towards target	Dec; 2 weeks; 7000 m3/s
4	5%	0.95	*c.* 18% towards target	Dec; 8 weeks; 4500 m3/s
5	10%	1.22	*c.* 23% towards target	Dec; 2 weeks; 10,000 m3/s
6	13%	1.30	*c.* 25% towards target	Feb; 2 weeks; 10,000 m3/s
7	21%	1.82	*c.* 36% towards target	Dec; 8 weeks; 7000 m3/s
8	30%	2.30	*c.* 46% towards target	Dec; 8 weeks; 10,000 m3/s

The results in Figure 16.5 and Table 16.1 are for all users combined, and include users that would not be benefited by the re-introduction of the annual flood. Naturally, these would be enhanced if consideration focused on those users expected to benefit. Conversely, the benefits could expect to be far less, and even detrimental if the focus was on those users not expected to benefit from the re-instatement of annual floods. Moreover, the fact that two users may both benefit from reinstatement of the annual floods does not mean necessarily that they would 'prefer' the same magnitude, duration or timing for that reintroduction.

The DRIFT Integrity scores for the annual flood change levels for the delta users that are expected to benefit from re-instatement of annual floods are given in Table 15.2. From Table 16.2 it is evident that while individual user benefits generally increase with increased magnitude and duration, not all users share exactly the same preference. This means that decisions on the timing, magnitude and duration of releases to provide annual floods should consider user need individually in order to avoid prejudicing one user unintentionally and unnecessarily.

This is further borne out by the DRIFT Integrity scores for the annual flood change levels for the delta users that are not expected to benefit from re-instatement of annual floods (Table 16.3), i.e., commercial agriculture and in-channel navigation. Here it is obvious that, although commercial agriculture and in-channel navigation would not necessarily benefit from annual flood releases, some releases (which could benefit other users) are not in fact expected to negatively affect them.

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[10] Numbering refers to the red squares in Figure 16.5, sequentially from left to right.

Table 16.2 The DRIFT Integrity scores for the annual flood change levels for the delta users that are expected to benefit from re-instatement of annual floods.

Least to most 'beneficial'	Small-scale agriculture	Coastal and estuarine fisheries	Mangrove estuarine fisheries	Freshwater fisheries	Livestock	Large mammals	Water birds	Floodplain Vegetation biodiversity	Invasive, undesired vegetation	Natural resources utilisation	Water quality	Groundwater supply
1	1.33	0.50	0.50	0.50	0.00	0.00	0.50	0.67	1.50	0.00	0.00	0.50
2	1.67	0.83	0.50	1.25	0.00	0.00	0.88	1.33	1.50	0.75	0.00	0.50
3	1.33	0.50	0.50	1.50	0.00	1.13	0.88	1.83	2.00	1.13	1.00	2.00
4	1.67	1.83	1.00	1.50	0.00	0.75	1.13	2.17	2.25	0.50	0.00	0.50
5	0.50	0.67	0.50	2.75	1.00	2.00	1.00	2.67	3.00	1.50	2.25	3.50
6	0.00	0.67	0.50	3.00	1.00	2.00	1.38	2.67	3.50	1.50	2.25	4.00
7	1.67	2.50	1.50	2.75	2.00	2.13	1.50	3.50	4.00	1.88	1.00	3.50
8	0.50	2.67	1.50	4.50	2.00	3.63	2.50	5.00	5.00	1.88	2.25	5.00

Table 16.3 The DRIFT Integrity scores for the annual flood change levels for the delta users that are not expected to benefit from re-instatement of annual floods.

Least to most 'beneficial'	Commercial agriculture	In-channel navigation
1	0.00	0.00
2	0.00	0.00
3	-0.50	-1.00
4	0.00	0.00
5	-1.00	-1.00
6	-1.00	-1.00
7	-0.50	-1.00
8	-1.00	-1.00

16.4 Discussion

There is no 'minimum flow requirement' for the Zambezi River delta. Rather, perceived benefits increase in the delta with an increase in magnitude and duration of the annual flood, provided it occurs sometime in the normal flooding period of December to February. Benefits to the delta users, however, offset by costs in terms of hydropower loss. Thus, in order for improvement in the delta to be achieved some trade off will need to be made, and it seems likely that that trade-off will involve a reduction in hydropower generation.

The hydrological and hydropower modelling presented in Section 3 showed that the releases considered in this study are achievable. Whether or not they are 'realistic' is a subjective assessment and cannot be made by the specialists involved in this study. While many people may feel that a 3% loss in hydropower for a 15% improvement for users in the delta (Table 16.1) is realistic and justified, there may be compelling reasons for others why this is not so. The intention of DRIFT and the specialists involved in the study is not to make decisions, but rather to provide objective information to facilitate communication and assist in decision-making.

What is certain from the results presented in this section, and indeed from the detailed specialist contributions to this report, is that there is a strong and consistent requirement for water in the delta from most users, and a strong and consistent message that reinstating at least some of the historic flow patterns will result in significant improvement in many of the areas that have been shown to be of concern. Furthermore, the level of consensus between the specialists provides compelling substantiation of the views expressed by individuals[11].

Reinstating the annual flood was singled out by all but two of the users as the most valuable change that could be made to the flow regime that currently reaches the delta. Under present day conditions, the occurrence of the historic annual flood is irregular and, when it does occur, its timing is erratic (Beilfuss 2001). Thus, while many users saw some benefit in the reinstatement of large flood events, such as the 1:5-year flood, and reduction of the dry season lowflows, the benefits of these interventions where generally seen as lower than those for reinstating the annual flood, and in some cases the negative effects were undeniable (e.g., the danger represented to human life by the 1:5 year flood). Additionally, there was generally greater within user conflict, and greater conflict between delta needs and hydropower generation, on the question of the reintroduction of the 1:5-year flood, and reduction of the dry season lowflows than there was for reinstating an annual flood.

The DRIFT combined flow requirements reflect a situation where the requirements of each user were given equal importance. It thus represents a fairly simple summary of the overall needs, and some form of weighting may be desirable in the future. Nonetheless, the outcome provides a useful indication of the flow requirements of the Zambezi Delta users. The flow requirements are off-set against the modelled hydropower losses associated with supplying each of the flow regimes. Here, the opportunities for a win-win situation are enormous as least one scenario indicates possibility of improvements with no GWH/a lost.

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[11] Consensus between recognised experts is considered to have considerable legal influence.

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Appendix A: DRIFT Consequences

A.1 Consequences for changes in dry season lowflows

Agriculture - commercial irrigated

		Agriculture - commercial irrigated		AVERAGE SCORE	Range	
		ICA			UPPER	LOWER
Present Day no change	Severity Rating	**0**	**0**			
	Dir. Of change	N/A	N/A			
	Toward/away from target	N/A	N/A			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	**0**	**0**			
	Dir. Of change	N/A	N/A			
	Toward/away from target	N/A	N/A			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	**0**	**0**			
	Dir. Of change	N/A	N/A			
	Toward/away from target	N/A	N/A			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	**0**	**0**			
	Dir. Of change	N/A	N/A			
	Toward/away from target	N/A	N/A			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	**0**	**0**			
	Dir. Of change	N/A	N/A			
	Toward/away from target	N/A	N/A			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	**0**	**0**			
	Dir. Of change	N/A	N/A			
	Toward/away from target	N/A	N/A			
	Integrity Rating	0	0	0.00	0.00	0.00
	General comments	With present operation a certain level of development is expected across all four sub-components. If operations rules are modified as indicated no effect is expected on that growth.				

weight	1	0	0	0
adjusted weight	1.0	0.0	0.0	0.0

Agriculture - small scale

		Agriculture - small scale						AVERAGE SCORE	Range	
		RAFC		RACC		NFR			UPPER	LOWER
Present Day no change	Severity Rating	**0**	**0**	**0**	**0**	**0**	**0**			
	Dir. Of change	N/A	N/A	N/A	N/A	N/A	N/A			
	Toward/away from target	N/A	N/A	N/A	N/A	N/A	N/A			
	Integrity Rating	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	**0**	**0**	**0**	**0**	**0**	**0**			
	Dir. Of change	N/A	N/A	N/A	N/A	N/A	N/A			
	Toward/away from target	N/A	N/A	N/A	N/A	N/A	N/A			
	Integrity Rating	0	0	0	0	0	0	0.00	0.00	0.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	**0**	**0**	**0**	**0**	**0**	**0**			
	Dir. Of change	N/A	N/A	N/A	N/A	N/A	N/A			
	Toward/away from target	N/A	N/A	N/A	N/A	N/A	N/A			
	Integrity Rating	0	0	0	0	0	0	0.00	0.00	0.00
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	**0**	**0**	**0**	**0**	**0**	**0**			
	Dir. Of change	N/A	N/A	N/A	N/A	N/A	N/A			
	Toward/away from target	N/A	N/A	N/A	N/A	N/A	N/A			
	Integrity Rating	0	0	0	0	0	0	0.00	0.00	0.00
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	**0**	**0**	**0**	**0**	**0**	**0**			
	Dir. Of change	N/A	N/A	N/A	N/A	N/A	N/A			
	Toward/away from target	N/A	N/A	N/A	N/A	N/A	N/A			
	Integrity Rating	0	0	0	0	0	0	0.00	0.00	0.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	**0**	**0**	**0**	**0**	**0**	**0**			
	Dir. Of change	N/A	N/A	N/A	N/A	N/A	N/A			
	Toward/away from target	N/A	N/A	N/A	N/A	N/A	N/A			
	Integrity Rating	0	0	0	0	0	0	0.00	0.00	0.00
	General comments	None								

weight	1	1	1
adjusted weight	0.3	0.3	0.3

Coastal and estuarine fisheries

		Coastal and estuarine fisheries							AVERAGE SCORE	Range	
		Shrimp		*Bottom fish*		*Prim.product*				UPPER	LOWER
Present Day no change	Severity Rating	0	0	0	0	0	0				
	Dir. Of change	none		none		none					
	Toward/away from target	N/a		N/a		N/a					
	Integrity Rating	0	0	0	0	0	0		0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	0	1	0	1	0	1				
	Dir. Of change	Decrease		Decrease		Decrease					
	Toward/away from target	Away		Away		Away					
	Integrity Rating	0	-1	0	-1	0	-1		-0.50	0.00	-1.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	0	1	0	1	0	1				
	Dir. Of change	Decrease		Decrease		Decrease					
	Toward/away from target	Away		Away		Away					
	Integrity Rating	0	-1	0	-1	0	-1		-0.50	0.00	-1.00
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	0	1	0	1	0	1				
	Dir. Of change	Decrease		Decrease		Decrease					
	Toward/away from target	Away		Away		Away					
	Integrity Rating	0	-1	0	-1	0	-1		-0.50	0.00	-1.00
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	0	1	0	1	0	1				
	Dir. Of change	Decrease		Decrease		Decrease					
	Toward/away from target	Away		Away		Away					
	Integrity Rating	0	-1	0	-1	0	-1		-0.50	0.00	-1.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	1	2	0	1	0	1				
	Dir. Of change	Decrease		Decrease		Decrease					
	Toward/away from target	Away		Away		Away					
	Integrity Rating	-1	-2	0	-1	0	-1		-0.83	-0.33	-1.33
	General comments	Lower flows than present will result in a slight reduction of stocks, due to possible reduction in habitat. The exception for level 5 means that a strong reduction in flows during recruitment season									
	weight	1		1		1		0			
	adjusted weight	0.3		0.3		0.3		0.0			

Mangrove fisheries

		Mangrove fisheries							AVERAGE SCORE	Range	
		Mangr.crab								UPPER	LOWER
Present Day no change	Severity Rating	0	0								
	Dir. Of change	none									
	Toward/away from target	N/a									
	Integrity Rating	0	0						0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	0	1								
	Dir. Of change	Decrease									
	Toward/away from target	Away									
	Integrity Rating	0	-1						-0.50	0.00	-1.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	0	1								
	Dir. Of change	Decrease									
	Toward/away from target	Away									
	Integrity Rating	0	-1						-0.50	0.00	-1.00
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	0	1								
	Dir. Of change	Decrease									
	Toward/away from target	Away									
	Integrity Rating	0	-1						-0.50	0.00	-1.00
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	0	1								
	Dir. Of change	Decrease									
	Toward/away from target	Away									
	Integrity Rating	0	-1						-0.50	0.00	-1.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	0	1								
	Dir. Of change	Decrease									
	Toward/away from target	Away									
	Integrity Rating	0	-1						-0.50	0.00	-1.00
	General comments										
	weight	1		0		0		0			
	adjusted weight	1.0		0.0		0.0		0.0			

Freshwater fisheries

	Freshwater fisheries									AVERAGE SCORE	Range	
		Clarius gari		*Oreochromi*		*Labeo altive*		*Hydrocynus*			UPPER	LOWER
Present Day no change	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from target	N/a		N/a		N/a		N/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	0	1	0	1	0	1	0	1			
	Dir. Of change	Decrease		Decrease		Decrease		Decrease				
	Toward/away from target	Away		Away		Away		Away				
	Integrity Rating	0	-1	0	-1	0	-1	0	-1	-0.50	0.00	-1.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	1	2	1	2	0	2	0	2			
	Dir. Of change	Decrease		Decrease		Decrease		Decrease				
	Toward/away from target	Away		Away		Away		Away				
	Integrity Rating	-1	-2	-1	-2	0	-2	0	-2	-1.25	-0.50	-2.00
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	2	3	2	3	0	2	0	2			
	Dir. Of change	Decrease		Decrease		Decrease		Decrease				
	Toward/away from target	Away		Away		Away		Away				
	Integrity Rating	-2	-3	-2	-3	0	-2	0	-2	-1.75	-1.00	-2.50
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	2	3	2	3	0	3	0	3			
	Dir. Of change	Decrease		Decrease		Decrease		Decrease				
	Toward/away from target	Away		Away		Away		Away				
	Integrity Rating	-2	-3	-2	-3	0	-3	0	-3	-2.00	-1.00	-3.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	2	3	2	3	0	3	0	3			
	Dir. Of change	Decrease		Decrease		Decrease		Decrease				
	Toward/away from target	Away		Away		Away		Away				
	Integrity Rating	-2	-3	-2	-3	0	-3	0	-3	-2.00	-1.00	-3.00
	General comments	resulting in larger surface area and thus more fish. Decreasing the unnaturally high low flows will result										
	Social comments	Higher flows than natural may benefit fish stocks but										
	weight	1		1		1		1				
	adjusted weight	0.3		0.3		0.3		0.3				

Large mammals

	Large mammals									AVERAGE SCORE	Range	
		Buffalo		**Waterbuck**		**Hippo**		**Zebra**			UPPER	LOWER
Present Day no change	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	0	0	0	0	1	1	0	0			
	Dir. Of change	none		none		Neg		none				
	Toward/away from target	n/a		n/a		Away		n/a				
	Integrity Rating	0	0	0	0	-1	-1	0	0	-0.25	-0.25	-0.25
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	0	0	0	0	1	1	0	0			
	Dir. Of change	none		none		Neg		none				
	Toward/away from target	n/a		n/a		Away		n/a				
	Integrity Rating	0	0	0	0	-1	-1	0	0	-0.25	-0.25	-0.25
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	0	0	0	0	2	2	0	0			
	Dir. Of change	none		none		Neg		none				
	Toward/away from target	n/a		n/a		Away		n/a				
	Integrity Rating	0	0	0	0	-2	-2	0	0	-0.50	-0.50	-0.50
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	0	0	0	0	2	2	0	0			
	Dir. Of change	none		none		Neg		none				
	Toward/away from target	n/a		n/a		Away		n/a				
	Integrity Rating	0	0	0	0	-2	-2	0	0	-0.50	-0.50	-0.50
	General comments	None										
	weight	1		1		1		1				
	adjusted weight	0.3		0.3		0.3		0.3				

	Livestock											
		Livestock								**AVERAGE SCORE**	**Range**	
		Livestock									**UPPER**	**LOWER**
Present Day no change	Severity Rating	0	0									
	Dir. Of change	None										
	Toward/away from target	n/a										
	Integrity Rating	0	0							0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	0	0									
	Dir. Of change	None										
	Toward/away from target	n/a										
	Integrity Rating	0	0							0.00	0.00	0.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	0	0									
	Dir. Of change	None										
	Toward/away from target	n/a										
	Integrity Rating	0	0							0.00	0.00	0.00
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	0	0									
	Dir. Of change	None										
	Toward/away from target	n/a										
	Integrity Rating	0	0							0.00	0.00	0.00
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	0	0									
	Dir. Of change	None										
	Toward/away from target	n/a										
	Integrity Rating	0	0							0.00	0.00	0.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	0	0									
	Dir. Of change	None										
	Toward/away from target	n/a										
	Integrity Rating	0	0							0.00	0.00	0.00
	General comments	None										
	weight	1		0		0		0				
	adjusted weight	1.0		0.0		0.0		0.0				

	Water birds											
		Water birds								**AVERAGE SCORE**	**Range**	
		G. caruncul		**P. gambens**		**A. goliath**		**R. flavirostr**			**UPPER**	**LOWER**
Present Day no change	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	0	0	0	0	0	0	0	0			
	Toward/away from target	N/a	N/a	N/a	N/a	N/a	N/a	N/a	N/a			
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	0	1	0	1	0	0	0	1			
	Dir. Of change	+	+	+	+	-	-	+	+			
	Toward/away from target	0	Towar	0	Towar	0	0	0	Towar			
	Integrity Rating	0	1	0	1	0	0	0	1	0.38	0.00	0.75
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	1	1	1	1	0	2	1	1			
	Dir. Of change	+	+	+	+	-	-	+	+			
	Toward/away from target	Towar	Towar	Towar	Towar	0	Towar	Towar	Towar			
	Integrity Rating	1	1	1	1	0	-2	1	1	0.50	0.75	0.25
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	1	1	1	1	0	2	1	1			
	Dir. Of change	+	+	+	+	-	-	+	+			
	Toward/away from target	Towar	Towar	Towar	Towar	0	Towar	Towar	Towar			
	Integrity Rating	1	1	1	1	0	-2	1	1	0.50	0.75	0.25
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	1	2	1	2	0	3	2	3			
	Dir. Of change	+	+	+	+	-	-	+	+			
	Toward/away from target	Towar	Towar	Towar	Towar	0	Towar	Towar	Towar			
	Integrity Rating	1	1	1	1	0	-3	1	1	0.38	0.75	0.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	1	2	1	2	0	3	1	3			
	Dir. Of change	+	+	+	+	-	-	+	+			
	Toward/away from target	Towar	Towar	Towar	Towar	0	Towar	Towar	Towar			
	Integrity Rating	1	1	1	1	0	-3	1	1	0.38	0.75	0.00
	General comments	The floodplain drought will		For the S. Goose as they have		Less water during the dry season						
	weight	1		1		1		1				
	adjusted weight	0.3		0.3		0.3		0.3				

Vegetation - biodiversity

		Vegetation - biodiversity							AVERAGE SCORE	Range	
		Mangrove w		Riparian for		Papyrus-do				UPPER	LOWER
Present Day no change	Severity Rating	0	0	0	0	0	0				
	Dir. Of change	NONE		NONE		NONE					
	Toward/away from target	N/A		N/A		N/A					
	Integrity Rating	0	0	0	0	0	0		0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	1	2	0	0	1	1				
	Dir. Of change	pos		n/a		neg					
	Toward/away from target	towards		n/a		away					
	Integrity Rating	1	2	0	0	-1	-1		0.17	0.00	0.33
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	1	2	0	0	1	1				
	Dir. Of change	pos		n/a		neg					
	Toward/away from target	towards		n/a		away					
	Integrity Rating	1	2	0	0	-1	-1		0.17	0.00	0.33
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	1	2	0	0	1	1				
	Dir. Of change	pos		n/a		neg					
	Toward/away from target	towards		n/a		away					
	Integrity Rating	1	2	0	0	-1	-1		0.17	0.00	0.33
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	1	2	0	0	1	1				
	Dir. Of change	pos		n/a		neg					
	Toward/away from target	towards		n/a		away					
	Integrity Rating	1	2	0	0	-1	-1		0.17	0.00	0.33
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	2	3	0	0	1	2				
	Dir. Of change	pos		n/a		neg					
	Toward/away from target	towards		n/a		away					
	Integrity Rating	2	3	0	0	-1	-2		0.33	0.33	0.33
	General comments	Both papyrus and mangrove are seral communities, i.e. they thrive on change, not on stability.									
	Site-specific and change-level s	DSLF have minimal effects on plant communities selected, apart from mangroves. There is probably no difference in effect due to timing of low-flow.Probably no real DSLF effect on riparian woodland as these are away from main channels.Logic is: (a) low DS									
	weight	1		1		1		0			
	adjusted weight	0.3		0.3		0.3		0.0			

Vegetation - invasives

		Vegetation - invasives						AVERAGE SCORE	Range	
		Savanna		Aquatic plar					UPPER	LOWER
Present Day no change	Severity Rating	0	0	0	0					
	Dir. Of change	None		None						
	Toward/away from target	n/a		n/a						
	Integrity Rating	0	0	0	0			0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	1	1	1	1					
	Dir. Of change	neg		neg						
	Toward/away from target	away		away						
	Integrity Rating	-1	-1	-1	-1			-1.00	-1.00	-1.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	1	1	1	1					
	Dir. Of change	neg		neg						
	Toward/away from target	away		away						
	Integrity Rating	-1	-1	-1	-1			-1.00	-1.00	-1.00
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	1	1	1	1					
	Dir. Of change	neg		neg						
	Toward/away from target	away		away						
	Integrity Rating	-1	-1	-1	-1			-1.00	-1.00	-1.00
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	1	1	1	1					
	Dir. Of change	neg		neg						
	Toward/away from target	away		away						
	Integrity Rating	-1	-1	-1	-1			-1.00	-1.00	-1.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	1	2	1	2					
	Dir. Of change	neg		neg						
	Toward/away from target	away		away						
	Integrity Rating	-1	-2	-1	-2			-1.50	-1.00	-2.00
	General comments	DSLF have minimal effects on plant communities selected. There is no difference in effect due to timing of low-flow								
	Site-specific and change-level s	Logic is that low DSLF will allow more terrestrialization to occur owing to soil drainage, and hence lead to an increase in savanna, which is considered negative to biodiversity goals.								
	weight	1		1		0	0			
	adjusted weight	0.5		0.5		0.0	0.0			

Natural resources utilisation

		Natural resources utilisation								AVERAGE SCORE	Range	
		Mangrove f		Riparian tre		Reed and pa		Palm savan			UPPER	LOWER
Present Day no change	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	1	2	0	0	1	1	1	1			
	Dir. Of change	pos		n/a		neg		pos				
	Toward/away from target	towards		n/a		away		away				
	Integrity Rating	1	2	0	0	-1	-1	-1	-1	-0.13	-0.25	0.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	1	2	0	0	1	1	1	1			
	Dir. Of change	pos		n/a		neg		pos				
	Toward/away from target	towards		n/a		away		away				
	Integrity Rating	1	2	0	0	-1	-1	-1	-1	-0.13	-0.25	0.00
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	1	2	0	0	1	1	1	1			
	Dir. Of change	pos		n/a		neg		pos				
	Toward/away from target	towards		n/a		away		away				
	Integrity Rating	1	2	0	0	-1	-1	-1	-1	-0.13	-0.25	0.00
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	1	2	0	0	1	1	1	1			
	Dir. Of change	pos		n/a		neg		pos				
	Toward/away from target	towards		n/a		away		away				
	Integrity Rating	1	2	0	0	-1	-1	-1	-1	-0.13	-0.25	0.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	2	3	0	0	1	2	1	1			
	Dir. Of change	pos		n/a		neg		pos				
	Toward/away from target	towards		n/a		away		away				
	Integrity Rating	-2	-3	0	0	-1	-2	-1	-1	-1.25	-1.00	-1.50
	General comments	Both papyrus and mangrove are seral communities, i.e. they thrive on change, not on stability.DSLF have minimal effects on plant communities selected, apart from mangroves.										
	Site-specific and change-level s	There is probably no difference in effect due to timing of low-flow.Probably no real DSLF effect on riparian woodland as these are away from main channels.Logic is: (a) low DSLF will allow creek salinity to increase upstream, hence also increase extent of										
	weight	1		1		1		1				
	adjusted weight	0.3		0.3		0.3		0.3				

Water quality

		Water quality								AVERAGE SCORE	Range	
		Sediment		Effluent dilu		Eutrophicat		Salinity intr			UPPER	LOWER
Present Day no change	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	None		None		None		None				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	None		None		None		None				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	None		None		None		None				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	None		None		None		None				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	None		None		None		None				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	None		None		None		None				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
	General comments Site-specific and change-level s Social comments	None										
	weight	1		1		1		1				
	adjusted weight	0.3		0.3		0.3		0.3				

Groundwater - water supply

		Groundwater - water supply		AVERAGE SCORE	Range	
		Recharge of			UPPER	LOWER
Present Day no change	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from target	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from target	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from target	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	0	1			
	Dir. Of change	Neg				
	Toward/away from target	Away				
	Integrity Rating	0	-1	-0.50	0.00	-1.00
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	1	2			
	Dir. Of change	Neg				
	Toward/away from target	Away				
	Integrity Rating	-1	-2	-1.50	-1.00	-2.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	1	2			
	Dir. Of change	Neg				
	Toward/away from target	Away				
	Integrity Rating	-1	-2	-1.50	-1.00	-2.00
	General comments					

weight	1	0	0	0
adjusted weight	1.0	0.0	0.0	0.0

In-channel navigation

		In-channel navigation		AVERAGE SCORE	Range	
		River naviga			UPPER	LOWER
Present Day no change	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from target	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 1 flow reduced to 2200 cms, Nov	Severity Rating	1	1			
	Dir. Of change	Neg				
	Toward/away from target	Toward				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 2 flow reduced to 2200 cms, Oct+Nov	Severity Rating	2	2			
	Dir. Of change	Neg				
	Toward/away from target	Toward				
	Integrity Rating	-2	-2	-2.00	-2.00	-2.00
Change level 3 flow reduced to 1750 cms, Nov	Severity Rating	1	1			
	Dir. Of change	Neg				
	Toward/away from target	Toward				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 4 flow reduced to 2200 cms, Oct+Nov	Severity Rating	2	2			
	Dir. Of change	Neg				
	Toward/away from target	Toward				
	Integrity Rating	-2	-2	-2.00	-2.00	-2.00
Change level 5 flow reduced to 1300 cms, Nov	Severity Rating	1	1			
	Dir. Of change	Neg				
	Toward/away from target	Toward				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
	General comments	I assume a threshold of 5 turbines (or four turbines and spillage), such that any reduction in flows below this threshold will impede downstream navigation. For any month in which flows are impeded, I conservatively estimate that no navigation is possible.				

weight	1	0	0	0
adjusted weight	1.0	0.0	0.0	0.0

A.2 Consequences for changes in the annual flood

1	Agriculture - commercial irrigated					
		Agriculture - commercial irrigated		AVERAGE SCORE	Range	
		ICA			UPPER	LOWER
Present Day No change	Severity Rating	0	0			
	Dir. Of change	n/a	n/a			
	Toward/away from natural	n/a	n/a			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	0	0			
	Dir. Of change	n/a	n/a			
	Toward/away from natural	n/a	n/a			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 2 Dec, 4 wk, 4500	Severity Rating	0	0			
	Dir. Of change	n/a	n/a			
	Toward/away from natural	n/a	n/a			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 3 Feb, 2 wk, 4500	Severity Rating	0	0			
	Dir. Of change	n/a	n/a			
	Toward/away from natural	n/a	n/a			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 4 Feb, 4 wk, 4500	Severity Rating	0	0			
	Dir. Of change	n/a	n/a			
	Toward/away from natural	n/a	n/a			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	0	0			
	Dir. Of change	n/a	n/a			
	Toward/away from natural	n/a	n/a			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	0	0			
	Dir. Of change	n/a	n/a			
	Toward/away from natural	n/a	n/a			
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 7 Dec, 2 wk, 7000	Severity Rating	0	-1			
	Dir. Of change	n/a	D			
	Toward/away from natural	n/a	Away			
	Integrity Rating	0	-1	-0.50	0.00	-1.00
Change level 8 Dec, 4 wk, 7000	Severity Rating	0	-1			
	Dir. Of change	n/a	D			
	Toward/away from natural	n/a	Away			
	Integrity Rating	0	-1	-0.50	0.00	-1.00
Change level 9 Feb, 2 wk, 7000	Severity Rating	0	-1			
	Dir. Of change	n/a	D			
	Toward/away from natural	n/a	Away			
	Integrity Rating	0	-1	-0.50	0.00	-1.00
Change level 10 Feb, 4 wk, 7000	Severity Rating	0	-1			
	Dir. Of change	n/a	D			
	Toward/away from natural	n/a	Away			
	Integrity Rating	0	-1	-0.50	0.00	-1.00
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	0	-1			
	Dir. Of change	n/a	D			
	Toward/away from natural	n/a	Away			
	Integrity Rating	0	-1	-0.50	0.00	-1.00
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	0	-1			
	Dir. Of change	n/a	D			
	Toward/away from natural	n/a	Away			
	Integrity Rating	0	-1	-0.50	0.00	-1.00
Change level 13 Dec, 2 wk, 10000	Severity Rating	-1	-1			
	Dir. Of change	D	D			
	Toward/away from natural	Away	Away			
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 14 Dec, 4 wk, 10000	Severity Rating	-1	-1			
	Dir. Of change	D	D			
	Toward/away from natural	Away	Away			
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 15 Feb, 2 wk, 10000	Severity Rating	-1	-1			
	Dir. Of change	D	D			
	Toward/away from natural	Away	Away			
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 16 Feb, 4 wk, 10000	Severity Rating	-1	-1			
	Dir. Of change	D	D			
	Toward/away from natural	Away	Away			
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	-1	-1			
	Dir. Of change	D	D			
	Toward/away from natural	Away	Away			
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	-1	-1			
	Dir. Of change	D	D			
	Toward/away from natural	Away	Away			
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
	General comments					

2	Agriculture - small scale									
		Agriculture - small scale						AVERAGE SCORE	Range	
		RAFC		RACC		NFR			UPPER	LOWER
Present Day No change	Severity Rating	0	0	0	0	0	0			
	Dir. Of change	n/a	n/a	n/a	n/a	n/a	n/a			
	Toward/away from natural	n/a	n/a	n/a	n/a	n/a	n/a			
	Integrity Rating	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	1	2	1	2	1	2			
	Dir. Of change	I	I	I	I	I	I			
	Toward/away from natural	owar	owar	owar	oward	owar	owar			
	Integrity Rating	1	2	1	2	1	2	1.50	1.00	2.00
Change level 2 Dec, 4 wk, 4500	Severity Rating	1	2	1	2	1	3			
	Dir. Of change	I	I	I	I	I	I			
	Toward/away from natural	owar	owar	owar	oward	owar	owar			
	Integrity Rating	1	2	1	2	1	3	1.67	1.00	2.33
Change level 3 Feb, 2 wk, 4500	Severity Rating	1	2	1	2	1	1			
	Dir. Of change	I	I	I	I	I	I			
	Toward/away from natural	owar	owar	owar	oward	owar	owar			
	Integrity Rating	1	2	1	2	1	1	1.33	1.00	1.67
Change level 4 Feb, 4 wk, 4500	Severity Rating	1	2	1	2	1	1			
	Dir. Of change	I	I	I	I	I	I			
	Toward/away from natural	owar	owar	owar	oward	owar	owar			
	Integrity Rating	1	2	1	2	1	1	1.33	1.00	1.67
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	1	2	1	2	2	3			
	Dir. Of change	I	I	I	I	I	I			
	Toward/away from natural	owar	owar	owar	oward	owar	owar			
	Integrity Rating	1	2	1	2	2	2	1.67	1.33	2.00
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	1	2	1	2	0	0			
	Dir. Of change	I	I	I	I	n/a	n/a			
	Toward/away from natural	owar	owar	owar	oward	n/a	n/a			
	Integrity Rating	1	2	1	2	0	0	1.00	0.67	1.33
Change level 7 Dec, 2 wk, 7000	Severity Rating	0	1	1	1	2	3			
	Dir. Of change	n/a	I	I	I	I	I			
	Toward/away from natural	n/a	owar	owar	oward	owar	owar			
	Integrity Rating	0	1	1	1	2	3	1.33	1.00	1.67
Change level 8 Dec, 4 wk, 7000	Severity Rating	0	1	1	1	3	3			
	Dir. Of change	n/a	I	I	I	I	I			
	Toward/away from natural	n/a	owar	owar	oward	owar	owar			
	Integrity Rating	0	1	1	1	3	3	1.50	1.33	1.67
Change level 9 Feb, 2 wk, 7000	Severity Rating	0	1	1	1	2	3			
	Dir. Of change	n/a	I	I	I	I	I			
	Toward/away from natural	n/a	owar	owar	oward	owar	owar			
	Integrity Rating	0	1	1	1	2	3	1.33	1.00	1.67
Change level 10 Feb, 4 wk, 7000	Severity Rating	0	1	1	1	2	3			
	Dir. Of change	n/a	I	I	I	I	I			
	Toward/away from natural	n/a	owar	owar	oward	owar	owar			
	Integrity Rating	0	1	1	1	2	3	1.33	1.00	1.67
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	0	1	1	1	3	4			
	Dir. Of change	n/a	I	I	I	I	I			
	Toward/away from natural	n/a	owar	owar	oward	owar	owar			
	Integrity Rating	0	1	1	1	3	4	1.67	1.33	2.00
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	0	1	1	1	0	0			
	Dir. Of change	n/a	I	I	I	n/a	n/a			
	Toward/away from natural	n/a	owar	owar	oward	n/a	n/a			
	Integrity Rating	0	1	1	1	0	0	0.50	0.33	0.67
Change level 13 Dec, 2 wk, 10000	Severity Rating	0	1	0	1	1	2			
	Dir. Of change	n/a	I	n/a	D	I	I			
	Toward/away from natural	n/a	owar	n/a	Away	owar	owar			
	Integrity Rating	0	1	0	-1	1	2	0.50	0.33	0.67
Change level 14 Dec, 4 wk, 10000	Severity Rating	0	-1	0	-1	2	2			
	Dir. Of change	n/a	D	n/a	D	I	I			
	Toward/away from natural	n/a	Away	n/a	Away	owar	owar			
	Integrity Rating	0	-1	0	-1	2	2	0.33	0.67	0.00
Change level 15 Feb, 2 wk, 10000	Severity Rating	0	1	0	1	1	1			
	Dir. Of change	n/a	D	n/a	D	I	I			
	Toward/away from natural	n/a	Away	n/a	Away	owar	owar			
	Integrity Rating	0	-1	0	-1	1	1	0.00	0.33	-0.33
Change level 16 Feb, 4 wk, 10000	Severity Rating	0	1	0	1	1	1			
	Dir. Of change	n/a	D	n/a	D	I	I			
	Toward/away from natural	n/a	Away	n/a	Away	owar	owar			
	Integrity Rating	0	-1	0	-1	1	1	0.00	0.33	-0.33
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	0	1	0	1	2	3			
	Dir. Of change	n/a	D	n/a	D	I	I			
	Toward/away from natural	n/a	Away	n/a	Away	owar	owar			
	Integrity Rating	0	-1	0	-1	2	3	0.50	0.67	0.33
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	0	1	0	1	0	0			
	Dir. Of change	n/a	D	n/a	D	n/a	n/a			
	Toward/away from natural	n/a	Away	n/a	Away	n/a	n/a			
	Integrity Rating	0	-1	0	-1	0	0	-0.33	0.00	-0.67
	General comments									

3	Coastal and estuarine fisheries									
		Coastal and estuarine fisheries						AVERAGE SCORE	Range	
		Shrimp		Bottom fish		rim.produc			UPPER	LOWER
Present Day No change	Severity Rating	0	0	0	0	0	0			
	Dir. Of change	None		None		None				
	Toward/away from natural	N/a		N/a		N/a				
	Integrity Rating	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	0	1	0	1	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	0	1	0	1	0	1	0.50	0.00	1.00
Change level 2 Dec, 4 wk, 4500	Severity Rating	1	2	0	1	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	1	2	0	1	0	1	0.83	0.33	1.33
Change level 3 Feb, 2 wk, 4500	Severity Rating	0	1	0	1	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	0	1	0	1	0	1	0.50	0.00	1.00
Change level 4 Feb, 4 wk, 4500	Severity Rating	1	2	0	1	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	1	2	0	1	0	1	0.83	0.33	1.33
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	2	3	1	2	1	2			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	2	3	1	2	1	2	1.83	1.33	2.33
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	1	3	1	2	1	2			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	1	3	1	2	1	2	1.67	1.00	2.33
Change level 7 Dec, 2 wk, 7000	Severity Rating	0	1	0	1	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	0	1	0	1	0	1	0.50	0.00	1.00
Change level 8 Dec, 4 wk, 7000	Severity Rating	1	2	1	2	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	1	2	1	2	0	1	1.17	0.67	1.67
Change level 9 Feb, 2 wk, 7000	Severity Rating	0	1	0	1	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	0	1	0	1	0	1	0.50	0.00	1.00
Change level 10 Feb, 4 wk, 7000	Severity Rating	0	2	1	2	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	0	2	1	2	0	1	1.00	0.33	1.67
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	4	5	1	2	1	2			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	4	5	1	2	1	2	2.50	2.00	3.00
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	2	4	1	3	1	2			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	2	4	1	3	1	2	2.17	1.33	3.00
Change level 13 Dec, 2 wk, 10000	Severity Rating	0	2	0	1	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	0	2	0	1	0	1	0.67	0.00	1.33
Change level 14 Dec, 4 wk, 10000	Severity Rating	1	2	1	2	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	1	2	1	2	0	1	1.17	0.67	1.67
Change level 15 Feb, 2 wk, 10000	Severity Rating	0	2	0	1	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	0	2	0	1	0	1	0.67	0.00	1.33
Change level 16 Feb, 4 wk, 10000	Severity Rating	0	2	1	2	0	1			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	0	2	1	2	0	1	1.00	0.33	1.67
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	4	5	1	3	1	2			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	4	5	1	3	1	2	2.67	2.00	3.33
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	0	2	1	3	1	2			
	Dir. Of change	Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward				
	Integrity Rating	0	2	1	3	1	2	1.50	0.67	2.33

4	Mangrove fisheries					
		Mangrove fisheries		AVERAGE SCORE	Range	
		Mangr.cra			UPPER	LOWER
Present Day No change	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	N/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	0	1			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 2 Dec, 4 wk, 4500	Severity Rating	0	1			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 3 Feb, 2 wk, 4500	Severity Rating	0	1			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 4 Feb, 4 wk, 4500	Severity Rating	0	1			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	0	2			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	0	2	1.00	0.00	2.00
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	0	2			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	0	2	1.00	0.00	2.00
Change level 7 Dec, 2 wk, 7000	Severity Rating	0	1			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 8 Dec, 4 wk, 7000	Severity Rating	1	2			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	1	2	1.50	1.00	2.00
Change level 9 Feb, 2 wk, 7000	Severity Rating	0	1			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 10 Feb, 4 wk, 7000	Severity Rating	1	2			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	1	2	1.50	1.00	2.00
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	1	2			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	1	2	1.50	1.00	2.00
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	1	2			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	1	2	1.50	1.00	2.00
Change level 13 Dec, 2 wk, 10000	Severity Rating	0	1			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 14 Dec, 4 wk, 10000	Severity Rating	1	2			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	1	2	1.50	1.00	2.00
Change level 15 Feb, 2 wk, 10000	Severity Rating	0	1			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 16 Feb, 4 wk, 10000	Severity Rating	1	2			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	1	2	1.50	1.00	2.00
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	1	2			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	1	2	1.50	1.00	2.00
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	1	2			
	Dir. Of change	Increase				
	Toward/away from natural	Toward				
	Integrity Rating	1	2	1.50	1.00	2.00

Freshwater fisheries

		Freshwater fisheries								AVERAGE SCORE	Range	
		Clarius ga		*Oreochron*		*Labeo alti*		*Hydrocyn*			UPPER	LOWER
Present Day No change	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	None		None		None		None				
	Toward/away from natural	N/a		N/a		N/a		N/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	0	1	0	1	0	1	0	1			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	0	1	0	1	0	1	0	1	0.50	0.00	1.00
Change level 2 Dec, 4 wk, 4500	Severity Rating	1	2	1	2	0	2	0	2			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	1	2	1	2	0	2	0	2	1.25	0.50	2.00
Change level 3 Feb, 2 wk, 4500	Severity Rating	0	1	0	1	0	1	0	1			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	0	1	0	1	0	1	0	1	0.50	0.00	1.00
Change level 4 Feb, 4 wk, 4500	Severity Rating	1	2	1	2	0	2	0	2			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	1	2	1	2	0	2	0	2	1.25	0.50	2.00
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	1	3	1	3	0	2	0	2			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	1	3	1	3	0	2	0	2	1.50	0.50	2.50
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	1	3	1	3	0	2	0	2			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	1	3	1	3	0	2	0	2	1.50	0.50	2.50
Change level 7 Dec, 2 wk, 7000	Severity Rating	1	2	1	2	1	2	1	2			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	1	2	1	2	1	2	1	2	1.50	1.00	2.00
Change level 8 Dec, 4 wk, 7000	Severity Rating	2	3	2	3	1	3	1	3			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	2	3	2	3	1	3	1	3	2.25	1.50	3.00
Change level 9 Feb, 2 wk, 7000	Severity Rating	1	2	1	2	1	2	1	2			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	1	2	1	2	1	2	1	2	1.50	1.00	2.00
Change level 10 Feb, 4 wk, 7000	Severity Rating	2	3	2	3	1	3	1	3			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	2	3	2	3	1	3	1	3	2.25	1.50	3.00
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	2	4	2	4	2	3	2	3			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	2	4	2	4	2	3	2	3	2.75	2.00	3.50
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	2	4	2	4	2	3	2	3			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	2	4	2	4	2	3	2	3	2.75	2.00	3.50
Change level 13 Dec, 2 wk, 10000	Severity Rating	2	4	2	4	2	3	2	3			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	2	4	2	4	2	3	2	3	2.75	2.00	3.50
Change level 14 Dec, 4 wk, 10000	Severity Rating	3	5	3	5	2	5	2	5			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	3	5	3	5	2	5	2	5	3.75	2.50	5.00
Change level 15 Feb, 2 wk, 10000	Severity Rating	2	4	2	4	2	4	2	4			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	2	4	2	4	2	4	2	4	3.00	2.00	4.00
Change level 16 Feb, 4 wk, 10000	Severity Rating	3	5	3	5	2	5	2	5			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	3	5	3	5	2	5	2	5	3.75	2.50	5.00
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	4	5	4	5	4	5	4	5			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	4	5	4	5	4	5	4	5	4.50	4.00	5.00
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	4	5	4	5	4	5	4	5			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from natural	Toward		Toward		Toward		Toward				
	Integrity Rating	4	5	4	5	4	5	4	5	4.50	4.00	5.00

Livestock

		Livestock		AVERAGE SCORE	Range	
		Livestock			UPPER	LOWER
Present Day No change	Severity Rating	0	0			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 2 Dec, 4 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 3 Feb, 2 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 4 Feb, 4 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 7 Dec, 2 wk, 7000	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 8 Dec, 4 wk, 7000	Severity Rating	1	1			
	Dir. Of change	Positive				
	Toward/away from natural	Towards				
	Integrity Rating	1	1	1.00	1.00	1.00
Change level 9 Feb, 2 wk, 7000	Severity Rating	1	1			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	1	1	1.00	1.00	1.00
Change level 10 Feb, 4 wk, 7000	Severity Rating	1	1			
	Dir. Of change	Positive				
	Toward/away from natural	Towards				
	Integrity Rating	1	1	1.00	1.00	1.00
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	2	2			
	Dir. Of change	Positive				
	Toward/away from natural	Towards				
	Integrity Rating	2	2	2.00	2.00	2.00
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	2	2			
	Dir. Of change	Positive				
	Toward/away from natural	Towards				
	Integrity Rating	2	2	2.00	2.00	2.00
Change level 13 Dec, 2 wk, 10000	Severity Rating	1	1			
	Dir. Of change	Positive				
	Toward/away from natural	Towards				
	Integrity Rating	1	1	1.00	1.00	1.00
Change level 14 Dec, 4 wk, 10000	Severity Rating	1	1			
	Dir. Of change	Positive				
	Toward/away from natural	Towards				
	Integrity Rating	1	1	1.00	1.00	1.00
Change level 15 Feb, 2 wk, 10000	Severity Rating	1	1			
	Dir. Of change	Positive				
	Toward/away from natural	Towards				
	Integrity Rating	1	1	1.00	1.00	1.00
Change level 16 Feb, 4 wk, 10000	Severity Rating	1	1			
	Dir. Of change	Positive				
	Toward/away from natural	Towards				
	Integrity Rating	1	1	1.00	1.00	1.00
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	2	2			
	Dir. Of change	Positive				
	Toward/away from natural	Towards				
	Integrity Rating	2	2	2.00	2.00	2.00
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	2	2			
	Dir. Of change	Positive				
	Toward/away from natural	Towards				
	Integrity Rating	2	2	2.00	2.00	2.00

	Large mammals											
		Large mammals								AVERAGE SCORE	Range	
		Buffalo		Waterbuck		Hippo		Zebra			UPPER	LOWER
Present Day No change	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	Neg		Neg		Neg		None				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	Neg		Neg		Neg		None				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 2 Dec, 4 wk, 4500	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	Neg		Neg		Neg		None				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 3 Feb, 2 wk, 4500	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	Neg		Neg		Neg		None				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 4 Feb, 4 wk, 4500	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	Neg		Neg		Neg		None				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	1	1	1	1	1	1	0	0			
	Dir. Of change	Pos		Pos		Pos		none				
	Toward/away from natural	Tow		Tow		Tow		n/a				
	Integrity Rating	1	1	1	1	1	1	0	0	0.75	0.75	0.75
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	Neg		Neg		Neg		None				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 7 Dec, 2 wk, 7000	Severity Rating	1	1	1	2	2	2	0	0			
	Dir. Of change	pos		pos		Pos		pos				
	Toward/away from natural	tow		tow		Tow		tow				
	Integrity Rating	1	1	1	2	2	2	0	0	1.13	1.00	1.25
Change level 8 Dec, 4 wk, 7000	Severity Rating	1	2	1	2	2	3	1	1			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	1	2	1	2	2	3	1	1	1.63	1.25	2.00
Change level 9 Feb, 2 wk, 7000	Severity Rating	1	1	1	2	2	2	0	0			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	1	1	1	2	2	2	0	0	1.13	1.00	1.25
Change level 10 Feb, 4 wk, 7000	Severity Rating	1	2	1	2	2	3	1	1			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	1	2	1	2	2	3	1	1	1.63	1.25	2.00
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	1	2	1	2	3	3	2	3			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	1	2	1	2	3	3	2	3	2.13	1.75	2.50
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	1	2	1	2	3	3	2	3			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	1	2	1	2	3	3	2	3	2.13	1.75	2.50
Change level 13 Dec, 2 wk, 10000	Severity Rating	2	2	2	2	3	3	1	1			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	2	2	2	2	3	3	1	1	2.00	2.00	2.00
Change level 14 Dec, 4 wk, 10000	Severity Rating	2	3	2	3	3	4	2	2			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	2	3	2	3	3	4	2	2	2.63	2.25	3.00
Change level 15 Feb, 2 wk, 10000	Severity Rating	2	2	2	2	3	3	1	1			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	2	2	2	2	3	3	1	1	2.00	2.00	2.00
Change level 16 Feb, 4 wk, 10000	Severity Rating	2	3	2	3	3	4	2	2			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	2	3	2	3	3	4	2	2	2.63	2.25	3.00
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	3	4	3	4	4	4	3	4			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	3	4	3	4	4	4	3	4	3.63	3.25	4.00
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	3	4	3	4	4	4	3	4			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	3	4	3	4	4	4	3	4	3.63	3.25	4.00

		Water birds										
		Water birds								**AVERAGE SCORE**	**Range**	
		G. carunc		**P. gamben**		**A. goliath**		**R. flaviros**			**UPPER**	**LOWER**
Present Day No change	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	0	0	0	0	0	0	0	0			
	Toward/away from natural	N/a	N/a	N/a	N/a	N/a	N/a	N/a	N/a			
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	0	0	0	0	0	1	1	2			
	Dir. Of change	0	0	0	0	+	+	+	+			
	Toward/away from natural	0	0	0	0	owar	owar	owar	owar			
	Integrity Rating	0	0	0	0	0	1	1	2	0.50	0.25	0.75
Change level 2 Dec, 4 wk, 4500	Severity Rating	0	1	0	1	0	2	1	2			
	Dir. Of change	0	0	+	+	+	+	+	+			
	Toward/away from natural	0	0	owar	Towar	owar	owar	owar	owar			
	Integrity Rating	0	1	0	1	0	2	1	2	0.88	0.25	1.50
Change level 3 Feb, 2 wk, 4500	Severity Rating	0	0	0	0	0	1	1	2			
	Dir. Of change	0	0	0	0	+	+	+	+			
	Toward/away from natural	0	0	0	0	owar	owar	owar	owar			
	Integrity Rating	0	0	0	0	0	1	1	2	0.50	0.25	0.75
Change level 4 Feb, 4 wk, 4500	Severity Rating	0	1	0	1	0	2	1	1			
	Dir. Of change	0	0	+	+	+	+	+	+			
	Toward/away from natural	0	0	owar	Towar	owar	owar	owar	owar			
	Integrity Rating	0	1	0	1	0	2	1	1	0.75	0.25	1.25
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	0	2	0	2	1	2	1	1			
	Dir. Of change	0	0	+	+	+	+	+	+			
	Toward/away from natural	0	0	owar	Towar	owar	owar	owar	owar			
	Integrity Rating	0	2	0	2	1	2	1	1	1.13	0.50	1.75
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	0	2	0	2	1	2	0	1			
	Dir. Of change	0	0	+	+	+	+	+	+			
	Toward/away from natural	0	0	owar	Towar	owar	owar	owar	owar			
	Integrity Rating	0	2	0	2	1	2	0	1	1.00	0.25	1.75
Change level 7 Dec, 2 wk, 7000	Severity Rating	0	3	0	1	0	2	0	1			
	Dir. Of change	0	0	+	+	+	+	+	+			
	Toward/away from natural	0	0	owar	Towar	owar	owar	owar	owar			
	Integrity Rating	0	3	0	1	0	2	0	1	0.88	0.00	1.75
Change level 8 Dec, 4 wk, 7000	Severity Rating	0	4	0	2	1	2	0	1			
	Dir. Of change	0	0	+	+	+	+	+	+			
	Toward/away from natural	0	0	owar	Towar	owar	owar	owar	owar			
	Integrity Rating	0	4	0	2	1	2	0	1	1.25	0.25	2.25
Change level 9 Feb, 2 wk, 7000	Severity Rating	0	3	0	1	0	2	0	1			
	Dir. Of change	0	0	+	+	+	+	+	+			
	Toward/away from natural	0	0	owar	Towar	owar	owar	owar	owar			
	Integrity Rating	0	3	0	1	0	2	0	1	0.88	0.00	1.75
Change level 10 Feb, 4 wk, 7000	Severity Rating	0	4	0	2	1	2	0	1			
	Dir. Of change	0	0	+	+	+	+	+	+			
	Toward/away from natural	0	0	owar	Towar	owar	owar	owar	owar			
	Integrity Rating	0	4	0	2	1	2	0	1	1.25	0.25	2.25
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	1	3	1	3	1	3	0	0			
	Dir. Of change	+	+	+	+	+	+	9	0			
	Toward/away from natural	owar	owar	owar	Towar	owar	owar	0	0			
	Integrity Rating	1	3	1	3	1	3	0	0	1.50	0.75	2.25
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	1	3	1	3	1	3	0	0			
	Dir. Of change	+	+	+	+	+	+	0	0			
	Toward/away from natural	owar	owar	owar	Towar	owar	owar	0	0			
	Integrity Rating	1	3	1	3	1	3	0	0	1.50	0.75	2.25
Change level 13 Dec, 2 wk, 10000	Severity Rating	1	1	0	2	0	3	0	1			
	Dir. Of change	+	+	+	+	+	+	+	+			
	Toward/away from natural	owar	owar	owar	Towar	owar	owar	owar	owar			
	Integrity Rating	1	1	0	2	0	3	0	1	1.00	0.25	1.75
Change level 14 Dec, 4 wk, 10000	Severity Rating	2	3	0	3	2	4	0	0			
	Dir. Of change	+	+	+	+	+	+	0	0			
	Toward/away from natural	owar	owar	owar	Towar	owar	owar	0	0			
	Integrity Rating	2	3	0	3	2	4	0	0	1.75	1.00	2.50
Change level 15 Feb, 2 wk, 10000	Severity Rating	1	1	0	2	2	4	0	1			
	Dir. Of change	+	+	+	+	+	+	+	+			
	Toward/away from natural	owar	owar	owar	Towar	owar	owar	owar	owar			
	Integrity Rating	1	1	0	2	2	4	0	1	1.38	0.75	2.00
Change level 16 Feb, 4 wk, 10000	Severity Rating	2	3	0	3	2	5	0	0			
	Dir. Of change	+	+	+	+	+	+	0	0			
	Toward/away from natural	owar	owar	owar	Towar	owar	owar	0	0			
	Integrity Rating	2	3	0	3	2	5	0	0	1.88	1.00	2.75
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	2	4	2	4	3	5	0	0			
	Dir. Of change	+	+	+	+	+	+	0	0			
	Toward/away from natural	owar	owar	owar	Towar	owar	owar	0	0			
	Integrity Rating	2	4	2	4	3	5	0	0	2.50	1.75	3.25
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	2	4	2	4	3	5	0	0			
	Dir. Of change	+	+	+	+	+	+	0	0			
	Toward/away from natural	owar	owar	owar	Towar	owar	owar	0	0			
	Integrity Rating	2	4	2	4	3	5	0	0	2.50	1.75	3.25

	Vegetation - biodiversity									
		Vegetation - biodiversity						AVERAGE SCORE	Range	
		Mangrove		Riparian		Papyrus			UPPER	LOWER
Present Day No change	Severity Rating	0	0	0	0	0	0			
	Dir. Of change	none		none		none				
	Toward/away from natural	n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	1	1	0	0	1	1			
	Dir. Of change	none		none		pos				
	Toward/away from natural	n/a		n/a		tow				
	Integrity Rating	1	1	0	0	1	1	0.67	0.67	0.67
Change level 2 Dec, 4 wk, 4500	Severity Rating	2	2	0	1	1	2			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	2	2	0	1	1	2	1.33	1.00	1.67
Change level 3 Feb, 2 wk, 4500	Severity Rating	1	1	0	0	1	1			
	Dir. Of change	none		none		pos				
	Toward/away from natural	n/a		n/a		tow				
	Integrity Rating	1	1	0	0	1	1	0.67	0.67	0.67
Change level 4 Feb, 4 wk, 4500	Severity Rating	2	2	0	1	1	2			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	2	2	0	1	1	2	1.33	1.00	1.67
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	3	3	2	2	1	2			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	3	3	2	2	1	2	2.17	2.00	2.33
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	3	3	2	2	1	2			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	3	3	2	2	1	2	2.17	2.00	2.33
Change level 7 Dec, 2 wk, 7000	Severity Rating	1	2	2	2	2	2			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	1	2	2	2	2	2	1.83	1.67	2.00
Change level 8 Dec, 4 wk, 7000	Severity Rating	2	3	2	3	2	3			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	2	3	2	3	2	3	2.50	2.00	3.00
Change level 9 Feb, 2 wk, 7000	Severity Rating	1	2	2	2	2	2			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	1	2	2	2	2	2	1.83	1.67	2.00
Change level 10 Feb, 4 wk, 7000	Severity Rating	2	3	2	3	2	3			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	2	3	2	3	2	3	2.50	2.00	3.00
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	4	4	3	4	3	3			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	4	4	3	4	3	3	3.50	3.33	3.67
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	4	4	3	4	3	3			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	4	4	3	4	3	3	3.50	3.33	3.67
Change level 13 Dec, 2 wk, 10000	Severity Rating	2	2	3	3	3	3			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	2	2	3	3	3	3	2.67	2.67	2.67
Change level 14 Dec, 4 wk, 10000	Severity Rating	4	4	4	4	4	4			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	4	4	4	4	4	4	4.00	4.00	4.00
Change level 15 Feb, 2 wk, 10000	Severity Rating	2	2	3	3	3	3			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	2	2	3	3	3	3	2.67	2.67	2.67
Change level 16 Feb, 4 wk, 10000	Severity Rating	4	4	4	4	4	4			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	4	4	4	4	4	4	4.00	4.00	4.00
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	5	5	5	5	5	5			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	5	5	5	5	5	5	5.00	5.00	5.00
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	5	5	5	5	5	5			
	Dir. Of change	pos		pos		pos				
	Toward/away from natural	tow		tow		tow				
	Integrity Rating	5	5	5	5	5	5	5.00	5.00	5.00

Vegetation - invasives

		Vegetation - invasives				AVERAGE SCORE	Range	
		Savanna		Aquatic plants			UPPER	LOWER
Present Day No change	Severity Rating	0	0	0	0			
	Dir. Of change	none		none				
	Toward/away from natural	n/a		n/a				
	Integrity Rating	0	0	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	1	1	1	2			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	1	1	1	2	1.25	1.00	1.50
Change level 2 Dec, 4 wk, 4500	Severity Rating	1	2	1	2			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	1	2	1	2	1.50	1.00	2.00
Change level 3 Feb, 2 wk, 4500	Severity Rating	1		1	2			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	1	2	1	2	1.50	1.00	2.00
Change level 4 Feb, 4 wk, 4500	Severity Rating	1	2	1	2			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	1	2	1	2	1.50	1.00	2.00
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	3	2	2	2			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	3	2	2	2	2.25	2.50	2.00
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	3	2	2	2			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	3	2	2	2	2.25	2.50	2.00
Change level 7 Dec, 2 wk, 7000	Severity Rating	1	1	3	3			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	1	1	3	3	2.00	2.00	2.00
Change level 8 Dec, 4 wk, 7000	Severity Rating	2	2	3	3			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	2	2	3	3	2.50	2.50	2.50
Change level 9 Feb, 2 wk, 7000	Severity Rating	1	1	3	3			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	1	1	3	3	2.00	2.00	2.00
Change level 10 Feb, 4 wk, 7000	Severity Rating	2	2	3	3			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	2	2	3	3	2.50	2.50	2.50
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	4	4	4	4			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	4	4	4	4	4.00	4.00	4.00
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	4	4	4	4			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	4	4	4	4	4.00	4.00	4.00
Change level 13 Dec, 2 wk, 10000	Severity Rating	2	2	4	4			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	2	2	4	4	3.00	3.00	3.00
Change level 14 Dec, 4 wk, 10000	Severity Rating	3	3	4	4			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	3	3	4	4	3.50	3.50	3.50
Change level 15 Feb, 2 wk, 10000	Severity Rating	2	2	4	4			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	3	3	4	4	3.50	3.50	3.50
Change level 16 Feb, 4 wk, 10000	Severity Rating	3	3	4	4			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	3	3	4	4	3.50	3.50	3.50
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	5	5	5	5			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	5	5	5	5	5.00	5.00	5.00
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	5	5	5	5			
	Dir. Of change	pos		pos				
	Toward/away from natural	tow		tow				
	Integrity Rating	5	5	5	5	5.00	5.00	5.00

Natural resources utilisation

		Natural resources utilisation								AVERAGE SCORE	Range	
		Mangrove		Riparian tr		Reed and		Palm sava			UPPER	LOWER
Present Day No change	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	0	0	0	0	1	0	0	0			
	Dir. Of change	none		none		pos		none				
	Toward/away from natural	n/a		n/a		tow		n/a				
	Integrity Rating	0	0	0	0	1	1	0	0	0.25	0.25	0.25
Change level 2 Dec, 4 wk, 4500	Severity Rating	1	1	0	1	1	2	0	0			
	Dir. Of change	pos		pos		pos		none				
	Toward/away from natural	tow		tow		tow		n/a				
	Integrity Rating	1	1	0	1	1	2	0	0	0.75	0.50	1.00
Change level 3 Feb, 2 wk, 4500	Severity Rating	0	0	0	0	1	1	0	0			
	Dir. Of change	none		none		pos		none				
	Toward/away from natural	n/a		n/a		tow		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 4 Feb, 4 wk, 4500	Severity Rating	1	1	0	1	1	2	0	0			
	Dir. Of change	pos		pos		pos		none				
	Toward/away from natural	tow		tow		tow		n/a				
	Integrity Rating	1	1	0	1	1	2	0	0	0.75	0.50	1.00
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	1	1	1	1	1	2	1	2			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		away				
	Integrity Rating	1	1	1	1	1	2	-1	-2	0.50	0.50	0.50
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	1	1	1	1	1	2	1	2			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		away				
	Integrity Rating	1	1	1	1	1	2	-1	-2	0.50	0.50	0.50
Change level 7 Dec, 2 wk, 7000	Severity Rating	1	1	1	2	2	2	0	0			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		n/a				
	Integrity Rating	1	1	1	2	2	2	0	0	1.13	1.00	1.25
Change level 8 Dec, 4 wk, 7000	Severity Rating	1	2	1	2	2	3	1	1			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	1	2	1	2	2	3	-1	-1	1.13	0.75	1.50
Change level 9 Feb, 2 wk, 7000	Severity Rating	1	1	1	2	2	2	0	0			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		n/a				
	Integrity Rating	1	1	1	2	2	2	0	0	1.13	1.00	1.25
Change level 10 Feb, 4 wk, 7000	Severity Rating	1	2	1	2	2	3	1	1			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		away				
	Integrity Rating	1	2	1	2	2	3	-1	-1	1.13	0.75	1.50
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	1	2	1	2	3	3	1	2			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		away				
	Integrity Rating	1	2	1	2	3	3	1	2	1.88	1.50	2.25
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	1	2	1	2	3	3	2	3			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		away				
	Integrity Rating	1	2	1	2	3	3	-2	-3	0.88	0.75	1.00
Change level 13 Dec, 2 wk, 10000	Severity Rating	2	2	2	2	3	3	1	1			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		away				
	Integrity Rating	2	2	2	2	3	3	-1	-1	1.50	1.50	1.50
Change level 14 Dec, 4 wk, 10000	Severity Rating	2	3	2	3	3	4	2	2			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		tow				
	Integrity Rating	2	3	2	3	3	4	-2	-2	1.63	1.25	2.00
Change level 15 Feb, 2 wk, 10000	Severity Rating	2	2	2	2	3	3	1	1			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		away				
	Integrity Rating	2	2	2	2	3	3	-1	-1	1.50	1.50	1.50
Change level 16 Feb, 4 wk, 10000	Severity Rating	2	3	2	3	3	4	2	2			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		away				
	Integrity Rating	2	3	2	3	3	4	-2	-2	1.63	1.25	2.00
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	3	4	3	4	4		3	4			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		away				
	Integrity Rating	3	4	3	4	4	4	-3	-4	1.88	1.75	2.00
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	3	4	3	4	4	4	3	4			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from natural	tow		tow		tow		away				
	Integrity Rating	3	4	3	4	4	4	-3	-4	1.88	1.75	2.00

	Water quality											
		Water quality								**AVERAGE SCORE**	**Range**	
		Sediment		**Effluent di**		**Eutrophic**		**Salinity in**			**UPPER**	**LOWER**
Present Day No change	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 2 Dec, 4 wk, 4500	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 3 Feb, 2 wk, 4500	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 4 Feb, 4 wk, 4500	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from natural	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 7 Dec, 2 wk, 7000	Severity Rating	1	1	0	0	1	2	1	2			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	1	1	0	0	1	2	1	2	1.00	0.75	1.25
Change level 8 Dec, 4 wk, 7000	Severity Rating	1	1	0	0	1	2	1	2			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	1	1	0	0	1	2	1	2	1.00	0.75	1.25
Change level 9 Feb, 2 wk, 7000	Severity Rating	1	1	0	0	1	2	1	2			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	1	1	0	0	1	2	1	2	1.00	0.75	1.25
Change level 10 Feb, 4 wk, 7000	Severity Rating	1	1	0	0	1	2	1	2			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	1	1	0	0	1	2	1	2	1.00	0.75	1.25
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	1	1	0	0	1	2	1	2			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	1	1	0	0	1	2	1	2	1.00	0.75	1.25
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	1	1	0	0	1	2	1	2			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	1	1	0	0	1	2	1	2	1.00	0.75	1.25
Change level 13 Dec, 2 wk, 10000	Severity Rating	2	2	0	0	3	4	3	4			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	2	2	0	0	3	4	3	4	2.25	2.00	2.50
Change level 14 Dec, 4 wk, 10000	Severity Rating	2	2	0	0	3	4	3	4			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	2	2	0	0	3	4	3	4	2.25	2.00	2.50
Change level 15 Feb, 2 wk, 10000	Severity Rating	2	2	0	0	3	4	3	4			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	2	2	0	0	3	4	3	4	2.25	2.00	2.50
Change level 16 Feb, 4 wk, 10000	Severity Rating	2	2	0	0	3	4	3	4			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	2	2	0	0	3	4	3	4	2.25	2.00	2.50
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	2	2	0	0	3	4	3	4			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	2	2	0	0	3	4	3	4	2.25	2.00	2.50
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	2	2	0	0	3	4	3	4			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from natural	Towards		n/a		Towards		Towards				
	Integrity Rating	2	2	0	0	3	4	3	4	2.25	2.00	2.50

Groundwater - water supply

		Groundwater - water supply		AVERAGE SCORE	Range	
		Recharge			UPPER	LOWER
Present Day No change	Severity Rating	0	0			
	Dir. Of change	0				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	0	1			
	Dir. Of change	None				
	Toward/away from natural	Towards				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 2 Dec, 4 wk, 4500	Severity Rating	0	1			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 3 Feb, 2 wk, 4500	Severity Rating	0	1			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 4 Feb, 4 wk, 4500	Severity Rating	0	1			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	0	1			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	0	1			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	1	0.50	0.00	1.00
Change level 7 Dec, 2 wk, 7000	Severity Rating	1	3			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	1	3	2.00	1.00	3.00
Change level 8 Dec, 4 wk, 7000	Severity Rating	2	3			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	2	3	2.50	2.00	3.00
Change level 9 Feb, 2 wk, 7000	Severity Rating	1	2			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	1	2	1.50	1.00	2.00
Change level 10 Feb, 4 wk, 7000	Severity Rating	2	3			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	2	3	2.50	2.00	3.00
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	3	4			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	3	4	3.50	3.00	4.00
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	3	4			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	3	4	3.50	3.00	4.00
Change level 13 Dec, 2 wk, 10000	Severity Rating	3	4			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	3	4	3.50	3.00	4.00
Change level 14 Dec, 4 wk, 10000	Severity Rating	4	5			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	4	5	4.50	4.00	5.00
Change level 15 Feb, 2 wk, 10000	Severity Rating	3	5			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	3	5	4.00	3.00	5.00
Change level 16 Feb, 4 wk, 10000	Severity Rating	4	5			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	4	5	4.50	4.00	5.00
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	5	5			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	5	5	5.00	5.00	5.00
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	5	5			
	Dir. Of change	Pos				
	Toward/away from natural	Towards				
	Integrity Rating	5	5	5.00	5.00	5.00

In-channel navigation

		In-channel navigation		AVERAGE SCORE	Range	
		River navi			UPPER	LOWER
Present Day No change	Severity Rating	0	0			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 1 Dec, 2 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 2 Dec, 4 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 3 Feb, 2 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 4 Feb, 4 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 5 Dec+Jan, 8 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 6 Feb+Mar, 8 wk, 4500	Severity Rating	0	0			
	Dir. Of change	None				
	Toward/away from natural	n/a				
	Integrity Rating	0	0	0.00	0.00	0.00
Change level 7 Dec, 2 wk, 7000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 8 Dec, 4 wk, 7000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 9 Feb, 2 wk, 7000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 10 Feb, 4 wk, 7000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 11 Dec+Jan, 8 wk, 7000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 12 Feb+Mar, 8 wk, 7000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 13 Dec, 2 wk, 10000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 14 Dec, 4 wk, 10000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 15 Feb, 2 wk, 10000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 16 Feb, 4 wk, 10000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 17 Dec+Jan, 8 wk, 10000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00
Change level 18 Feb+Mar, 8 wk, 10000	Severity Rating	1	1			
	Dir. Of change	Negative				
	Toward/away from natural	Away				
	Integrity Rating	-1	-1	-1.00	-1.00	-1.00

A.3 Consequences for changes in the 1:5-year return period flood

1	Agriculture - commercial irrigated											
		Agriculture - commercial irrigated								AVERAGE SCORE	Range	
		ICA									UPPER	LOWER
Present Day PD	Severity Rating	0	0									
	Dir. Of change											
	Toward/away from target											
	Integrity Rating	0	0							0.00	0.00	0.00
Change level 1 1500	Severity Rating	1	1									
	Dir. Of change	D	D									
	Toward/away from target	A	A									
	Integrity Rating	-1	-1							-1.00	-1.00	-1.00
	General comments											
	weight	1		0		0		0				
	adjusted weight	1.0		0.0		0.0		0.0				

2	Agriculture - small scale											
		Agriculture - small scale								AVERAGE SCORE	Range	
		RAFC		RACC		NFR					UPPER	LOWER
Present Day PD	Severity Rating	0	0	0	0	0	0					
	Dir. Of change	na	na	na	na	na	na					
	Toward/away from target	na	na	na	na	na	na					
	Integrity Rating	0	0	0	0	0	0			0.00	0.00	0.00
Change level 1 1500	Severity Rating	1	1	2	2	1	1					
	Dir. Of change	D	D	D	D	D	D					
	Toward/away from target	A	A	A	A	A	A					
	Integrity Rating	-1	-1	-2	-2	-1	-1			-1.33	-1.33	-1.33
	General comments											
	weight	1		1		1		0				
	adjusted weight	0.3		0.3		0.3		0.0				

3	Coastal and estuarine fisheries											
		Coastal and estuarine fisheries								AVERAGE SCORE	Range	
		Shrimp		*Bottom fi*		*Prim.prod*					UPPER	LOWER
Present Day PD	Severity Rating	0	0	0	0	0	0					
	Dir. Of change	None		None		None						
	Toward/away from target	N/a		N/a		N/a						
	Integrity Rating	0	0	0	0	0	0			0.00	0.00	0.00
Change level 1 1500	Severity Rating	2	3	1	2	0	1					
	Dir. Of change	Increase		Increase		Increase						
	Toward/away from target	Toward		Toward		Toward						
	Integrity Rating	2	3	1	2	0	1			1.50	1.00	2.00
	General comments	Shrimp production will be enhanced during the flood year but, for the other species, increased yields can only be expected in the few months after the flow receeds. Prim. Product. May be hampered by high siltation levels.										
	Site-specific and change-leve											
	Social and other comments	Having floods every fifth year will prove disruptive for fishermen, and may even provoke damage to the fleets. There may be significant increases in catches for about two years following the flood, but will then decrease .										
	weight	1		1		1		0				
	adjusted weight	0.3		0.3		0.3		0.0				

4

Mangrove fisheries

		Mangrove fisheries								AVERAGE SCORE	Range	
		Mangr.cra									UPPER	LOWER
Present Day PD	Severity Rating	0	0									
	Dir. Of change	None										
	Toward/away from target	N/a										
	Integrity Rating	0	0							0.00	0.00	0.00
Change level 1 1500	Severity Rating	1	2									
	Dir. Of change	Increase										
	Toward/away from target	Toward										
	Integrity Rating	1	2							1.50	1.00	2.00
	General comments											
	Site-specific and change-leve											
	Social and other comments											
	weight	1		0		0		0				
	adjusted weight	1.0		0.0		0.0		0.0				

Freshwater fisheries

		Freshwater fisheries								AVERAGE SCORE	Range	
		Clarius ga		*Oreochro*		*Labeo alti*		*Hydrocyn*			UPPER	LOWER
Present Day PD	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	None		None		None		None				
	Toward/away from target	N/a		N/a		N/a		N/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 1500	Severity Rating	3	4	3	4	2	4	2	4			
	Dir. Of change	Increase		Increase		Increase		Increase				
	Toward/away from target	Toward		Toward		Toward		Toward				
	Integrity Rating	3	4	3	4	2	4	2	4	3.25	2.50	4.00
	General comments	A large flood provides outstanding conditions for these species, resulting in very high recruitment and ideal growth conditions with high nutrient release from flooded terrestrial vegetation and soils, resulting in increased stocks. In non-flood years, non-optimal conditions will reduce recruitment and yields.				Tigerfish will benefit from improved production of prey species on the floodplain in the flood year, which become vulnerable to predation when forced off the floodplain as it dries. In years of no flood, tigerfish will be less successful.						
	Site-specific and change-leve											
	Social and other comments	Having floods every fifth year will prove disruptive for fishermen. They will benefit from large increases in catches for about two years following the flood, but will then face greatly reduced yields until the next major flood.										
	weight	1		1		1		1				
	adjusted weight	0.3		0.3		0.3		0.3				

Livestock

		Livestock								AVERAGE SCORE	Range	
		Livestock									UPPER	LOWER
Present Day PD	Severity Rating	0	0									
	Dir. Of change	None										
	Toward/away from target	n/a										
	Integrity Rating	0	0							0.00	0.00	0.00
Change level 1 1500	Severity Rating	2	2									
	Dir. Of change	Positive										
	Toward/away from target	Towards										
	Integrity Rating	2	2							2.00	2.00	2.00
	General comments											
	weight	1		0		0		0				
	adjusted weight	1.0		0.0		0.0		0.0				

Large mammals

		Large mammals								AVERAGE SCORE	Range	
		Elephant		Hippo		Buffalo		Waterbuck			UPPER	LOWER
Present Day PD	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 1500	Severity Rating	3	2	2	1	2	1	2	1			
	Dir. Of change	pos		pos		pos		pos				
	Toward/away from target	tow		tow		tow		tow				
	Integrity Rating	3	2	2	1	2	1	2	1	1.75	2.25	1.25
	General comments	Heavy flooding every few years could lead to some mortality of animals if they could not escape the flood, but its is unlikely that these major floods would be too devastating for the wildlife, although reports from the 2000 flood seem to suggest otherwise. They would however contribute to improved carrying capapcity in the delta.										
	weight	1		1		1		1				
	adjusted weight	0.3		0.3		0.3		0.3				

Water birds

		Water birds								AVERAGE SCORE	Range	
		G. carunc		P. gambei		A. goliath		R. flaviros			UPPER	LOWER
Present Day PD	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	0	0	0	0	0	0	0	0			
	Toward/away from target	N/a	N/a	N/a	N/a	N/a	N/a	N/a	N/a			
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 1500	Severity Rating	1	4	1	5	1	5	4	1			
	Dir. Of change	+	+	+	+	+	+	-	-			
	Toward/away from target	Towa	Towa	Towa	Towa	Towa	Towa	Away	Away			
	Integrity Rating	1	4	1	5	1	5	-4	-1	2.50	-0.25	3.25
	General comments											
	weight	1		0		0		0				
	adjusted weight	1.0		0.0		0.0		0.0				

Vegetation - biodiversity

		Vegetation - biodiversity								AVERAGE SCORE	Range	
		Mangrov		2 Riparian		3 Papyrus					UPPER	LOWER
Present Day PD	Severity Rating	0	0	0	0	0	0					
	Dir. Of change	none		none		none						
	Toward/away from target	n/a		n/a		n/a						
	Integrity Rating	0	0	0	0	0	0			0.00	0.00	0.00
Change level 1 1500	Severity Rating	2	2	3	3	3	3					
	Dir. Of change	pos		pos		pos						
	Toward/away from target	tow		tow		tow						
	Integrity Rating	2	2	3	3	3	3			2.67	2.67	2.67
	General comments	Heavy flooding every few years, sufficient to flush out nutrients and fill backwaters, is the main hydrological attribute of benefit to the natural vegetation.										
	weight	1		1		1		0				
	adjusted weight	0.3		0.3		0.3		0.0				

Vegetation - invasives

		Vegetation - invasives								AVERAGE SCORE	Range	
		Savanna		quatic plan							UPPER	LOWER
Present Day PD	Severity Rating	0	0	0	0							
	Dir. Of change	none		none								
	Toward/away from target	n/a		n/a								
	Integrity Rating	0	0	0	0					0.00	0.00	0.00
Change level 1 1500	Severity Rating	3	3	3	3							
	Dir. Of change	pos		pos								
	Toward/away from target	tow		tow								
	Integrity Rating	3	3	3	3					3.00	3.00	3.00
	General comments	Heavy flooding every few years, sufficient to flush out nutrients and fill backwaters, is the main hydrological attribute of benefit to the natural vegetation.										
	weight	1		1		0		0				
	adjusted weight	0.5		0.5		0.0		0.0				

Natural resources utilisation

		Natural resource utilisation								AVERAGE SCORE	Range	
		Mangrove		Riparian t		Reed and		Palm sava			UPPER	LOWER
Present Day PD	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	none		none		none		none				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 1500	Severity Rating	1	2	1	2	2	3	2	3			
	Dir. Of change	pos		pos		pos		neg				
	Toward/away from target	tow		tow		tow		away				
	Integrity Rating	1	2	1	2	2	3	-2	-3	0.75	0.50	1.00
	General comments											
	Site-specific and change-leve											
	Social and other comments											
	weight	1		1		1		1				
	adjusted weight	0.3		0.3		0.3		0.3				

Water quality

		Water quality								AVERAGE SCORE	Range	
		Sediment		Effluent d		Eutrophic		Salinity in			UPPER	LOWER
Present Day PD	Severity Rating	0	0	0	0	0	0	0	0			
	Dir. Of change	None		None		None		None				
	Toward/away from target	n/a		n/a		n/a		n/a				
	Integrity Rating	0	0	0	0	0	0	0	0	0.00	0.00	0.00
Change level 1 1500	Severity Rating	3	3	0	0	4	5	4	5			
	Dir. Of change	Pos		None		Pos		Pos				
	Toward/away from target	Towards		n/a		Towards		Towards				
	Integrity Rating	3	3	0	0	4	5	4	5	3.00	2.75	3.25
	General comments											
	weight	1		1		1		1				
	adjusted weight	0.3		0.3		0.3		0.3				

Groundwater - water supply

		Groundwater - water supply								AVERAGE SCORE	Range	
		Recharge									UPPER	LOWER
Present Day PD	Severity Rating	0	0									
	Dir. Of change	None										
	Toward/away from target	n/a										
	Integrity Rating	0	0							0.00	0.00	0.00
Change level 1 1500	Severity Rating	3	3									
	Dir. Of change	Pos										
	Toward/away from target	Towards										
	Integrity Rating	3	3							3.00	3.00	3.00
	General comments	Extreme fl										
	weight	1		0		0		0				
	adjusted weight	1.0		0.0		0.0		0.0				

In-channel navigation

		In-channel navigation								AVERAGE SCORE	Range	
		River navi									UPPER	LOWER
Present Day PD	Severity Rating	0	0									
	Dir. Of change	None										
	Toward/away from target	n/a										
	Integrity Rating	0	0							0.00	0.00	0.00
Change level 1 1500	Severity Rating	2	2									
	Dir. Of change	Negative										
	Toward/away from target	Away										
	Integrity Rating	-2	-2							-2.00	-2.00	-2.00
	General comments	Extreme floods result in shut down of navigation, as with the larger annual floods. I assume that navigation is restricted during the entire period that overbank flooding occurs on the Zambezi (flows exceeding 4500 cms); this may occur for up to three months (3 months = 1/4 of year = 25% of year) during a large event. I define severity level 2 as 20-40% impact.										
	Site-specific and change-leve											
	Social and other comments											
	weight	1		0		0		0				
	adjusted weight	1.0		0.0		0.0		0.0				