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SHIRE RIVER BASIN MANAGEMENT PROGRAMME (PHASE I) PROJECT

CLIMATE RESILIENT LIVELIHOODS AND SUSTAINABLE NATURAL RESOURCE MANAGEMENT IN THE ELEPHANT MARSH, MALAWI

Analysis of the potential effects of alternative future scenarios of flow and/or management on the ecological condition of the Elephant Marsh

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Acronyms

DEM	Digital Elevation Model
DoS	Department of Surveys
DRIFT	Downstream Response to Imposed Flow Transformation
DSS	Decision Support System
EM	Elephant Marsh
IDA	International Development Agency
SANSA	South African National Space Agency
SRBMP	Shire River Basin Management Program

1 Introduction

1.1 Background to the study

The Government of Malawi received a credit and a grant from the International Development Agency (IDA – World Bank Group) to finance the implementation of the Shire River Basin Management Program (SRBMP), Phase I. The overall objective of the SRBMP is to enhance the sustainable social, economic and environmental benefits of the Shire Basin resources through effective and collaborative planning, development and management.

This project, **Climate resilient livelihoods and sustainable natural resources management in the Elephant Marsh**, falls under the umbrella of the SRBMP, and has three key objectives:

1) to improve understanding of the functional ecology of the Marshes;
2) to assess the feasibility of designating the marshes as a community-managed protected area and a Ramsar site, and;
3) to identify strategies and development options that would build the resilience of local communities to environmental change.

These objectives are being addressed in four sub-studies: Livelihoods, Hydromorphology, Ecosystem Services and Biodiversity, each with specific objectives, and linked through a Synthesis sub-study (Figure 1.1).

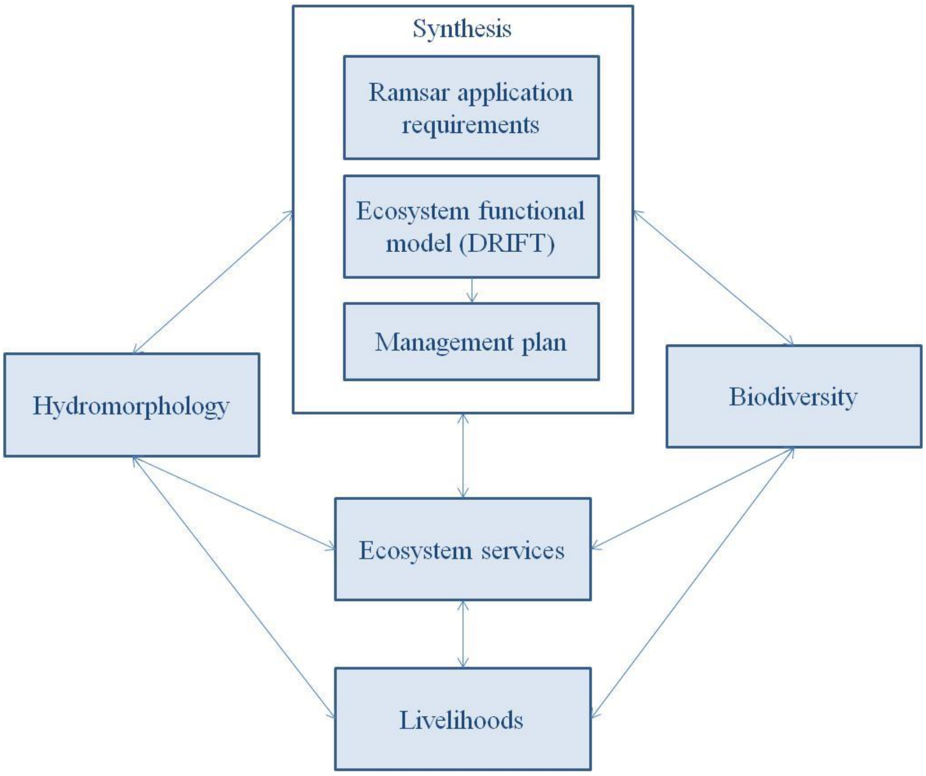

Figure 1.1 Sub-studies of the climate resilient livelihoods and sustainable natural resources management in the Elephant Marsh Project

The Synthesis sub-study is divided into three distinct areas (Figure 1.1), each with a specific objective:

1. Ramsar Application Requirements, which aims to determine the importance of the Elephant Marshes from a biodiversity perspective, inform decisions about its management and conservation, and to assess the merits of the Elephant Marsh as a Ramsar wetland;
2. Ecosystem Functional Model (DRIFT), which is required to explore the potential effects of alternative future scenarios of flow and/or management on the ecological condition of the Elephant Marsh, and;
3. Management report, which provides recommendations for the development of a Management Plan for the Elephant Marsh to meet a range of biodiversity-protection objectives set on the basis of the project as a whole.

This report is on the second of these, *viz*.: the ecosystem functional model (DRIFT).

1.1.1 ToR for Synthesis Sub-task 2

The second element of the synthesis sub-study is the use of the Ecosystem Functional Model (DRIFT) to bring together and interpret the findings of the ecological components of the sub-studies and to assess the likely responses to the provided change scenarios. The contributions of DRIFT to the synthesis study are arranged in six tasks:

- Task 1: DRIFT DSS;
- Task 2: Scenario construction;
- Task 3: Set up and adjustments to DRIFT;
- Task 4: Population and calibration of DRIFT;
- Task 5: Assess scenarios in DRIFT, and;
- Task 6: Summarise DRIFT results for synthesis report.

1.2 Ecosystem Functional Model (DRIFT)

The objective of the Ecosystem Functional Model (DRIFT) was to use the information generated in the Hydromorphology, Ecosystem Services and Biodiversity sub-studies to construct a DRIFT Decision Support System (DSS) that could be used to assess likely responses of the marsh ecosystem to scenarios of change in flow, sediment and livelihood pressures.

DRIFT (Brown *et al.* 2013) has been specifically developed for use in studies involving planning, development or management of inland aquatic ecosystems (e.g., King and Brown 2009). In the DRIFT-DSS a network of indicators is used to describe the aquatic ecosystem and its human users. Arrows that link indicators show the flow of cause-and-effect. In essence, the lines are the processes and the indicators represent the outcomes of the processes, with the network as a whole representing a simplified ecosystem model (Figure 1.2).

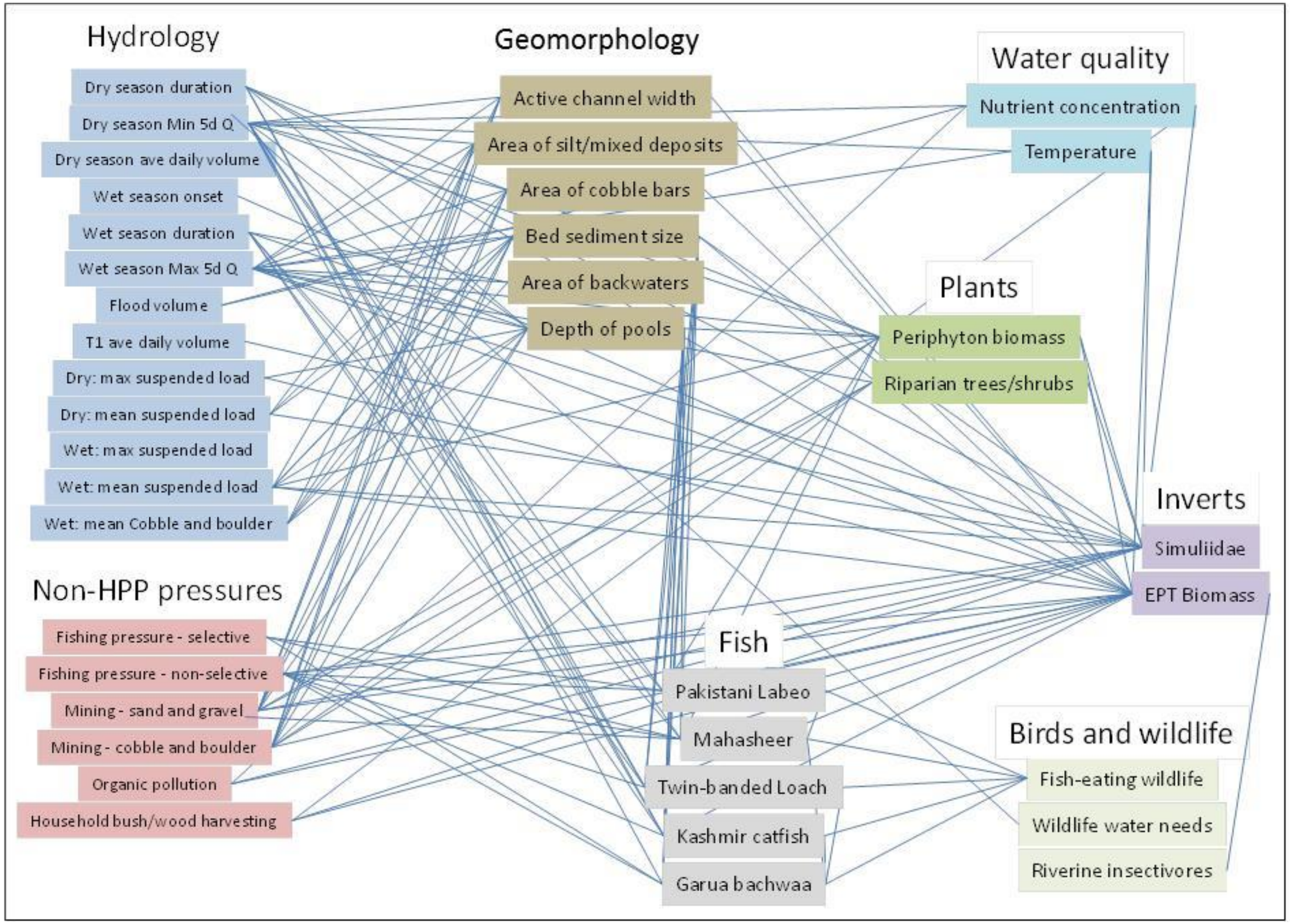

Figure 1.2 A typical DRIFT network of linked indicators (from Poonch River EFlows Assessment, Kashmir; Brown *et al*. 2017)

The indicators are used to describe:

- some aspect of the physical drivers of the ecosystem, such as water or sediment flow;
- a range of ecosystem attributes, and;
- a range of ecosystem-linked social attributes and pressures.

Once constructed the DSS can be used to describe how the ecosystem attributes would change under different flow and sediment regimes and/or levels of human utilization.

1.3 Study team

The project team members who were actively involved in the population of the DRIFT DSS and the construction and assessment of scenarios are listed in Table 1.1.

Table 1.1 Project team members involved in Synthesis Sub-task 2

Name	Organisation	Role in project
Dr Cate Brown	Southern Waters	DRIFT process co-ordinator, geomorphology, management
Dr Alison Joubert	Southern Waters	DRIFT DSS manager, scenarios
Dr Andrew Birkhead	Steamflow Solutions	Hydrodynamic modelling, geomorphology
Dr Karl Reinecke	Southern Waters	Vegetation
Katherine Forsythe	Anchor Environmental	Invertebrates, amphibians, herpetofauna, mammals
Dr Tim Davies	MRag	Fish
Dr Jane Turpie	Anchor Environmental	Birds

Also, some of the information used in the study was provided by:

- Robert Arthur (MRag). Selection of development and climate change scenario.
- Kevin Greaves (DHI). Provision of hydrological information of the baseline and scenarios.

1.4 Report layout

This report is structured with an introduction (Section 1), a description of the study area (Section 2), an overview of the DRIFT approach (Section 3), the conceptual model for the Elephant Marsh (Section 4), discipline specific explanations for indicators and links (Section 5), a description of the 2014 ecological condition of the Elephant Marsh (Section 6), selection (Section 7), and evaluation (Section 8) of scenarios; and conclusions and potential implications for management (Section 9).

2 The study area

2.1 Location and extent

The Elephant Marsh is a mosaic of rooted-swamp vegetation (sudd), floating vegetation and open water with grassy margins (Turpie *et al.* 2016). It lies in the floodplains of the Lower Shire River (S14°25’–17°50’ and E35°15’–35°15; Figure 2.1) in Malawi, East Africa (Figure 2.1). While size varies between wet and dry seasons, the Elephant Marsh is estimated to cover an area up to 600km2 (Birkhead et al., 2016).

The Marsh extends from the south eastern part of Illovo Sugar Estate at Chikwawa to the confluence of the Shire and Ruo Rivers near Chiromo (Figure 2.2).

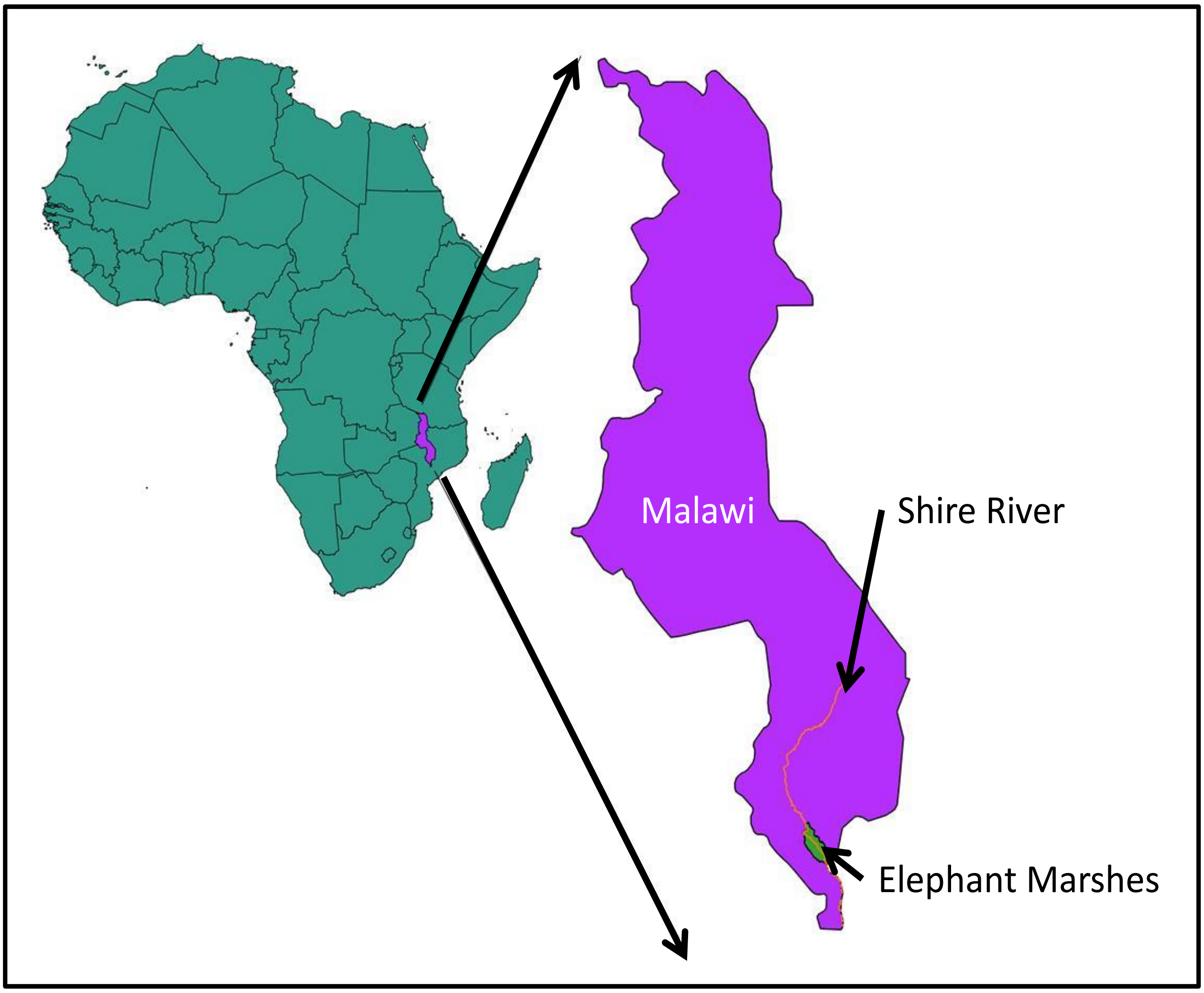

Figure 2.1 Location of the Elephant Marsh in Malawi, East Africa, on the Lower Shire River

Figure 2.2 The Elephant Marsh showing the local villages on its outer margins

Detail on the location, history, contemporary context, biodiversity and future threats to the Elephant Marsh is provided in other project reports, including Arthur *et al.* (2015); Birkhead *et al.* (2016) and Turpie *et al.* (2016).

2.2 Focus areas for the assessment

The Elephant Marsh comprises a diversity of aquatic and floodplain habitats and is utilised to different extents in different parts. For instance, the northern region of the marsh comprises the Shire River main channel and adjacent cultivated floodplain that is seasonally inundated, while the southern marsh regions are less cultivated being mostly perennially inundated lake and sudd (marsh reeds and papyrus). Thus, for the purposes of the DRIFT assessment, the marsh was sub-divided into five focus areas on the basis of vegetation type, hydromorphological influences, stage of transformation by cultivation, and priorities for fishing and/or harvesting of natural materials.

The five focus areas included in the assessment are (Figure 2.3):

Northern	~81.8 km^2; characterised by the Shire River flowing into the marsh;
Western	~208.2 km^2; characterised by cultivated fields;
Eastern	~128.2 km^2; characterised by anastomosing and distributary channels;

Central	~108.9 km^2; characterised by distributary channels through predominantly indigenous marsh vegetation[1] but including some cultivated fields primarily along channel margins, and;
Southern	~56.7 km^2; characterised by open water lakes, marsh vegetation and some cultivated fields.

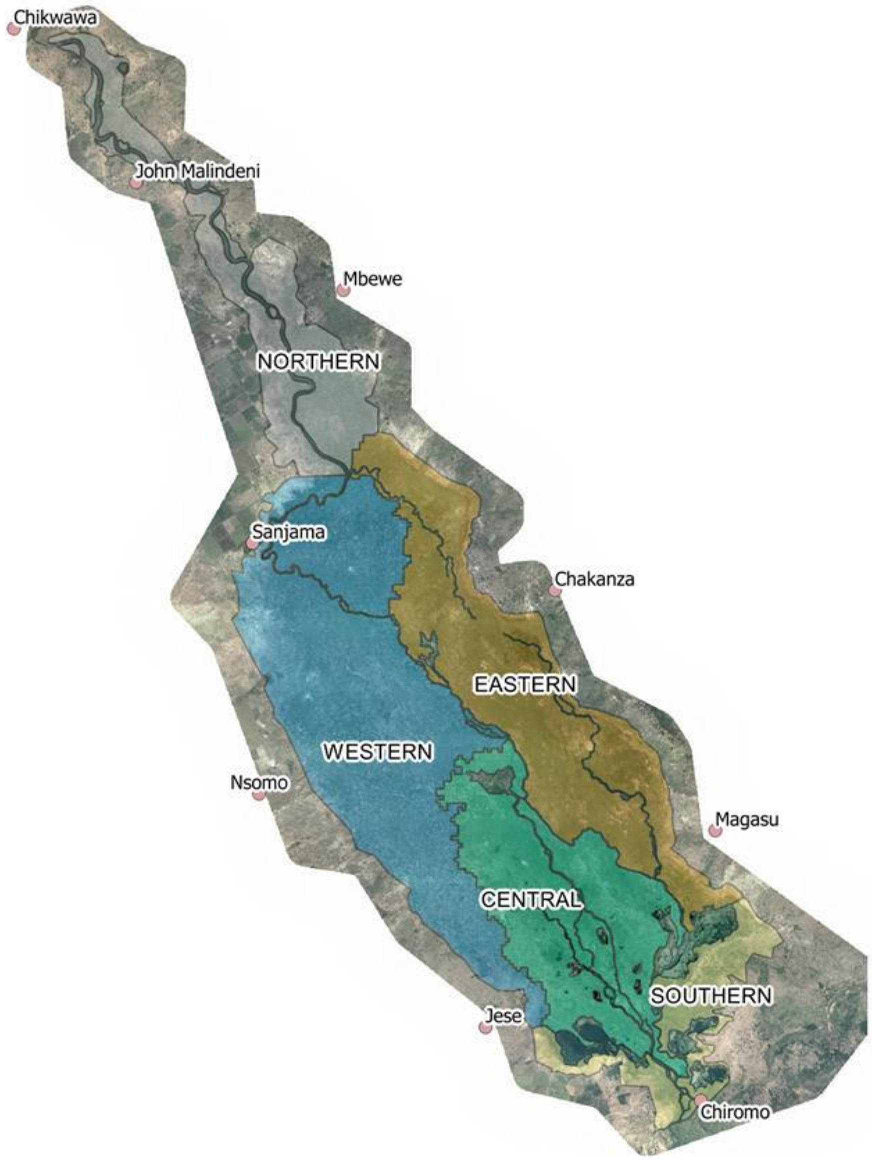

Figure 2.3 Sub-division of the Elephant Marsh into five focus areas for the DRIFT assessment

A sixth area, called 'Downstream', was also delineated, but not modelled.

These areas are described from the perspective of each discipline in Section 4.

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[1] Marsh vegetation is found in perennial- or seasonally-inundated areas with slow flow that are well vegetated (Turpie *et al.* 2016).

2.3 General morphology and functioning

The Elephant Marsh is a floodplain wetland that responds to the water and sediment regimes of the Shire River. Floodplain wetlands experience short duration flooding at an annual or longer term frequency. The volume, timing and character of flow (and sediment transport) through the river, and the geological character and history of the landscape, create site specific fluctuations in surface and groundwater flow. This varied fluvial geomorphology of the marsh influences plant growth characteristics and results in extremely variable vegetation ranging from narrow riparian areas along anastomosing channels and dominated by grasses and sedges or trees and shrubs, to permanently inundated reed marshes and lakes, and broad seasonally-inundated floodplains and pans (Rogers 1995).

The channel in the Northern and Western focus areas meanders broadly before entering the anastomosing channels and distributaries of the Eastern and Central marsh. The channels are ~rectangular in cross-section, vary in width and depth at different points, and are stabilised by *Phragmites* spp., *Cyperus papyrus* and *Vossia cuspidata*. Flow through some channels discharges into marsh or lakes directly while some lakes are only connected to channels during the wet season. Flow also moves from the channels into the marsh through the permeable channel margins comprised of decomposed plant material. Bedload sediments are confined within the channels but suspended sediments are transmitted through the channel banks into the marsh areas.

As with other floodplain wetlands, sedimentation causes constant change in wetland structure as channels aggrade and scour in response to changes in flow and sediment regimes (McCarthy *et al.* 1986). Sedimentation processes may lead to a decline in flow velocity through direct channel aggradation, which may then be accompanied by secondary encroachment of papyrus from the channel margins into the channel (McCarthy *et al.* 1998). Encroaching papyrus rhizomes, culms and umbels further constrict the channel, forming a tangled debris mat (called a sudd) that breaks off and floats into the channel (Ellery *et al*. 1995). The growth of *Vossia cuspidata* is favoured in this situation and further constricts the channel, thus trapping debris mats and further enabling papyrus encroachment (McCarthy 1992). A debris dam may form that diverts flow beneath the blockage, scouring a new depression in the channel bed that will increase flow to the surrounding marsh around the failing channel, or into hippo trails that become enlarged and form new channels (Ellery *et al.* 2000).

This constantly changing mosaic of wetland habitats is typical of floodplain wetlands and means there is no temporally-fixed “template” over a reasonable (for data collection) time period for a marsh of this sort.

Effectively, the only constant is change.

2.4 Historical changes in the morphology and biodiversity of the Elephant Marsh

The morphology of the Elephant Marsh has undergone major transformations in the last 150 years or so[2]. Birkhead *et al*. (2016) provide a summary of the history of the Elephant Marsh such as can be gleaned from the writing and recording of early (19th Century; Figure 2.4) travellers, and more recent records, reports and images that document the extensive changes that have occurred in the Marsh over time. For the purposes of understanding Marsh functioning and contextualising the implications of future changes on the Marsh, the most important of these are:

- periodic, and presumably natural, cessations of flows from Lake Malawi into the Shire River. For instance, low Shire River levels after 1896 made water transport more difficult and resulted in the construction of a railway from Nsanje to Mangochi, via Chiromo and Blantyre;
- the extensive influence of the Chiromo Bridge[3], and its accompanying embankments, constructed as part of the above-mentioned railway, which was completed in 1907, and washed away in 1948; and its replacement, the three-span structure existing today, which was constructed in 1949;
- order of magnitude increases in sediment supply to the Marsh as a result of population pressures and severe land degradation in the Shire River Basin;
- the decimation of the large animal populations, such a hippos and elephants, from the Marsh, and;
- intense pressure on the natural resources as a result of a *c.* 3% per annum increase in people living adjacent to the Marsh (Kosamu *et al.* 2012). This has resulted in increased water abstraction, conversion of natural vegetation, sediment input, movement and deposition, as well as biodiversity losses. The resultant high turbidity also reduces the productivity of the littoral zone, smothers substrates, and reduces food source availability and fish visibility (which can affect hunting for many species; Turpie *et al.* 2016).

Figure 2.4 ***Borassus aethiopum*** **(African fan palm) on the Elephant Marsh** ***c.*** **1859. These palm trees grow on the margins of marsh environs.**

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[2] and possibly even greater changes over a longer period.

[3] 400 ft: 10 spans with one opening section of 100 ft.

In one or other combination, the above-listed factors have led to past changes in the morphology of the Marsh that are unlikely to have reached a state of equilibrium and, as such, can be expected to trigger yet more changes into the future. These include but are not limited to:

- a reduction in the capacity, and eventual abandonment, of the western arm of the Shire River, which prior to the construction of the embankments and bridge was deep and wide enough to allow passage of small steamers;
- changes in the extent of the seasonally-inundated grassland habitat that characterizes the less-saturate portions of the Marsh to cultivated fields; coupled with the enormous harvesting pressure on vegetation, fish and other resources these are likely to have seriously reduced the abundance of natural flora and fauna, and reduced biodiversity in the Marsh[4];
- loss of megafauna, especially hippopotamus (*Hippopotamus amphibius*) and elephant (*Loxodonta africana*), interactions with the environment that are essential for maintaining fish populations (e.g., Mosopele *et al.* 2009). Movement of these animals creates incised, vegetation-free pathways through which water can flow during flooding, diverting water and sediment into adjacent areas. These channels may become major river channels when the old channels fill with sand and avulse (McCarthy *et al*. 1998). These ever-changing channels and lagoons created by the actions of large mammals are major habitats for fish;
- incision of the Shire River channel feeding into the Marsh, and build-up of the adjacent floodplain areas, leading (very very slowly) to less flooding of adjacent areas;
- changes in the extent of Lake Bangula, Lake Tomoninjobi and other lakes in the southern portion of the Marsh linked to construction, and subsequent breaches and repairs, of the railway embankment;
- changes in the extent of papyrus and reed beds in the Southern portion of the Marsh linked to construction and subsequent breaches and repairs of the railway embankment, and;
- changes to the course of the Ruo River, mostly as a result of sedimentation at the confluence between the Shire and Ruo Rivers caused by a combination of increased sediment loads and reduce velocities as a result of the bridge and various breaches of the embankments.

As mentioned previously, these changes are ongoing, and can be expected to lead to other changes, such as, infilling of Tomoninjobi Lake as a result of the rerouting of the sediment-laden Ruo River.

While many of these changes are captured, to a greater or lesser extent, in the DRIFT assessments that are the subject of this report, some are not. In general, changes as a result of incremental functional wetland processes, such as erosion, deposition, harvesting of resources and changes in flows into the Marsh are captured in the DRIFT DSS. Changes as a result of sudden, relatively unpredictable events that change the hydromorphology of the Marsh, such as breaching (or repair) of the embankment and/or rerouting of major water ways, e.g., Ruo River, are not captured in the DSS. This is because the approach followed was to compile an “average” recent condition for the Marsh, largely driven by data availability, including (Birkhead *et al*. 2016):

- a range of historical maps and aerial photographs;

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[4] Note. These changes are not one-way. During the period when flows from Lake Malawi ceased, *c*. 1904-1916 (Mawell 1954), the extent of cultivated areas (c. 1915 to 1933) were greater than those recorded in 2015 (Richards 1954).

- RapidEye multispectral satellite imagery dated 22 November 2014 for vegetation mapping;
- a limited measurement-based Baseline hydrological time series from October 2003 to 2009 (but with apparent errors due to outdated rating curves);
- a DEM dated August 2013 of insufficient quality to capture the topography of the marsh (e.g., does not account for depth of active channels or lakes), and;
- aerial photography coinciding with the date of the DEM.

All of these data pre-date, and therefore exclude, changes that took place during the severe flood of January/February 2015, which altered the channel planform in some locations, the path of the Ruo River and also broke through the Chiromo Road embankment in several places, through which the now Shire River flows. The Steering Committee was made aware that the latest available DEM did not take account of these recent changes during the Inception, but decided that a new DEM would not be surveyed.

The baseline template of the Elephant Marsh habitats upon which the DRIFT assessment was conducted therefore spans the dates August 2013 (DEM) to November 2014 (RapidEye), and hereafter is termed **Baseline2014**.

2.5 Main threats to the functioning and biodiversity of the Elephant Marsh

The main threats to the functioning and biodiversity of the Elephant Marsh are:

- the growing human population, not only directly surrounding the marsh but within the catchment and Malawi as a whole. This threat manifests in numerous ways, the most immediate of which are:
    - over-harvesting of resources;
    - removal of vegetation for cultivation;
    - increased sediment supply from denuded catchments, and;
    - increased incidence and severity of fire.
- climate change, which is expected to result in longer dry periods and more intense floods, both of which are likely to affect a marsh that is defined by, inter alia, its relationship to the flow of water and sediments entering it. For instance, as noted in Section 2.4, water flows from Lake Malawi into the Shire River have ceased in the past and are likely to do so again in the future, which would lead to drying out of large areas of the marsh and an increase in cultivation (e.g., Richards 1954). Conversely, wetter periods will result in a reduction in cultivation, or possibly a change in crop selection, and;
- water-resource development.

3 Overview of the DRIFT approach

The approach adopted for this assessment is based on the DRIFT EFlows Decision Support System DSS) and process (Brown *et al.* 2013; Brown *et al*. 2017; www.drift-eflows.com), which allow data and knowledge about the functional organisation of aquatic ecosystems to be used to their best advantage in a structured way.

EFlows are defined as "*the quantity, frequency, timing, and quality of water and sediment flows necessary to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems*[5]".

The DRIFT process is explained in more detail in Appendix A, and more information is available at www.drift-eflows.com. Additional detail on DRIFT is also available in Brown *et al.* (2013).

3.1 The DRIFT DSS

The DRIFT DSS is a framework for a simplified ecosystem model, which focusses on those aspects of an aquatic ecosystem that are expected to be vulnerable to change in flow or water supply (e.g., as a result of water-resource developments), sediment supply (e.g., as a result of dams or land-use changes) and/or management issues (e.g., harvesting of resources).

3.2 The DRIFT process

The DRIFT process is summarised in Figure 3.1.

Step 1: Decide on the nature of the scenarios to be evaluated. In this study they related to water and sediment flows into the Elephant Marsh, plus various levels of direct use by people living adjacent to the Marsh (Section 7).

Step 2: Select the focus areas for the assessment (see Section 2.4).

Step 3: Obtain time-series of water level/hydraulics for the Baseline and other scenarios in each zone and translate these into water level and hydraulic indicator time-series (e.g. if there are 50 years of record, an indicator such as "average depth on the floodplain" will have 50 values, one for each year). The Baseline hydrology and hydraulics form the foundation upon which the ecosystem predictions of change are built.

Step 4: Select an array of water level, hydraulic, ecosystem and/or social indicators to represent the study site. In the case of the Elephant Marsh, the descriptors thought to be most relevant to the study were decided upon by the specialists collectively. The reasons for their selection are summarised in Section 4.

Step 5: Describe the baseline (2014) ecological condition (Section 6).

Step 6: The specialists define the links between their indicators and other DRIFT indicators (Section 5). Together the indicators and links form the conceptual framework for the predictions of change (Section 4). For each link, the specialists constructed a response curve (Figure 3.3) that describes the relationship between the two indicators. Each

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[5] Amended from Brisbane Declaration (2007)

response curve describes the expected impact of a single ‘driving’ indicator on a single ‘responding’ indicator.

Step 7: The response curves are calibrated to best reflect known conditions for the Baseline. Values outside of the known range are usually calibrated with reference to ‘calibration scenarios’ that allow the specialist to explore likely consequences.

Step 8: The scenarios selected in Step 1 and developed in Step 3, use the DSS to provide outcomes for the ecosystem and the people depending on it (Section 7).

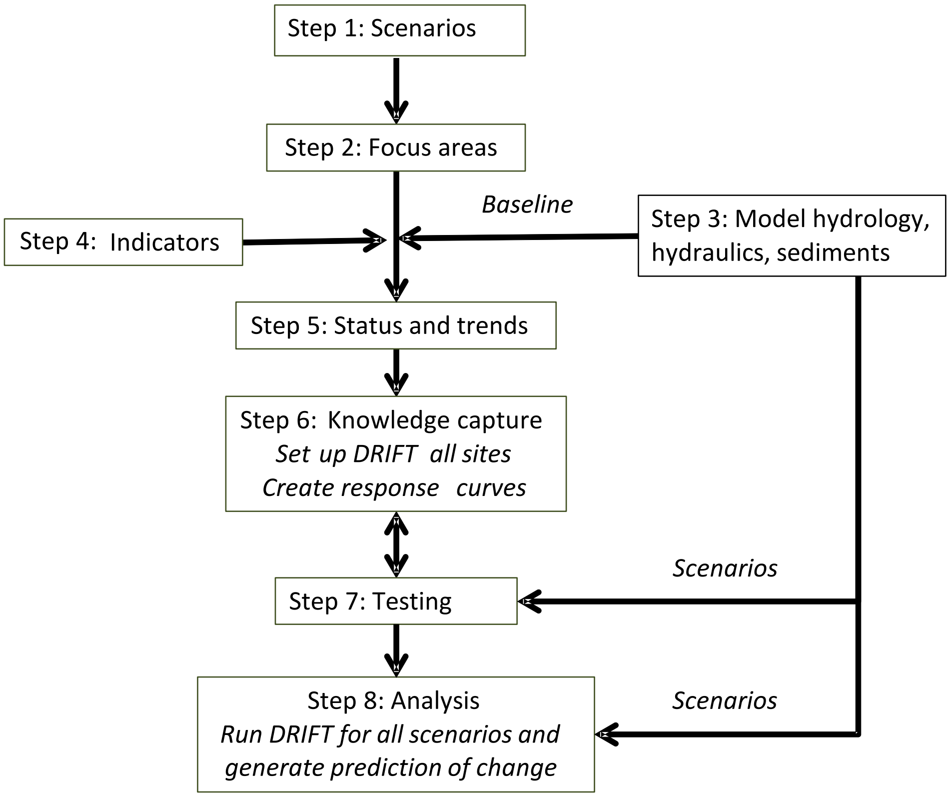

Figure 3.1 The DRIFT process

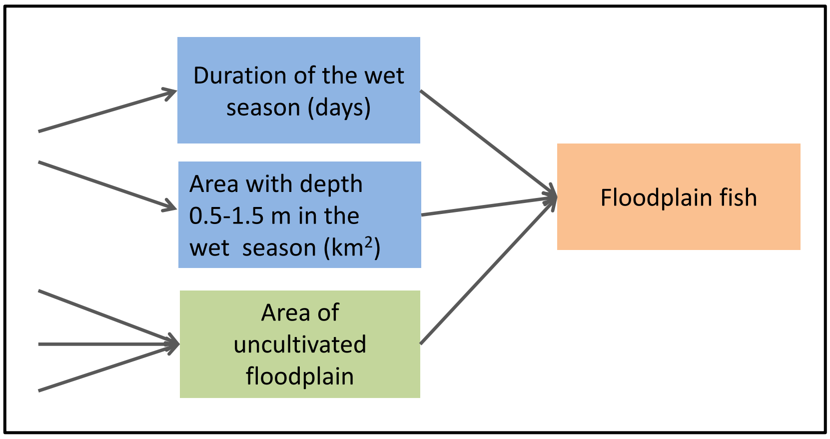

Figure 3.2 Schematic illustrating the concept of ‘linked’ indicators in DRIFT

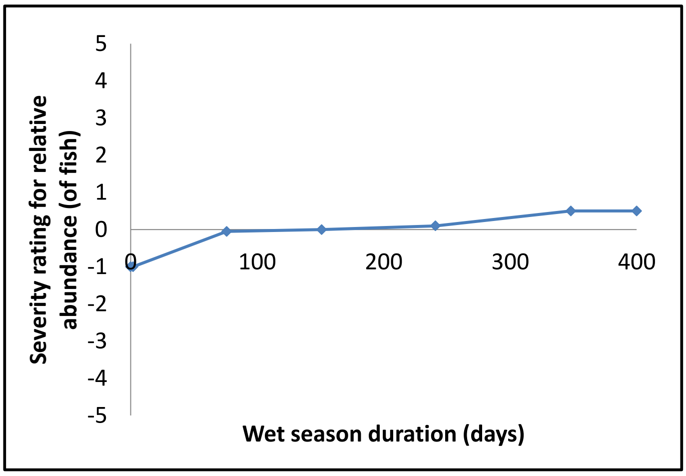

Figure 3.3 Example of a DRIFT response curve

Response curves (Figure 3.3) are constructed using a severity ratings on a continuous scale from -5 (large reduction) to +5 (very large gain; Brown *et al*. 2008; Table 3.1), where the + or – denotes an increase or decrease in abundance or extent. These ratings are converted to percentages using the relationships provided in Table 3.1. The scale accommodates uncertainty, as each rating encompasses a range of percentages; however, greater uncertainty can also be expressed through providing a range of severity ratings (i.e. a range of ranges) for any one predicted change (after King *et al.*, 2003).

Table 3.1 DRIFT severity ratings and their associated abundances and losses – a negative score means a loss in abundance relative to baseline, a positive means a gain

Severity rating	Severity	% abundance change
5	Critically severe	501% gain ∞ up to pest proportions
4	Severe	251-500% gain
3	Moderate	68-250% gain
2	Low	26-67% gain
1	Negligible	1-25% gain
0	None	no change
-1	Negligible	80-100% retained
-2	Low	60-79% retained
-3	Moderate	40-59% retained
-4	Severe	20-39% retained
-5	Critically severe	0-19% retained includes local extinction

3.3 The specialist workshop

Steps 6 and 7 were done, for the most part, in a workshop setting.

A workshop was convened from the 15th – 19th August 2016 at the offices of Southern Waters in Cape Town. All specialists listed in Section 1.3 participated and interacted with one another, sharing insights and knowledge about the marsh and their respective disciplines, to populate and calibrate the response curves in the DRIFT DSS. Dr Tim Davies joined proceedings and participated in the workshop from London via Skype.

3.4 Benefits and limitations

3.4.1 Benefits

DRIFT (King *et al.* 2003; Brown *et al.* 2013) has the following relevant benefits for a study such as the Elephant Marsh assessment:

- The DRIFT DSS, once populated with the results of the data-collection phase, allows investigation of any number of scenarios of interest to managers and decision makers, without reconvening specialist workshops.
- It is a time-series based approach that may be used with daily or hourly flow/water level data (depending on the operating rules of upstream water-resource, e.g., hourly data would be needed to evaluate the impacts of peak-power production).
- It addresses key aspects of the flow, sediment and/or hydraulic regime in a structured approach.
- It allows for the evaluation of the implication for biodiversity of various management interventions.
- Its setup for each project is adapted to suit the aquatic ecosystem under investigation (and the availability of data) rather than the ecosystem having to 'fit' the method.
- It has been the focus of 25 years of applied development, and is published in numerous international scientific journals (e.g., King *et al*. 2003; Brown and Joubert 2003; King and Brown 2009; Brown *et al.* 2017).
- It has been widely applied internationally: e.g., Berg, Breeede, Groot, Mthaltuze, Mkuze, Assegaai, Silver, Kaaimans, Vaarings, Olifants-Doorn, Olifants and Pongola rivers, South Africa; Senqu, Malibatmatso and Senqunyane rivers, Lesotho; Cunene River, Angola and Namibia; Huaura River, Peru; Mekong River (including the Vietnam Delta, the Cambodian Floodplains and Tonle Sap Great Lake), Thailand, Lao PDR, Cambodia and Vietnam; Nile River, Sudan; Neelum/Jhellum and Poonch rivers, Kashmir/Pakistan; Odzi and Pungwe Rivers, Zimbabwe; Okavango River, Angola, Namibia and Botswana; Kouilou-Niari River, Republic of Congo; Cuanza River, Angola; Pangani and Ruvu rivers, Tanzania; Zambezi River, Zambia, Zimbabwe, Mozambique, and; Lake Sibaya and the Pongolo Floodplain, South Africa.
- It produces predictions that detail how the ecosystem could change, and how this could impact people, in ways that stakeholders and decision-makers can relate to.

3.4.2 Limitations

Data are always a limiting factor in environmental studies. With contemporary understanding of how aquatic ecosystems function, it has become easier to predict what will change and the direction of change. It is less easy to predict by how much ecosystem components will change and how long it will take. For this reason:

- all predictions should be evaluated with due cognisance of the assumptions necessitated by the constraints of the study, and;
- it is better to evaluate the outcome of the scenarios relative to one another rather than as absolute individual predictions of change.

4 The conceptual model for the Elephant Marsh

4.1 Indicators used

Hydrological, hydraulic, ecosystem and management indicators were selected to capture the response of the Marsh to changes in water level, sediment supply and management initiatives, and the effects of those responses on people who use the Marsh. Selection was done by the specialist team outlined in Table 1.1, based on insights gained from the work done for the biodiversity (Turpie *et al.* 2016) and hydromorphology reports (Birkhead *et al*. 2016), both of which included field work and an extensive literature search.

The hydraulic, ecosystem and management indicators, and the reasons for selection are provided in Table 4.1, Table 4.2 and Table 4.3, respectively; and additional detail is provided for individual disciplines in Sections 5.1 to 5.8.

Table 4.1 Hydraulic indicators

Indicator		Units	Reason for selection
Channel / Channel margins	Mean annual depth	m	Changes in mean annual depth influence the riparian zone of uncultivated and cultivated channel margins.
	Dry onset	calendar week	Onset and duration of seasons are important ecologically in that they: • link with climatic factors • cue fruiting and flowering • cue migration and breeding • support life-history patterns.
	Dry duration	days	
	Wet onset	calendar week	
	Wet duration	days	
	Dry minimum 5 day depth	m	Water depth and velocity are key defining variables for aquatic habitat. They also dictate shear-stress, which partly controls erosion and deposition.
	Wet maximum 5 day depth	m	
	Dry average channel velocity	m/s	
	Wet average channel velocity	m/s	
Marsh and floodplain	Area with depth 0.03-0.5 m in the wet season	km^2	Cultivated areas are inundated to the least extent. Shallow seasonal inundation of the cultivated areas favours crop growth (see Section 5.3).
	Area with depth 0.6-0.85 m in the wet season	km^2	Seasonally-inundated indigenous vegetation grows on the uncultivated parts of the floodplain (see Section 5.3) that are too wet for the favoured crops but not wet enough to sustain reeds and papyrus.
	Area with depth 0.9-1.1 m in the wet season	km^2	Reeds are drowned if inundated for long periods at depths greater than 1.1 m but can also tolerate some periods of drying out (see Section 5.3).
	Area with depth 1.15-1.6 m in the wet season	km^2	Papyrus grows in areas that are inundated permanently and can grow in deeper water as sudd (floating mats of interconnected papyrus culms and rhizomes (see Section 5.3).

Indicator		Units	Reason for selection
	Area with depth >0.6 m in the dry season	km^2	Rooted aquatics grow best at depths less than 1.0 m and start to become stressed when depths fall below 0.6 m (see Section 5.3).
	Area with depth 0.5-1.5 m in the wet season	km^2	Shallow water habitats (<2 m) on floodplains and lake margins are important breeding areas and also are depths that contain high abundances of diatoms, an important food source for fish (see Section 5.5)
	Area with depth < 10 cm	km^2	Small waders forage specifically in shallow water at lake margins, or the muddy fringes and will vacate an area where these foraging depths are not available (Harrison *et al*. 1997; see Section 5.8)
	Average total marsh area in the wet season	km^2	When the water spreads out over the floodplain - it slows down and drops much of its sediment (more if there is a lake or reeds). So total inundated marsh area is an important determinant for sediment retention (see Section 5.2).
	Lake area in the wet season	km^2	Lakes are important breeding and feedings grounds for an array of bird species (see Section 5.8)

Table 4.2 Ecosystem indicators

Discipline	Indicator	Reason for selection
Geomorphology	Sediment input/retention/ output/	Sediment input, retention and output, together with water inflow, are fundamental in determining the existence, functioning and change over time of the Marsh
	Turbidity	Turbidity is inversely related to water clarity, or transparency, and refers to the depth of light penetration within a water body. This indicator is important as it is a major control on the growth of aquatic plants, including algae. Material suspended in the water column causes turbidity, which scatters reducing the photic depth of the water.
	Channelisation	The extent of flooding of the Marsh area can change in response to various factors, one of which is channelisation. Channelisation results in channels with higher conveyance capacities, which require a larger volume of water to overtop and flood the marsh than do non-channelised channels. Channelisation is directly related to sediment storage on the adjacent floodplain/marsh/lake areas, since sedimentation of these areas results in a reduction in flow interflow between channels and the marsh. However, concomitant bed aggradation, which appears to have taken place, will reduce this effect, and the above response is likely to be conservative (i.e. overestimate channelisation).
	Change in flood extent	The extent of flooding of the Marsh is a key determinant in the existence, functioning and use of the Elephant Marsh. As channelisation increases, flood extent will reduce. Extreme floods will still overtop the banks/levees and inundate the floodplain, but not to the same extent.

Discipline	Indicator	Reason for selection
Vegetation	Rooted aquatics	Rooted aquatic plants dominate the lakes and provide important habitat for aquatic invertebrates, fish and birds. Rigid hornwort is also used to build fish pens around the lake margins and the tubers of the white lily are eaten.
	Floating exotics	Floating exotics can completely cover water bodies, with serious consequences for indigenous flora and fauna.
	Area of cultivated floodplain	The populations of the villages and towns surrounding the marsh subsist on crops cultivated on the floodplains, notably in the Northern and Western areas.
	Area of uncultivated floodplain	Uncultivated areas of floodplain provide important grazing areas for cattle and goats but also for hippos, reptiles and small mammals; and are spawning areas for some fish.
	Area of reeds	Reeds and emergent grasses are one of the main marsh vegetation types (the other being papyrus). These have numerous ecological and social uses. For instance, the submerged portions of the plants provide important habitat and/or refugia for aquatic invertebrates and juvenile fish. The exposed plant parts provide habitat for birds, and are harvested to make a variety of products (reed baskets, hats, mats).
	Area papyrus	Papyrus sedge is one of the main marsh vegetation types (the other being reeds and grasses). These have numerous ecological and social uses. For instance, the submerged portions of the plant provide important habitat and/or refugia for aquatic invertebrates and juvenile fish. The exposed plant parts provide habitat for birds, and are harvested to make a variety of products (fences, mats, coal, brooms).
	Area uncultivated channel margin	Uncultivated channel margins are important habitat for a variety of aquatic macroinvertebrates, fish and birds. They are also basking areas for crocodiles and exit areas for hippos to access grazing areas on the floodplain.
Invertebrates	Invertebrate community health	Relative diversity of aquatic macroinvertebrates informs about the condition and diversity of aquatic habitats and water quality. The presence of pollution sensitive taxa indicate better water quality conditions while a range of functional feeding groups indicate better habitat conditions.
	Invertebrate pests	Malaria and Filaria carrying *Anopheles* mosquitoes occur more frequently near the densely populated villages around the marsh than in the marsh itself, being reared in temporary pools and other standing water bodies with algae (Berner 1955). Other biting midges and flies are also present in the marsh that make living and working in the marsh difficult and could be, under pest proportions, intolerable.
Fish	Floodplain migrant fish	Floodplain migrants undertake lateral migrations onto and off the floodplain. Juveniles are strongly dependent on shallow areas as feeding areas. Many floodplain migrant fish are important fisheries species.
	River channel fish	River channel fish are longitudinal migrants that also undertake migrations onto and off the floodplain, which they use for breeding, nursery grounds and feeding. Many species are key predators of other fish.
	Demersal fish	Demersal species live and breed on river bed habitats and can be affected by extreme physical hydrograph changes. Many demersal fish are important fisheries species.
	Channel margin fish	Channel margin fish have a strong association with peripheral submerged and emergent vegetation and therefore are susceptible to changes in flow that affect riparian habitat.

Discipline	Indicator	Reason for selection
Herpetofauna	Crocodiles	Large Nile crocodiles (>3 m) are still common in the Shire River and Elephant Marsh and conflict with humans that cultivate in the marsh. Several human deaths are reported each year. Crocodiles are important as they affect humans, livestock and other wildlife they take as prey, for example fish and birds.
	Small reptiles	Small reptiles are influenced by human disturbance and changes in the extent and condition of aquatic and floodplain habitat.
	Amphibians	Amphibians are influenced by human disturbance and changes in the extent and condition of aquatic and marsh habitat.
Mammals	Hippos	Hippos are the only remaining large herbivore in the marsh and play an important role in the marsh ecosystem functioning, maintaining open channels and facilitating nutrient transfer and cycling between the marsh and floodplain.
	Small mammals	Small mammals are influenced by human disturbance and changes in the extent and condition of floodplain habitat. These groups are also hunted opportunistically as a food source by humans.
Birds	African skimmer	This threatened species has a sizeable population in the region due to the abundance of sand bar resting sites. This species was chosen in particular for its conservation value that is crucial to gain RAMSAR status for the marsh.
	Cormorants	These species are piscivorous, breed and roost on riparian trees and feed by diving into lakes.
	Wading birds	These long-legged species hunt on foot in shallow water, sometimes co-operatively, and feed on small fish, amphibians and invertebrates.
	Water fowl	Waterfowl feed by dabbling or diving or on foot (some rallids) and are omnivorous.
	Waders	These small birds feed on benthic macroinvertebrates in/on exposed mud or sand flats.
	Gulls and terns	Gulls and terns are typically found on the lakes feeding on small prey at the near the surface.
	Kingfishers	These open-water piscivores dive for small fish prey.

Table 4.3 Management indicators

Indicator	Reason for selection
Access	Access is a major determinant of human pressures on the Elephant Marshes. Where access is easy, most of the natural features of the Marsh have been significantly altered. Where access is difficult, harvesting and other pressures are lower and the natural character of the Marsh remains intact.
Fire	Fire is a frequently used means of management in the Marsh. It is extremely damaging to the vegetative structure of the Marsh, with knock-on effects on Marsh functioning, and kills or displaces animals living in the vegetation. In many cases, clearing by fire is also a precursor to cultivation.
Cultivation	Removal of vegetation and manipulation of banks and channels for cultivation is one of the main human pressures on the Marsh. It is particularly damaging to seasonally flooded grasslands, because it targets the same areas.
Harvesting pressure	Harvesting for building/craft materials or food, or simply killing for protection or to reduce competition, is an overriding influence on a range of natural resources in the Marsh, including vegetation, some invertebrates, fish, birds, snakes, hippos, frogs, small mammals and crocodiles.

Each of the indicators is linked with other indicators deemed to drive change. The aim is not try to capture every conceivable link, but rather to restrict the linkages to those that are most meaningful and can be used to predict the bulk of the likely responses to a change in the supply of water, or sediment, to the Marsh, or as a result of a change in management of the Marsh.

Hydraulic indicators are driving indicators derived from the hydrodynamic model, so they do not have links in the DRIFT DSS. A full list of linked indicators is provided for the geomorphology indicators (Section 5.2) and for each of the ecosystem and management indicators (Section 5.3 to 5.8) together with the response curves describing each of the links and explanations for the shape of the response curves.

4.2 Links and the conceptual model for the Elephant Marsh

The broad conceptual framework used in this assessment is depicted in Figure 4.1 and the actual links between indicators as used in the DRIFT conceptual model are shown in Figure 4.2. Response curves for each of these links are described in Section 5.

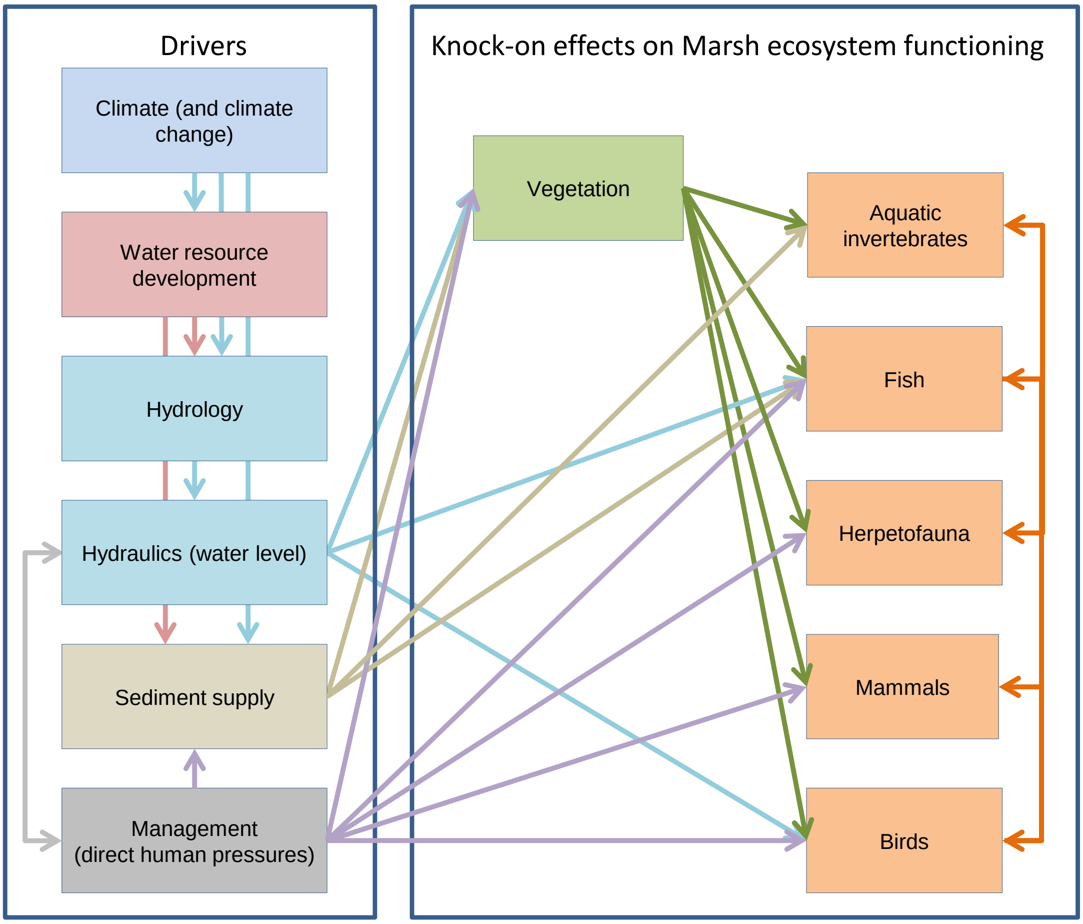

Figure 4.1 A simplified schematic of the links between the abiotic drivers (climate, hydraulics, geomorphology and management) and the knock-on links to biota, which comprise the Elephant Marsh conceptual model.

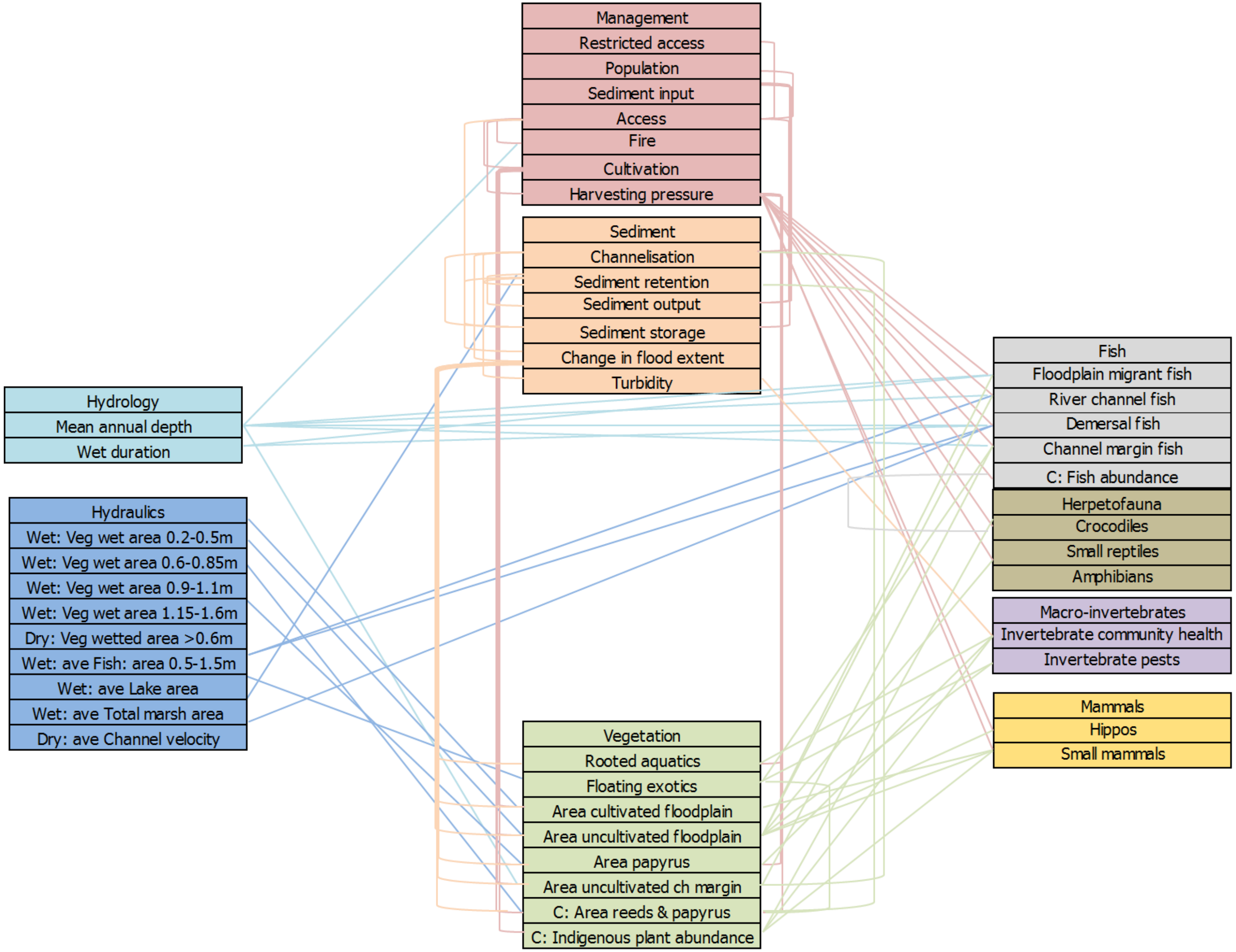

Figure 4.2 **Schematic showing the indicators and links in the DRIFT DSS used to conceptualise the functioning of the Elephant Marsh**

5 Discipline specific explanations for indicators and links

5.1 Hydrology and hydraulics

The compilation of the baseline daily hydrological time-series used in this assessment and the development and use of the hydrodynamic model developed to derive the hydraulics of the five focus areas linked to the hydrological sequence are covered in detail in the Hydromorphology Report (Birkhead *et al*. 2016) and are not addressed further here.

The baseline daily hydrological time-series used covered the period 1976-2009, i.e., 33 years (Figure 5.1). Figure 5.1 clearly shows that the hydrology over this period comprised three distinct phases: an early wet phase (c. 1976-1990), middle dry phase (1991-2002) and a later medium phase (2003-2009). This led to some difficulty in calibrating a baseline condition for the ecosystem indicators in the DSS, and so it was eventually agreed to calibrate to the latter 'medium' condition[6]. The three periods were also separated and repeated to cover the whole period (1976-2009) and used as scenarios (see Section 7).

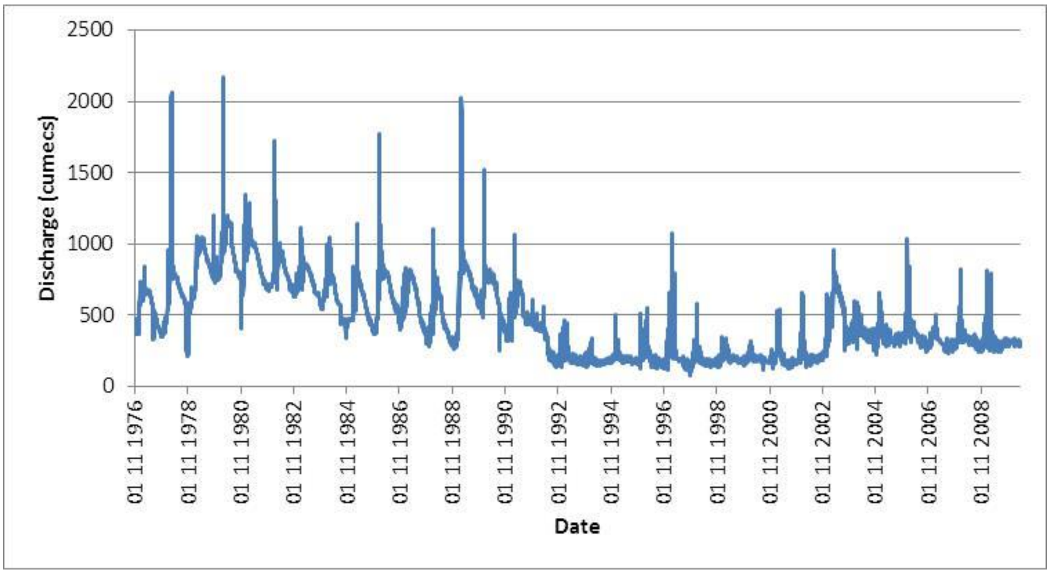

Figure 5.1 Baseline daily hydrological time-series, 1976 - 2009

Since Marsh water levels are key in defining marsh morphology and vegetation communities, and thus in dictating the biotic responses, the hydrological data were not used directly, but were converted to water depth in the five focus areas, which were then used as the main driving variables in the DRIFT assessment (see Section 7.2).

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[6] DRIFT presents results as percentage change relative to the baseline condition. By definition, baseline must be set at/calibrated to 100%.

5.2 Geomorphology

5.2.1 Geomorphology indicators

Six geomorphological indicators were selected for the DRIFT DSS. These are defined in Table 5.1, along with an indication of the main variables likely to drive change in the indicator.

Table 5.1 Geomorphology indicators and their main driving variable in the Marsh

Indicator	Driving variables
Sediment retention	Sediment retention is related to attenuation of flows and slowing of water as a result of flooding out of the channel and into the Marsh, which result in deposition of suspended sediments. It is also related to the extant and density of vegetation, which slows water flow, causing deposition of sediment.
Turbidity	Turbidity is related to the concentration and grain-size distribution of suspended material, and the shear stress of the water column. Small particles (clay) are more likely to cause turbidity in the Marsh than larger particles (sand), which will drop out of suspension at higher shear stresses.
Channelisation	Many of the historic and more recent changes in Marsh dynamics promote channelisation. These include: breaches to the embankment associated with Chiromo Bridge; change in course of the Ruo River; human use/removal of vegetation, especially from the channel banks; increased sediment inputs.
Change in flood extent	A change in flood extent can occur for many reasons, the most important of which are: change in inflowing hydrological regime, and; change in the topography of the Marsh, such as channelisation.
Sediment output	Sediment output is mainly determined by sediment input and sediment retention.
Sediment storage	Sediment storage is sediment input minus sediment output.

5.2.1.1 Composite indicators for geomorphology

None.

5.2.2 Linked indicators, response curves and motivations

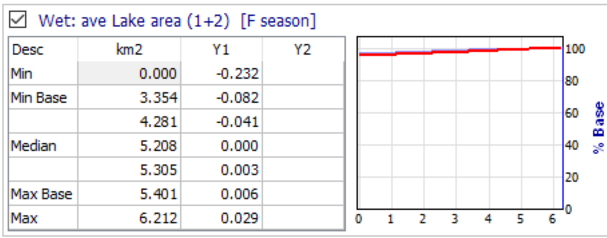
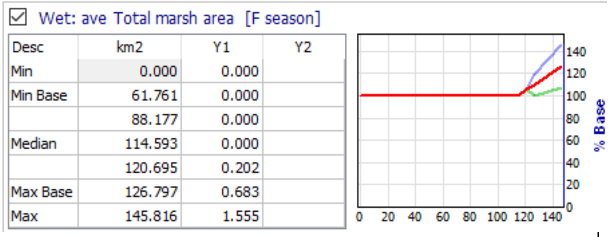
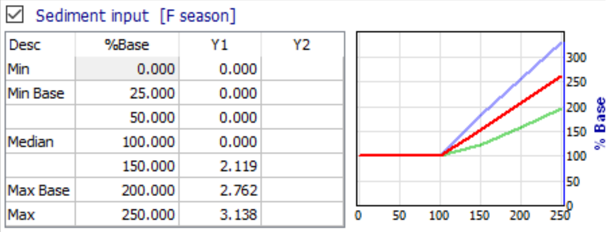
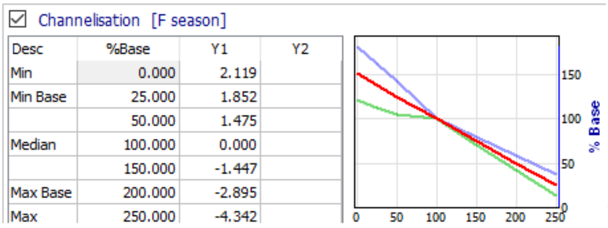
The linked indicators, the response curves and the explanations of the shape of the response curves for each of the geomorphology indicators are tabulated as follows (Eastern Site used as an example):

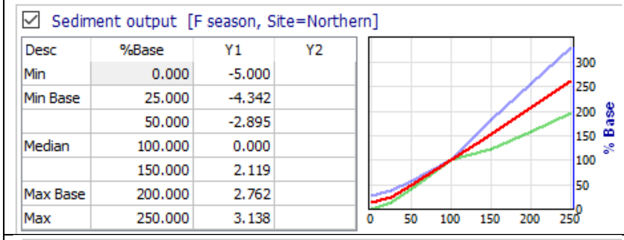
Table 5.2	Sediment retention: Linked indicators, response curves and motivations.
Table 5.3	Turbidity: Linked indicators, response curves and motivations
Table 5.4	Channelisation: Linked indicators, response curves and motivations.
Table 5.5	Change in flood extent: Linked indicators, response curves and motivations.
Table 5.6	Sediment output: Linked indicators, response curves and motivations.
Table 5.7	Sediment storage: Linked indicators, response curves and motivations.

NB: The response curves do not address any of the scenarios directly. The curves are drawn for a range of possible changes in each linked indicator, regardless of what is expected to occur in any of the scenarios. For this reason, some of the explanations and/or X-axes refer to conditions that are unlikely to occur under any of the scenarios but are needed for completion of the Response Curves. In addition, each response curve has a shape that assumes that all other conditions (indicators) remain at baseline.

The relationships are similar across all areas, although the actual curves may differ slightly from what is shown here. For the exact relationship used for each focus area please refer to the DSS. The focus area used as an example is denoted in the caption.

Table 5.2 Sediment retention: Linked indicators, response curves and motivations (Eastern)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☑ Wet: ave Lake area (1+2) [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.232</td><td></td></tr>
<tr><td>Min Base</td><td>3.354</td><td>-0.082</td><td></td></tr>
<tr><td></td><td>4.281</td><td>-0.041</td><td></td></tr>
<tr><td>Median</td><td>5.208</td><td>0.000</td><td></td></tr>
<tr><td></td><td>5.305</td><td>0.003</td><td></td></tr>
<tr><td>Max Base</td><td>5.401</td><td>0.006</td><td></td></tr>
<tr><td>Max</td><td>6.212</td><td>0.029</td><td></td></tr>
</table>
</td><td>Lakes (open water surfaces) constitute a small proportion (4%) of the overall landuse/vegetation type (refer to the Hydromorphology Report), but nonetheless enhance sediment deposition through greater depths and reduced velocities. This relationship has been set as linear, with the percentage change reflecting the areal coverage (4%) by lakes.</td></tr>
<tr><td>
☑ Wet: ave Total marsh area [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>61.761</td><td>0.000</td><td></td></tr>
<tr><td></td><td>88.177</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>114.593</td><td>0.000</td><td></td></tr>
<tr><td></td><td>120.695</td><td>0.202</td><td></td></tr>
<tr><td>Max Base</td><td>126.797</td><td>0.683</td><td></td></tr>
<tr><td>Max</td><td>145.816</td><td>1.555</td><td></td></tr>
</table>
</td><td>The Eastern Site is characterised by predominantly marsh-type vegetation and lakes (83%), with terminal channels that promote substantial sediment filtering, to the extent that clear flows emerge at its downstream end (certainly during the dry season when vegetation is emergent and trapping efficiency is high). Unlike some of the other sites (namely Northern, Western and Southern), sediment retention is less dependent on flooded marsh area, as deposition is not mainly through "overbank deposition", but also due to "forced filtering" due to terminal channels. Hence a 100% direct relationship has been applied, but only for values below the median marsh area.</td></tr>
<tr><td>
☑ Sediment input [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.119</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.762</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.138</td><td></td></tr>
</table>
</td><td>Lateral sediment inputs from tributaries feeding directly into the marsh: a 100% change in retention is applied (high, as the input is filtered through the marsh, which will allow for high rates of deposition), truncated at 100% as it is unlikely that inputs and hence retention can practically be reduced and furthermore the Eastern Site has high trapping/filtering efficiency.</td></tr>
<tr><td>
☑ Channelisation [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>2.119</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.852</td><td></td></tr>
<tr><td></td><td>50.000</td><td>1.475</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.447</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-2.895</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-4.342</td><td></td></tr>
</table>
</td><td>Channelisation will lead to less flooded marsh area and hence reduced propensity for sediment retention. The Eastern Site is characterised by terminal channels and substantial retention capabilities, and an increase in channelisation will have a much greater effect on retention than for other sites (*viz*. Northern and Western). An inverse 50% relation is applied.</td></tr>
</table>

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


☑ Sediment output [F season, Site=Northern]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.342</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.895</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.119</td><td></td></tr>
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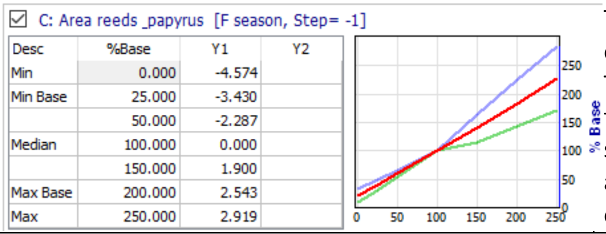
<tr><td>Max</td><td>250.000</td><td>3.138</td><td></td></tr>
</table>

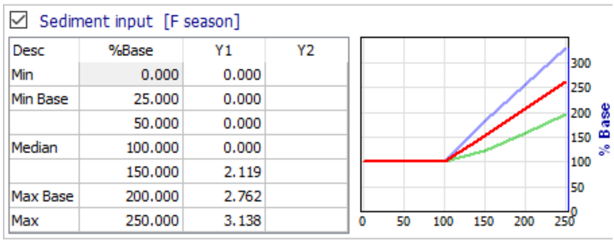
</td><td>Sediment input from upstream: output from the Northern Site. Given a well-defined channel at its upstream end with terminal channels further downstream, a 100% change in retention is estimated (as per the lateral inputs with no truncated lower-limit at 100%).</td></tr>
<tr><td>


☑ C: Area reeds _papyrus [F season, Step= -1]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-4.574</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-3.430</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.287</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.900</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.543</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.919</td><td></td></tr>
</table>

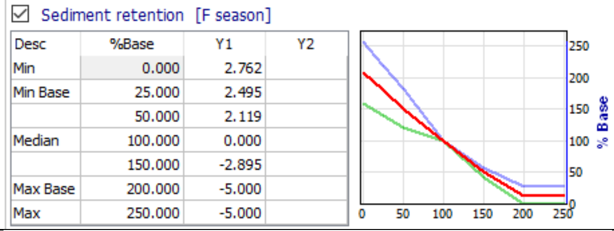
</td><td>The marsh vegetation (viz. reeds, papyrus and sedges) enable sediment filtering through the Eastern Site. There is a high relative proportion of these compared to many of the other sites. This relationship has been set as linear, with the percentage change reflecting the areal coverage (79%) by reeds and papyrus and other essentially indigenous marsh vegetation.</td></tr>
</table>

Table 5.3 Turbidity: Linked indicators, response curves and motivations (Eastern)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


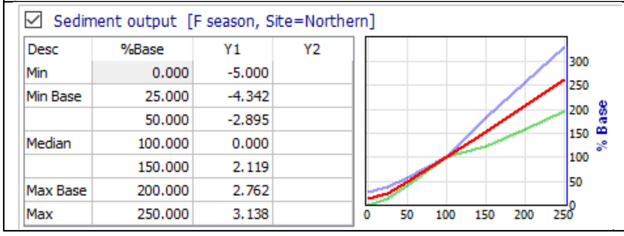
☑ Sediment input [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.119</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.762</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.138</td><td></td></tr>
</table>

</td><td>Lateral sediment inputs from tributaries feeding directly into the marsh: a 100% change in retention is applied (high, as the input is filtered through the marsh, which will allow for high rates of deposition), truncated at 100% as it is unlikely that inputs and hence retention can practically be reduced and furthermore the Eastern Site has high trapping/filtering efficiency.</td></tr>
<tr><td>


☑ Sediment retention [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>2.762</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>2.495</td><td></td></tr>
<tr><td></td><td>50.000</td><td>2.119</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-2.895</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-5.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-5.000</td><td></td></tr>
</table>

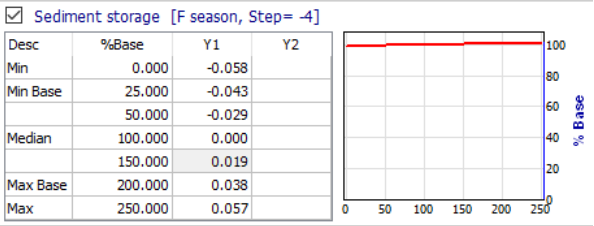
</td><td>Sediment output is indirectly related to sediment retention.</td></tr>
<tr><td>


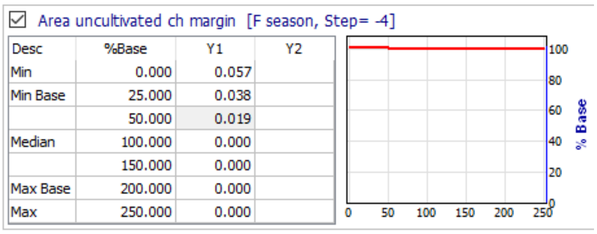
☑ Sediment output [F season, Site=Northern]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.342</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.895</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.119</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.762</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.138</td><td></td></tr>
</table>

</td><td>Sediment input from upstream: output from the Northern Site. Given a well-defined channel at its upstream end with terminal channels further downstream, a 100% change in retention is estimated (as per the lateral inputs with no lower-limit truncation at 100%).</td></tr>
</table>

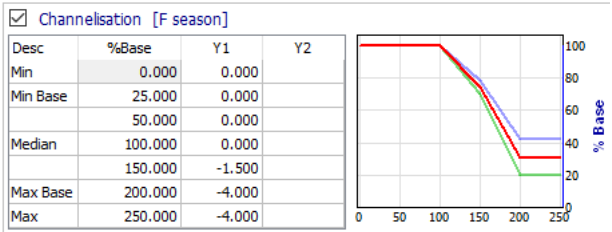
Table 5.4 Channelisation: Linked indicators, response curves and motivations (Eastern)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Sediment storage [F season, Step= -4]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.058</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.043</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.029</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.019</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.038</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.057</td><td></td></tr>
</table>

</td><td>Channelisation is related to sediment storage in the adjacent marsh/lake areas. However, sediment storage in the Marsh has two forms, build-up of the floodplain (which will lead to increased channelisation) and build-up of the channel beds (which will reduce channelisation). Overall the effect is probably close to neutral, with possibly a slight increase in channelisation.</td></tr>
<tr><td>

☑ Area uncultivated ch margin [F season, Step= -4]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.057</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.038</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.019</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.000</td><td></td></tr>
</table>

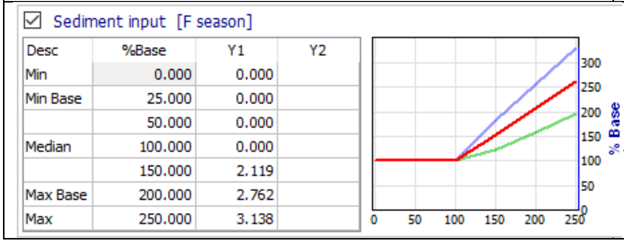
</td><td>Channelisation is indirectly related to area of uncultivated channel margin, since cultivation reduces bank stability leading to channel widening. Conversely, indigenously-vegetated banks trap sediment and enhance channel narrowing, which, in-turn, leads to channel blockages and the development of new flow paths and channels (i.e., reduces channelisation). The relationship is truncated at 100%, as a reduction from Present Day (due to increased uncultivated channel margin) is not expected.</td></tr>
</table>

Table 5.5 Change in flood extent: Linked indicators, response curves and motivations (Eastern)

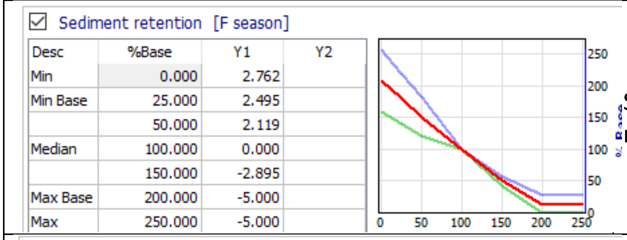
<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Channelisation [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-4.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-4.000</td><td></td></tr>
</table>

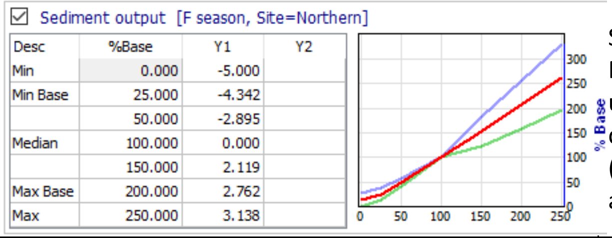
</td><td>Reduced channelisation should not have any effect on change in flood extent, since under present conditions, the Eastern Site displays little channelisation. The relationship is thus truncated at 100% (actually, channelisation can only increase). As channelisation increases, flood extent will reduce, with a 50% increase resulting in an estimated 25% reduction of the flood extent. Even with substantial channelisation, extreme floods will overtop the banks/levees and inundate the floodplain, but not to the same extent, since the channels will have higher conveyance.</td></tr>
</table>

Table 5.6 Sediment output: Linked indicators, response curves and motivations (Eastern)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Sediment input [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.119</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.762</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.138</td><td></td></tr>
</table>

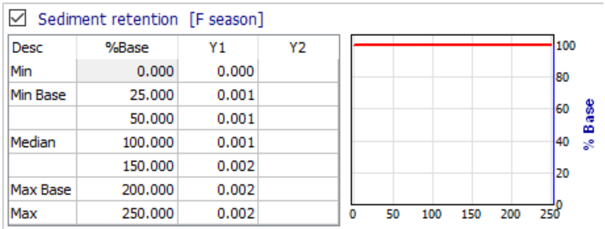
</td><td>Lateral sediment inputs from tributaries feeding directly into the marsh: a 100% change in retention is applied (high, as the input is filtered through the marsh, which will allow for high rates of deposition), truncated at 100% as it is unlikely that inputs and hence retention can practically be reduced and the Eastern Site has high trapping/filtering efficiency.</td></tr>
</table>

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Sediment retention [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>2.762</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>2.495</td><td></td></tr>
<tr><td></td><td>50.000</td><td>2.119</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-2.895</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-5.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-5.000</td><td></td></tr>
</table>

</td><td>Sediment output is indirectly related to sediment retention.</td></tr>
<tr><td>

☑ Sediment output [F season, Site=Northern]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.342</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.895</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.119</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.762</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.138</td><td></td></tr>
</table>

</td><td>Sediment input from upstream: output from the Northern Site. Given a well-defined channel at its upstream end with terminal channels further downstream, a 100% change in retention is estimated (as per the lateral inputs with no lower-limit truncation at 100%).</td></tr>
</table>

Table 5.7 Sediment storage: Linked indicators, response curves and motivations (Eastern)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Sediment retention [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.001</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.001</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.001</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.002</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.002</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.002</td><td></td></tr>
</table>

</td><td>There are very few data to support the estimation of actual rates of floodplain/marsh sedimentation, which in this context is relate to sediment retention. However, the carbon dating of limited sediment cores provides some insights, when combined with the circumstantial evidence that the rate of aggradation may have considerably increased over the past 50 years or so, relative to before that. To develop this relationship the following was applied: (1) Carbon dating indicates historical rates of sedimentation of approximately 1 mm/annum; with the more recent (50 year) rate substantially higher at approximately 30 mm/annum. (2) Over the 33-year hydrological period and for an estimated alluvial depth of 100 m, the change in storage has thus been of the order 1 m, or 101% relative to baseline at 100%. The curve is therefore a linear function (through the origin at 0% Min) of cumulative sediment retention, giving storage of 101% in 2009. (3) There are insufficient data to differentiate between sites, so this estimate is applied uniformly across the floodplain (Northern) and marsh (downstream). One of the 3 sediment cores was extracted from the Eastern Site.</td></tr>
</table>

5.3 Vegetation

The data collection and analyses underlying the selection of vegetation indicators are presented in Turpie *et al*. (2016) and Birkhead *et al.* (2016). These led to the delineation of eight main vegetation 'types', including areas of water (Figure 5.2), *viz*.:

1. Open water
2. Floating/rooted aquatic vegetation

3. Bare
4. Cultivated
5. Recently burnt
6. Seasonally-inundated indigenous vegetation
7. Reeds/grasses
8. Papyrus.

The focus areas introduced in Section 2.2 were selected partly on the basis of these mapped vegetation types, and thus differ with respect to the presence and proportion of the eight vegetation types, summarised in Table 5.8. In basic terms:

- the Northern and Western areas are dominated by cultivated fields, which have replaced the natural seasonally-inundated indigenous vegetation;
- the Eastern and Central Areas are dominated by indigenous reeds and emergent grasses, however:
    - in Central, much of the remainder of the vegetation comprised of seasonally-inundated indigenous vegetation and cultivation;
    - Eastern is generally far wetter, and has the highest proportion of papyrus (~12%).
- the Southern Area is dominated by cultivated areas, but it also has the biggest lakes, and the most area covered by open water. Apart from agriculture, the proportions of open water, floating/rooted aquatic vegetation; reeds/grasses and papyrus are roughly equal.

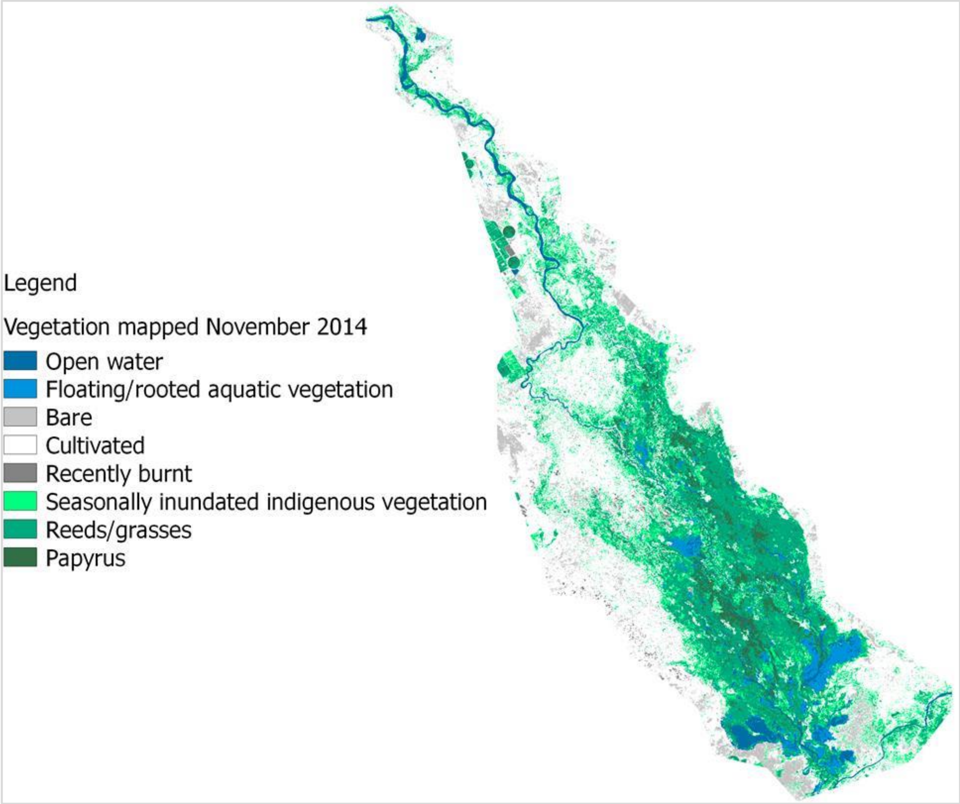


Figure 5.2 Vegetation types of the Elephant Marsh as at November 2014

Table 5.8 Extent of mapped vegetation ‘types’ per site and for the Whole Marsh (green denotes the dominant vegetation type in each area)

Focus Area	Northern		Western		Eastern		Central		Southern		Whole Marsh	
Type	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Open water	1.6	2.0	0.5	0.2	2.2	1.7	3.9	3.6	9.7	17.1	17.8	3.0
Floating/rooted aquatic vegetation	0.1	0.1	0.2	0.1	3.2	2.5	6.5	6.0	11.0	19.4	21.0	3.6
Bare	5.1	6.2	15.6	7.5	1.9	1.5	0.1	0.1	5.4	9.5	28.1	4.8
Cultivated	51.1	62.5	139.9	67.2	7.1	5.5	7.1	6.5	15.4	27.2	235.7	40.4
Recently burnt	0.6	0.7	3.9	1.9	0.4	0.3	0.4	0.4	0.2	0.4	5.5	0.9
Seasonally-inundated indigenous vegetation	14.0	17.1	25.5	12.2	24.3	19.0	16.6	15.2	6.7	11.8	87.1	14.9
Reeds/grasses	9.0	11.0	13.8	6.6	74.6	58.2	59.8	54.9	9.1	16.0	166.2	28.5
Papyrus	0.4	0.5	1.1	0.5	14.9	11.6	14.8	13.6	0.9	1.6	32.2	5.5
Indigenous vegetation (composite)	*23.4*	*28.6*	*40.4*	*19.4*	*113.8*	*88.8*	*91.2*	*83.7*	*16.7*	*29.5*	*285.5*	*48.9*
Total	81.8	100	208.2	100	128.2	100	108.9	100	56.7	100	583.8	100

5.3.1 Vegetation indicators

Seven vegetation indicators were selected for the DRIFT DSS. These are defined in Table 5.9 along with representative species and an indication of the main variables likely to drive change in the indicator. The grouping the vegetation types into the indicators is shown in Table 5.10.

Table 5.9 Vegetation indicators, representative species and their main links to water levels in the Marsh

Indicator		Representative species	Driving variables
Marsh and floodplain	Rooted indigenous aquatics	Plants with submersed leaves (e.g., rigid hornwort *Ceratophyllum demersum*) or floating leaves (e.g. white lily *Nymphaea lotus*)	Linked closely to the availability of open water at depths <0.6 m (www.plantzafrica.com; K. Reinecke, Pers. Obs., this study).
	Floating exotics	The two dominant free-floating exotics on the Marsh are *Pistia stratioites* (water lettuce) and *Eichhornia crassipes* (water hyacinth), both of which originate in South America.	Exotic free-floating exotics lack natural predators and so their proliferation can be fairly independent of other environmental factors, such as water depth. However, they will benefit if indigenous plant species are stressed (less rigorous competition for space). They also benefit from high dissolved nutrients and low flushing flows (Hazelton *et al.* 2016).
	Area cultivated floodplain	Various cultivated crop varieties are present (e.g., sorghum, maize, rice, mango, banana, beans).	Lower water levels allow for a greater extent of the marsh to be accessed and cleared for cultivation.
	Area uncultivated floodplain	Typically grass dominated and comprising species such as *Cynodon dactylon* (grazing grass) and *Miscanthus junceus* (vlei grass).	Closely linked to the frequency, duration and magnitude of floods that inundate the floodplain (Ellery *et al.* 2003; Gaudet 1992; Keddy 2005; McCarthy *et al.* 1986).

Indicator		Representative species	Driving variables
	Area reeds	Dominated by the common reed (*Phragmites australis*) and hippo grass (*Vossia cuspidata*).	Closely linked to the seasonal fluctuations in the flow regime (Fraser and Keddy 2005; Gaudet 1992; McCarthy *et al.* 1993; Tulbure and Johnston 2010).
	Area papyrus	Perennially inundated areas inhabited by papyrus sedge (*Cyperus papyrus*).	Papyrus sedge benefits from stable water levels. It inhabits permanently inundated areas and cannot tolerate drying out (Denny 1985; Ellery *et al.* 1995; Fraser and Keddy 2005; Gaudet 1992; Petr 2000; Sutcliffe 1974; Whigham *et al.* 1993).
Channel margins	Area uncultivated channel margin	Seasonally inundated channel margins inhabited by common reed (*Phragmites australis*), hippo grass (*Vossia cuspidata*), papyrus sedge (*Cyperus papyrus*).	Closely linked to the seasonal fluctuations in the flow regime, including onset and duration of floods, magnitude and frequency of floodplain and dry season discharge/water level (Reinecke 2013).

Table 5.10 Grouping of vegetation indicators for calculating hydraulic relationships at floodplain and marsh areas

Mapped vegetation types	Relevant vegetation indicators
Open water	Rooted indigenous aquatics, plus floating exotics
Floating/rooted aquatic vegetation	
Bare	Area cultivated floodplain
Cultivated	
Recently burnt	
Seasonally-inundated indigenous vegetation	Area uncultivated floodplain
Reeds/grasses	Area reeds
Papyrus	Area papyrus

The uncultivated floodplain and uncultivated channel margins represent the same kinds of vegetation but the way in which hydraulic information was generated for them from the hydraulic modelling differed and so they needed to be considered as separate vegetation indicators.

For the uncultivated floodplain and the other floodplain indicators, reeds, papyrus and rooted aquatics, the well-documented and strong links between vegetation types and flooding depth, frequency and duration meant that the hydrodynamic model could be used to derive a first level range of “suitable” water depths based on the flooding characteristics for baseline. The resultant median annual depths of inundation for the baseline hydrological time-series, per vegetation type and per focus area, are presented in Figure 5.3.

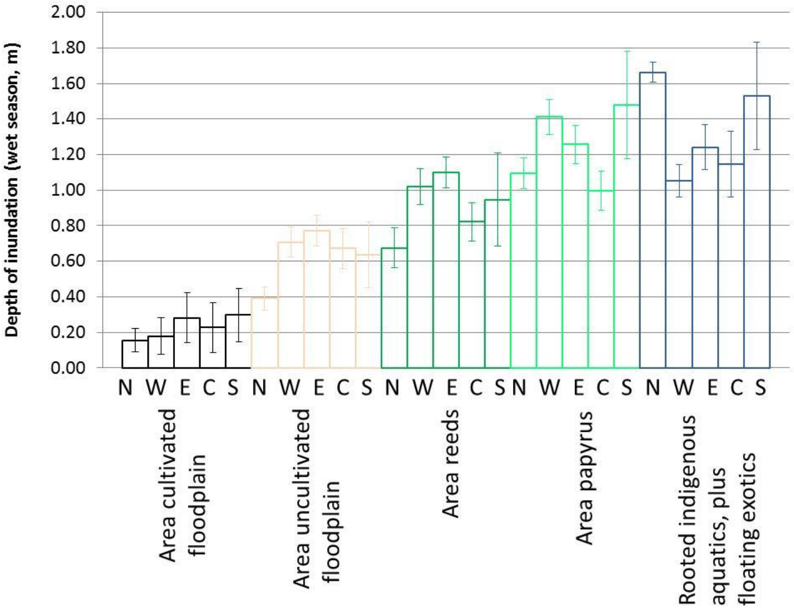


Figure 5.3 **Median inundation depth (± standard deviation) per vegetation type (types as per Table 5.10) per site**

Obviously, the indicators represent points in a continuum and so it is not surprising that there is some overlap between the indicators in Figure 5.3. This is particularly the case for rooted aquatics and papyrus, as both of these must be permanently inundated to survive. Notwithstanding this, the data were used to estimate the median (± standard deviation (SD)) average depth of inundation and the minimum and maximum range of average inundation depths, per vegetation type per site (Figure 5.4); and are denoted as 'modelled' in Table 5.11.

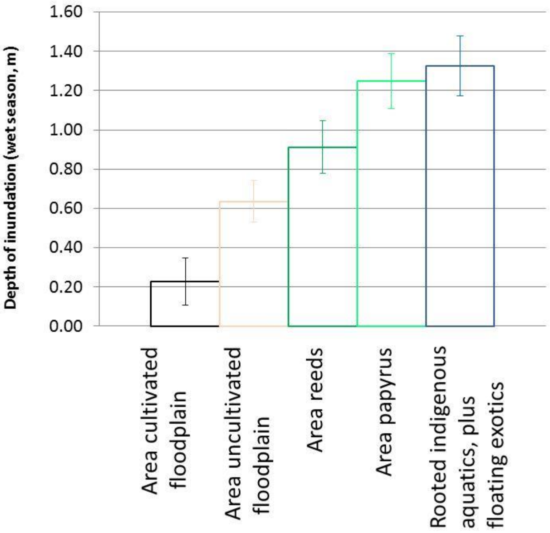


Figure 5.4 **Average of median inundation depth (± standard deviation) per vegetation type (types as per Table 5.10)**

Table 5.11 Modelled and adjusted wet season depths of inundation for vegetation indicators

Vegetation indicator	Wet season depth (m)						References
	Modelled				Adjusted		
	Mean	SD	Min	Max	Min	Max	
Area cultivated floodplain	0.23	0.12	0.11	0.35	0.03	0.5	Gaudet (1992); Keddy (2005); K. Reinecke, Pers. Obs. (this study).
Area uncultivated floodplain	0.64	0.11	0.53	0.74	0.6	0.85	Ellery *et al.* (2003); Gaudet (1992); Keddy (2005); McCarthy *et al.* (1986); K. Reinecke, Pers. Obs. (this study).
Area reeds	0.91	0.13	0.78	1.05	0.9	1.1	Fraser and Keddy (2005); Gaudet (1992); McCarthy *et al.* (1993); Tulbure and Johnston (2010); K. Reinecke, Pers. Obs. (this study).
Area papyrus	1.25	0.14	1.11	1.39	1.15	1.6	Denny (1985); Ellery *et al.* (1995); Fraser and Keddy (2005); Gaudet (1992); Petr (2000); Sutcliffe (1974); Whigham *et al.* (1993); K. Reinecke, Pers. Obs. (this study).
Rooted aquatics	1.33	0.15	1.17	1.48	-	> 0.6	www.plantzafrica.com; pers. obs. (this study)

These were then adjusted using depth data for the representative species from the literature, to arrive at ‘adjusted’ depth ranges (Table 5.11) that were used as the depth ranges under which each of the vegetation types would persist; or conversely, would succumb outside of these ranges either for physiological reasons or competition from another type better suited to the conditions.

The annual areas (km^2) associated with each of the depth ranges were then modelled as a hydraulic indicator (see Table 4.1) and denoted as linked indicators for the relevant vegetation indicator in Table 5.13.

The full list of linked indicators for each vegetation indicator is provided in Section 5.3.2, together with the response curves describing each of the links, with explanations for the shape of the response curves.

5.3.1.1 Composite indicators for vegetation

Two composite indicators (denoted in the DSS as C:*) were calculated for vegetation:

- C: Area reeds + Area papyrus, which combined the areas of reeds and papyrus.
- C: Indigenous Plant Abundance, which combined the area of reeds, papyrus, uncultivated channel margins and rooted aquatics.

Weights used for these composite indicators are shown in Table 5.12, where the numbers represent the relative contribution of each vegetation type to the composite at each site.

Table 5.12 Weights for composite vegetation indicators

Site	C: Area reeds + Area papyrus		C: Indigenous Plant Abundance		
	Area reeds	Area papyrus	C: Area reeds + Area papyrus	Area uncultivated ch margin	Rooted aquatics
Northern	24	1	20	0.1	1
Western	12	1	1	0.1	-
Eastern	5	1	5	0.1	1
Central	4	1	1	0.1	1
Southern	10	1	1	0.1	1

5.3.2 Linked indicators, response curves and motivations

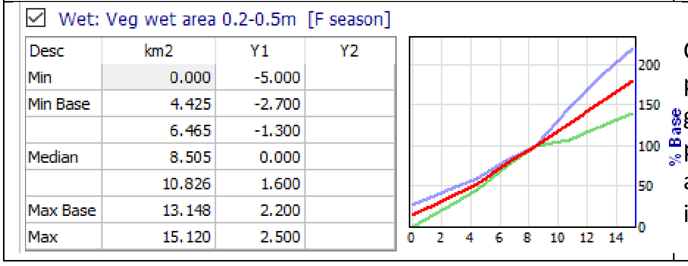
The linked indicators, the response curves and the explanations of the shape of the response curves for each of the vegetation indicators are tabulated as follows:

Table 5.13	Area cultivated floodplain: Linked indicators, response curves and motivations
Table 5.14	Area uncultivated floodplain: Linked indicators, response curves and motivations
Table 5.15	Area reeds: Linked indicators, response curves and motivations
Table 5.16	Area papyrus: Linked indicators, response curves and motivations
Table 5.17	Area rooted aquatics: Linked indicators, response curves and motivations

NB: The response curves do not address any of the scenarios directly. The curves are drawn for a range of possible changes in each linked indicator, regardless of what is expected to occur in any of the scenarios. For this reason, some of the explanations and/or X-axes refer to conditions that are unlikely to occur under any of the scenarios but are needed for completion of the Response Curves. In addition, each response curve has a shape that assumes that all other conditions (indicators) remain at baseline.

The relationships are similar across all areas, although the actual curves may differ slightly from what is shown here. For the exact relationship used for each focus area please refer to the DSS. The focus area used as an example is denoted in the caption.

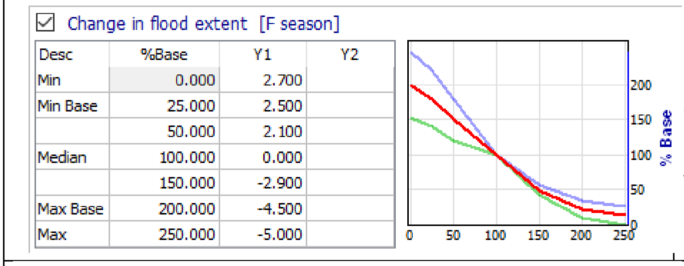
Table 5.13 Area cultivated floodplain: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

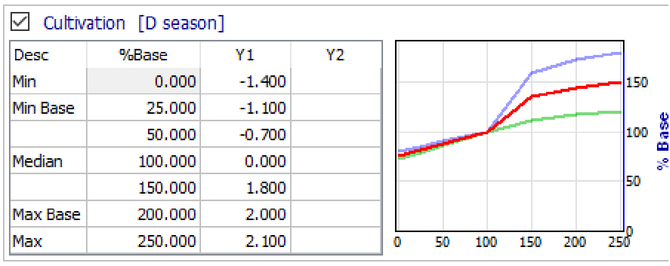
☑ Wet: Veg wet area 0.2-0.5m [F season]

Desc	km2	Y1	Y2
Min	0.000	-5.000	
Min Base	4.425	-2.700	
	6.465	-1.300	
Median	8.505	0.000	
	10.826	1.600	
Max Base	13.148	2.200	
Max	15.120	2.500	

</td><td>Cultivated areas are inundated least often. In dry periods the extent of cultivation is greater as a greater area of the marsh is dry. During wet periods people migrate out of the marsh abandoning their cultivated fields that get inundated.</td></tr>
</table>

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


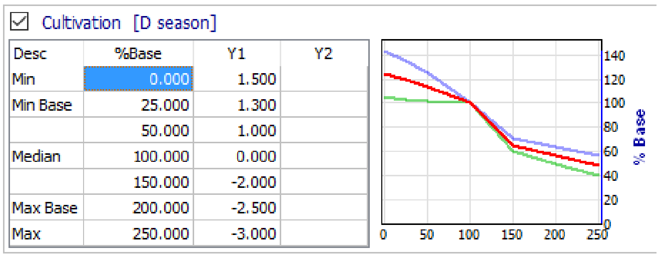
☑ Change in flood extent [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>2.700</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>2.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>2.100</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-2.900</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-4.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-5.000</td><td></td></tr>
</table>
</td><td>Sedimentation leads to channelisation, which leads to a reduction in flooding extent as higher water levels are needed to breach the artificial levees/berms. Reduced flooding extent increases the abundance of dry floodplain available to cultivation.</td></tr>
<tr><td>


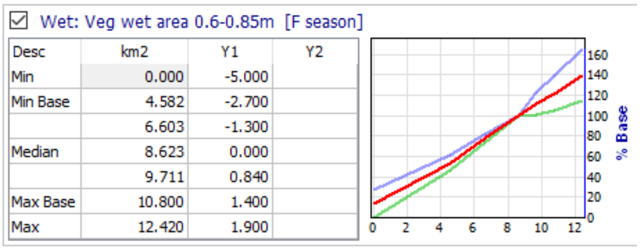
☑ Cultivation [D season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.400</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.100</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.700</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.800</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.100</td><td></td></tr>
</table>
</td><td>More floodplain areas are cultivated to sustain the increased need for cultivated produce; in response to increased access to the marsh, immigration of people in dry periods. 10% of the Central site is currently cultivated so an increase in cultivation will disproportionately increase the extent of cultivated fields when compared to the decrease in extent as pressure decreases.</td></tr>
</table>

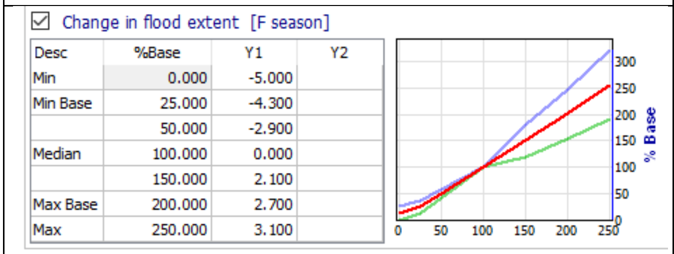
Table 5.14 Area uncultivated floodplain: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


☑ Cultivation [D season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.300</td><td></td></tr>
<tr><td></td><td>50.000</td><td>1.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-2.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-2.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-3.000</td><td></td></tr>
</table>
</td><td>If cultivation is low the abundance of fallow abandoned fields increases in extent. This increases in direct proportion to the decrease in cultivated fields.</td></tr>
<tr><td>


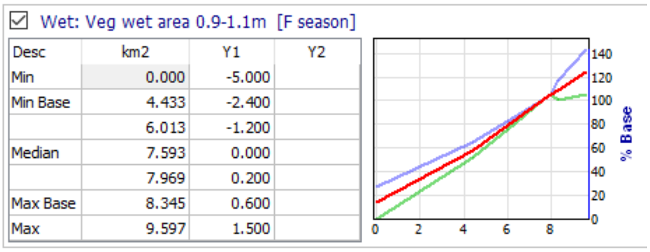
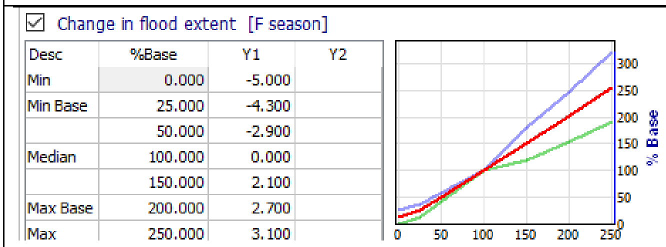
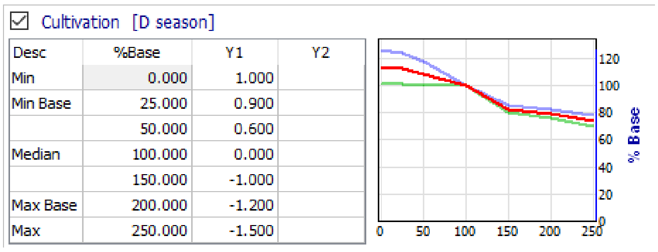
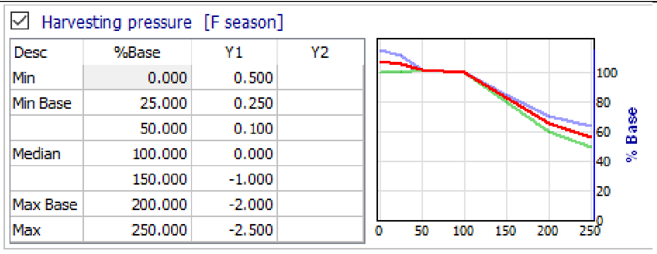
☑ Wet: Veg wet area 0.6-0.85m [F season]

<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>4.582</td><td>-2.700</td><td></td></tr>
<tr><td></td><td>6.603</td><td>-1.300</td><td></td></tr>
<tr><td>Median</td><td>8.623</td><td>0.000</td><td></td></tr>
<tr><td></td><td>9.711</td><td>0.840</td><td></td></tr>
<tr><td>Max Base</td><td>10.800</td><td>1.400</td><td></td></tr>
<tr><td>Max</td><td>12.420</td><td>1.900</td><td></td></tr>
</table>
</td><td>Wet season flooding depths of >0.6 m are unsuitable for cultivation (Ellery *et al.* 2003; Gaudet 1992 Keddy 2005; McCarthy *et al.* 1986). Thus, there are areas of the Marsh that, in drier years, are burnt, cleared and cultivated, or grazed. These fields lie fallow in wet years, during which time *Cynodon dactylon, Phragmites australis, Miscanthus junceus* will grow.</td></tr>
<tr><td>


☑ Change in flood extent [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.300</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.900</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.700</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.100</td><td></td></tr>
</table>
</td><td>Sedimentation leads to channelisation, which leads to a reduction in flooding extent as higher water levels are needed to breach the artificial levees/berms. Increased extent of flooding floods cultivated areas that may then recover back to being vegetated by indigenous grasses and reeds.</td></tr>
</table>

Table 5.15 Area reeds: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☑ Wet: Veg wet area 0.9-1.1m [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>4.433</td><td>-2.400</td><td></td></tr>
<tr><td></td><td>6.013</td><td>-1.200</td><td></td></tr>
<tr><td>Median</td><td>7.593</td><td>0.000</td><td></td></tr>
<tr><td></td><td>7.969</td><td>0.200</td><td></td></tr>
<tr><td>Max Base</td><td>8.345</td><td>0.600</td><td></td></tr>
<tr><td>Max</td><td>9.597</td><td>1.500</td><td></td></tr>
</table>
</td>
<td><i>Phragmites</i> grows where inundation depths do not exceed 1.3 m for longer than 10 days, or 1.18 m for 30 days each year (Gaudet 1992). Stage fluctuations greater than 1 m also limit the distribution of this plant (Tulbure and Johnston 2010). <i>Phragmites</i> can survive inundation of 0.6 m for some time but juveniles perish at this stage (Pagter <i>et al</i>. 2005). <i>Phragmites</i> does best over alternating wet/dry years as are able to tolerate drying better than other competitors for this niche (<i>Tyhpa domingensis, Vossia cuspidata, Phragmites mauritianus, Papyrus cyperus</i>; Keddy 2005).</td></tr>
<tr><td>
☑ Change in flood extent [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.300</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.900</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.700</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.100</td><td></td></tr>
</table>
</td>
<td>Sedimentation leads to channelisation, which leads to a reduction in flooding extent as higher water levels are needed to breach the artificial levees/berms. Increased extent of flooding favours plant growth, flowering and seed set.</td></tr>
<tr><td>
☑ Cultivation [D season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.900</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.600</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.200</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-1.500</td><td></td></tr>
</table>
</td>
<td>If cultivation is low, during wet years, the abundance of <i>Phragmites</i> increases as fewer reed beds are cleared for cultivation. This is set at 50% of the proportion given over to fallow fields, which are favoured for cultivation since <i>Phragmites</i> occupies surfaces inundated to a greater extent than fallow fields.</td></tr>
<tr><td>
☑ Harvesting pressure [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
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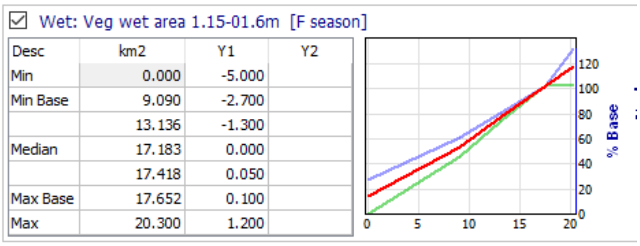
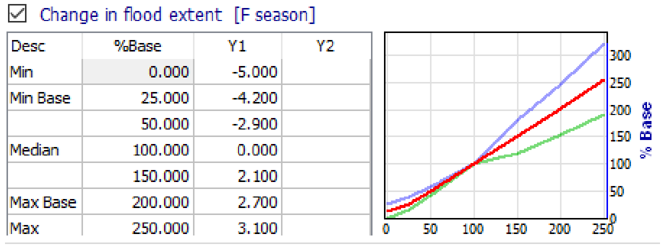
<tr><td>Min Base</td><td>25.000</td><td>0.250</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.100</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-2.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-2.500</td><td></td></tr>
</table>
</td>
<td><i>Phragmites</i> reeds are harvested for making a variety of handcrafts (baskets, drying mats (fish, rice), fences, hats, huts); the more harvesting takes place the fewer reeds remain.</td></tr>
</table>

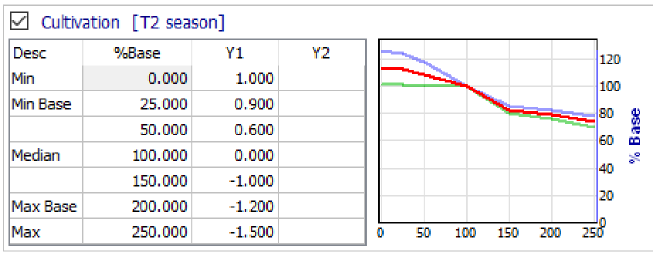
Table 5.16 Area papyrus: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☑ Wet: Veg wet area 1.15-01.6m [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>9.090</td><td>-2.700</td><td></td></tr>
<tr><td></td><td>13.136</td><td>-1.300</td><td></td></tr>
<tr><td>Median</td><td>17.183</td><td>0.000</td><td></td></tr>
<tr><td></td><td>17.418</td><td>0.050</td><td></td></tr>
<tr><td>Max Base</td><td>17.652</td><td>0.100</td><td></td></tr>
<tr><td>Max</td><td>20.300</td><td>1.200</td><td></td></tr>
</table>
</td>
<td>Areas flooded in excess of 1.3 m support rooted Papyrus (Gaudet 1992) up to a maximum of 1.5 m in stage (Sutcliffe 1974). Papyrus requires permanently flooded rhizomes to persist; the rhizomes cannot be aerially exposed (Ellery <i>et al.</i> 1995). Papyrus is drowned out at deeper depths if it does not detach from the substrate to form a sudd, which can take place over depths of 10m (Whigham <i>et al</i>. 1993). <i>Papyrus</i> is favoured by stable water levels and cannot cope when these change rapidly as adjustments in rhizome height</td></tr>
</table>

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td></td><td>are slow (Denny 1985).</td></tr>
<tr><td>


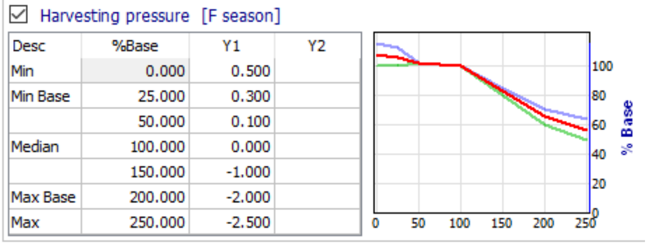
☑ Change in flood extent [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.200</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.900</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.700</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.100</td><td></td></tr>
</table>

</td><td>Sedimentation leads to channelisation, which leads to a reduction in flooding extent as higher water levels are needed to breach the artificial levees/berms. Increased extent of flooding stimulates plant growth, flowering and seed set.</td></tr>
<tr><td>


☑ Cultivation [T2 season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.900</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.600</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.200</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-1.500</td><td></td></tr>
</table>

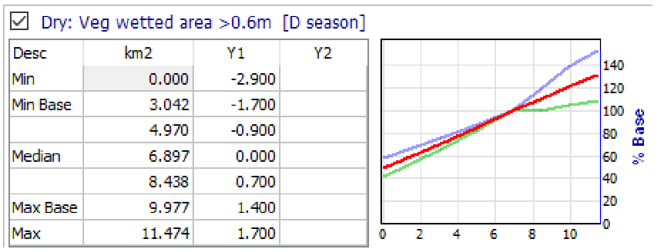
</td><td>If cultivation is low, during wet years, the abundance of *Cyperus papyrus* increases as fewer papyrus beds are cleared for cultivation. This is set at 50% of the proportion given over to fallow fields, which are favoured for cultivation since Papyrus occupies surfaces inundated to a greater extent than *Phragmites* fields.</td></tr>
<tr><td>


☑ Harvesting pressure [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.300</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.100</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-2.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-2.500</td><td></td></tr>
</table>

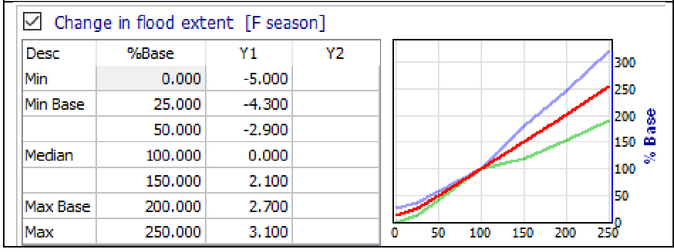
</td><td>Papyrus is harvested for a variety of handcrafts (coal making, fences, mattresses, window frames, brooms, baskets); the more harvesting the less sedge remains.</td></tr>
</table>

Table 5.17 Area rooted aquatics: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


☑ Dry: Veg wetted area >0.6m [D season]

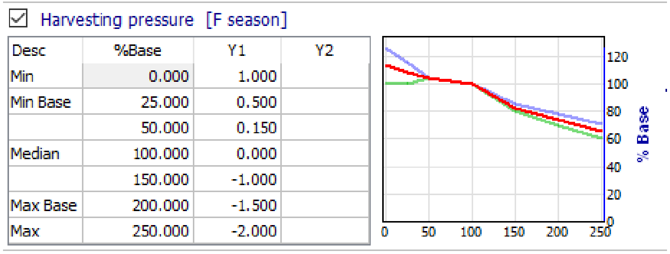
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.900</td><td></td></tr>
<tr><td>Min Base</td><td>3.042</td><td>-1.700</td><td></td></tr>
<tr><td></td><td>4.970</td><td>-0.900</td><td></td></tr>
<tr><td>Median</td><td>6.897</td><td>0.000</td><td></td></tr>
<tr><td></td><td>8.438</td><td>0.700</td><td></td></tr>
<tr><td>Max Base</td><td>9.977</td><td>1.400</td><td></td></tr>
<tr><td>Max</td><td>11.474</td><td>1.700</td><td></td></tr>
</table>

</td><td>Rooted aquatics (*Nymphaea lotus, Ceratophyllum demersum*) require water depths between 0.3-0.9 m to grow optimally (www.plantzafrica.com). Decreases in depth below 0.6 m will begin to stress the plant and depths lower than 0.3 m will strand the plant. Stranding is tolerated for short periods in the growing season. Depths greater > 0.6 m in the dry season will provide abundant suitable habitat for growth. Set at 50%, half the depth before stress is maximised.</td></tr>
<tr><td>


☑ Change in flood extent [F season]

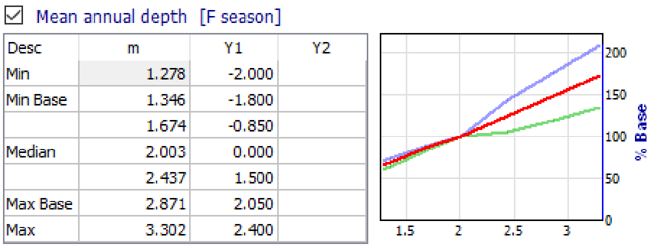
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.300</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.900</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.700</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.100</td><td></td></tr>
</table>

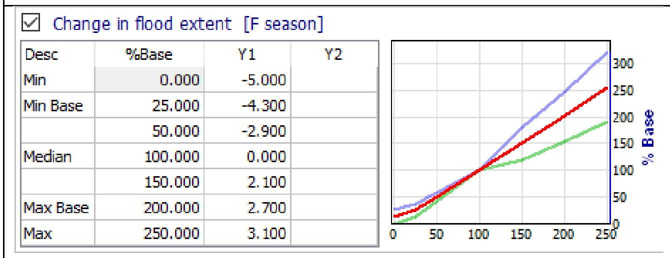
</td><td>Sedimentation leads to channelisation, which leads to a reduction in flooding extent as higher water levels are needed to breach the artificial levees/berms. Increased extent of flooding increases the habitat available for rooted aquatics.</td></tr>
</table>

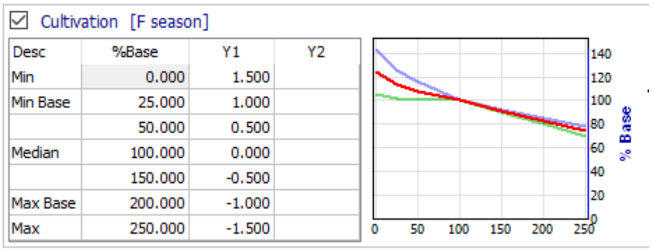
<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Harvesting pressure [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.150</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-2.000</td><td></td></tr>
</table>

</td><td>*Nymphaea lotus* and *Trapa natans* are harvested, *Nymphaea* for its bulbs and *Trapa* for the milky substance contained in the fruits. The Central site is not densely populated and the rooted aquatics present are available for harvest. If harvesting pressure decreases the abundance of rooted aquatics will increase, if harvesting pressure increases the abundance will decrease.</td></tr>
</table>

Table 5.18 Area uncultivated channel margin: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Mean annual depth [F season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>1.278</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>1.346</td><td>-1.800</td><td></td></tr>
<tr><td></td><td>1.674</td><td>-0.850</td><td></td></tr>
<tr><td>Median</td><td>2.003</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.437</td><td>1.500</td><td></td></tr>
<tr><td>Max Base</td><td>2.871</td><td>2.050</td><td></td></tr>
<tr><td>Max</td><td>3.302</td><td>2.400</td><td></td></tr>
</table>

</td><td>Channel margins inundated to a greater extent year on year will drown cultivated crops. Banks inundated less regularly and to a lesser extent will be favoured for cultivated crops year on year. During wet years, fewer banks will be available to cropping and regrowth of *Phragmites, Vossia, Tyhpa* and *Papyrus* will take place. Conversely, naturally vegetated channel margins can be cleared/burnt/harvested and then cultivated within one dry year and cultivated for that period.</td></tr>
<tr><td>

☑ Change in flood extent [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.300</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.900</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.700</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.100</td><td></td></tr>
</table>

</td><td>Sedimentation leads to channelisation, which leads to a reduction in flooding extent as higher water levels are needed to breach the artificial levees/berms. Increased extent of flooding stimulates plant growth, flowering and seed set.</td></tr>
<tr><td>

☑ Cultivation [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-1.500</td><td></td></tr>
</table>

</td><td>More uncultivated banks will be cleared and cultivated as cultivation pressure increases.</td></tr>
</table>

5.4 Aquatic invertebrates

5.4.1 Invertebrates indicators

Two invertebrate indicators were selected for the DRIFT DSS. These are defined in Table 5.19, along with representative species and an indication of the main variables likely to drive change in the indicator.

Table 5.19 Invertebrate indicators, representative species and their main links to water levels in the Marsh

Indicator	Definition and/or representative species	Driving variables
Invertebrate community health	Community composition and health of aquatic macro-invertebrates.	Largely influenced by the ecological condition of the marsh and the condition and diversity of aquatic habitat.
Invertebrate pests	Mosquitoes and blackflies	Berner (1955) recorded 15 species of mosquito and blackfly along the Shire River, nine of these were found at the Elephant Marsh. Some *Anopheles* mosquitoes carry Malaria and Filaria, but these are more commonly found near human settlements in drying pools with algae rather than in the main Marsh (Berner 1955).

5.4.1.1 Composite indicators for invertebrates

None.

5.4.2 Linked indicators, response curves and motivations

The linked indicators, the response curves and the explanations of the shape of the response curves for each of the invertebrate indicators are tabulated as follows:

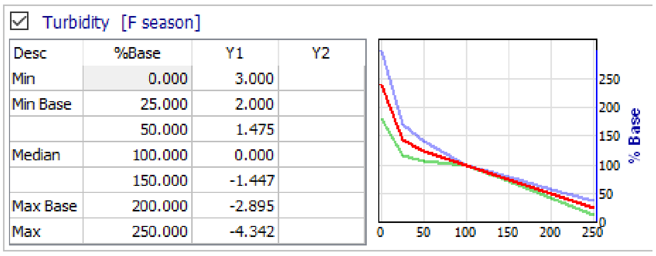
Table 5.20 Invertebrate community health: Linked indicators, response curves and motivations (Central)

Table 5.21 Invertebrate pests: Linked indicators, response curves and motivations.

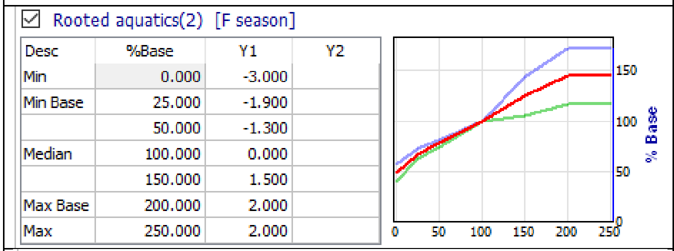
NB: The response curves do not address any of the scenarios directly. The curves are drawn for a range of possible changes in each linked indicator, regardless of what is expected to occur in any of the scenarios. For this reason, some of the explanations and/or X-axes refer to conditions that are unlikely to occur under any of the scenarios but are needed for completion of the Response Curves. In addition, each response curve has a shape that assumes that all other conditions (indicators) remain at baseline.

The relationships are similar across all areas, although the actual curves may differ slightly from what is shown here. For the exact relationship used for each focus area please refer to the DSS. The focus area used as an example is denoted in the caption.

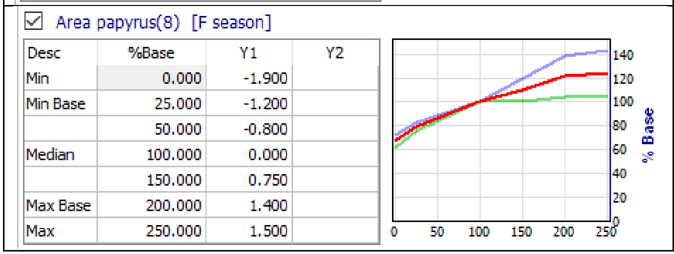
Table 5.20 Invertebrate community health: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


☑ Turbidity [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>3.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>2.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>1.475</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.447</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-2.895</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-4.342</td><td></td></tr>
</table>
</td><td>Turbidity is high under current conditions and the current health of the aquatic invertebrate community is somewhat impaired. If turbidity were to decrease we'd expect a dramatic increase in community health (Madej & Ozaki 2009). However further increases in turbidity will not have much of an effect as the community is dominated by tolerant species that withstand high turbidity.</td></tr>
<tr><td>


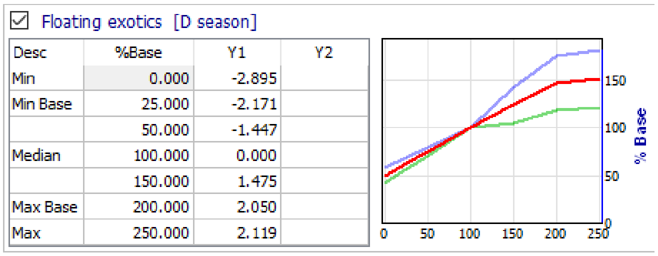
☑ Rooted aquatics(2) [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-3.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.900</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.300</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.000</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.000</td><td></td></tr>
</table>
</td><td>Many aquatic invertebrates use rooted aquatics as habitat, a source of food and to take refuge from predation (Hann 1995). In 2014 there was quite good coverage of these, increases in the extent of rooted aquatics will not have as strong effects as decreases.</td></tr>
<tr><td>


☑ Area papyrus(8) [F season]

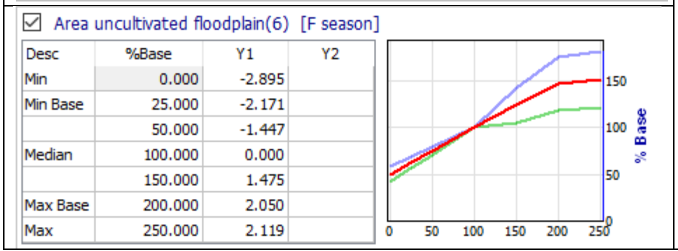
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.900</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.200</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.800</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.750</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.400</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.500</td><td></td></tr>
</table>
</td><td>Papyrus provides aquatic habitat for certain other invertebrates not associated with floating aquatic plants (Masifwa *et al.* 2001). The abundance of this community increases in response to increases in the abundance of papyrus.</td></tr>
</table>

Table 5.21 Invertebrate pests: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


☑ Floating exotics [D season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.895</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.171</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.447</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.475</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.050</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.119</td><td></td></tr>
</table>



☑ Area uncultivated floodplain(6) [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.895</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.171</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.447</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.475</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.050</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.119</td><td></td></tr>
</table>
</td><td>There are numerous mosquito species that occur in and around the Marsh. Berner (1955) recorded 15 species along the Shire River, of which at least nine were recorded within the Elephant Marsh. Most of the species occurring in the marsh were associated with floating aquatics such as *Pistia* and *Azolla*. Other nuisance mosquitoes were associated with wet grasses. Malaria and Filaria carrying *Anopheles* mosquitoes occur mainly near human settlements breeding in stagnant pools with algae rather than in the marsh itself (Berner 1955). Both relationships are positive, but tailoring off at large increases.</td></tr>
</table>

5.5 Fish

5.5.1 Fish indicators

Four fish indicators were selected representing four flow-linked fish guilds, based on the main species typifying the Elephant Marsh, including those of important ecological or livelihoods value. These are defined in Table 5.22 along with reasons for their selection and predicted changes in response to changing water levels.

Table 5.22 Fish indicators, representative species and their main links to water levels in the Marsh

Indicator	Representative species	Driving variables
Floodplain migrants	*Oreochromis mossambicus,* *Clarius gariepinus*	Closely linked to area of inundation and duration of flooding (Willoughby and Tweddle 1978; Bowen 1979; Bruton and Jackson 1983; Skelton 2001; Chimatiro 2004; Welcomme *et al.* 2006).
River channel fish	*Hydrocynus vittatus*	Linked to extent and duration of inundation, especially area of shallow water habitats for breeding (Jackson 1961; Skelton 2001; Thorstad *et al.* 2002; Chimatiro 2004; Welcomme *et al.* 2006).
Demersal fish	*Distichodus* spp., *Mormyrops* spp., *Labeo* spp.	Sensitive to significant reduction in channel depth low flow velocity (Skelton 2001; Welcomme *et al.* 2006).
Channel margin fish	*Barbus* spp., *Micropanachax* spp.	Closely linked to channel depth and the total area of uncultivated margin (Skelton 2001; Thorstad *et al.* 2002; Welcomme 1985).

5.5.1.1 Composite fish indicators

Two composite indicators (denoted in the DSS as C:*) were calculated for fish:

- C: Fish abundance (crocs), which combined estimated abundances of floodplain migrants, river channel fish and demersal fish on the basis of biomass.
- C: Overall fish abundance, which combined estimated abundances of floodplain migrants, river channel fish, demersal fish, and channel margin fish on the basis of biomass.

Weights used for these composite indicators are shown in Table 5.23, where the numbers represent the relative contribution of each fish guild to the composite at each site.

Table 5.23 Weights for composite fish indicators

Site	C: Fish abundance (crocs)			C: Overall fish abundance		C: Demersal fish (WM)	C: Channel margin fish (WM)
	Floodplain migrants	River channel fish	Demersal fish	C: Fish abundance (crocs)	Channel margin fish		
Northern	0.6	0.1	0.3	1	0.5	1	0.8
Western						1	0.9
Eastern						0.9	1
Central						1	1
Southern						0.9	1

5.5.2 Linked indicators, response curves and motivations

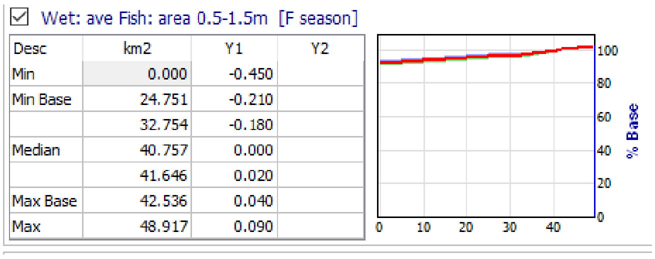
The linked indicators, the response curves and the explanations of the shape of the response curves for each of the fish indicators are tabulated as follows:

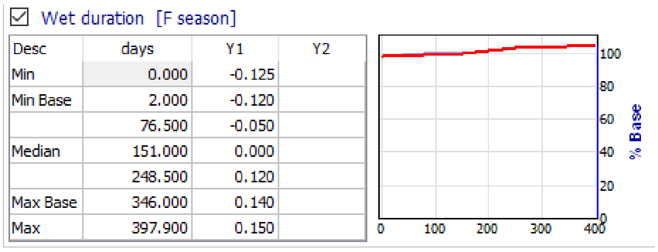
Table 5.24 Floodplain migrant fish: Linked indicators, response curves and motivations.
Table 5.25 River channel fish: Linked indicators, response curves and motivations.
Table 5.26 Demersal fish: Linked indicators, response curves and motivations.
Table 5.27 Channel margin fish: Linked indicators, response curves and motivations.

NB: The response curves do not address any of the scenarios directly. The curves are drawn for a range of possible changes in each linked indicator, regardless of what is expected to occur in any of the scenarios. For this reason, some of the explanations and/or X-axes refer to conditions that are unlikely to occur under any of the scenarios but are needed for completion of the Response Curves. In addition, each response curve has a shape that assumes that all other conditions (indicators) remain at baseline.

The relationships are similar across all areas, although the actual curves may differ slightly from what is shown here. For the exact relationship used for each focus area please refer to the DSS. The focus area used as an example is denoted in the caption.

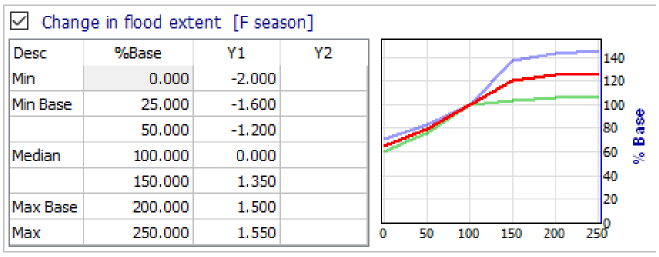
Table 5.24 Floodplain migrant fish: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☑ Wet: ave Fish: area 0.5-1.5m [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.450</td><td></td></tr>
<tr><td>Min Base</td><td>24.751</td><td>-0.210</td><td></td></tr>
<tr><td></td><td>32.754</td><td>-0.180</td><td></td></tr>
<tr><td>Median</td><td>40.757</td><td>0.000</td><td></td></tr>
<tr><td></td><td>41.646</td><td>0.020</td><td></td></tr>
<tr><td>Max Base</td><td>42.536</td><td>0.040</td><td></td></tr>
<tr><td>Max</td><td>48.917</td><td>0.090</td><td></td></tr>
</table>
</td><td>Shallow water habitats (<2 m) on floodplains and lake margins are the main breeding areas for most floodplain migrant species (Bruton and Jackson 1983). High abundances of diatoms occur in waters between 0.5 and 1.5 m, which are very important in the diet of juvenile *O. mossambicus* (Bowen 1979). Likewise, juvenile *C. gariepinus* inhabit shallow inundated areas that have an abundant food source, including *O. mossambicus* fry (Bruton 1979).</td></tr>
</table>

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


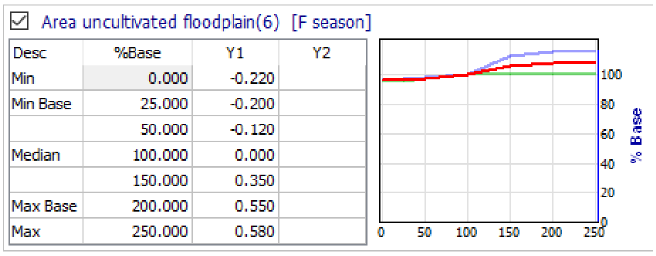
☑ Wet duration [F season]

<table>
<tr><th>Desc</th><th>days</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.125</td><td></td></tr>
<tr><td>Min Base</td><td>2.000</td><td>-0.120</td><td></td></tr>
<tr><td></td><td>76.500</td><td>-0.050</td><td></td></tr>
<tr><td>Median</td><td>151.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>248.500</td><td>0.120</td><td></td></tr>
<tr><td>Max Base</td><td>346.000</td><td>0.140</td><td></td></tr>
<tr><td>Max</td><td>397.900</td><td>0.150</td><td></td></tr>
</table>

</td><td>During seasonal flooding events floodplain migrant species fish undergo breeding migrations onto floodplains and marginal lagoons, returning to the main channels when water levels fall (Skelton 2001). In the Lower Shire, *O. mossambicus* might spawn throughout the year when conditions allow it to, although peak spawning occurs from October to February (Skelton 2001; Chimatiro 2004). *C. gariepinus* has a protracted spawning season from September to March, with peak spawning activity occurring between October and December (Chimatiro 2004). For both species, higher and longer floods can result in stronger year-class strength, whereas juvenile growth and recruitment tends to suffer in short flood seasons when floodplain habitat is limited in extent and duration (Chimatiro 2004).</td></tr>
<tr><td>


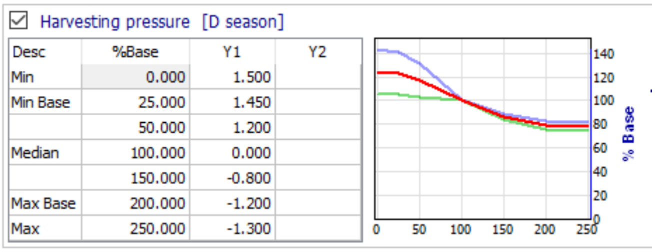
☑ Change in flood extent [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.600</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.350</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.550</td><td></td></tr>
</table>

</td><td>The extent of area available for breeding and developing fry is an important factor in determining annual population dynamics. For most floodplain migrants, higher and longer floods can result in stronger year-class strength, whereas juvenile growth and recruitment tends to suffer in short flood seasons when floodplain habitat is limited in extent and duration (Chimatiro 2004).</td></tr>
<tr><td>


☑ Area uncultivated floodplain(6) [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.220</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.200</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.120</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.350</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.550</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.580</td><td></td></tr>
</table>

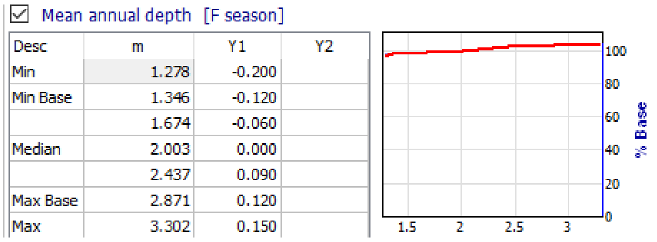
</td><td>Most breeding and juvenile floodplain migrants have an affinity for submerged vegetated habitats, which provide or host an abundance of food and serve as a predation refuge (Skelton 2001; Welcomme 1985). Decaying vegetation during the high water level further enriches the detritus, which is a primary food source for *O. mossambicus* (Weyl and Hecht 1998) and a significant proportion of the diet of *C. gariepinus* during flood in the Lower Shire (Willoughby and Tweddle 1978).</td></tr>
<tr><td>


☑ Harvesting pressure [D season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.450</td><td></td></tr>
<tr><td></td><td>50.000</td><td>1.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.800</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.200</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-1.300</td><td></td></tr>
</table>

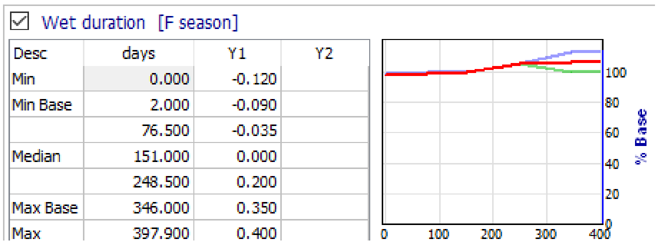
</td><td>Small scale fisheries occur throughout the Elephants Marsh using four main gear types: gillnets, longlines, cast nets, and fish traps. Floodplain migrant species are a major component of the catch, in particular *C. gariepinus* and *O. mossambicus* (M. Manase, Malawi DoF, pers. comm.). Catches of these species ted to be largest during the flood season when fishermen have relatively easy access to fish in floodplains.</td></tr>
</table>

Table 5.25 River channel fish: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


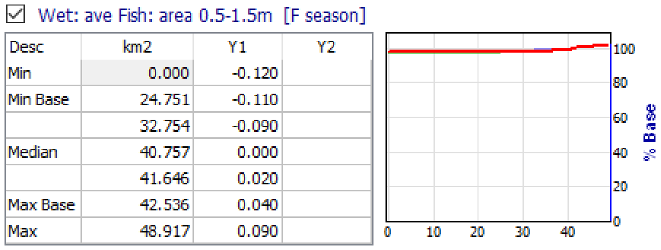
☑ Mean annual depth [F season]

<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>1.278</td><td>-0.200</td><td></td></tr>
<tr><td>Min Base</td><td>1.346</td><td>-0.120</td><td></td></tr>
<tr><td></td><td>1.674</td><td>-0.060</td><td></td></tr>
<tr><td>Median</td><td>2.003</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.437</td><td>0.090</td><td></td></tr>
<tr><td>Max Base</td><td>2.871</td><td>0.120</td><td></td></tr>
<tr><td>Max</td><td>3.302</td><td>0.150</td><td></td></tr>
</table>

</td><td>Channel residents require sufficient river channel habitat for most of the adult (non-breeding) life stages (Skelton 2001). <i>H. vittatus</i> prefer clean water and utilise a range of depths, generally favouring surface waters and shallow areas at night (Thorstad <i>et al</i>. 2002). Very low flow is likely to negatively affect <i>H. vittatus</i> and most other river channel species due to associated habitat loss, e.g. resulting in a narrow, shallow channel with periodic pools.</td></tr>
<tr><td>


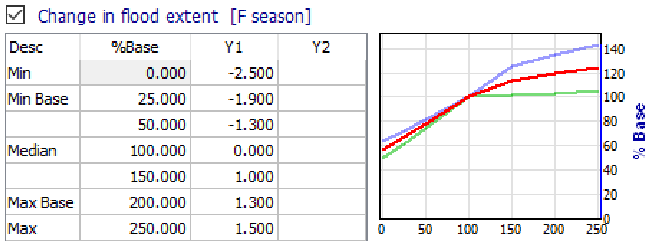
☑ Wet duration [F season]

<table>
<tr><th>Desc</th><th>days</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.120</td><td></td></tr>
<tr><td>Min Base</td><td>2.000</td><td>-0.090</td><td></td></tr>
<tr><td></td><td>76.500</td><td>-0.035</td><td></td></tr>
<tr><td>Median</td><td>151.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>248.500</td><td>0.200</td><td></td></tr>
<tr><td>Max Base</td><td>346.000</td><td>0.350</td><td></td></tr>
<tr><td>Max</td><td>397.900</td><td>0.400</td><td></td></tr>
</table>

</td><td>During seasonal flooding events many channel fish, including <i>H. vittatus</i>, undergo breeding migrations onto floodplains and marginal lagoons, returning back to the main channels when water levels fall (Skelton 2001). As for other floodplain migrants (Chimatiro 2004), higher and longer floods can result in stronger year-class strength, whereas juvenile growth and recruitment tends to suffer when floodplain habitat is limited in extent and duration (Chimatiro 2004).</td></tr>
<tr><td>


☑ Wet: ave Fish: area 0.5-1.5m [F season]

<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.120</td><td></td></tr>
<tr><td>Min Base</td><td>24.751</td><td>-0.110</td><td></td></tr>
<tr><td></td><td>32.754</td><td>-0.090</td><td></td></tr>
<tr><td>Median</td><td>40.757</td><td>0.000</td><td></td></tr>
<tr><td></td><td>41.646</td><td>0.020</td><td></td></tr>
<tr><td>Max Base</td><td>42.536</td><td>0.040</td><td></td></tr>
<tr><td>Max</td><td>48.917</td><td>0.090</td><td></td></tr>
</table>

</td><td>Shallow water habitats (<2m) on floodplains and lake margins are the main breeding areas for most floodplain migrant species, including <i>H. vittatus</i> (Skelton 2001). The females spawn a great number of eggs in shallow water, among the stems of grasses and other submerged and partly submerged vegetation and here the young live until the falling of the flood water forces them out of this refuge (Jackson 1961). These areas are probably not hunting grounds, as it is suggested that the pursuit method of attack used by <i>H. vittatus</i> is poorly-suited for capturing prey in lentic habitats containing much aquatic vegetation (Thorstad <i>et al.</i> 2002).</td></tr>
<tr><td>


☑ Change in flood extent [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.900</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.300</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.300</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.500</td><td></td></tr>
</table>

</td><td>The extent of area available for breeding and developing fry is an important factor in determining annual population dynamics. For most floodplain migrants, and likely including <i>H. vittatus</i>, higher and longer floods can result in stronger year-class strength, whereas juvenile growth and recruitment tends to suffer in short flood seasons when floodplain habitat is limited in extent and duration (Chimatiro 2004).</td></tr>
</table>

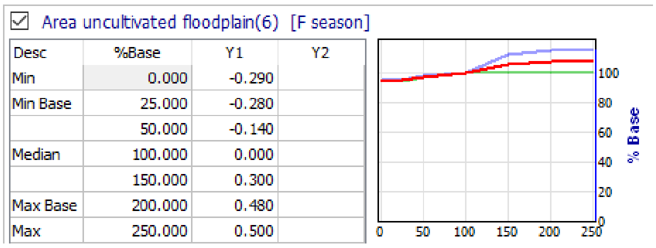
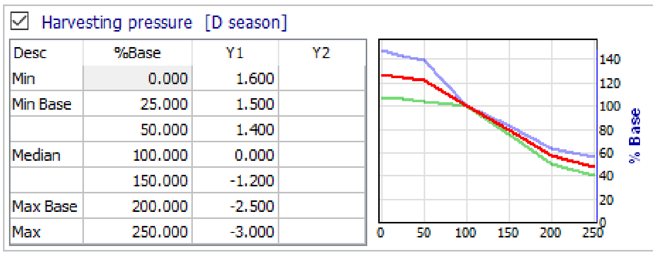
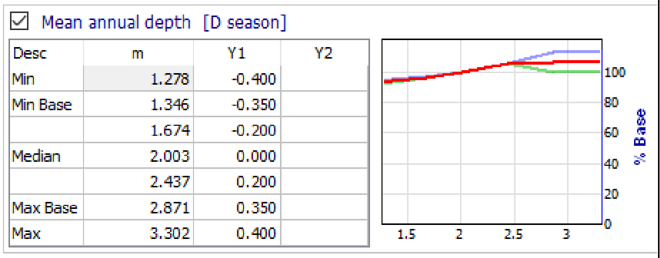
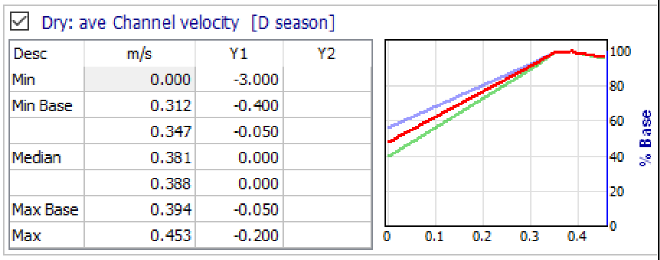
<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☑ Area uncultivated floodplain(6) [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.290</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.280</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.140</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.480</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.500</td><td></td></tr>
</table>
</td>
<td>Submerged vegetated habitats on floodplains serves as a predation refuge for eggs and fry. *H. vittatus* spawns on a sandy substrate in the vicinity of aquatic vegetation (Steyn *et al*. 1996). The females spawn a great number of eggs in shallow water, among the stems of grasses and other submerged and partly submerged vegetation and here the young live until the falling of the flood water forces them out of this refuge (Jackson 1961). These areas are probably not hunting grounds, as it is suggested that the pursuit method of attack used by *H. vittatus* is poorly-suited for capturing prey in lentic habitats containing much aquatic vegetation (Thorstad *et al*. 2002).</td></tr>
<tr><td>
☑ Harvesting pressure [D season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.600</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>1.400</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.200</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-2.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-3.000</td><td></td></tr>
</table>
</td>
<td>Small scale fisheries occur throughout the Elephants Marsh using four main gear types: gillnets, longlines, cast nets, and fish traps. Many river channel species are important in subsistence fisheries year round, and larger species, including *H. vittatus*, are also caught in the recreational fishery that occurs mainly throughout northern, western and southern parts of the Elephant Marsh (T. Davies, MRAG, pers. obs.).</td></tr>
</table>

Table 5.26 Demersal fish: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☑ Mean annual depth [D season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>1.278</td><td>-0.400</td><td></td></tr>
<tr><td>Min Base</td><td>1.346</td><td>-0.350</td><td></td></tr>
<tr><td></td><td>1.674</td><td>-0.200</td><td></td></tr>
<tr><td>Median</td><td>2.003</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.437</td><td>0.200</td><td></td></tr>
<tr><td>Max Base</td><td>2.871</td><td>0.350</td><td></td></tr>
<tr><td>Max</td><td>3.302</td><td>0.400</td><td></td></tr>
</table>
</td>
<td>Demersal species require sufficient river channel habitat for most of the adult (non-breeding) life stages (Skelton 2001). Most demersal species are fairly resilient to changes in flow and are largely unaffected by anything but extreme physical hydrograph changes, e.g. adult fish are susceptible to anoxic waters below the thermocline and eggs/larvae impacted by poor aeration caused by low flow (Welcomme *et al.* 2006). Very low flow is also likely to negatively affect most demersal species due to associated habitat loss, e.g. resulting in a narrow, shallow channel with periodic pools.</td></tr>
<tr><td>
☑ Dry: ave Channel velocity [D season]
<table>
<tr><th>Desc</th><th>m/s</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-3.000</td><td></td></tr>
<tr><td>Min Base</td><td>0.312</td><td>-0.400</td><td></td></tr>
<tr><td></td><td>0.347</td><td>-0.050</td><td></td></tr>
<tr><td>Median</td><td>0.381</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.388</td><td>0.000</td><td></td></tr>
<tr><td>Max Base</td><td>0.394</td><td>-0.050</td><td></td></tr>
<tr><td>Max</td><td>0.453</td><td>-0.200</td><td></td></tr>
</table>
</td>
<td>In very low flow adult fish are susceptible to anoxic waters below the thermocline and eggs/larvae impacted by poor aeration caused by low channel velocity (Welcomme *et al.* 2006). Increases in sediment load associated with change in flow velocity, erosion of gravel or complete submergence of riffles may also affect this group (Welcomme *et al.* 2006).</td></tr>
</table>

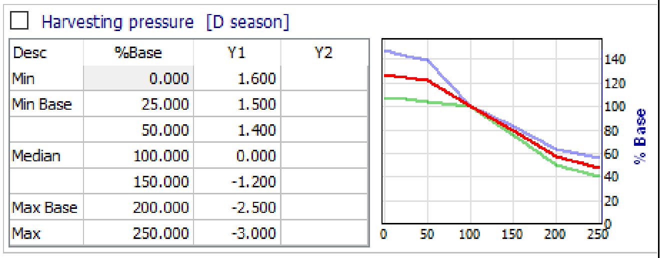
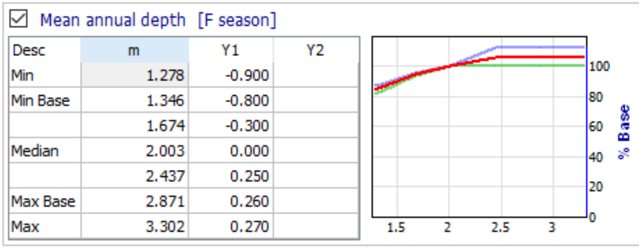
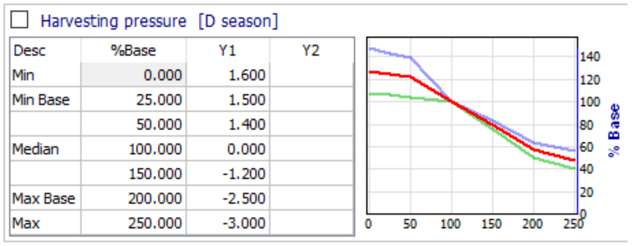
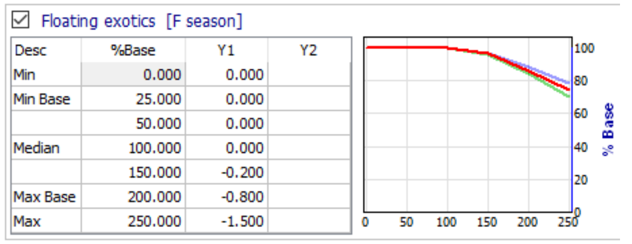
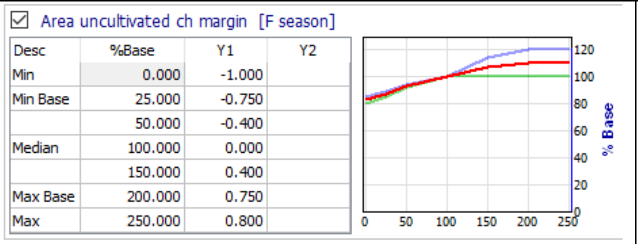
<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☐ Harvesting pressure [D season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.600</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>1.400</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.200</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-2.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-3.000</td><td></td></tr>
</table>
</td>
<td>Small scale fisheries occur throughout the Elephants Marsh using four main gear types: gillnets, longlines, cast nets, and fish traps. Many deep channel species are important in subsistence fisheries year round, including <i>Distichodus</i> spp., <i>Mormyrops</i> spp., <i>Labeo</i> spp. (T. Davies, MRAG, pers. obs.).</td></tr>
</table>

Table 5.27 Channel margin fish: Linked indicators, response curves and motivations (Central)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☑ Mean annual depth [F season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>1.278</td><td>-0.900</td><td></td></tr>
<tr><td>Min Base</td><td>1.346</td><td>-0.800</td><td></td></tr>
<tr><td></td><td>1.674</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>2.003</td><td>0.000</td><td></td></tr>
<tr><td></td><td>2.437</td><td>0.250</td><td></td></tr>
<tr><td>Max Base</td><td>2.871</td><td>0.260</td><td></td></tr>
<tr><td>Max</td><td>3.302</td><td>0.270</td><td></td></tr>
</table>
</td>
<td>Most river margin species have a strong association with peripheral submerged and emergent vegetation at channel edges (Skelton 2001). Populations can suffer when very low or very high channel levels restrict access to marginal vegetation, increasing predation risk by birds and fish predators such as <i>H. vittatus</i> (Thorstad <i>et al.</i> 2002).</td></tr>
<tr><td>
☐ Harvesting pressure [D season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.600</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>1.400</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-1.200</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-2.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-3.000</td><td></td></tr>
</table>
</td>
<td>Small scale fisheries occur throughout the Elephants Marsh using four main gear types: gillnets, longlines, cast nets, and fish traps. Many river margin species are important in subsistence fisheries, even small barbs and minnow caught in fine mesh nets, especially during the dry season when floodplain fish are not available (T. Davies, MRAG, pers. obs.).</td></tr>
<tr><td>
☑ Floating exotics [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.000</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.200</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-0.800</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-1.500</td><td></td></tr>
</table>
</td>
<td>Most channel margin species including <i>Micropanchax</i> spp. and <i>Barbus</i> spp. prefer vegetated habitats on river margins (Skelton 2001) which are used as predation refugia, spawning areas, nurseries, and feeding habitats (Welcomme 1985). However, high densities of floating exotic plant, such as water hyacinth which can cause low oxygen environments (Navarro and Phiri 2000), may impact the quality of river bank habitat.</td></tr>
<tr><td>
☑ Area uncultivated ch margin [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.750</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.400</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.400</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.750</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.800</td><td></td></tr>
</table>
</td>
<td>Most channel margin species including <i>Micropanchax</i> spp. and <i>Barbus</i> spp. prefer vegetated habitats on river margins which are used as predation refugia, spawning areas, nurseries, and feeding habitats (Skelton 2001; Welcomme 1985).</td></tr>
</table>

5.6 Herpetofauna

5.6.1 Herpetofauna indicators

Three herpetofauna indicators were selected for the DRIFT DSS. These are defined in Table 5.28, along with representative species and an indication of the main variables likely to drive change in the indicator.

Table 5.28 Herpetofauna indicators, representative species and their main links to water levels in the Marsh

Indicator	Definition and/or representative species	Driving variables
Crocodiles	Nile crocodile, *Crocodylus niloticus*	Large Nile crocodiles (>3 m) are still common in the Shire River and Elephant Marsh, and do attack people (Kalokekamo 2000). Crocodiles influence the distribution of people in the marsh and also abundance of livestock, but in turn are hunted and are influenced by the overall health of the marsh and require a healthy fish population to persist in a particular region (Wallace and Leslie 2008).
Small reptiles	Floodplain and wetland reptile groups such as agama and skinks, snakes including pythons, cobras and smaller snakes as well as terrapins.	These floodplain species are sensitive to human disturbances and changes in the condition of aquatic and floodplain habitat (W. Branch Pers. Comm.).
Amphibians	Wetland amphibian species such as puddle and reed frogs.	These marshland species are sensitive to human disturbances and changes in the condition of aquatic and floodplain habitat (W. Branch Pers. Comm).

5.6.1.1 Composite indicators for herpetofauna

None.

5.6.2 Linked indicators, response curves and motivations

The linked indicators, the response curves and the explanations of the shape of the response curves for each of the herpetofauna indicators are tabulated as follows:

Table 5.29	Crocodiles: Linked indicators, response curves and motivations (Central)
Table 5.30	Small reptiles: Linked indicators, response curves and motivations
Table 5.31	Amphibians: Linked indicators, response curves and motivations

NB: The response curves do not address any of the scenarios directly. The curves are drawn for a range of possible changes in each linked indicator, regardless of what is expected to occur in any of the scenarios. For this reason, some of the explanations and/or X-axes refer to conditions that are unlikely to occur under any of the scenarios but are needed for completion of the Response Curves. In addition, each response curve has a shape that assumes that all other conditions (indicators) remain at baseline.

The relationships are similar across all areas, although the actual curves may differ slightly from what is shown here. For the exact relationship used for each focus area please refer to the DSS. The focus area used as an example is denoted in the caption.

Table 5.29 Crocodiles: Linked indicators, response curves and motivations (Central)

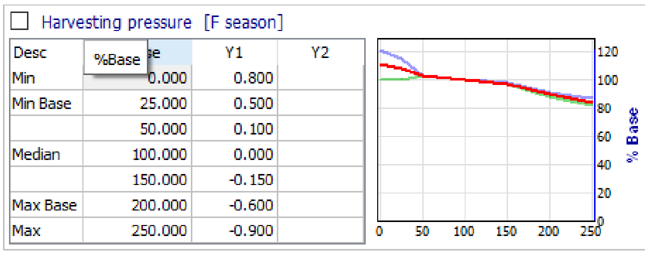
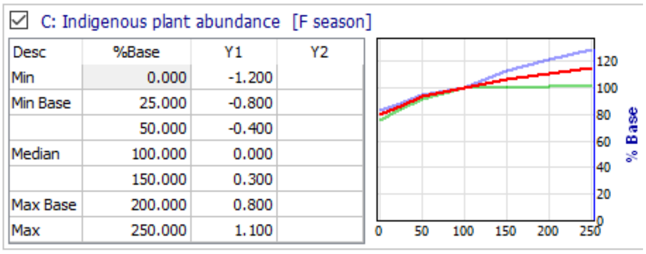
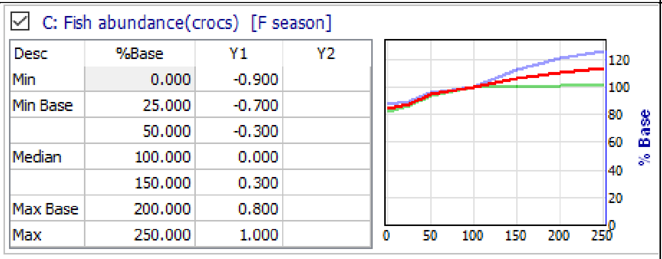
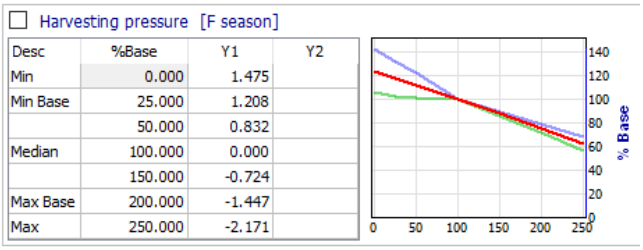
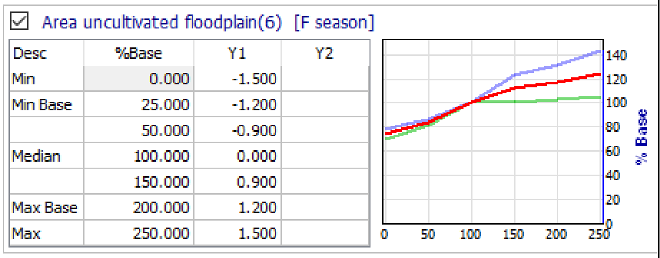
<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☐ Harvesting pressure [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.800</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.500</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.100</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.150</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-0.600</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-0.900</td><td></td></tr>
</table>
</td><td>There is a mostly direct negative relationship between harvesting pressure and crocodiles. While there is some level of hunting of crocodiles within the marsh (Kosamu *et al.* 2012), little evidence of persecution was observed during the biodiversity surveys (Turpie *et al.* 2016). The more hunting takes place the lower will be the population present. Crocodile harvesting is currently not especially high in the central areas, and as such these areas will be more sensitive to increases in harvesting, whereas areas under high harvesting pressure will be more sensitive to drops in pressure.</td></tr>
<tr><td>
☑ C: Indigenous plant abundance [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.200</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.800</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.400</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.800</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.100</td><td></td></tr>
</table>
</td><td>Crocodiles spend most of their time in the water in channels and lakes, but also require un-inhabited banks to bask and breed (Fergusson 2010). The composite of the indigenous vegetation indicators provides a mix of all natural habitats (both fully aquatic and otherwise) and represents non-cultivated natural areas with close association to the water. As such, increases in the available habitat should reflect increases in population, however at some point the population would become limited by food.</td></tr>
<tr><td>
☑ C: Fish abundance(crocs) [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.900</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.700</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.800</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.000</td><td></td></tr>
</table>
</td><td>There is a direct positive relationship to food that tailors off since at some point the abundance of food will exceed demand; crocodiles are currently more limited by food than by habitat availability.</td></tr>
</table>

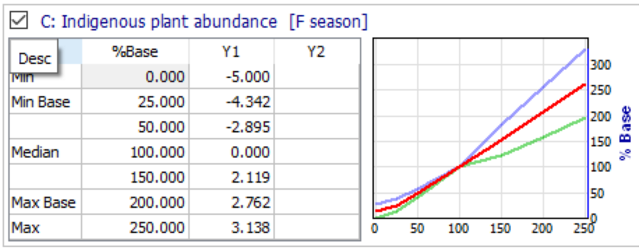
Table 5.30 Small reptiles: Linked indicators, response curves and motivations

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☐ Harvesting pressure [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.475</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.208</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.832</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.724</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.447</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-2.171</td><td></td></tr>
</table>

</td><td>Small reptiles are hunted opportunistically as an additional protein source in poor communities. The harvesting pressure will be greatest in areas with higher human population such as the north and west of the marsh. The relationship to small reptile abundance is direct and negative. The relationship will also be more sensitive to reductions in harvesting in the north and west, and more sensitive to increases in the central, south and east.</td></tr>
<tr><td>

☑ Area uncultivated floodplain(6) [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.200</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.900</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.900</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.200</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.500</td><td></td></tr>
</table>

</td><td>Small reptiles comprise mainly savannah and floodplain species, rather than marsh or wetland species (Turpie *et al.* 2016). They are sensitive to human disturbance through cultivation, fire and habitat alternation and so occur mostly on uncultivated floodplains. The relationship is positive, as numbers of small reptiles will increase within increasing habitat.</td></tr>
</table>

Table 5.31 Amphibians: Linked indicators, response curves and motivations

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ C: Indigenous plant abundance [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.342</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.895</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.119</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.762</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.138</td><td></td></tr>
</table>

</td><td>Amphibian abundance is limited by suitable habitat and so responds positively to the abundance of indigenous plants as a proxy for marsh habitat in good and suitably wet condition. Frogs require water for essential parts of their lifecycle but are able to inhabit a range of wetted habitats (de Preez and Carruthers 2009). The relationship is positive as abundance of amphibians increases with increased abundance of indigenous plants.</td></tr>
</table>

5.7 Mammals

5.7.1 Mammal indicators

Two mammal indicators were selected for the DRIFT DSS. These are defined in Table 5.32, along with representative species and an indication of the main variables likely to drive change in the indicator.

Table 5.32 Mammal indicators, representative species and their main links to water levels in the Marsh

Indicator	Definition and/or representative species	Driving variables
Hippos	Hippopotamus, *Hippopotamus amphibius*	Hippos are hunted and killed to protect cultivated fields. They prefer deeper river channels in the centre of the marsh, away from human habitation (Turpie *et al.* 2016). They prefer grazing floodplain grasses but may also eat grasses from the channel margins (Pienaar *et al.* 1996). They also play an important role in the marsh ecosystem, maintaining channels and assisting with nutrient recycling (McCarthy et al 1998).
Small mammals	Small mammal abundance. Includes rodents, such as *Mastomys* and *Otomys,* and other small carnivores, such as mongeese.	These floodplain species are sensitive to human disturbance and changes in habitat condition and diversity (Avenant 2011). These groups are also hunted opportunistically as a food source for humans.

5.7.1.1 Composite indicators for mammals

None.

5.7.2 Linked indicators, response curves and motivations

The linked indicators, the response curves and the explanations of the shape of the response curves for each of the mammal indicators are tabulated as follows:

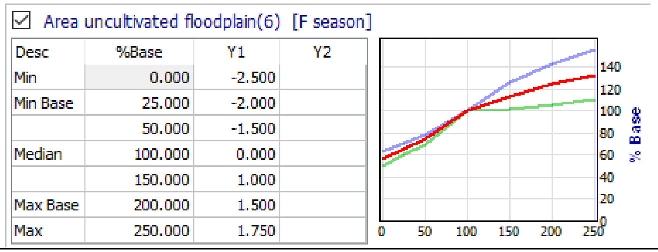
Table 5.33 Hippos: Linked indicators, response curves and motivations (Central).

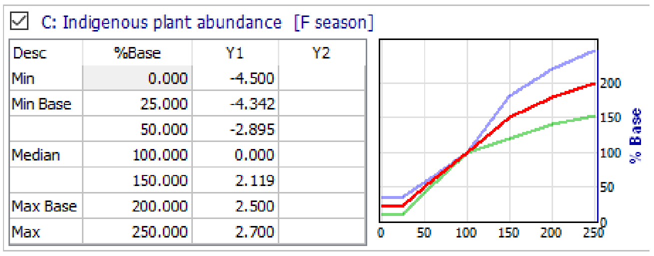
Table 5.34 Small mammals: Linked indicators, response curves and motivations.

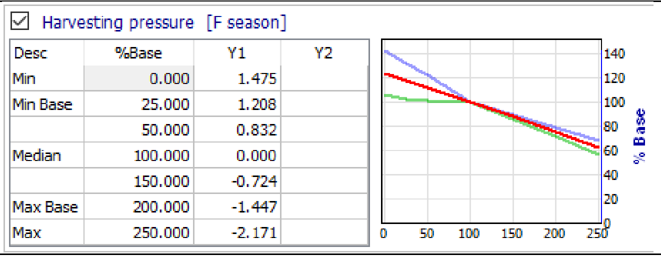
NB: The response curves do not address any of the scenarios directly. The curves are drawn for a range of possible changes in each linked indicator, regardless of what is expected to occur in any of the scenarios. For this reason, some of the explanations and/or X-axes refer to conditions that are unlikely to occur under any of the scenarios but are needed for completion of the Response Curves. In addition, each response curve has a shape that assumes that all other conditions (indicators) remain at baseline.

The relationships are similar across all areas, although the actual curves may differ slightly from what is shown here. For the exact relationship used for each focus area please refer to the DSS. The focus area used as an example is denoted in the caption.

Table 5.33 Hippos: Linked indicators, response curves and motivations (Central)

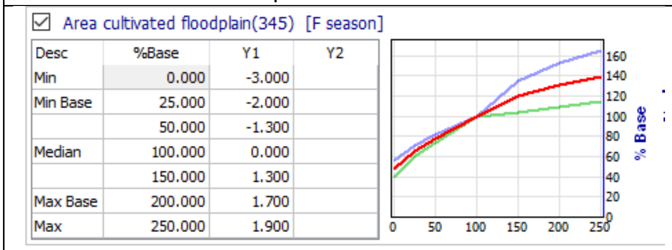
<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Area uncultivated floodplain(6) [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.500</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.000</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.750</td><td></td></tr>
</table>

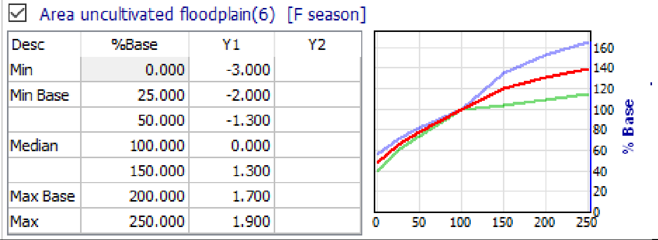
</td><td>In 2014 hippos competed with humans for grazing land as they forage on uncultivated floodplains in close proximity to cultivated fields (Chansa *et al.* 2011). If the area of uncultivated floodplain decreases hippos may be forced to forage in cultivated fields and this will lead to their being culled to protect the fields.</td></tr>
<tr><td>

☑ C: Indigenous plant abundance [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-4.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.342</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.895</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.119</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.700</td><td></td></tr>
</table>

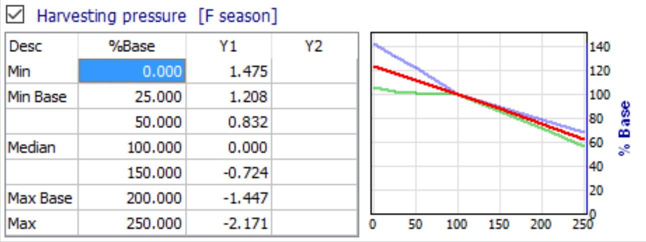
</td><td>Hippos retire in the densely vegetated parts of the marsh during the day (Field 1970) preferring to spend most of their time away from humans (J.Turpie Pers. Obs.). The abundance of indigenous plants is used as a proxy for these densely vegetated refugia bearing a strong positive relationship to increases in their abundance. The relationship levels off at higher percentages as other density dependent factors come into play (Theophile *et al.* 2012).</td></tr>
<tr><td>

☑ Harvesting pressure [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.475</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.208</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.832</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.724</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.447</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-2.171</td><td></td></tr>
</table>

</td><td>Hippos are not usually hunted but can be when food shortages are dire as they provide a large quantity of meat. Their populations have suffered extensively from poaching in the past (Kosamu *et al.* 2012) and thus react negatively to increased harvesting pressure.</td></tr>
</table>

Table 5.34 Small mammals: Linked indicators, response curves and motivations

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Area cultivated floodplain(345) [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-3.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.300</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.300</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.700</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.900</td><td></td></tr>
</table>

</td><td>Cultivated floodplain, while not 100% natural, still provides both habitat and food for small mammal species. As the area of these habitats increase so would the populations of small mammals.</td></tr>
<tr><td>

☑ Area uncultivated floodplain(6) [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-3.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-2.000</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.300</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.300</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.700</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.900</td><td></td></tr>
</table>

</td><td>Uncultivated floodplain provides both habitat and food for small mammal species. As the area of these habitats increase so would the populations of small mammals.</td></tr>
<tr><td>

☑ Harvesting pressure [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>1.475</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>1.208</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.832</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.724</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-1.447</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-2.171</td><td></td></tr>
</table>

</td><td>Small mammals are hunted opportunistically as a food source and for traditional muti (Avenant *et al.* 2014). Hippos are the only large mammal left while small mammals like rodents and mongoose still survive in the marsh outside of the protected areas.</td></tr>
</table>

5.8 Birds

5.8.1 Bird indicators

Seven bird indicators were selected for the DRIFT DSS. These are defined in Table 5.35, along with their representative species and an indication of the main variables likely to drive change in the indicator.

Table 5.35 Bird indicators, representative species and their main links to water levels in the Marsh

Indicator	Representative species	Driving variables
African skimmer	*Rynchops flavirostris*	Regional populations of African skimmers are limited by sandbank nesting sites (Harrison *et al.* 1997), it is uncertain if the birds currently breed within the marsh. As such their presence within the marsh is driven by available foraging habitat and food.
Cormorants	The White Breasted and Reed Cormorants.	Cormorant populations are limited by both food and available habitat. In addition they are susceptible to disturbance by humans.
Wading birds	Herons, egrets, ibises, storks and spoonbills.	Wading bird populations are limited by both food and available habitat. In addition they are susceptible to disturbance by humans.
Water fowl	Ducks and rallid species. Dominated by white-faced tree duck, knob-billed duck in this system.	Waterfowl populations are limited by both food and available habitat. In addition they are susceptible to disturbance and hunting by humans.
Waders	Wading birds in the Charadriiformes. Main species in the marsh include Little stint and Ruff.	Wading birds are limited by accessible foraging areas which occur in shallow water on the fringes of lakes.
Gulls and terns	Grey-headed Gulls, Whiskered and White-winged terns.	Gull and tern populations are limited by both food and available habitat.
Kingfishers	Kingfishers, dominated by the Pied kingfisher.	Kingfisher populations are limited by both food and available habitat.

5.8.1.1 Composite indicators for birds

One composite indicator (denoted in the DSS as C:*) was calculated for fish:

- C: Bird abundance, which combined estimated abundances of all bird indicators on the basis of biomass.

Weights used for these composite indicators are shown in Table 5.36, where the numbers represent the relative contribution of each vegetation type to the composite at each site.

Table 5.36 Weights for composite bird indicators

Bird indicator	C: Bird abundance
African skimmer	1
Cormorants	7
Wading birds	100
Water fowl	45
Waders	30
Gulls and terns	8
Kingfishers	1

5.8.2 Linked indicators, response curves and motivations

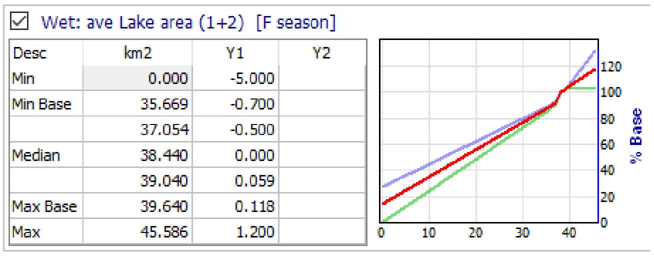
The linked indicators, the response curves and the explanations of the shape of the response curves for each of the bird indicators are tabulated as follows:

Table 5.37	African skimmer: Linked indicators, response curves and motivations (Whole Marsh).
Table 5.38	Cormorants: Linked indicators, response curves and motivations (Whole Marsh).
Table 5.39	Wading birds: Linked indicators, response curves and motivations (Whole Marsh).
Table 5.40	Water fowl: Linked indicators, response curves and motivations (Whole Marsh).
Table 5.41	Waders: Linked indicators, response curves and motivations (Whole Marsh).
Table 5.42	Gulls and terns: Linked indicators, response curves and motivations (Whole Marsh).
Table 5.43	Kingfishers: Linked indicators, response curves and motivations (Whole Marsh).

NB: The response curves do not address any of the scenarios directly. The curves are drawn for a range of possible changes in each linked indicator, regardless of what is expected to occur in any of the scenarios. For this reason, some of the explanations and/or X-axes refer to conditions that are unlikely to occur under any of the scenarios but are needed for completion of the Response Curves. In addition, each response curve has a shape that assumes that all other conditions (indicators) remain at baseline.

The relationships are similar across all areas, although the actual curves may differ slightly from what is shown here. For the exact relationship used for each focus area please refer to the DSS. The focus area used as an example is denoted in the caption.

Table 5.37 African skimmer: Linked indicators, response curves and motivations (Whole Marsh)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Wet: ave Lake area (1+2) [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>35.669</td><td>-0.700</td><td></td></tr>
<tr><td></td><td>37.054</td><td>-0.500</td><td></td></tr>
<tr><td>Median</td><td>38.440</td><td>0.000</td><td></td></tr>
<tr><td></td><td>39.040</td><td>0.059</td><td></td></tr>
<tr><td>Max Base</td><td>39.640</td><td>0.118</td><td></td></tr>
<tr><td>Max</td><td>45.586</td><td>1.200</td><td></td></tr>
</table>

</td><td>Skimmers forage by flying low over open water with their lower mandible skimming the waters' surface, closing when it intercepts a prey item. These birds require open areas of water to forage (Coppinger *et al.* 1998) and will leave the vicinity of the marsh if there are no open area of water.</td></tr>
</table>

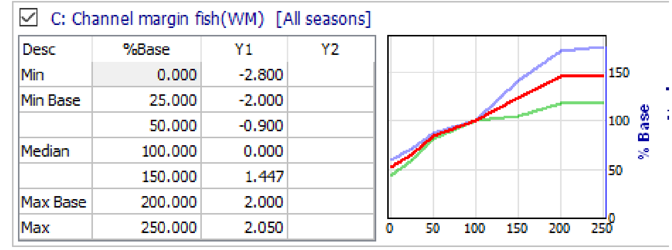
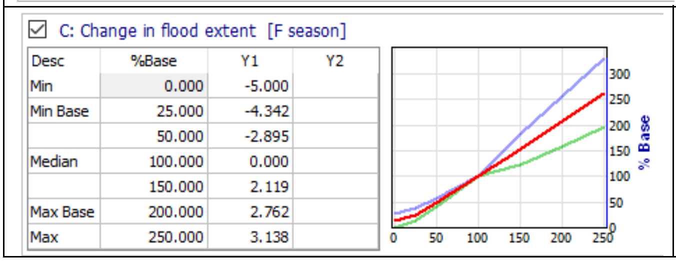
<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☑ C: Channel margin fish(WM) [All seasons]<table><tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr><tr><td>Min</td><td>0.000</td><td>-2.800</td><td></td></tr><tr><td>Min Base</td><td>25.000</td><td>-2.000</td><td></td></tr><tr><td></td><td>50.000</td><td>-0.900</td><td></td></tr><tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr><tr><td></td><td>150.000</td><td>1.447</td><td></td></tr><tr><td>Max Base</td><td>200.000</td><td>2.000</td><td></td></tr><tr><td>Max</td><td>250.000</td><td>2.050</td><td></td></tr></table></td><td>Skimmers feed on small to medium sized fish (Coppinger <i>et al.</i> 1998), best represented by the members of the channel margin fish group, such as <i>Barbus</i> and <i>Micropanch</i> spp. As prey abundance declines so too would the abundance of skimmers.</td></tr>
<tr><td>
☑ C: Change in flood extent [F season]<table><tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr><tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr><tr><td>Min Base</td><td>25.000</td><td>-4.342</td><td></td></tr><tr><td></td><td>50.000</td><td>-2.895</td><td></td></tr><tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr><tr><td></td><td>150.000</td><td>2.119</td><td></td></tr><tr><td>Max Base</td><td>200.000</td><td>2.762</td><td></td></tr><tr><td>Max</td><td>250.000</td><td>3.138</td><td></td></tr></table></td><td>Reduced flooding extent decreases the areas of shallow lake margins in which to forage, while increased flooding increases extent of shallow lake margins.</td></tr>
</table>

Table 5.38 Cormorants: Linked indicators, response curves and motivations (Whole Marsh)

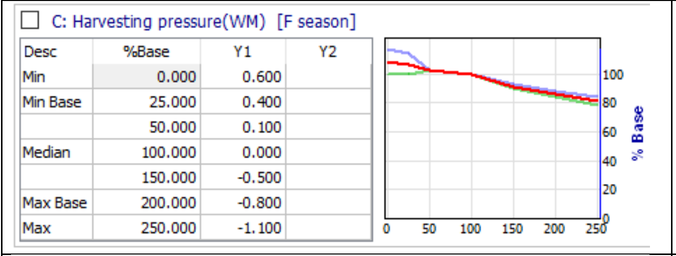
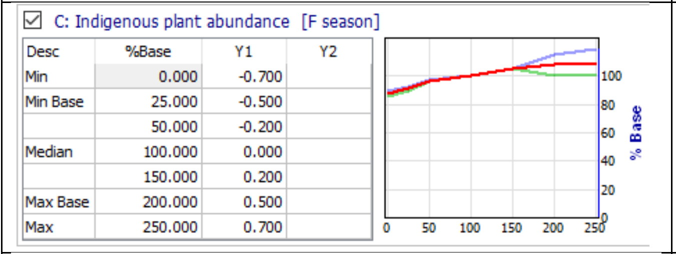
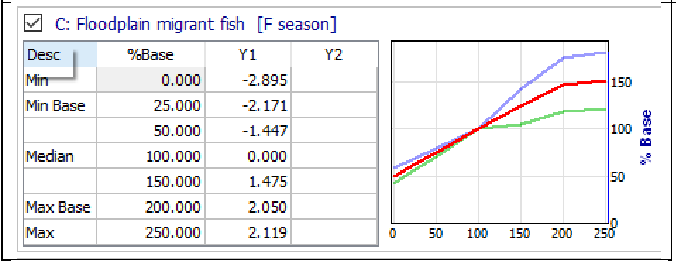
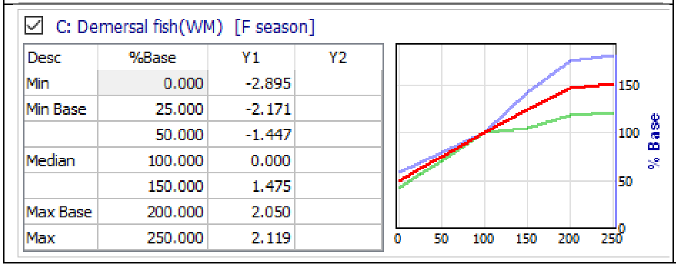
<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☐ C: Harvesting pressure(WM) [F season]<table><tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr><tr><td>Min</td><td>0.000</td><td>0.600</td><td></td></tr><tr><td>Min Base</td><td>25.000</td><td>0.400</td><td></td></tr><tr><td></td><td>50.000</td><td>0.100</td><td></td></tr><tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr><tr><td></td><td>150.000</td><td>-0.500</td><td></td></tr><tr><td>Max Base</td><td>200.000</td><td>-0.800</td><td></td></tr><tr><td>Max</td><td>250.000</td><td>-1.100</td><td></td></tr></table></td><td>Cormorants are not specifically hunted but are caught in hunting nets as by-catch, so suffer increased mortality when harvesting pressure increases; a strong negative relationship.</td></tr>
<tr><td>
☑ C: Indigenous plant abundance [F season]<table><tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr><tr><td>Min</td><td>0.000</td><td>-0.700</td><td></td></tr><tr><td>Min Base</td><td>25.000</td><td>-0.500</td><td></td></tr><tr><td></td><td>50.000</td><td>-0.200</td><td></td></tr><tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr><tr><td></td><td>150.000</td><td>0.200</td><td></td></tr><tr><td>Max Base</td><td>200.000</td><td>0.500</td><td></td></tr><tr><td>Max</td><td>250.000</td><td>0.700</td><td></td></tr></table></td><td>Cormorants have non-specific habitat requirements being found in lake areas, small backwaters and floodplain wetlands (Turpie <i>et al.</i> 2016). They respond to the abundance of indigenous plants as a proxy for habitat condition, a positive relationship.</td></tr>
<tr><td>
☑ C: Floodplain migrant fish [F season]<table><tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr><tr><td>Min</td><td>0.000</td><td>-2.895</td><td></td></tr><tr><td>Min Base</td><td>25.000</td><td>-2.171</td><td></td></tr><tr><td></td><td>50.000</td><td>-1.447</td><td></td></tr><tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr><tr><td></td><td>150.000</td><td>1.475</td><td></td></tr><tr><td>Max Base</td><td>200.000</td><td>2.050</td><td></td></tr><tr><td>Max</td><td>250.000</td><td>2.119</td><td></td></tr></table></td><td rowspan="2">Cormorants forage for fish in lakes and river channels. Their diet comprise cichilds, from the floodplain migrant group, and <i>Mormyrops</i> spp., from the demersal fish group (Birkhead 1978) so their abundance increases if the abundance of these fish increases.</td></tr>
<tr><td>
☑ C: Demersal fish(WM) [F season]<table><tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr><tr><td>Min</td><td>0.000</td><td>-2.895</td><td></td></tr><tr><td>Min Base</td><td>25.000</td><td>-2.171</td><td></td></tr><tr><td></td><td>50.000</td><td>-1.447</td><td></td></tr><tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr><tr><td></td><td>150.000</td><td>1.475</td><td></td></tr><tr><td>Max Base</td><td>200.000</td><td>2.050</td><td></td></tr><tr><td>Max</td><td>250.000</td><td>2.119</td><td></td></tr></table></td></tr>
</table>

Table 5.39 Wading birds: Linked indicators, response curves and motivations (Whole Marsh)

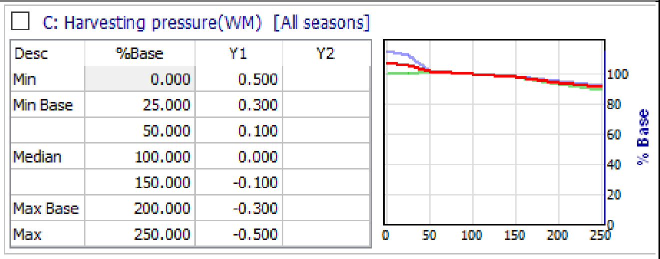
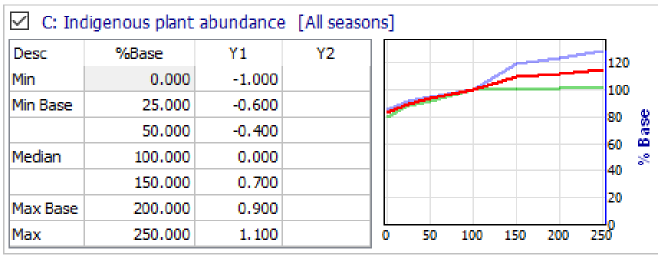
<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☐ C: Harvesting pressure(WM) [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.500</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.300</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.100</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-0.300</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-0.500</td><td></td></tr>
</table>
</td><td>Wading birds are not harvested as food directly but are caught in nets as by-catch therefore their abundance decreases as harvesting pressure increases.</td></tr>
<tr><td>
☑ C: Indigenous plant abundance [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.400</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.700</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.900</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.100</td><td></td></tr>
</table>
</td><td>Waders have non-specific habitat requirements being found near papyrus, on floating aquatic plants and on uncultivated floodplains (Turpie *et al.* 2016). They respond to the abundance of indigenous plants as a proxy for habitat condition, a positive relationship.</td></tr>
</table>

Table 5.40 Water fowl: Linked indicators, response curves and motivations (Whole Marsh)

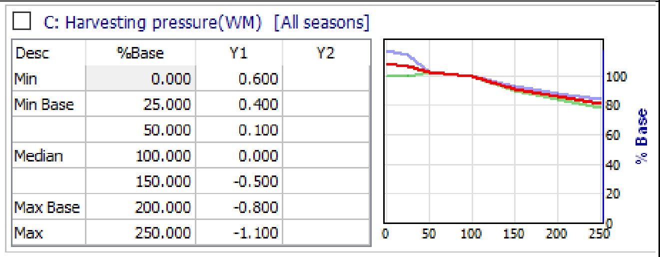
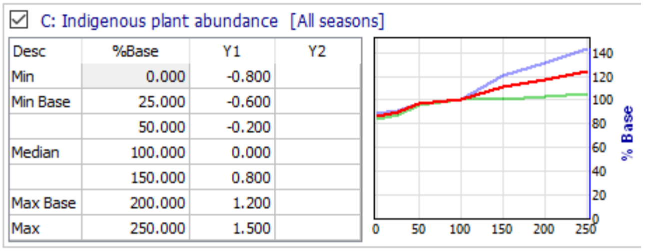
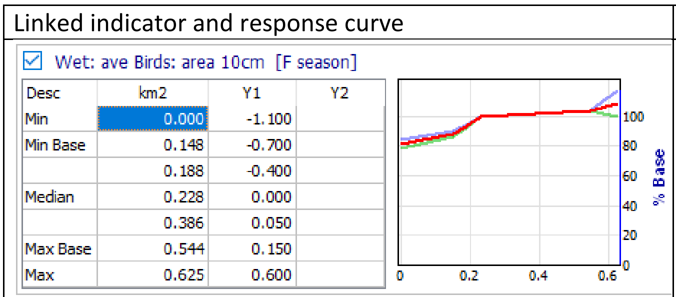
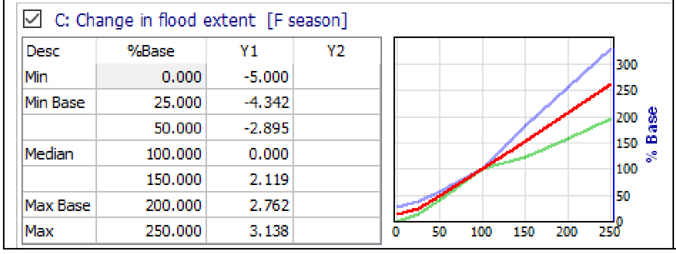
<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>
☐ C: Harvesting pressure(WM) [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>0.600</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>0.400</td><td></td></tr>
<tr><td></td><td>50.000</td><td>0.100</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>-0.500</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>-0.800</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>-1.100</td><td></td></tr>
</table>
</td><td>Waterfowl are hunted for food in the Elephant Marsh (Kosamu *et al.* 2012) so their abundance will decrease as harvesting pressure increases.</td></tr>
<tr><td>
☑ C: Indigenous plant abundance [All seasons]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.800</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.800</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.200</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>1.500</td><td></td></tr>
</table>
</td><td>Waterfowl have non-specific habitat requirements being found in lake areas, channels and undisturbed marginal areas of the marsh (Turpie *et al.* 2016). They respond to the abundance of indigenous plants as a proxy for habitat condition, a positive relationship.</td></tr>
</table>

Table 5.41 Waders: Linked indicators, response curves and motivations (Whole Marsh)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


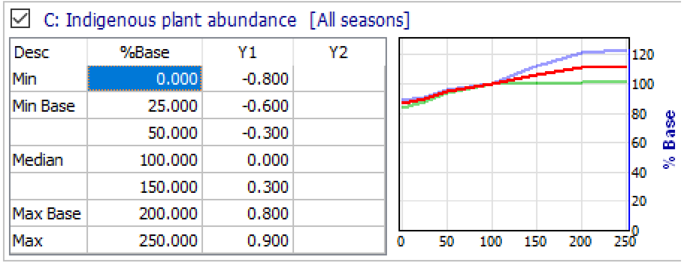
☑ Wet: ave Birds: area 10cm [F season]

<table>
<tr><th>Desc</th><th>km2</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.100</td><td></td></tr>
<tr><td>Min Base</td><td>0.148</td><td>-0.700</td><td></td></tr>
<tr><td></td><td>0.188</td><td>-0.400</td><td></td></tr>
<tr><td>Median</td><td>0.228</td><td>0.000</td><td></td></tr>
<tr><td></td><td>0.386</td><td>0.050</td><td></td></tr>
<tr><td>Max Base</td><td>0.544</td><td>0.150</td><td></td></tr>
<tr><td>Max</td><td>0.625</td><td>0.600</td><td></td></tr>
</table>
</td><td>Small waders forage specifically in shallow water at lake margins, or the muddy fringes (Harrison *et al*. 1997). If these habitats are not available the birds will leave the vicinity and numbers will drop.</td></tr>
<tr><td>


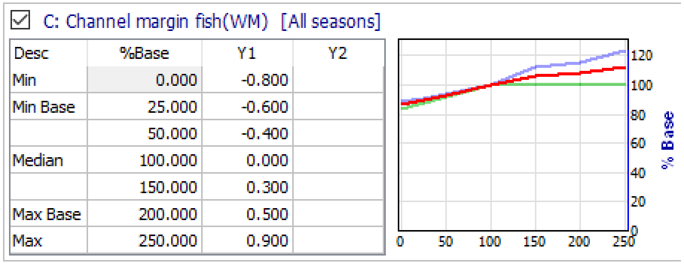
☑ C: Change in flood extent [F season]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.342</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.895</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.119</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.762</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.138</td><td></td></tr>
</table>
</td><td>Reduced flooding extent reduces the area of open water from which to forage, while increased flooding increases extent of open water.</td></tr>
</table>

Table 5.42 Gulls and terns: Linked indicators, response curves and motivations (Whole Marsh)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


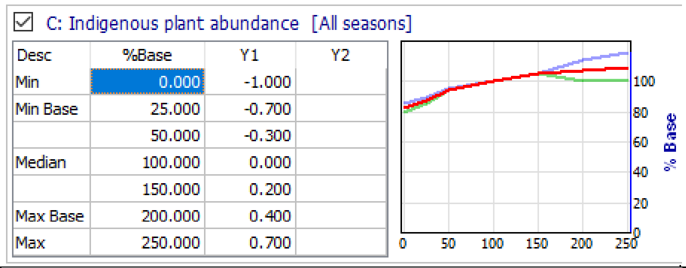
☑ C: Indigenous plant abundance [All seasons]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.800</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.800</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.900</td><td></td></tr>
</table>
</td><td>Gulls and terns forage in a broad range of habitats including open water, marshes and reed beds (Harrison et al. 1997), so respond to the abundance of indigenous plants as a proxy for habitat condition.</td></tr>
<tr><td>


☑ C: Channel margin fish(WM) [All seasons]

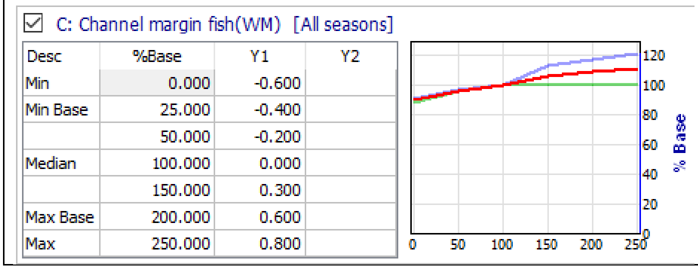
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.800</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.600</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.400</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.500</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.900</td><td></td></tr>
</table>
</td><td>The diet of gulls and terns include insects, small amphibians and crustaceans, but mainly consists of small fish (Harison et al 1997), typical of the channel margin fish group. The abundance of gulls and terns will increase in response to a greater abundance of channel margin fish.</td></tr>
</table>

Table 5.43 Kingfishers: Linked indicators, response curves and motivations (Whole Marsh)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


☑ C: Indigenous plant abundance [All seasons]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-1.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.700</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.300</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.200</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.400</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.700</td><td></td></tr>
</table>

</td><td>Kingfishers are territorial animals so are less responsive to increase and decreases in habitat and food as they are territorial (Harrison <i>et al.</i> 1997). The respond positively to increases in indigenous plant abundance as a proxy for foraging and breeding habitat.</td></tr>
<tr><td>


☑ C: Channel margin fish(WM) [All seasons]

<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-0.600</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-0.400</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-0.200</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.300</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>0.600</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>0.800</td><td></td></tr>
</table>

</td><td>The diet of kingfishers includes small fish they hunt visually in clear waters (Harrison <i>et al.</i> 1997), typical found in the channel margin fish group. Their abundance increases as more of these fish are present.</td></tr>
</table>

5.9 Management

5.9.1 Management indicators

Four management indicators were selected for the DRIFT DSS. These are defined in Table 5.44 along with an indication of the main variables likely to drive change in the indicator.

Table 5.44 Management indicators, representative species and their main links to water levels in the Marsh

Indicator	Driving variables
Access	Access is dictated by dryness/wetness of the wetland and the size of the human population inhabiting the areas around the Marsh.
Fire	Fire is dictated by access.
Cultivation	Cultivation is dictated by access.
Harvesting pressure	Harvesting pressure is dictated by access.

5.9.1.1 Composite indicators for management

None.

5.9.2 Linked indicators, response curves and motivations

The linked indicators, the response curves and the explanations of the shape of the response curves for each of the management indicators are tabulated as follows:

Table 5.45 Access: Linked indicators, response curves and motivations (Southern).

Table 5.46 Fire: Linked indicators, response curves and motivations (Southern).

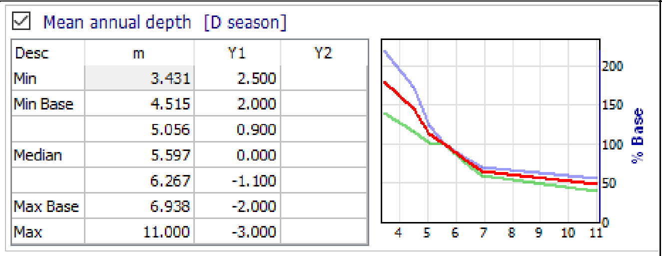
Table 5.47 Cultivation: Linked indicators, response curves and motivations (Southern).

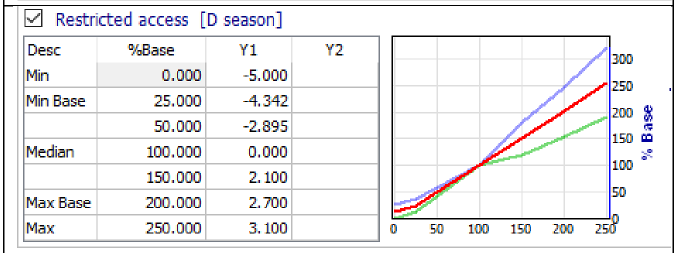
Table 5.48 Harvesting pressure: Linked indicators, response curves and motivations (Southern).

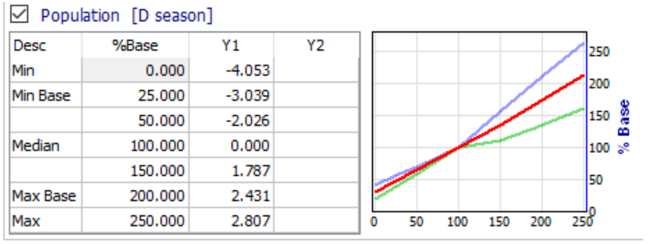
NB: The response curves do not address any of the scenarios directly. The curves are drawn for a range of possible changes in each linked indicator, regardless of what is expected to occur in any of the scenarios. For this reason, some of the explanations and/or X-axes refer to conditions that are unlikely to occur under any of the scenarios but are needed for completion of the Response Curves. In addition, each response curve has a shape that assumes that all other conditions (indicators) remain at baseline.

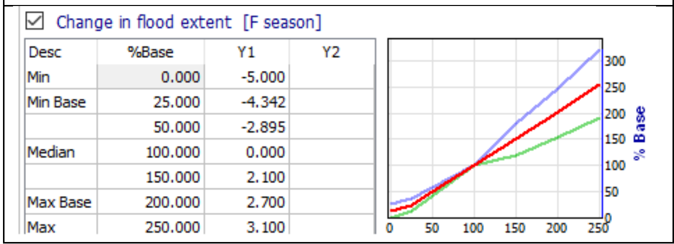
The relationships are similar across all areas, although the actual curves may differ slightly from what is shown here. For the exact relationship used for each focus area please refer to the DSS. The focus area used as an example is denoted in the caption.

Table 5.45 Access: Linked indicators, response curves and motivations (Southern)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>

☑ Mean annual depth [D season]
<table>
<tr><th>Desc</th><th>m</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>3.431</td><td>2.500</td><td></td></tr>
<tr><td>Min Base</td><td>4.515</td><td>2.000</td><td></td></tr>
<tr><td></td><td>5.056</td><td>0.900</td><td></td></tr>
<tr><td>Median</td><td>5.597</td><td>0.000</td><td></td></tr>
<tr><td></td><td>6.267</td><td>-1.100</td><td></td></tr>
<tr><td>Max Base</td><td>6.938</td><td>-2.000</td><td></td></tr>
<tr><td>Max</td><td>11.000</td><td>-3.000</td><td></td></tr>
</table>

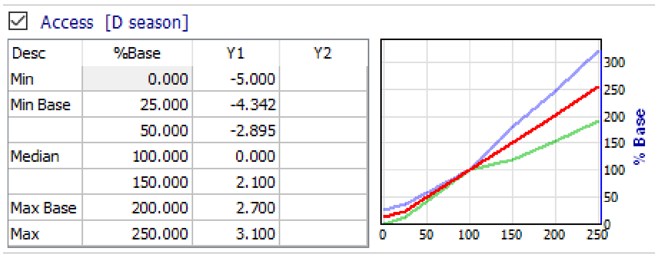
</td><td>Wetness will affect access, as drier ground is easier to traverse. Also, when the levels are very high they can be dangerous to cross.</td></tr>
<tr><td>

☑ Restricted access [D season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.342</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.895</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.700</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.100</td><td></td></tr>
</table>

</td><td>There is a straight line relationship between access and restricted access.</td></tr>
<tr><td>

☑ Population [D season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-4.053</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-3.039</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.026</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>1.787</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.431</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.807</td><td></td></tr>
</table>

</td><td>If the population is doubled, access to Southern will increase but not as much as in some other more accessible areas. If Northern is set at 100% access, we have estimated that Southern is 70% access. We have used this to translate immigration to access, i.e., for Southern doubling of people will result in a +/- 70% increase in access.</td></tr>
<tr><td>

☑ Change in flood extent [F season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.342</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.895</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.700</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.100</td><td></td></tr>
</table>

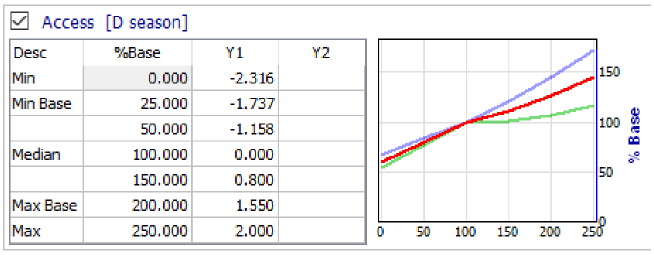
</td><td>Morphological changes to the marsh may affect the extent to which the area floods at the same discharge. There is a 1:1 relationship between these sorts of changes and wetness, therefore a 1:1 relationship to access.</td></tr>
</table>

Table 5.46 Fire: Linked indicators, response curves and motivations (Southern)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


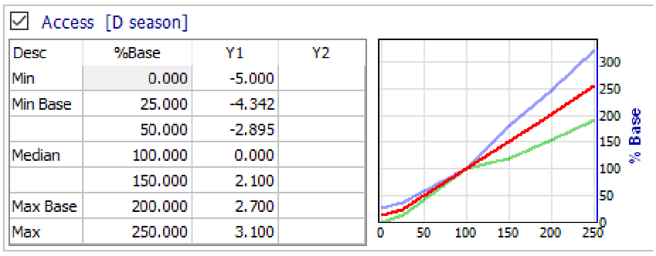
☑ Access [D season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.342</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.895</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.700</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.100</td><td></td></tr>
</table>
</td><td>Fire is directly correlated with access. The relationship has been set as a straight line with a 100% correlation. This means that if access decreases by +/-100% then fire will decrease by 100%. The reason 1:1 relationship is that fire is used to clear the marsh to increase accessibility, and so is one of the first activities engaged in when access increases.</td></tr>
</table>

Table 5.47 Cultivation: Linked indicators, response curves and motivations (Southern)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


☑ Access [D season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-2.316</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-1.737</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-1.158</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>0.800</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>1.550</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>2.000</td><td></td></tr>
</table>
</td><td>Cultivation is directly correlated with access. The relationship has been set as a straight line with a 40% correlation. This means that if access decreases by +/-50% then cultivation will decrease by 22%. The reason for the +/-40% relationship is that cultivation tends to favour the more accessible parts of the marsh - and so it will not be affected by reductions on a 1:1 basis. Similar reasoning applies to increases in access - which will leave some areas still not favourable to cultivation even if they are accessible for other activities.</td></tr>
</table>

Table 5.48 Harvesting pressure: Linked indicators, response curves and motivations (Southern)

<table>
<tr><th>Linked indicator and response curve</th><th>Explanation</th></tr>
<tr><td>


☑ Access [D season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y1</th><th>Y2</th></tr>
<tr><td>Min</td><td>0.000</td><td>-5.000</td><td></td></tr>
<tr><td>Min Base</td><td>25.000</td><td>-4.342</td><td></td></tr>
<tr><td></td><td>50.000</td><td>-2.895</td><td></td></tr>
<tr><td>Median</td><td>100.000</td><td>0.000</td><td></td></tr>
<tr><td></td><td>150.000</td><td>2.100</td><td></td></tr>
<tr><td>Max Base</td><td>200.000</td><td>2.700</td><td></td></tr>
<tr><td>Max</td><td>250.000</td><td>3.100</td><td></td></tr>
</table>
</td><td>Harvesting pressure is directly correlated with access. The relationship has been set as a straight line with a 100% correlation. This means that if access decreases by +/-100% then fire will decrease by 100%. The reason 1:1 relationship is that hunting/harvesting is one of the first activities engaged in when access increases, possibly even before fire.</td></tr>
</table>

6 Ecological status

The scores and descriptions for different Ecological Status categories are provided in Table 6.1.

Table 6.1 Categories for Baseline Ecological Status (after Kleynhans 1996)

Ecological category	Description of the habitat condition
A	Unmodified. Still in a natural condition.
B	Slightly modified. A small change in natural habitats and biota has taken place but the ecosystem functions are essentially unchanged.
C	Moderately modified. Loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged.
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	Critically / Extremely modified. The system has been critically modified with an almost complete loss of natural habitat and biota. In the worst instances, basic ecosystem functions have been changed and the changes are irreversible.

6.1 Baseline Ecological Status of the Elephant Marsh (2014)

The Baseline Ecological Status (BES) of the Elephant Marsh as at 2014 is summarised in Table 6.2.

The BES for each discipline is described in the Biodiversity Report (Turpie *et al*. 2016), and summarised in Sections 6.1.1 to 6.1.6.

Table 6.2 BES of the focus areas and the whole Elephant Marsh as at 2014. WM = Whole Marsh

Discipline		N	W	E	C	S	WM
Vegetation	Site score	E	E	B	B	C	D
Aquatic invertebrates	Site score	C	C	C	B	B	C
Fish	Site score	D	D	C	B	C	C
Herpetofauna	Site score	D	D	B	B	B	C
Mammals	Site score	E	E	E	D	D	E
Birds	Site score	Not assessed at focus area level					B
Overall BES	Site score	D	D	C	C	C/D	D

6.1.1 Vegetation

The Elephant Marsh has undergone significant transformation in terms of the extent of cultivation taking place on the floodplains. Hydrologically there have also been some changes with the shifting of the Shire River channel, which have likely led to drying out (and subsequent transformation to agriculture) on the western side of the marsh. Despite these changes, the two most common marsh species, *Phragmites australis* and *Cyperus papyrus,* are extremely resilient to clearing and sprout rapidly and more densely in response to being cut. The biggest changes over the past century would have been in the loss of riparian woody vegetation along the main river banks. It is likely these large woody species would have been removed to allow for agriculture or used for building materials and charcoal production.

The BES of the marsh vegetation was estimated to be a D category, where the system is largely modified from its historical condition and/or associated with a large loss of habitat, biota and basic ecosystem functioning.

6.1.2 Aquatic invertebrates

Based on the low abundance of flow- and habitat-sensitive taxa and the high diversity and abundance of flow- and pollution-tolerant taxa, the BES of the marsh invertebrates was determined to be a C. The condition of the westward-flowing tributaries, however are considered as severely modified, with little resemblance to their original state.

6.1.3 Fish

Overall, the current fish biodiversity is probably significantly modified from pristine conditions due to fishing pressure and major changes in riverine habitat over the past 100 years or more. The loss of seasonal floodplain habitat to cultivation throughout the marsh is likely to have reduced the extent of available breeding and feeding habitat for many species, and therefore their overall abundance in the Elephant Marsh. However, this change has probably not led to the local extinction of any species, at least in recent decades, as considerable seasonal floodplain habitat still exists. Similarly, the extensive loss of tall and dense riparian woodland along the river banks has reduced available habitat for dense vegetation specialists (e.g. some small cyprinids), although these species appear to have persisted in the marsh.

Fishing pressure is reasonably high in some parts of the Elephant Marsh (conversely, some areas are probably fished at low intensity due to difficulty in access) and the abundance of some species may be locally suppressed in these areas. Fishing effort would have to be very high throughout the Elephant Marsh as a whole to have driven any species to local extinction, and therefore this is unlikely to have occurred for any resident species.

The BES of the marsh fish was estimated to be in a C category, where moderate modification of natural habitat and biota has occurred, but the basic ecosystem functions are still unchanged.

6.1.4 Herpetofauna

Prior to human impact the Elephant Marsh would have had more extensive marshy areas, particularly in the surrounding area currently under cultivation. In addition there would have been far more tree cover in the marsh itself and the entire area surrounding the marsh would have comprised tall woodland providing a greater diversity of habitats for reptilian and amphibian fauna. Despite these dramatic habitat changes it is likely that amphibian diversity and populations numbers today still reflect what originally existed in the Marsh. There are on the other hand probably fewer species of arboreal snakes, larger terrestrial reptiles, and specialised aquatic amphibians, and those that remain do so at a lower abundance than would be natural.

The BES of the marsh herpetofauna was estimated to be in a C category, moderately modified from natural due to loss and change of natural habitat and biota but with basic ecosystem functions predominantly unchanged.

6.1.5 Mammals

Most medium and large sized mammals only occur in fenced and protected areas today. There is a low diversity of small mostly generalist mammals that persist in the marsh. The numbers of hippopotamus have declined drastically; high numbers were recorded up to 1990, now there are only a few sightings.

The BES of the marsh mammals was estimated to be an E category, far from the natural / historical, condition and bearing little resemblance to the historical state.

6.1.6 Birds

Under natural conditions, there would have been a greater extent of undisturbed marsh vegetation of all types providing a rich tapestry for bird life. There were also riparian trees along the inflowing tributaries and the Shire River, and the drier areas surrounding the Elephant Marsh would have comprised woodland. In addition, there were fewer people and thus less harvesting of birds for food.

The BES for marsh birds was determined to be 61-89%, i.e. somewhere between “B - largely natural” and “C - significant modifications to biodiversity”. A small number of species have either disappeared from the system or are greatly reduced in number.

6.2 Calculations of predicted Ecological Integrity (Condition) of the Elephant Marsh

The process for calculating Ecological Integrity in DRIFT is described in Appendix A.2.2. This section records the weights applied in those calculations.

6.2.1 Discipline and focus area integrities

The weights applied to individual indicator scores when calculating discipline and focus area integrities are given in Table 6.3.

Table 6.3 Weights applied to individual indicator scores when calculating Discipline and Focus Area integrities

Discipline	Indicator	Discipline	Focus Area
Geomorphology	Sediment input	0	1
	Sediment output	0	
	Sediment retention	1	
	Turbidity	1	
	Channelisation	0	
	Change in flood extent	1	
Vegetation	Rooted aquatics	1	1
	Floating exotics	1	
	Area of cultivated floodplain	0	
	Area of uncultivated floodplain	1	
	Area of reeds	1	
	Area papyrus	1	
	Area uncultivated channel margin	1	
Invertebrates	Invertebrate community health	1	1
	Invertebrate pests	1	
Fish	Floodplain migrant fish	1	1
	River channel fish	1	
	Demersal fish	1	
	Channel margin fish	1	
Herpetofauna	Crocodiles	1	**1**
	Small reptiles	1	
	Amphibians	1	
Mammals	Hippos	1	**1**
	Small mammals	1	
Birds	African skimmer	1	Not applicable
	Cormorants	1	
	Wading birds	1	
	Water fowl	1	
	Waders	1	
	Gulls and terns	1	
	Kingfishers	1	

6.2.2 Whole Marsh

To calculate the overall predicted FES of the Elephant Marsh as a whole, the integrities for the individual focus area for geomorphology, vegetation, macroinvertebrates, fish, herpetofauna and mammals were weighted in proportion to their area, *viz*.:

- Northern = 81.8 km^2
- Western = 208.2 km^2
- Eastern = 128.2 km^2
- Central = 108.9 km^2
- Southern = 56.7 km^2.

Birds were analysed at the whole marsh level only, and so it was not necessary to compute a whole marsh score.

7 Selection and evaluation of scenarios

The Elephant Marsh assessment comprises consideration of a series of scenarios against a **2014 baseline**, which represents the Marsh under conditions that have prevailed for about the last 10 years or so, but excludes some of the most recent changes brought about by the January 2015 flood. In particular, baseline excludes the influence of the Ruo River, which changed its course during those floods and now discharges directly into Tomoninjobi Lake rather than having a confluence with the Shire River downstream of Chimromo Bridge (which is what is modelled in this assessment).

7.1 Scenario selection process

The Request for Proposals (RFP) called for the assessment of three future management scenarios. These three future management scenarios – business as usual, best practice, and a worst case scenario – could be run with and/or without climate change; and/or with and/or without upstream water-resource developments.

The ToR for the Environmental Flows model and decision support (DRIFT) - Task 5: DRIFT Scenario assessment (Inception Report) required that the DRIFT DSS be run to provide the consequences for the Elephant Marsh ecosystem, for:

- A range of past conditions aimed at identifying ecological tipping points.
- A range of future conditions aimed at testing the resilience of the system.
- Agreed scenarios.

It was not possible to address both of these requirements through the evaluation of only three scenarios, particular since the scenarios needed to comprise a mixture of changes in:

- water volumes and patterns in the Shire River as a result of climate change;
- water volumes and patterns in the Shire River as a result of water resource developments;
- sediment supply (via the Shire and the lateral tributaries feeding the Marsh) as a result of catchment activities;
- human pressures on the Marsh ecosystem (cultivation, fire and harvesting) as a result of population pressure and access.

Thus, after considerable consultation within the study team, it was decided to increase the number of scenarios evaluated to 20. The feeling is that these scenarios go a considerable way towards addressing the requirements to identify ecological tipping points; test the resilience of the system; and evaluate the effects of climate change and proposed water-resource developments in the upstream Shire River.

The 21 scenarios evaluated in this report are given in Section 7.2.

The increase in number notwithstanding; the scenarios evaluated in this report are a small sub-set of the possible permutations. However, with the DRIFT DSS now set up for the Elephant Marshes, there is both scope for and merit in analysis of further water-resource and management options (particularly restricted access and reduction of landscape erosion through the implementation of coherent catchment management policies) in order to arrive at a solution for the Elephant Marshes that takes account of:

- the high social dependence on the floodplain;
- the impacts of this dependence on the sustainability of the resource;
- the impact of operating rules for upstream water-resource development on the Marsh;
- climate change, and;
- the need to optimise social AND ecological benefits.

7.2 Scenarios evaluated in this report

The 21 scenarios evaluated in this report are listed in Table 7.1. To aid presentation and understanding of the results, the scenarios are divided into three main groups, *viz*.: 'flow only' scenarios (six scenarios); 'sediment only' scenario (one scenario) and 'flow and access' scenarios (14 scenarios; Table 7.1).

Table 7.1 Scenarios evaluated in this report

#	Scenario code	Description	Restricted access applied
Flow only			
1	Base2014	Base2014 hydrology Baseline sediment supply set at 100% Baseline population[7] supply set at 100% Baseline access supply set at 100%	None
2	Dry Calibration	Dry range hydrological regime, comprised of 1991-2002 in the baseline record repeated for the 33-year record Baseline sediment supply Baseline population Baseline access	None
3	Mid Calibration	Middle range hydrological regime, comprised of 2003-2009 in the baseline record repeated for the 33-year record Baseline sediment supply Baseline population Baseline access	None
4	Wet Calibration	Wet range hydrological regime, comprised of 1976-1990 in the baseline record repeated for the 33-year record Baseline sediment supply Baseline population Baseline access	None

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[7] Human population resident alongside and dependent on the Marsh ecosystem services

#	Scenario code	Description	Restricted access applied
5	DevCC	Maximum proposed water-resource development in the Shire Basin Modelled climate change Baseline sediment supply Baseline population Baseline access	None
6	DryDevCC	DevCC changes on the dry range hydrological regime, comprised of 1991-2002, and repeated for the 33-year record Maximum proposed water-resource development in the Shire Basin Modelled climate change Baseline sediment supply Baseline population Baseline access	None
Sediment only scenario			
7	B2014_1P_0RA_20S	Base2014 hydrology Baseline sediment supply set at 20% of baseline Baseline population supply set at 100% Baseline access supply set at 100%	None
Access and flow			
8	B2014_1P_N100RA_100S	Base2014 hydrology Baseline sediment supply Baseline population 100% restricted access to each area separately	North
9	B2014_1P_E100RA_100S		East
10	B2014_1P_C100RA_100S		Central
11	B2014_1P_W100RA_100S		West
12	B2014_1P_S100RA_100S		South
13	DevCC_1P_N100RA_100S	DevCC hydrology Baseline sediment supply Baseline population 100% restricted access to each area separately	North
14	DevCC_1P_E100RA_100S		East
15	DevCC_1P_C100RA_100S		Central
16	DevCC_1P_W100RA_100S		West
17	DevCC_1P_S100RA_100S		South
18	B2014_1P_ESCRA_100S	100% restricted access to Central 50% restricted access to East and South	East, South and Central
19	DevCC_1P_ESCRA_100S	100% restricted access to Central 50% restricted access to East and South	East, South and Central
20	B2014_2P_0RA_100S	Base2014 hydrology Baseline sediment supply Baseline population Baseline access Double baseline population	None
21	DevCC_2P_0RA_100S	DevCC hydrology Baseline sediment supply Baseline population Baseline access Double baseline population	None

7.2.1 Depth time-series for the scenarios

The depth time-series for the Northern Area for scenarios where the inflow from the Shire River varies, i.e., Base2014, DryCalib, MidCalib, WetCalib, DevCC and DryDevCC, are depicted in Figure 7.1 to Figure 7.6, respectively.

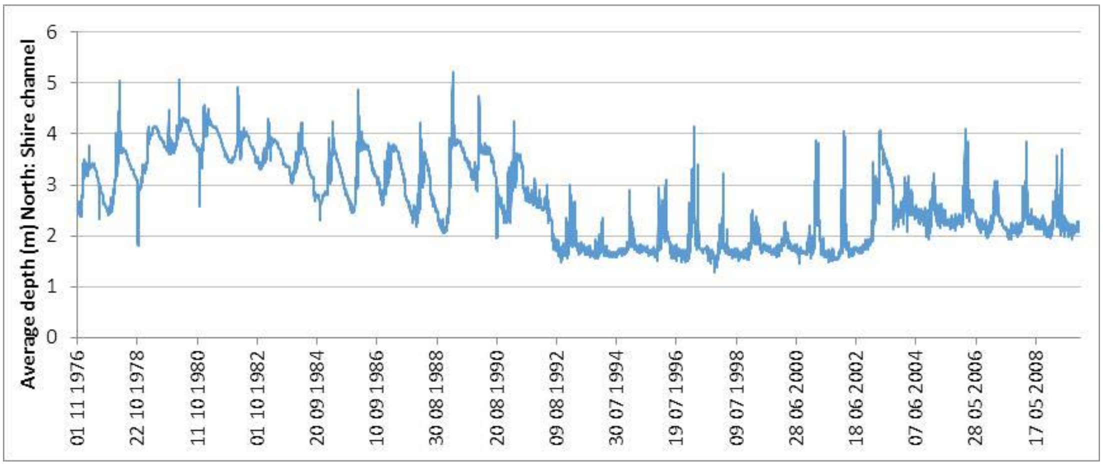

Figure 7.1 Base2014 scenario: Average depth in the channel (Northern focus area), 1976 - 2009

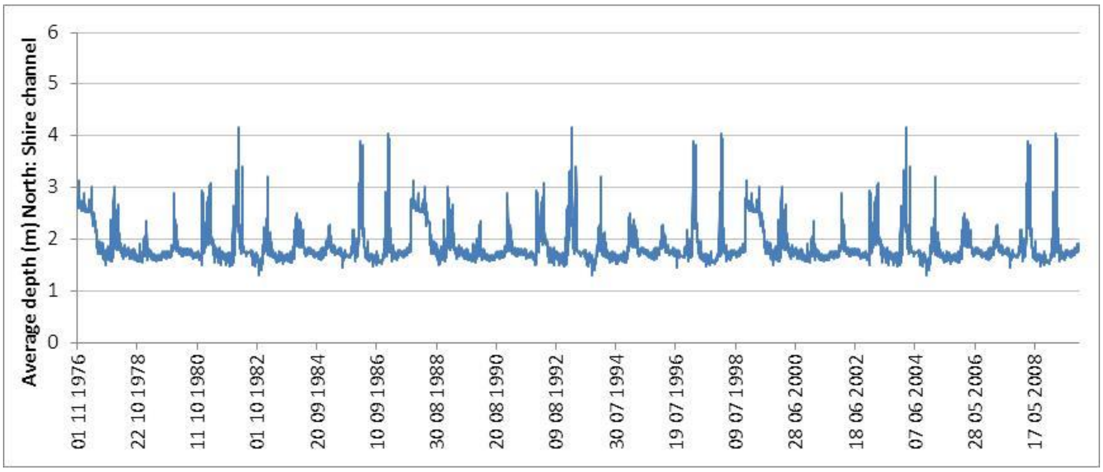

Figure 7.2 DryCalib scenario: Average depth in the channel (Northern focus area), 1976 - 2009

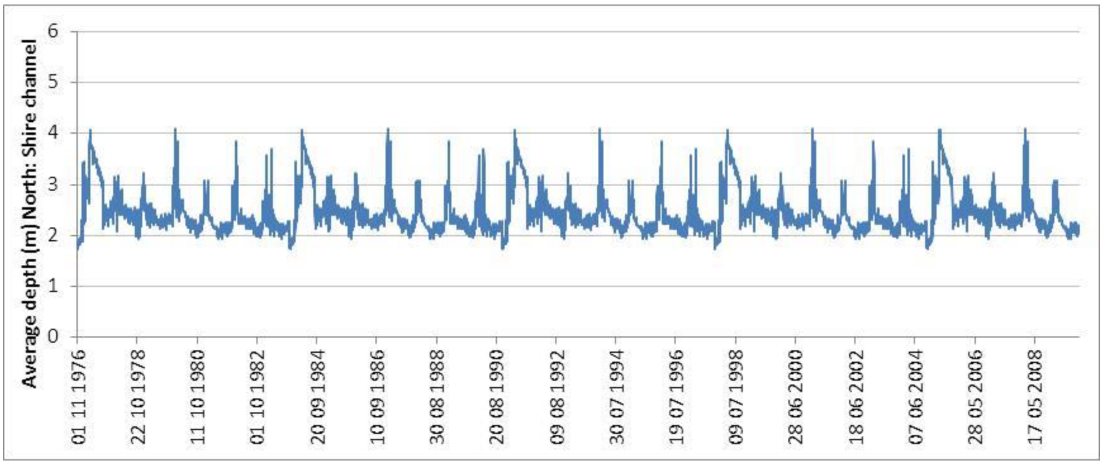

Figure 7.3 MidCalib scenario: Average depth in the channel (Northern focus area), 1976 - 2009

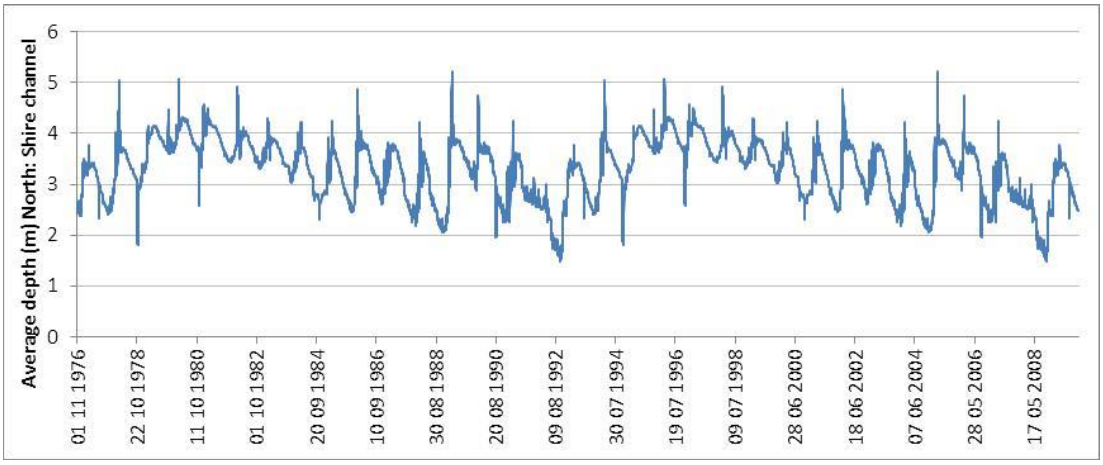

Figure 7.4 WetCalib scenario: Average depth in the channel (Northern focus area), 1976 - 2009

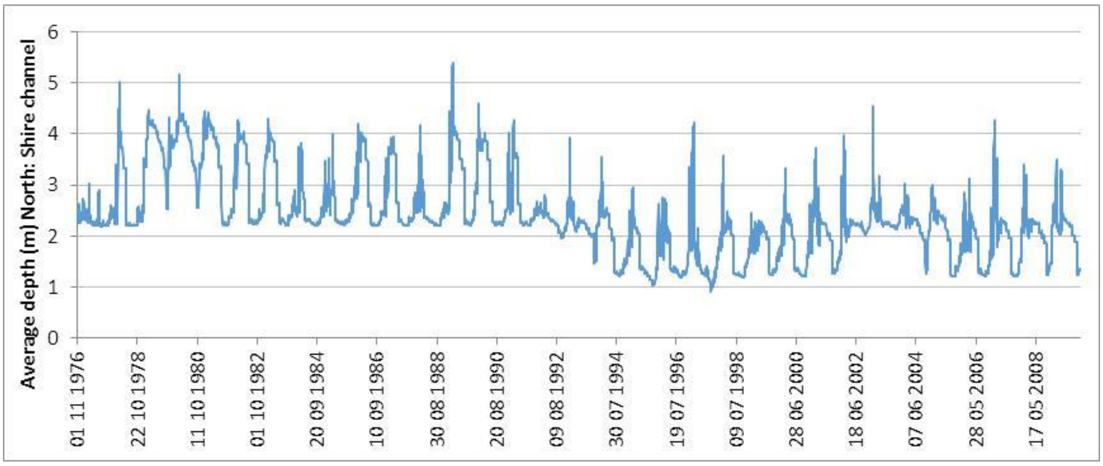

Figure 7.5 DevCC scenario: Average depth in the channel (Northern focus area), 1976 - 2009

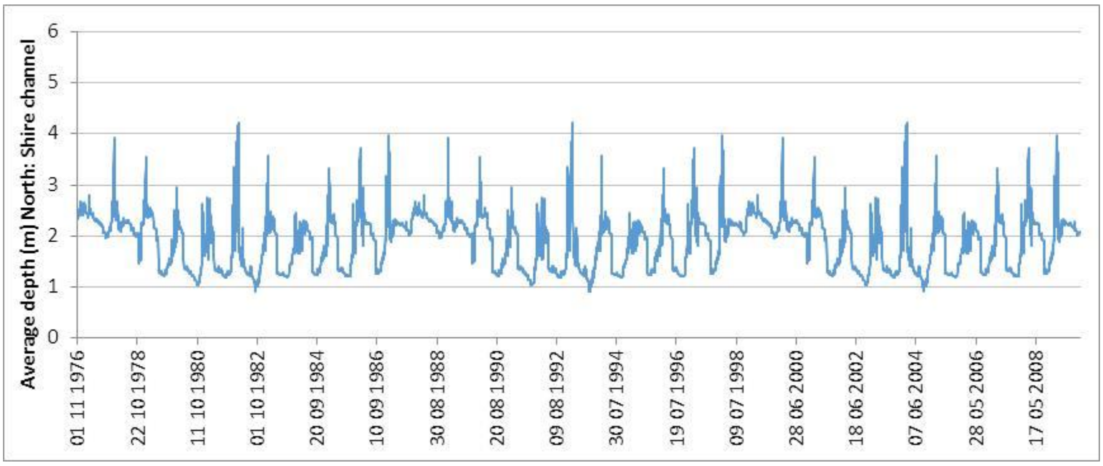

Figure 7.6 DryDevCC scenario: Average depth in the channel (Northern focus area), 1976 - 2009

7.3 Criteria used to define "ecological tipping point"

The ToRs for this exercise require, *inter alia*, the identification of an "ecological tipping point" for the Marsh (see Section 1.1.1). While the concept of an ecological tipping point is useful, the practicalities of identifying 'the tipping point' for an ecosystem such as the Elephant Marshes is considerably more complicated. This is mostly because the historical evidence suggests that the extent and characteristics of the Marsh are defined as much by their elasticity as anything else, and because the changes are on a continuum selecting a single point is difficult.

To overcome some of these difficulties, the vegetation template that defines the Marsh habitat under its baseline condition was used to derive criteria to define a "sustainable" Elephant Marsh. These criteria are based on the proportion of different vegetation types that would be required for the Elephant Marsh to be improved from the BES D category to a C category[8], and are drawn largely from the ecological status assessments done for vegetation and the apportioning of vegetation types in the different focus areas as outlined in Table 5.8.

For the purposes of this assessment, a "sustainable" Elephant Marsh is defined as an area where:

- Overall ecosystem integrity is judged to be in a C category, or better.
- >8% is comprised of Papyrus and/or Rooted Aquatics (see Table 5.9 for definition).
- >30% is comprised of reeds and grasses.
- <42% is cultivated.

Failure to achieve the criteria for "sustainable" Elephant Marsh was then used to identify "ecological tipping points" in the scenario results.

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[8] Moderately modified. A loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged.

8 Scenario outcomes

Presentation of scenario outcomes for the Elephant Marsh is somewhat complicated by the fact that some indicators, such as the hydraulic and vegetation indicators, show different vulnerabilities to changes in the pattern and volume of water and sediment entering the Marsh for the different focus areas. For instance:

- the Northern and Western Areas are more vulnerable to decreases in water flows than are the other areas, particularly given the human pressures in these areas and that any marsh that dries out sufficiently is converted to crops;
- the Central and Eastern Areas are less vulnerable to decreases in water flows than the Western and Northern Areas (mainly because they are considerably wetter and thus require greater level of change before they are vulnerable to conversion to crops) but fairly vulnerable to removal of channelization.
- the Southern Area is particularly vulnerable to change as a result of an increase in the lateral supply of sediments, e.g., from the Ruo River.

For many of the other indicators, however, it does not make sense to present the results for individual focus areas as these are essentially artificial boundaries drawn to aid interpretation and analysis, and are not representative of natural divisions within the Marsh. It is thus conceivable, or even likely, that individual animals range over more than one focus area; and many may range over the whole marsh, e.g., birds.

For these reasons, the scenario outcomes are presented in several different ways:

1. outcomes for hydraulic and vegetation indicators in individual focus areas as a result of changes in Shire River hydrology only (Section 8.1), *viz*.:
    a. Dry calibration
    b. Mid Calibration
    c. Wet calibration
    d. DevCC.
2. outcomes for hydraulic and vegetation indicators in individual focus areas as a result of changes in incoming sediment only (Section 8.2), *viz*.:
    a. B2014_1P_0RA_20S.
3. outcomes for ecosystem indicators, and biodiversity in general, for the Marsh as a whole, which include consideration of changes in Shire River hydrology and incoming sediment flows, but which explore the potential ecological benefits of restricting human access to core focus areas (Section 8.3). To this end variations on restricted access are considered:
    a. with baseline (B2014) flows:
        i. B2014_1P_N100RA_100S
        ii. B2014_1P_E100RA_100S
        iii. B2014_1P_C100RA_100S
        iv. B2014_1P_W100RA_100S
        v. B2014_1P_S100RA_100S
        vi. B2014_1P_ESCRA_100S

        vii. B2014_2P_0RA_100S
    b. with development and climate (DevCC) change flows:
        i. DevCC_1P_N100RA_100S
        ii. DevCC_1P_E100RA_100S
        iii. DevCC_1P_C100RA_100S
        iv. DevCC_1P_W100RA_100S
        v. DevCC_1P_S100RA_100S
        vi. DevCC_1P_ESCRA_100S
        vii. DevCC_2P_0RA_100S.

The whole Marsh results were generated using “composite indicators” which merged the results from the focus areas as follows:

Hydraulics:	Areas for relevant indicators in each focus area added or averaged as relevant to obtain Whole Marsh areas. Other indicators, such as onset and duration, are reported for individual focus areas.
Vegetation:	Percentage change was used to calculate area of each vegetation type in each focus area and then added to obtain Whole Marsh area.
Aquatic invertebrates, Fish, Herpetofauna and Mammals:	As per weights provided in Appendix Table 4.
Birds:	Assessed for Whole Marsh only.

8.1 The implications of the flow only scenarios, i.e., changes in Shire River hydrology, on Marsh vegetation

The implications for hydraulics and vegetation of changes in incoming water flows are evaluated through consideration of the following scenarios relative to Baseline (B2014):

a. Dry calibration (DryCalib)
b. Mid Calibration (MidCalib)
c. Wet calibration (WetCalib)
d. Development and climate change (DevCC)
e. Dry - Development and climate change (DryDevCC).

The basic hydraulics associated with each of the scenarios in each of the focus areas are presented in Table 8.1. These illustrate that the changes in incoming water flows associated with the scenarios affect not only the volume of water, and thus the area of Marsh that is inundated, but also the onset and duration of the seasons. In general, the hydraulic differences between the wet and dry calibration scenarios can be summarised as:

- Total wet season marsh areas in the driest (DryCalib) and wettest (WetCalib) scenarios are 191 and 403 km^2, respectively.
    - The biggest absolute change in area is for the Western Area, which has a 75 km^2 increase from DryCalib to WetCalib, followed by Eastern with 47 km^2.
    - The biggest proportional change in area is for the Northern Area, where DryCalib area is only 14% of WetCalib area, followed by Western Area where DryCalib is 27% of WetCalib.

  - DryCalib is ≥ 60%.of WetCalib for Eastern, Central and Southern Areas.

Table 8.1 Median values for onset, duration and timing of the seasons in the Marsh and Seasonal Total Marsh area associated with each of the scenarios in each of the areas

Focus Areas	Base2014	DryCalib	MidCalib	WetCalib	DevCC	DryDevCC
Northern						
Mean annual depth (m)	2.49	1.82	2.39	3.31	2.31	1.78
Dry onset (weeks)	27.00	13.00	13.00	31.00	13.00	8.00
Dry duration (days)	166.00	265.00	244.00	141.00	250.00	296.00
Wet onset (weeks)	5.00	4.00	4.00	6.00	5.00	5.00
Wet duration (days)	151.00	16.00	7.00	183.00	15.00	4.00
Dry: Total marsh area (km^2)	12.33	3.52	9.39	25.28	9.03	3.93
Wet: Total marsh area (km^2)	30.73	5.68	14.67	40.20	19.36	9.03
Western						
Mean annual depth (m)	3.90	2.89	3.78	4.53	3.67	2.85
Dry onset (weeks)	31.00	9.00	8.00	31.00	13.00	7.00
Dry duration (days)	193.00	311.00	303.00	106.00	246.00	317.00
Wet onset (weeks)	4.00	3.00	4.00	4.00	5.00	6.00
Wet duration (days)	145.00	28.00	41.00	212.00	41.00	7.00
Dry: Total marsh area (km^2)	58.90	15.91	55.00	90.25	52.38	20.16
Wet: Total marsh area (km^2)	94.08	27.74	67.43	103.09	76.80	53.14
Eastern						
Mean annual depth (m)	1.80	1.28	1.73	2.21	1.67	1.28
Dry onset (weeks)	31.00	10.00	6.00	31.00	13.00	7.00
Dry duration (days)	167.00	304.00	330.00	101.00	270.00	325.00
Wet onset (weeks)	2.00	3.00	2.00	5.00	5.00	6.00
Wet duration (days)	151.00	29.00	43.00	196.00	63.00	9.00
Dry: Total marsh area (km^2)	91.96	58.66	90.21	110.93	86.14	53.23
Wet: Total marsh area (km^2)	114.59	71.37	97.82	119.21	103.12	87.89
Central						
Mean annual depth (m)	2.00	1.47	1.93	2.50	1.86	1.47
Dry onset (weeks)	31.00	10.00	10.00	31.00	14.00	8.00
Dry duration (days)	161.00	302.00	313.00	109.00	279.00	323.00
Wet onset (weeks)	3.00	2.00	2.00	5.00	6.00	6.00
Wet duration (days)	151.00	16.00	30.00	196.00	41.00	10.00
Dry: Total marsh area (km^2)	70.23	44.98	69.13	84.43	66.92	40.11
Wet: Total marsh area (km^2)	87.62	55.70	75.25	90.65	80.22	69.58
Southern						
Mean annual depth (m)	5.60	4.73	5.48	6.39	5.36	5.44
Dry onset (weeks)	27.00	9.00	7.00	31.00	13.00	11.00
Dry duration (days)	177.00	299.00	310.00	122.00	274.00	272.00
Wet onset (weeks)	4.00	4.00	2.00	5.00	5.00	6.00
Wet duration (days)	151.00	7.0	14.0	217.0	20.0	44.00
Dry: Total marsh area (km^2)	37.58	23.92	34.96	44.75	32.55	34.00
Wet: Total marsh area (km^2)	48.35	30.72	40.11	49.89	44.56	45.75

- The mean duration of the dry season is on average 180 days longer in the driest (DryCalib) scenario relative to the wettest (WetCalib) scenario:

  - The Western and Eastern Areas are most affected in this regard, with a 204-day difference in duration.
  - The Northern Area is the least affected, with a 124-day difference.
- Similar relationships between the areas are evident for wet season duration.

For the development and climate change scenarios, the DevCC scenario, which has the same wet, medium and dry periods as the baseline record (see Section 7.1), the overall changes in the hydraulics are well-within the ranges circumscribed by the calibration scenarios. Even if only the DRY portion of the development and climate change scenario is considered, the expected changes fall inside the bounds of what has happened in the past.

The proportional changes in flooding are entirely consistent with the fact that the Northern and Western Areas are higher, therefore flood shallower, and are thus more vulnerable to changes in flooding depth than the other areas that are lower with deeper flooding.

Changes in the timing of seasons have been shown to have significant implications for a range of life-history features of biota in any kind of aquatic ecosystem, such as breeding and survival of young-of-year. The implications of these changes are explored in more detail in Section 9.

Figure 8.1 gives a broad overview of the impacts on vegetation integrity in the different focus areas as a result of changes in the volume and pattern of water flows into the Marsh.

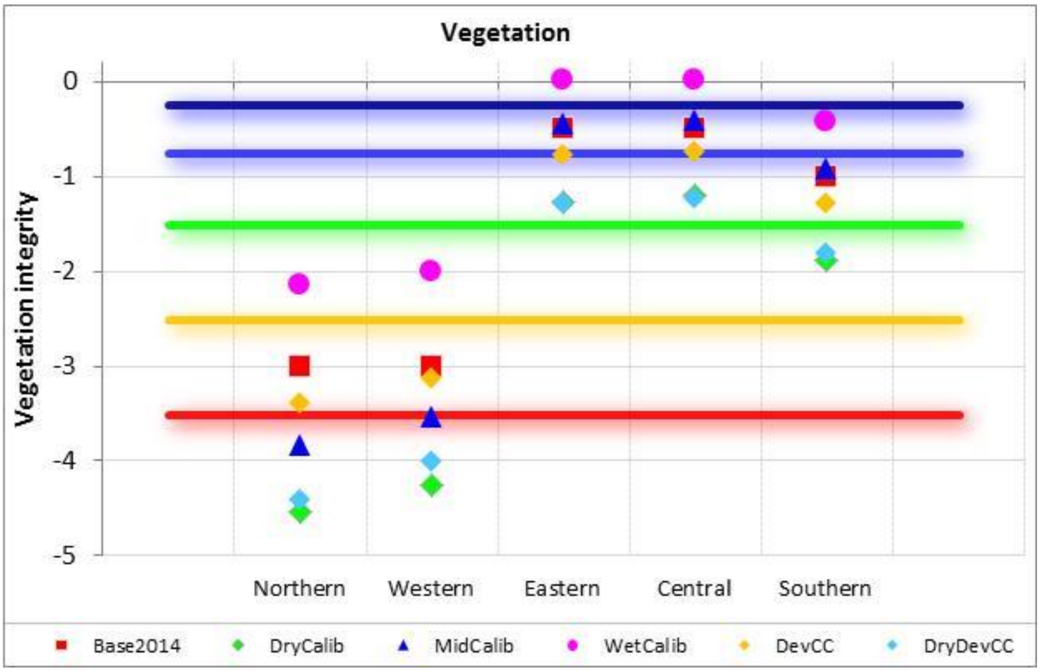

Figure 8.1 Impacts on overall marsh vegetation condition (integrity) as a result of changes in the volume and pattern of water flows into the Marsh as per the four scenarios[9]

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[9] The scenario scores have been restricted to ≤0. It is however possible that the DSS will return a score >0 because the analyses are based on the assumption that a wetter and bigger Marsh is better.

The following is evident from Figure 8.1:

- The scenarios DryCalib, MidCalib and WetCalib represent the range of historical changes in the Shire River flow regime, and thus the range in vegetation condition that has occurred naturally in the past. For instance, we know that in c. 1915 to 1934 when flows from Lake Malawi ceased (Pike and Rimmington 1965), the Marsh area was smaller than it is now, and cultivation extended considerably further into the Marsh than it does now (Figure 8.2 – see speckled gray particularly in Northern and Western areas)
- The Northern and Western Areas (range = 2 integrity points) are expected to react more strongly to flow changes in the Shire River than the Eastern, Central and Southern Areas (range < 1.5 integrity points). This too is borne out by historical evidence that shows the drier parts of the Marsh (Northern and Western) are more susceptible to conversion to cultivation.
- Reduction in flows as represented by DryCalib and DevCC will result in a decline in the ecological integrity of the vegetation in the Marsh.
- DevCC is expected to result in a decline in vegetation condition relative to baseline but its impact on overall vegetation condition is expected to be less than that which has occurred naturally in the past (e.g., DryCalib). *This of course calls into question whether the climate change predictions in DevCC are sufficiently severe, as they represent hydrological changes in the Shire River that are considerably less severe than those known to have happened in the past, and is why the DryDevCC scenario focuses on the dry period in the record*.
- Under DryDevCC vegetation condition declines to a similar extent as under DryCalib.
- WetCalib would increase vegetation condition by one category in Northern, and half a category in the other areas.

Greater detail on the changes in different types of vegetation is provided in Table 8.2, which gives the mean change in area relative to baseline for the last ten years of the hydrological record and Table 8.3, which gives area (km^2) of vegetation types associated with each of the scenarios also for the last ten years of the hydrological record. These are important because they show the actual changes that underlie the changes in overall condition of the marsh vegetation reported above.

Focusing on the drier of the scenarios, the most notable of these are:

- Substantial loss in rooted aquatics and papyrus, particularly in the Eastern, Central and Southern Areas under DevCC and DryDevCC.
- Concomitant increase in cultivated floodplain, particularly in the Eastern, Central and Southern Areas (increase of 25-30% under Dev CC), which under baseline, are somewhat protected by higher water levels than the heavily-cultivated Northern and Western Areas.

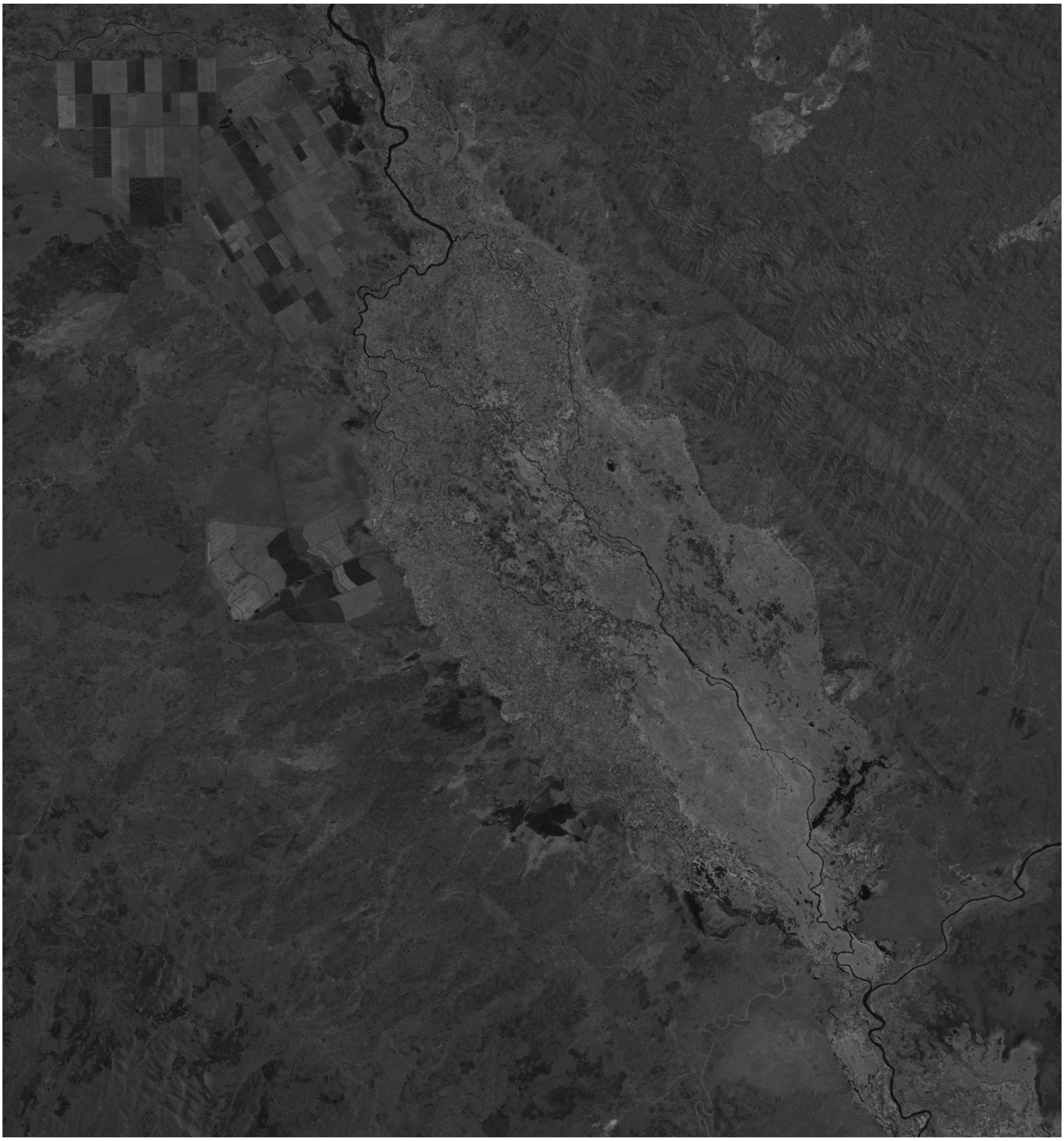

Figure 8.2 A 1999 LandSAT image of the Elephant Marshes, showing greater areas of cultivation than under Baseline 2014.

Table 8.2 Percentage change in area of vegetation types relative to baseline at 100% associated with each of the scenarios in the focus areas – using the last 10 years of the record

Vegetation indicator	DryCalib	MidCalib	WetCalib	DevCC	Dry Dev CC
Northern					
Rooted aquatics	-12.3	9.5	33.0	-15.5	-19.5
Floating exotics	3.4	0.9	-8.1	0.9	2.0
Area cultivated floodplain	-17.4	1.0	13.0	5.6	2.7
Area uncultivated floodplain	-9.6	4.5	47.5	3.4	-1.6
Area reeds	-16.1	5.4	70.0	4.7	-3.2
Area papyrus	-14.0	5.2	87.7	3.0	-2.9
Area uncultivated ch margin	-20.7	9.8	52.5	-8.8	-19.2
Western					
Rooted aquatics	-	-	-	-	-
Floating exotics	-	-	-	-	-
Area cultivated floodplain	0.8	0.9	-11.0	6.2	11.8
Area uncultivated floodplain	-16.0	5.5	25.7	-1.2	-4.8
Area reeds	-8.7	4.8	52.2	10.1	1.3
Area papyrus	-9.7	4.5	57.8	5.8	-1.5
Area uncultivated channel margin	-23.8	11.6	35.1	-10.3	-22.6
Eastern					
Rooted aquatics	-14.1	7.3	20.3	-26.3	-33.6
Floating exotics	3.0	-0.9	-2.2	0.0	1.7
Area cultivated floodplain	14.4	-5.1	-29.8	-1.6	3.3
Area uncultivated floodplain	-11.2	4.4	-12.9	-3.4	-4.1
Area reeds	-23.8	11.3	6.3	-1.3	-13.6
Area papyrus	-17.4	7.5	30.6	-1.6	-7.3
Area uncultivated ch margin	-28.3	12.0	42.6	-10.9	-27.1
Central					
Rooted aquatics	-20.0	12.8	27.1	-33.9	-38.5
Floating exotics	2.7	-1.0	-1.5	-0.3	1.1
Area cultivated floodplain	11.6	-4.2	-31.8	-6.2	-0.6
Area uncultivated floodplain	-5.8	2.0	-12.6	-7.5	-10.2
Area reeds	-14.0	6.8	2.6	-5.2	-7.5
Area papyrus	-22.3	10.5	19.7	2.5	-4.2
Area uncultivated ch margin	-21.9	11.5	49.1	-9.4	-21.2
Southern					
Rooted aquatics	-19.7	13.6	25.9	-37.2	-42.2
Floating exotics	2.6	-1.2	-2.4	-0.3	0.9
Area cultivated floodplain	7.3	-4.9	-33.7	-4.5	-1.7
Area uncultivated floodplain	-10.7	4.6	0.2	-8.1	-7.2
Area reeds	-24.6	11.4	13.2	-2.9	-9.2
Area papyrus	-29.8	12.7	31.9	5.1	-5.3
Area uncultivated channel margin	-16.0	8.3	27.4	-5.5	-14.3

Table 8.3 Area of vegetation types associated with each of the scenarios in the focus areas – using the last 10 years of the record[10]

Vegetation indicator	Base2014	DryCalib	MidCalib	WetCalib	DevCC	Dry Dev CC
Northern						
Rooted aquatics	0.10	0.09	0.11	0.13	0.08	0.08
Floating exotics	n/a	n/a	n/a	n/a	n/a	n/a
Area cultivated floodplain	51.11	42.23	51.64	57.74	53.97	52.47
Area uncultivated floodplain	14.01	12.67	14.64	20.67	14.48	13.79
Area reeds	9.01	7.57	9.50	15.33	9.44	8.72
Area papyrus	0.37	0.32	0.39	0.70	0.38	0.36
Area uncultivated channel margin	n/a	n/a	n/a	n/a	n/a	n/a
Western						
Rooted aquatics	n/a	n/a	n/a	n/a	n/a	n/a
Floating exotics	n/a	n/a	n/a	n/a	n/a	n/a
Area cultivated floodplain	139.85	140.99	141.12	124.44	148.49	156.30
Area uncultivated floodplain	25.54	21.45	26.93	32.11	25.23	24.32
Area reeds	13.79	12.59	14.45	20.98	15.17	13.96
Area papyrus	1.15	1.03	1.20	1.81	1.21	1.13
Area uncultivated channel margin	n/a	n/a	n/a	n/a	n/a	n/a
Eastern						
Rooted aquatics	3.20	2.75	3.43	3.85	2.36	2.12
Floating exotics	n/a	n/a	n/a	n/a	n/a	n/a
Area cultivated floodplain	22.28	25.48	21.14	15.65	21.92	23.01
Area uncultivated floodplain	24.25	21.53	25.32	21.12	23.43	23.26
Area reeds	74.57	56.80	83.00	79.25	73.62	64.47
Area papyrus	14.93	12.33	16.05	19.49	14.69	13.84
Area uncultivated channel margin	n/a	n/a	n/a	n/a	n/a	n/a
Central						
Rooted aquatics	6.54	5.24	7.38	8.32	4.32	4.03
Floating exotics	n/a	n/a	n/a	n/a	n/a	n/a
Area cultivated floodplain	7.07	7.88	6.77	4.82	6.62	7.02
Area uncultivated floodplain	16.57	15.61	16.90	14.47	15.32	14.87
Area reeds	59.78	51.41	63.83	61.34	56.65	55.31
Area papyrus	14.85	11.53	16.41	17.77	15.22	14.22
Area uncultivated channel margin	n/a	n/a	n/a	n/a	n/a	n/a

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[10] Area is not available for uncultivated channel margin or floating exotics

Vegetation indicator	Base2014	DryCalib	MidCalib	WetCalib	DevCC	Dry Dev CC
Southern						
Rooted aquatics	10.99	8.83	12.49	13.83	6.90	6.35
Floating exotics	n/a	n/a	n/a	n/a	n/a	n/a
Area cultivated floodplain	15.35	16.48	14.60	10.19	14.66	15.09
Area uncultivated floodplain	6.71	5.99	7.02	6.72	6.17	6.23
Area reeds	9.07	6.84	10.10	10.27	8.81	8.24
Area papyrus	0.88	0.62	0.99	1.16	0.93	0.84
Area uncultivated channel margin	n/a	n/a	n/a	n/a	n/a	n/a

Table 8.4 Area (km^2) of vegetation types associated with each of the scenarios in the whole Marsh – using the last 10 years of the record

Vegetation type	Base2014	DryCalib	MidCalib	WetCalib	DevCC	DryDevCC
	Km^2					
Rooted aquatics	20.83	16.90	23.40	26.13	13.66	12.58
Area cultivated floodplain	235.65	233.06	235.27	212.83	245.66	253.89
Area uncultivated floodplain	87.07	77.25	90.80	95.09	84.62	82.46
Area reeds	166.22	135.20	180.88	187.18	163.70	150.70
Area papyrus	32.17	25.83	35.04	40.93	32.43	30.38

8.2 The implications of changes in incoming sediment flows on Marsh geomorphology

Reducing the sediment supply to the Marsh by 80% (B2014_1P_0RA_20S) has very little impact on any of the indicators or on overall condition. This is mostly because major changes to the topography of the Marsh related to a change in sediment supply are likely to take far longer than the 31 years of the record used in this evaluation. For instance, the small changes in channelization in the Northern, Western and Eastern Areas (Table 8.5) would, over much longer periods, result in a significant change to Marsh topography, and hence hydraulics and vegetation.

Table 8.5 Predicted change in geomorphology indicators relative to Base2014 under an 80% reduction in baseline sediment load (average percentages over the last 10 years)

Indicator	B2014_1P_0RA_20S
Northern	
Sediment retention	-0.5
Turbidity	-16.1
Channelisation	-3.7
Change in flood extent	-0.1
Sediment output	0.1
Sediment storage	-3.7
Western	
Sediment retention	-0.1
Turbidity	-1.3
Channelisation	-0.3
Change in flood extent	0.0
Sediment output	0.0
Sediment storage	-0.3
Eastern	
Sediment retention	0.0
Turbidity	-2.8
Channelisation	-0.7
Change in flood extent	0.0
Sediment output	0.0
Sediment storage	-0.7
Central	
Sediment retention	0.0
Turbidity	-0.2
Channelisation	0.0
Change in flood extent	0.0
Sediment output	0.0
Sediment storage	0.0
Southern	
Sediment retention	0.0
Turbidity	-0.1
Channelisation	0.0
Change in flood extent	0.0
Sediment output	0.0
Sediment storage	0.0

8.3 The implications for ecosystem integrity and biodiversity of the Marsh on access restrictions and changes in the human population alongside the Marsh

The predicted overall ecosystem integrity, or condition, for the Elephant Marsh under different access restrictions is depicted in Figure 8.3. By far the most effective measure for improving ecosystem condition, and thus ensure sustainability of the Elephant Marsh is to impose some access restrictions on one or more area of the Marsh. Of the options for access restrictions modelled, the best outcome is achieved for 100% restricted access to Central and 50% restricted access to Eastern and Southern Areas. This option returns an improvement in baseline Marsh conditions even under DevCC hydrology. At the other end of the scale, an increase in the utilisation pressures to double those under baseline will lead to a severe decline in overall Marsh condition (B2014_2P_0RA_100S and DEVCC_2P_0RA_100S).

As discussed briefly in Section A.2.1, there is automatic and fixed level of uncertainty to the DRIFT predictions[11], particularly where these predictions concern a condition that is far removed from the baseline. This reflects uncertainty around the response of the indicators to the flow regime under discussion, to the proposed protection measures and inherent difficulties in predicting the future in dynamic systems. The "Min" and "Max" levels shown on Figure 8.3 represent the 90% confidence range is calculated using Hozo *et al.*'s (2005) estimation of sample variance.

$$S^2 = \frac{1}{12}\left(\frac{(a-2m+b)^2}{4} + (b-a)^2\right).$$

The area (km^2) of vegetation types associated with each of the flow and access scenarios in the whole Marsh are shown in Table 8.6.

The scenario that returns the best ecological condition for the marsh is B2014_1P_ESCRA_100S, which comprises:

- Base2014 hydrology
- Baseline sediment supply
- Baseline population
- 100% restricted access to Central
- 50% restricted access to East and South.

The scenario that returns the least favourable ecological outcome is highlighted in red (DevCC_2P_0RA_100S), which comprises:

- DevCC hydrology
- Baseline sediment supply
- Baseline population
- Baseline access
- Double baseline population.

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[11] There is an option in DRIFT for specialists to increase this uncertainty but this was not used /needed in this assessment.

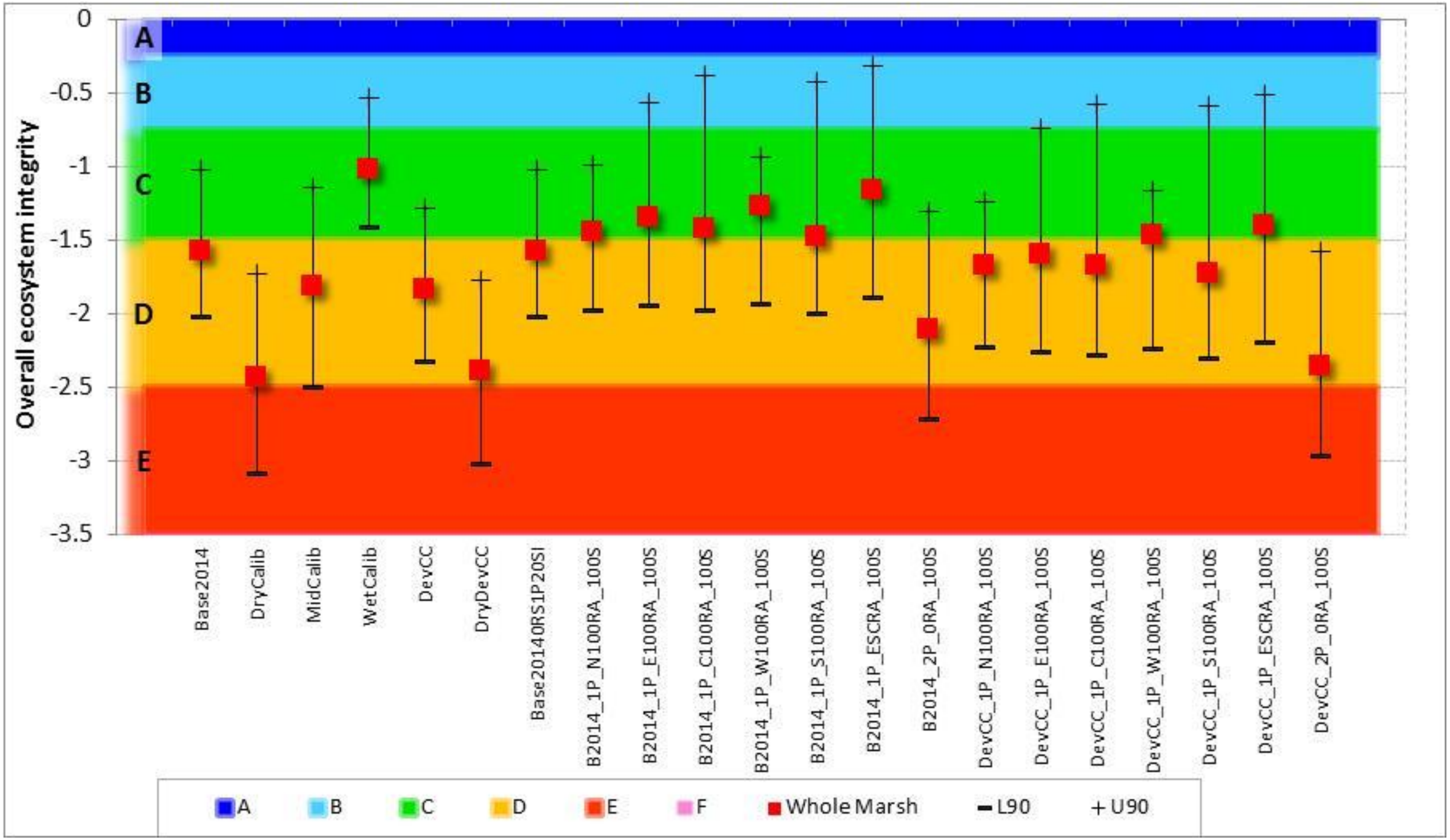

Figure 8.3 Overall ecosystem integrity for the Elephant Marsh under different access restrictions

Table 8.6 Area (km^2) of vegetation types and percentage of Marsh area, associated with each of the flow and access scenarios in the whole Marsh – using the last 10 years of the record

Vegetation type	Base2014		B2014_1P_N100RA_100S		B2014_1P_E100RA_100S		B2014_1P_C100RA_100S		B2014_1P_W100RA_100S		B2014_1P_S100RA_100S		B2014_1P_ESCRA_100S		B2014_2P_0RA_100S		DevCC_1P_N100RA_100S		DevCC_1P_E100RA_100S		DevCC_1P_C100RA_100S		DevCC_1P_W100RA_100S		DevCC_1P_S100RA_100S		DevCC_1P_ESCRA_100S		DevCC_2P_0RA_100S	
Overall Marsh Category	D		C/D		C/D		C/D		C		C/D		C		D		D		D		D		C/D		D		C/D		E/F	
Open water	20	4%	20	4%	20	4%	20	4%	20	4%	20	4%	20	4%	20	4%	20	4%	20	4%	20	4%	20	4%	20	4%	20	4%	20	4%
Rooted aquatics	21	4%	21	4%	21	4%	22	4%	21	4%	23	4%	24	4%	17	3%	14	3%	14	3%	15	3%	14	3%	16	3%	18	3%	10	2%
Area cultivated floodplain	236	44%	221	41%	233	43%	234	43%	197	36%	232	43%	230	42%	255	47%	232	43%	243	45%	245	45%	206	38%	241	44%	240	44%	265	49%
Area uncultivated floodplain	87	16%	93	17%	92	17%	91	17%	99	18%	90	17%	96	18%	77	14%	91	17%	90	17%	88	16%	96	18%	88	16%	94	17%	74	14%
Area reeds	166	31%	171	32%	186	34%	182	34%	174	32%	170	31%	199	37%	127	23%	169	31%	185	34%	181	33%	172	32%	168	31%	199	37%	125	23%
Area papyrus	32	6%	32	6%	36	7%	36	7%	33	6%	33	6%	40	7%	25	5%	33	6%	37	7%	37	7%	33	6%	33	6%	40	7%	25	5%
Total area	562				558				588				585				524				548				609				521	

Severity rating	Severity change	Equivalent Loss or gain
5	Very large	501-∞ (to pest proportions)
4	Large	251-500
3	Moderate	68-250
2	Low	26-67
1	Negligible	1-25
0	None	No change
-1	Negligible	0-20
-2	Low	20-40
-3	Moderate	40-60
-4	Large	60-80
-5	Very large	100-80

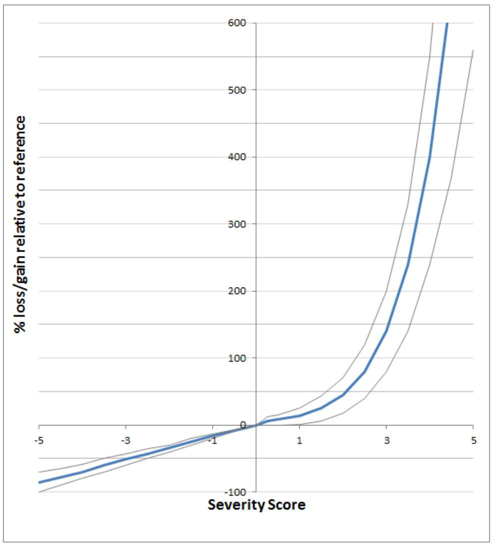

Figure 8.4 Uncertainty margins around severity scores used in DRIFT

Importantly, the following options all meet the criteria for a “sustainable” Elephant Marsh as defined in Section 7.3:

- B2014_1P_W100RA_100S
- B2014_1P_ESCRA_100S

Six other scenarios return an improvement on the baseline status and come close to meeting the criteria for a “sustainable” Marsh:

- B2014_1P_N100RA_100S
- B2014_1P_E100RA_100S
- B2014_1P_C100RA_100S
- B2014_1P_S100RA_100S
- DevCC_1P_W100RA_100S
- DevCC_1P_ ESCRA_100S

Of these eight scenarios, those that completely restrict access to the Eastern or Central areas are deemed to be more feasible than those that restrict access to the Northern, Western and/or Southern areas. This is because the latter three (particularly the North and West) are the most used by the surrounding population, and so 100% restricted access would be both difficult to implement and prejudicial to a large number of people.

The two scenarios that offer the best outcome for the Marsh, and by inference for the long term support of the people that depend on its resources, are those that completely restrict access to the core of the Marsh (Central) and limit access to the Eastern and Southern areas, viz. B2014_1P_ESCRA_100S and DevCC_1P_ESCRA_100S (Figure 8.5 and Table 8.7).

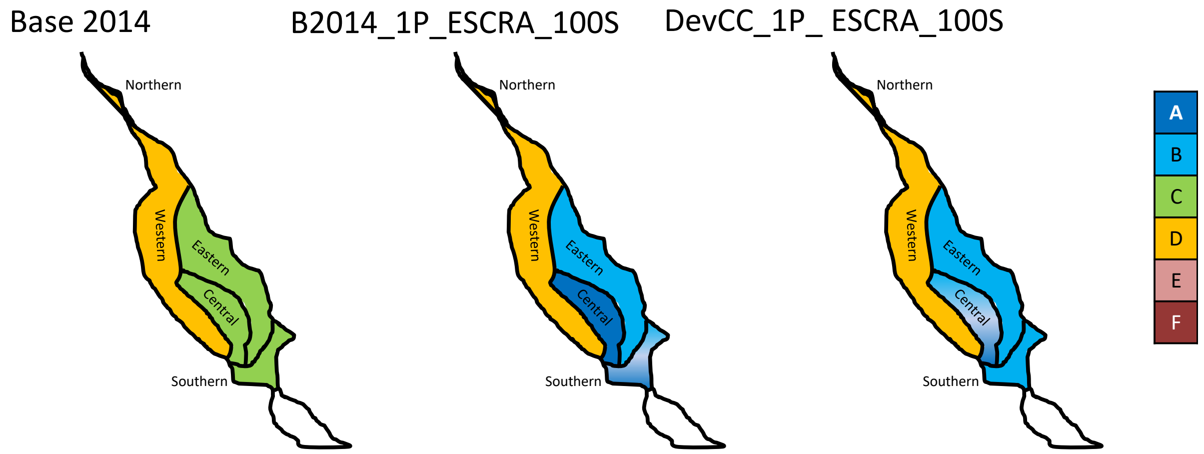

Figure 8.5 **Overall integrity for the focus areas under Base2014, B2014_1P_ESCRA_100S and DevCC_1P_ESCRA_100S.**

The predicted changes relative to baseline for all the indicators at all the focus areas and for all the scenarios are given in Appendix B.

Table 8.7 **Overall integrity for the focus areas under the scenarios**

Focus area	Base2014	Base20140RS1P20SI	B2014_1P_N100RA_100S	B2014_1P_E100RA_100S	B2014_1P_C100RA_100S	B2014_1P_W100RA_100S	B2014_1P_S100RA_100S	B2014_1P_ESCRA_100S	B2014_2P_0RA_100S	DevCC_1P_N100RA_100S	DevCC_1P_E100RA_100S	DevCC_1P_C100RA_100S	DevCC_1P_W100RA_100S	DevCC_1P_S100RA_100S	DevCC_1P_ESCRA_100S	DevCC_2P_0RA_100S
N	D	D	C	D	D	D	D	D	E	C	D/E	D/E	D/E	D/E	D/E	E
W	D	D	D	D	D	C	D	D	E	D/E	D/E	D/E	C/D	D/E	D/E	E
W	C	C	C	A/B	C	C	C	B	D	C/D	B	C/D	C/D	C/D	B	D
C	C	C	C	C	A	C	C	A	C	C	C	A/B	C	C	A/B	C
S	C	C	C	C	C	C	A	A/B	D	C	C	C	C	A/B	B	D
ALL	D	D	C/D	C/D	C/D	C	C/D	C	D	D	D	D	C/D	D	C/D	D/E

8.4 Scenario-based implications for environmental services

The Elephant Marsh environmental services are being considered under a separate sub-study (Sub-study 3), which has the following objectives:

- Describe and quantify the ecosystem services provided by the Elephant Marshes.
- Draw comparisons with other wetlands in Africa of a similar nature.
- Determine the how capacity of the system to deliver these services responds to hydromorphology.
- Determine the wetland's sensitivity and adaptive capacity to multiple pressures.
- Develop and analyse up to three different future management scenarios.

As input to Sub-study 3, the DRIFT analysis was asked to provide the response of the following to the scenarios analysed in this report:

- Total area of each of the different vegetation types (Table 8.8).
- Marsh-wide estimates for important fisheries groups (demersal, floodplain migrants and river channel fish).
- Marsh-wide estimates for invertebrate pests, small mammals, hippos, crocodiles, and reptiles.
- Marsh-wide estimates for waterfowl and also for skimmers
- Marsh-wide estimate of sediment retention.

Some of these are among those already presented and some required compilation of additional composite indicators. For ease of reference, all are provided here (Table 8.9).

Table 8.8 Scenario results for total area (km^2) of each of the different vegetation types

Vegetation type	Base2014	B2014_1P_N100RA_100S	B2014_1P_E100RA_100S	B2014_1P_C100RA_100S	B2014_1P_W100RA_100S	B2014_1P_S100RA_100S	B2014_1P_ESCRA_100S	B2014_2P_0RA_100S	DevCC_1P_N100RA_100S	DevCC_1P_E100RA_100S	DevCC_1P_C100RA_100S	DevCC_1P_W100RA_100S	DevCC_1P_S100RA_100S	DevCC_1P_ESCRA_100S	DevCC_2P_0RA_100S
Open water	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Rooted aquatics	21	21	21	22	21	23	24	17	14	14	15	14	16	18	10
Area cultivated floodplain	236	221	233	234	197	232	230	255	232	243	245	206	241	240	265
Area uncultivated floodplain	87	93	92	91	99	90	96	77	91	90	88	96	88	94	74
Area reeds	166	171	186	182	174	170	199	127	169	185	181	172	168	199	125
Area papyrus	32	32	36	36	33	33	40	25	33	37	37	33	33	40	25

Table 8.9 Scenario results as a percentage relative to baseline for sediment retention, and for biomass important fisheries groups; invertebrate pests, small mammals, hippos, crocodiles, reptiles; waterfowl and African skimmers

	Base2014	DryCalib	MidCalib	WetCalib	DevCC	DryDevCC	Base20140RS1P20SI	B2014_1P_N100RA_100S	B2014_1P_E100RA_100S	B2014_1P_C100RA_100S	B2014_1P_W100RA_100S	B2014_1P_S100RA_100S	B2014_1P_ESCRA_100S	B2014_2P_0RA_100S	DevCC_1P_N100RA_100S	DevCC_1P_E100RA_100S	DevCC_1P_C100RA_100S	DevCC_1P_W100RA_100S	DevCC_1P_S100RA_100S	DevCC_1P_ESCRA_100S	DevCC_2P_0RA_100S
C: Sediment storage (WM)	0.0	-1.9	0.7	1.1	-0.1	-1.8	0.0	0.1	0.1	0.1	0.4	0.1	0.2	-0.4	0.0	0.0	-0.1	0.3	-0.1	0.1	-0.5
C2: Rooted aquatics(WM)	0.0	-18.1	12.0	25.0	-34.3	-38.9	0.0	0.4	2.8	5.7	0.0	11.8	16.4	-18.9	-33.8	-31.1	-27.9	-34.3	-20.9	-16.0	-52.4
C2: Floating exotics	0.0	2.5	-1.0	-2.0	0.1	1.3	0.0	0.0	-0.5	-1.1	0.0	-3.5	-3.8	3.5	0.0	-0.5	-1.1	0.1	-3.5	-3.7	3.6
C2: Area cultivated floodplain(WM)	0.0	-2.2	0.4	-8.3	4.6	8.0	0.0	-6.5	-0.4	-0.4	-17.8	-1.9	-2.1	8.0	-2.0	4.1	4.1	-13.3	2.6	2.5	12.7
C2: Area uncultivated floodplain(WM)	0.0	-8.3	3.3	1.7	-4.5	-6.1	0.0	4.8	4.0	9.9	8.8	3.1	14.8	-10.9	0.3	-0.3	6.4	4.4	-1.4	11.2	-15.5
C2: Area reeds(WM)	0.0	-17.2	8.2	12.3	-1.1	-8.0	0.0	2.9	12.0	9.4	4.6	2.2	19.7	-23.2	1.8	11.9	9.2	3.6	1.2	19.8	-24.5
C2: Area papyrus(WM)	0.0	-18.4	8.8	26.7	1.1	-4.3	0.0	0.7	12.6	12.3	1.9	1.2	22.5	-21.8	1.8	14.5	14.5	3.0	2.3	25.1	-20.9
C2: Area uncultivated ch margin(WM)	0.0	-22.2	10.4	42.7	-8.9	-20.8	0.0	7.5	7.0	1.4	1.4	4.2	6.9	-8.3	-1.3	-1.4	-7.4	-7.3	-4.6	-1.5	-17.4
C: Invertebrate pests	0.0	-4.3	1.6	2.7	-1.2	-2.0	0.0	3.1	2.9	1.2	3.8	1.6	4.4	-4.7	2.0	1.9	0.1	2.7	0.5	3.3	-5.9
C: Biomass important fisheries fishes	0.0	-10.3	5.4	33.0	-6.4	-11.9	0.0	8.0	9.5	9.0	14.4	7.0	23.2	-32.6	1.9	3.5	2.9	8.6	0.9	17.2	-38.2
C2: Crocodiles(WM)	0.0	-16.6	0.4	25.2	-4.9	-15.5	0.0	7.6	8.6	7.1	18.2	4.1	15.8	-22.9	3.2	4.1	2.5	14.6	-0.7	11.2	-27.6
C2: Small reptiles(WM)	0.0	-6.0	2.5	10.8	-2.2	-3.7	0.0	5.0	7.5	6.5	21.0	4.0	13.2	-22.2	2.8	5.5	4.7	19.3	2.0	11.3	-24.7
C2: Amphibians	0.0	-10.5	5.4	20.7	-3.9	-8.7	0.0	2.9	2.7	4.2	7.5	0.7	6.6	-9.7	-0.8	-0.9	0.5	3.8	-3.0	3.1	-13.5
African skimmer	0.0	-23.4	0.8	56.4	-5.8	-20.9	0.0	5.8	7.6	7.3	6.8	7.8	21.5	-24.1	0.3	2.0	1.9	1.4	2.4	16.7	-29.8
Water fowl	0.0	-19.0	4.7	39.2	-7.1	-17.6	0.0	12.6	24.1	15.2	15.6	8.7	35.8	-51.3	7.0	17.7	9.6	10.3	-0.2	36.1	-69.6
C2: Hippos(WM)	0.0	49.7	7.3	28.4	38.2	48.9	27.0	26.0	38.4	-0.3	14.0	-4.7	12.2	13.2	22.4	3.2	14.0	17.2	20.9	13.3	17.7
C2: Small mammals(WM)	0.0	11.5	2.5	5.2	12.7	14.2	6.1	7.4	13.7	-16.8	2.4	-5.5	6.6	1.2	0.8	-1.8	2.4	4.9	2.9	0.3	2.9

9 Conclusions and potential implications for management

EFlows are arguably the most important way of ensuring the sustainability of freshwater ecosystems in the face of much needed development of those self-same resources, but there is no single magical flow amount (other than the natural flow regime) that maintains a healthy river or wetland. Rather, as soon as flow manipulations begin the ecosystem starts to change, and it then becomes a question of how much change is acceptable in return for the development benefits sought (King and Brown In press).

EFlows scenarios help to answer that question by describing different possible futures, which can be used in negotiations and discussion. The scenarios should be designed so that the three streams of information - ecological integrity, economic wealth, and social equity - are represented equally, not all subsumed into an economic bottom line.

This study was neither required to make, nor has it made, any recommendations as to the EFlows required to 'maintain' the Elephant Marsh. There are numerous reasons why this is so:

- as stated in Section 2.4, and demonstrated through the analysis of the flow scenarios, the Marsh has experienced many changes in the hydrological regime supporting it; many of these outside of what it is currently experiencing; and there is no one single "flow" that can be supplied that has in the past, or will in future, 'maintain' the Marsh, *viz*.: change is the only constant;
- the final allocation of water for ecosystem maintenance – and thus of ecosystem condition – should not be technically pre-determined but rather be a societal choice involving considered trade-offs between resource protection and development;
- the concept of sustainable ecosystem use recognizes that society as a whole should be involved in discussions on the trade-off point between development and resource protection, with government(s) making the final decision, as this facilitates buy-in regarding decisions and a will to help make them work;
- assessments, such as the one done here for the Elephant Marshes, that consider a range of possible scenarios provide the information needed for and support discussion and negotiation between all the stakeholders through examination of trade-offs;
- the scenario assessments should help stakeholders[12] and decision-makers identify what might constitute acceptable and unacceptable futures for the Elephant Marsh, and may well lead to a request for additional scenarios that further explore a sub-set of favoured options (King and Brown In press);
- the 2-d hydrodynamic model and the DRIFT DSS established as part of this project are available for use in generating and assessing such additional scenarios, should it be required.

The conclusions from the 33-year horizon analyses of the potential effects of alternative future scenarios of flow and/or management on the ecological condition of the Elephant Marsh, using a pre-2015 morphological template, are as follows:

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[12] Stakeholders of rivers may be defined as any group with an interest in the way the river is developed and managed.

- The Marsh is fairly resilient to short-term flow and sediment changes, having endured significant fluctuations in both in its history.
- Development and climate change in the short term as assessed in this report do not represent a significant threat to the long-term integrity and sustainability of the Elephant Marshes, but may represent a threat in the longer term if overlain on dry periods such as those known to have occurred in the past.
- The most immediate and significant threat to the integrity and sustainability of the Elephant Marshes is pressure from subsistence users, including clearing of marsh areas for cultivation and over-harvesting a wide range of resources.

Restricting access to some parts of the Marsh, in particular the core in the Eastern, Central and Southern Areas will markedly improve the overall condition of the Marsh, increase many of its resources and improve its resilience to Climate Change.

Of the access restrictions accessed, the greatest benefit is achieved with 100% restricted access to Central and 50% restricted access to Eastern and Southern Areas.

It is worth noting, however, that these conclusions are for analyses based on a 33-year hydrological record and a *c.* 2013/2014 hydromorphological template, which changed significantly in Jan 2015. The hydromorphology sub-study (Birkhead *et al*. 2016) highlights that while it may be true that the Marsh is fairly resilient to short-term changes in average climatic conditions, it is susceptible to longer term climatic cycles and sudden and catastrophic changes in channel planform geometry resulting from excessive sediment loads combined with flooding. These are not included in the analyses in this report. The long-term future of the Marsh is very much tied to long-term natural climate (Malawi lake-level) variations and possibly climate change, since flows in the Shire River are extremely sensitive to changes in rainfall and/or evaporation (Birkhead *et al*. 2016). Analyses in Birkhead *et al*. (2016) suggest that there have been frequent and prolonged periods of zero flow from Lake Malawi into the Shire River in the past, including at least one per century as far back as the 18th century. Also, the morphological changes resulting from the January 2015 flood were extensive, and are discussed in some detail in Birkhead *et al*. (2016). Possibly the most significant of these are:

  - reduced inundation of the Southern and Central areas as a result of the diversion of majority of the flow in Shire River through the recent breach in the railway embankment instead of passing under Chiromo Bridge;
  - infilling of Lake Tomaninjobi as result of the rerouting of the sediment-laden Ruo River into the Southern area.

While these, and other long-term trends, fall outside of the current set of analyses, it is possible to include them in future assessments using the DSS established in this project.

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Appendix A. OVERVIEW OF DRIFT

This appendix is a generic overview of DRIFT and as such may use examples from areas other than the Elephant Marsh. The Elephant Marsh assessment was completed using Drift2_v2.95.exe.

DRIFT is a process and data-management DSS, allowing data and knowledge to be used to their best advantage in a structured way. Within DRIFT, discipline specialists, use their own discipline-specific methods to derive the links between river flow and river condition. The central rationale of DRIFT is that different aspects of the flow or sediment regime of a river elicit different responses from the riverine ecosystem. Thus, removal of part or all of a particular element of the flow or sediment regime will affect the riverine ecosystem differently than will removal of some other element.

In DRIFT, the long-term daily-flow time-series is partitioned into parts of the flow regime that are thought to play different roles in sculpting and maintaining the river ecosystem, such as the onset of important flow seasons, which may affect breeding cycles, or the magnitude of the annual flood, which may inundate a floodplain. This makes it easier for ecologists to predict how changes in the flow regime could affect the ecosystem. The ‘parts’ of the flow regime used in DRIFT are called flow indicators. The indicators used for the Elephant Marsh are presented in Section 4.1.

The variability of the flow regime in timing and magnitude, both in its natural state and in any future scenario, is captured automatically through algorithms within the hydrological module of the DSS that identify the nature of the flow indicators year-by-year. Thus, the 33 annual values of each flow indicator are provided for the 33 years of flow record. This means the specialists can consider a response to a condition for a particular time-step rather than thinking of an averaged response over several years. They can also use data from a particular year or season to calibrate time-series responses.

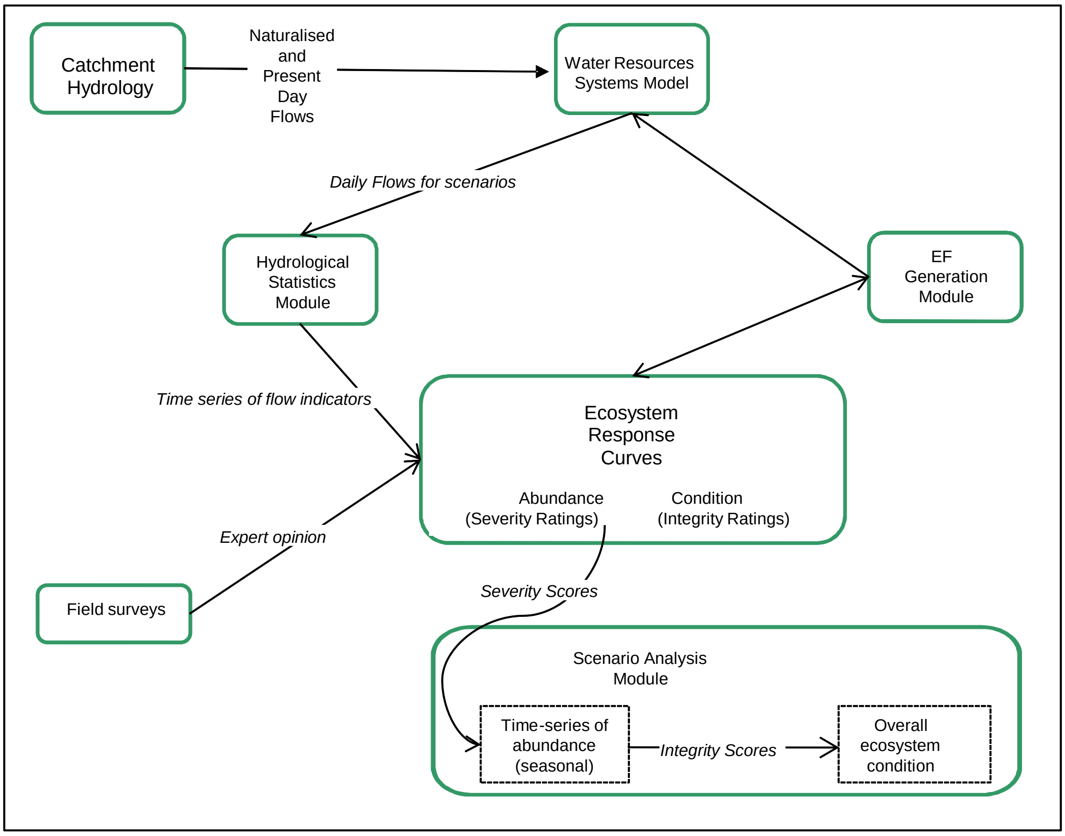
The study process was structured as follows:

1. The study focused on five focus areas in the Elephant Marsh (Figure 2.3).
2. The flow changes were converted to water depths across the marsh via a hydromorphologial model (Birkhead *et al.* 2016) that were evaluated in terms of:
    i. Changes in magnitude.
    ii. Changes in duration.
    iii. Changes in timing (e.g., delayed onset of wet season).
3. Specialists provided opinion on the consequences of these changes in the form of Response Curves. The disciplines represented were:
    i. Hydraulics
    ii. Geomorphology
    iii. Vegetation
    iv. Aquatic invertebrates
    v. Fish

    vi. Herpetofauna
    vii. Mammals
    viii. Birds
4. Each specialist provided a list of ecosystem attributes that they believe could change with flow change. These are called ecosystem indicators.
5. The database was used to evaluate
    i. changes in sediments and vegetation for each focus area and scenario;
    ii. changes in aquatic invertebrates, fish, herpetofauna and birds for the Whole Marsh for each scenario, and;
    iii. changes in the overall condition of the Whole Marsh for each scenario.
6. The outputs of the DRIFT database are written up in Section 8.

The basic sequence of activities in the DRIFT DSS can be summarised as follows (Appendix Figure 1):

1. Collect data for the study at the river.
2. Augment with expert knowledge for similar river systems and a global understanding of river functioning.
3. Model current catchment hydrology and scenarios of future changes.
4. Calculate annual flow indicator time-series for all scenarios.
5. Construct relationships for the expected response of individual ecosystem indicators to changes in aspects of the flow regime (Response Curves). The Response Curves show the extent of change (i.e. severity of change – on a scale of 0 (no change) to 5 (very high change)) from baseline to that what would be expected from an ecosystem indicator in response to specific changes in flow.
6. Use Response Curves to predict time-series of abundance changes in each ecosystem indicator as a response to flow and consequent other changes.
7. Calculate Integrity for each indicator by assigning a direction of change, i.e., whether an increase in abundance will be expected to move the indicator away from the natural ecosystem condition or the opposite, and from this calculate discipline and site level Integrity.



Appendix Figure 1 Flow chart of DRIFT process

A.1. RESPONSE CURVES[13]

Response Curves depict the relationship between a biophysical indicator and a driving variable (e.g., flow). In this EFlows assessment, Response Curves linked an indicator to any other indicator deemed to be driving change. The aim is not try to capture every conceivable link, but rather to restrict the linkages to those that are most meaningful and can be used to predict the bulk of the likely responses to a change in the flow or sediment regimes of the river.

A Response Curve for the relationship between relative fish (e.g., Alwan Snow Trout) abundance (given as a severity rating – see Section A.2 for an explanation of the scoring system used) and a flow category, in this case, onset of the wet season, is shown in Appendix Figure 2. In this figure, an early or late start to the wet season would lead to decreased abundance.

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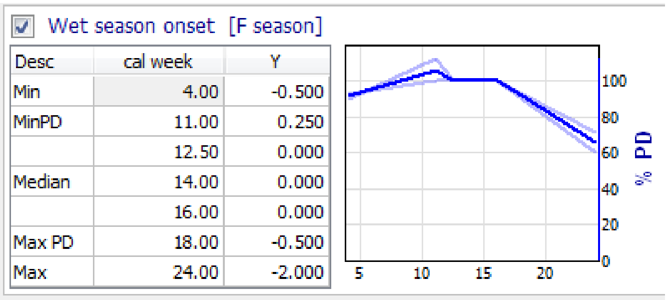
[13] The bulk of this section is taken from Joubert *et al*., 2009.



☑ Wet season onset [F season]

Desc	cal week	Y
Min	4.00	-0.500
MinPD	11.00	0.250
	12.50	0.000
Median	14.00	0.000
	16.00	0.000
Max PD	18.00	-0.500
Max	24.00	-2.000

Appendix Figure 2 Example of a Response Curve – in this case of the relationship between the calendar week when the wet season begins and the abundance of Alwan Snow Trout.

The units on the x-axis depend on the driving variable under consideration. For instance, in the case of wet season onset (Appendix Figure 2), these are weeks of the year.

The y-axis may refer to abundance as in Appendix Figure 2, but also to other measures such as concentration or area, depending on the indicator. Response curves are constructed using severity ratings (Section A.2).

The number of Response Curves constructed for an EFlows assessment depends on the level of detail at which a flow assessment is done. In the NJHEP assessment, for example, the specialists collectively completed 57 Response Curves for Site 2. These were used to evaluate scenarios by taking the value of the flow indicator for any one scenario and reading off the resultant values for the biophysical indicators from their respective Response Curves. Once this had been done the database combined these values to predict the overall change in each biophysical indicator and in the overall ecosystem under each scenario.

A.1.1. Construction of the Response Curves

The Response Curves used in this project were constructed at a workshop held in Cape Town from the 15th – 19th August 2016. The Response Curves and explanations for their shape are contained in the DRIFT DSS, and in Section 5.

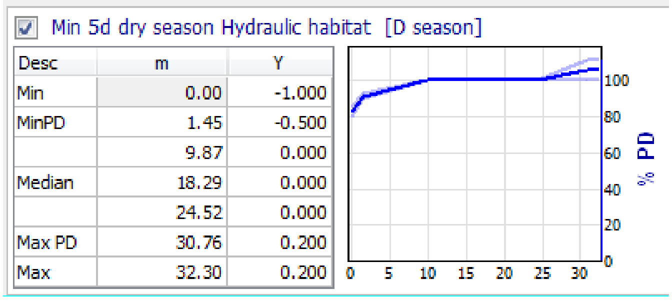
A.1.2. Response Curves and cumulative change

The time-series approach means that the Response Curves are used to predict the likely seasonal change in an ecosystem indicator in response to the flow/sediment conditions experienced in that, or possibly preceding, seasons. For instance, the kind of questions and discussion typically addressed to facilitate setting the dry season discharge Response Curve for Alwan Snow Trout are:

- “If the dry season discharge declines from baseline values, what will be the consequences for the abundance of Alwan Snow Trout?”
  - Do Alwan Snow Trout use the main river in the dry season?

- Do Alwan Snow Trout abundances change noticeably over the climatic range covered in the baseline, i.e., are they noticeably more abundant in wet years than in dry years, or vice versa?
- What kinds of habitat do adult Alwan Snow Trout use in the main river?
- Do Alwan Snow Trout breed in the dry season?
- Do they breed in the main river or in the tributaries?
- Where do Alwan Snow Trout lay their eggs?
- What sorts of habitat do fry, fingerlings and juvenile trout use in the main river?
- At what discharge(s) does the favoured habitat(s) disappear?
- What is the consequence of these habitats not being available for one season?
- If discharge reaches zero for one season, are there pools that the trout will be able to survive in?
- Can the Alwan Snow Trout survive for a dry season in pools?
- Is water temperature a concern, i.e., would the river freezing be an issue for Alwan Snow Trout if discharge decreased?
- What do Alwan Snow Trout adults/juveniles/fingerlings/fry eat?
- How will the food base be affected by changes in dry season low flows?
- Etc.

Often, a species such as Alwan Snow Trout will be expected to survive even an extremely-dry dry season, with possibly only minor changes (5-10%) in overall abundance, resulting in a Response Curve similar to that shown in Appendix Figure 3, which predicts a 20-40% seasonal decline in trout abundance if dry season flows drop to zero, even though the lowest 5-day minimum ever recorded at the Line of Control under baseline is 11.78 m^3/s. If, however, the flows drop to this level in the dry season year after year, then the cumulative effect on trout populations is likely to be far greater. The time-series enable the DSS to capture this cumulative effect.



☑ Min 5d dry season Hydraulic habitat [D season]

Desc	m	Y
Min	0.00	-1.000
MinPD	1.45	-0.500
	9.87	0.000
Median	18.29	0.000
	24.52	0.000
Max PD	30.76	0.200
Max	32.30	0.200

Appendix Figure 3 **Response curve for Alwan Snow Trout response to changes in minimum 5-day dry season discharge.**

A.2. SCORING SYSTEM

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 in order to facilitate discussion and trade-offs, it is nevertheless necessary to quantify these predictions as accurately as possible.

To aid this, two types of information are generated for each biophysical indicator, *viz*.:

- Severity ratings, which describe increase/decreases for an indicator in response to changes in the flow indicators, and;
- Integrity ratings, which indicate whether the predicted change is a move towards or away from the natural ecosystem condition, i.e., how the change influences overall ecosystem condition.

The severity ratings are used to construct the Response Curves. The Integrity ratings are used to predict changes in overall ecosystem condition/health.

A.2.1. Severity ratings

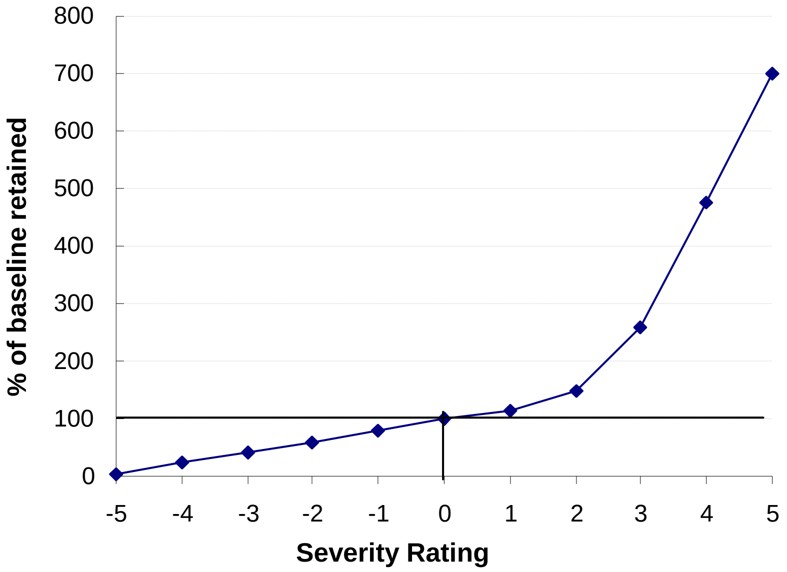
The severity ratings are on a continuous scale from -5 (large reduction) to +5 (very large change; Brown *et al*., 2008; Appendix Table 1), where the + or – denotes an increase or decrease in abundance or extent. These ratings are converted to percentages using the relationships provided in Appendix Table 1. The scale accommodates uncertainty, as each rating encompasses a range of percentages; however, greater uncertainty can also be expressed through providing a range of severity ratings (i.e. a range of ranges) for any one predicted change (after King *et al.* 2003).

Appendix Table 1 DRIFT severity ratings and their associated abundances and losses – a negative score means a loss in abundance relative to baseline, a positive means a gain.

Severity rating	Severity	% abundance change
5	Critically severe	501% gain to ∞ up to pest proportions
4	Severe	251-500% gain
3	Moderate	68-250% gain
2	Low	26-67% gain
1	Negligible	1-25% gain
0	None	no change
-1	Negligible	80-100% retained
-2	Low	60-79% retained
-3	Moderate	40-59% retained
-4	Severe	20-39% retained
-5	Critically severe	0-19% retained includes local extinction

Note that the percentages applied to severity ratings associated with gains in abundance are strongly non-linear[14] and that negative and positive percentage changes are not symmetrical (Appendix Figure 4; King *et al*. 2003).

For each year of the hydrological record, and for each ecosystem indicator, the severity rating corresponding to the value of a driving indicator is read off its Response Curve and converted to a percentage change. The severity ratings for each driving indicator are then combined to produce an overall change in abundance for each season, which combined provide an indication of how abundance, area or concentration of an indicator is expected to change under the given flow conditions over time, relative to the changes that would have been expected under baseline conditions in the catchment.



Appendix Figure 4 The relationship between severity ratings and percentage abundance lost or retained as used in DRIFT and adopted for the DSS. (Baseline is always = 100%).

A.2.2. Integrity ratings

Integrity ratings are on a scale from 0 to -5.

The integrity ratings are calculated by assigning a positive or negative sign to changes in abundance depending on whether an increase in abundance is a move towards natural or away. The integrity ratings for each indicator are then combined to provide a discipline level Integrity score. Discipline level integrity scores are in turn combined to provide an overall site level Integrity Score, which is used to place a flow scenario within a classification of overall river condition, using the South African

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[14] The non-linearity is necessary because the scores have to be able to show that a critically-severe loss equates to local extinction whilst a critically severe gain equates to proliferation to pest proportions.

Eco-classification categories A to F (Appendix Table 2; Kleynhans 1996; Kleynhans 1999; Brown and Joubert 2003).

The ecological condition of a river is defined as its ability to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components on a temporal and spatial scale that are comparable to the natural characteristics of ecosystems of the region. As an example, if the baseline ecological status (BES) of a river is a B-category, and there is a decrease in a fish species, which is a move away from natural, this will cause the integrity score to be more negative, representing movement in the direction of categories C to F.

Appendix Table 2 Definitions of the Baseline Ecological State (BES) categories (after Kleynhans 1996).

Ecological category	Corresponding DRIFT Overall Integrity Score	Description of the habitat condition
A	>-0.25	Unmodified. Still in a natural condition.
B	>-0.75	Slightly modified. A small change in natural habitats and biota has taken place but the ecosystem functions are essentially unchanged.
C	>-1.5	Moderately modified. Loss and change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged.
D	>-2.5	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.
E	>-3.5	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	<-3.5	Critically / Extremely modified. The system has been critically modified with an almost complete loss of natural habitat and biota. In the worst instances, basic ecosystem functions have are completely altered and the changes are irreversible.

Overall Integrity Scores are calculated for the ecosystem as a whole, i.e., the combined effect of changes in the indicators at each site. The results can be plotted as overall Integrity Score (y-axis) vs. percentage or volume of MAR (x-axis) or, where there are relatively few points, as a plot of Integrity Scores per site, which allows for easy comparison between sites. The categories represent points along a continuum, thus the ‘divisions’ between the categories are only guides as to the general position at which the ecological condition might be expected to shift from one category to the next. Furthermore, the rules for the integrity categories were developed on rivers outside of Malawi, and have not been tested on the Elephant Marsh. They provide an indication of the relative categories associated with each scenario and should not be misconstrued as an absolute prediction of future condition.

A.3. IDENTIFICATION OF ECOLOGICALLY-RELEVANT ELEMENTS OF THE FLOW REGIME

One of the main assumptions underlying the DRIFT EFlows process is that it is possible to identify ecologically-relevant elements of the flow regime and isolate them within the historical hydrological record. Thus, one of the first steps in the DRIFT process is to identify these ecologically-important flow indicators. To do this, the historical flow record at provided for the Shire River was used (see Birkhead *et al*. 2016 for details).

The hydrological record for the Shire River suggests that this is a flood-pulse system, with well-defined ecological seasons. The seasonal divisions chosen for the assessment were:

- Dry season
- Transitional season 1
- Flood season
- Transitional season 2.

The rules for defining the seasons are provided in Appendix Table 3. Due to the moving nature of the seasons, start and end dates are defined for every year of the hydrological time-series.

Appendix Table 3 Rules for defining the end of the four ecological seasons

Season	How the end of the season was defined
Dry Season/Transition 1	Crossing of 2 x minimum dry season discharge
Transition 1/ Flood Season	Up crossing of 1 .1 mean annual discharge
Flood Season/ Transition 2	Down crossing of 1 .1 mean annual discharge
Transition 2/Dry Season	Recession rate < 0.07 m^3/s per day

A.4. MAJOR ASSUMPTIONS AND LIMITATIONS OF DRIFT

Predicting the effect of flow changes on rivers is difficult because the actual trajectory and magnitude of the change is additionally dependent on so many other variables, such as climate, sediment supply and human use of the system. Thus, several assumptions underlie the predictions. Should any of these assumptions prove to be invalid, the actual changes may not match the predicted changes. This does not necessarily make the predictions themselves incorrect or invalid, but simply means that the surrounding set of circumstances that support the predictions has changed.

The following important major assumptions apply:

- The baseline hydrology closely approximates the actual flow conditions in the river over the period of record.
- Different parts of the flow regime sustain the river ecosystem in different ways. Changing one part of the flow regime will change the river in a different way than will changing another part.
- It is possible to identify ecologically-relevant elements of the flow regime and isolate them within the historical hydrological record (see Section A.3)
- 2014 conditions were used as a Baseline for predicting change, and change was expressed as a percentage move towards or away from the BES.
- Predicted changes in ecological status are relative to the BES (2014).

- Predictions are based on a 33-year horizon.

The main limitation is the paucity of data. This is a universal problem, as ecosystems are complex and we will probably never have complete certainty of their present and possible future characteristics. Instead it is essential to push ahead cautiously and aid decision-making, using best available information. The alternative is that water resource development decisions are made without consideration of the consequences for the supporting ecosystems, eventually probably making management of sustainability impossible. Data paucity is addressed in the DRIFT process by accessing every kind of knowledge available - general scientific understanding, international scientific literature, local wisdom and specific data from the river under consideration or from similar ones – and capturing these in a structured process that is transparent, with the DSS inputs and outputs checked and approved at every step. The Response Curves used (and the reasoning used to construct them) are available for scrutiny within the DSS and they, as well as the DRIFT DSS, can be updated as new information becomes available.

A second aspect of the paucity of data is that it is neither known what the river was like in its pristine condition nor exactly how abundant each ecosystem aspect (sand bars, fish, etc.) was then or is now. To address this, all DRIFT predictions are made relative to the baseline situation (there will be a little more, or a lot less, than today, and so on).

These inherent uncertainties also mean that the trends and relative position of the scenarios are more reliable predictors of the impacts of the scenarios than are their absolute values. Also, DRIFT is designed to predict overall condition, and focusing on one indicator to the exclusion of others is not recommended.

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Appendix B. WEIGHTS USED FOR WHOLE MARSH RESULTS

Appendix Table 4 Weights used for combining focus area results into Whole Marsh results

Site	Aquatic invertebrate		Fish				Herpetofauna			Mammals
	Community health	Pests	Floodplain migrant fish	River channel fish	Demersal fish	Channel margin fish	Crocodiles	Small reptiles	Amphibians	Hippos
Northern	81.8	81.8	1	1	1	0.8	81.8	81.8	81.8	81.8
Western	208.2	208.2	1	1	1	0.9	208.2	208.2	208.2	208.2
Eastern	128.2	128.2	0.9	1	0.9	1	128.2	128.2	128.2	128.2
Central	108.9	108.9	0.9	1	1	1	108.9	108.9	108.9	108.9
Southern	56.7	56.7	1	1	0.9	1	56.7	56.7	56.7	56.7

Appendix C. SCENARIO RESULTS: MEAN PERCENTAGE CHANGE

Appendix Table 5 **The mean percentage changes in abundance (relative to 2014 Baseline) as predicted for the Northern Area. Blue and green are major changes that represent a move towards natural: green = 40-70%; blue = >70%. Orange and red are major changes that represent a move away from natural: orange = 40-70%; red = >70%.**

	DryCalib	MidCalib	WetCalib	DevCC	DryDevCC	Base20140RS1P20SI	B2014_1P_N100RA_100S	B2014_1P_E100RA_100S	B2014_1P_C100RA_100S	B2014_1P_W100RA_100S	B2014_1P_S100RA_100S	B2014_1P_ESCRA_100S	B2014_2P_0RA_100S	DevCC_1P_N100RA_100S	DevCC_1P_E100RA_100S	DevCC_1P_C100RA_100S	DevCC_1P_W100RA_100S	DevCC_1P_S100RA_100S	DevCC_1P_ESCRA_100S	DevCC_2P_0RA_100S
Macroinvertebrates																				
Invertebrate community health	-17.4	-1.3	32.9	-8.7	-15.8	1.0	35.7	0.0	0.0	0.0	0.0	0.0	-10.7	30.5	-8.7	-8.7	-8.7	-8.7	-8.7	-19.1
Invertebrate pests	-3.8	1.6	17.2	1.1	-0.7	0.0	16.7	0.0	0.0	0.0	0.0	0.0	-4.0	18.0	1.1	1.1	1.1	1.1	1.1	-2.8
Fish																				
Floodplain migrant fish	-5.2	0.8	27.7	-2.3	-4.9	0.0	39.0	0.0	0.0	0.0	0.0	0.0	-22.3	37.5	-2.3	-2.3	-2.3	-2.3	-2.3	-23.7
River channel fish	-9.4	2.1	41.1	-4.3	-9.2	0.1	47.3	0.0	0.0	0.0	0.0	0.0	-55.8	44.9	-4.3	-4.3	-4.3	-4.3	-4.3	-59.3
Demersal fish	-17.6	13.3	56.8	-14.2	-24.5	0.0	65.1	0.0	0.0	0.0	0.0	0.0	-84.9	53.6	-14.2	-14.2	-14.2	-14.2	-14.2	-97.6
Channel margin fish	-15.5	7.1	38.7	-6.7	-14.4	0.0	38.1	0.0	0.0	0.0	0.0	0.0	-47.4	33.3	-6.7	-6.7	-6.7	-6.7	-6.7	-53.3
Herpetofauna																				
Crocodiles	-21.1	-1.2	34.5	-7.7	-21.2	0.0	39.3	0.0	0.0	0.0	0.0	0.0	-25.5	35.0	-7.7	-7.7	-7.7	-7.7	-7.7	-32.7
Small reptiles	-4.8	2.2	21.5	0.2	-1.9	0.0	35.9	0.0	0.0	0.0	0.0	0.0	-21.6	36.5	0.2	0.2	0.2	0.2	0.2	-21.5
Amphibians	-10.0	4.8	20.6	-4.0	-9.0	0.0	11.6	0.0	0.0	0.0	0.0	0.0	-5.7	9.3	-4.0	-4.0	-4.0	-4.0	-4.0	-9.8
Mammals																				
Hippos	62.3	5.0	32.6	32.6	32.6	24.2	24.2	24.2	8.3	13.2	-3.8	25.3	12.1	23.1	1.3	13.2	13.2	13.2	12.1	12.1
Small mammals	61.9	10.0	15.5	15.5	15.5	14.9	14.9	14.9	-47.6	11.4	-5.5	57.6	7.6	35.8	3.4	11.4	11.4	11.4	7.6	7.6

Appendix Table 6 **The mean percentage changes in abundance (relative to 2014 Baseline) predicted for the Western Area. Blue and green are major changes that represent a move towards natural: green = 30-70%; blue = >70%. Orange and red are major changes that represent a move away from natural: orange = 30-70%; red = >70%.**

	DryCalib	MidCalib	WetCalib	DevCC	DryDevCC	Base20140RS1P20SI	B2014_1P_N100RA_100S	B2014_1P_E100RA_100S	B2014_1P_C100RA_100S	B2014_1P_W100RA_100S	B2014_1P_S100RA_100S	B2014_1P_ESCRA_100S	B2014_2P_0RA_100S	DevCC_1P_N100RA_100S	DevCC_1P_E100RA_100S	DevCC_1P_C100RA_100S	DevCC_1P_W100RA_100S	DevCC_1P_S100RA_100S	DevCC_1P_ESCRA_100S	DevCC_2P_0RA_100S
Macroinvertebrates																				
Invertebrate community health	-17.6	0.4	19.2	1.1	-9.3	0.1	0.2	0.0	0.0	10.5	0.0	0.0	-7.2	1.3	1.1	1.1	11.4	1.1	1.1	-5.3
Invertebrate pests	-6.6	2.0	9.5	-0.8	-2.1	0.0	0.0	0.0	0.0	17.1	0.0	0.0	-5.3	-0.8	-0.8	-0.8	16.7	-0.8	-0.8	-6.0
Fish																				
Floodplain migrant fish	-7.2	1.1	25.6	-3.8	-6.7	0.0	0.0	0.0	0.0	39.6	0.0	0.0	-22.1	-3.8	-3.8	-3.8	37.3	-3.8	-3.8	-24.6
River channel fish	-10.6	3.9	38.6	-5.8	-10.3	0.0	0.0	0.0	0.0	48.4	0.0	0.0	-53.8	-5.7	-5.8	-5.8	45.5	-5.8	-5.8	-58.5
Demersal fish	-17.2	13.9	59.7	-13.5	-24.5	0.0	0.0	0.0	0.0	65.6	0.0	0.0	-80.9	-13.5	-13.5	-13.5	55.7	-13.5	-13.5	-93.0
Channel margin fish	-15.9	8.3	37.5	-7.5	-15.3	0.0	0.0	0.0	0.0	38.0	0.0	0.0	-46.1	-7.5	-7.5	-7.5	32.9	-7.5	-7.5	-52.9
Herpetofaunca																				
Crocodiles	-18.8	-3.0	31.1	-4.0	-16.8	0.0	0.0	0.0	0.0	52.1	0.0	0.0	-32.2	-4.0	-4.0	-4.0	51.3	-4.0	-4.0	-35.3
Small reptiles	-8.0	2.9	16.7	-1.9	-3.7	0.0	0.0	0.0	0.0	59.1	0.0	0.0	-34.4	-1.9	-1.9	-1.9	58.8	-1.9	-1.9	-36.9
Amphibians	-6.6	3.5	27.1	2.4	-2.6	0.0	0.0	0.0	0.0	23.6	0.0	0.0	-9.1	2.4	2.4	2.4	26.8	2.4	2.4	-6.5
Mammals																				
Hippos	78.3	13.6	43.3	43.3	102.1	35.6	35.6	35.6	6.3	22.1	-5.8	21.7	21.7	36.6	8.9	22.1	22.1	40.9	21.7	21.7
Small mammals	15.0	6.8	6.0	6.0	31.0	6.5	6.5	6.5	-7.2	4.0	-4.9	3.7	3.7	6.3	2.2	4.0	4.0	5.9	3.7	3.7

Appendix Table 7 **The mean percentage changes in abundance (relative to 2014 Baseline) predicted for the Eastern Area. Blue and green are major changes that represent a move towards natural: green = 30-70%; blue = >70%. Orange and red are major changes that represent a move away from natural: orange = 30-70%; red = >70%. Baseline, by definition, equals 100%.**

	DryCalib	MidCalib	WetCalib	DevCC	DryDevCC	Base20140RS1P20SI	B2014_1P_N100RA_100S	B2014_1P_E100RA_100S	B2014_1P_C100RA_100S	B2014_1P_W100RA_100S	B2014_1P_S100RA_100S	B2014_1P_ESCRA_100S	B2014_2P_0RA_100S	DevCC_1P_N100RA_100S	DevCC_1P_E100RA_100S	DevCC_1P_C100RA_100S	DevCC_1P_W100RA_100S	DevCC_1P_S100RA_100S	DevCC_1P_ESCRA_100S	DevCC_2P_0RA_100S
Macroinvertebrates																				
Invertebrate community health	-22.7	8.6	25.1	-20.0	-29.6	0.3	0.5	20.1	0.0	0.0	0.0	14.6	-27.6	-19.5	5.8	-20.0	-20.0	-20.0	-2.6	-45.8
Invertebrate pests	-4.2	1.9	-5.1	-1.3	-1.6	0.0	0.0	8.3	0.0	0.0	0.0	5.7	-5.2	-1.3	7.4	-1.3	-1.3	-1.3	4.5	-6.5
Fish																				
Floodplain migrant fish	-7.5	1.7	15.8	-3.6	-7.3	0.0	0.0	36.3	0.0	0.0	0.0	32.0	-15.8	-3.6	33.9	-3.6	-3.6	-3.6	28.0	-18.8
River channel fish	-10.5	4.2	26.6	-5.2	-10.3	0.0	0.0	44.9	0.0	0.0	0.0	39.0	-30.0	-5.2	42.0	-5.2	-5.2	-5.2	35.2	-35.5
Demersal fish	-16.9	14.1	48.4	-12.3	-22.5	0.0	0.0	65.9	0.0	0.0	0.0	58.6	-44.3	-12.3	56.5	-12.3	-12.3	-12.3	48.0	-56.8
Channel margin fish	-16.4	8.5	33.1	-6.8	-15.7	0.0	0.0	38.3	0.0	0.0	0.0	32.7	-25.1	-6.8	33.5	-6.8	-6.8	-6.8	27.0	-32.0
Herpetofaunca																				
Crocodiles	-14.6	4.9	17.7	-4.7	-13.5	0.0	5.4	39.3	0.0	0.0	0.0	26.8	-20.6	1.5	36.4	-4.7	-4.7	-4.7	22.2	-25.7
Small reptiles	-5.0	2.4	1.3	-2.0	-2.6	0.0	0.0	33.9	0.0	0.0	0.0	19.4	-14.8	-2.0	33.3	-2.0	-2.0	-2.0	17.1	-17.0
Amphibians	-11.3	5.4	8.3	-3.2	-8.8	0.0	0.0	12.3	0.0	0.0	0.0	8.6	-12.2	-3.2	10.3	-3.2	-3.2	-3.2	6.0	-15.4
Mammals																				
Hippos	21.9	7.4	14.8	59.8	14.8	9.6	9.6	42.5	-7.1	7.1	-4.0	3.9	3.9	9.1	3.8	7.1	21.6	7.1	3.9	14.9
Small mammals	-5.9	-1.2	1.6	35.7	1.6	-1.5	-1.5	20.8	-15.3	-1.7	-7.2	-4.9	-4.9	-13.2	-5.3	-1.7	9.5	-1.7	-4.9	2.2

Appendix Table 8 **The mean percentage changes in abundance (relative to 2014 Baseline) predicted for the Central Area. Blue and green are major changes that represent a move towards natural: green = 30-70%; blue = >70%. Orange and red are major changes that represent a move away from natural: orange = 30-70%; red = >70%. Baseline, by definition, equals 100%.**

	DryCalib	MidCalib	WetCalib	DevCC	DryDevCC	Base20140RS1P20SI	B2014_1P_N100RA_100S	B2014_1P_E100RA_100S	B2014_1P_C100RA_100S	B2014_1P_W100RA_100S	B2014_1P_S100RA_100S	B2014_1P_ESCRA_100S	B2014_2P_0RA_100S	DevCC_1P_N100RA_100S	DevCC_1P_E100RA_100S	DevCC_1P_C100RA_100S	DevCC_1P_W100RA_100S	DevCC_1P_S100RA_100S	DevCC_1P_ESCRA_100S	DevCC_2P_0RA_100S
Macroinvertebrates																				
Invertebrate community health	-20.5	6.5	19.1	-13.8	-20.7	0.0	0.0	0.0	14.7	0.2	0.0	14.7	-8.9	-13.8	-13.8	2.9	-13.5	-13.8	2.9	-22.5
Invertebrate pests	-1.7	0.6	-5.3	-3.0	-3.5	0.0	0.0	0.0	8.3	0.0	0.0	8.3	-4.0	-3.0	-3.0	6.1	-3.0	-3.0	6.1	-7.0
Fish																				
Floodplain migrant fish	-6.6	1.7	16.5	-3.1	-6.1	0.0	0.0	0.0	36.2	0.0	0.0	36.2	-8.1	-3.1	-3.1	34.0	-3.1	-3.1	34.0	-11.1
River channel fish	-9.3	3.5	28.2	-5.3	-9.7	0.0	0.0	0.0	44.4	0.0	0.0	44.4	-14.0	-5.3	-5.3	41.1	-5.3	-5.3	41.1	-19.3
Demersal fish	-17.5	12.7	54.5	-16.2	-30.2	0.0	0.0	0.0	65.3	0.0	0.0	65.3	-20.4	-16.2	-16.2	51.9	-16.2	-16.2	51.9	-36.5
Channel margin fish	-15.4	7.1	36.4	-6.8	-15.1	0.0	0.0	0.0	37.9	0.0	0.0	37.9	-11.8	-6.8	-6.8	33.1	-6.8	-6.8	33.1	-18.6
Herpetofaunca																				
Crocodiles	-12.0	1.1	17.9	-5.7	-13.4	0.0	0.0	0.0	38.0	0.0	0.0	38.0	-5.9	-5.7	-5.7	33.7	-5.7	-5.7	33.7	-11.6
Small reptiles	-3.7	1.7	3.8	-4.1	-5.2	0.0	0.0	0.0	35.0	0.0	0.0	35.0	-10.6	-4.1	-4.1	33.2	-4.1	-4.1	33.2	-14.7
Amphibians	-17.7	9.9	27.5	-15.5	-20.7	0.0	0.0	0.0	22.3	0.0	0.0	22.3	-9.4	-15.5	-15.5	8.2	-15.5	-15.5	8.2	-25.0
Mammals																				
Hippos	17.2	-2.7	10.9	10.9	10.9	38.0	0.6	38.0	-6.1	3.8	-3.0	-4.5	-4.5	5.9	-6.2	3.8	3.8	3.8	9.5	9.5
Small mammals	-11.1	-5.2	0.1	0.1	0.1	10.6	-5.8	10.6	-12.6	-2.9	-5.2	-8.4	-8.4	-17.0	-8.6	-2.9	-2.9	-2.9	-5.0	-5.0

Appendix Table 9 **The mean percentage changes in abundance (relative to 2014 Baseline) predicted for the Southern Area. Blue and green are major changes that represent a move towards natural: green = 30-70%; blue = >70%. Orange and red are major changes that represent a move away from natural: orange = 30-70%; red = >70%. Baseline, by definition, equals 100%.**

	DryCalib	MidCalib	WetCalib	DevCC	DryDevCC	Base20140RS1P20SI	B2014_1P_N100RA_100S	B2014_1P_E100RA_100S	B2014_1P_C100RA_100S	B2014_1P_W100RA_100S	B2014_1P_S100RA_100S	B2014_1P_ESCRA_100S	B2014_2P_0RA_100S	DevCC_1P_N100RA_100S	DevCC_1P_E100RA_100S	DevCC_1P_C100RA_100S	DevCC_1P_W100RA_100S	DevCC_1P_S100RA_100S	DevCC_1P_ESCRA_100S	DevCC_2P_0RA_100S
Macroinvertebrates																				
Invertebrate community health	-36.0	13.5	26.6	-22.4	-35.1	0.0	0.0	0.0	0.0	0.0	22.3	17.4	-33.4	-22.4	-22.4	-22.4	-22.4	4.2	-2.5	-52.9
Invertebrate pests	-4.2	1.9	0.1	-3.2	-2.9	0.0	0.0	0.0	0.0	0.0	17.0	12.0	-4.3	-3.2	-3.2	-3.2	-3.2	14.1	8.2	-7.5
Fish																				
Floodplain migrant fish	-5.1	4.2	21.0	-3.4	-5.6	0.0	0.0	0.0	0.0	0.0	42.1	34.4	-18.6	-3.4	-3.4	-3.4	-3.4	39.6	29.4	-20.9
River channel fish	-11.0	7.5	35.8	-5.6	-10.6	0.0	0.0	0.0	0.0	0.0	51.7	43.0	-44.0	-5.6	-5.6	-5.6	-5.6	48.6	38.4	-49.7
Demersal fish	-18.1	14.0	54.8	-7.1	-14.4	0.0	0.0	0.0	0.0	0.0	71.1	61.0	-65.8	-7.1	-7.1	-7.1	-7.1	68.6	56.4	-73.1
Channel margin fish	-17.9	9.9	38.6	-6.2	-15.6	0.0	0.0	0.0	0.0	0.0	40.3	33.6	-37.9	-6.2	-6.2	-6.2	-6.2	36.8	29.1	-44.2
Herpetofaunca																				
Crocodiles	-13.3	2.0	20.9	-4.9	-12.7	0.0	0.0	0.0	0.0	0.0	41.7	28.7	-19.8	-4.9	-4.9	-4.9	-4.9	38.5	24.1	-25.7
Small reptiles	-6.9	3.6	8.8	-4.2	-5.3	0.0	0.0	0.0	0.0	0.0	41.6	24.5	-17.5	-4.2	-4.2	-4.2	-4.2	39.4	20.1	-21.4
Amphibians	-6.2	3.6	6.7	-4.6	-6.7	0.0	0.0	0.0	0.0	0.0	7.7	5.3	-7.7	-4.6	-4.6	-4.6	-4.6	4.5	1.5	-12.5
Mammals																				
Hippos	47.5	5.0	27.8	27.8	27.8	15.4	76.8	58.3	-12.2	15.6	-5.7	7.1	33.0	26.6	0.2	15.6	15.6	15.6	7.1	27.5
Small mammals	9.2	-0.8	6.0	6.0	6.0	1.0	45.7	28.2	-19.4	3.2	-5.7	-2.1	13.6	-1.8	-4.9	3.2	3.2	3.2	-2.1	7.9