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Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

RESERVE DETERMINATION STUDIES FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE USUTU/MHLATUZE WATER MANAGEMENT AREA
WP 10544

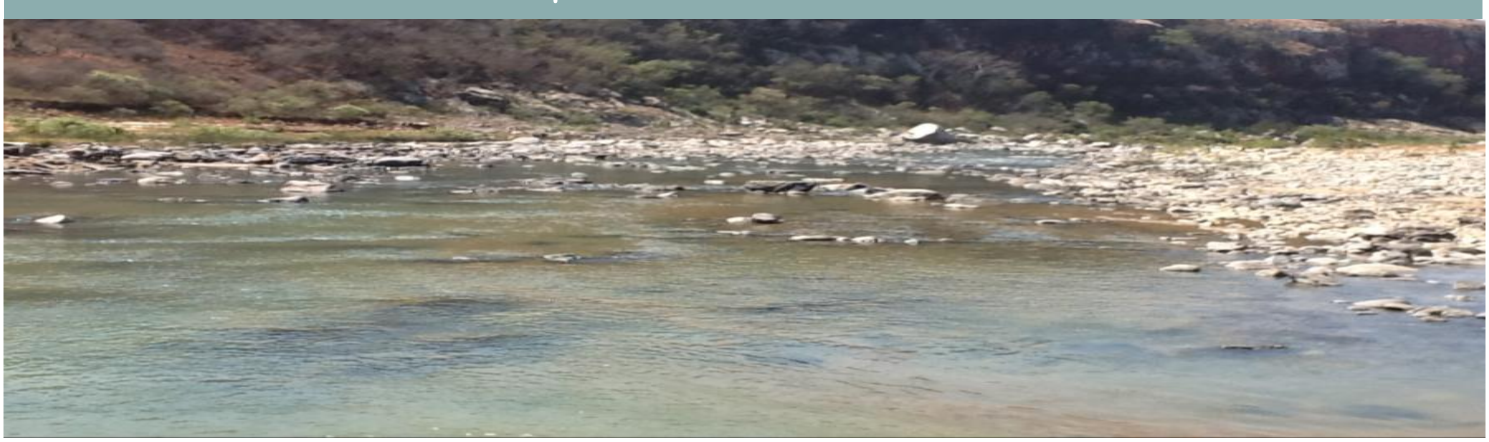
LAKE SIBAYA

VOLUME 2 - INTERMEDIATE EWR ASSESSMENT REPORT

FINAL

JUNE 2016

Report No. RDM/WMA6/CON/COMP/1713



DEPARTMENT OF WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEMS
CONTRACT NO. WP 10544

RESERVE DETERMINATION STUDIES FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE USUTHU/MHLATUZE WATER MANAGEMENT AREA:

LAKE SIBAYA
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Contract Title: Reserve determination studies for selected surface water, groundwater, estuaries and wetlands in the Usuthu - Mhlathuze Water Management Area

Report Title: Lake Sibaya – Volume 2 - Intermediate EWR Assessment Report

Editors K. Reinecke and A Joubert

Revision	Date	Report Status
Draft 1.2	30 October 2015	Draft for external comment
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<u>Consultants: Tlou Consulting (Pty) Ltd and Southern Waters</u>

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- Karl Reinecke
- Alison Joubert
- Andrew Birkhead
- Steve Weerts
- Jane Turpie
- James Mackenzie
- Ricky Taylor
- Susan Taljaard
- Cate Brown
- Toriso Tlou
- Adhishri Singh
- Molla Demlie

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ABBREVIATIONS AND ACRONYMS

AEC	Alternative Ecological Category
DRIFT	Downstream Response to Imposed Flow Transformation
DSS	Decision Support System
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EIS	Ecological Importance and Sensitivity
EMC	Ecological Management Class
EWR	Environmental Water Requirements
LWR	Lake Water Requirement App[roach
PES	Present Ecological Status
REC	Recommended Ecological Condition
WMA	Water Management Area

GLOSSARY OF TERMS

- **Ecological Categories.** A distinction is made between Management Classes, which form part of the National Classification System, and Ecological Categories, which forms part of the Ecological Water Requirement assessment.
- **Ecological Category** (EC) replaces former terms used, namely: Ecological Reserve Category (ERC), Desired Future State (DFS) and Ecological Management Class (EMC).
- **Ecological Water Requirements** (EWR) should be used instead of the term Instream Flow Requirements (IFR) for various reasons, including international acceptance of the former term.
- **Ecosystem Integrity**: refers to the integrated composition of physicochemical, habitat and biotic characteristics on a temporal and spatial scale that are comparable to the characteristics of natural ecosystems of the region.
- **Preliminary Reserve** refers to Reserve signed off by the Minister or her representative in the absence of the Classification Process having been undertaken in the basin.
- **Recommended Ecological Condition** (REC) The target maintenance Ecological Condition for a water resource based solely on ecological criteria.
- **Reserve** refers to the EWR for maintaining a particular ecological condition where operational limitations and stakeholder consultation are taken into account. The Reserve includes both ecological and Basic Human Needs (BHN) requirements.

1 INTRODUCTION

1.1 Background to the study

The Chief Directorate: Resource Directed Measures (RDM); Department of Water and Sanitation (DWS), issued an open tender invitation for the "*Appointment of a Professional Service Provider to undertake Reserve Determinations for selected Surface water, Groundwater, Estuaries and Wetlands in the Usuthu to Mhlatuze Basins*". The focus on this area was a result of the high conservation status and importance of various water resources in the basin and the significant development pressures affecting the availability of water in the area.

Reserve determinations are required to assist the DWS in making informed decisions with respect to the magnitude of the impacts of the proposed developments on the water resources in the Water management Area (WMA), and to provide the input data for Water Resource Classification of the area, and eventual gazetting of the Reserve (DWAF1999a).

In July 2013, DWS appointed Tlou Consulting to undertake the project.

1.1.1 Study objectives

The objectives of the study are to:

- determine the Ecological Reserve (DWAF 1999a) at various levels of detail, for the Nyoni, Matigulu, Mlalazi, Mhlatuze, Mfolozi, Nyalazi, Hluhluwe, Mzinene, Mkuze, Assegaai and Pongola Rivers;
- determine the Ecological Reserve, at an Intermediate level, for the Pongola Floodplain;
- determine the Ecological Reserve, at an Intermediate level, for the St Lucia/Mfolozi, Estuary System;
- determine the Ecological Reserve, at an Rapid level, for the Mlalazi Estuary;
- determine the Ecological Reserve, at a Rapid level, for the Amatikulu Estuary;
- determine the Ecological Reserve, at an Intermediate level, for Lake Sibaya;
- determine the Ecological Reserve, at a Rapid level for Kozi Lake and Estuary;
- classify the causal links between water supply and condition of key wetlands;
- incorporate existing EWR assessments on the Mhlatuze (river and estuary) and Nhlabane (lake and estuary) into study outputs;
- determine the groundwater contribution to the Ecological Reserve, with particular reference to the wetlands;
- determine the Basic Human Needs Reserve for the Usuthu/Mhlatuze WMA;
- outline the socio-economic water use in the Usuthu/Mhlatuze WMA;
- build the capacity of team members and stakeholders with respect to EWR determinations and the ecological Reserve.

1.1.2 Study team

The names and affiliations of the members of the study team for the Lake Sibaya assessment are provided in Table 1.1.

Table 1.1 Members of the study team for Lake Sibaya

Name	Affiliation	Role
Adhishri Singh	Tlou Consulting	Project Manager
Alison Joubert	Southern Waters	DRIFT DSS manager
Karl Reinecke	Southern Waters	EWR process co-ordinator
Drew Birkhead	Streamflow Solutions	Hydraulics
Susan Taljaard	CSIR	Water quality
James MacKenzie	BioRiver Solutions	Vegetation
Ricky Taylor	University of KZN	Herpetofauna, semi-aquatic mammals, molluscs and crustacea
Steven Weerts	CSIR	Ichthyofauna
Jane Turpie	Anchor Environmental	Avifauna
Toriso Tlou	Tlou consulting	Social
Cate Brown	Southern Waters	Internal review

1.2 This report

This report is Volume 2 of four volumes of the Lake Sibaya Intermediate EWR Report:
Volume 1: Ecoclassification Report
Volume 2: EWR Assessment Report
Volume 3: Specialists reports
Volume 4: Ecospecs and Monitoring Programme.

This report Volume 2: EWR Assessment provides:

- an overview of the study area (Section 2);
- an overview of the approach adopted for the EWR assessment (Section 3);
- a summary of the Ecoclassification results (Section 4);
- a description of the indicators used in the assessment (Section 5);
- a description of the scenarios assessed (Section 6)
- the results of the scenario assessments (Section 7 and 8);
- a recommended water-level scenario for lake Sibaya (Section 9), and;

2 ORGANISATION OF THE STUDY AREA

2.1 Delineation of Lake Sibaya

The morphology of Lake Sibaya is a result of sedimentary processes, driven by fluctuating water levels and wind driven currents that dictate Lake Sibaya's morphology through the processes of infilling and shoreline progradation associated with the lake segmentation process (Miller 1998). Importantly, lake morphology is driven by lake water level, with the highest levels of erosion, and hence sediment deposition in the lake, occurring at high water levels (Miller 1998).

For the purposes of this assessment Lake Sibaya was subdivided into five zones, the: Main Basin, Northern Arm, Western Arm, Southwestern Basin and Southern Basin (Hill 1979, cited in Miller 1998; Figure 2.1) and zone codes for each are provided in Table 2.1.

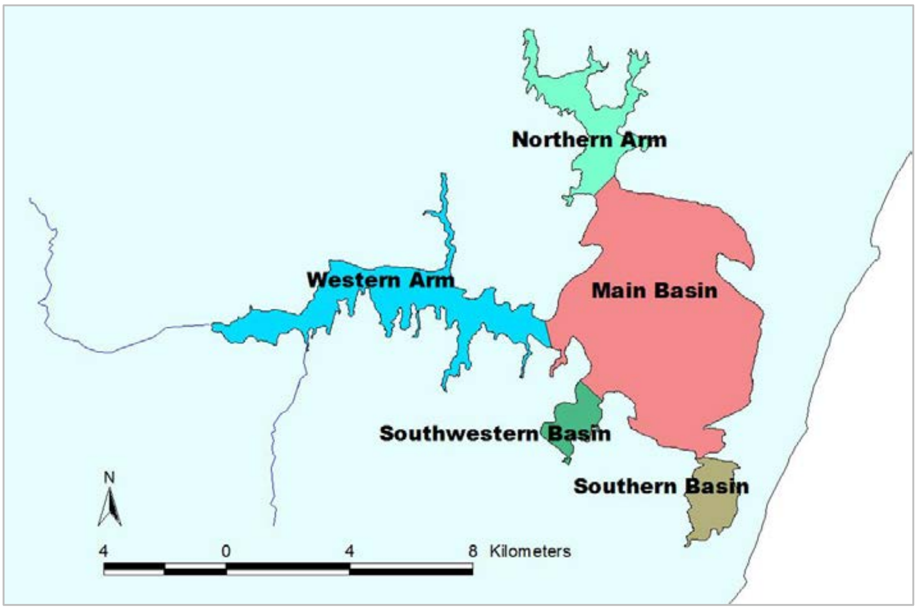


Figure 2.1 The five EWR zones of the lake

Table 2.1 Zones codes for the five EWR zones

EWR Zone	Code
Main Basin	MB
Northern Arm	NA
Western Arm	WA
Southwestern Basin	SWB
Southern Basin	SB

3 APPROACH

3.1 Introduction

As per the Inception Report, the EWR assessment for Lake Sibaya was done at an Intermediate level.

The approach used is in line with that for determining the Reserve for lakes and pans provided by Harding (1999), called the Lake Water-Level Requirement Approach (LWR; Section 3.1.1).

3.1.1 The Lake Water-Level Requirement Approach (Harding 1999)

The LWR involves the following steps applied independently for each lake (or resource unit within a lake):

- Identify the reference conditions of the resource unit.
- Discuss the present operation of the lakes for the provision of water.[1]
- Assess the present status for each of the ecological determinants of the resource unit.
- Assess the habitat integrity for the water body and the littoral / riparian zone.
- Determine the ecological importance of the resource unit.
- Determine the social importance of the resource unit.
- Assess an achievable Ecological Management Class (EMC) for the water body and the littoral / riparian zone.
- Consider the future management classes either side of the EMC and list the flow related and non-flow related activities which would be required to meet these classes.
- Prioritise and list the objectives required to attain the EMC. Recommend the water levels required to achieve the EMC and motivate these levels based on ecological grounds backed up by hydrological records where available.
- Specify the degree of confidence in the recommendations and identify further work required to increase the confidence.

The LWR steps are a combination of those followed for Ecoclassification and those to evaluate the ecological and social consequences of lake-water level scenarios of change.

The results of the Ecoclassification process, listed below and provided in Volume 1 (Section 1.2), are summarised in Section 4:

- Data availability.
- Ecological Importance and Sensitivity (EIS).
- Reference conditions.
- Baseline ecological condition, including:
    - individual component Ecoclassification;
    - cause and sources;

[1] A description of domestic water use is provided in the Social specialist report, Volume 3: Section 9

  - o trends; and
  - o ecostatus.
- Recommended Ecological category (REC) for each specialist component and ecostatus.
- Alternative Ecological categories (AEC) for each specialist component and ecostatus.
- Confidence in the results.

The LWR does not, however, stipulate the methodologies to be used in evaluating scenarios of lake-water level changes so the DRIFT approach (as per the Inception Report, Brown et al. 2013) was selected.

3.2 The DRIFT approach

Lake water levels are key in protecting the lake, defining morphology and in dictating the biotic response. Thus, in accordance with the LWR (Section 3.1.1), water levels were used as the main driving variable in the EWR determination, which focussed on the implications of variations in lake level from full supply to below those measured to date.

The DRIFT Decision Support System (DSS) was populated as outlined in Section 3.2.1, using water-level time-series.

The present condition of the lake was described and then, through scenarios, predictions were made as to how this could change with changes in water level. Each scenario changed water levels in a different way, with different repercussions for the lake system. Once these water level changes had been simulated, the response curves within the DRIFT DSS were used to provide predictions of the consequent changes in the biotic and abiotic aspects of the lake.

The DRIFT-DSS is a data-management tool that allows data and knowledge about the functional organisation of aquatic ecosystems to be used to their best advantage in a structured way. It 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). In the case of Lake Sibaya, the descriptors thought to be most relevant to the study were decided upon by the specialists collectively during the workshop and are summarised in section 5.

DRIFT (King et al. 2003; Brown et al. 2013) has the following relevant strengths:

- The DRIFT Decision Support System (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.

- It addresses all aspects of the flow and/or hydraulic regime in a structured approach.
- It is adaptable – its setup for each project is adapted to suit the aquatic ecosystem under investigation rather than the ecosystem having to 'fit' the method
- It has been the focus of 18 years of applied development, and is published in international scientific journals (e.g., King *et al*. 2004; Brown and Joubert 2004).
- It has been widely applied internationally: e.g., Cunene River, Angola and Namibia; Huaura River, Peru; Mekong River, Thailand, Lao PDR, Cambodia and Viet Nam; Nile River, Sudan; Neelum/Jhellum and Poonch rivers, Kashmir/Pakistan, Odzi and Pungwe Rivers, Zimbabwe; Okavango River, Angola, Namibia and Botswana; Cuanza River, Angola; Pangani and Ruvu rivers, Tanzania; Zambezi River, Zambia, Zimbabwe, Mozambique.
- It produces predictions that detail how the ecosystem could change, and how this could impact people, in ways that stakeholders can relate to.

3.2.1 The DRIFT process

The DRIFT process can be summarised as (Figure 3.1):

- Decide on the nature of the scenarios to be evaluated. In this study they related to water levels in Lake Sibaya (Section 3.1).
- Choose the Baseline scenario: all other scenarios will be evaluated relative to the Baseline. In this study the Baseline scenario selected was the measured and (modified) 47-year monthly stage record from June 1968 to May 2015 obtained from the Hydrological Services of the DWS as daily averages for DWS Gauging Station W7R001 at Lake Sibaya (see Section 2, Volume 3: EWR Specialists Reports).
- Select the EWR zones (see Section 2).
- Obtain time-series of flow/hydraulics for the Baseline and other scenarios in each zone and translate these into flow 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.
- Assign the present ecological status and trends (Section 4.1).
- Select an array of flow, hydraulic, ecosystem and/or social indicators to represent the study site (Section 5).
- Define the links between the indicators (see Volume 3: EWR Specialists Reports). Together the indicators and links form the conceptual framework for the predictions of change (Section 5).
- The specialists first choose their indicators and draw a diagram that shows its linked indicators Figure 3.2.
- For each link, construct a response curve (Figure 3.3) that describes the relationship between the indicators. Each response curve describes the expected impact of a single 'driving' indicator on a single 'responding' indicator.
- Response curves use a fixed severity rating scale from -5 to +5 that relate to a fixed scale of percentages changes in abundance.
- A responding percentage change is determined for each driving indicator for each year. Thus, in the example provided (Figure 3.3) for a 50 year record, 50 annual values will be calculated of the response of a fish indicator to dry season duration in

each year. These individual responses are translated to the health or integrity of the particular discipline, or overall.

- Calibrate the response curves 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.
- Analyse scenarios using the DSS and provide outcomes for ecosystem and the people depending on it (Section 7).

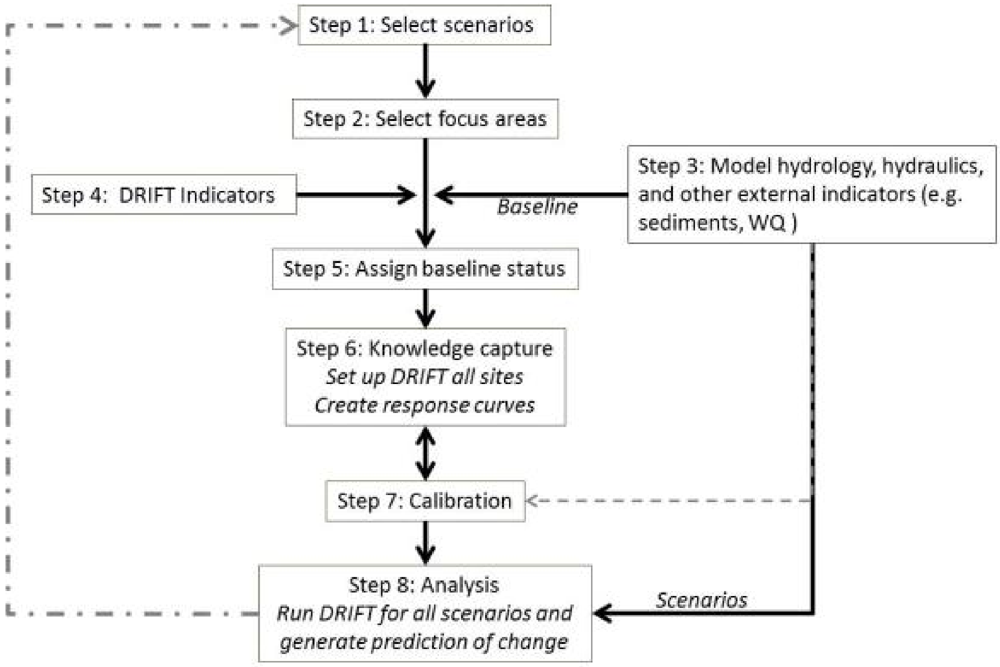


Figure 3.1 The DRIFT process

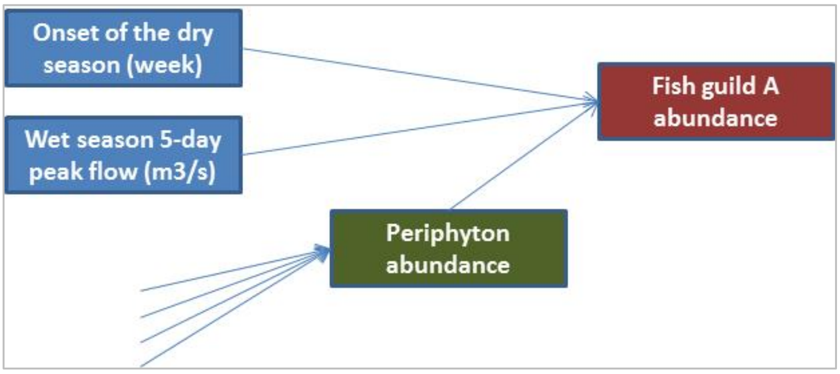


Figure 3.2 Schematic illustrating the concept of 'linked' indicators in DRIFT

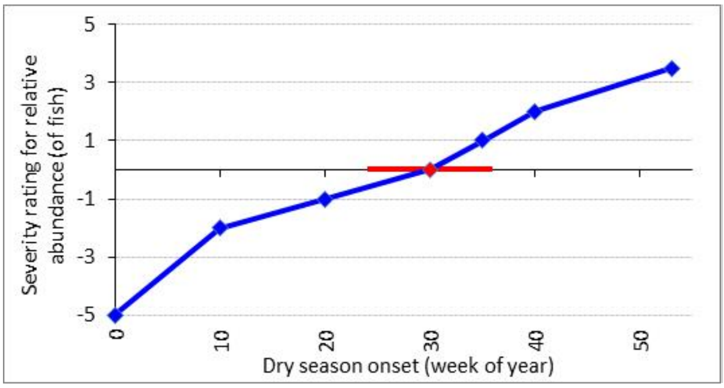


Figure 3.3 Example of a DRIFT response curve

Additional detail on DRIFT is available in Brown et al. (2013).

3.2.2 Data collection

The dates and locations visited for data collection involved are provided in Table 3.1. The coastal dunes were also visited by the vegetation specialist but no specific area was established as a zone for an EWR assessment. Team members involved in the data collection are provided in Table 3.2.

Table 3.1 Dates and locations visit for sampling

Date	Area	Locations visited	Latitude	Longitude
14-Jul-15	Main Basin	Site C	27°19'56"S	32°42'50"E
		Site D	27°22'38"S	32°42'53"E
15-Jul-15	Western Arm	Site K	27°21'16"S	32°33'38"E
		Site L	27°21'15"S	32°33'55"E
14-Jul-15	Northern Arm	Site B	27°16'55"S	32°40'58"E
15-Jul-15	Southwestern Basin	Site H	27°22'23"S	32°40'34"E
		Site I	27°22'58"S	32°40'18"E
		Site J	27°23'22"S	32°39'11"E
16-Jul-15 14-Jul-15	Southern Basin	Site M	27°23'46"S	32°42'36"E
		Site G	27°25'11"S	32°41'52"E
		Site E	27°23'47"S	32°42'42"E
		Site F	27°25'12"S	32°41'44"E
17-Jul-15 18 Jul-15	Coastal dune forest	-	27°22'37"S	32°42'54"E
			27°23'45"S	32°42'43"E

Table 3.2 Team members involved in field sampling

	Participants	Dates attended
Project Team	Steven Weerts	13-16 July 2015
	Ricky Taylor	
	James MacKenzie	
	Jerry Matlawa	
	Adhishri Singh	
DWS: RDM	Molefi Mazibuko	
	Philane Khoza	
	Qoko Mathabo	
eZemvelo Wildlife	Scotty Kyle	15 July 2015

3.2.3 EWR workshop

The EWR workshop was held at the offices of Tlou Consulting in Pretoria from the 31st August to the 4th September. The participants who attended are listed in Table 3.3.

Table 3.3 Participants at Workshop

	Participants	Dates attended
Project Team	Adhishri Singh	31 August – 4 September 2015
	Alison Joubert	
	Karl Reinecke	
	Drew Birkhead	
	Ricky Taylor	
	Jane Turpie	
	Steven Weerts	
	Susan Taljaard	
	Cate Brown	
	Molla Demlie	
DWS: RDM	Philane Khoza	1 September 2015
	Nancy Motebe	
	Molefi Mazibuko	
	Pule Malefetsane	

The workshop schedule is provided below (Table 3.4).

Table 3.4 EWR Workshop programme

Day	Time	Activities	Focus zone	Responsibilities - Specialists	Responsibilities -Process Team	Process Leaders
Monday	8:30-10:00	Introduction to week				Alison and Karl
	10:20-12:30	Ecoclassification	All	Specialists present summary of Ecoclassification results	Adjust and collate summary ecoclassification tables	Karl
	1:30-2:30	Finalise indicators	All	List of indicators and links	Gather all inputs	Alison and Karl
	2:45-5:00		All			
Tuesday	8:30-10:00	DRIFT set up, and instruction	SE Basin	Upload DRIFT DAY 1	DRIFT set-up for Day 1, and instruction for use	Alison and Karl
	10:30-12:30	Population of response curves	SE Basin	DSS response curves for SE Basin	Advise and assist with DRIFT DSS	Alison and Karl
	1:30-3:00	Population of response curves	SE Basin			
	3:00-4:45	Population of response curves	SE Basin			
	4:45-5:00	Provide updated DSS to Karl	SE Basin		Gather all inputs	Karl
	5:00- 7:00	Updating of DRIFT			Update and synthesise DSS inputs from specialists	All
Wednesday	8:00-9:30	DRIFT set up, and discussion	SE Basin & Main Basin	Upload DRIFT DAY 2 and discussion	DRIFT set-up for Day 2. ID issues	Alison and Karl
	10:00-12:30	Population of response curves	SE Basin	Complete DSS response curves for SE AND Main Basin	Advise and assist with DRIFT DSS	Karl
	1:30-3:00	Main Basin	Main Basin			
	3:30-4:45	Population of response curves	Main Basin			
	4:45-5:00	Provide updated DSS to Karl	All		Gather all inputs	Karl
	5:00- 7:00	Updating of DRIFT			Update and synthesise DSS inputs from specialists	All
Thursday	8:30-9:30	DRIFT set up, and discussion	SE, Main Basin & Northern Arm	Upload DRIFT DAY 3 and discussion	DRIFT set-up for Day 3. ID issues	Karl
	10:00-12:30	Population of response curves	Main Basin	Complete DSS response curves for SE & Main Basin & Northern Arm	Advise and assist with DRIFT DSS	Karl
	1:30-3:00	Population of response curves	Northern Arm			
	3:30-4:45	Population of response curves	Northern Arm			

Day	Time	Activities	Focus zone	Responsibilities - Specialists	Responsibilities -Process Team	Process Leaders
	4:45-5:00	Provide updated DSS to Karl	All		Gather all inputs	Karl
	5:00- 7:00	Updating of DRIFT			Update and synthesise DSS inputs from specialists	All
Friday	8:30 - 9:00	DRIFT set up, and discussion	All	Uploading of DRIFT DAY 4 and discussion	DRIFT set-up for Day 4. ID issues	Karl
	9:30-11:00	Population of response curves	SW Basin	Complete DSS response curves for SE, SW & Main Basin, Northern & Western Arm		Alison and Karl
	11:00-12:30	Population of response curves	Western Arm			Karl
	12:30-01:00	Provide updated DSS to Karl	All		Gather all inputs	All
	2:00-3:00	Process team packaging of information			Ecoclassification Report	Karl
	03:00	Workshop ends				

3.3 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 ECOCLASSIFICATION, ECOLOGICAL SENSITIVITY AND IMPORTANCE, AND THE RECOMMENDED AND ALTERNATIVE ECOLOGICAL CATEGORIES

This section summarises the outcome of the discipline-specific Ecoclassification (Present Ecological Status; PES) and Ecological Importance and Sensitivity assessments (EIS), which are provided in Volume 1: Ecoclassification report.

4.1 Present Ecological Status and Ecological Importance and Sensitivity

The PES and EIS of each of the EWR zones are provided in Table 4.1.

Table 4.1 PES of each of the EWR zones

Zone	Code	PES	EIS
Main Basin	MB	B/C	High
Northern Arm	NA	B/C	High
Western Arm	WA	B/C	High
Southwestern Basin	SWB	B/C	High
Southern Basin	SB	C	High
Whole lake	WL	B/C	High

Trends for each discipline at each EWR zone are indicated in Table 4.2.

Table 4.2 Trends in PES for each EWR zone

<table>
<tr><th>Code</th><th>WQ</th><th>Vegetation.</th><th>Molluscs/ Crustaceans</th><th>Fish</th><th>Herpetofauna/ Mammals</th><th>Birds[2]</th></tr>
<tr><td>MB</td><td>Absent</td><td rowspan="5">Alien species stable, indigenous species negative</td><td rowspan="5">Negative/ absent</td><td rowspan="5">Negative</td><td rowspan="5">Negative</td><td rowspan="5">Negative for decreasers, positive for increasers</td></tr>
<tr><td>NA</td><td rowspan="4">Negative</td></tr>
<tr><td>WA</td></tr>
<tr><td>SWB</td></tr>
<tr><td>SB</td></tr>
</table>

The main reasons provided for the decline in condition from natural were contamination from DDT in muddy extremities and nutrient enrichment in shallow waters; altered plant species composition in the aquatic zone and shoreline vegetation as well as reduced non-woody cover on the shore; invasion by an alien mollusc *Tarebia;* changes to habitat preferred by

[2] Birds were assessed at the level of the Whole Lake and the same trends were extrapolated to the EWR zones.

crustaceans due to the presence of an invasive aquatic weed *Myriophyllum;* lake water level reductions reducing the availability of shallow water habitat preferred by fish for feeding and breeding; and reduced numbers of crocodiles and hippopotami from poaching and harvesting of crocodile eggs.

4.2 Recommended and alternative ecological categories

The recommended and alternative ecological categories for each of the Sibaya EWR zones are provided in Table 4.3. These are based solely on ecological considerations.

In accordance with the requirements of the NWRCS, EWRs are normally determined for (at minimum) the REC and two AECs, one class higher and one class lower.

Table 4.3 The recommended and alternative ecological categories (EC) for each of the EWR zones

Zone	Code	PES	REC	AEC1
Main Basin	MB	B/C	B/C	C
Northern Arm	NA	B/C	B/C	C
Western Arm	WA	B/C	B/C	C
Southwestern Basin	SWB	B/C	B/C	C
Southern Basin	SB	C	B/C	C
Whole lake	WL	B/C	B/C	C

5 DRIFT INDICATORS AND ASSESSMENT FRAMEWORK

For the Lake Sibaya EWR assessment, DRIFT made use of a series of hydraulic, ecosystem and social indicators to capture the response of the lake ecosystem to changes in lake-level, and the effects of those responses on the people who use the lake. These are detailed in the Specialist Reports (Volume 3 of the Sibaya EWR report series). This section lists the indicators used.

5.1 Hydraulic and other external indicators

The 23 hydraulic indicators calculated for use in the DRIFT DSS are provided in Table 5.1 along with one other external indicator for accessibility. The relevant summary results of the performance of each hydraulic indicator at each EWR zones are provided in Section 7.1.1 – Section 7.6.1.

Table 5.1 Hydraulic and other external indicators calculated for the Baseline and scenarios

Indicator	Units
Mean annual water level	metres
Volume	Mm^3
Area	km^2
Perimeter	km
Area exposed below 20.39 (beach)	km^2
Area 0 to 7 m deep	metres
Area between 0.65 below and 0.3 above	km^2
Area of beach between 0.6 and 3.8 above	km^2
Area of beach between 4.8 and 8.8 above	km^2
VerDist from water level to fixed (masl) tree-line	Metres above sea level
Area deeper than 7 m	km^2
Area 1 to 1.8 m deep	km^2
Area 2 to 5 m deep	km^2
Area 1.5 to 2 m deep	km^2
Area 1 to 1.5 m deep	km^2
Area 0.5 to 1 m deep	km^2
Area 0 to 0.5 m deep	km^2
Area 0 to 0.3 m deep	km^2
HorDist to tree line	metres
Max Depth	metres
Volume up to 2 m	Mm^3
Volume deeper than 2 m	Mm^3
Rate of change in water level (annual)	metres per annum
Accessibility/Use	Index 1-5.

5.2 Ecosystem and social indicators

The ecosystem indicators used in this assessment are listed in Table 5.2.

Table 5.2 Ecosystem indicators used in the DRIFT DSS. I = increaser, D = decreaser

Disciplines	Indicators	Disciplines	Indicators
Water quality	Conductivity	Herpetofauna and semi-aquatic mammals	Frogs
	Dissolved oxygen		Hippos
	Vol where DIN c. 0.23mg/l		Crocodiles
	Vol where DIN c. 0.07mg/l		Crocs juvenile
	Vol where DIP c. 0.02mg/l	Birds	Little Grebe
	Vol where DIP c. 0.04mg/l		Cormorants
Vegetation	Free floating veg		Darters
	Submerged, rooted veg		Wading birds (I)
	Emergent macrophytes		Wading birds (D)
	Non-woody 'beach' macrophytes		Waterfowl (I)
	Woody 'lake dependent' vegetation		Waterfowl (D)
	Swamp forest		Waders (I)
	Wetlands, Pans connection		Waders (D)
Macro-invertebrates	*Bulinus globosus* (hosts bilharzia)		Gulls & terns (I)
	Tarebia		FW terns (D)
	Melanoides		Kingfishers & birds of prey
	Pulmonates	Social	Domestic use
	Caridina (shrimp)		Recreational use
	Potamonautes (crab)		Fishing
	Hymenosoma (crab)		Water lily harvesting
Fish	Mozambique tilapia (*Oreochromis mossambicus*)		Reeds and sedges
	Sharptooth catfish (*Clarias gariepinus*)		Health (Bilharzia)
	Climbing Perch (*Ctenopoma multispine*)		Cattle watering
	Top minnow and Barb (Cypriniodontidae and Cyprinid)		
	Pelagic fish		
	Other cichlids		
	Gobies		
	Number of species		
	Fishery biomass		

5.3 Assessment framework

The discipline-level assessment framework is shown in Figure 5.1. The inputs to the DRIFT DSS are the modelled time-series' of hydraulics indicators and the other external indicator (accessibility). The individual links between indicators as specified by the specialists, are seen in an example provided for the EWR zone Western Arm (Figure 5.2). Each link between indicators corresponds to a response curve that has been populated in the DSS by the relevant specialist and describes the relationship between the input and output indicators (Section 3.2.1).

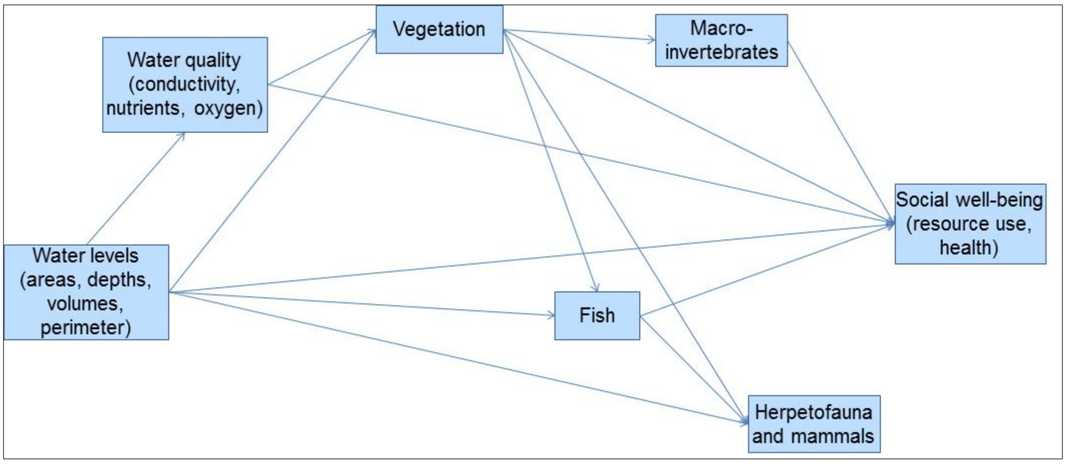


Figure 5.1 Discipline-level assessment framework for the Lake Sibaya EWR assessment

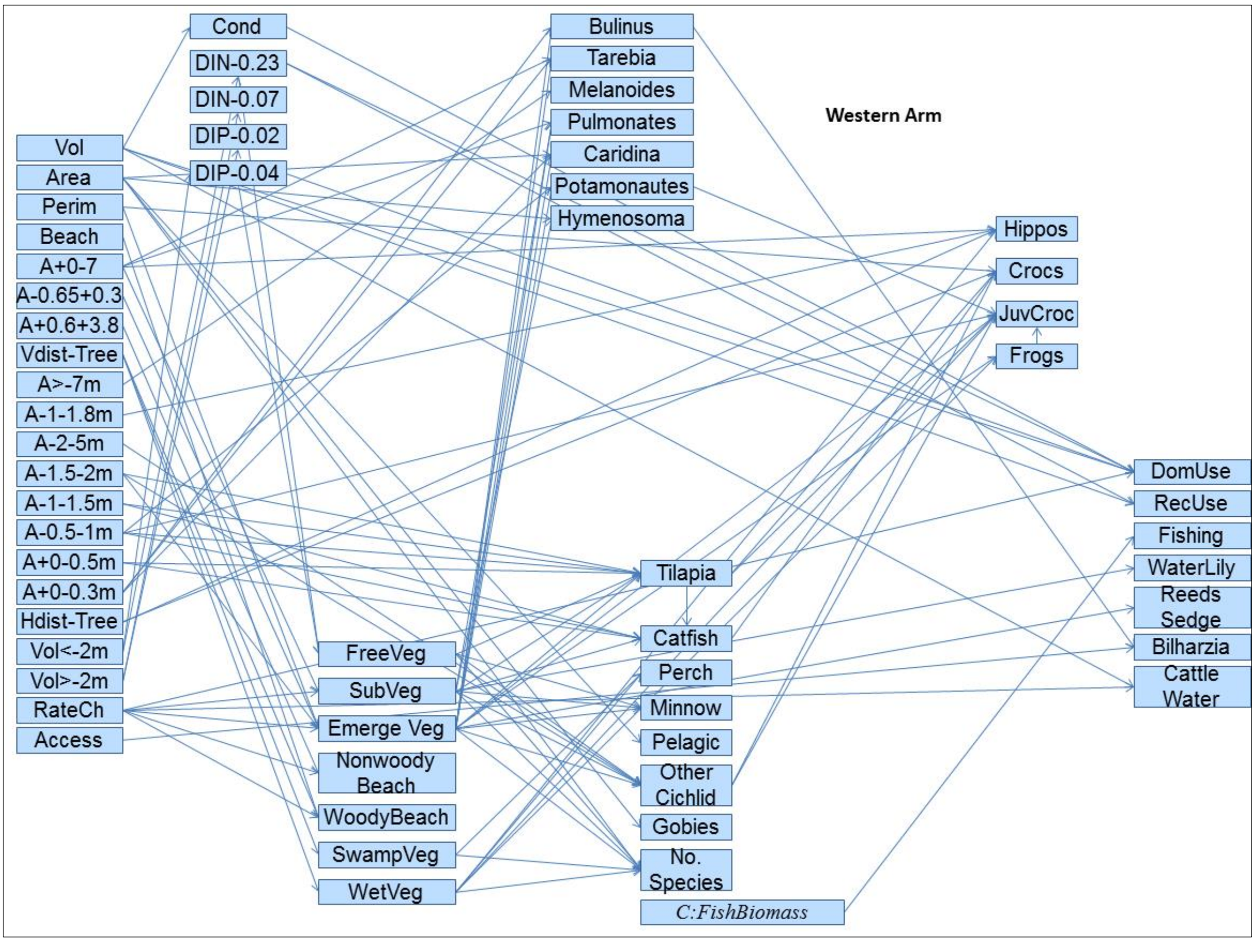


Figure 5.2 The links between indicators at the Western Arm in the Lake Sibaya DRIFT DSS

5.4 Aggregation of lake zones into Whole Lake

For assessment purposes the lake was divided into five zones (see Section 2). However, an overall assessment for the Lake Sibaya as a whole was also needed, so a sixth "zone" was added to DRIFT, and named the "Whole Lake". Apart from Birds, the assessment for the Whole Lake was done by aggregating the assessments of the five basins. Technically within DRIFT, this was done through creating "composite indicators" in the Whole Lake zone which were comprised the equivalent indicators from each of the zones. For example, the fish indicator "Gobies" at the Whole Lake level was calculated by taking a weighted sum of the Goby values (for each season, for the whole time-series) from each lake zone (see Figure 5.3 for a printscreen of this part of the DRIFT-DSS).

The weights applied to the composite indicators are provided in Section 5.5.

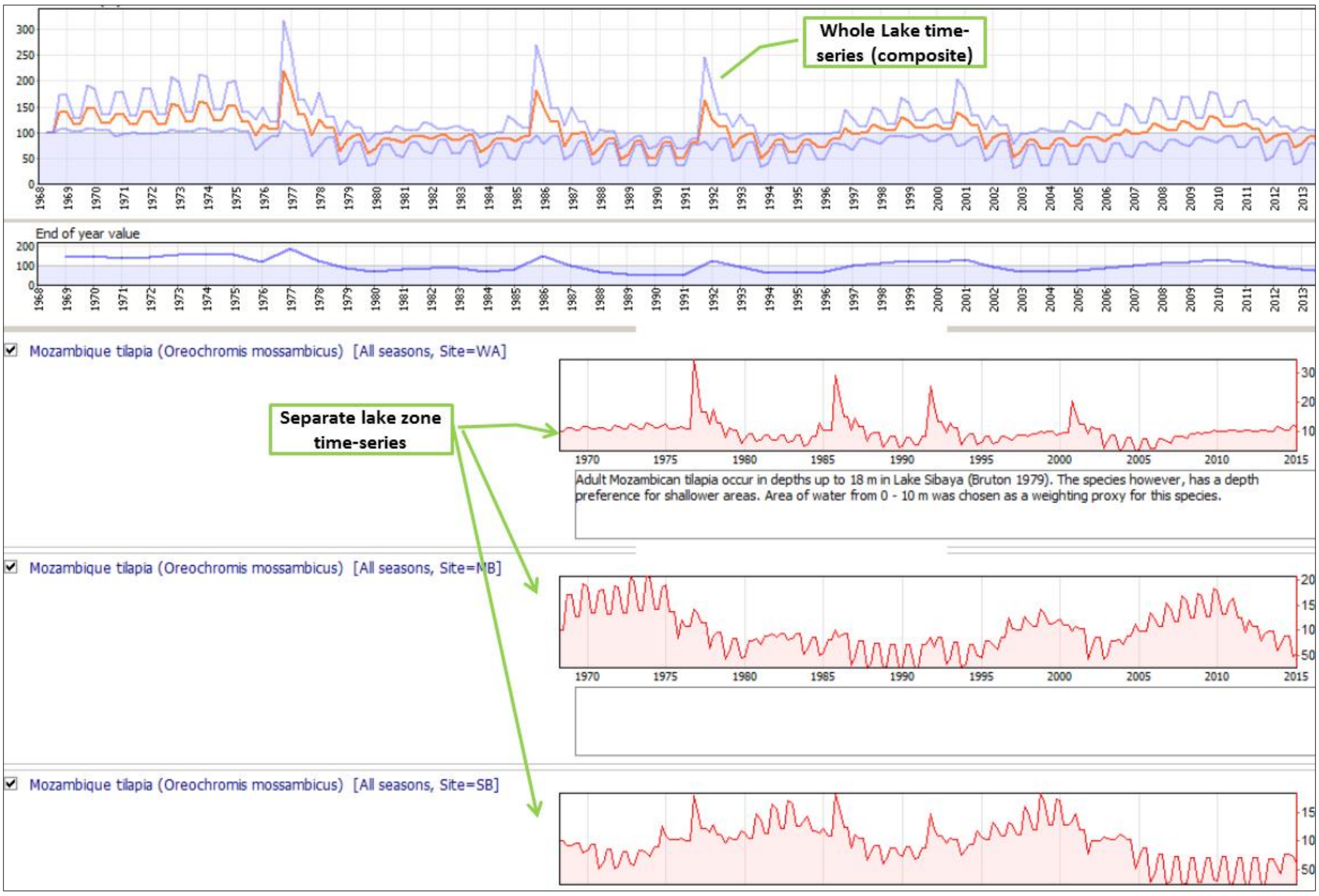


Figure 5.3 An example of a composite Whole Lake indicator as viewed in the DRIFT DSS

5.5 Weights

There are a number of places within the DRIFT method, where weights may be applied. These are:

- when aggregating composite indicators (indicators constructed by taking a weighted sum of other indicators)
- when aggregating individual indicators to calculate overall discipline level integrity
- when aggregating individual discipline to calculate overall site level integrity

Note that weights are always normalised to sum to 1.

In this application, all weights were equal, apart from where composite indicators were created, and where indicators were omitted from contributing to the overall discipline level integrity (e.g. fishery biomass was given a zero weight in the integrity score calculation).

At the individual lake zone level, the only composite indicator was "Fishery biomass", which was a measure of the fish biomass available for local fishers, and thus an aggregation of various fish indicators (Table 5.3).

Table 5.3 Weights for calculating composite Fish biomass at each lake zone

Fishery biomass	Weights
Mozambique tilapia (*Oreochromis mossambicus*)	35
Sharptooth catfish (*Clarias gariepinus*)	28
Climbing Perch (*Ctenopoma multispine*)	0
Top minnow and Barb (Cypriniodontidae and Cyprinid)	1
Pelagic fish	0
Other cichlids	35
Gobies	2

Composite indicators were also created for every ecosystem and social indicator, in order to calculate the Whole Lake results (as described in Section 5.4). All weights are shown in Table 5.4.

Table 5.4 Weights for calculating Whole Lake time-series for all indicators

Discipline	Indicator	MB	SB	SWB	WA	NA
Water quality	All indicators	0.7	0.04	0.03	0.15	0.08
Vegetation	Free floating veg	n/a	1	n/a	2	n/a
	Submerged, rooted veg	1	1	1	2	2
	Emergent macrophytes	1	1	1	3	3
	Non-woody 'beach' macrophytes	2	1	1	2	2
	Woody 'lake dependent' vegetation	2	1	1	2	2
	Swamp forest	n/a	n	n/a	1	2
	Wetlands, Pans connection	n/a	1	1	3	2
Macro-invertebrates	Equal weights across all lake zones for all indicators	1	1	1	1	1

Discipline	Indicator	MB	SB	SWB	WA	NA
Fish	Mozambique tilapia (*Oreochromis mossambicus*)	16.15	1.82	1.8	7	4.63
	Sharptooth catfish (*Clarias gariepinus*)	34.98	3.31	2.76	12.21	6.96
	Climbing Perch (*Ctenopoma multispine*)	2.39	0.3	0.3	2.88	2.43
	Top minnow and Barb (Cypriniodontidae & Cyprinid)	8.77	0.97	0.89	3.56	2.48
	Pelagic fish	27.97	2.34	1.87	8.65	4.47
	Other cichlids	24.97	3.19	2.74	11.85	6.51
	Gobies	30.64	3.3	2.76	12.21	6.86
	Fishery biomass	1	1.87	1.14	2.24	1.87
	Number of species	16.15	1.82	1.8	7	4.63
	Fishery biomass	1	1.87	1.14	2.24	1.87
Herpetofauna and Mammal	Frogs	1	1	1	1	1
	Hippos	10	10	20	40	20
	Crocodiles	20	10	10	30	30
	Croc juveniles	20	10	10	30	30

MB=Main Basin, SB=Southern Basin, SWB=Southwestern Basin, WA=Western Arm, NA=Northern Arm

6 SELECTION AND EVALUATION OF SCENARIOS

6.1 Introduction

In accordance with the requirements of the NWRCS, EWRs are normally determined for (at minimum) the REC and at least one AEC. The DRIFT approach considers the consequences of a range of water level scenarios that anticipate potential future changes in water level, for a range of possible reasons, including those that may occur outside of the present day range of conditions. These broad sets of scenarios are designed to capture as full a range as possible of changes in water level so that the ecological and social consequences of each can be considered.

The process begins with the population of the DRIFT DSS by the specialists during the workshop, and calibration of the response curves with the "calibration scenarios". Once the DSS is populated and calibrated, the outcomes of the EWR scenarios are calculated in the DRIFT DSS. The calibration and EWR scenarios considered in this study are given in Figure 6.1. Scenarios were evaluated for each of the five EWR lake zones, and for the 'Whole Lake', which is a weighted aggregation (see Section 5.4) of the scores for the five lake zones.

6.2 Calibration and EWR scenarios

One baseline and two "calibration" scenarios were used by the specialists to calibrate their response curves. These were:

Baseline:	The Baseline (**Base**) scenario contained the measured water level data from DWS, with some corrections made (see Section 2, Volume 3; EWR Specialists' Reports).
Modelled Natural:	This scenario (**ModNat**: for "modelled natural") used the Baseline data up to April 2006 and then modelled water levels using the relationship between rainfall and water level (see Appendix A[3]), as naturalised water level data were not available. Thus, from 1968 to 2006, Baseline data were used, and from April 2006 to June 2015, modelled data were used.
Drying 2006 levels:	This scenario (**Dry2006**) started at the water level recorded as at January 2006 from the start of the time-series and continued the downward trajectory for the entire period i.e. up to July 2015.

Subsequently a range of "EWR scenarios" were developed and assessed in:

EWR scenarios:	The EWR scenarios were calculated by taking the ModNat scenario, as a starting point, and successively reducing the levels, at 0.5 m intervals. Nine scenarios were created at decreased levels from 0.5 m to 4.5 m (called **MN05** to **MN45**) (Figure 6.1).

[3] A good relationship was found between the 5-year running average rainfall and measured water levels (see Appendix A).

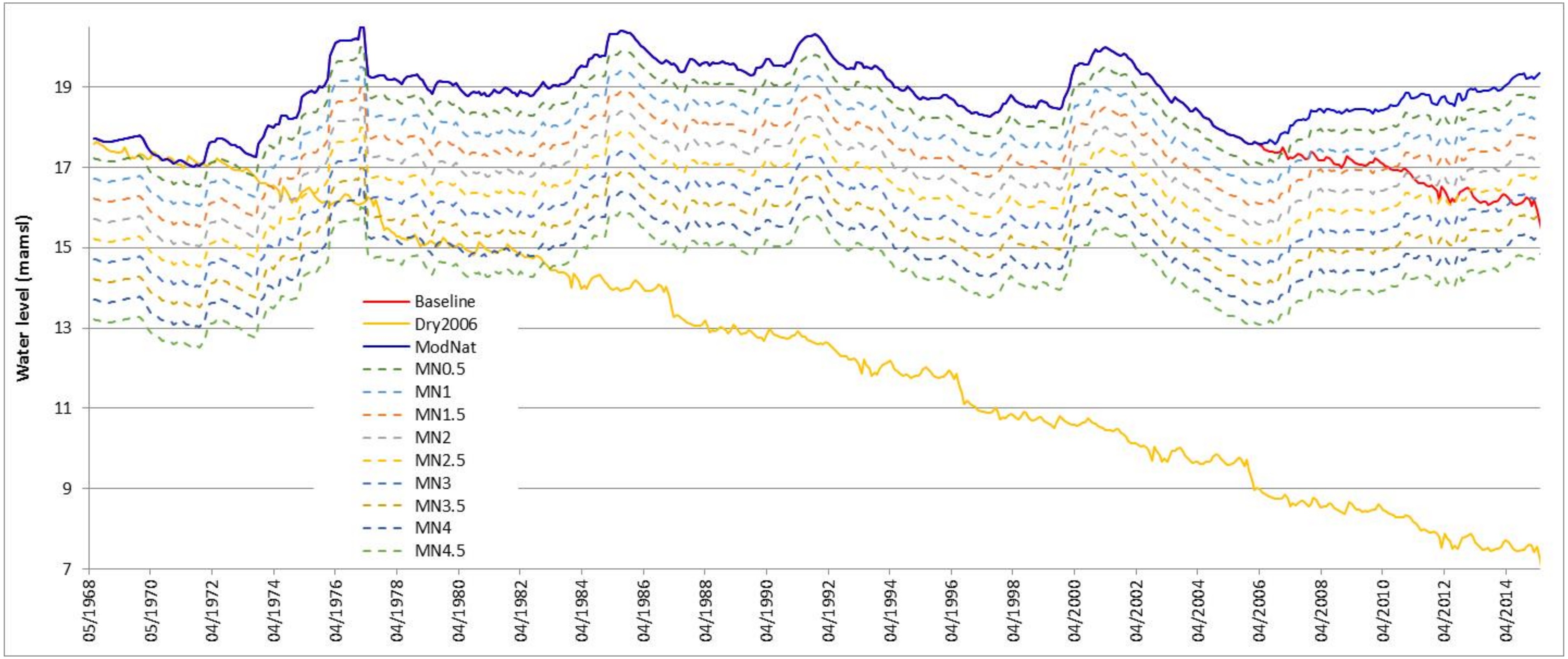


Figure 6.1 Calibration scenarios, together with first set of EWR selection scenarios[4]

[4] Baseline, Dry2006 and ModNat are calibration scenarios. All others are EWR scenarios.

6.3 Selection of scenarios for REC and AEC

The 12 scenarios (three calibration and nine EWR) were run in the DRIFT DSS, to produce an overall ecosystem integrity result per scenario for each EWR zone (Figure 6.3) and for the Whole Lake (Figure 6.2).

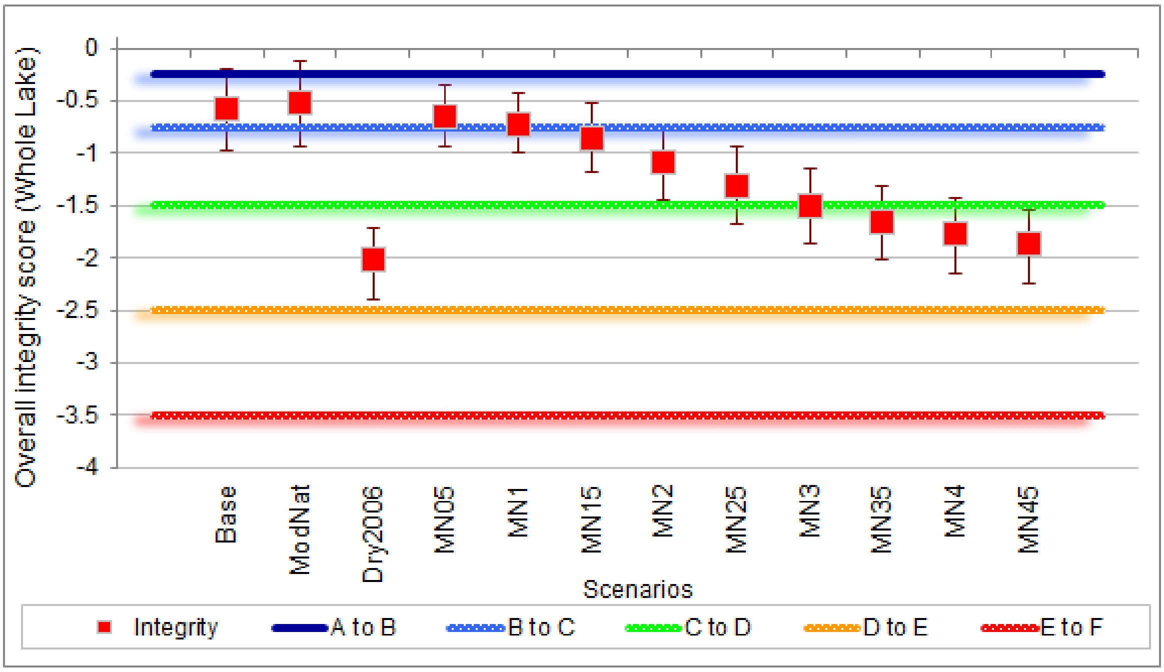


Figure 6.2 Overall ecosystem integrity for the 12 scenarios

For the Whole Lake (Figure 6.1), as expected, the modelled natural scenario returned a greater (better) ecosystem integrity score than the Baseline as the ecosystem integrity recovered as water levels rise from April 2006 – July 2015 under modelled natural conditions. Similarly, the worst ecosystem integrity generated was that for the extreme scenarios - Dry2006, followed by successively improved scores for MN45 to MN05, which represent increasing base water levels from 4.5 m lower than those in ModNat to 0.5 m lower than ModNat.

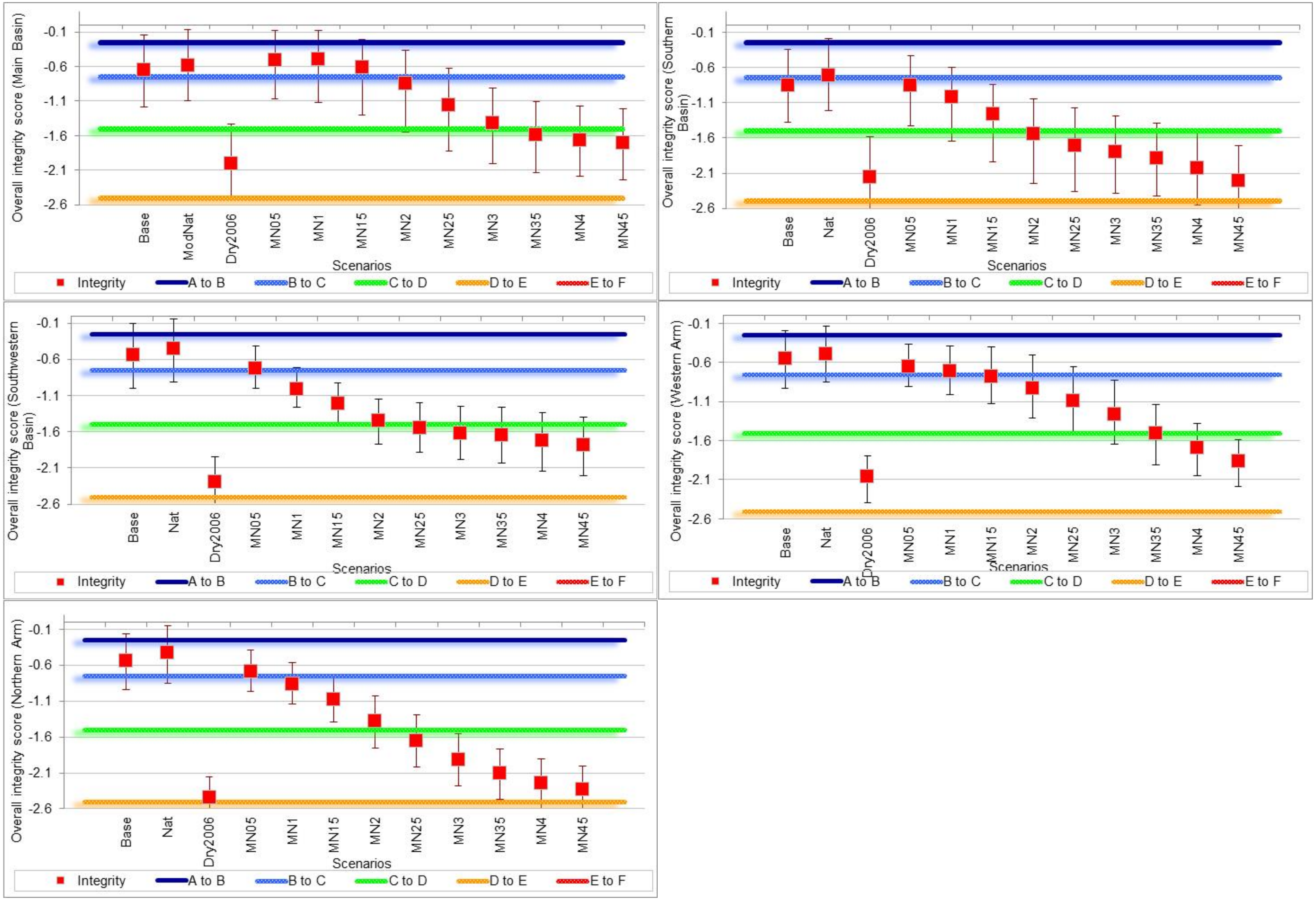


Figure 6.3 Overall ecosystem integrity for the 12 scenarios for the five EWR lake zones

A similar pattern was seen in all the five EWR zones (Figure 6.3), although the extent to which the integrity scores changed from Baseline differed between the zones.

The pattern for the Main Basin and Western Arms were most similar to those for the Whole Lake, whereas the integrity scores for the EWR scenarios in the Southern and Southwestern Basin and the Northern Arm were relatively lower. The Ecological Categories associated with the changes in integrity for the Whole Lake and the five EWR zones are provided in Table 6.1.

Table 6.1 Ecological categories associated with the scenarios Base, ModNat, MN05, MN1, MN15, MN2 and MN25 for the five Lake Sibaya areas

	PES	REC	AEC	Base	Nat	MN05	MN1	MN15	MN2	MN25
Main Basin	B/C	B/C	C	B/C	B/C	B/C	B	B/C	C	C
Northern Arm	B/C	B/C	C	B/C	B	B/C	C	C	C/D	C/D
Western Arm	B/C	B/C	C	B/C	B	B/C	B/C	C	C	C
Southwestern Basin	B/C	B/C	C	B/C	B	B/C	C	C	C/D	C/D
Southern Basin	C	B/C	C	C	B/C	C	C	C	C/D	C/D
Whole Lake	B/C	B/C	C	B/C	B/C	B/C	B/C	C	C/D	C/D

The REC (and PES) of the Whole Lake is a B/C category that is returned by two scenarios, MN05 and MN1 (Table 6.1), while the AEC category C for the Whole Lake is returned by MN15. However, there is variation in the configuration of ecological categories returned at the five EWR zones within each of these scenarios. It is important to recognise that this variation in response between the EWR zones and the Whole Lake occurs because of differences in the way some indicators respond to changing water levels mainly as a result of localised differences in physical, ecological and social characteristics of the EWR zones.

Of the options presented in Table 6.1, the three scenarios that were considered as EWRs are MN05, MN1 and MN15. The first two return the required REC of a B/C category, and MN15 returns the AEC of a C. The water level fluctuations in these three scenarios, relative to the Baseline, are shown in Figure 6.4.

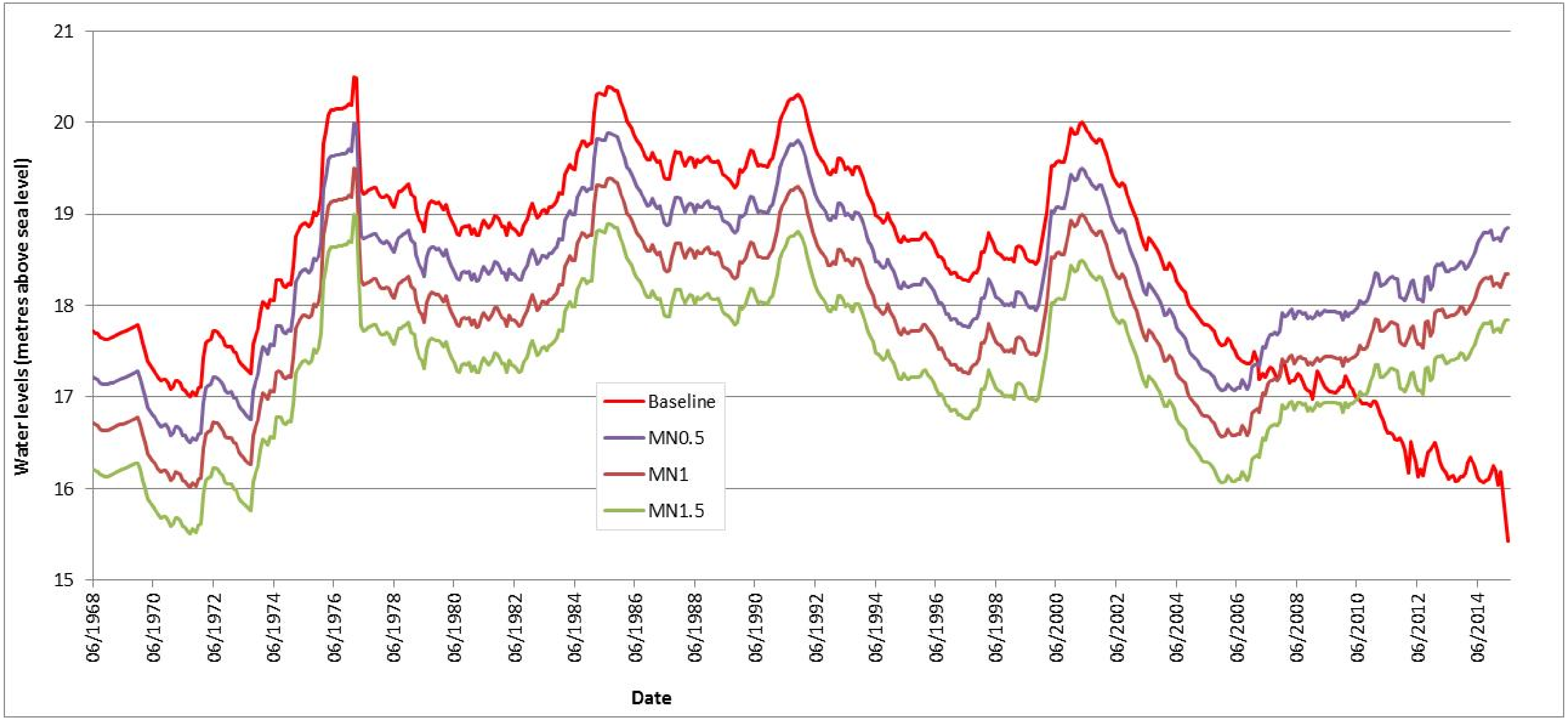


Figure 6.4 Water levels for MN05, MN1, and MN1.5

While MN05 returns the REC ecological categories more closely than does MN1, there are several reasons why MN1 was considered a preferable REC scenario. These include the minimum water levels reached in the two scenarios, and other comparative statistics.

As can be seen in Figure 6.4, MN1 reaches a similar minimum water level to Baseline (0.5 metres above those measured in July 2015), whereas MN05's minimum is a full metre above Baseline's. The fact that the Baseline, with current water levels of 15.43 masl, is a B/C, implies that the ecostatus is not dependent on water levels being retained at levels higher than this *at all times*, as in MN05.

The team appreciated that the whole of Northern KwaZulu Natal is currently in a severe drought. The extremely low levels as at July 2015 are considered to be a result of the combination of a severe drought and concomitant reduced rainfall but is without doubt exacerbated by abstractions and forestry in the Lake basin. It is, however, clear from the scenarios that the specialists were unanimous in the opinion that:

1. lake water levels have undergone large fluctuations in the past – even in the absence of abstraction (Pitman and Hutchinson 1975), and as such the lake ecosystem is adapted to both low and high water levels;
2. the variation in lake level is an important component factor in both the biodiversity and the resilience of the lake ecosystem;
3. ecostatus for the individual zones changes significantly once the water level drops to a level that results in the separation of some zones from the whole lake (the Southern Basin is the first to become separated; Section 8.2) – and that this therefore represents an important threshold for a maintenance EWR;
4. the Lake ecosystem will recover from 2015 water levels if the water level rises again, and;
5. water levels will rise in response to higher rainfall.

For this reason, and on the basis of the results in Table 6.1, MN1 was selected as the REC as it returns the required REC of a B/C category for the Whole Lake and the Western Arm, along with a B category in the Main Basin and C categories for the Northern Arm and the Southern and Southwestern Basins, and has reached to within 0.5 m of the present day water level at one point in its duration (at 1971). Importantly, MN1 means that the five zones of Lake Sibaya remain connected.

To cater for the current drought situation, the REC Reserve is augmented with DROUGHT water level threshold, which should only apply in drought events (see Section 9.4).

MN15 was selected as the AEC1 as it returns the required C for the Whole Lake, the Northern and Western Arms and the Southwestern and Southern Basins, along with a B/C for the Main Basin, and has reached down to present day water levels at one point in its duration (at 1971).

MN05 was selected as the AEC2 for the better case scenario should water levels recover in the future, which returns the required B/C for the Whole Lake and higher individual categories for the five component EWR zones, including a B category for the Main Basin. Higher water levels will not necessarily improve the condition of the lake further, as many of the impacts resulting in the PES being Category B/C are not flow related, e.g., hunting of hippos and crocodiles.

Table 6.2 Ecological categories associated with the scenarios Base, ModNat, MN05, MN1 and MN15 for the five Lake Sibaya areas

		REC	AEC1	AEC2
	PES	MN1	MN15	MN05
Main Basin	B/C	B	B/C	B/C
Northern Arm	B/C	C	C	B/C
Western Arm	B/C	B/C	C	B/C
Southwestern Basin	B/C	C	C	B/C
Southern Basin	C	C	C	C
Whole Lake	B/C	B/C	C	B/C

7 DRIFT RESULTS FOR THE EWRS FOR REC AND AEC

This Section provides the results for the EWRs to maintain REC, AEC1 and AEC2. These include:

- time-series plots showing expected variations in each indicator with climatic variations;
- predicted changes in percentage of 2015 abundance for each indicator, and;
- predicted change in overall ecosystem integrity and overall social well-being, relative to Baseline.

The EWRs and the expected ecological condition associated with each are provided in Table 7.1.

Table 7.1 The scenarios and Ecological Categories for REC, AEC1 and AEC2

		REC	AEC1	AEC2
Lake Zone	Code	MN1	MN15	MN05
Main Basin	B/C	B	B/C	B/C
Northern Arm	B/C	C	C	B/C
Western Arm	B/C	B/C	C	B/C
Southwestern Basin	B/C	C	C	B/C
Southern Basin	C	C	C	C
Whole Lake	B/C	B/C	C	B/C

EWRs were evaluated for each lake zone for each discipline, apart from Birds, which were assessed for the Whole Lake only as the available data did not allow a more disaggregated assessment.

It is worth noting that increased lake levels, such as that associated with a B-Category versus a B/C-Category do not necessarily result in a universal improvement in all indicators. This is because:

- changes in water level do not have a uni-directional relationship with all hydraulic indicators (e.g. decreasing water levels may result in increased 0-2 metre depth habitat, up until a certain point, followed by decreased habitat, and this relationship will be different in each lake zones), and
- water levels affect different species differently, and hence change the balance between the species.

Additional detail on the reasoning behind the responses of each indicator is provided in the Specialist Report (Volume 3) of the Sibaya report series for this project.

7.1 Main Basin

7.1.1 Hydraulics

The main hydraulic characteristics associated with each of the scenarios at the Main Basin, and the index score for accessibility, are given in Table 7.2.

Table 7.2 Hydraulic characteristics of each scenario at the Main Basin. Median values are given for the hydraulic indicators and a ranked score is given for accessibility

		REC	AEC1	AEC2
Main Basin	Base	MN1	MN15	MN05
Mean annual water level	18.82	17.87	18.32	18.37
Volume	511.87	477.68	493.63	495.59
Area	36.78	35.39	36.12	36.18
Perimeter	32.10	36.13	33.49	33.21
Area exposed below 20.39 (beach)	3.15	4.54	3.81	3.75
Area 0 to 7 m deep	12.18	12.19	12.21	12.27
Area between 0.65 below and 0.3 above	1.84	1.71	1.85	1.49
Area of beach between 0.6 and 3.8 above	5.32	5.98	6.06	5.80
Area of beach between 4.8 and 8.8 above	0.00	0.00	0.00	0.00
VerDist from water level to fixed (amsl) tree-line	1.47	2.42	2.92	1.92
Area deeper than 7 m	24.44	23.20	23.78	23.85
Area 2 to 5 m deep	1.40	1.71	1.49	1.60
Area 1.5 to 2 m deep	5.22	5.02	5.08	5.08
Area 1 to 1.8 m deep	0.86	1.03	1.00	1.08
Area 1 to 1.5 m deep	0.85	1.08	0.92	0.96
Area 0.5 to 1 m deep	0.80	0.96	0.86	0.89
Area 0 to 0.5 m deep	0.79	0.89	0.82	0.80
Area 0 to 0.3 m deep	0.47	0.51	0.48	0.46
HorDist to tree line	96.06	144.25	119.40	117.21
Max Depth	41.73	40.78	41.22	41.28
Volume up to 2 m	3.59	4.15	3.74	3.98
Volume deeper than 2 m	507.91	473.30	489.27	491.25
Rate of change in water level (annual)	-0.09	0.02	-0.09	0.02
Accessibility/Use	1.00	1.00	1.00	1.00

7.1.2 Time-series of responses

The time-series of predicted abundance changes relative to Baseline under the EWRs for maintaining a B and B/C are provided for the indicators for each discipline (Figure 7.1 to Figure 7.6). These illustrate the sorts of annual fluctuations that can be expected as a result of climatic variations and the responses of different indicators to these changes.

Note: Where a graph is blank the indicator was not used for the zone.

Figure 7.1 Water quality time-series for Baseline, REC, AEC1 and AEC2 at the Main Basin[5]

[5] Blank graphs were not indicators in this zone

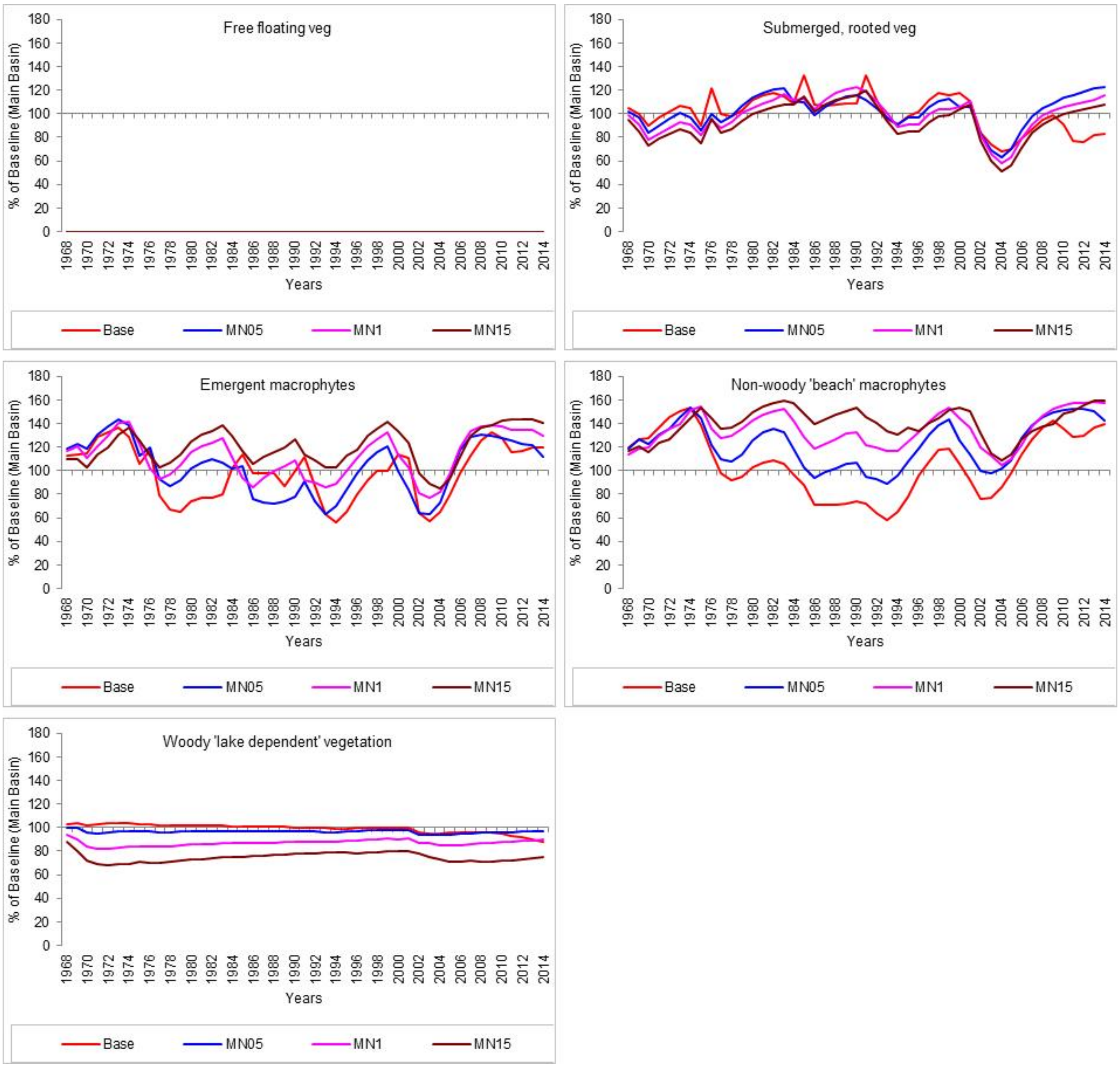
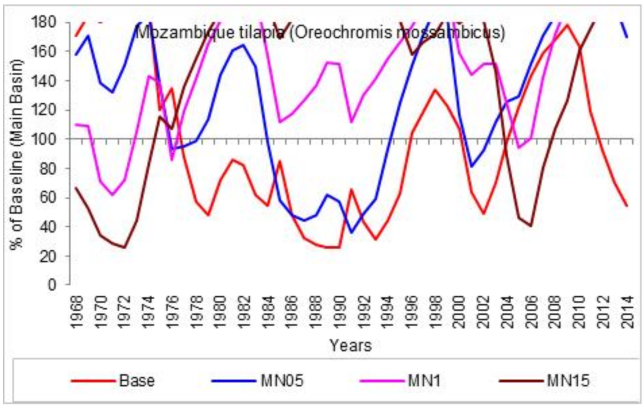
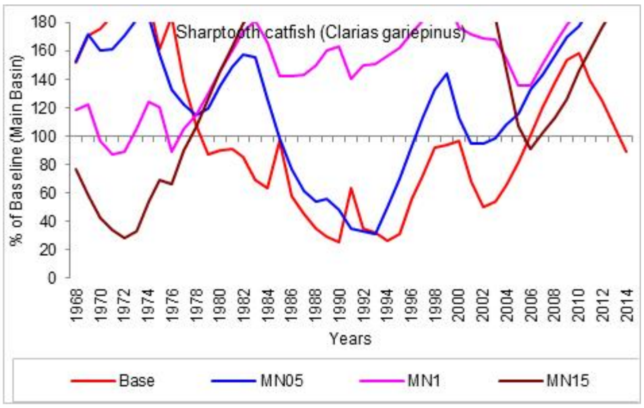


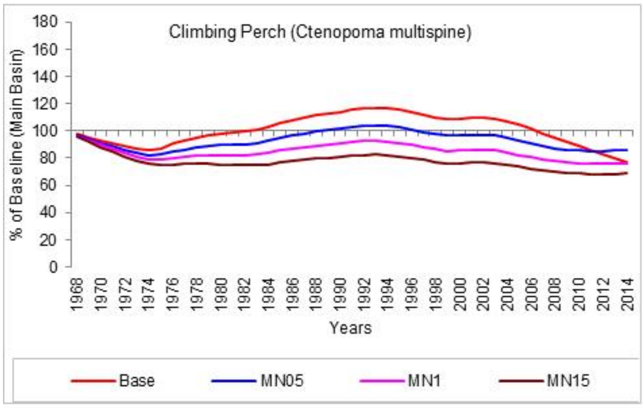
Figure 7.2 Vegetation time-series for Baseline, REC, AEC1 and AEC2 at the Main Basin[6]

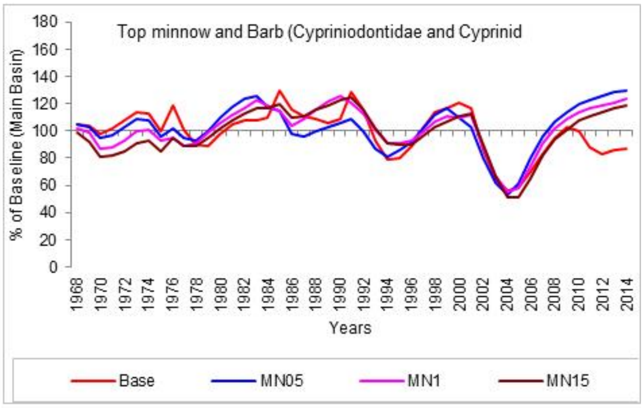
[6] Blank graphs were not indicators in this zone

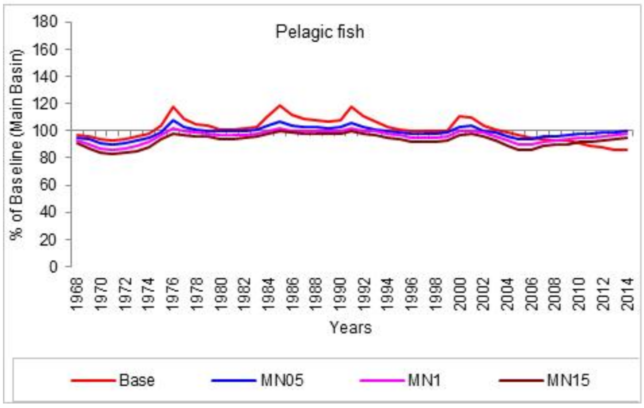
Figure 7.3 Macroinvertebrate time-series for Baseline, REC, AEC1 and AEC2 at the Main Basin

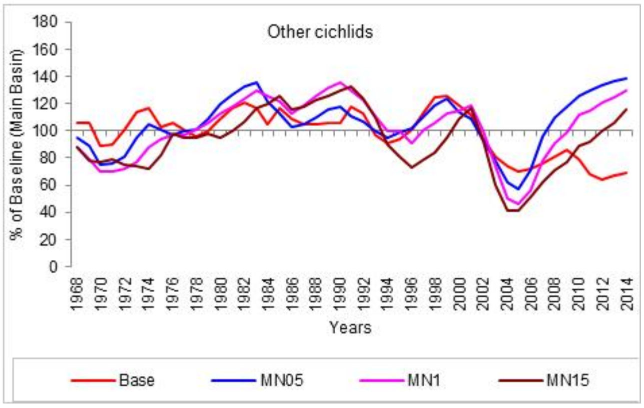












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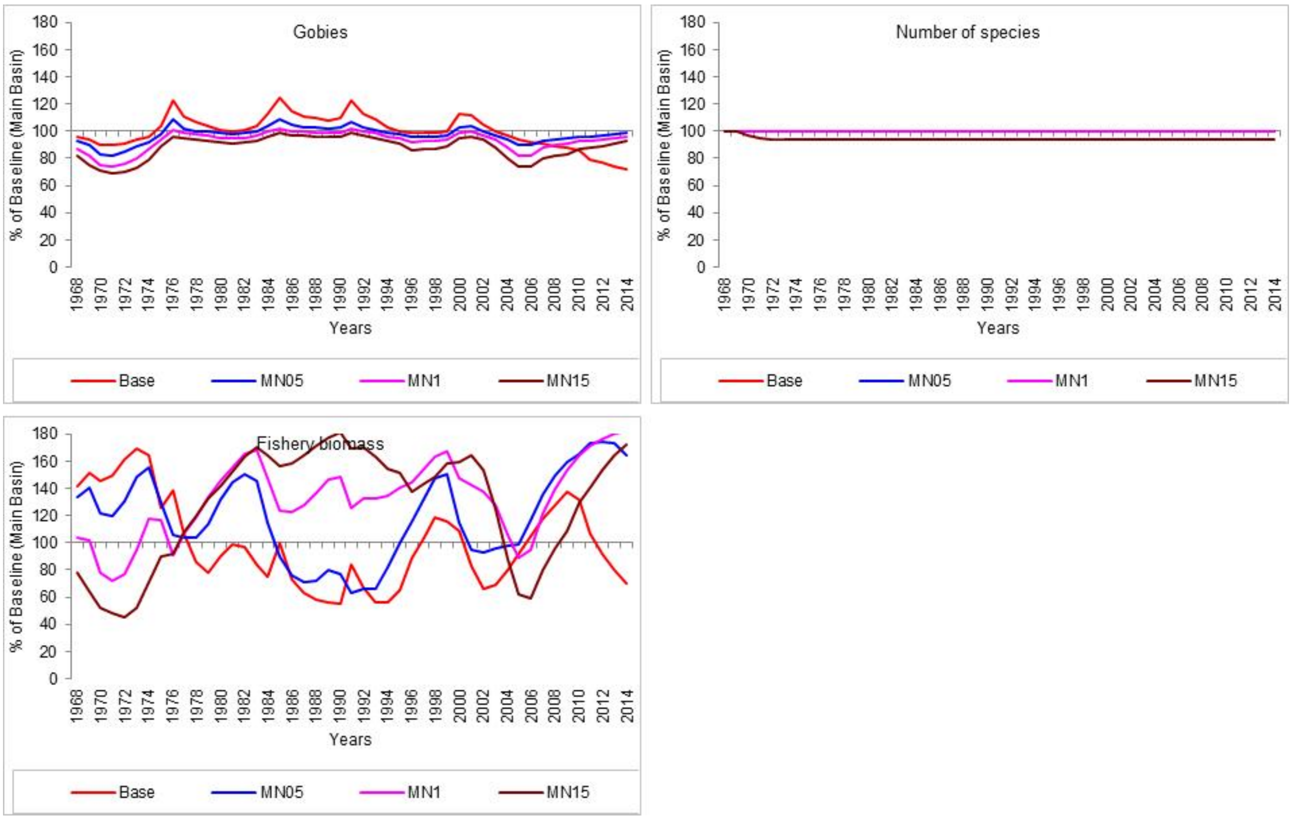


Figure 7.4 Fish time-series for Baseline, REC, AEC1 and AEC2 at the Main Basin

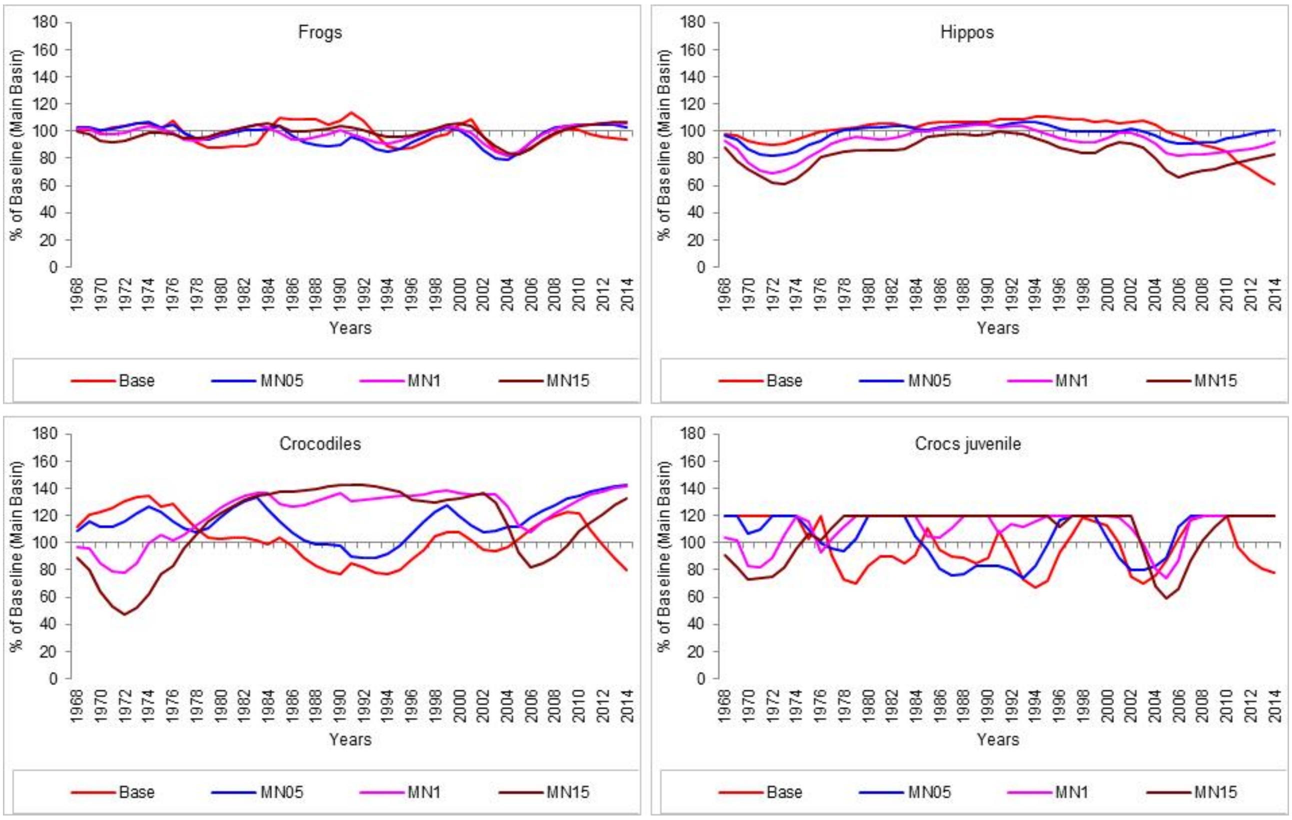


Figure 7.5 Herpetofauna and Mammals time-series for Baseline, REC, AEC1 and AEC2 at the Main Basin

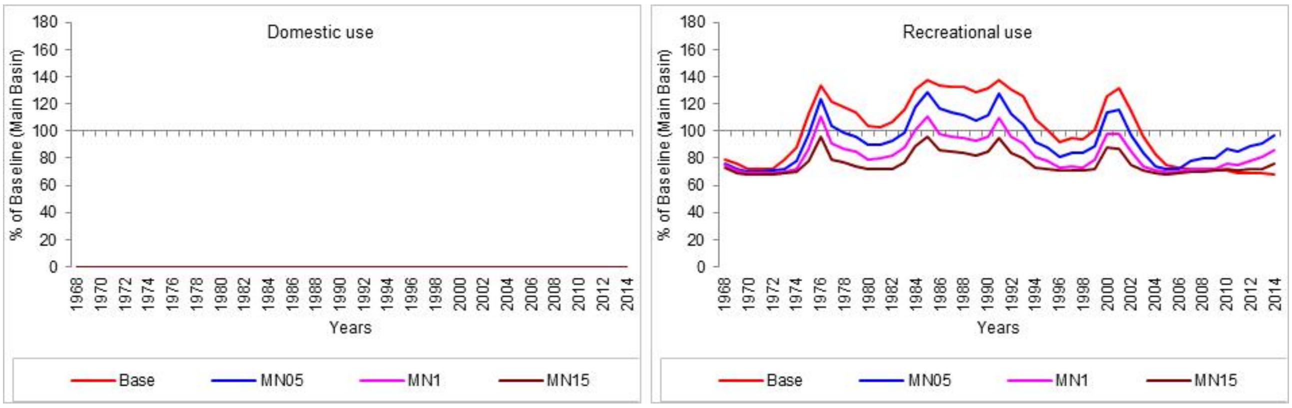


Figure 7.6 Social time-series for Baseline, REC, AEC1 and AEC2 at the Main Basin[7]

7.1.3 Mean percentage changes

The mean percentage changes (relative to Baseline) for the ecosystem indicators for the EWRs selected for REC, AEC1 and AEC2 at the Main Basin are given in Table 7.3. The changes illustrate that there is little difference overall between the Baseline and EWR scenarios, despite some increased abundances of non-woody beach macrophytes, Mozabique Tilapia and Sharptooth Catfish. Overall, however, the B-scenario is expected to maintain a better ecological condition than the B/C-scenarios.

Table 7.3 Main Basin: The mean percentage changes in abundance (relative to 2015) for the indicators for the EWRs for maintaining a B/C and C category.

Blue and green = increases. Green = 30-50%; Blue = >50%.
Orange and red = decreases. Orange = 30-50%; Red = >50%.
Baseline, by definition, should be close to 100%.

Discipline	Indicator		REC	AEC1	AEC2
		Base	MN1	MN15	MN05
Water quality	Conductivity	-3.6	1.7	3.1	-0.7
	Dissolved oxygen	0.5	1.1	1.5	0.6
	Vol where DIN c. 0.23mg/l				
	Vol where DIN c. 0.07mg/l	-2.5	-1.7	-4.3	-0.3
	Vol where DIP c. 0.02mg/l	-2.5	-1.7	-4.3	-0.3
	Vol where DIP c. 0.04mg/l				
Vegetation	Free floating veg				
	Submerged, rooted veg	0.6	-1.1	-5.3	1.7
	Emergent macrophytes	-1.4	9.9	16.1	2.3
	Non-woody 'beach' macrophytes	4.6	29.3	33.9	18.8
	Woody 'lake dependent' vegetation	-1.0	-12.6	-24.4	-3.5
	Swamp forest				
	Wetlands, Pans connection				

[7] Blank graphs were not indicators in this zone

Discipline	Indicator	Base	REC MN1	AEC1 MN15	AEC2 MN05
Macro-invertebrates	*Bulinus globosus* (bilharzia host)	10.2	14.6	29.7	2.5
	Tarebia	11.1	13.7	25.1	4.6
	Melanoides	-2.5	-6.2	-9.1	-3.2
	Pulmonates	-0.2	1.8	2.6	0.6
	Caridina (shrimp)	1.0	-0.5	-0.7	-0.1
	Potamonautes (crab)	-0.6	4.0	5.8	1.0
	Hymenosoma (crab)	-0.2	-3.5	-6.0	-1.2
Fish	Mozambique tilapia (*Oreochromis mossambicus*)	0.7	34.4	33.3	20.3
	Sharptooth catfish (*Clarias gariepinus*)	-0.5	42.1	39.7	19.0
	Climbing Perch (*Ctenopoma multispine*)	0.7	-13.2	-19.4	-6.0
	Top minnow & Barb (Cypriniodontidae & Cyprinid	-0.5	1.2	-1.0	1.2
	Pelagic fish	0.8	-2.9	-4.9	-0.8
	Other cichlids	-0.9	1.3	-4.9	3.7
	Gobies	0.3	-5.0	-8.3	-1.8
	Number of species	0.0	-0.2	-5.6	0.0
	Fishery biomass	-0.2	24.2	20.9	13.7
Herpetofauna and Mammals	Frogs	-1.4	-1.4	-1.0	-2.2
	Hippos	-0.2	-7.1	-13.8	-1.6
	Crocodiles	3.3	18.9	11.3	13.0
	Crocs juvenile	-1.4	6.4	4.7	2.4
Socio-economics	Domestic use				
	Recreational use	0.5	-14.5	-20.3	-5.8
	Fishing				
	Water lily harvesting				
	Reeds and sedges				
	Health (Bilharzia)				
	Cattle watering				

7.1.4 Ecosystem integrity and social well-being

The Overall Ecological Integrity of the Main Basin for each scenario is illustrated in Figure 7.7.

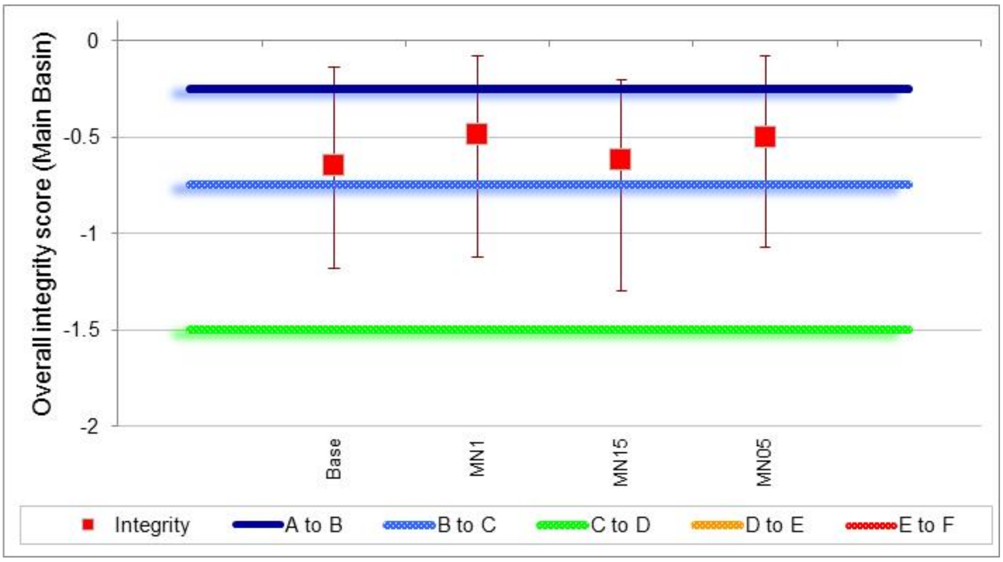


Figure 7.7 Overall ecosystem integrity scores for the Main Basin

The Baseline is a B/C for the Main Basin (for details see Volume 1: Ecoclassification Report). MN1 returns an improved category B while MN15 and MN05 return the REC B/C condition.

The social well-being scores for the Main Basin are illustrated in Figure 7.8 and depict a decrease in social well-being for all the scenarios. The main reason for this is reduced recreational use of the Main Basin at lower lake levels.

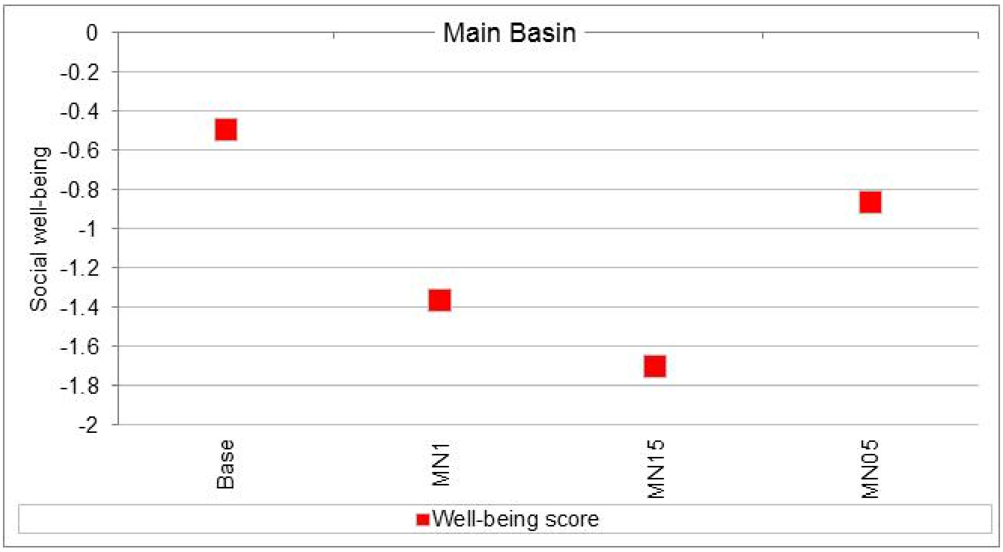


Figure 7.8 Social well-being scores for the Main Basin

7.2 Northern Arm

7.2.1 Hydraulics

The main hydraulic characteristics associated with each of the scenarios at the Northern Arm, and the index score for accessibility, are given in Table 7.4.

Table 7.4 Hydraulic characteristics of each scenario at the Northern Arm. Median values are given for the hydraulic indicators and a ranked score is given for accessibility

Northern Arm		REC	AEC1	AEC2
	Base	MN1	MN15	MN05
Mean annual water level	18.82	17.87	18.32	18.37
Volume	58.28	51.90	54.84	55.21
Area	6.97	6.46	6.75	6.77
Perimeter	39.75	40.17	39.81	39.75
Area exposed below 20.39 (beach)	1.73	2.23	1.95	1.93
Area 0 to 7 m deep	3.26	3.15	3.23	3.24
Area between 0.65 below and 0.3 above	0.54	0.55	0.55	0.54
Area of beach between 0.6 and 3.8 above	3.34	3.74	3.75	3.61
Area of beach between 4.8 and 8.8 above	0.00	0.00	0.00	0.00
VerDist from water level to fixed (amsl) tree-line	1.47	2.42	2.92	1.92
Area deeper than 7 m	3.70	3.31	3.51	3.53

Northern Arm		REC	AEC1	AEC2
	Base	MN1	MN15	MN05
Area 2 to 5 m deep	0.45	0.47	0.46	0.46
Area 1.5 to 2 m deep	1.37	1.20	1.26	1.27
Area 1 to 1.8 m deep	0.28	0.27	0.29	0.30
Area 1 to 1.5 m deep	0.27	0.30	0.28	0.29
Area 0.5 to 1 m deep	0.28	0.29	0.28	0.29
Area 0 to 0.5 m deep	0.28	0.29	0.28	0.28
Area 0 to 0.3 m deep	0.17	0.17	0.17	0.17
HorDist to tree line	45.66	54.21	49.15	48.84
Max Depth	41.73	40.78	41.22	41.28
Volume up to 2 m	1.10	1.15	1.12	1.16
Volume deeper than 2 m	57.11	50.74	53.63	53.99
Rate of change in water level (annual)	-0.09	0.02	-0.09	0.02
Accessibility/Use	3.50	3.50	3.50	3.50

7.2.2 Time-series of responses

The time-series of predicted abundance changes relative to Baseline under the EWRs for a B/C and C-category are provided for the indicators for each discipline (Figure 7.9 to Figure 7.14).

Figure 7.9 Water quality time-series for Baseline, REC, AEC1 and AEC2 at the Northern Arm[8]

[8] Blank graphs were not indicators in this zone

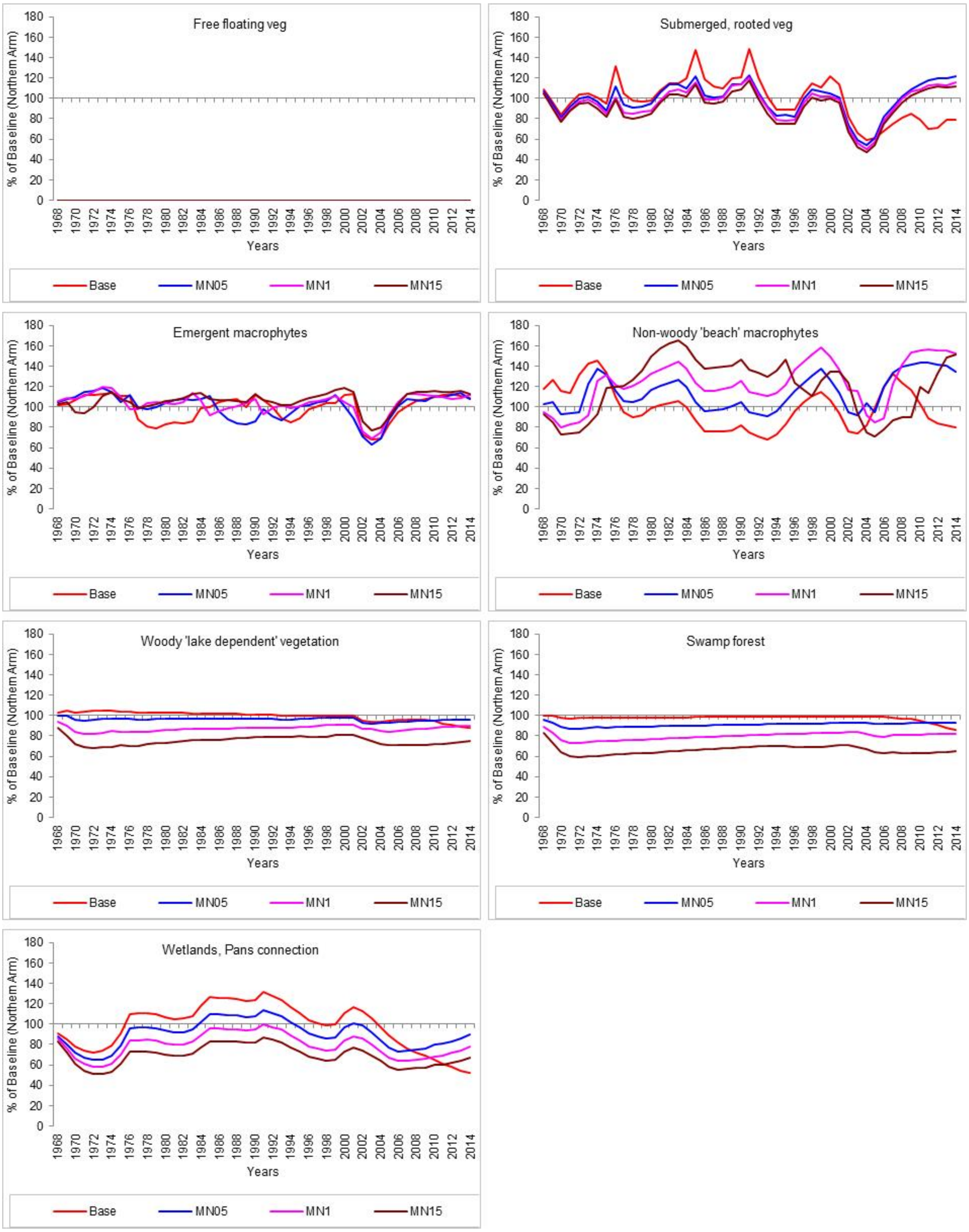
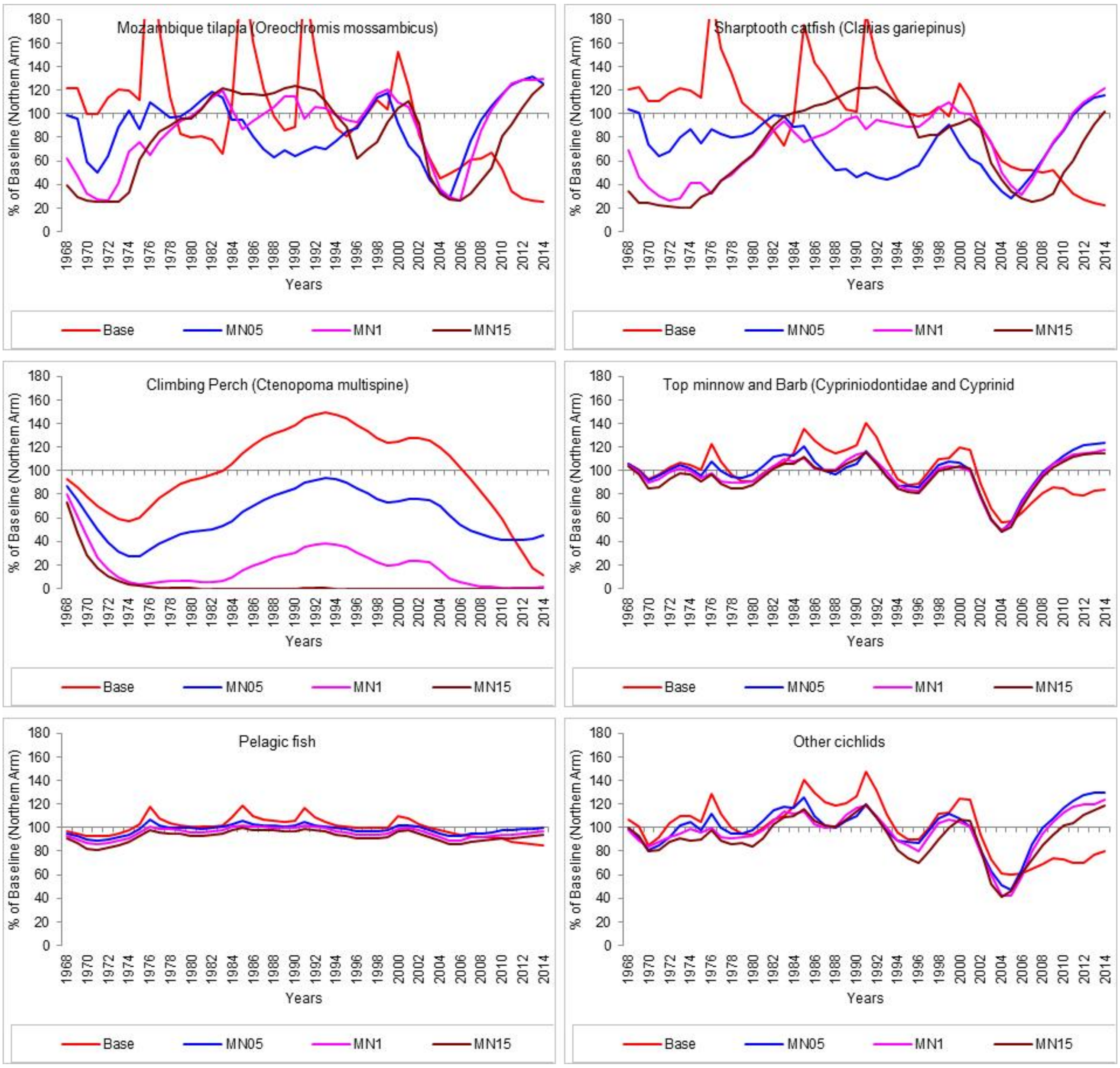


Figure 7.10 Vegetation time-series for Baseline, REC, AEC1 and AEC2 at the Northern Arm[9]

[9] Blank graphs were not indicators in this zone

Figure 7.11 Macroinvertebrate time-series for Baseline, REC, AEC1 and AEC2 at the Northern Arm[10]

[10] Blank graphs were not indicators in this zone



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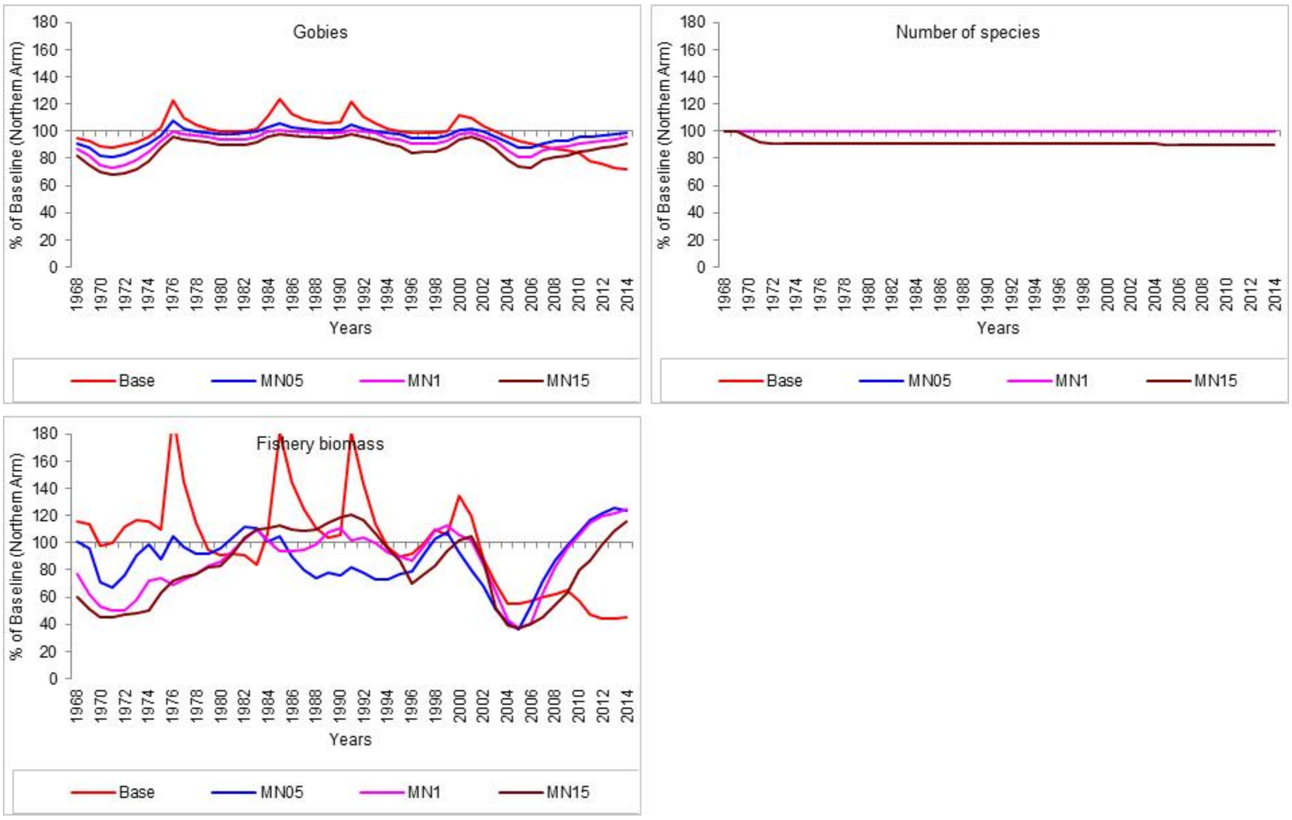


Figure 7.12 Fish time-series for Baseline, REC, AEC1 and AEC2 at the Northern Arm

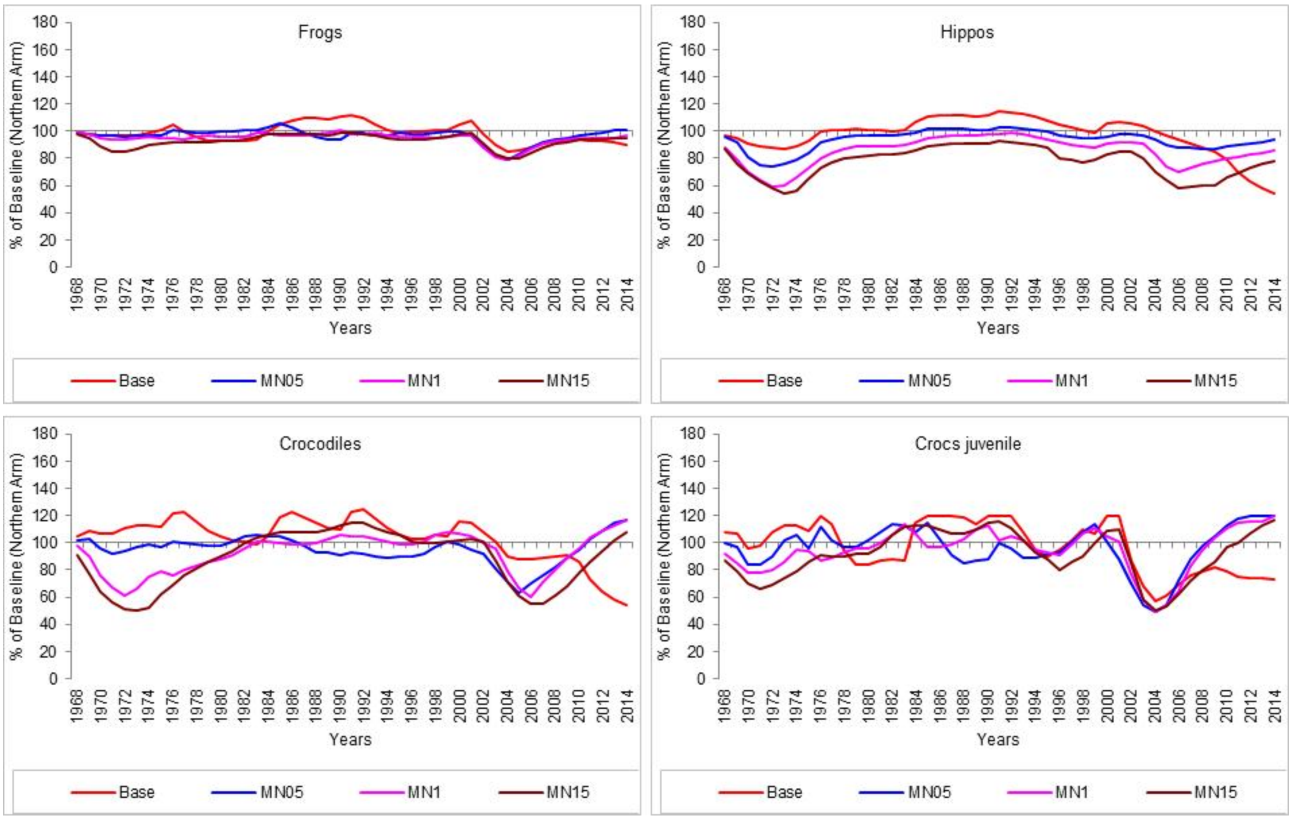


Figure 7.13 Herpetofauna and Mammals time-series for Baseline, REC, AEC1 and AEC2 at the Northern Arm

Figure 7.14 Social time-series for Baseline, REC, AEC1 and AEC2 at the Northern Arm[11]

[11] Blank graphs were not indicators in this zone

7.2.3 Mean percentage changes

The mean percentage changes (relative to Baseline) for the ecosystem indicators for the EWRs selected for REC, AEC1 and AEC2 at the Northern Arm are given in Table 7.5. The changes illustrate that some change is expected from baseline with each scenario. For example, there is a severe reduction in the abundance of Climbing Perch under both scenarios, mostly in response to the reduction in swamps and wetlands, which is more severe under MN15. There is also a reduction in the abundance of swamp forest under MN1 (AEC1). Overall, however, the B/C-scenario is expected to maintain a better ecological condition than the C-scenario.

Table 7.5 Northern Arm: The mean percentage changes in abundance (relative to 2015) for the indicators for the EWRs for maintaining a B/C and C category

Blue and green = increases. Green = 30-50%; Blue = >50%.
Orange and red = decreases. Orange = 30-50%; Red = >50%.
Baseline, by definition, should be close to 100%.

Discipline	Indicator		REC	AEC1	AEC2
		Base	MN1	MN15	MN05
Water quality	Conductivity	-3.4	1.7	3.2	-0.6
	Dissolved oxygen				
	Vol where DIN c. 0.23mg/l				
	Vol where DIN c. 0.07mg/l	-1.7	-3.5	-6.9	-1.0
	Vol where DIP c. 0.02mg/l	-1.7	-3.5	-6.9	-1.0
	Vol where DIP c. 0.04mg/l				
Vegetation	Free floating veg				
	Submerged, rooted veg	-0.6	-4.0	-6.6	-0.8
	Emergent macrophytes	-0.8	2.7	4.8	0.6
	Non-woody 'beach' macrophytes	-0.6	19.9	16.7	12.0
	Woody 'lake dependent' vegetation	-0.6	-12.4	-24.1	-3.7
	Swamp forest	-2.5	-19.0	-31.9	-8.5
	Wetlands, Pans connection	-1.3	-17.5	-25.9	-8.1
Macro-invertebrates	*Bulinus globosus* (bilharzia host)	2.4	-3.7	-1.2	-5.2
	Tarebia	0.0	-10.7	-11.4	-8.3
	Melanoides	-2.4	-5.7	-8.6	-2.8
	Pulmonates	-0.2	0.5	0.9	0.2
	Caridina (shrimp)	0.0	-2.4	-3.6	-1.1
	Potamonautes (crab)	-0.8	2.4	4.1	0.3
	Hymenosoma (crab)	-1.5	-4.8	-7.1	-2.3
Fish	Mozambique tilapia (*Oreochromis mossambicus*)	0.1	-8.5	-13.1	-8.6
	Sharptooth catfish (*Clarias gariepinus*)	0.0	-20.5	-23.5	-22.0
	Climbing Perch (*Ctenopoma multispine*)	-0.8	-69.2	-81.2	-32.7
	Top minnow & Barb (Cypriniodontidae & Cyprinid	-0.4	-2.4	-3.9	-0.6
	Pelagic fish	0.2	-3.3	-5.4	-1.3
	Other cichlids	0.1	-2.7	-5.6	-0.1
	Gobies	-0.6	-5.6	-9.1	-2.5
	Number of species	0.0	-0.3	-8.7	0.0
	Fishery biomass	0.1	-9.8	-13.2	-9.2
Herpetofauna and Mammals	Frogs	-1.2	-3.9	-5.3	-2.4
	Hippos	-1.8	-12.5	-19.1	-5.4
	Crocodiles	3.2	-6.7	-10.1	-4.4
	Crocs juvenile	-1.5	-3.1	-5.0	-2.2

Socio-economics	Domestic use				
	Recreational use	-2.4	-28.0	-39.6	-12.4
	Fishing	0.3	-4.8	-6.4	-4.6
	Water lily harvesting	-0.3	-3.0	-4.8	-0.9
	Reeds and sedges	0.4	1.9	3.1	1.1
	Health (Bilharzia)	1.9	5.4	4.0	5.6
	Cattle watering	-1.0	-5.6	-7.7	-2.2

7.2.4 Ecosystem integrity and social well-being

The Overall Ecological Integrity of the Northern Arm for each scenario is illustrated in Figure 7.15. The Baseline is a B/C category for (for details see Volume 1: Ecoclassification Report). Both MN1 and MN15 return a category C, while MN05 returns the desired B/C category, provided lake levels recover and do not drop further at the Northern Arm.

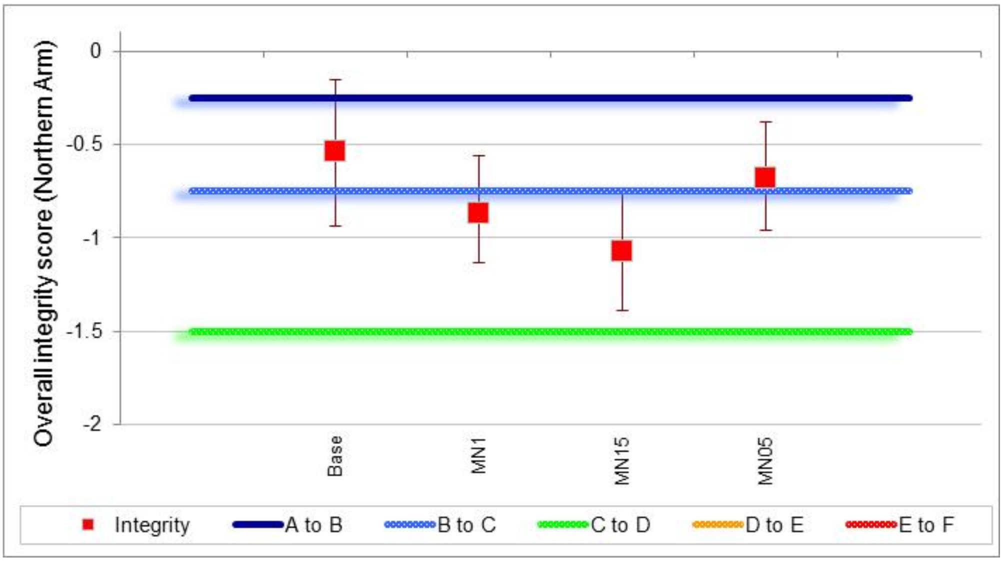


Figure 7.15 Overall ecosystem integrity scores for the Northern Arm

The social well-being scores for the Northern Arm are illustrated in Figure 7.16 and depict a slight decrease in social well-being for all scenarios. The main reasons for this include reduced recreational use at the Northern Arm at lower lake levels and to a lesser extent reduced fishing, cattle-watering, abundance of water-lilies, reeds and sedges, and the presence of bilharzia.

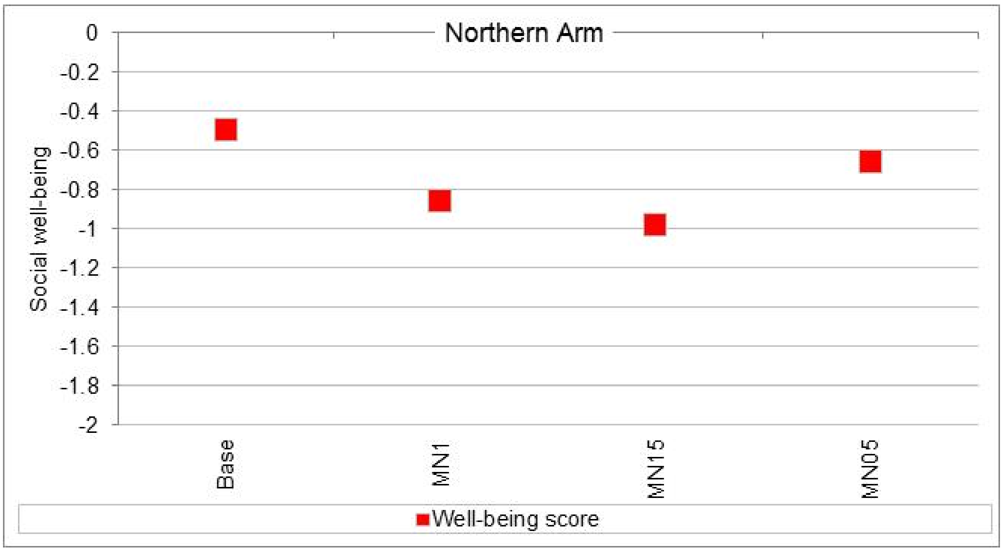


Figure 7.16 Overall social well-being scores for the Northern Arm

7.3 Western Arm

7.3.1 Hydraulics

The main hydraulic characteristics associated with each of the scenarios at the Main Basin, and the index score for accessibility, are given in Table 7.6.

Table 7.6 Hydraulic characteristics of each scenario at the Western Arm. Median values are given for the hydraulic indicators and a ranked score is given for accessibility

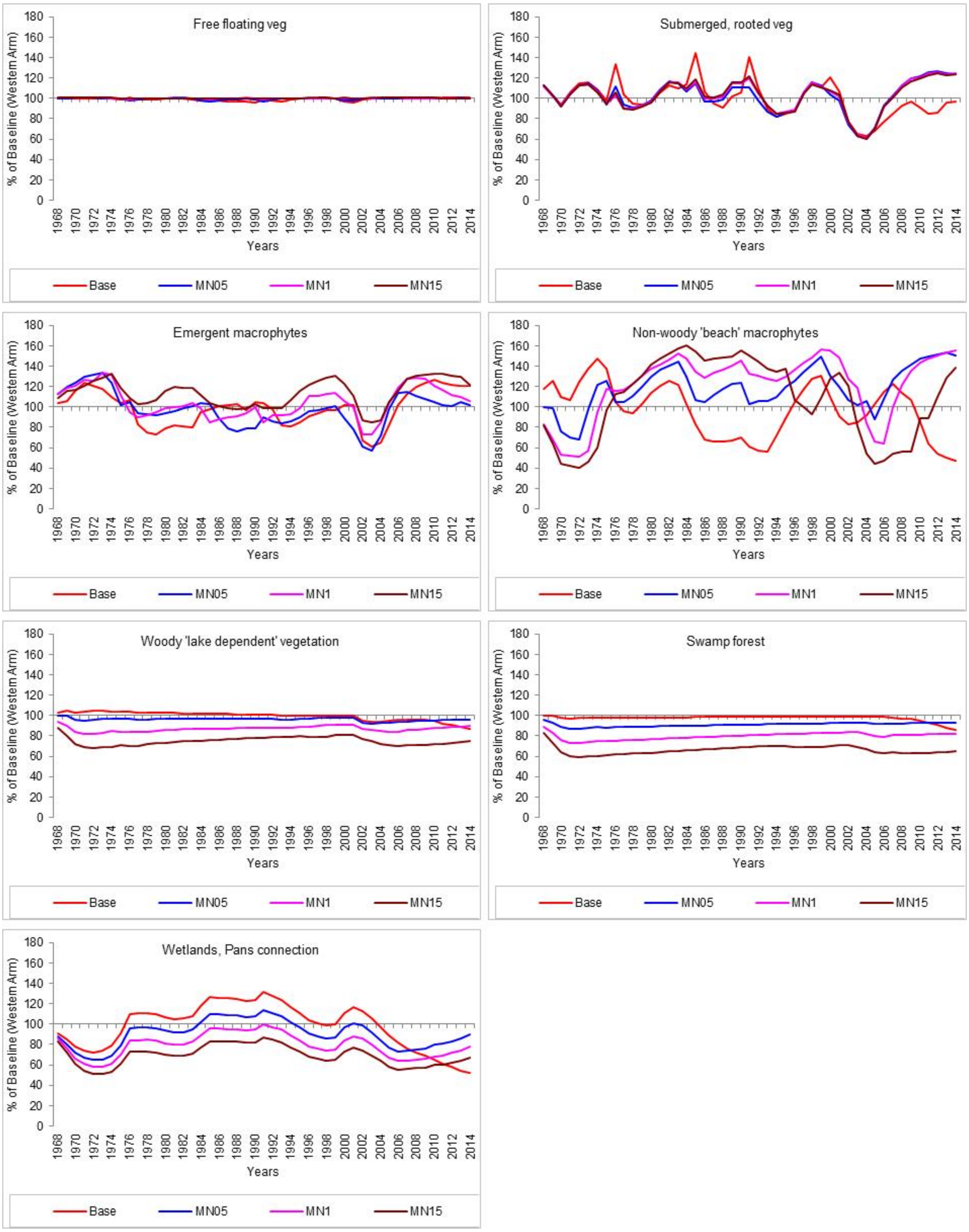
		REC	AEC1	AEC2
Western Arm	Base	MN1	MN15	MN05
Mean annual water level	18.82	17.87	18.32	18.37
Volume	112.44	101.12	106.39	107.03
Area	12.21	11.65	11.97	11.99
Perimeter	72.69	73.18	72.74	72.70
Area exposed below 20.39 (beach)	2.62	3.19	2.86	2.85
Area 0 to 7 m deep	4.98	5.01	4.98	5.00
Area between 0.65 below and 0.3 above	0.68	0.67	0.68	0.63
Area of beach between 0.6 and 3.8 above	5.33	6.54	6.50	6.35
Area of beach between 4.8 and 8.8 above	0.00	0.00	0.00	0.00
VerDist from water level to fixed (amsl) tree-line	1.47	2.42	2.92	1.92
Area deeper than 7 m	7.25	6.63	6.92	6.95
Area 2 to 5 m deep	0.56	0.58	0.58	0.58
Area 1.5 to 2 m deep	2.21	2.21	2.21	2.21
Area 1 to 1.8 m deep	0.36	0.37	0.37	0.37
Area 1 to 1.5 m deep	0.35	0.37	0.36	0.36
Area 0.5 to 1 m deep	0.34	0.36	0.35	0.34
Area 0 to 0.5 m deep	0.34	0.34	0.34	0.34
Area 0 to 0.3 m deep	0.20	0.21	0.20	0.20

		REC	AEC1	AEC2
Western Arm	Base	MN1	MN15	MN05
HorDist to tree line	36.18	42.16	38.66	38.42
Max Depth	41.73	40.78	41.22	41.28
Volume up to 2 m	1.42	1.44	1.44	1.43
Volume deeper than 2 m	111.01	99.71	104.92	105.56
Rate of change in water level (annual)	-0.09	0.02	-0.09	0.02
Accessibility/Use	5.00	5.00	5.00	5.00

7.3.2 Time-series of responses

The time-series of predicted abundance changes relative to Baseline under B/C and C-category EWRs are provided for the indicators for each discipline (Figure 7.17 to Figure 7.22).

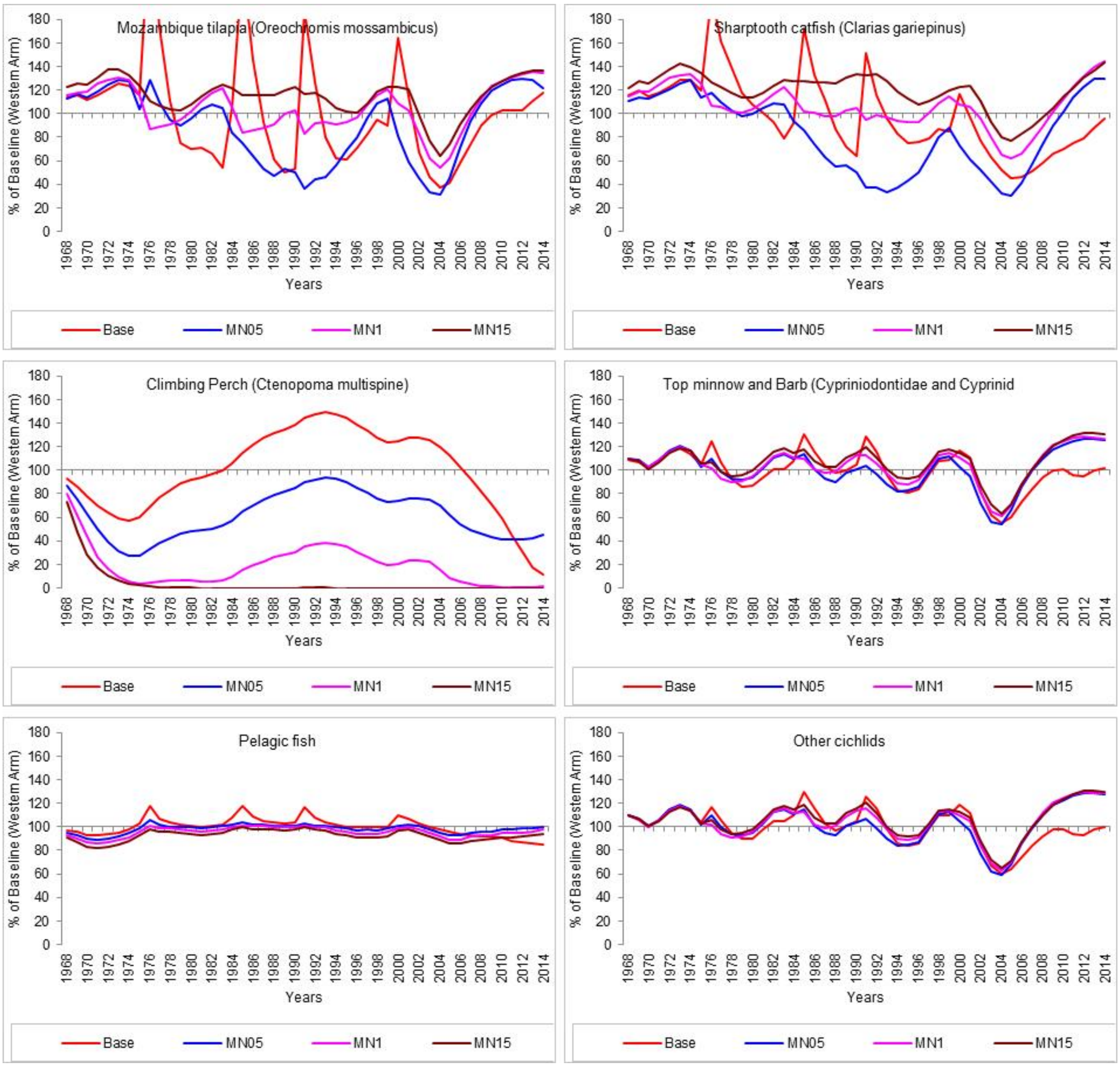
Figure 7.17 Water quality time-series for Baseline, REC, AEC1 and AEC2 at the Western Arm[12]



[12] Blank graphs were not indicators in this zone

Figure 7.18 Vegetation time-series for Baseline, REC, AEC1 and AEC2 at the Western Arm

Figure 7.19 Macroinvertebrate time-series for Baseline, REC, AEC1 and AEC2 at the Western Arm



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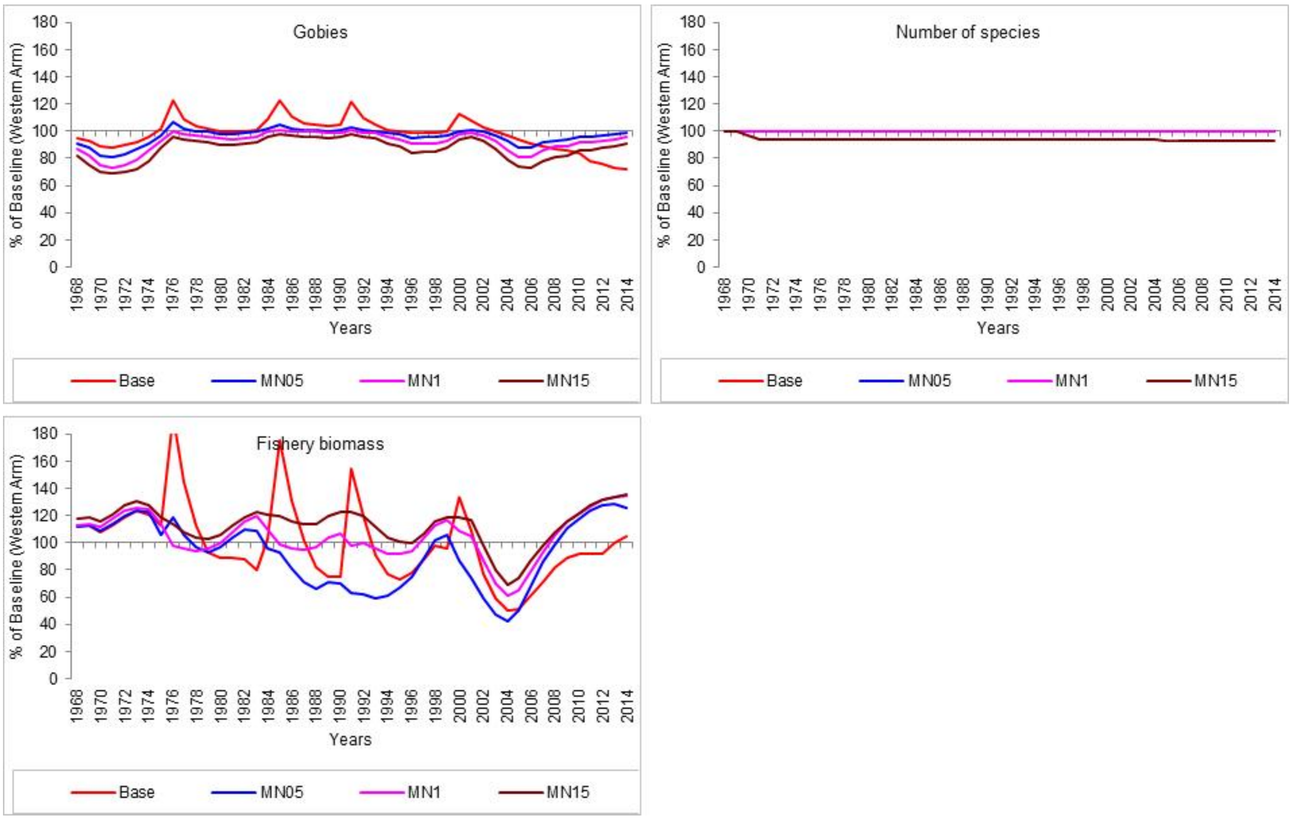


Figure 7.20 Fish time-series for Baseline, REC, AEC1 and AEC2 at the Western Arm

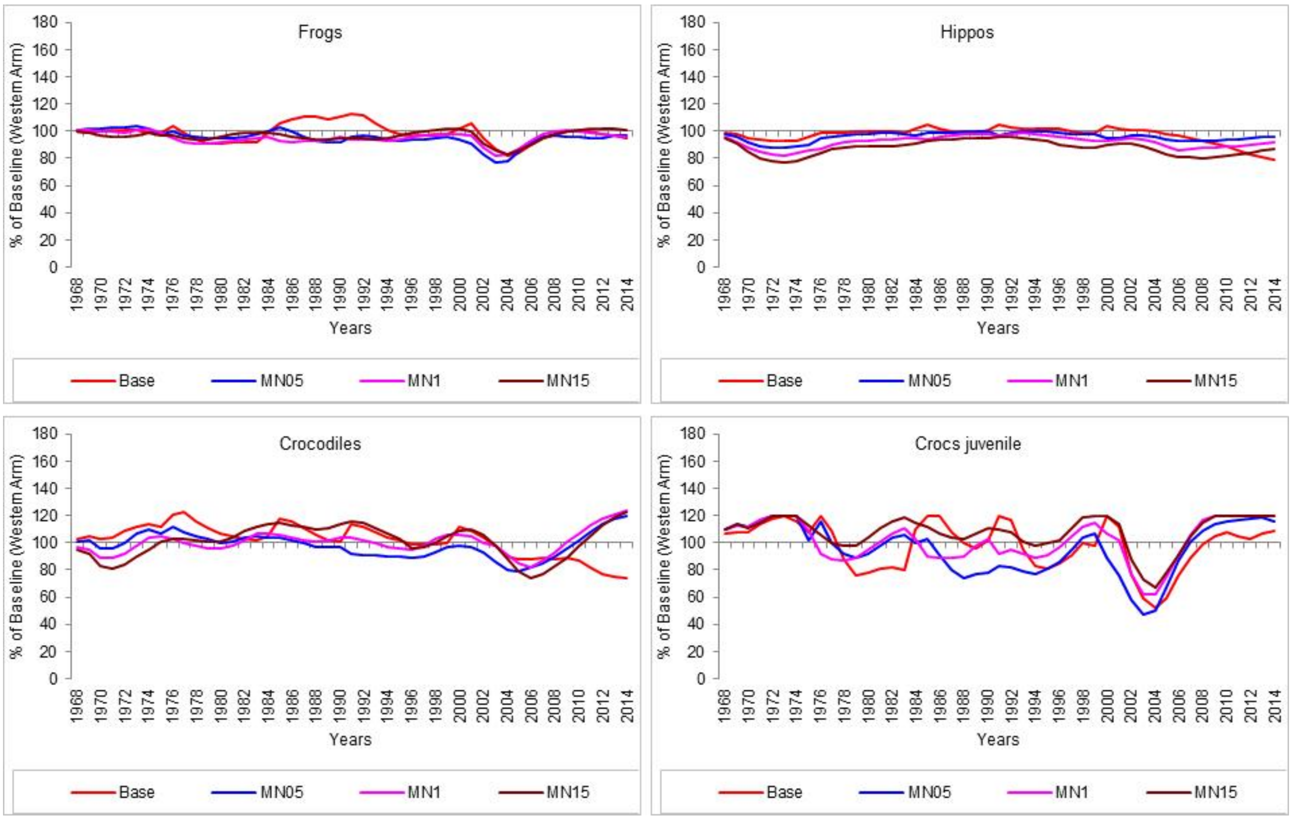


Figure 7.21 Herpetofauna and Mammals time-series for Baseline, REC, AEC1 and AEC2 at the Western Arm

Figure 7.22 Social time-series for Baseline, REC, AEC1 and AEC2 at the Western Arm

7.3.3 Mean percentage changes

The mean percentage changes (relative to Baseline) for the indicators for the EWRs selected for REC, AEC1 and AEC2 at the Western Arm are given in Table 7.7. The changes illustrate that some change is expected from baseline with each scenario. For example, there is a severe reduction in the abundance of Climbing Perch under both scenarios, mostly in response to the reduction in swamps and wetlands, which is more severe under MN15. Overall, however, the B/C-scenario is expected to maintain a better ecological condition than the C-scenario.

Table 7.7 Western Arm: The mean percentage changes in abundance (relative to 2015) for the indicators for the EWRs for maintaining a B/C and C category.

Blue and green = increases. Green = 30-50%; Blue = >50%.
Orange and red = decreases. Orange = 30-50%; Red = >50%.
Baseline, by definition, should be close to 100%.

Discipline	Indicator	Base	MN1	MN15	MN05
Water quality	Conductivity	-3.5	1.7	3.1	-0.7
	Dissolved oxygen				
	Vol where DIN c. 0.23mg/l	-1.3	0.2	0.6	-0.6
	Vol where DIN c. 0.07mg/l	-1.0	-3.0	-4.5	-1.5
	Vol where DIP c. 0.02mg/l	-1.0	-3.0	-4.5	-1.5
	Vol where DIP c. 0.04mg/l	-1.3	0.2	0.6	-0.6
Vegetation	Free floating veg	-0.5	0.0	0.2	-0.3
	Submerged, rooted veg	0.0	2.3	2.3	1.8
	Emergent macrophytes	-1.1	3.8	11.1	-1.7
	Non-woody 'beach' macrophytes	-2.3	18.0	6.2	15.6
	Woody 'lake dependent' vegetation	-0.8	-12.5	-24.2	-3.7
	Swamp forest	-2.5	-19.0	-31.9	-8.5
	Wetlands, Pans connection	-1.3	-17.5	-25.9	-8.1
Macro-invertebrates	*Bulinus globosus* (bilharzia host)	-1.9	-4.3	0.8	-7.7
	Tarebia	-3.9	-4.3	1.2	-8.7
	Melanoides	-2.4	-5.9	-8.8	-3.0
	Pulmonates	-0.2	1.2	3.2	-0.3
	Caridina (shrimp)	-0.3	-2.3	-3.0	-1.4
	Potamonautes (crab)	-1.4	2.9	9.0	-1.9
	Hymenosoma (crab)	-1.0	-3.1	-4.9	-1.5
Fish	Mozambique tilapia (*Oreochromis mossambicus*)	0.8	2.8	10.6	-7.7
	Sharptooth catfish (*Clarias gariepinus*)	-1.3	4.7	15.8	-13.8
	Climbing Perch (*Ctenopoma multispine*)	-0.8	-69.2	-81.2	-32.7
	Top minnow & Barb (Cypriniodontidae & Cyprinid	-0.6	2.7	4.7	0.6
	Pelagic fish	0.0	-3.2	-5.3	-1.4
	Other cichlids	-0.2	2.9	4.2	1.5
	Gobies	-0.9	-5.5	-8.9	-2.6
	Number of species	0.0	-0.2	-6.2	0.0
	Fishery biomass	-0.2	3.3	9.6	-6.1
Herpetofauna and Mammals	Frogs	-0.7	-3.6	-2.6	-3.5
	Hippos	-2.1	-6.7	-10.2	-3.5
	Crocodiles	1.8	0.1	0.9	-1.5
	Crocs juvenile	-1.1	0.7	4.6	-2.7
Socio-economics	Domestic use	6.7	-14.4	-23.3	-2.4
	Recreational use	-2.9	-22.3	-34.4	-9.1
	Fishing	1.3	2.4	5.5	-1.1
	Water lily harvesting	-2.8	-0.9	-0.9	-1.3
	Reeds and sedges	-1.0	1.8	5.6	-1.2
	Health (Bilharzia)	-4.1	0.2	-2.2	0.4
	Cattle watering	0.0	-3.9	-6.0	-0.8

7.3.4 Ecosystem integrity and social well being

The Overall Ecological Integrity of the Western Arm for each scenario is illustrated in Figure 7.24. The baseline ecostatus for the Western Arm is a B/C category (for details see Volume 1: Ecoclassification Report). With this in mind MN1 and N05 return a B/C condition for the Western Arm while MN15 returns a C condition, provided lake levels recover and do not drop further.

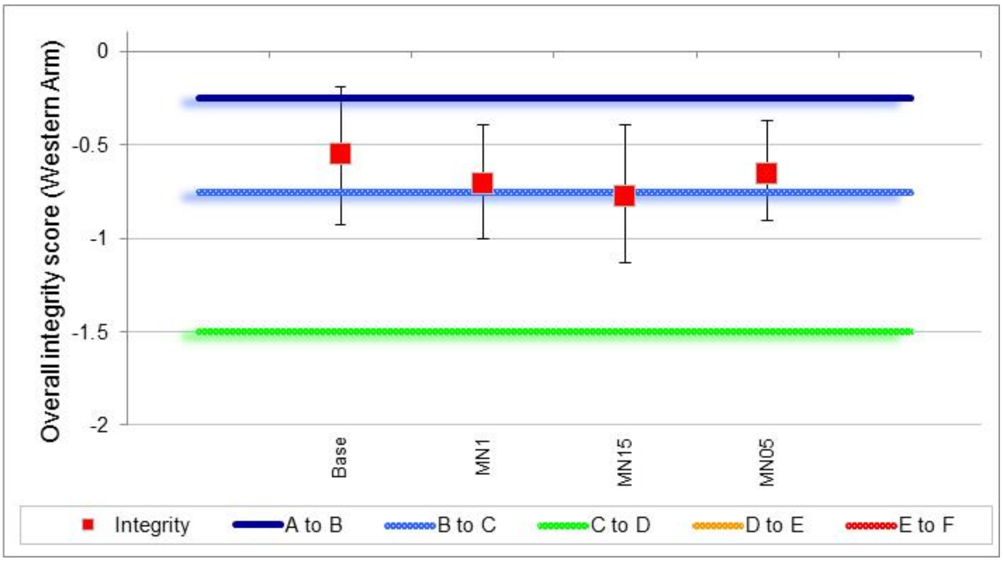


Figure 7.23 Overall ecosystem integrity scores for the Western Arm

The social well-being scores for the Main Basin are illustrated in Figure 7.24 and depict a slight decrease in social well-being for both scenarios. The main reasons for this include reduced domestic use from, and recreational use at, the Western Arm at lower lake levels.

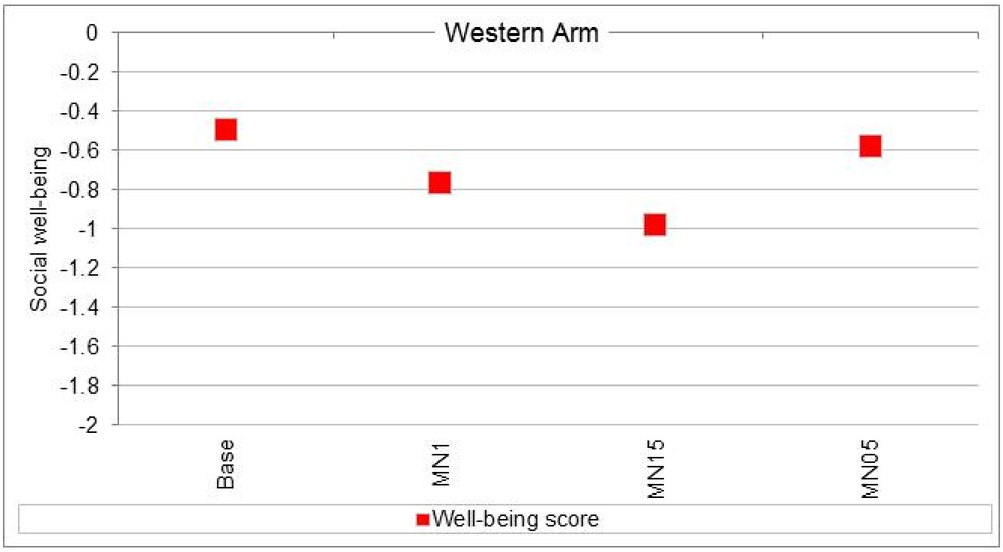


Figure 7.24 Overall social well-being scores for the Western Arm

7.4 Southwestern Basin

7.4.1 Hydraulics

The main hydraulic characteristics associated with each of the scenarios at the Main Basin, and the index score for accessibility, are given in Table 7.8.

Table 7.8 Median values for the hydraulic characteristics, rate of change in water level and accessibility of each scenario at the Southwestern Basin

		REC	AEC1	AEC2
Southwestern Basin	Base	MN1	MN15	MN05
Mean annual water level	18.82	17.87	18.32	18.37
Volume	22.47	19.93	21.10	21.25
Area	2.76	2.58	2.68	2.68
Perimeter	12.18	12.08	12.03	11.93
Area exposed below 20.39 (beach)	0.78	0.97	0.87	0.86
Area 0 to 7 m deep	1.22	1.19	1.21	1.22
Area between 0.65 below and 0.3 above	0.19	0.19	0.19	0.19
Area of beach between 0.6 and 3.8 above	1.35	1.51	1.52	1.45
Area of beach between 4.8 and 8.8 above	0.00	0.00	0.00	0.00
VerDist from water level to fixed (amsl) tree-line	1.47	2.42	2.92	1.92
Area deeper than 7 m	1.55	1.38	1.46	1.46
Area 2 to 5 m deep	0.16	0.13	0.16	0.16
Area 1.5 to 2 m deep	0.50	0.49	0.49	0.49
Area 1 to 1.8 m deep	0.10	0.08	0.09	0.09
Area 1 to 1.5 m deep	0.10	0.09	0.10	0.10
Area 0.5 to 1 m deep	0.10	0.10	0.10	0.10
Area 0 to 0.5 m deep	0.10	0.10	0.10	0.10
Area 0 to 0.3 m deep	0.06	0.06	0.06	0.06
HorDist to tree line	61.41	78.65	69.50	68.73
Max Depth	41.73	40.78	41.22	41.28
Volume up to 2 m	0.40	0.35	0.37	0.38
Volume deeper than 2 m	22.05	19.58	20.73	20.87
Rate of change in water level (annual)	-0.09	0.02	-0.09	0.02
Accessibility/Use	2.00	2.00	2.00	2.00

7.4.2 Time-series of responses

The time-series of predicted abundance changes relative to Baseline under the EWRs for a B/C and C-category are provided for the indicators for each discipline (Figure 7.25 to Figure 7.30).

Figure 7.25 Water quality time-series for Baseline, REC, AEC1 and AEC2 at the Southwestern Basin[13]

[13] Blank graphs were not indicators in this zone

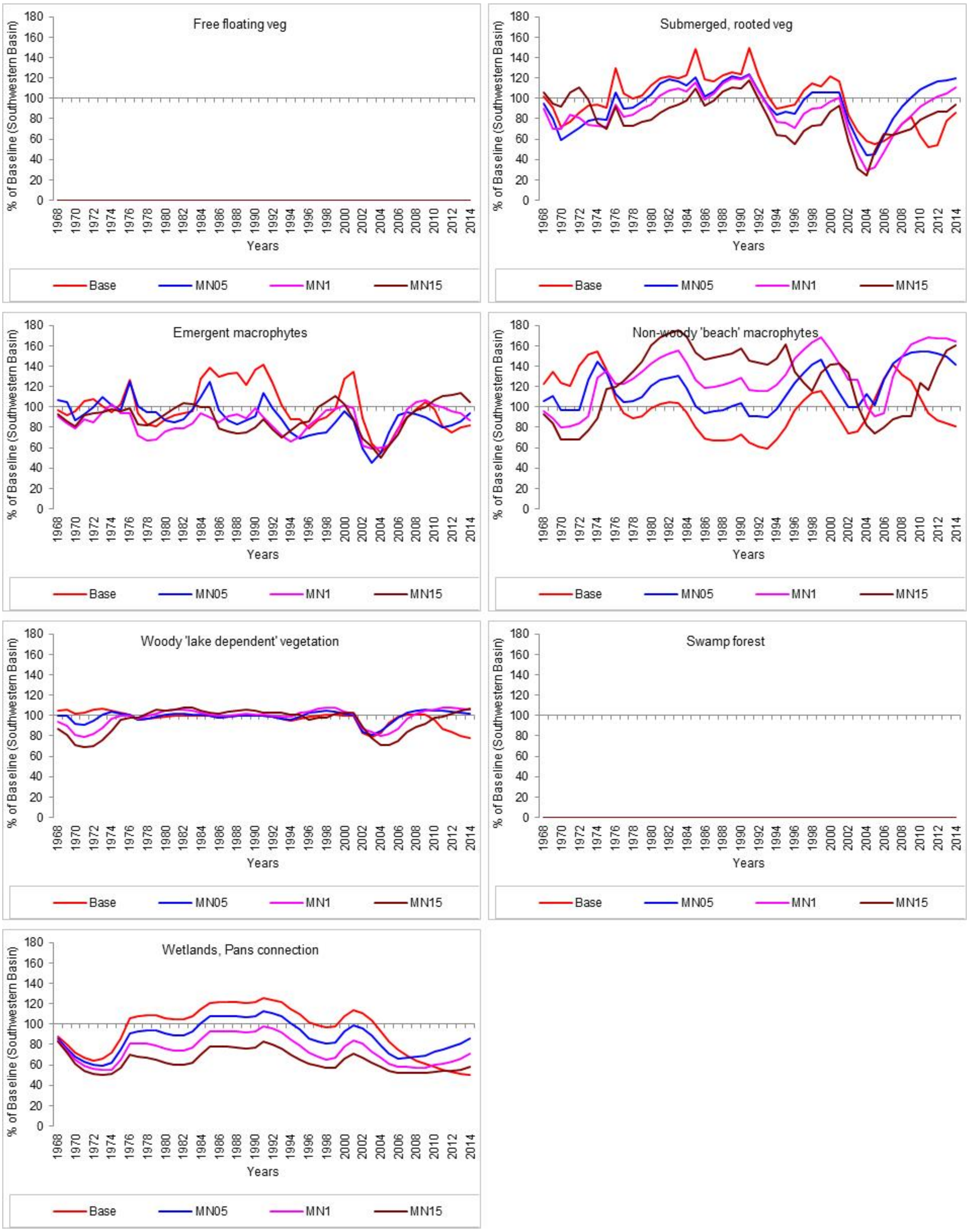
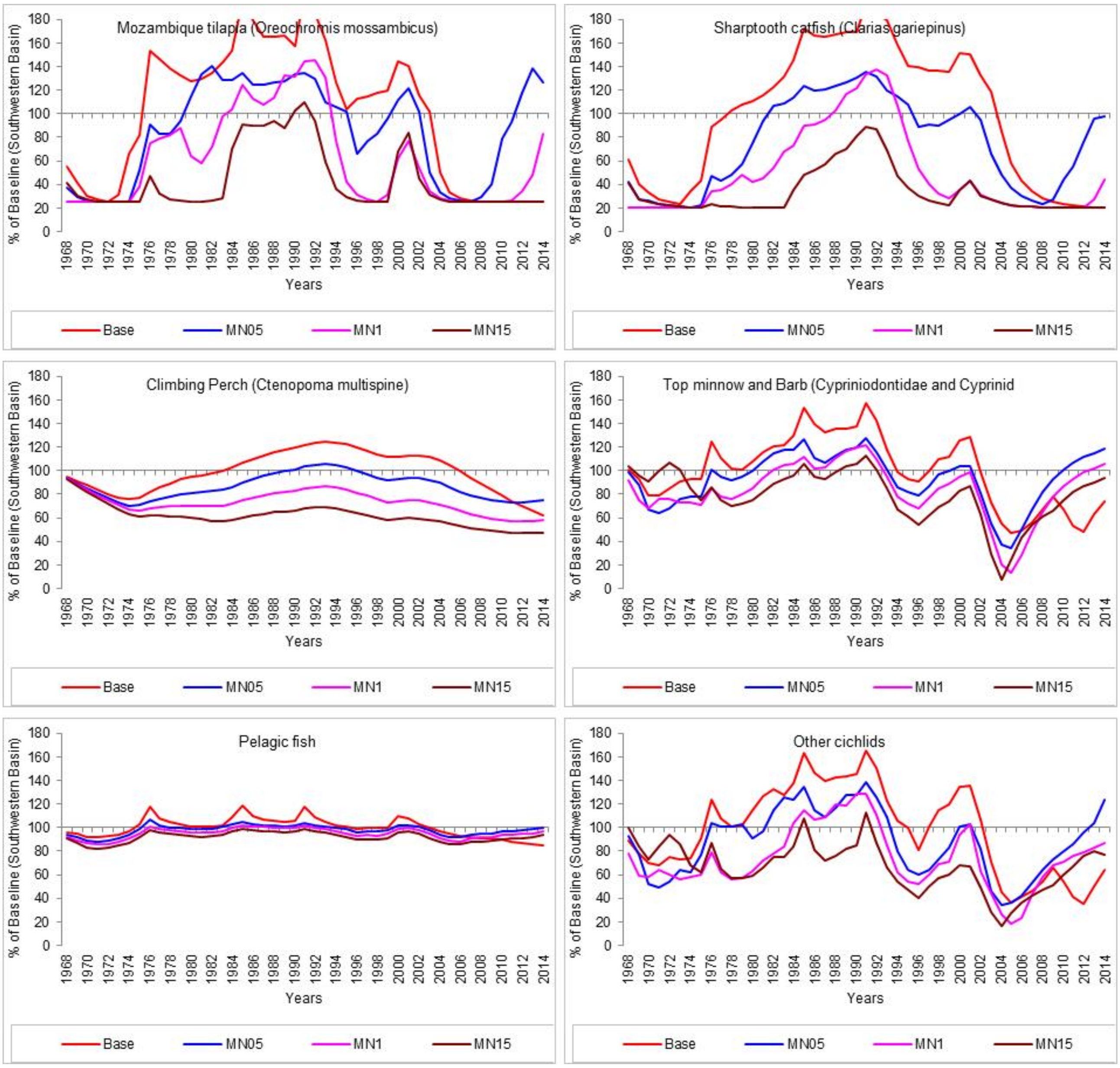


Figure 7.26 Vegetation time-series for Baseline, REC, AEC1 and AEC2 at the Southwestern Basin[14]

[14] Blank graphs were not indicators in this zone

Figure 7.27 Macroinvertebrate time-series for Baseline, REC, AEC1 and AEC2 at the Southwestern Basin[15]

[15] Blank graphs were not indicators in this zone



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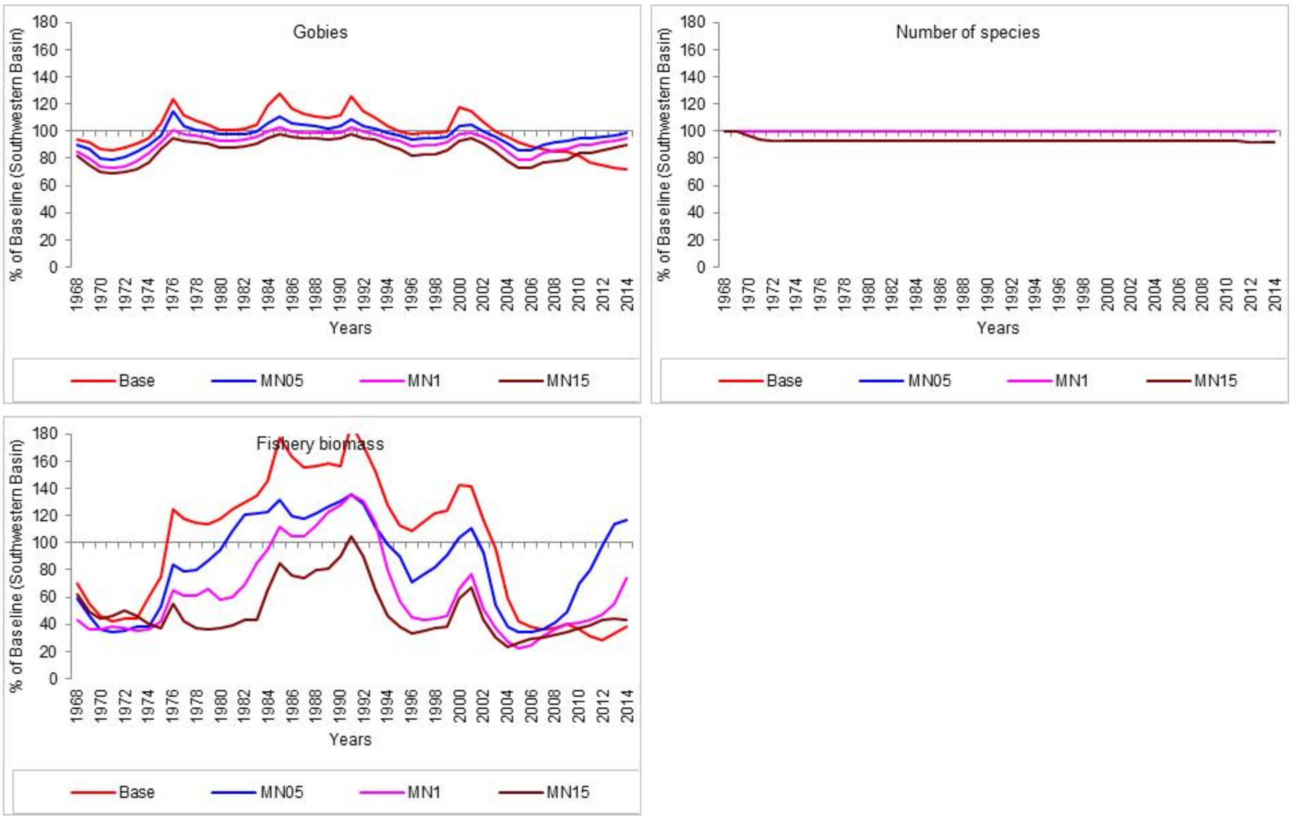


Figure 7.28 Fish time-series for Baseline, REC, AEC1 and AEC2 at the Southwestern Basin

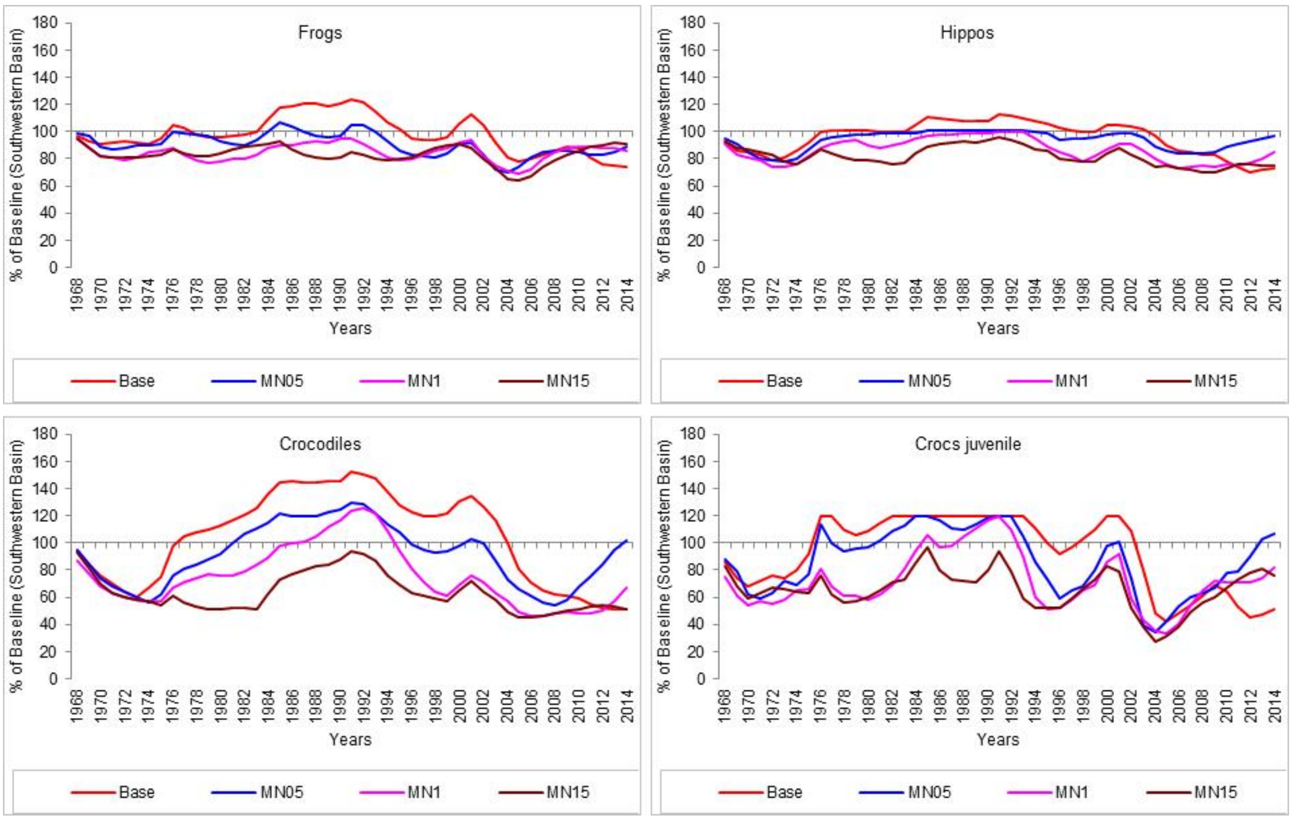


Figure 7.29 Herpetofauna and Mammals time-series for Baseline, REC, AEC1 and AEC2 at the Southwestern Basin

Figure 7.30 Social time-series for Baseline, REC, AEC1 and AEC2 at the Southwestern Basin[16]

7.4.3 Mean percentage changes

The mean percentage changes (relative to Baseline) for the indicators for the EWRs were selected as potential Reserves to maintain the REC, AEC1 and AEC2 at the Southwestern Basin are given in Table 7.9. The changes illustrate that some change is expected from baseline with each scenario. For example, there are reductions in the abundance of wetlands and pans that drive reduced abundance of Climbing Perch under MN15, along with reduced abundance of Mozambique Tilapia, crocodiles and Sharptooth Catfish, the latter also being reduced in

[16] Blank graphs were not indicators in this zone

abundance under MN1. Overall, however, the B/C-scenario is expected to maintain a better ecological condition than the C-scenario.

Table 7.9 Southwestern Basin: The mean percentage changes in abundance (relative to 2015) for the indicators for the EWRs for maintaining a B/C and C category.

Blue and green = increases. Green = 30-50%; Blue = >50%.
Orange and red = decreases. Orange = 30-50%; Red = >50%.
Baseline, by definition, should be close to 100%.

Discipline	Indicator	Base	MN1	MN15	MN05
Water quality	Conductivity	-3.4	1.7	3.2	-0.6
	Dissolved oxygen				
	Vol where DIN c. 0.23mg/l				
	Vol where DIN c. 0.07mg/l	-3.4	-7.6	-10.7	-4.2
	Vol where DIP c. 0.02mg/l	-3.4	-7.6	-10.7	-4.2
	Vol where DIP c. 0.04mg/l				
Vegetation	Free floating veg				
	Submerged, rooted veg	-1.6	-9.9	-13.8	-3.7
	Emergent macrophytes	-0.1	-11.3	-8.4	-8.2
	Non-woody 'beach' macrophytes	-0.1	25.4	21.5	15.5
	Woody 'lake dependent' vegetation	-2.0	-1.2	-3.8	-0.7
	Swamp forest				
	Wetlands, Pans connection	-4.5	-21.5	-30.4	-11.2
Macro-invertebrates	*Bulinus globosus* (bilharzia host)	5.0	-7.7	-6.7	-2.2
	Tarebia	3.2	-13.6	-15.1	-4.6
	Melanoides	-2.2	-5.7	-8.5	-2.8
	Pulmonates	-0.1	-3.6	-3.1	-2.4
	Caridina (shrimp)	0.4	-2.2	-2.8	-1.0
	Potamonautes (crab)	-0.4	-10.3	-7.8	-7.5
	Hymenosoma (crab)	-1.0	-4.5	-6.6	-2.0
Fish	Mozambique tilapia (*Oreochromis mossambicus*)	0.5	-26.4	-39.6	-9.6
	Sharptooth catfish (*Clarias gariepinus*)	-0.3	-39.3	-52.7	-19.1
	Climbing Perch (*Ctenopoma multispine*)	-0.9	-22.6	-32.4	-11.2
	Top minnow & Barb (Cypriniodontidae & Cyprinid	-0.1	-11.6	-14.5	-4.8
	Pelagic fish	0.0	-3.6	-5.7	-1.5
	Other cichlids	-1.1	-18.2	-23.1	-8.4
	Gobies	0.3	-6.0	-9.8	-2.2
	Number of species	0.0	-0.2	-6.7	0.0
	Fishery biomass	-0.3	-26.8	-36.9	-11.7
Herpetofauna and Mammals	Frogs	-1.2	-11.4	-12.5	-7.1
	Hippos	-3.3	-11.5	-15.1	-5.3
	Crocodiles	4.2	-20.6	-30.7	-7.1
	Crocs juvenile	-4.2	-16.8	-20.5	-8.1
Socio-economics	Domestic use				
	Recreational use	0.9	-7.1	-11.6	-2.0
	Fishing				
	Water lily harvesting	0.0	-5.0	-7.1	-1.6
	Reeds and sedges	0.4	-4.3	-3.2	-3.0
	Health (Bilharzia)	-1.7	3.7	3.2	1.7
	Cattle watering				

7.4.4 Ecosystem integrity and social well being

The Overall Ecological Integrity of the Southwestern Basin for each scenario is illustrated in Figure 7.31. The baseline ecostatus for the Southwestern Basin is a B/C category (for details see

Volume 1: Ecoclassification Report). With this in mind both MN1 and MN15 return a C category for the Southwestern Basin, while MN05 returns a B/C, provided lake levels recover and do not drop further.

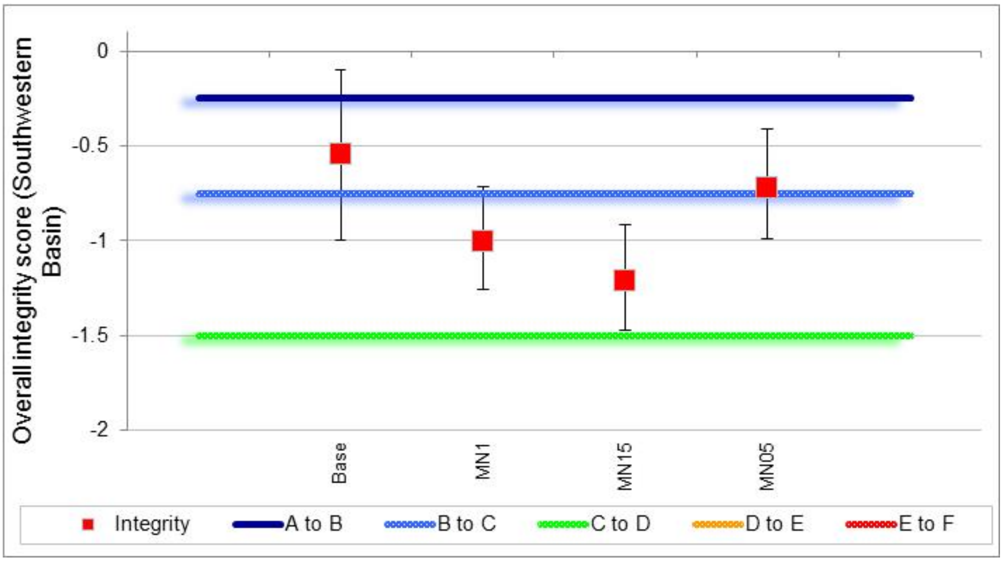


Figure 7.31 Overall ecosystem integrity scores for the Southwestern Basin

The social well-being scores for the Southwestern Basin are illustrated in Figure 7.32 and depict a very slight decrease in social well-being for both scenarios. The main reasons for this include are reduced recreational use and harvesting of water lilies from the Southwestern Basin at lower lake levels.

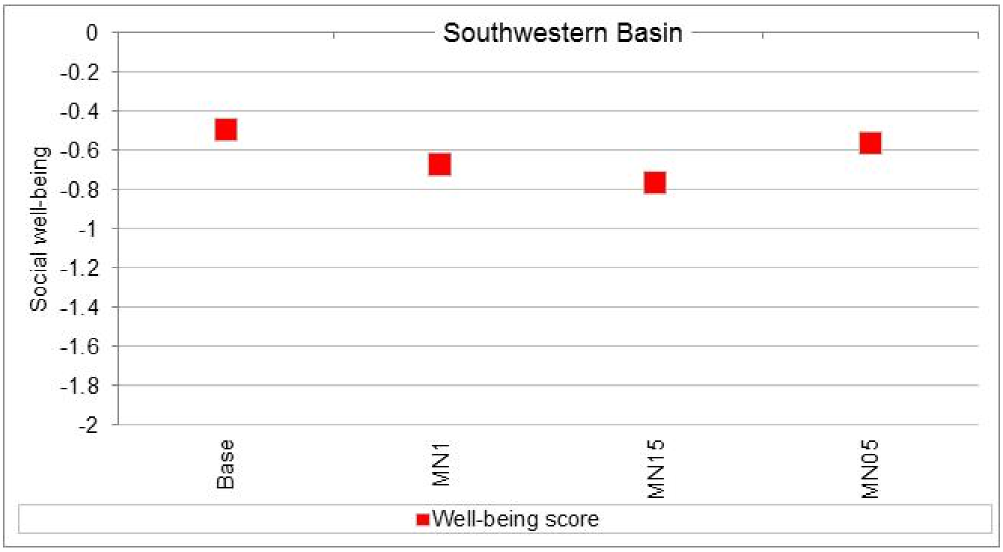


Figure 7.32 Overall social well-being scores for the Southwestern Basin

7.5 Southern Basin

7.5.1 Hydraulics

The main hydraulic characteristics associated with each of the scenarios at the Main Basin, and the index score for accessibility, are given in Table 7.10.

Table 7.10 Median values for the hydraulic characteristics, rate of change in water level and accessibility of each scenario at the Southern Basin

		REC	AEC1	AEC2
Southern Basin	Base	MN1	MN15	MN05
Mean annual water level	18.82	17.87	18.32	18.37
Volume	30.67	27.61	29.03	29.21
Area	3.32	3.15	3.24	3.25
Perimeter	12.47	12.88	12.79	12.78
Area exposed below 20.39 (beach)	0.60	0.77	0.67	0.67
Area 0 to 7 m deep	1.25	1.22	1.24	1.25
Area between 0.65 below and 0.3 above	0.18	0.19	0.20	0.18
Area of beach between 0.6 and 3.8 above	1.53	1.78	1.75	1.75
Area of beach between 4.8 and 8.8 above	0.00	0.00	0.00	0.00
VerDist from water level to fixed (amsl) tree-line	1.47	2.42	2.92	1.92
Area deeper than 7 m	2.06	1.93	2.00	2.00
Area 2 to 5 m deep	0.16	0.16	0.16	0.16
Area 1.5 to 2 m deep	0.56	0.54	0.55	0.55
Area 1 to 1.8 m deep	0.10	0.10	0.10	0.10
Area 1 to 1.5 m deep	0.10	0.10	0.10	0.11
Area 0.5 to 1 m deep	0.09	0.11	0.10	0.11
Area 0 to 0.5 m deep	0.09	0.11	0.09	0.10
Area 0 to 0.3 m deep	0.05	0.06	0.05	0.06
HorDist to tree line	48.08	59.52	52.84	52.58
Max Depth	41.73	40.78	41.22	41.28
Volume up to 2 m	0.39	0.38	0.39	0.39
Volume deeper than 2 m	30.24	27.25	28.64	28.81
Rate of change in water level (annual)	-0.09	0.02	-0.09	0.02
Accessibility/Use	3.50	3.50	3.50	3.50

7.5.2 Time-series of responses

The time-series of predicted abundance changes relative to Baseline under the EWRs for a C-category are provided for the indicators for each discipline (Figure 7.33 to Figure 7.38).

Figure 7.33 Water quality time-series for Baseline, REC, AEC1 and AEC2 at the Southern Basin[17]

[17] Blank graphs were not indicators in this zone

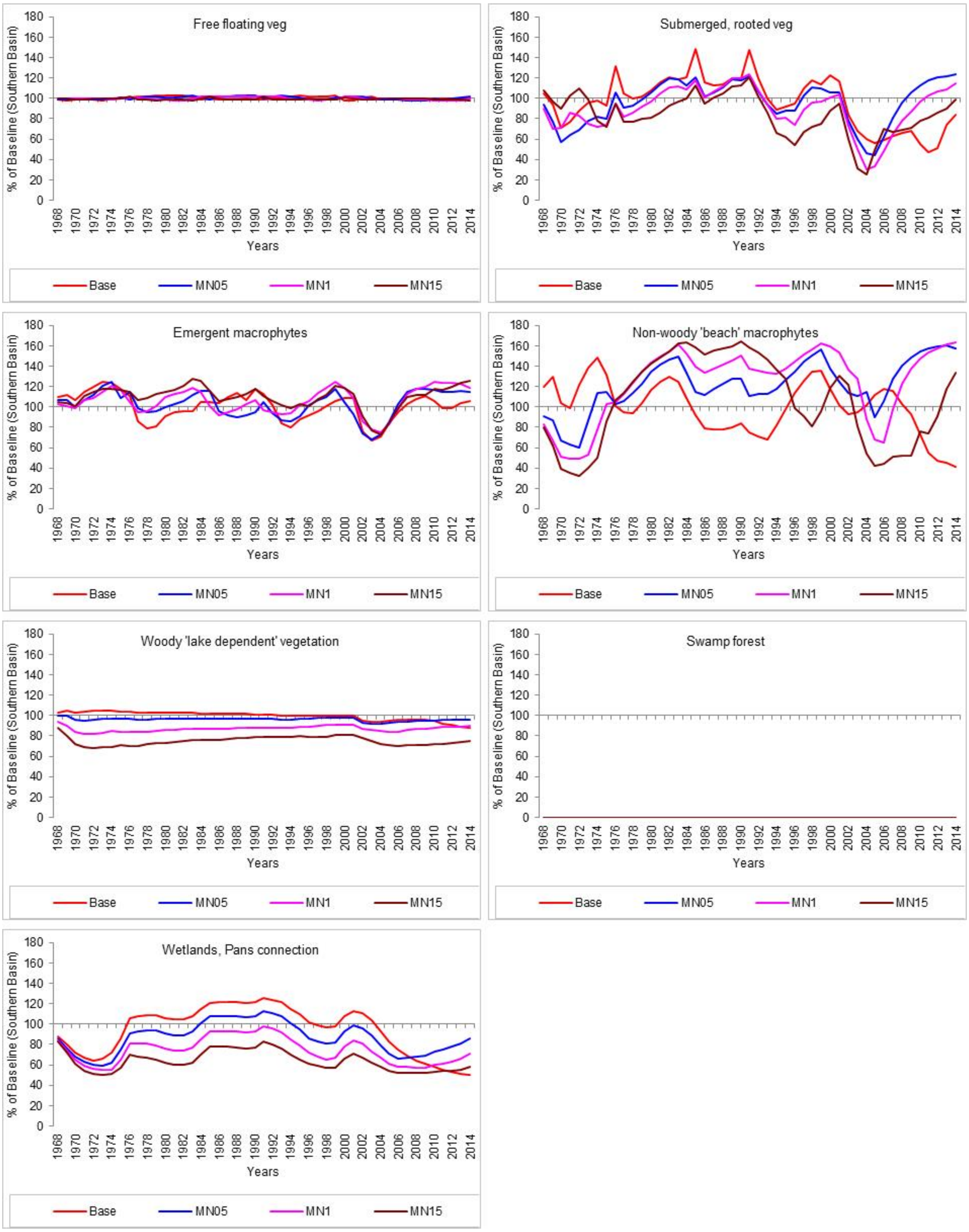
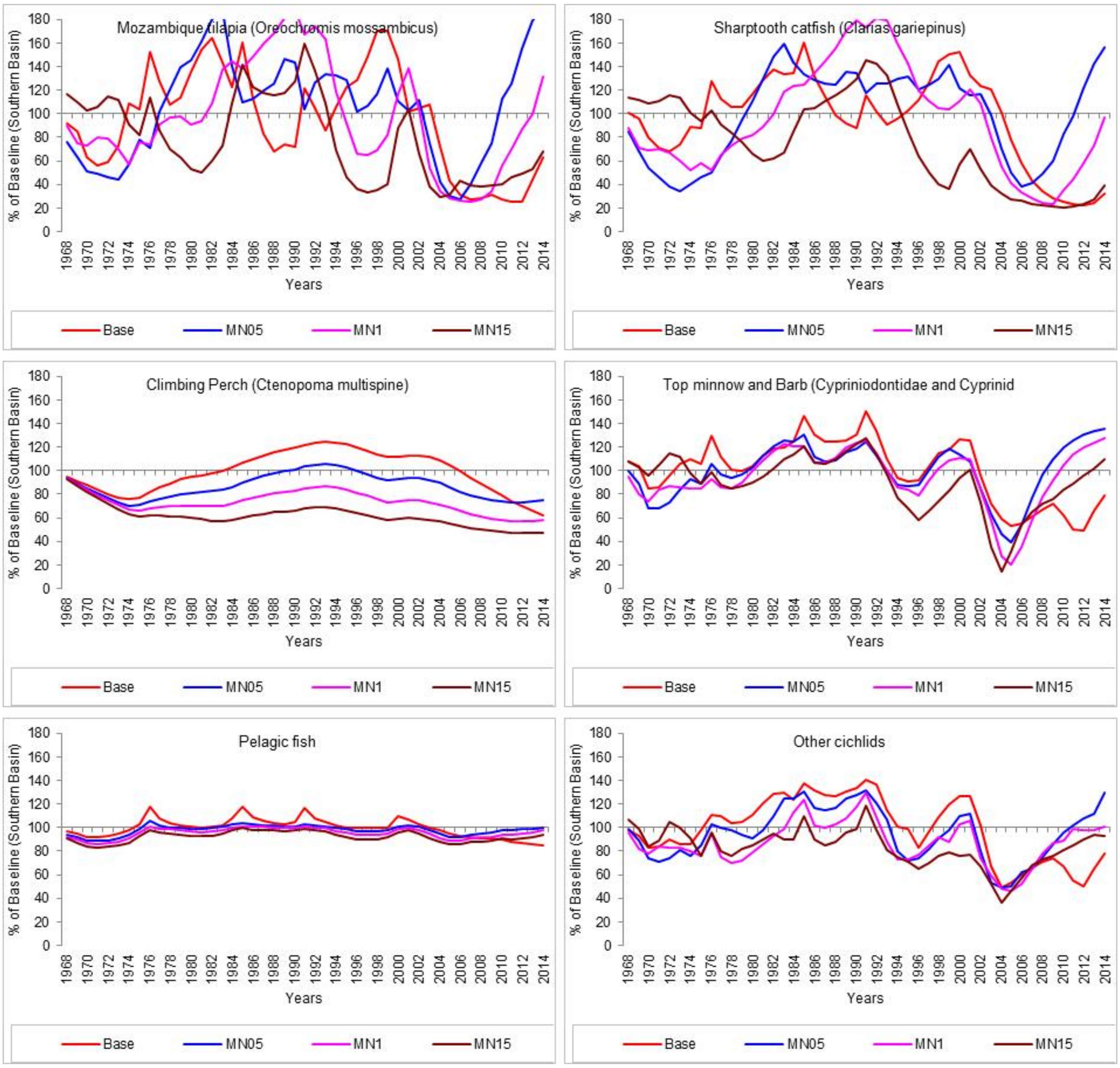


Figure 7.34 Vegetation time-series for Baseline, REC, AEC1 and AEC2 at the Southern Basin[18]

[18] Blank graphs were not indicators in this zone

Figure 7.35 Macroinvertebrate time-series for Baseline, REC, AEC1 and AEC2 at the Southern Basin



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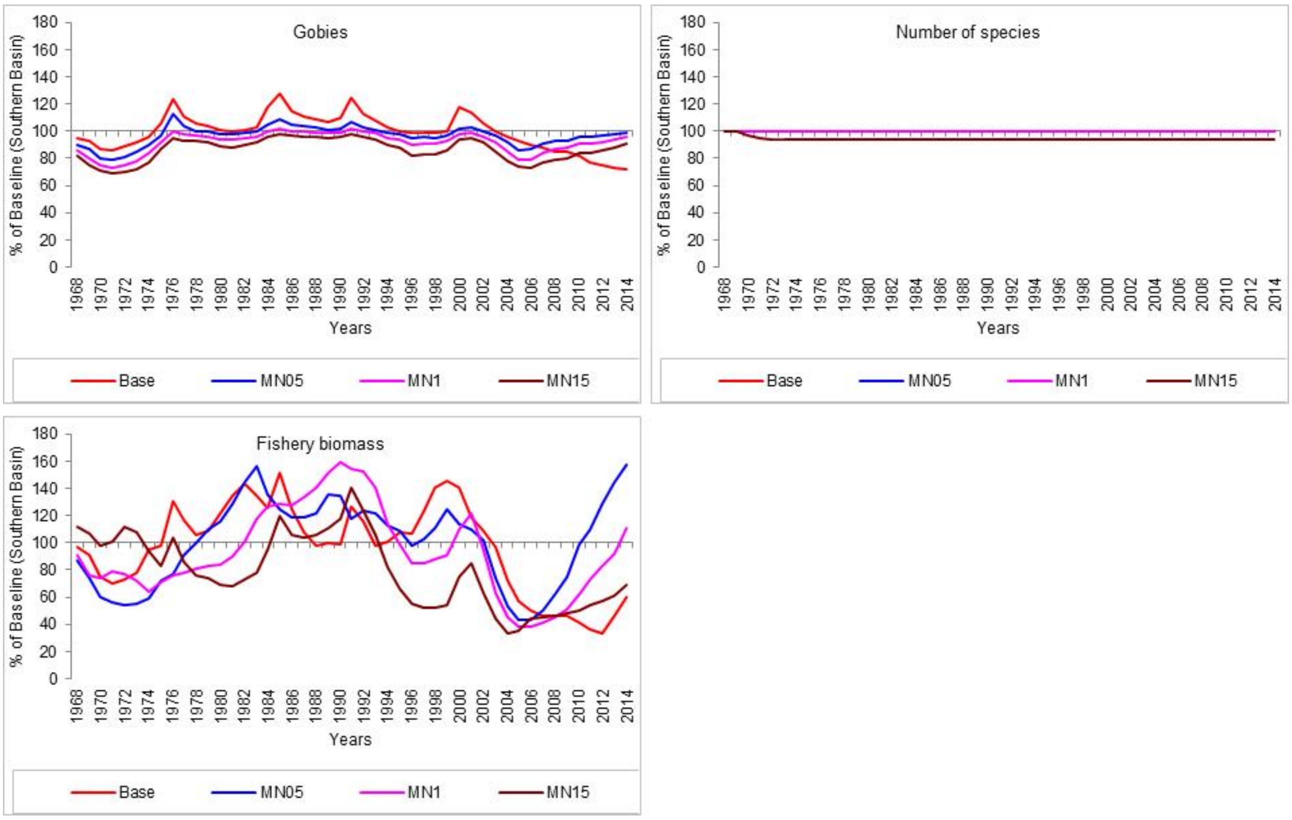


Figure 7.36 Fish time-series for Baseline, REC, AEC1 and AEC2 at the Southern Basin

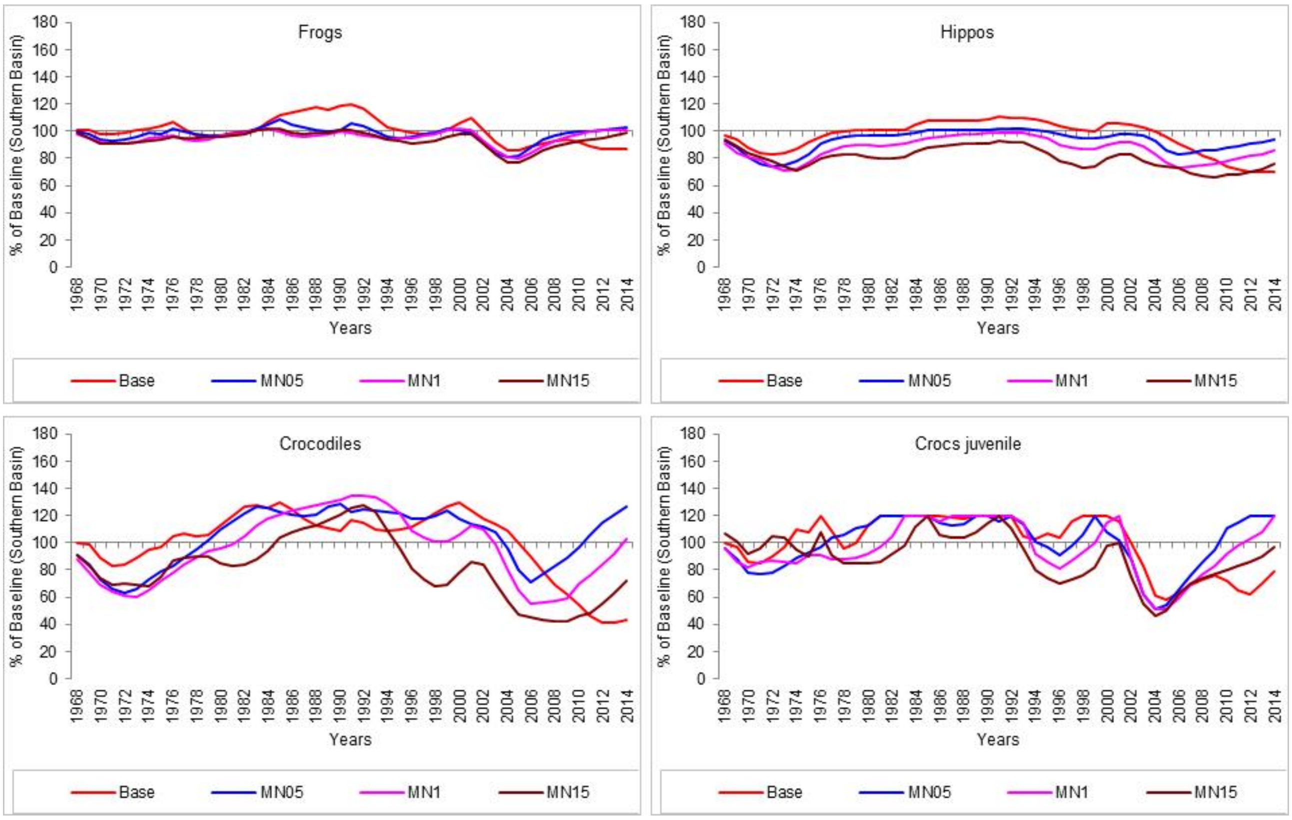


Figure 7.37 Herpetofauna and Mammals time-series for Baseline, REC, AEC1 and AEC2 at the Southern Basin

Figure 7.38 Social time-series for Baseline, REC, AEC1 and AEC2 at the Southern Basin

7.5.3 Mean percentage changes

The mean percentage changes (relative to Baseline) for the indicators for the EWRs for REC, AEC1 and AEC2 at the Southern Basin are given in Table 7.11. The changes illustrate that some change is expected from baseline with each scenario. For example, there are reductions in the abundance of wetlands and pans that drive reduced abundance of Climbing Perch under MN15.

Table 7.11 Southern Basin: The mean percentage changes in abundance (relative to 2015) for the indicators for the EWRs for maintaining a B/C and C category.

Blue and green = increases. Green = 30-50%; Blue = >50%.
Orange and red = decreases. Orange = 30-50%; Red = >50%.
Baseline, by definition, should be close to 100%.

Discipline	Indicator	Base	MN1	MN15	MN05
Water quality	Conductivity	-3.5	1.7	3.1	-0.7
	Dissolved oxygen				
	Vol where DIN c. 0.23mg/l	-0.2	-0.5	-1.3	0.2
	Vol where DIN c. 0.07mg/l	-1.0	-3.0	-4.5	-1.5
	Vol where DIP c. 0.02mg/l	-1.0	-3.0	-4.5	-1.5
	Vol where DIP c. 0.04mg/l	-0.2	-0.5	-1.3	0.2
Vegetation	Free floating veg	0.1	-0.1	-0.4	0.2
	Submerged, rooted veg	-2.7	-8.1	-12.8	-3.1
	Emergent macrophytes	0.5	4.9	7.7	2.2
	Non-woody 'beach' macrophytes	0.4	20.4	4.4	18.3
	Woody 'lake dependent' vegetation	-0.6	-12.5	-24.1	-3.7
	Swamp forest				
	Wetlands, Pans connection	-4.5	-21.5	-30.4	-1.4
Macro-invertebrates	*Bulinus globosus* (bilharzia host)	2.0	1.2	4.1	-4.2
	Tarebia	-0.5	-4.9	-4.5	-2.2
	Melanoides	-1.8	-4.9	-7.7	0.4
	Pulmonates	-0.1	0.7	1.1	-0.3
	Caridina (shrimp)	0.2	-0.8	-1.3	2.5
	Potamonautes (crab)	0.6	4.8	6.9	-1.8
	Hymenosoma (crab)	-1.4	-4.0	-6.2	-1.4
Fish	Mozambique tilapia (*Oreochromis mossambicus*)	-3.3	-2.3	-14.9	4.4
	Sharptooth catfish (*Clarias gariepinus*)	-3.5	-4.4	-19.5	-0.1
	Climbing Perch (*Ctenopoma multispine*)	-0.9	-22.6	-32.4	-11.3
	Top minnow & Barb (Cypriniodontidae & Cyprinid	0.1	-4.0	-7.0	-0.1
	Pelagic fish	-0.1	-3.4	-5.5	-1.5
	Other cichlids	-0.5	-8.8	-11.9	-3.6
	Gobies	-0.1	-5.8	-9.5	-2.3
	Number of species	0.0	-0.2	-5.6	0.0
	Fishery biomass	-2.3	-5.2	-15.0	0.2
Herpetofauna and Mammals	Frogs	0.6	-3.4	-4.5	-1.6
	Hippos	-2.9	-11.1	-16.6	-5.9
	Crocodiles	1.0	-3.9	-15.8	3.6
	Crocs juvenile	-0.1	-2.7	-6.2	0.3
Socio-economics	Domestic use	-1.6	-23.6	-34.2	-10.0
	Recreational use	3.0	-11.1	-17.2	-3.3
	Fishing	1.8	0.8	-3.0	2.8
	Water lily harvesting	-3.4	-8.9	-13.3	-4.1
	Reeds and sedges	1.2	3.3	4.9	1.9
	Health (Bilharzia)	2.8	1.1	-0.1	2.3
	Cattle watering	-3.5	-10.3	-14.7	-4.7

7.5.4 Ecosystem integrity and social well being

The Overall Ecological Integrity of the Southern Basin for each scenario is illustrated in Figure 7.39. The baseline ecostatus for the Southern Basin is a C category (for details see Volume 1: Ecoclassification Report). With this in mind both all three scenarios return a C category for the Southern Basin, provided lake levels recover and do not drop further.

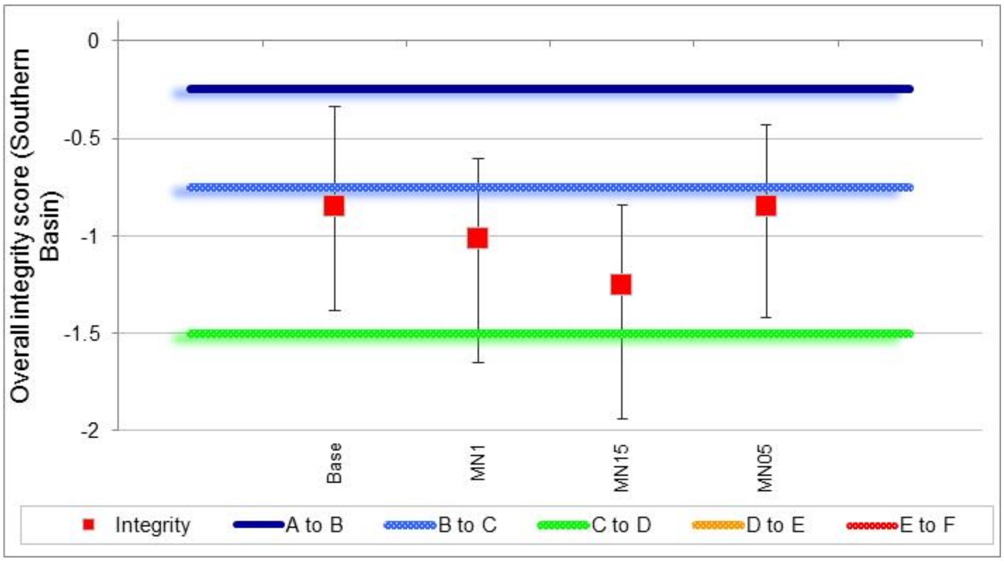


Figure 7.39 Overall ecosystem integrity scores for the Southern Basin

The social well-being scores for the Southern Basin are illustrated in Figure 7.40 and depict a very slight decrease in social well-being for both scenarios. The main reasons for this include are reduced recreational and domestic use of water and reduced availability of water lilies from the Southern Basin at lower lake levels.

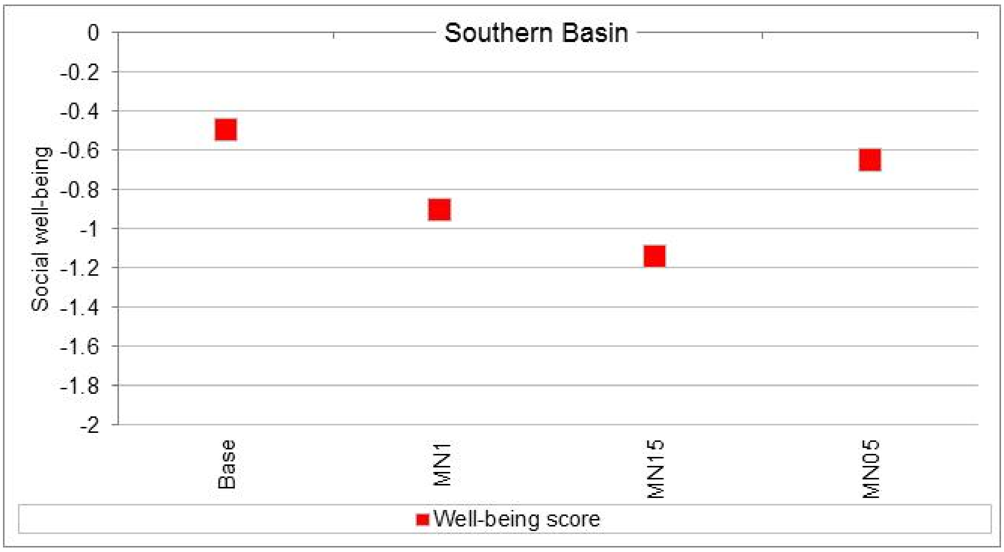


Figure 7.40 Overall social well-being scores for the Southern Basin

7.6 Whole Lake

7.6.1 Hydraulics

The main hydraulic characteristics associated with each of the scenarios at the Main Basin, and the index score for accessibility, are given in Table 7.12.

Table 7.12 Median values for the hydraulic characteristics, rate of change in water level and accessibility of each scenario for the Whole Lake

		REC	AEC1	AEC2
Whole Lake	Base	MN1	MN15	MN05
Mean annual water level	18.82	17.87	17.37	18.37
Volume	735.73	678.24	649.05	708.29
Area	62.04	59.24	57.47	60.87
Perimeter	167.74	174.66	181.95	170.36
Area exposed below 20.39 (beach)	8.89	11.69	13.45	10.06
Area 0 to 7 m deep	22.81	22.78	22.42	22.92
Area between 0.65 below and 0.3 above	3.48	3.34	3.44	3.06
Area of beach between 0.6 and 3.8 above	17.37	19.55	19.36	18.56
Area of beach between 4.8 and 8.8 above	0.00	0.00	0.00	0.00
VerDist from water level to fixed (amsl) tree-line	1.47	2.42	2.92	1.92
Area deeper than 7 m	39.00	36.46	35.08	37.80
Area 2 to 5 m deep	9.85	9.44	9.41	9.57
Area 1.5 to 2 m deep	1.70	1.81	1.60	1.89
Area 1 to 1.8 m deep	2.71	3.05	2.79	3.00
Area 1 to 1.5 m deep	1.70	1.89	1.81	1.80
Area 0.5 to 1 m deep	1.66	1.80	1.89	1.72
Area 0 to 0.5 m deep	1.70	1.72	1.80	1.68
Area 0 to 0.3 m deep	1.01	1.02	1.07	0.99
HorDist to tree line	57.46	75.71	86.43	65.23
Max Depth	41.73	40.78	40.28	41.28
Volume up to 2 m	6.68	7.54	7.04	7.44
Volume deeper than 2 m	728.31	670.57	642.00	700.49
Rate of change in water level (annual)	-0.09	0.02	0.02	0.02
Accessibility/Use	5.00	3.00	3.00	3.00

7.6.2 Time-series of responses

The time-series of predicted abundance changes relative to baseline (2015) under the EWRs for maintaining a B/C and C-category are provided for the indicators for each discipline (Figure 7.41 to Figure 7.47).

7.6.2.1 Water Quality

Figure 7.41 Water quality time-series for Baseline, REC, AEC1 and AEC2 for the Whole Lake

7.6.2.2 *Vegetation*

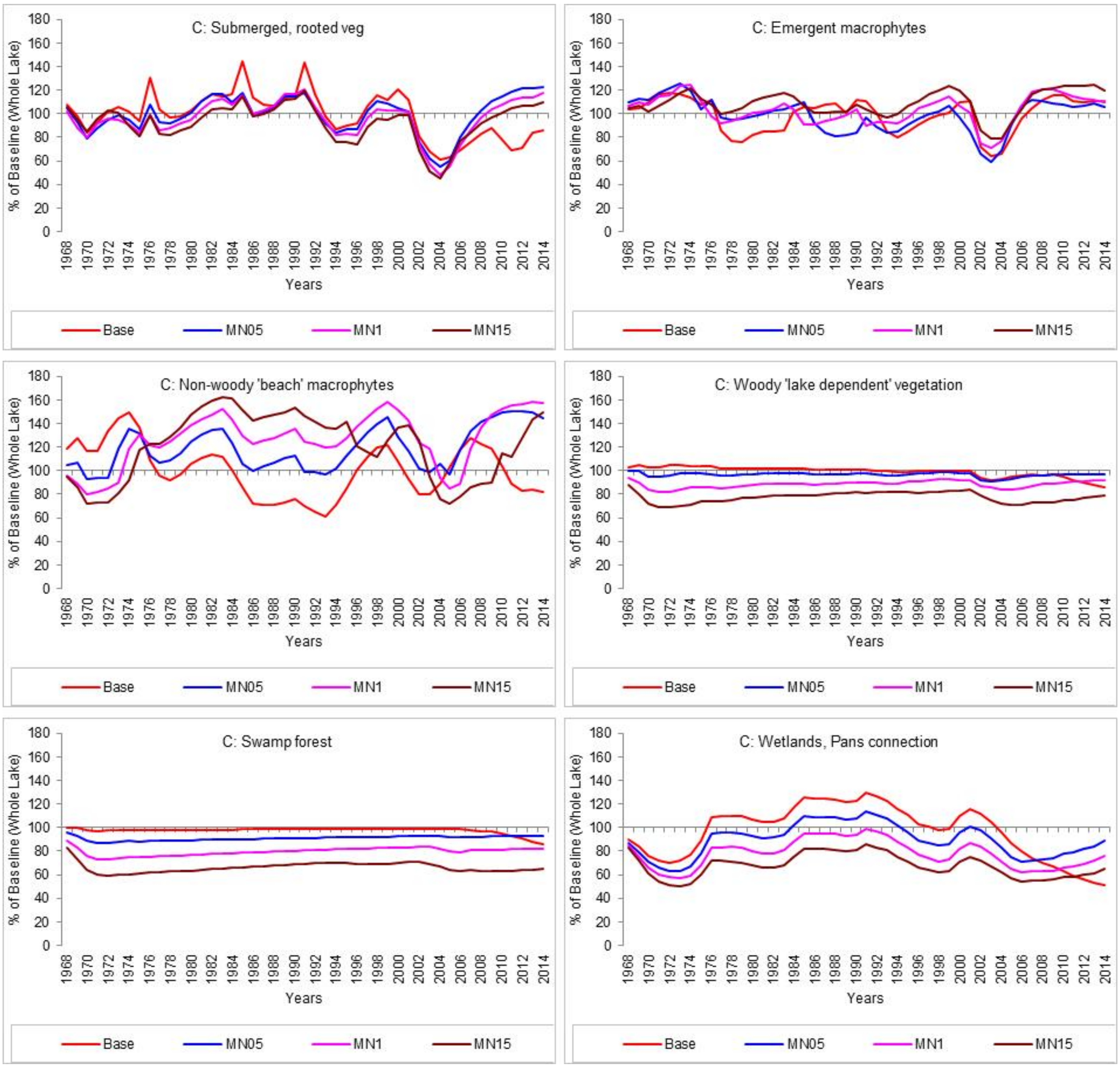


Figure 7.42 Vegetation time-series for Baseline, REC, AEC1 and AEC2 for the Whole Lake

7.6.2.3 Macroinvertebrates

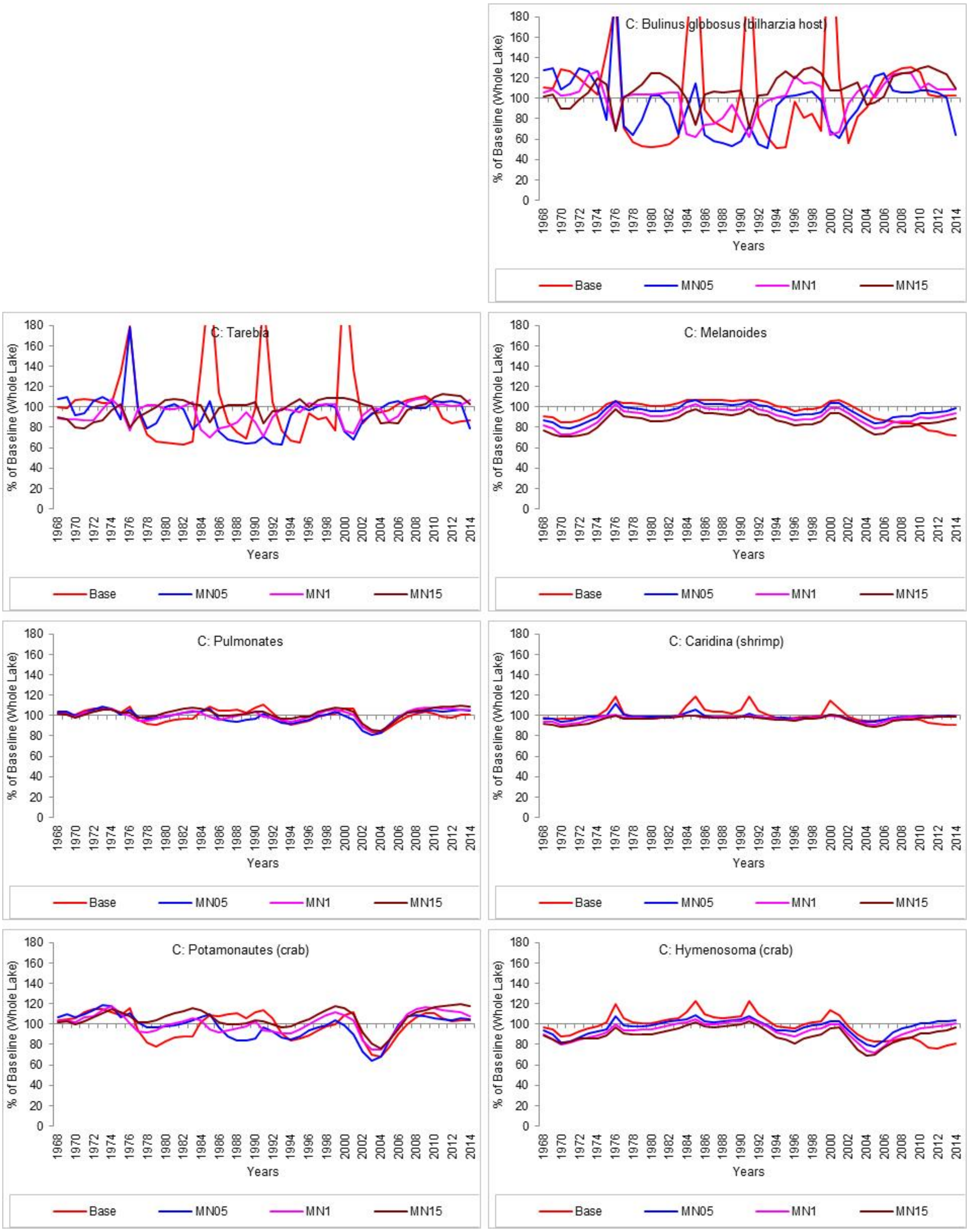
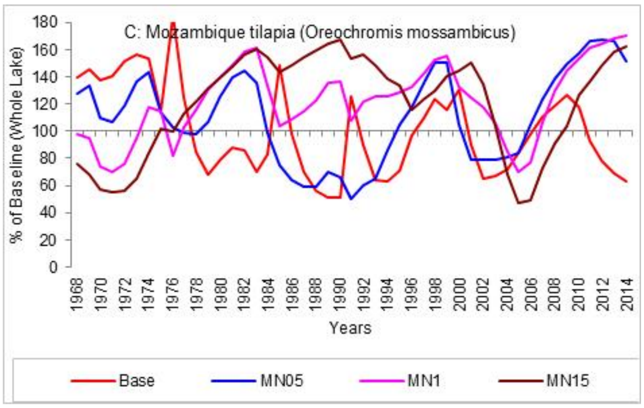
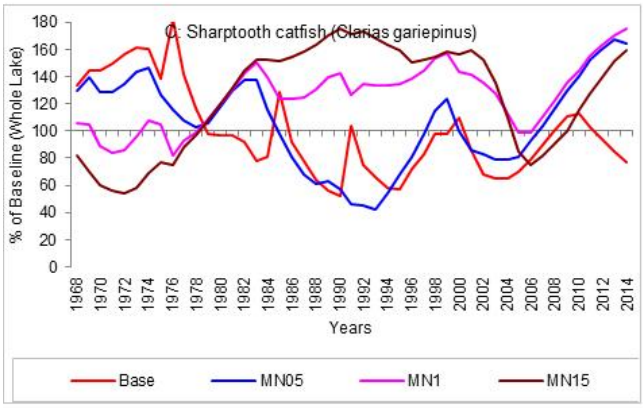
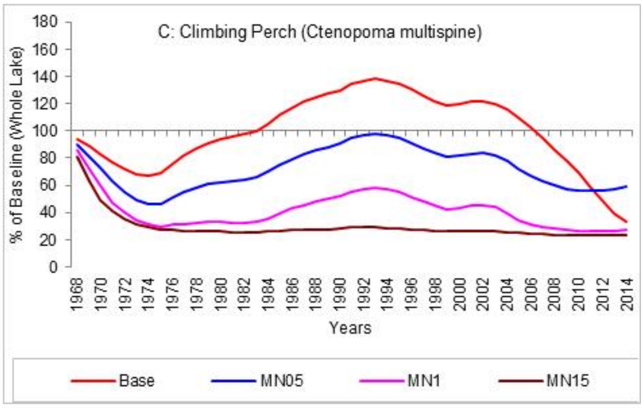


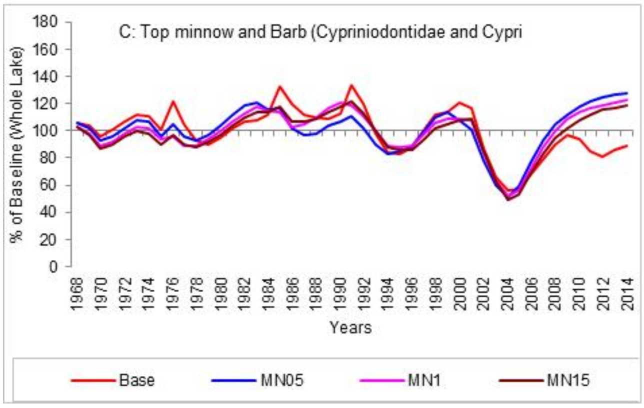
Figure 7.43 Macroinvertebrate time-series for Baseline, REC, AEC1 and AEC2 for the Whole Lake

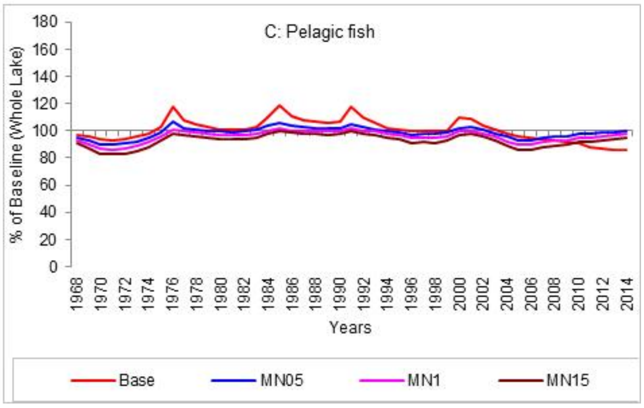
7.6.2.4 Fish











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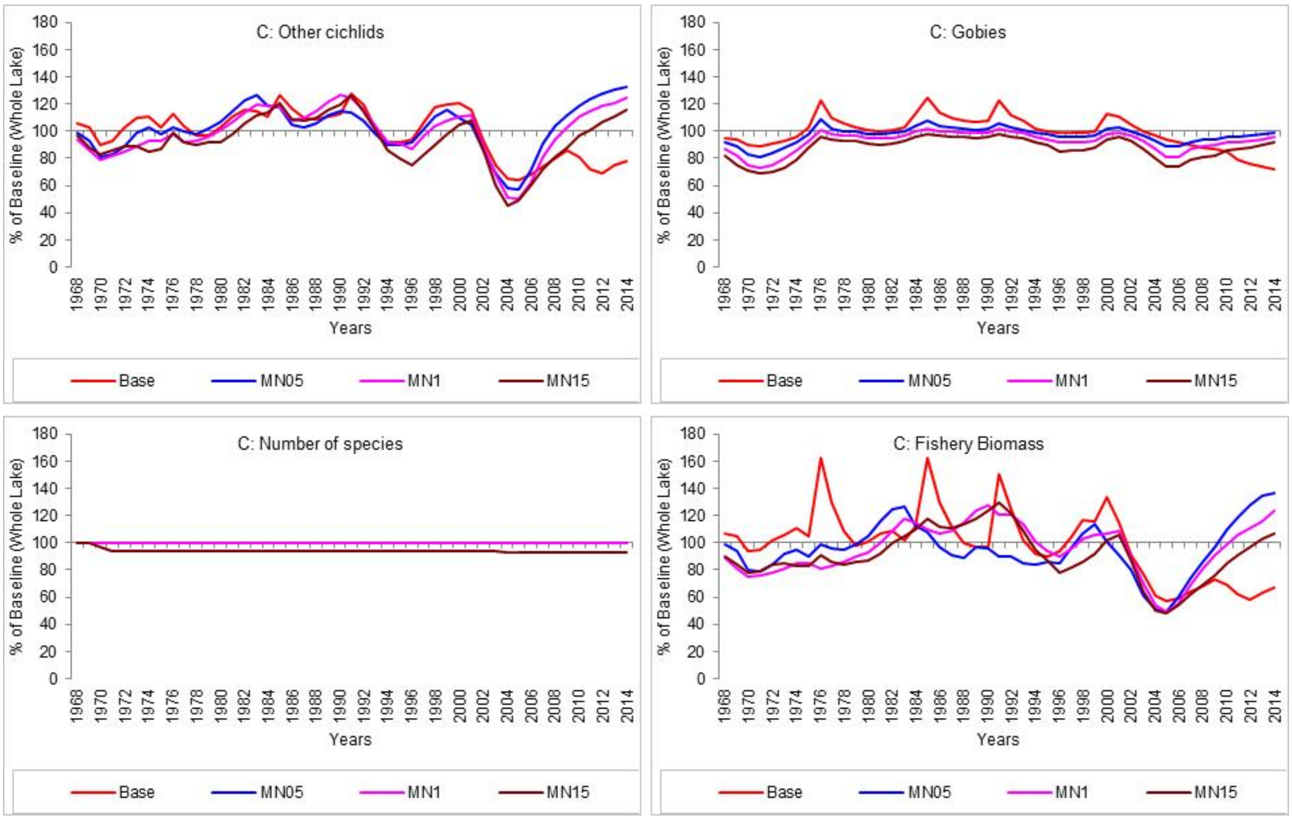


Figure 7.44 Fish time-series for Baseline, REC, AEC1 and AEC2 for the Whole Lake

7.6.2.5 Herpetofauna and Mammals

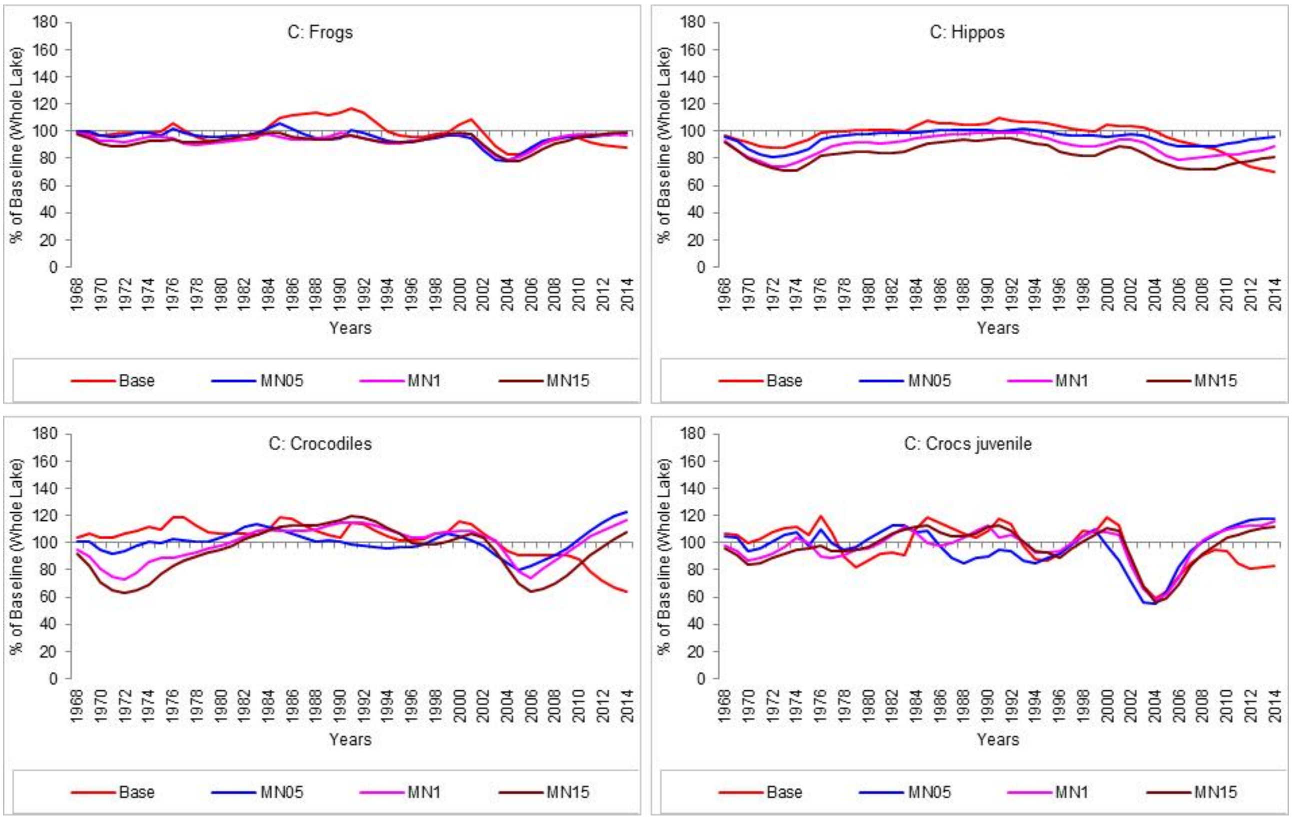
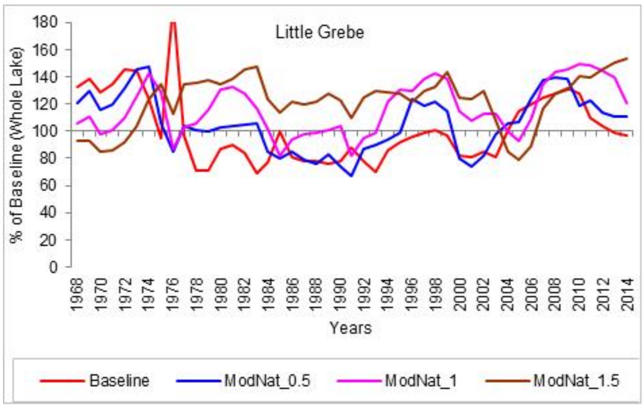
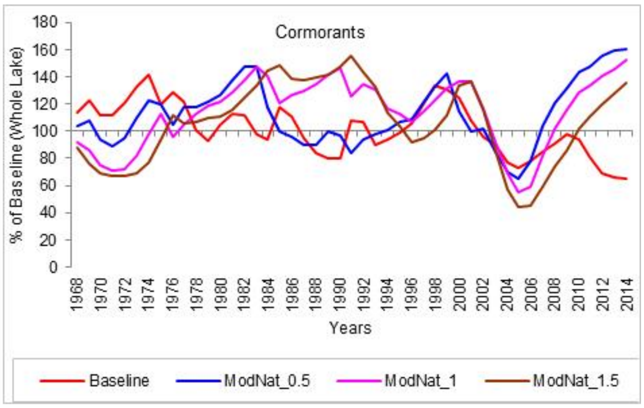
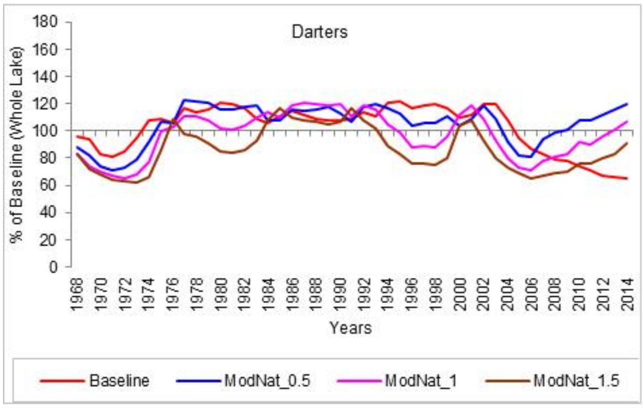


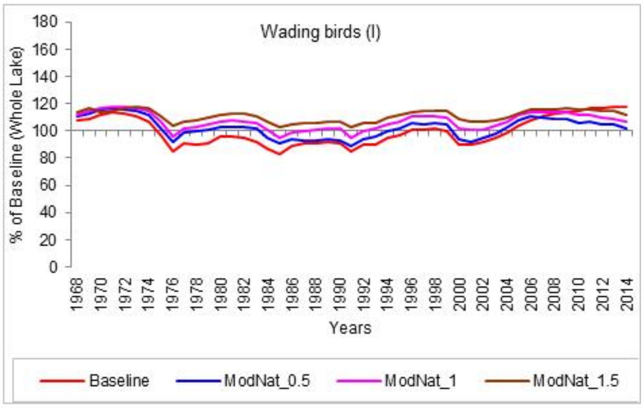
Figure 7.45 Herpetofauna and Mammals time-series for Baseline, REC, AEC1 and AEC2 for the Whole Lake

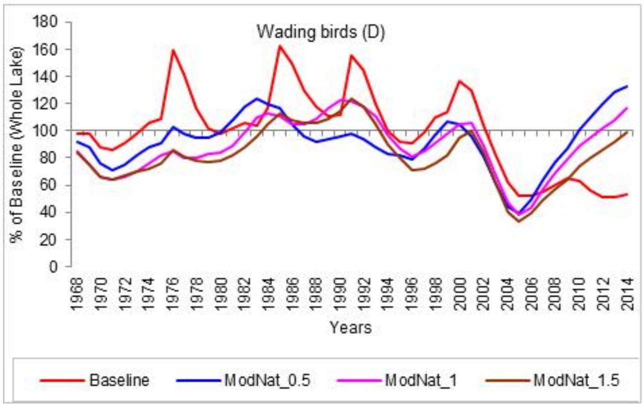
7.6.2.6 Birds

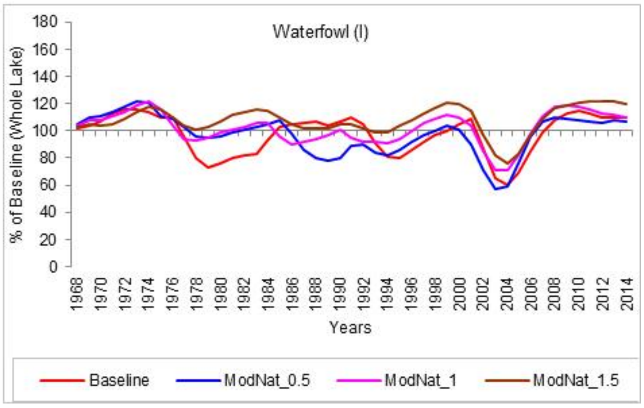












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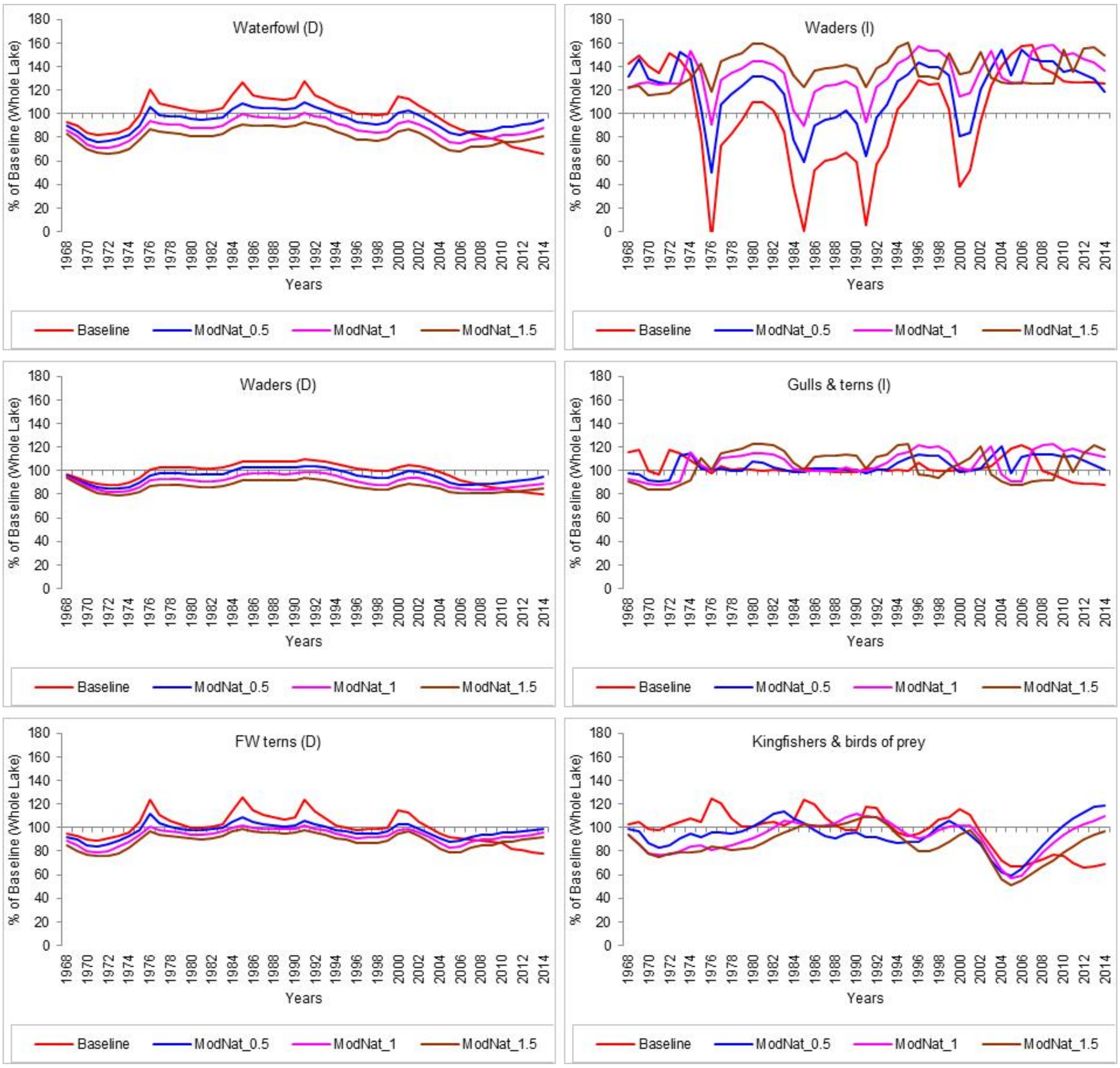

Figure 7.46 Birds time-series for Baseline, REC, AEC1 and AEC2 for the Whole Lake

7.6.2.7 Socio-economics

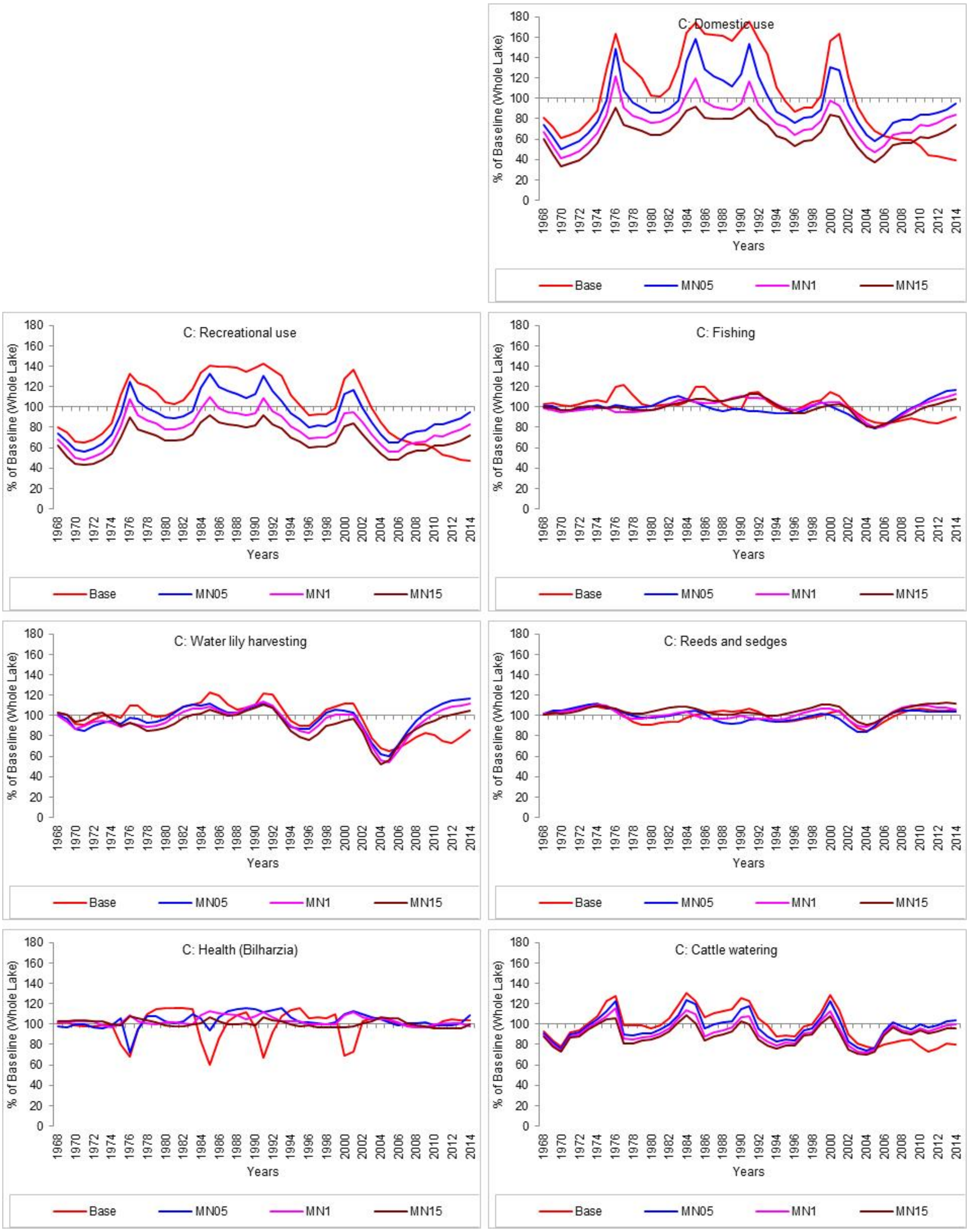

Figure 7.47 Social time-series for Baseline, REC, AEC1 and AEC2 for the Whole Lake

7.6.3 Mean percentage changes

The mean percentage changes (relative to Baseline) for the indicators for the EWRs were selected as potential Reserves to maintain the REC, AEC1 and AEC2 at the Whole Lake are given in Table 7.13. Change relative to baseline is expected under all scenarios. For example, there are reductions in the abundance of wetlands and pans that drive reduced abundance of Climbing Perch under MN1 and MN15. In addition, not all changes are negative even for the C-category, i.e., some indicators are expected to do better (e.g., Little Grebe and Waders (I)). Overall, however, the B/C-scenario is expected to maintain a better ecological condition than the C-scenario.

Table 7.13 Whole Lake: The mean percentage changes in abundance (relative to 2015) for the indicators for the EWRs for maintaining a B/C and C category.

Blue and green = increases. Green = 30-50%; Blue = >50%.
Orange and red = decreases. Orange = 30-50%; Red = >50%.
Baseline, by definition, should be close to 100%.

Discipline	Indicator	Base	MN1	MN15	MN05
Water quality	Conductivity	-3.5	1.7	3.1	-0.7
	Dissolved oxygen	0.5	1.1	1.5	0.6
	Vol where DIN c. 0.23mg/l	-1.1	0.0	0.2	-0.5
	Vol where DIN c. 0.07mg/l	-2.2	-2.3	-4.7	-0.7
	Vol where DIP c. 0.02mg/l	-2.2	-2.3	-4.7	-0.7
	Vol where DIP c. 0.04mg/l	-1.1	0.0	0.2	-0.5
Vegetation	Free floating veg	-0.3	0.0	0.0	-0.1
	Submerged, rooted veg	-0.7	-3.2	-5.8	-0.5
	Emergent macrophytes	-0.7	2.5	7.0	-0.8
	Non-woody 'beach' macrophytes	0.5	22.5	17.5	15.8
	Woody 'lake dependent' vegetation	-0.9	-11.1	-21.7	-3.3
	Swamp forest	-2.5	-19.0	-31.9	-8.5
	Wetlands, Pans connection	-2.2	-18.7	-27.2	-9.0
Macro-invertebrates	*Bulinus globosus* (bilharzia host)	3.5	0.0	5.3	-2.8
	Tarebia	2.0	-4.0	-0.9	-4.2
	Melanoides	-2.2	-5.7	-8.6	-2.8
	Pulmonates	-0.2	0.1	0.9	-0.3
	Caridina (shrimp)	0.3	-1.7	-2.3	-0.8
	Potamonautes (crab)	-0.5	0.7	3.6	-1.1
	Hymenosoma (crab)	-1.0	-4.0	-6.2	-1.8
Fish	Mozambique tilapia (*Oreochromis mossambicus*)	0.4	15.4	14.4	7.1
	Sharptooth catfish (*Clarias gariepinus*)	-0.7	21.0	20.1	4.8
	Climbing Perch (*Ctenopoma multispine*)	-0.4	-49.7	-59.9	-23.5
	Top minnow & Barb (Cypriniodontidae & Cyprinid	-0.5	0.0	-1.3	0.4
	Pelagic fish	0.5	-3.0	-5.1	-1.0
	Other cichlids	-0.6	-0.6	-4.3	1.5
	Gobies	-0.1	-5.3	-8.7	-2.1
	Number of species	0.0	-0.2	-6.3	0.0
	Fishery biomass	-0.6	-3.3	-6.5	-3.7
Herpetofauna and Mammals	Frogs	-0.8	-4.8	-5.2	-3.4
	Hippos	-2.1	-9.3	-14.0	-4.3
	Crocodiles	2.7	-0.6	-5.2	0.5
	Crocs juvenile	-1.5	-1.4	-1.8	-1.8

Discipline	Indicator	Base	MN1	MN15	MN05
Birds	Little Grebe	1.0	11.4	15.0	3.9
	Cormorants	1.3	8.4	3.9	7.3
	Darters	1.7	-1.8	-8.1	3.1
	Wading birds (I)	-0.2	4.2	6.6	1.4
	Wading birds (D)	0.2	-7.0	-11.0	-5.1
	Waterfowl (I)	-1.7	1.3	5.0	-1.6
	Waterfowl (D)	-0.7	-7.8	-11.8	-3.5
	Waders (I)	0.4	23.6	26.5	14.0
	Waders (D)	-1.1	-5.6	-8.1	-2.8
	Gulls & terns (I)	1.5	5.2	3.9	3.2
	FW terns (D)	0.2	-4.1	-6.5	-1.7
	Kingfishers & birds of prey	-1.7	-5.3	-9.3	-4.0
Socio-economics	Domestic use	2.6	-19.0	-28.8	-6.2
	Recreational use	-0.5	-17.9	-26.6	-7.1
	Fishing	1.1	-0.2	-0.4	-1.0
	Water lily harvesting	-1.9	-4.0	-5.9	-1.9
	Reeds and sedges	0.1	1.3	3.5	-0.1
	Health (Bilharzia)	-0.5	2.2	0.6	2.4
	Cattle watering	-1.3	-6.3	-9.1	-2.4

7.6.4 Ecosystem integrity and social well being

The Overall Ecological Integrity of the Whole Lake for each scenario is illustrated in Figure 7.48. The baseline ecostatus for the Whole Lake is a B/C category (for details see Volume 1: Ecoclassification Report). With this in mind MN1 and MN05 return a B/C category for the Whole Lake while MN15 returns a C category, provided lake levels recover and do not drop further.

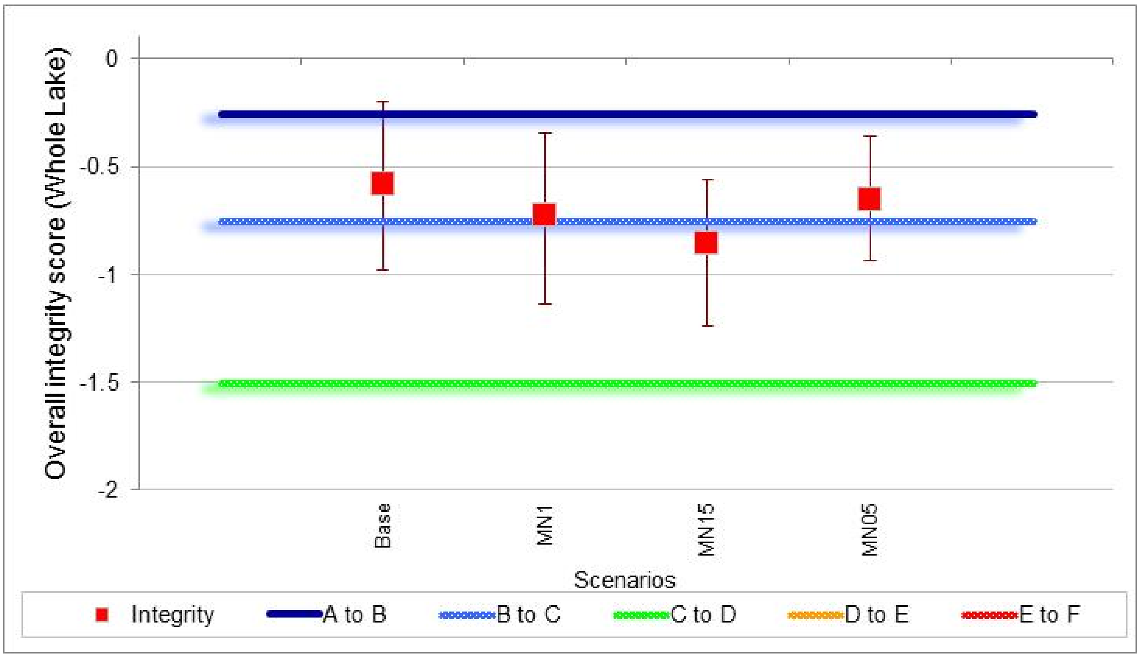

Figure 7.48 Overall ecosystem integrity scores for the Whole Lake

The social well-being scores for the Southern Basin are illustrated in Figure 7.49 and depict a very slight decrease in social well-being for both scenarios. The main reasons for this include are reduced recreational and domestic use of water and reduced availability of water lilies from the Southern Basin at lower lake levels.

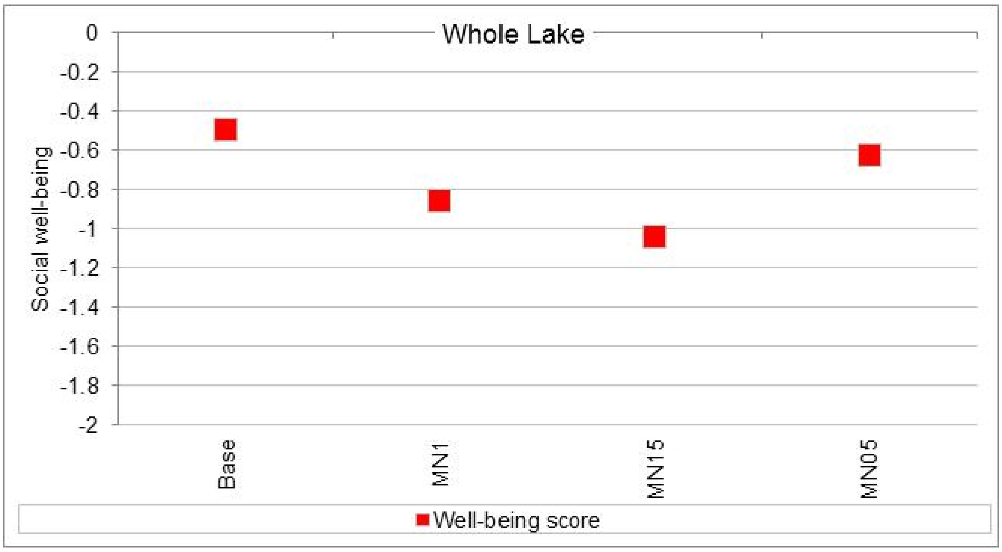

Figure 7.49 Overall social well-being scores for the Whole Lake

The overall integrity scores for each lake zone, Baseline, MN05, MN1 and MN1.5 are summarised in Figure 7.50.

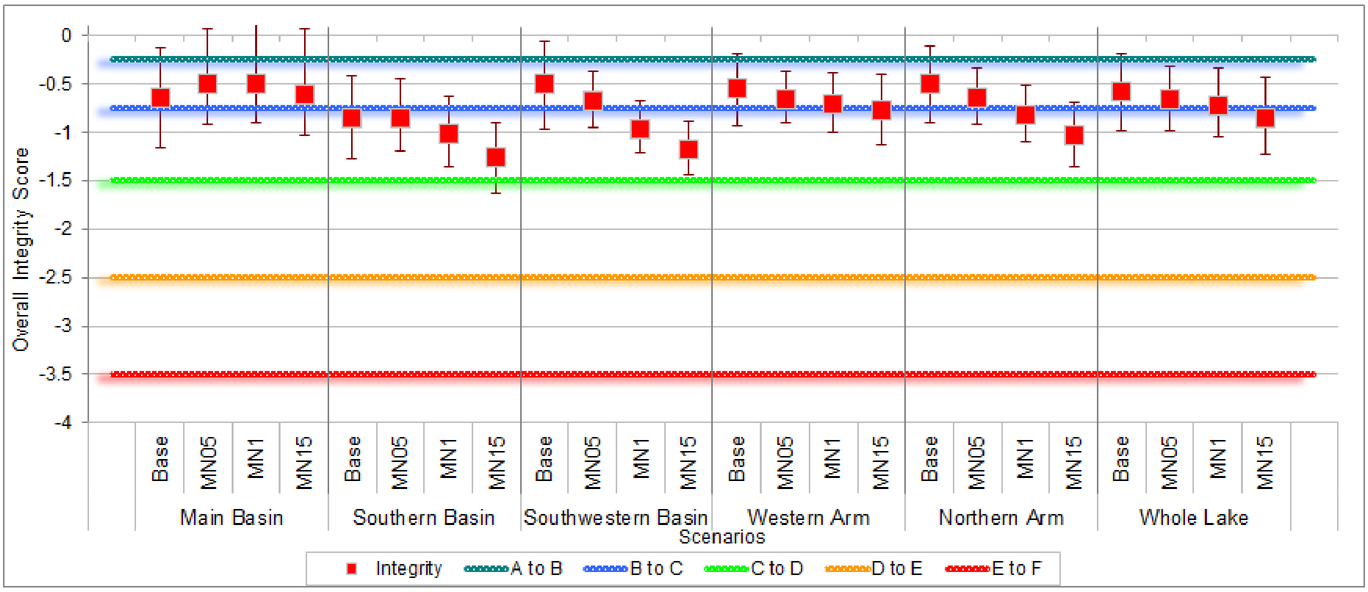

Figure 7.50 Overall integrity scores for the scenarios at Lake Sibaya

8 FURTHER EXPLORATION OF THE REC AND AECS

8.1 The importance of variability

There is little monthly or seasonal variation in the water levels of Lake Sibaya, but there are strong, long-term, quasi-cyclical variations that show a clear relationship with rainfall (see Appendix A). The importance of this variability in maintaining lake integrity was tested as follows:

In order to further explore the requirements the selected scenarios were further assessed.

To explore the effect of low water levels, the following scenarios were evaluated:

- Base1: This scenario is identical to MN1 (ModNat / Baseline less **1** metre) until April 2006, and thereafter is identical to Baseline until June 2015.
- Base05: This scenario is identical to MN1 (ModNat / Baseline less **1** metre) until April 2006, and thereafter equals Baseline minus 0.5 m until June 2015.
- Base15: This scenario is identical to MN1.5 (ModNat / Baseline less **1** metre) until April 2006, and thereafter equals Baseline minus 1.5 m until June 2015.

To explore the effect of high water levels, the following scenarios were evaluated:

- MN05LoP (MN-0.5_LowPeaks): This scenario is identical to MN05 (ModNat / Baseline less **0.5** metres) except that the peak water levels are capped at 19.18 metres (half way between the max and the median of MN05).
- B05LoP: This scenario is identical to Base05 until April 2006, but then follows Baseline (with no reduction), *and* has flows capped at 19.18 m.

The overall integrity results for these scenarios plus Baseline, REC and AEC1 are shown in Figure 8.1, and clearly show that lower water levels have a greater negative effect on integrity than do lower peak water levels.

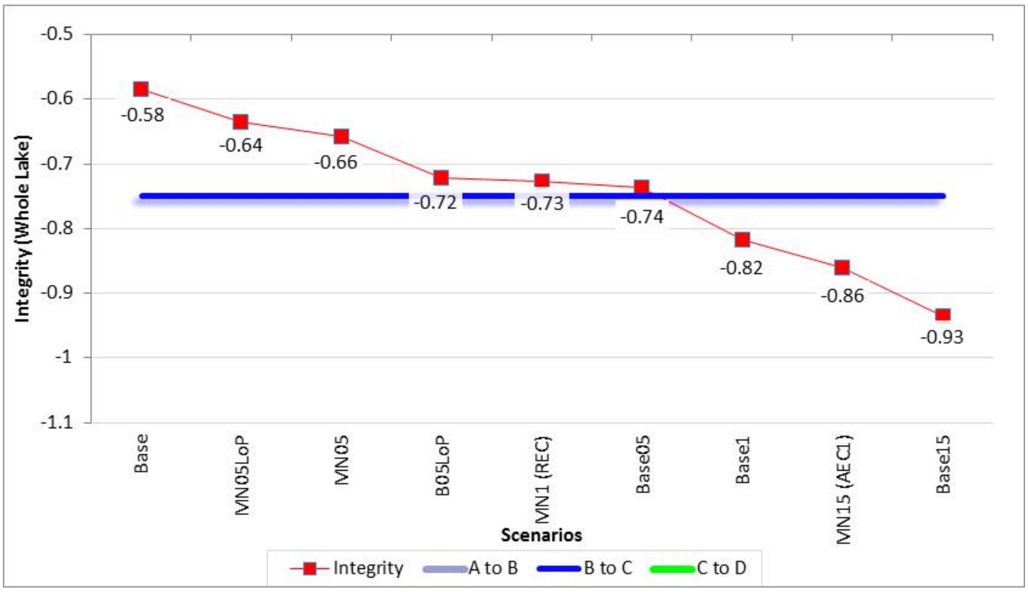

Figure 8.1 Overall integrity for the Whole Lake for MN1 (REC) and MN15 (AEC1), together with comparative drought and reduced peak scenarios, in order of decreasing integrity scores

8.2 Separation of Southern Basin

It is unclear at what water level the Southern Basin separates from the Main Basin. Available water level data, combined with aerial photography and Google imagery provides some insights into the status of the Southern Basin at various water levels. Similar low water levels (17-17.3 masl) were experienced in 1971 and 2009 (Figure 8.2), and although the neck between the Southern and Main Basins is much reduced compared to e.g. 1942 (unknown water level) or 2003 (18.5 to 19 masl) there is still a connection. Although the DEM estimates that separation will occur at around 17 masl, it is clear from these images, together with that for 2014 (top right of Figure 8.2) that actual physical separation occurs around 16.5 m, although functional disconnection may happen earlier. Therefore, the REC, should avoid (a) dropping below 16.5 m, and (b) if 16.5 m or below 16.5 m levels are unavoidable due to climate conditions, these low levels should not be allowed to persist longer than is indicated by those climate conditions.

It is also informative to look at the relationship between mean annual water level and the integrity scores at each basin and for the Whole Lake (Figure 8.3). As can be seen, a water level around 17 masl is, in most cases, on the steepest slope (in other words most rapid change in integrity relative to water level), or else close to the start of that slope.

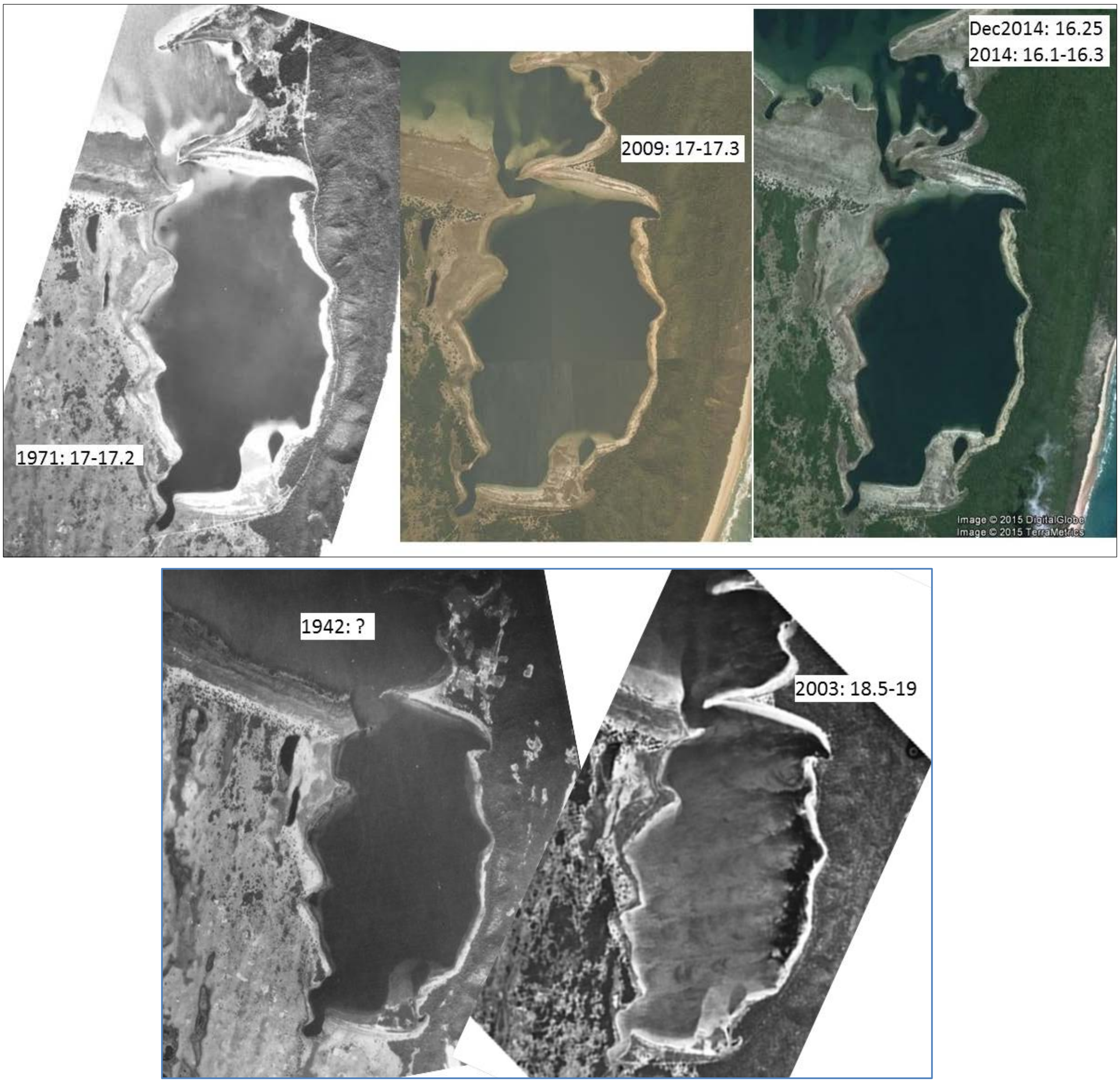

Figure 8.2 Aerial photos (top left, middle, and bottom) and a Google Earth image (top right), showing TOP: low water levels (Southern Basin at around 17 to 17.3 masl in 1971 and 2009), and lower level (16.1 – 16.3 masl in 2014), and BOTTOM: higher water levels

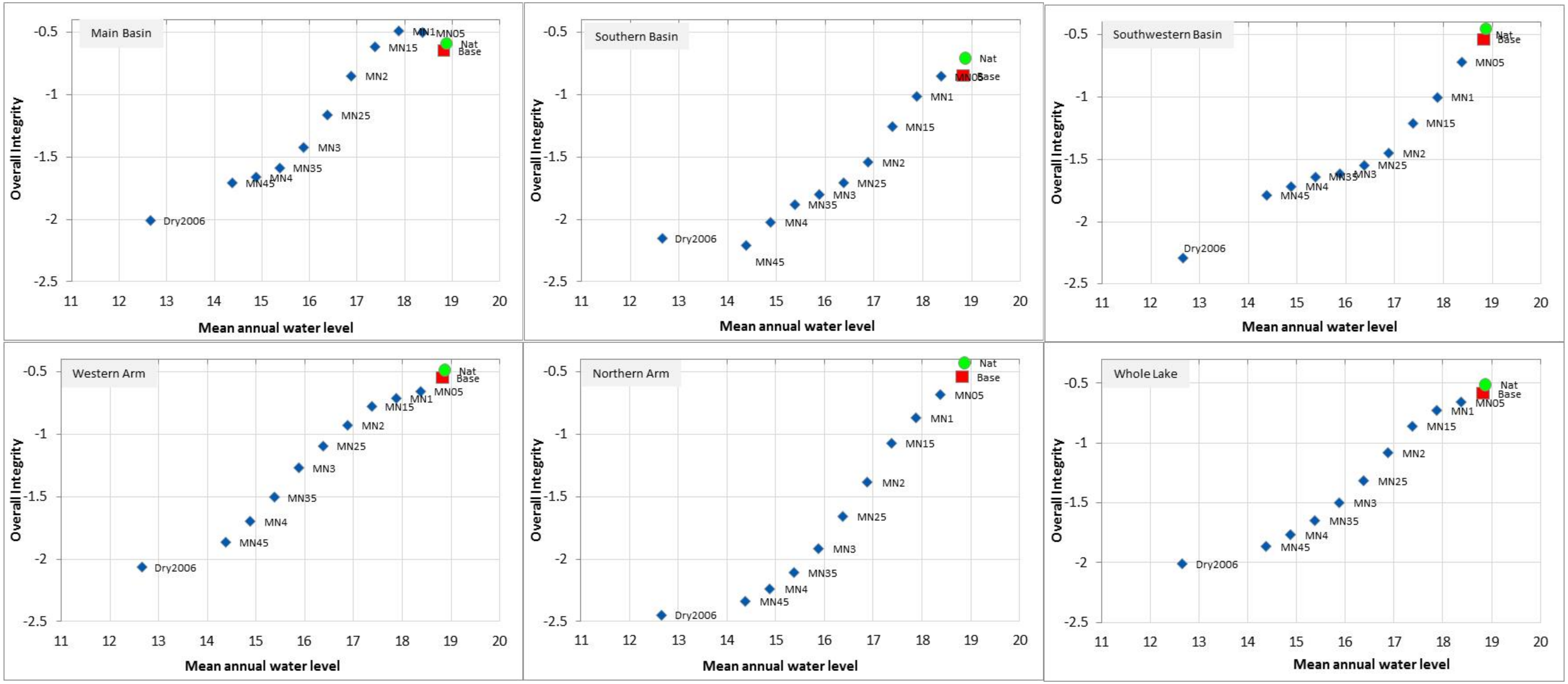

Figure 8.3 Relationship between integrity scores and mean annual water level for the lake zones and Whole Lake

8.3 Indicators requiring special attention

8.3.1 Fish and herpetofauna

Although the REC scenario (MN1) returns an overall B/C category, three basins were in C categories (Southern and Southwestern Basins and the Northern Arm). The two disciplines that are most responsive in most of the lake zones, are Fish and Herpetofauna (Figure 8.4 and Figure 8.5), and these two disciplines contribute the most to the C categories at these basins.

Under MN1, Fish in the Northern Arm, Southern and Southwestern Basins (brown squares, pink diamonds and green circles in Figure 8.4) are reduced from A/B to C. Under MN15, the fish in the Southwestern Basin are reduced to close to a C/D. As fishing pressures are low, and the current ecological category is A/B or B for fish, implementation of MN1 should be carefully monitored to ensure that fish integrity (and by inference biomass and fishing yield) does not decrease below the mid C-category predicted, or indeed to establish if the fish are more resilient than modelled in DRIFT.

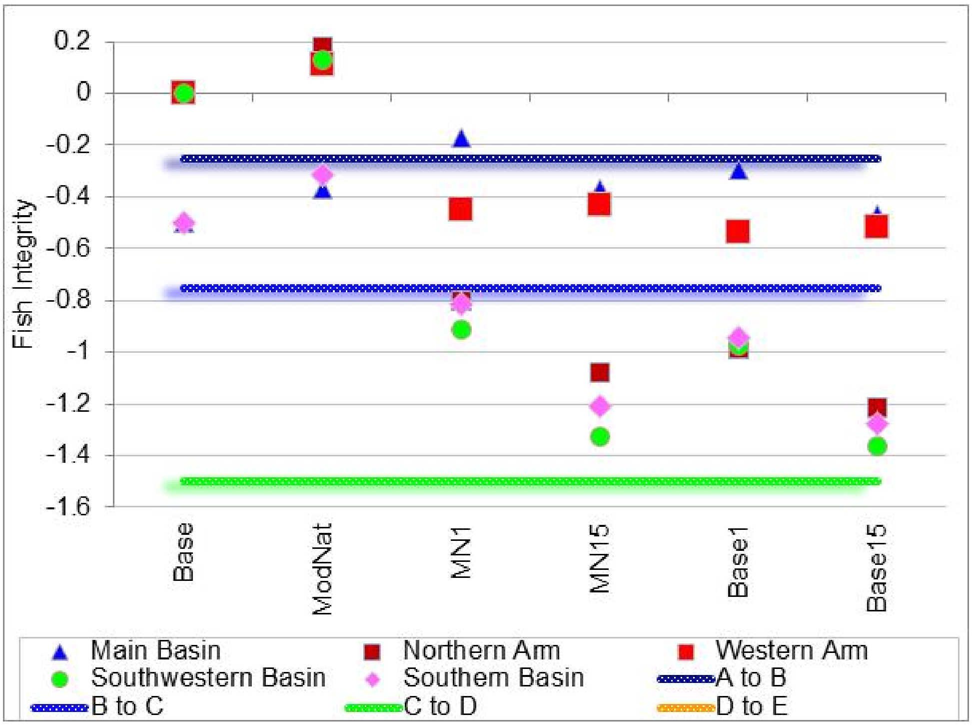

Figure 8.4 Fish integrity for MN1, MN15, Base1, Base15

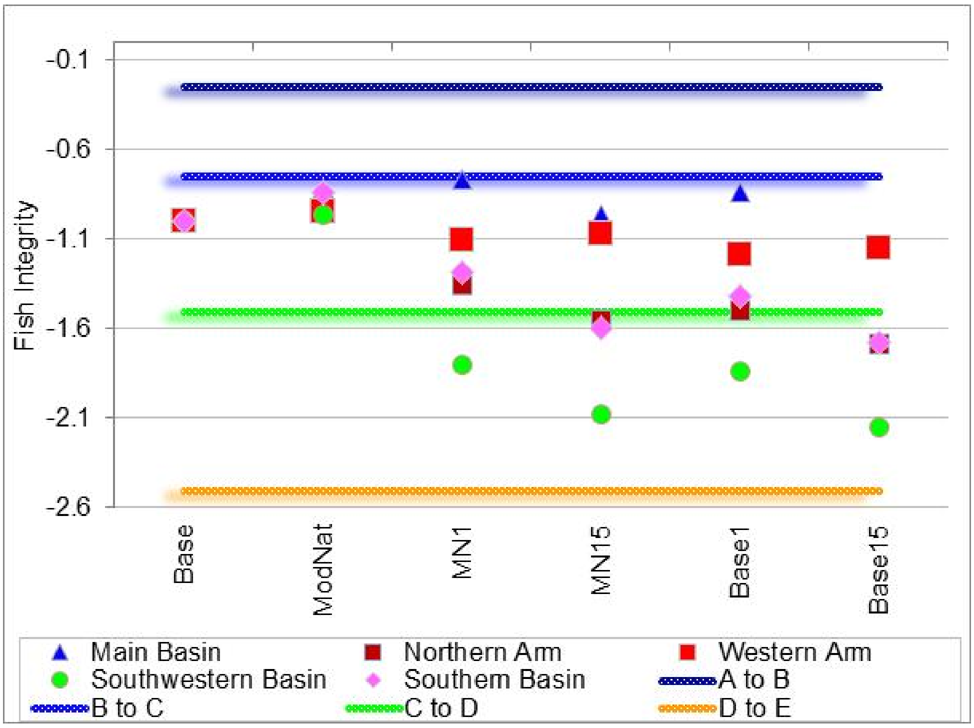

Figure 8.5 Herpetofauna and mammals integrity for MN1, MN15, Base1, Base15

Under all scenarios herpetofauna and mammals in the Southwestern Basin (green circles in Figure 8.5) are reduced from a C to D category. Further, Base1 and Base15 both result in D categories in the Main and Southern Basins.

As current ecological category is C for herpetofauna, implementation of the EWR for REC should be carefully monitored to ensure that herpetofauna integrity does not decrease below a C-category or to establish if the herpetofauna are more resilient than modelled in DRIFT, and / or other protection measures should be implemented to increase abundance.

8.3.2 Social well-being

Social well-being under MN1 and MN15 is reduced to a larger extent than is ecosystem integrity (Figure 8.6). This appears to be largely due to effects on recreational and domestic use (see Section 7). However, this reduction may be somewhat offset by domestic water supply through abstractions from the groundwater and lake.

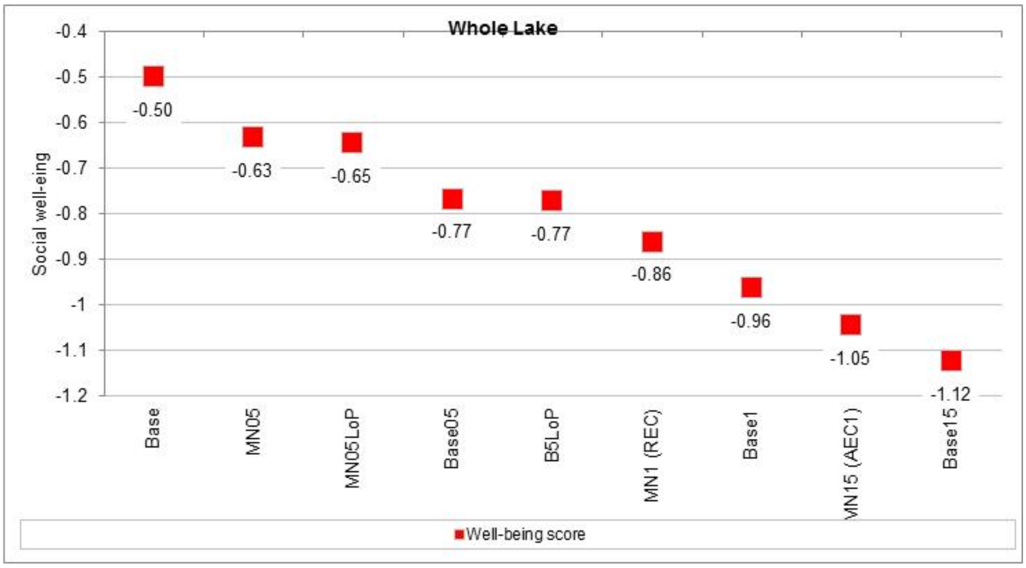

Figure 8.6 Overall social well-being for the Whole Lake for MN1 (REC) and MN15 (AEC1), together with comparative drought and reduced peak scenarios, in order of decreasing well-being scores.

9 ECOLOGICAL WATER REQUIREMENTS

9.1 Recommended Ecological Category – B/C

REC water levels should (Figure 9.1):

- reflect natural climate conditions, in particular five to six year averages in rainfall, as well as shorter term (one year) rainfall conditions;
- retain variability, including periods of high and low water levels;
- median water levels over a 30-year period should be between 17.39 and 18.48 masl;
- should not have more than five consecutive years < 16.5 masl (DROUGHT water level threshold; see Section 9.4);
- should have at least six years in a 30 year cycle > 19.2 masl.

9.2 Alternative Ecological Category 1 - C

AEC1 water levels should (Figure 9.1):

- reflect natural climate conditions, in particular five to six year averages in rainfall, as well as shorter term (one year) rainfall conditions;
- retain variability, including periods of high and low water levels;
- median water levels over a 30-year period should be between 16.89 and 17.98 masl;
- should not have more than five consecutive years < 16.5 masl (DROUGHT water level threshold; see Section 9.4);
- should have at least one year within a 30 year cycle > 19.2 masl;
- reflect natural climate conditions, in particular five to six year averages in rainfall, as well as shorter term (one year) rainfall conditions;

9.3 Alternative Ecological Category 2 – B/C with some B

AEC2 water levels should (Figure 9.1):

- reflect natural climate conditions, in particular five to six year averages in rainfall, as well as shorter term (one year) rainfall conditions;
- retain variability, including periods of high and low water levels;
- median water levels over a 30-year period should be between 17.89 and 18.98 masl;
- should not have more than five consecutive years < 16.5 masl (DROUGHT water level threshold; see Section 9.4);
- should have at least 12 years within a 30 year cycle > 19.2 masl;
- reflect natural climate conditions, in particular five to six year averages in rainfall, as well as shorter term (one year) rainfall conditions;

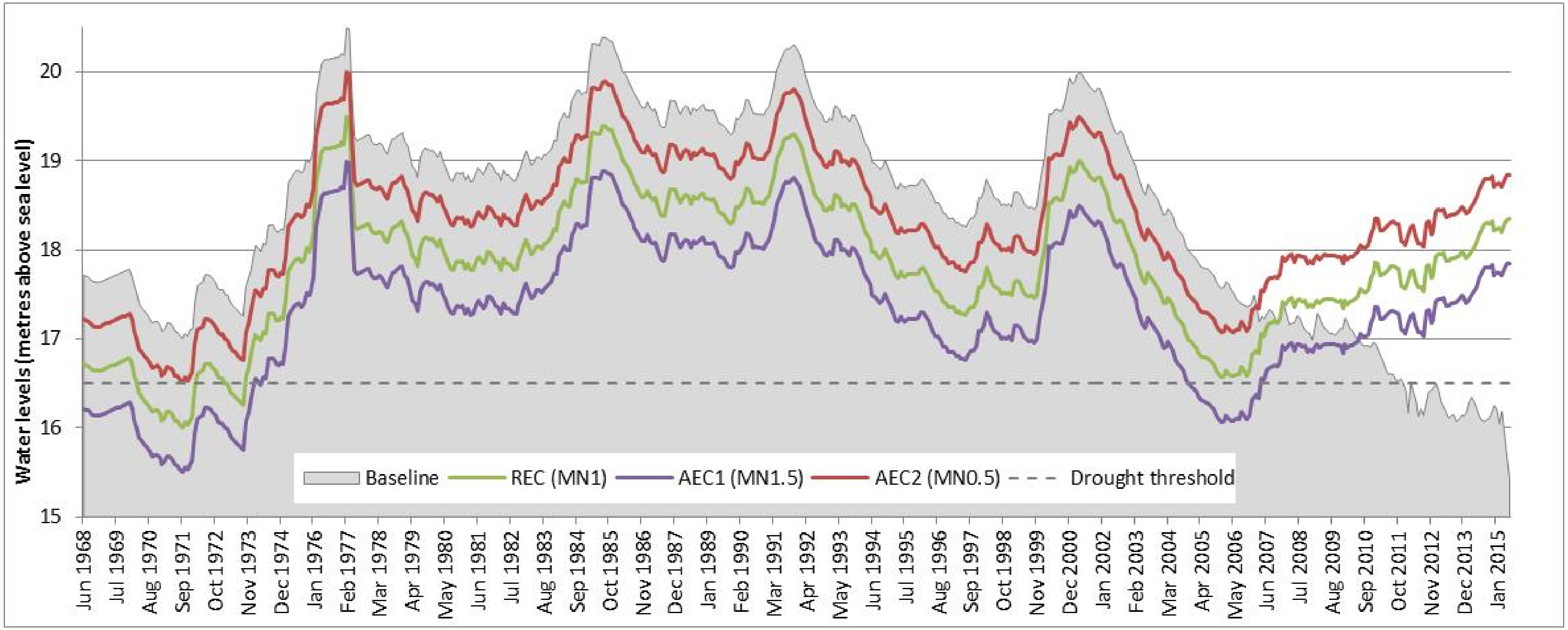

Figure 9.1 EWRs for REC, AEC1 and AEC2 relative to Baseline

9.4 Drought water level threshold

The drought water level threshold is set at c. 16.5 masl (see Section 8) on the basis of the results achieved for DRY2006 and the exploratory scenarios presented in Figure 8.3, and the hydraulic data, which suggest a tipping point for the Southern Basin at around 17 m. Water levels in the lake should not be lower than 16.5 masl for more than six consecutive years.

That said, it is appreciated that, if the lake levels are low in genuine response to a drought situation, there is very little that can be done to manage the low water levels. However, it should be emphasised that the lake will only maintain its condition if these levels are temporary and infrequent, and that the lake cannot be managed for these levels and be expected to maintain the REC.

9.5 Summary statistics for REC and AECs

The summary statistics for REC and the AECs are in Table 9.1.

Table 9.1 Summary statistics of the REC and AECs

Scenario		REC	AEC1	AEC2
Statistic	Baseline	MN1	MN1.5	MN0.5
Min	15.43	16.01	15.51	16.51
Max	20.5	19.5	19	20
Ave	18.48	17.83	17.33	18.33
Median	18.75	17.87	17.37	18.37
75th percentile	19.48	18.48	17.98	18.98
25th percentile	17.51	17.39	16.89	17.89
Max no. consecutive years below 16.5 masl	5.4	6.1	7.3	2.3
Number of years with flow above 19.2 masl	19	6	1	12
Drought threshold	-	16.5	16.5	16.5
Std Deviation	1.16	0.79	0.79	0.79

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Appendix A. DERIVATION OF THE MODELLED NATURAL SCENARIO

In absence of naturalised data from any other source, Southern Waters explored the available water level and rainfall data to assess relationships, and on this basis developed a modelled natural scenario.

It is important to note that, the resulting "ModNat" scenario is a representation of what natural water levels might have been, and is included to provide range of water levels, and trends against which Baseline can be compared, particularly with respect to the downward water levels trends from around 2006 onwards.

Rainfall data was available for three rainfall stations in the region for different, but often overlapping periods of time (Appendix Table 1). For much of the period of interest (that for which reliable water level data was available: 1968-2015), there was rain data available for three stations. However, since Feb 2013, only one set of data was available. The average of the (usually three) available rain data sets was therefore used for comparison with water levels.

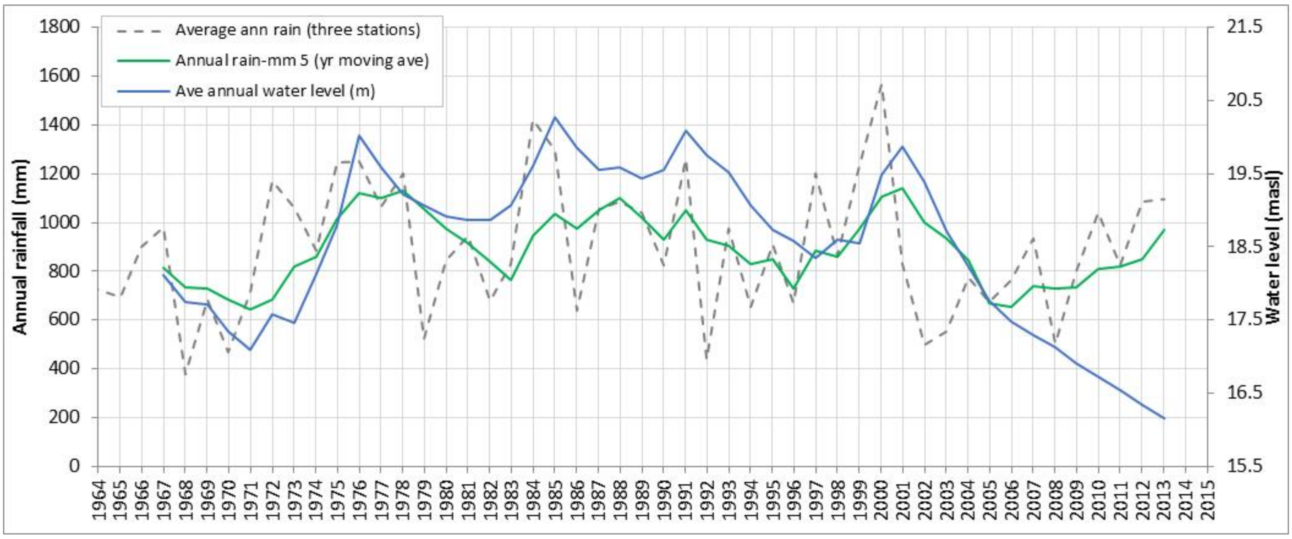
Appendix Table 1 Rain stations used and available data

Station name	Start date	End date	Comments
Hlabisa Mbazwana [0412180 0]	Jan 1972	Nov 2014	
Mseleni Hospital	Jan 1934	Jun 2008	1954-1962 missing
Ingwavuma Kosi Bay	Jan 1972	Feb 2013	

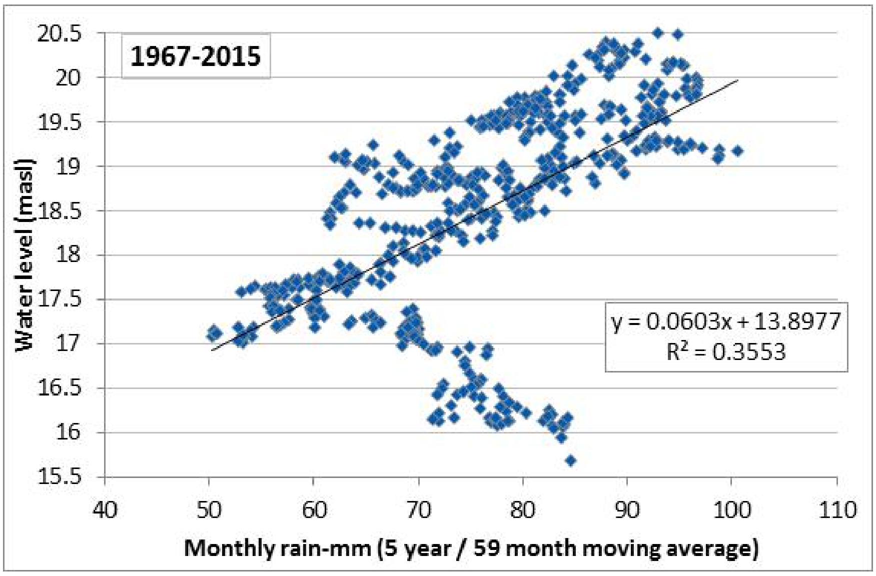
Plotting water level against rainfall (Appendix Figure 1) showed that there was a strong relationship between rain and lake water level, and through trial and error, a five year moving average of rain data was found to produce a good relationship.

Although this relationship can be seen both visually in the time-series (Appendix Figure 1) and when viewed as a regression, the regression between the 5 year moving average and water level is not particularly high (r^2 = 0.3553: Appendix Figure 2).

Note that the regressions are between moving average of monthly rainfall over 59 months (roughly five years) and monthly water levels.

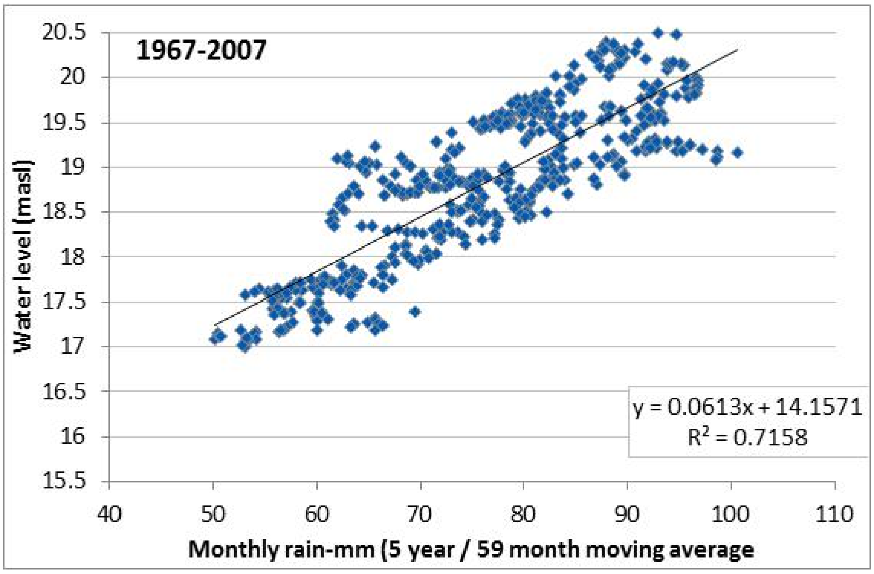


Appendix Figure 1 Time-series of annual water level, annual rainfall, and a 5 year moving average of annual rainfall



Appendix Figure 2 Regression of water level against a 5 year running average of average rainfall data across three stations for the whole time-period

However, a much improved correlation was found by using only the data from 1967 to December 2007 (i.e. omitting 2008 to 2015) (r^2 = 0.7158: Appendix Figure 3).



Appendix Figure 3 Regression of water level against a 5 year running average of average rainfall data across three stations for the period 1967-Dec 2007

The reasons for the lack of correlation since 2007 could be:

- The two rainfall stations with data for the period from June 2008 to February 2013 are not reliable during that time;
- The one rainfall station with data for the period from March 2013 to November 2014 is not reliable during that time;
- A significant increase in water abstraction from the lake or associated groundwater took place during the relevant period; and
- A combination of the above, together with other unknown reasons.

It was felt that a scenario which reflected the relationship from 1967-2007, but continued the same relationship after 2007 would be of interest. On the one hand, this could possibly reflect a more natural water level regime than the current one which shows such a strong downward trend in the latter years, and on the other hand, it provides a scenario which after reaching low levels (similar to those in 1971) would continue to follow the rainfall patterns, rather than continuing downwards, and thus might inform questions around recovery of the ecosystem after low water level periods.

A scenario was therefore included, which followed baseline up until August 2005, and thereafter used the modelled water level data, using the regression equation shown on Appendix Figure 3. This produced the water level scenario shown together with the baseline scenario in Appendix Figure 4, and hereafter called the Modelled Natural (or ModNat).

Appendix Figure 4 Water level time-series for the Baseline and Modelled Natural (ModNat) scenarios