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

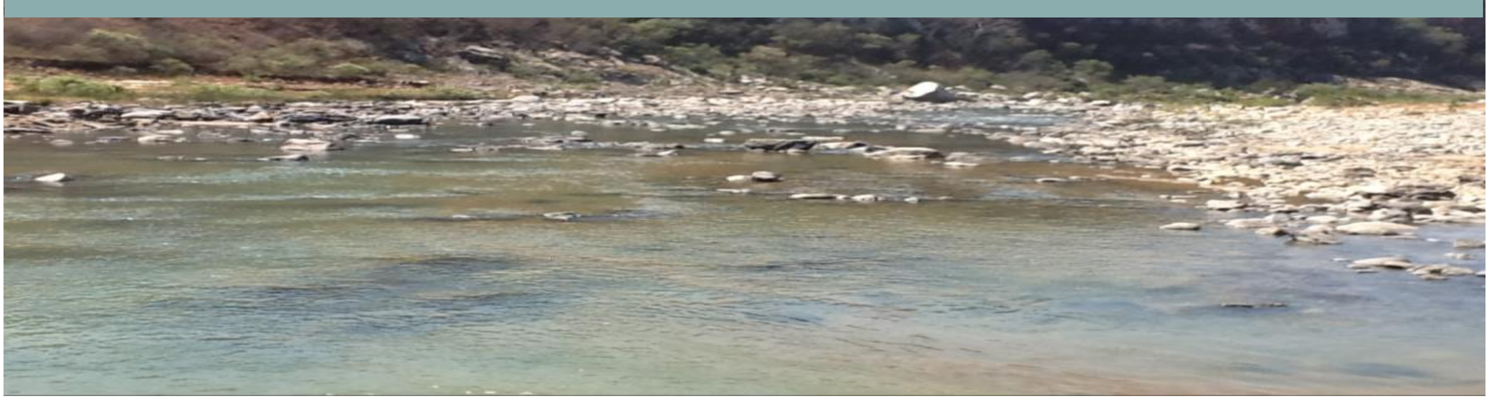
PONGOLA FLOODPLAIN

EWR REPORT

FINAL

JUNE 2015

Report No. RDM/WMA6/CON/COMP/1213



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 USUTU/MHLATUZE WATER MANAGEMENT AREA:

PONGOLA FLOODPLAIN

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- Alison Joubert
- Gary Warneweck
- Toriso Tlou
- Bruce Paxton
- Adhishri Singh.

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We are indebted to those who contributed towards Heeg and Breen (1982).

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ABBREVIATIONS AND ACRONYMS

ADP	Acoustic Doppler Profiler
amsl	above msl
Av	average
c.	approximately
CD:RDM	Chief Directorate: Resource Directed Measures
CFGEN	Department of Water and Sanitation
CRS	Coordinate Reference System
DEM	Digital Elevation Model
dms	degrees minutes seconds
DRIFT	Downstream Response to Imposed Flow Transformation
DWA	Department of Water Affairs (2009 to 2012)
DWAF	Department of Water Affairs and Forestry (pre-2009)
DWS	Department of Water and Sanitation (post-2012)
eg.	for example
EWR	Ecological Water Requirement
GE	Google Earth
GIS	Geographic Information System
ie.	that is
ito	in terms of
MRL	maximum retention level
msl	mean se level
NGI	National Geo-spatial Information
PD	Present Day
RMAPLT	RMA PLoT
RMAGEN	RMA geometry GENerator
RMA	Resource Management Associates
SMS	Surfacewater Modelling Systems
TPTC	Tripartite Permanent Technical Committee
USACE	United States Army Corps of Engineers
viz.	namely
Vol	volume
WES	Waterways Experiment Station
WR2005	Water Resources 2005
RMAPLT	RMA PLoT
1d	one-dimensional
2d	two-dimensional

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 are provided in Table 1-1.

Table 1-1 Members of the study team

Name	Affiliation	Role
Adhishri Singh	Tlou Consulting	Project Manager
Cate Brown	Southern Waters	Process Manager
Alison Joubert	Southern Waters	DSS Manager
Andrew Birkhead	Streamflow Solutions	Hydrodynamic Modeller
Anton Sparks	Aurecon	Water-resource Modeller
Gary Marneweck	Wetland Consulting Services	Vegetation/wetland ecologist
Bruce Paxton	Private	Fish ecologist
Toriso Tlou	Tlou Consulting	Social assessor

1.2 This report

This is the EWR Report for the Intermediate Reserve determination of the Pongola Floodplain. The report provides a:

- review of literature on the Pongola Floodplain, its history, social, economic and ecological state, and releases from Jozini Dam (Sections 2 and 3);
- a delineation of the floodplain (Section 4);
- an overview of the approach adopted for the EWR assessment (Section 5);
- a summary of the data collection and collation activities undertaken as part of the study (Section 6);
- ecostatus assessments for vegetation and fish, and a description the 2014 social status (Section 7);
- a description of the hydrology and hydrodynamic model used in the assessment (Section 8);

- a description of the indicators used in the assessment (Section 10);
- a list of the Jozini Dam release scenarios evaluated (Section 11);
- the outcome of the assessment for 12 pans and their associated floodplains, and the Pongola River (Sections 12 to 18);
- a recommended release scenario for Jozini Dam (Section 19), and;
- suggestions for next steps with respect to the protection and sustainable utilization of the Pongola Floodplain.

2 DESCRIPTION OF THE PONGOLA FLOODPLAIN

The Pongola Floodplain is located immediately downstream of the Jozini Dam[1]. The area below the dam comprises two distinct ecosystems. One, the Pongola floodplain, which is directly dependent on the seasonal floodwaters of the Pongola River, comprises the river course and the areas adjacent to it that are inundated during floods. The other, the Makhatini Flats, adjoins the floodplain on both sides of the river, and is an area where some irrigated agriculture occurs. The people living in the villages on the Makhatini Flats, out of the normal reach of the floodwaters (Heeg and Breen 1982), are heavily dependent on the resources of the Pongola Floodplain (Figure 2.1; Appendix A).

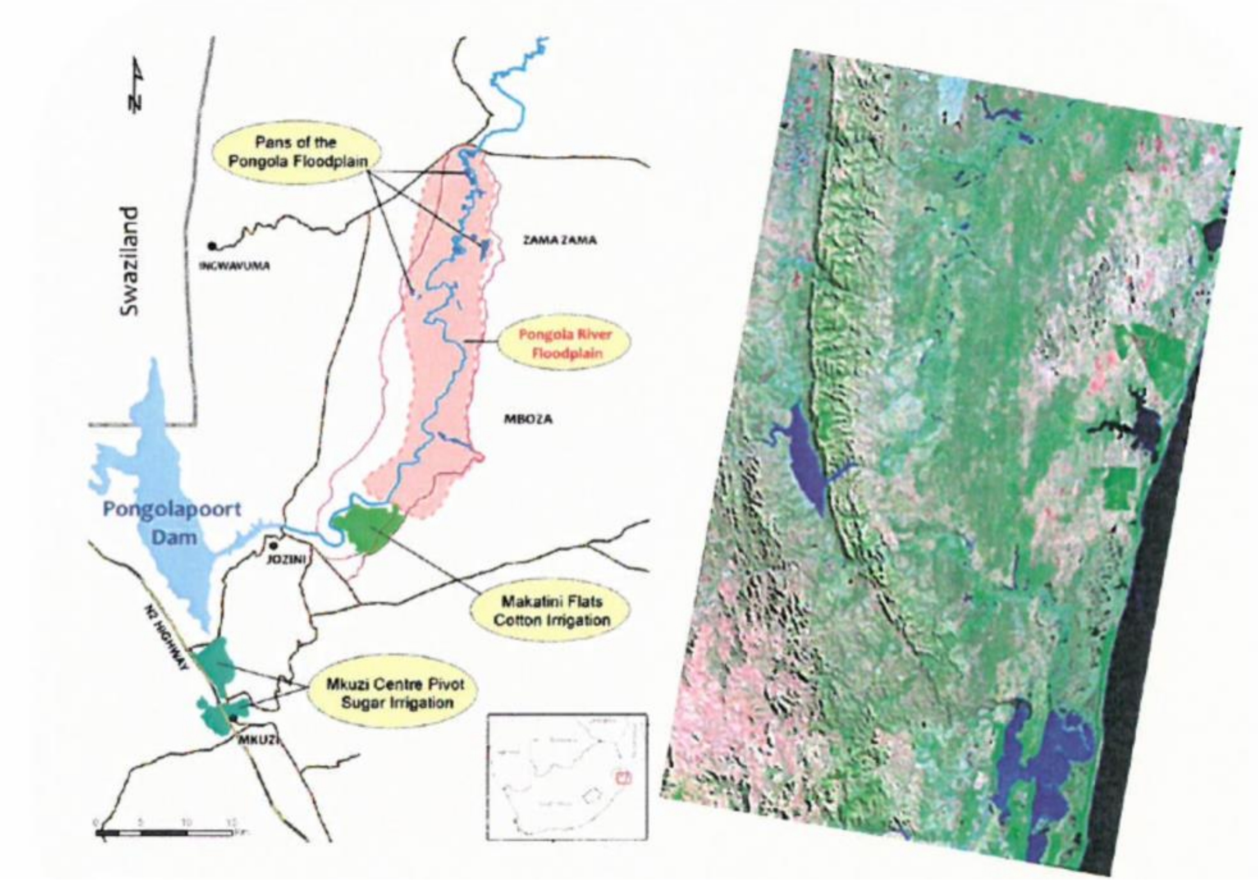

Figure 2.1 Pongola Floodplain and Makhatini Flats downstream of Jozini Dam (Lankford et al. 2010)

The Pongola Floodplain extends from just downstream of the Jozini Dam to the confluence of the Pongola and Usuthu Rivers on the border with Mozambique. The floodplain comprises a low-lying area adjacent to the river that covers approximately 130 km^2. There

[1] Previously Pongolapoort Dam.

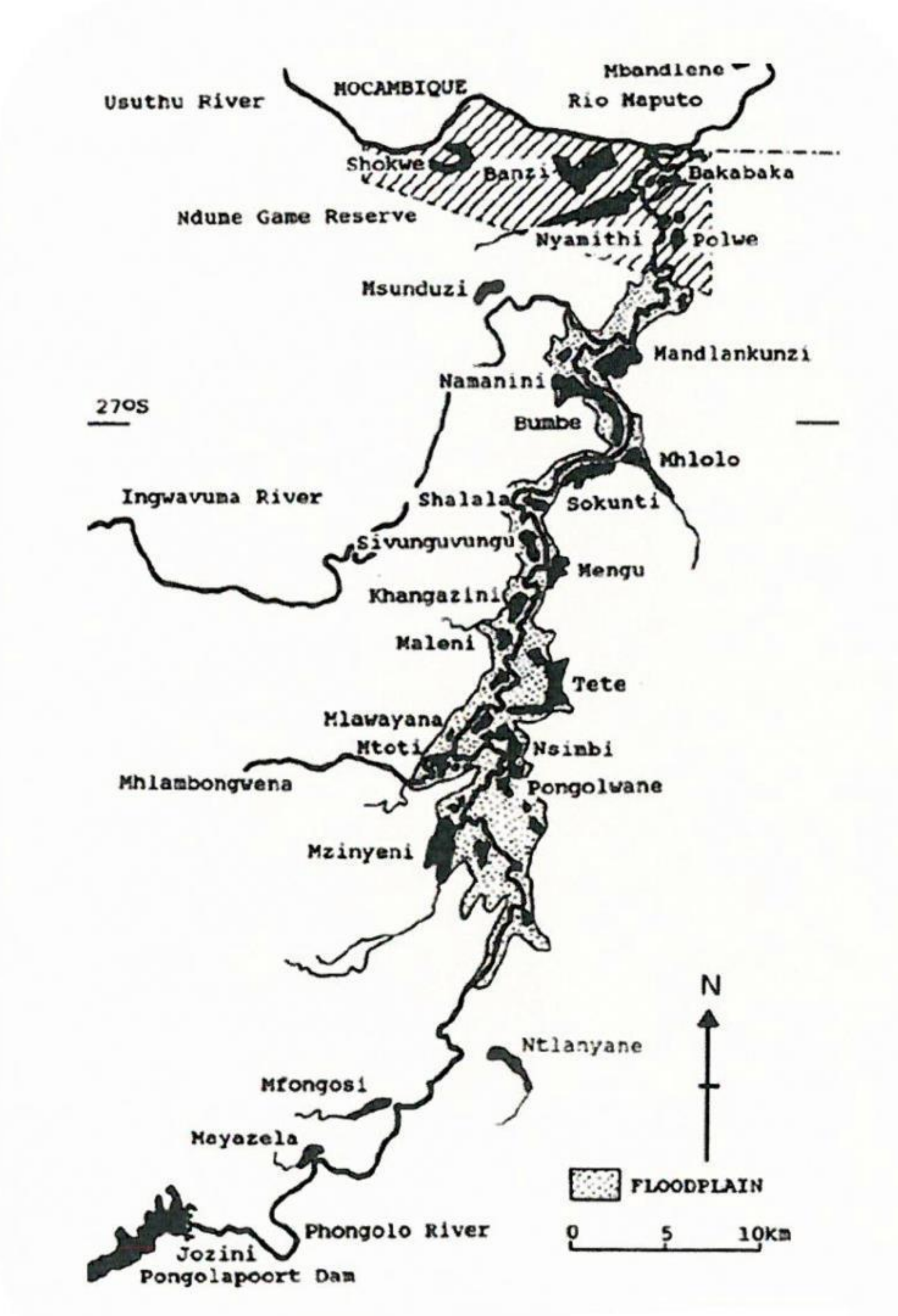

Figure 2.2 The major pans of the Pongola Floodplain (Heeg and Breen 1982)

are numerous depressions (pans) that are dependent on the periodic flooding from the river (Heeg and Breen 1982; Figure 2.2). These are filled by floodwaters at different times and remain filled for varying lengths of time. When an aggrading river overflows its banks during a flood, most of the sediment is deposited on or adjacent to the river bank forming a natural levee. Consequently, the alluvial plain generally slopes away from the river banks creating slackwater access areas that retain water when the flood recedes. The meander pattern of the river changes with time. Occasionally these meanders are cut off when the river takes a new course forming oxbow lakes or pans, which are separated from the river by the new levees (Heeg and Breen 1982). This is the process that led to the formation of the pans on the Pongola Floodplain (Figure 2.2).

There are some 65 named and at least 25 unnamed pans of varying size, permanence and importance on the 13 000 ha floodplain. Some of the pans in the north are also part of the Usuthu River system (see shading in Figure 2.2). At maximum retention level, i.e., immediately following a flood of sufficient volume and duration to inundate the full extent of the floodplain, the pans have an estimated collective area of 2 600 ha (Heeg and Breen 1982).

The southern portion of the floodplain is narrow and almost restricted to the main river course and its associated lower terraces. Although there are a few pans of significant size, such as Mayazela, Mfongozi and Nhlanjane, most of these are fed from their own catchments, and only receive water from the Pongola River during exceptionally high floods.

At a latitude of approximately 27°15’ S, the floodplain widens and for the next 50 km to the Mozambique border, the width varies between 0.8 and 4.8 km. The most socially-significant part of the floodplain is the Shemula area, which lies roughly between Shalala and Tete. While some of the pans in the northern sector have local catchments, all the pans are under the direct influence of the Pongola River and depend on its floodwaters for the bulk of their water supply (Heeg and Breen 1982). Basson *et al*. (2006) indicated that the deeper pans close to the river retain water for longer than the smaller shallower pans at higher elevations.

The first comprehensive document describing the many-faceted aspects of the Pongola Floodplain is “*Man and the Pongola*” (Heeg and Breen 1982), which remains a landmark account over three decades later. This document is a synthesis of contributions to a workshop held in February 1979, and covers the following aspects: general description (including geology, climate, vegetation and human links to the floodplain); hydrology; water quality; the ecosystem; man and Pongola; impact of development and development options; conservation and the cost thereof. This account not only provides a comprehensive compilation of knowledge from the late 1970’s, but also carries this through with a suggested pattern of flows to “*maintain the floodplain through the removal of accumulated wastes, stimulation of fish migration and spawning; submergence of marginal vegetation for a sufficiently long period to allow assimilation into the aquatic system and the provision of flood irrigation to cultivated lands on the floodplain.*” It is worth noting that the controlled flooding regime suggested by Heeg and Breen (1982) was a decade before (South African) Instream Flow Requirements for river maintenance, which were first addressed nationally in the late 1980’s (King and Louw, 1998). Of concern, however, is more than 30 years later, there are no operational releases[2] specifically targeted at maintaining the floodplain ecosystem and its services which support the livelihoods of the local communities.[3] Since 1998[4], annual releases peaking between 450 and 700 m^3/s (average daily) have been made regularly at the end of the dry season[5], primarily to meet the needs of recession floodplain agriculture and (ostensibly at the same time) to inundate the Ndumo Floodplain near the Usuthu River confluence. This timing is asynchronous with natural flooding patterns, where the highest volumes generally occurred in January/February[6]. These and other issues are discussed in the article "*Pongolapoort Dam: development steeped in controversy*" (van Vuuren 2009).

2.1 Geology and soils

The Pongola Floodplain is located on the Maputaland Plain, within comprises late Pleistocene and Holocene sand deposits overlying much older marine sediments (Mid to late Cretaceous and Mio-Pliocene). Fluctuations in sea level and periods of uplift resulted in the sea retreating eastwards from the foot of the Lebombo Mountains to its current position with the formation of the Maputaland Plain. The sediments that underlie the more recent sands cause elevated salinity in much of the groundwater. Remnant dune ridges on the plain also influence the route of the Pongola River, deflecting it north to enter the Indian Ocean south of Maputo in Mozambique.

Heeg and Breen (1979) describe the soils of the Pongola Floodplain and Makhathini flats as originating from four key sources:

- weathering of the acid volcanic rocks of the Lebombo and Ubombo ranges;
- weathering of the cretaceous deposits at the base of these mountains;
- windblown sands; and
- alluvium deposited by the river.

The irrigable soils of the Makhathini Flats and the deep deposits on the Pongola Floodplain are alluvial soils deposited there as a result of fluctuating sea levels during the Pleistocene and Holocene glacial cycles (Heeg and Breen 1982).

2.2 Climate in the area

Extracted from Lankford et al. (2010).

[2] from the upstream Jozini Dam
[3] A Preliminary Reserve determination using the Desktop Model (Hughes and Münster, 2000) was done by DWAF (2000), and provided for an allocation of 223 $10^6 m^3/a$ for an Ecological State C river. Flows are provided as monthly volumes.
[4] but excluding 2001
[5] September/October
[6] depending on the data source

"The floodplain is located in a warm to hot, humid subtropical climatic region with most rainfall falling in the summer months (January, February, March) and a drier winter period (June, July and August). Climatic data from the Makhathini Agricultural Research Station, adjacent to the floodplain, show a variation in mean monthly temperature from 16.6 ℃ in June to 26.8 ℃ in January, for the period 1966 to 1975.

Rainfall over the same time period varied from a monthly mean of 4.6 mm in June to 105.6 mm in February with an annual mean of 572.6 mm. Hot summer temperatures and high winds, particularly in the period September to December result in high evaporation rates with mean annual evaporation approximately four times the mean annual rainfall (Heeg and Breen 1994), emphasizing the importance of the riverine flood waters for the supply of sufficient water to maintain the ecosystem and carry out cultivation in the floodplain."

2.3 Hydrology of the floodplain

The Pongola Floodplain depends on the volume of water delivered by the river, but flooding extent is also driven by the rate and duration of flow. Before the construction of the Jozini Dam, the flooding season was characterized by several flood peaks of relatively short duration rather than a single flood pulse (DWS gauging records). Mean monthly maximum discharges varied considerably; from c.15 m^3s^{-1} in August to c. 250 m^3s^{-1} in February. Mean minimum discharge showed less variation but were highest in February at 25 m^3s^{-1} (Heeg and Breen 1982).

Since the closure of the dam (c. 1973), the hydrology of the downstream river has been controlled by releases from the dam. The pattern of these releases has varied over time according to changing management. In general though, flows downstream of the dam have reduced in frequency, changed with respect to the timing of periods of high and low flow, and become more stable (i.e. fewer peaks, more constant lowflows and more sudden cessation of flows; Jaganyi *et al*. 2008). Development upstream of Jozini Dam, such as the Bivane Dam built in 1995 for the Impala irrigation scheme, has also reduced flows into the dam, particular post 2000 (Jaganyi *et al*. 2008; Lankford et al. 2010), with a knock-on effect on natural spills into the downstream reaches of the river.

2.4 Ecological importance of the Pongola Floodplain

"The Pongola Floodplain, as a natural ecosystem, is unique in the Republic of South Africa. Its biota, which includes tropical and other rare species, is adapted to changing floodplain water levels. Productivity of the whole system depends upon the annual summer floods." (Heeg and Breen 1994).

The Pongola floodplain vegetation has been described in terms of six communities, which may be grouped according to their relative periods of exposure and inundation (Furness and Breen 1980; Heeg and Breen 1982). These include: (i) two communities of high lying areas which are only inundated for short periods; (ii) three of low lying gently sloping areas which only become exposed as water approaches and drops below the Maximum Retention Level (MRL); (iii) and a community which occupies the intermediate areas where the slope is slightly steeper so that the water drains off fairly rapidly. Refer to Figure 2.3.

Communities of the high lying areas

a. An *Acacia xanthophlea- Dyschoriste depressa* community that occurs towards the edge of the floodplain where drier conditions prevail. It formed a narrow belt along both sides of the floodplain (Furness and Breen 1980; Heeg and Breen 1982 and 1994).
b. A *Ficus sycomorus – Rauvolfia caffra* community located along the levees of the Pongola and Usuthu rivers. Throughout the area, but particularly outside of the Ndumo Game Reserve, it has incurred significant cutting and burning and is largely degraded (Furness and Breen 1980; Heeg and Breen 1982; and 1994; Marneweck pers. obs. 2014).

Communities of the low-lying areas

c. Two Phragmites communities, which are found in the wettest areas of the floodplain. Phragmites australis favours flat, swampy areas and dominated the floodplain. Phragmites mauritianus prefers river banks, inlet-outlet channels and pan margins where there are fluctuating water levels (Furness and Breen 1980; Heeg and Breen 1982 and 1994).
d. The Cyperus fastigiatus - Echinochloa pyramidalis community is located in swampy areas of the floodplain. Large stands were originally found west of Tete and Nsimbi pans and in Ndumo Game Reserve (Furness and Breen 1980; Heeg and Breen 1982; and 1994), but these have been reduced, probably as a result of infrequent and inappropriately timed flooding.

Communities of intermediate areas

e. A Cynodon dactylon grass community that occupies areas that regularly experience alternating inundation and exposure. Prior to the Jozini Dam these were particularly well developed around shallow pans where they formed ‘lawns’ or ‘meadows’ (Furness and Breen 1980; Heeg and Breen 1982 and 1994), but are now severely degraded by over grazing and reduced in extent as a result of infrequent flooding and cultivation.
f. Aquatic algal communities that comprise both phytoplankton, which are free in the water column, and epiphyton, which are attached to stones, large plants and other substrates. Phytoplankton communities consist of both cyanobacteria, or blue-green algae, and the diatom Melosira granulosa. Limited information is available on the epiphyton community although it is

known that this community is found in substantial amounts in the system and plays an important function in fixing atmospheric nitrogen and inducing senescence in Potamogeton crispus (Heeg and Breen 1982; 1994).

g. Aquatic hydrophyte communities that are either permanent or seasonal. Permanent hydrophyte communities are dominated by water chestnut (Trapa bispinosa) and various water lilies (Nymphea species). These communities prefer pans in which the water levels are not subject to excessive seasonal fluctuations. Seasonal communities are dominated by Potamogeton crispus and Najas pectinata, and generally occur in pans where a reasonable water depth is maintained over the dry season (Heeg and Breen 1982; 1994).

Seasonal aquatic communities dominated by *Potamogeton crispus* (Rogers 1984; Mitchell and Rogers 1985) and the community of intermediate areas dominated by *Cynodon dactylon* have significant importance for the productivity of the floodplain pans (Furness and Breen 1982 and 1985; Heeg and Breen 1982). *Cynodon dactylon* and the *Cyperus fastigiatus - Echinochloa pyramidalis* community are important for terrestrial grazers (cattle and hippo) and *Echinochloa pryamidalis* are grazed by the fish species *Tilapia rendalli* (Heeg and Breen 1982 and 1994). The different plant communities require different flooding regimes.

Alterations to the flooding regime and changes in sediment load since the dam construction have changed the ecology as have human activities. The reduction in sediment has reduced the nutrient status (Heeg and Breen 1994). *Potamogeton crispus* (pond weed) is important for water fowl and secondary productivity but is reduced in some pans, for example in Khangazini pan where summer flooding is not followed by winter stability (Heeg and Breen 1994).

The aquatic vegetation is an important source of food for the diverse array of invertebrate and fish species, which in turn supply a variety of larger fish and the human population (Heeg and Breen 1994). Pans differ in their benthic biomass content (aquatic insects, freshwater shrimp and many snails) probably due to different vegetation and detritus input and differences in the density of the fauna resulting from fluctuating water levels, with marginal areas of the pans are more diverse than the mid-pan sediments (Heeg and Breen 1994).

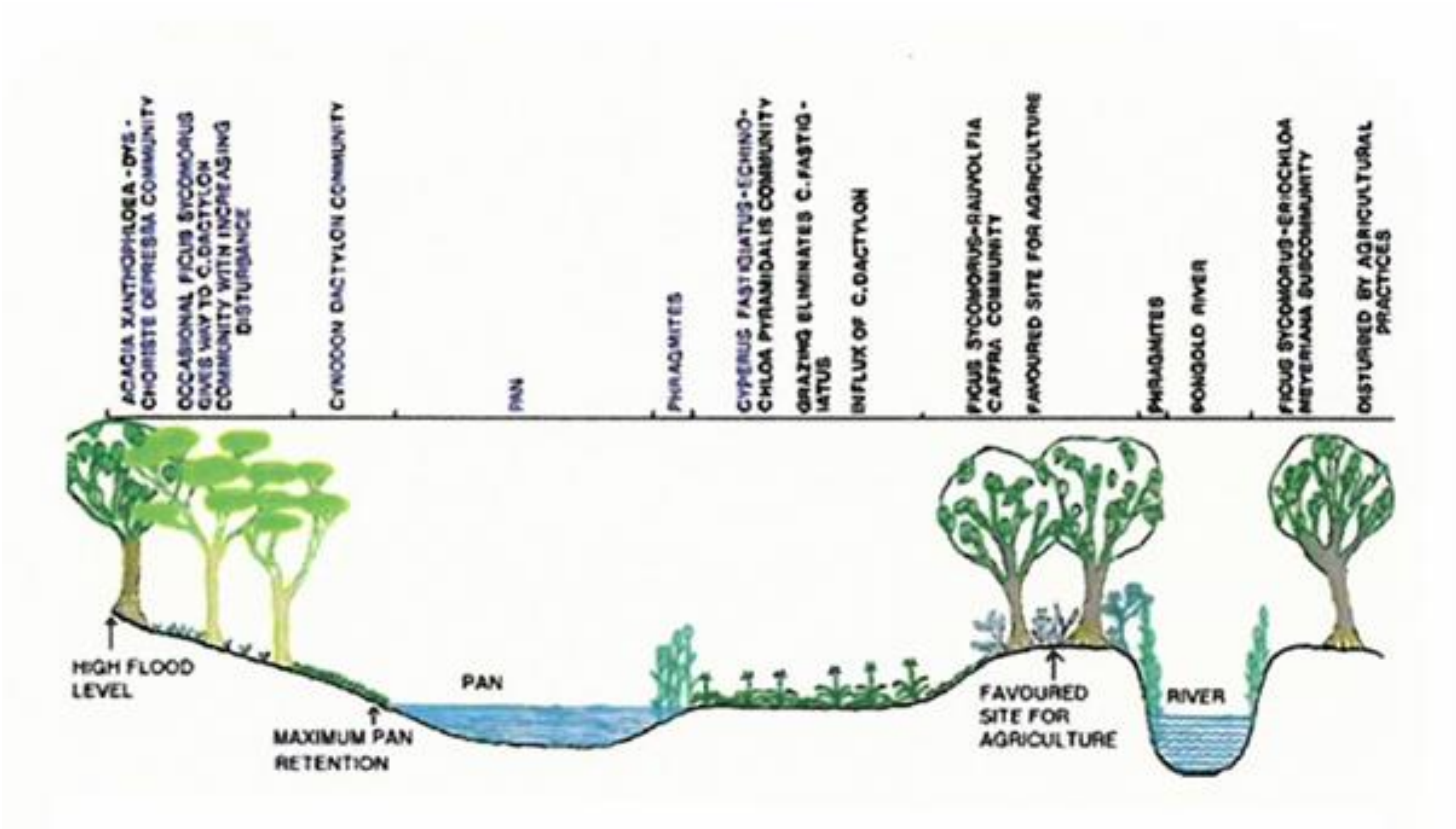

Figure 2.3 Diagrammatic section across the Pongola floodplain showing the distribution of different plant communities (Lankford et al. 2010, modified from Furness and Breen 1980).

According to Lankford *et al*. (2010), approximately 50 species of fish are found on the floodplain, making it the most diverse fish fauna population in South Africa. Almost half of the fish on the floodplain have their southern limit of distribution in the Pongola system. The high diversity of fish is likely to be partly a result of the different preferential diets of fish, which reduces competition. Other vertebrates on the floodplain include Crocodiles (*Crocodylus niloticus*), birds (including 30 endangered species listed in the South African Red Data Book; Siegfried et al. 1976 in Heeg and Breen 1994) and others that are not endangered such as large flocks of White-faced ducks (*Dendrocygnus viduata*) that feed on the floodplain in winter (Heeg and Breen 1994; Marneweck pers. obs. 2014). The mammal population, which may once have been extensive, is now much less diverse and abundant. For example, in the 19th Century, elephant, rhinoceros, buffalo, kudu, nyala, bush pig, baboon and small antelope were recorded, but the larger of these is seldom recorded now. Some of these do remain in the floodplain, mostly in the Ndumo Game Reserve, with estimated 220 hippopotamus remaining in 1994.

According to Heeg and Breen (1994), the rich biodiversity of the Pongola pans and surrounding area is increasingly threatened by the salinity of water in the pans because of groundwater seepage and the concentration by evaporation in the absence of sufficient flushing by flood water. In addition fewer food materials are brought into the pans if flooding does not occur. Heeg and Breen (1994) state that: "*The maintenance of the whole ecosystem therefore hinges on a regular supply of floodwater, sufficient in magnitude to flush out the system and to allow for fish migration, and sufficient in duration to allow an adequate transfer of energy rich organic material from the terrestrial to the aquatic components*".

2.5 Social importance of the floodplain

The Tembe-Thonga people have lived adjacent to the Pongola floodplain for hundreds of years as water was easily accessible to both humans and livestock (Heeg and Breen 1982), and the ground was rich and arable. The villages are on high ground, safe from any risk of flooding (Heeg and Breen 1982).

The alluvial plains between the pans and Pongola River (called the madotsheni) have always been extensively cultivated, as the soils surrounding the floodplain are dry and sandy with very low agricultural potential (Heeg and Breen 1982). The area is also characterised by high evaporation and low rainfall, which severely limits the agricultural potential outside of the floodplain (Heeg and Breen 1982). Prior to the construction of the Jozini Dam, the series of flash floods that coincided with the rainy season each year deposited rich alluvial sediments that re-enriched the soils and supported the most important local economic activities, namely recession agriculture and, of course, fishing.

The relative isolation and poverty levels in the area compounded the dependency of local communities on natural resources from the floodplain (Heeg and Breen 1982). Floodplain vegetation provides fuel and traditional building materials such as thatch and reeds for the local households as well as food stuffs such as fish and wild plants (Heeg and Breen 1982). Fish have always, and still do, represent a major source of animal protein in the household diet (Prof. Nico Smit, North-West University, pers. com.). In the past, a variety of fishing methods were practiced including: isifonya (people using dome-shaped baskets move in line across a pan and driving the fish into the shallows); mona baskets (valve-traps made from reeds to trap fish and constructed in a reed barrier across a water course); a primitive form of seine netting (using long bundles of grass and weeds which are pushed through the water trapping small fish), and; line fishing (with or without a rod). These fishing techniques were complimentary as they caught different types and sizes of fish (Heeg and Breen 1982). More recently, however, there is widespread use of modern seine and gill nets, which catch even the very young and small fish and disrupt fish breeding patterns and reduce stocks.

Much of the construction material, such as reeds, thatch and poles, for building houses was also harvested from the floodplain, namely reeds, thatch and building poles, although more commercial materials such as corrugated iron roofs are now increasingly popular (Prof. Nico Smit North-West University, pers. com.). Sedges are used for weaving mats and baskets. Indigenous food resources such as water lilies, water chestnuts, and fruits such as figs also provided nutritional supplements (Heeg and Breen 1982).

The areas surrounding the Pongola floodplain are predominantly rural in character, dominated by scattered homesteads and associated subsistence level agriculture. There are no homesteads or permanent settlements on the floodplain; however it is extensively cultivated with much of the area transformed into small household farming plots. Households typically also have small fields off the floodplain close to their homesteads where they cultivate crops, but the sandy soils and scarcity of water off the floodplain means these fields contribute little to household food security (Heeg and Breen 1982).

In recent times there have been significant migration of the people (Stats SA 2001, and 2011) to three main areas of the Pongola Floodplain, namely Nondabuya just below the Jozini Dam on the left bank, Shemula approximately 60 km downstream of the dam and Ndumo, which borders the Ndumo Game Reserve. The Ndumo area has also been earmarked for major development by the Umkhanyakude

2.5.1 Population and demographics

The Pongola Floodplain is located in the Umhlabuyalinga and Jozini Local Municipalities, which also include areas outside of the floodplain. Thus, the 2001 and 2011 population data (Stats SA) for these areas were adjusted to provide an estimate of households that are directly dependent on the floodplain. This adjustment was done on the basis of discussion with the communities in terms of their access to the pans and floodplain areas.

Table 3.1 summarises the demographic profile of the Pongola floodplain (2001 and 2011) divided into four sections (Figure 4.1). The number of people per hectare of floodplain has increased by (on average) 1.7% per annum over the last 10 years, but this growth is not evenly distributed. The population between Shalala and Ndumo Game Reserve has grown significantly faster than in other areas (2.2% per annum) resulting in an additional 2 000 people per ha from 2001 (8 200 per hectare) to 2011 (10 200 per hectare).

The increased population has exerted considerable pressure on the natural resources of the floodplain and has transformed large parts into residential and agricultural (both cultivation and livestock grazing) use. This is particularly the case in the Shalala to Ndumo region.

Table 2-1 Demographic profile of Pongola River (Stats SA 2011)

Floodplain section	Individuals		Households		Rate
	2001	2011	2001	2011	
Dam to Mzinyoni	38846	45780	-	9192	+1.66%
Mzinyoni to Shalala	42464	48438	-	-	+1.32%
Shalala to Ndumo NR	34250	42600	-	-	+2.21%
Ndumo NR	69	36	-	-	n/a
Total	115560	136818	0	9192	+1.70%

2.5.2 Household income

The household income levels of the Tembe-Tonga people living adjacent to the Pongola floodplain highlight the social pressures exerted by the high levels of unemployment in the area and a high dependence on the floodplain for their livelihoods (Table 2-2). Table 2-2 provides the profile of the household income in the four sections of the Pongola Floodplain. Approximately 10% of the households have no income and are therefore dependent on the informal economy driven by the natural resources and service provided by the Pongola Floodplain. The total number of household that can be considered to be below the poverty datum is approximately 57% taking R4 000 per month as the poverty threshold.

Table 2-2 Distribution of annual household (HH) income in the four sections of the Pongola Floodplain (*2013 Household Survey, Stats SA*)

Floodplain section	# HH	# income	< R9600	> R9600 < R38200	R38200 to R153800	> R153800
Dam to Below Mzinyoni	9192	1470	2181	3942	1212	387

		16%	24%	43%	13%	4%
Mzinyoni to Shalala pans	8040	1650	2365	2530	1050	445
		21%	29%	31%	13%	6%
Above Shalala to Ndumo	8160	1191	2352	3435	927	255
		15%	29%	42%	11%	3%
Below Ndumo	30	3	3	6	18	0
		10%	10%	20%	60%	0%
Total	25422	4314	6901	9913	3207	1087
		17%	27%	39%	13%	4%

More than 13 000 households adjacent to the Pongola Floodplain are directly dependent on the landscape and biodiversity attributes of the floodplain. The communities outside of the Floodplain also benefit indirectly from the sale of the goods and/or services from the floodplain.

3 HISTORICAL RELEASES FROM JOZINI DAM

Prior to the construction of the Jozini Dam, which took place between 1963 and 1973, the natural flooding regime governed many of the characteristics of the floodplain, including the presence and nature of the pans, the biodiverse ecosystems and patterns of land use by communities.

The Jozini Dam was constructed for the upliftment of white farmers, with a focus on sugarcane production in the Makhathini Flats. The main objectives were to control floods and provide an assured supply of water for irrigation to approximately 40 000 ha of land. It was also intended that white farmers would open up the trading frontiers with Swaziland and Mozambique, and envisaged that as irrigation agriculture increased, cropping in the floodplain would decline and tourism would increase. The planned increase in irrigated agriculture was never realised, largely due to a significant drop in the price of sugar, and only c. 3000 ha of irrigated agriculture has been established on the Flats (Lankford et al. 2010), most of which is sugarcane and cotton.

Between 1973 and 1987, releases from Jozini Dam (by DWS) was made without any consultation with the people living on the floodplain margins, and dependent on its resource, and the negative impacts on the Thonga people were enormous (van Vuuren 2009). Research in the late 1970s (Heeg and Breen 1982), led to the belated recognition that floodplain ecosystem services were significant, and of "*greater economic and social benefit than if the water were used to grow sugarcane under irrigation*" (van Vuuren 2009).

Heeg and Breen (1982) proposed a flood regime aimed at maintaining ecological services. Winter flows were set at around 2 m^3/, and periodic increases in flows (approximately 80 m^3/s) were proposed for early summer (November to January) to flush out saline water from the pans and to replenish water for use by people and livestock at the end of the dry winter. A second larger release (600-800 m^3/s) was suggested for February, which would provide the trigger for fish migration and breeding and increase plant growth as the water receded, thereby providing grazing in the winter months (van Vuuren 2009). This flow regime is discussed further in Section 11.

Towards the end of the Heeg and Breen (1982) study, social scientists suggested that local farmers switch from their usual multi-coloured maize to white maize as it had the potential to produce higher yields. However, the white maize requires a longer growing period than the traditional varieties and meant that floods often destroyed fields before the grain had had a chance to mature (van Vuuren 2009). As a result, farmers requested that the floods be timed to allow the maize to mature. This began an unstructured process of negotiated dam-releases, which deviated substantially from those proposed by the scientists (van Vuuren 2009). Between 1984 and 2005 there were 25 releases total but these were fairly sporadic.

In some years there were two or three flood releases, and in other year none at all. The timing of releases was also entirely unpredictable. This lack of structure and certainty about flood releases, resulted in conflicts developing between agriculturists, grazers and fishermen who no longer knew how to manage and protect their respective resources. For instance, cattle had easy access to fields on the floodplain as the pans that would usually have been filled with water during the growing season dried up without the natural flood releases (van Vuuren, 2009). Nor did the releases take account of the emerging interests of those who used the floodplain for commercial cultivation.

In c. 2000-2005 this situation changed with the advent of the October flood release. The current pattern of releases comprises a large October flood release, a 4 m^3s^{-1} baseflow in the river throughout the year[7] (which does not affect the floodplain) and periodic spills later on in the wet season (c. February; see Sections 8 and 11). The magnitude of the October flood release has increased from c. 450 to c. 800 m^3s^{-1} over that time. The reasons for the increase are not clear, but it seems that (at least in part) this was to fill the pans at Ndumo Game Reserve. This, however, is a problematic notion as, prior to Jozini Dam, the Ndumo pans were filled through the combined actions of both the Pongola and the Usuthu rivers (see Section 8), but floods in the Usuthu River do not start until the rains in late November/early December (which is when the Pongola floods used to start before Jozini Dam). This means that in an effort to fill the pans in the absence of the 'holding action' of flood flows in the Usuthu River, the October released flood is now unnaturally large for the system. Not only that but, even at the current elevated magnitude, it is not wholly successful in filling the Ndumo pans as evidenced by terrestrialisation of parts of these pans. A more recent, and compounding, factor is that there has been significant erosion of the some of the Ndumo Pans and surrounding areas, e.g., Banzi Pan (see Section 4.2.1) as a result of the change in the flow and sediment regime of the Pongola River, and the disjunction between flooding events in the Pongola and Usuthu rivers, which has further reduced the flooding extent likely to result from a flood event of any given magnitude.

[7] Future release will be *c.* 1 m^3s^{-1} higher to provide a 30 MCM per annum to Shemula for domestic use.

4 ORGANISATION OF THE STUDY AREA

4.1 Delineation of the Pongola Floodplain

The delineation of the Pongola Floodplain used for this EWR study is shown in Figure 4.1.

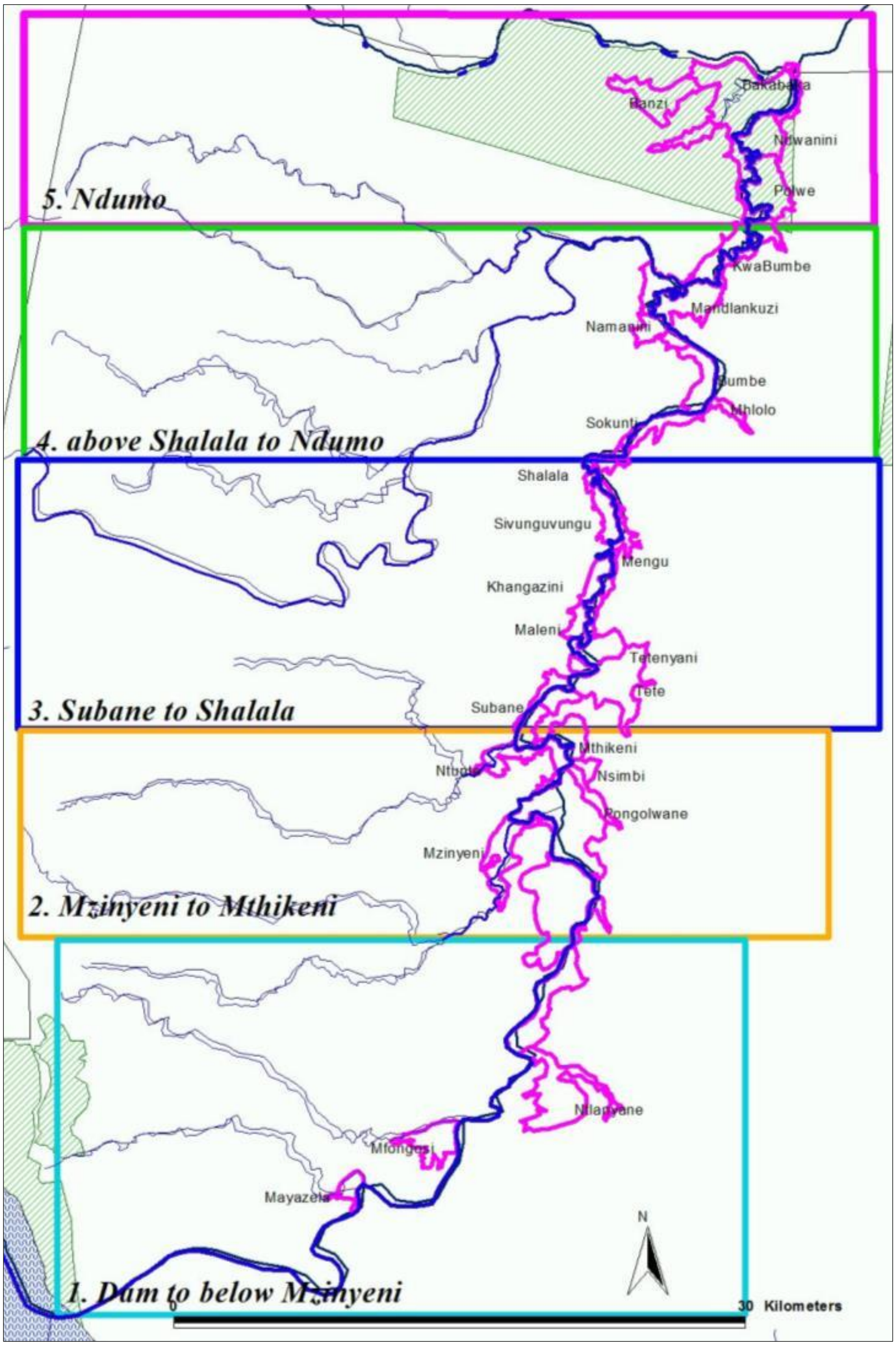

Figure 4.1 Delineation of the Pongola Floodplain used for this EWR study

4.2 Study sites/areas

The study sites/areas that were assessed were chosen mainly on the basis that they yielded fairly reliable results in the hydrodynamic model. In the event, they also represent an array of important pans and floodplain areas. Each study site includes a pan and its surrounding study area.

The study sites/areas included in the DRIFT DSS are:

JOZINI DAM TO UPSTREAM OF MZINYENI

- Ntlanyane Pan and Floodplain

MZINYENI TO MTHIKENI

- Mzinyeni Pan and Floodplain
- Mthikeni Pan and Floodplain

SUBANE TO SHALALA

- Tete Pan and Floodplain
- Khangazini Pan and Floodplain

SHALALA TO NDUMO BORDER

- Shalala Pan and Floodplain
- Sokunti Pan and Floodplain
- Namanini Pan and Floodplain
- MandlaNkuzi Pan and Floodplain

NDUMO

- Nyamithi Pan and Floodplain
- Bakabaka Pan and Floodplain

PONGOLA RIVER

The Pongola River site was located on the river adjacent to Tete Pan (Figure 4.1).

4.2.1 Exclusion of Banzi Pan (located in Ndumo Game Reserve)

Banzi Pan (top northern portion of the system; Figure 4.1 and Figure 4.3) was excluded from the EWR assessment. The reasons for this were that Banzi Pan is mainly filled by the Usuthu River, but also because erosion of the pan and surrounding area as a result of the change in the flow and sediment regime of the Pongola River (and to a lesser extent the Usuthu River) means that the filling and emptying mechanisms for Banzi Pan seem to be in flux, and it does not retain water in the same way as it used to (based on information in the literature) – an artificial weir built to retain water has been breached. Thus, in terms of the hydrodynamic analyses done for the EWR, Banzi Pan fills with releases from Jozini Dam but drains immediately once floods recede, whereas in the past it (presumably) acted more like the other pans and drained slowly over time following flooding.

Figure 4.2 Photographs of Banzi Pan showing: (top row) the upper reaches of the pan now channelised and encroached with trees, shrubs and reeds; (second and third row) lower end of the pan immediately above the weir also encroached with vegetation, mainly *Persicaria* (November 2014).

Figure 4.3 Photographs of Banzi Pan showing: (top row) incision/channel in the *Ficus* forest resulting from elevated flows around the southern end of the weir; (second row) the weir at the historical pan outlet; and (bottom row) channel incision resulting from elevated flows (now the main channel) around the northern end of the weir (November 2014).

5 APPROACH

5.1 Introduction

There are no formal RDM methods that are appropriate for use for the Pongola Floodplain. Furthermore, investigations of the EWR for the area are meaningless without a reliable and efficient hydrodynamic model to predict the extent and duration or flooding on the floodplain.

For this reason, the approach adopted for the Pongola Floodplain EWR assessments was to:

- focus on developing a reliable and efficient hydrodynamic model to predict the extent and duration or flooding on the floodplain (Section 8).
- undertake wetland typing and ecostatus assessment;
- review the literature for fish and undertake an ecostatus assessment based on existing information;
- identify key social concerns with respect to the timing and magnitude of flooding;
- populate a DRIFT DSS for use in the assessment of flood releases on the Pongola Floodplain;
- evaluate the ecological and social outcome for a suite of release options from Jozini Dam.

The flow assessment relied heavily on the information provided in Heeg and Breen (1982) as this comprehensive assessment provided the ecological (and many of the social) underpinnings and reasoning for an environmental flow release regime from Jozini Dam. They also recognised the need for "*the construction of a hydraulic model of the system, which will establish relationships between river flow and flood levels, and will provide the means for testing the effects of this*[8] *and other engineering alternatives for the optimisation of the use of available water resources*". The value added by this study was to construct the hydrodynamic model and to their (and other) data to construct a decision support framework, which was used to generate a systemic and systematic analysis of variations on the releases recommended in Heeg and Breen (1982), and used to evaluate the tradeoffs between ecological and social requirements on the floodplain and the needs or water users supplied by Jozini Dam.

It is difficult to evaluate where this process fits in terms of the Comprehensive-Intermediate-Rapid categorisation of Ecological Reserve determinations in South Africa because these are judged based on procedure rather than overall confidence in the outcome (although the latter is inferred). However, given the hydrodynamic model developed, and the extensive

[8] refers specifically to inflatable weirs, which were considered a promising solution for increasing floodplain inundation

amount of information available on the flow/flood relationships for vegetation and fish on the Pongola Floodplain, e.g., Heeg and Breen (1982) and Lankford et al. (2010), the floodplain assessment probably equates to at least an Intermediate Level confidence. Nonetheless, the prediction made should be read with due considerations of the assumptions that were used to generate the data and the response curves that underlie the analyses.

The river site EWR assessment is equivalent to a Rapid III river EWR assessment.

5.2 Overview of DRIFT

The DRIFT Decision Support (DSS) framework (King et al. 2003; Brown et al. 2013) was used to predict ecosystem and social responses on the floodplain to future changes in the release regime from Jozini Dam.

The DRIFT-DSS is a data-management tool that allows data and knowledge from disparate sources pertaining to 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 (e.g., as a result 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 the Pongola Floodplain, these were reduced to a sub-set of descriptors thought to be most relevant to the study (Figure 5.1).

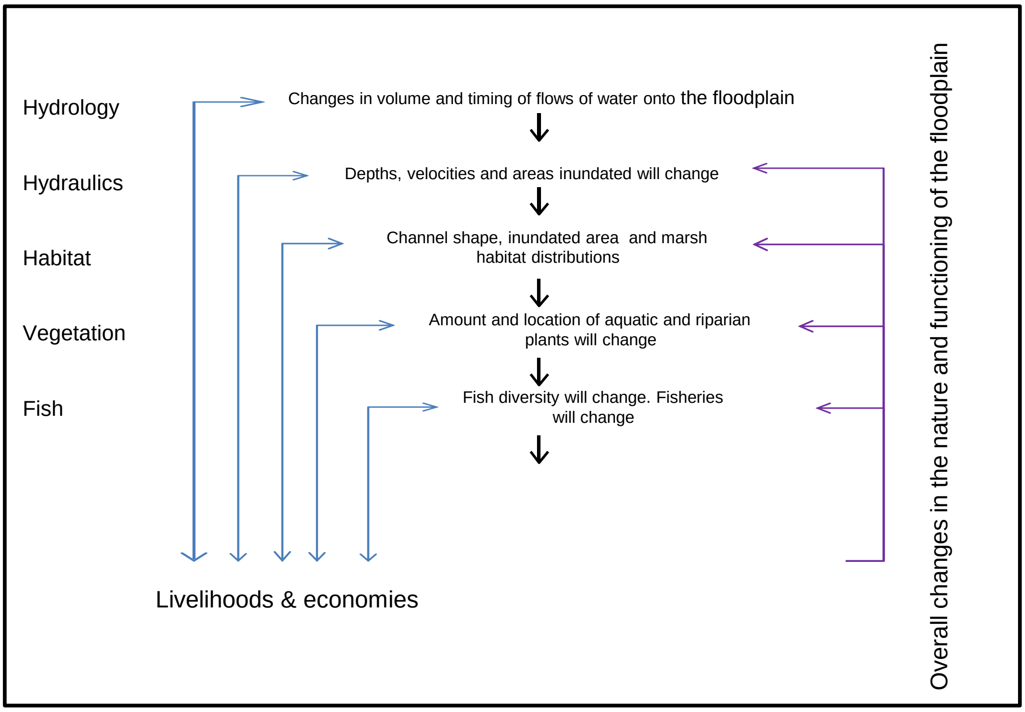

Figure 5.1 A simplified cause-and-effect sequence through the major descriptors used for the Pongola Floodplain, with acknowledgement of key linkages and feedback loops.

DRIFT (King et al. 2003; Brown et al. 2013) is adaptable and suited to the task at hand:

- Its custom-designed 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 is equally applicable to daily or hourly fluctuations in flow.
- It addresses all aspects of the flow and/or hydraulic regime in a structured single approach.
- It is adaptable and so in a project it is adapted to suit the river under investigation rather than the river 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 easily understood predictions that detail how the ecosystem could change, and how this could impact people, in way that stakeholders can relate to.

DRIFT has been used before in a similar setting as the Pongola Floodplain, when it facilitated an analysis of the implications of different releases from Cahorra Bassa on the Zambezi Delta (Beilfuss and Brown 2010).

5.2.1.1 The DRIFT process

The DRIFT process can be summarised as (Figure 5.2):

1. Decide on the nature of the scenarios to be evaluated. In this study they related to flood releases from the Jozini Dam (Section 11). Choose the baseline scenario: all other scenarios will be evaluated relative to the baseline.
2. Select the focus areas/study sites (see Section 4.2).
3. Obtain time-series of flow and hydraulics for the baseline and other scenarios at each study site (see Section 8; these time-series are translated 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 and social predictions of change are built.

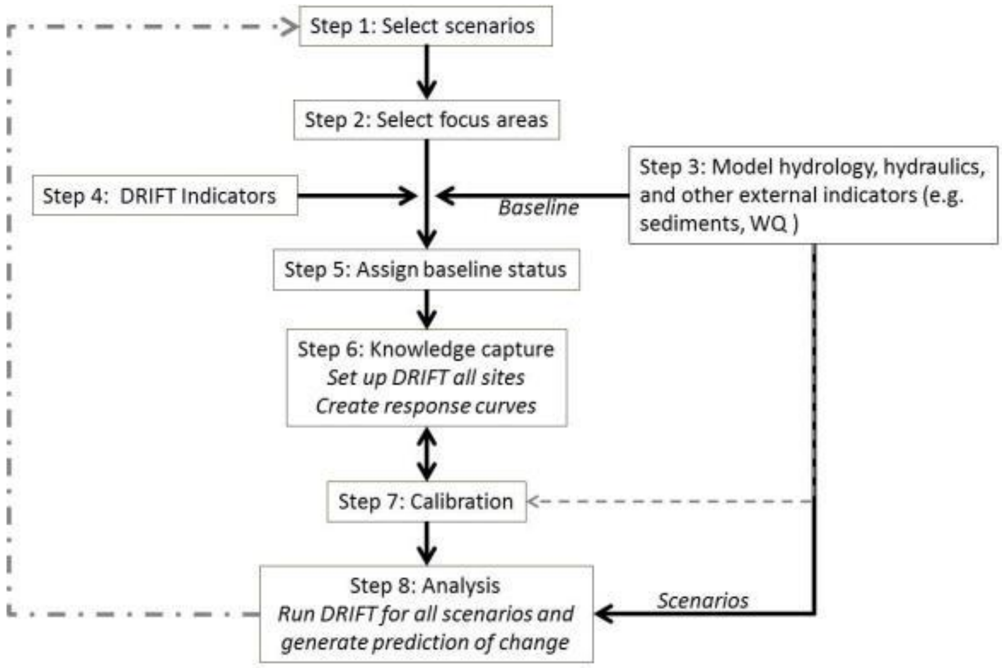

Figure 5.2 The DRIFT process

4. Select an array of flow, hydraulic, ecosystem and social indicators to represent the study site (Section 10). Define the links between the indicators (Appendix A-D). Together the indicators and links form the conceptual framework for the predictions of change.
5. Assign the present ecological status and trends (Section 7).
6. Construct a response curve (Figure 5.3; Appendix A-D) for each link that describes the relationship between the indicators. Each response curve describes the expected impact of a single 'driving' indicator on a single 'responding' indicator. A driving indicator in one relationship may become a responding indicator in another link: thus a change in flow can be followed through various linked indicators to a change in river condition or human well-being.
7. Response curves use a fixed severity rating scale, which is linked to fixed scale of percentages. A responding percentage change is determined for each driving indicator for each year. Thus, 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.
8. 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.
9. Analyse scenarios using the DSS and provide outcome for ecosystem and people depending on it (Sections 12 to 17).

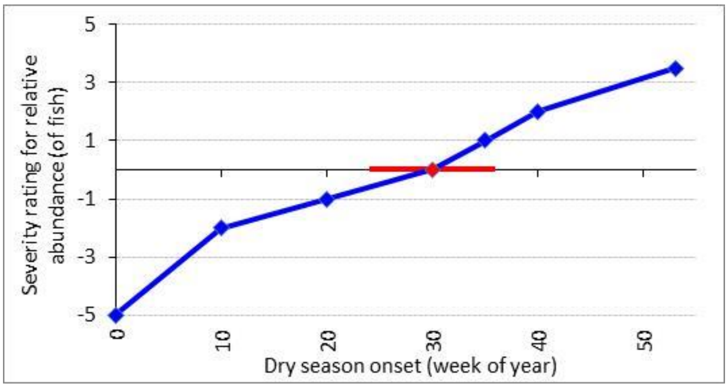

Figure 5.3 Example of a DRIFT response curve

Response curves form the heart of the DSS. They are compiled by the relevant specialists, based on all available relevant knowledge. Each response curve depicts the relationship between a driving indicator and a responding indicator. A responding biophysical indicator in one response curve can be a driving indicator in another (e.g. a change in the area a pan affects the abundance of submerged macrophytes, which in turn affects the abundance of fish guild A). Each curve describes the expected impact of a one driving indicator on the abundance of a single responding indicator, as Severity ratings on a scale of 0 (no response) to 5 (critically high), where a negative sign indicates a decrease in abundance and a positive sign indicates an increase. In the case illustrated in Figure 5.3, if the onset of the dry season in a certain year is in week 30, it is not expected to influence abundance of fish guild A, but if it were to start earlier (e.g. week 20) it could contribute to a reduced abundance (e.g. Severity -1) and if it started later it could contribute to an increased abundance.

The -5 to +5 severity ratings related to percentage changes in abundance. The specialists first choose their indicators and draw a diagram that shows its linked indicators Figure 5.4.

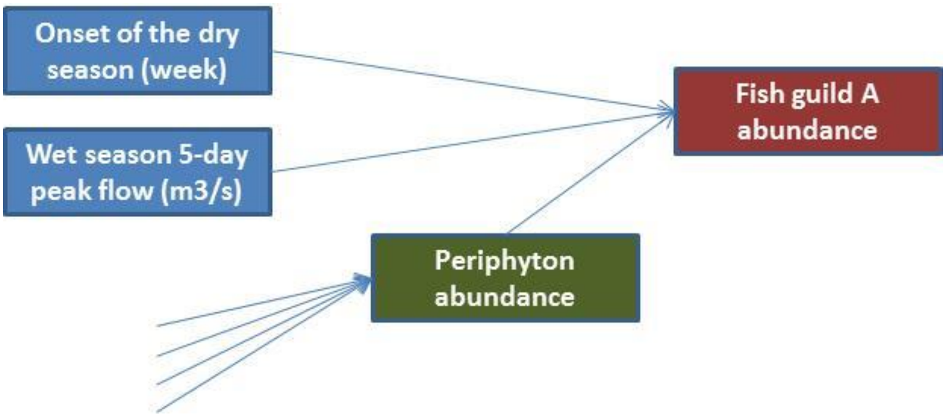

Figure 5.4 Schematic illustrating the concept of 'linked' indicators in DRIFT

In effect they create a simplistic ecosystem model, which when joined with all other links diagrams, forms a more complex web. They then draw a response curve for each of the link lines, using the DRIFT software.

For the Pongola Floodplain, the DSS was populated and calibrated for Tete Pan and Floodplain, only, and then the response curves were used for all of the study sites. This is possible to do because an indicator's response to the hydraulic regime on the floodplain is driven by the hydrodynamics around each pan rather than by any site-specific differences in their response curves.

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

5.3 Limitations

Data are always a limiting factor in environmental studies. With contemporary understanding of how river 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;
- it is better to evaluate the outcome of the scenarios relative to one another rather than as absolute individual predictions of change.

These inherent limitations notwithstanding, this study was limited more by the available time than by the available data or the tools that were used. Set-up and calibration of the hydrology and hydrodynamic models, and of DRIFT-DSS was time consuming, as was running of the scenarios. This meant that the number of scenarios evaluated was limited to nine, including natural and baseline (2014).

Given that the selection of the Reserve for the Pongola Floodplain is likely to be an iterative process with a negotiated outcome, there is both scope for and merit in further optimisation based on the analysis of additional release scenarios for Jozini Dam.

6 DATA COLLECTION AND COLLATION

6.1 Hydrology and hydraulics

Hydrology and hydraulics are covered in DWS (2014a) and Section 9, respectively.

6.2 Vegetation

A literature review was conducted, a summary of which is included in this report. As part of the baseline data for the vegetation portion of the study, the historical vegetation map of Heeg and Breen (1982) was scanned, manually ortho-rectified and captured in ArcGis. The historical vegetation community boundaries were then digitized in ArcGis for use as base maps for the fieldwork comparisons and the DRIFT workshop. Comparisons were then made with more recent aerial imagery (2009) of the area to identify vegetation changes on the floodplain and around the pans since 1982.

Gary Marneweck attended an integration team meeting in Cape Town on 31 October 2014 in preparation for the DRIFT workshop and to run through the results of the hydrological modelling (see Section 8). Vegetation indicators and linked indicators were identified based on the literature review.

Gary Marneweck and Bhuti Dlamini visited Ndumo and the Pongola floodplain from the 18th to 22nd November 2014. Fifteen pans were visited, as were sections of the floodplain including areas within and south of Ndumo Game Reserve. General observations were recorded and specific attention was given to identifying changes in the floodplain system through comparison with the vegetation maps of Furness and Breen (1982). In particular, areas that appeared to have changed using recent aerial imagery were visited. Where possible, GPS points were taken of flood debris lines and visible markers of flood levels of the October 2014 releases (Jozini Dam October flood release). These points were used to verify field observations and to contextualise hydrological modelling outcomes.

Gary Marneweck attended the DRIFT application workshop in Cape Town from the 24th to the 28th November 2014. At the workshop response curves were derived for each of the vegetation indicators and their linked indicators. Motivations for each response curve were also drafted based on specialist knowledge and information in the scientific literature, and evidence-based motivations for each were prepared (see Section 10.2 and Appendix B).

6.3 Fish

For the purposes of this study, historical fish distributions for the lower Pongola River were obtained from records held by the South African Institute for Biodiversity (SAIAB) and from Ezemvelo Kwazulu Natal Wildlife. The two datasets were combined, cleaned and sorted and all ambiguous species records (designated *sp*.) were removed. Marine and estuarine species that were not considered freshwater dependant were excluded from the dataset. The primary freshwater fish dataset was overlaid on a secondary catchment layer and a spatial join in QGIS was used to produce a list of species for the lower Pongola River (Table 6-1). This species list was checked against historical records, notably Heeg and Breen (1982), Merron et al. (1993a) and Merron et al. (1993b).

Table 6-1 Fish species distributions (from SAIAB and Ezemvelo Kwazulu-Natal Wildlife records).

ORDER	FAMILY	COMMON NAME	TAXON
Anguilliformes	Anguillidae	African mottled eel	*Anguilla bengalensis labiata*
		Giant mottled eel	*Anguilla marmorata*
		Longfin eel	*Anguilla mossambica*
Characiformes	Characidae	Imberi	*Brycinus imberi*
		Silver robber	*Micralestes acutidens*
		Tigerfish	*Hydrocynus vittatus*
Cyprinidontiformes	Aplocheilidae	Spotted killifish	*Nothobranchius orthonotus*
Cypriniformes	Cyprinidae	Beira barb	*Barbus radiates*
		Bowstripe barb	*Barbus viviparous*
		Broadstriped barb	*Barbus annectens*
		Bushveld smallscale yellowfish	*Labeobarbus polylepis*
		Carp	*Cyprinus carpio*
		East coast barb	*Barbus toppini*
		Goldie barb	*Barbus pallidus*
		Hunyani labeo	*Labeo altivelis*
		Hyphen barb	*Barbus bifrenatus*
		Leaden labeo	*Labeo molybdinus*
		Longbeard barb	*Barbus unitaeniatus*
		Plump barb	*Barbus afrohamiltoni*
		Purple labeo	*Labeo congoro*
		Redeye labeo	*Labeo cylindricus*

ORDER	FAMILY	COMMON NAME	TAXON
		Rednose labeo	*Labeo rosae*
		River Sardine	*Mesobola brevianalis*
		Southern barred minnow	*Opsaridium peringueyi*
		Straightfin barb	*Barbus paludinosus*
		Threespot barb	*Barbus trimaculatus*
		Tugela labeo	*Labeo rubromaculatus*
Elopiformes	Megalopidae	Oxeye tarpon, Indo-Pacific tarpon	*Megalops cyprinoides*
Osteoglosiformes	Mormyridae	Bulldog	*Marcusenius macrolepidotus*
		Churchill	*Petrocephalus catostoma*
Perciformes	Cichilidae	Banded tilapia	*Tilapia sparrmanii*
		Black tilapia	*Oreochromis placidus*
		Mozambique tilapia	*Oreochromis mossambicus*
		Redbreast tilapia	*Tilapia rendalli*
		Southern mouthbrooder	*Pseudocrenilabrus philander*
	Gobiidae	Checked goby	*Redigobius dewaali*
		Freshwater goby	*Awaous aeneofuscus*
		River goby	*Glossogobius callidus*
		Tank goby	*Glossogobius giuris*
Siluriformes	Clariidae	Blunttooth catfish	*Clarias ngamensis*
		Sharptooth catfish	*Clarias gariepinus*
		Snake catfish	*Clarias theodorae*
	Mochokidae	Brown squeaker	*Synodontis zambezensis*
		Lowveld suckermouth	*Chiloglanis swierstrai*
		Sawfin suckermouth	*Chiloglanis paratus*
	Schilbeidae	Silver catfish	*Schilbe intermedius*
Syngnathiformes	Sygnathidae	Freshwater pipefish	*Microphis fluviatilis*

The data from a recent Water Research Commission study of the area, including detailed fish surveys were not available to the study. The reports from these studies are due for release in c. May 2015 (Prof. Nico Smit, North-West University, pers. comm.).

Dr Bruce Paxton visited the Pongola floodplain from the 7th to the 13th July 2015.

Dr Bruce Paxton attended the DRIFT application workshop in Cape Town from the 24th to the 28th November 2014. At the workshop response curves were derived for each of the fish indicators and their linked indicators. Evidence-based motivations for each response curve were also drafted based on specialist knowledge and information in the scientific literature (see Section 10.2.3 and Appendix C).

6.4 Social

As part of the baseline data for the social portion of the study, a literature review was conducted (see Section 2.5).

Toriso Tlou attended an integration team meeting in Cape Town on 31 October 2014 in preparation for the DRIFT workshop and to run through the results of the hydrological modelling (see Section 8). Social indicators and linked indicators were identified based on the literature review.

Toriso Tlou visited the Pongola floodplain from the 18th to the 21st November 2014.

Toriso Tlou attended the DRIFT application workshop in Cape Town from the 24th to the 28th November 2014. At the workshop response curves were derived for each of the social indicators and their linked indicators. Evidence-based motivations for each response curve were also drafted based on specialist knowledge and information in the scientific literature (see Section 10.3 and Appendix D).

7 ECOSTATUS

7.1 Description of the 2014 status of the Pongola Floodplain

7.1.1 Vegetation

7.1.1.1 Present Ecological State

To provide a description of general floodplain and pan condition, a broad level wetland health assessment was done using the concept of Present Ecological State (PES), which provides an indication of the state of an ecological system relative to its "natural" state (Kleynhans 1996; 1999). PES, when applied to wetlands, is closely linked to function, implying that a wetland with a high PES is more likely to deliver benefits to society than with a low PES (Table 7-2).

Table 7-1 Definitions of categories of PES used to describe the integrity of wetlands (based on Kleynhans 1999).

Impact category	Description	Present Ecological State
None	Unmodified, natural	A
Small	Largely natural with few modifications. A slight change in ecosystem processes is discernible and a small loss of natural habitats and biota may have taken place	B
Moderate	Moderately modified. A moderate change in ecosystem processes and loss of natural habitats has taken place but the natural habitat remains predominantly intact	C
Largely Modified	A large change in ecosystem processes and loss of natural habitat and biota and has occurred	D
Serious	The change in ecosystem processes and loss of natural habitat and biota is great but some remaining natural habitat features are still recognizable	E
Critical	Modifications have reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota	F

A tool for assessing the PES of wetlands was first developed in 1999 (DWAF 1999a). More recently an assessment method called WET-Health (Macfarlane *et.al*. 2007) was developed. WET-Health uses indicators based on geomorphology, hydrology and vegetation to evaluate the PES. It was primarily developed to assess wetland condition in linear systems where the wetland is linked to a drainage line. Despite its value as a wetland assessment tool, WET-Health is not applicable for assessing the PES of pans and as such was not considered as an appropriate for use on the Pongola Floodplain. An attempt was made to assess PES using a pan assessment method modified from the scoring system as first described in the in DWAF (1999a) and then converted to the Impact and Integrity Scores used in WET-Health. This also proved problematic as it was developed for pans on the Highveld grasslands and as such does not deal with flood-related drivers. , no formal PES assessment could be done for the pans.

As a result, a general indication of the PES of the floodplain was derived using the Wetland Index of Habitat Integrity (DWAF 2007). This is made up of the PES category scores for the driving process hydrology, geomorphology and water quality plus land-use using the vegetation alteration score based on field observations relative to the vegetation mapped by Furness and Breen (1982). For the sections of the floodplain that were visited and which did not have pans, the WET-Health tool was used to derive level 1 PES category scores for the hydrology, geomorphology and vegetation components. These were used to check that the scores derived from the application of the Wetland IHI to the whole system were comparable and made sense from a general floodplain health perspective.

7.1.1.2 Importance and sensitivity

Ecological “importance" and "sensitivity" (EIS) of the floodplain were also assessed. These reflect the importance of maintaining ecological diversity and functioning on local and wider scales; and the system’s ability to resist or recover from disturbance, respectively. The method described in the draft rapid Reserve guideline document (DWA 2012) was used to assess the EIS of the floodplain system in general. This was augmented with field observations, in particular, those related to changes in the extent and distribution or certain vegetation communities relative to Furness and Breen (1982). A summary of these, with supporting photographs, is provided here.

The expansion of commercial agriculture is evident throughout the floodplain. This is supported by Lankford *et al*. (2010) who demonstrated substantial changes in many of the vegetation functional cover classes. In particular they highlight changes to the cultivated land and terrestrial tree components, the former of which increased substantially between 1955 and 2003 (from 0.44% to almost 43% in the transects considered) while the latter showed an opposite trend. They also showed a significant decrease in extent of the *Cyperus* community (Lankford et al. 2010) over the same period., and showed that although the majority of the *Cyperus* community had been converted to cultivation, a large portion had changed to grass (Lankford et al. 2010), which suggests that flow-related impacts have played a role in the demise of the *Cyperus* community. This is supported by results from the Ndumo Game Reserve, where Lankford *et al*. (2010) reported a significant reduction in the area of the *Cyperus* community, with concomitant increases in terrestrial components, notably the shrub/tree and grass communities. Spatial analysis conducted by Lankford *et al.* (2010), however, attributed the proximal cause of the change in extent of the *Cyperus* community to landuse, rather than flow. They did, however, acknowledge that these may have come about because large areas of the floodplain had dried out, and were thus more amenable to cultivation, as a result of reduced summer flooding.

Lankford *et al*. (2010) attribute the reduction in the terrestrial tree component of the floodplain to slash and burn agricultural activities in the area. This practice comprises cutting and burning of trees to make way for agricultural fields.

The observations made during the November 2014 field visit support the findings of Lankford *et al*. (2010). The following pans were visited:

- Banzi and Nyamithi in Ndumo Game Reserve;
- Mandlankunzi;
- Namanini;
- Ngodo and Bumbe;
- Mhlolo;
- Sokunti;
- Shalala;
- Sivunguvungu;
- Tete and Tetomncane;
- Mthikeni; and
- Mzinyeni; and
- A small pan to the east of Bumbe.

In all cases, there was evidence of cultivation extending up to the maximum retention level of the pans (Figure 7.1). In most cases livestock fences had been erected around the fields. Also evident was the decrease in area of *Cynodon dactylon* lawns around the pans (Figure 7.2) particularly around Namanini (Figure 5-5) where they used to be extensive (Heeg and Breen 1982). The main reason for the decrease was the conversion to cultivated lands, although overgrazing also appeared to have the abundance of *C. dactylon* in the remaining areas. In some cases, *C. dactylon* had been replaced by weedy plants including a small *Cyperus* species in highly disturbed areas.








Figure 7.1 Photographs showing cultivation around the edges of pans and in many cases right up to the edge of the retention level of the pan (November 2014).

Figure 7.2 Photographs related to the *Cynodon dactylon* community showing: (top row left) livestock paddocks within a remaining stand of *C. dactylon*; (top row right and second row left) low cover-abundance within a remaining stand of *C. dactylon* and a complete change in species composition in some places; (second row right and third row) relatively healthy remaining stands of *C. dactylon*; (fourth, fith and sixth row) highly degraded and overgrazed *C. dactylon* stands on the edge of some pans; and (last row) previous stands of *C. dactylon* converted to agricultural fields (November 2014).

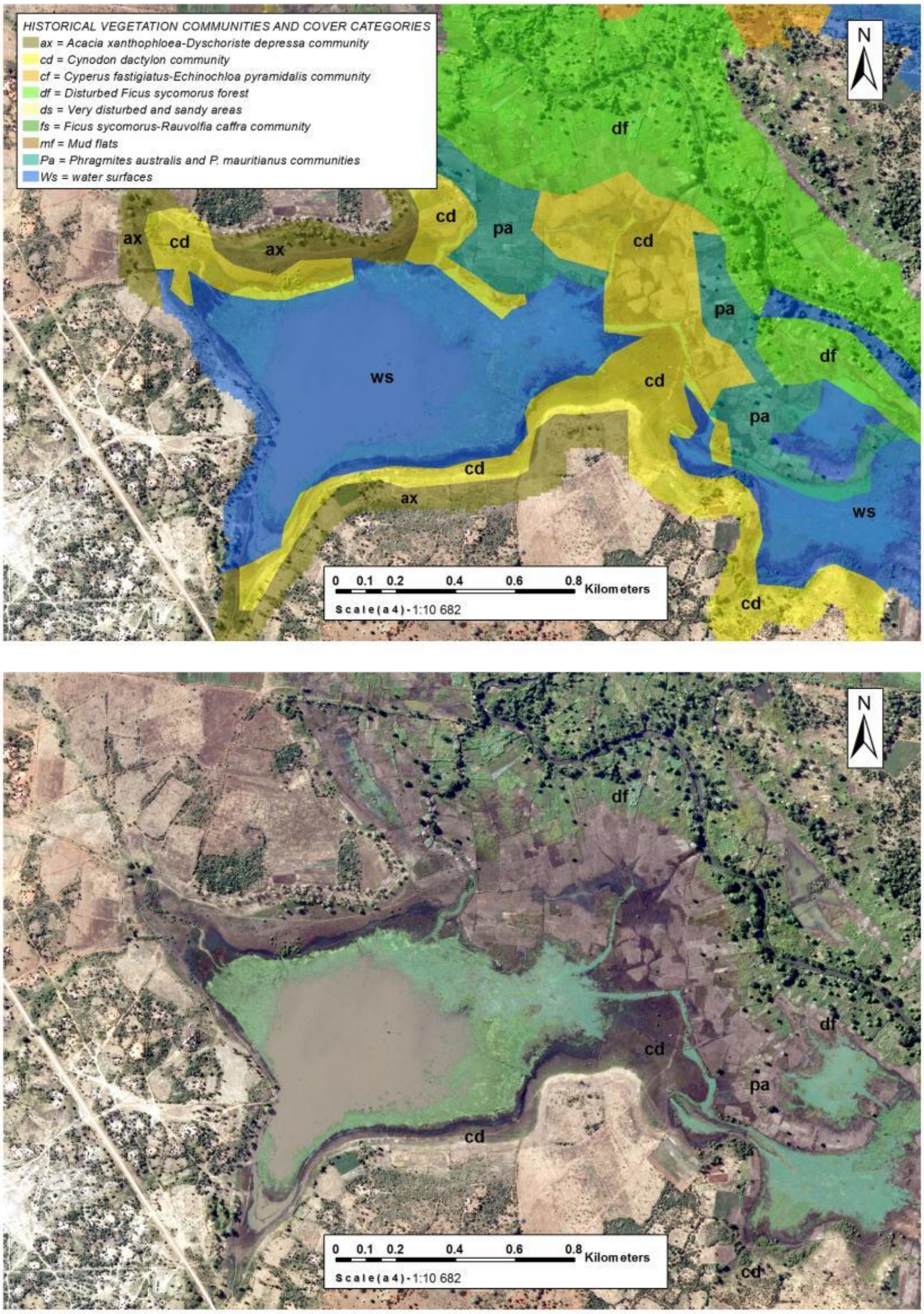

Figure 7.3 Vegetation community distribution around Namanini pan as mapped by Heeg and Breen (1982; top) in relation to an aerial image from 2009 (bottom), which clearly shows the conversion of most of the *C.dactylon* lawns to cultivated land.

Also evident was the dearth of large riparian trees in areas previously described as comprising these communities. Slash and burn practices to make way for additional cultivated lands (Figure 7.4) appear to be ongoing and seem to be the main contributing factor for the loss of woody vegetation.

Figure 7.4 Photographs of the clearing of trees on the floodplain: (top row left) cutting of areas of the *Acacia xanthophloea* tree community; (top row right) slashing and burning of terrestrial tree habitat on the upper edges of the floodplain; (second and third rows) cutting and burning of riparian habitat including large *Ficus sycomorus* trees to make additional land available for cultivation within the floodplain; (fourth row) large scale clearing of riparian trees along a tributray of the floodplain near the confluence; and (last row) Slash and burn clearing on the floodplain immedialtely south of Ndumo (November 2014).

A number of areas away from the pans but on the floodplain were also visited, in particular those previously indicated as comprising *Cyperus fastigiatus – Echinochloa pyramidalis* communities. Here too the conversion of the *Cyperus fastigiatus – Echinochloa pyramidalis* community to cultivated lands (Figure 7.3) was evident, but so were the effects of changes in the lateral flooding within the floodplain. This was particularly so for the floodplain area immediately south of the border of Ndumo Game Reserve (Figure 7.4), and the areas around Tetomncane and Tete pans (Figure 7.5). Despite having been flooded only a month prior to the site visit, most of the areas visited were dry. This would prejudice the indigenous vegetation and make the areas more accessible for cultivation.

Figure 7.5 Photographs of the cultivation of areas previously recorded as being *Cyerus fastigiatus - Echinocloa pyramidalis* vegetation communities (Heeg and Breen 1982)(Photo: November 2014).

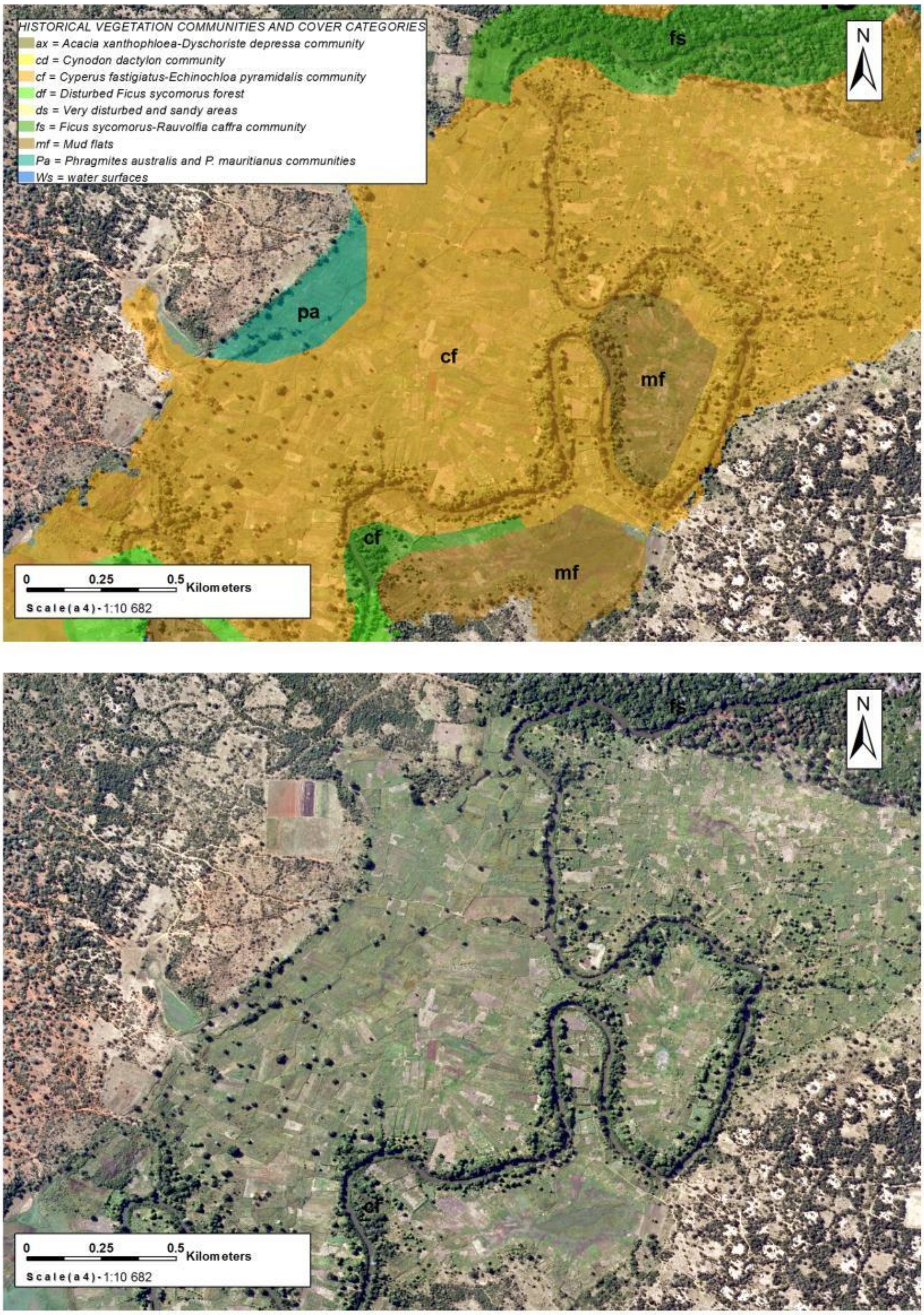

Figure 7.6 Vegetation community distribution on the Pongola floodplain immediately south of the Ndumo Game Reserve border as mapped by Heeg and Breen (1982) (top) in relation to an aerial image from 2009 (bottom) which clearly shows the conversion of most of *the C. fastigiatus* – E. pyramidalis community to cultivated land.

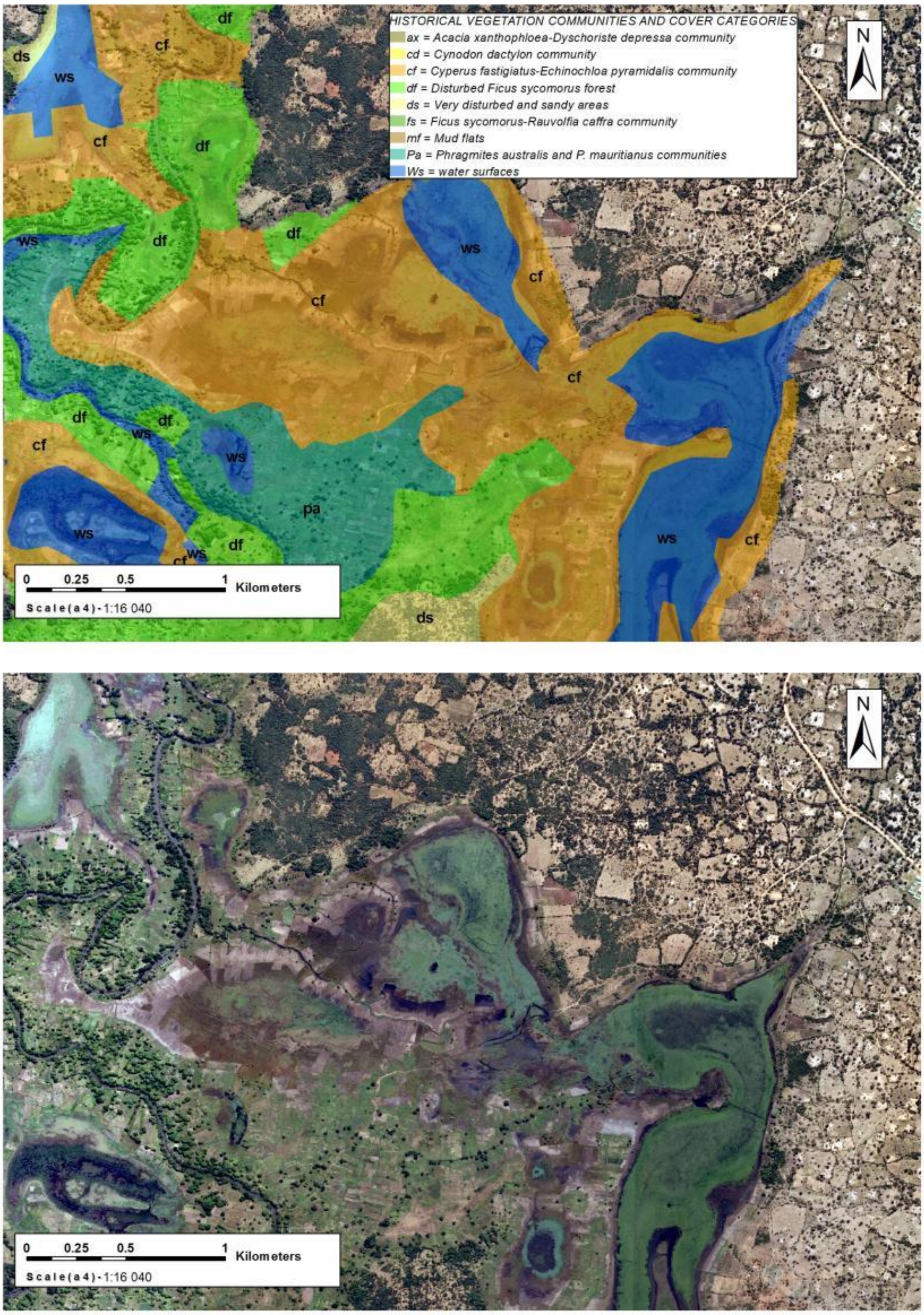

Figure 7.7 Vegetation community distribution on the Pongola Floodplain around Tetomncane and Tete pans as mapped by Heeg and Breen (1982; overlayed on 2009 aerial image; top) in relation to an aerial image from 2009 (bottom), which clearly shows the conversion of most of the *C. fastigiatus – E. pyramidalis* community to cultivted land. Also noticeable is the small number of large trees making up the disturbed *F. sycomorus* forest.

In contrast to the more upstream areas, the vegetation at Nyamithi Pan in Ndumo Game Reserve appeared to be in relatively good condition with representative examples of most of the main vegetation communities found on the floodplain (Figure 7.8). It is thought that the contribution to flooding of the lower Pongola floodplain from the Usuthu River helps to maintain Nyamithi pan and the lower floodplain of the Pongola in the Ndumo Game Reserve (Birkhead PC 2014).

Figure 7.8 Nyamithi pan in Ndumo Game Reserve, which contains examples of most of the main floodplain vegetation communities (November 2014).

The floodplain towards the southern boundary of the Ndumo Game Reserve appears to be drier. This is possibly because it is not influenced by the back-flooding effects of the Usuthu River. Reduce summer flooding has contributed towards the degradation of the *Cyerus fastigiatus - Echinocloa pyramidalis* vegetation communities, particularly those close to the southern boundary of the reserve. Lankford *et al*. (2010) also reported notable reductions in the *Cyperus* community with increases in terrestrial components, notably the shrub/tree and grass communities in Ndumo Game Reserve (Figure 7.9).

Figure 7.9 The degraded *Cyperus fastigiatus - Echinocloa pyramidalis* vegetation community near the southern boundary in the Ndumo Game Reserve ((November 2014).

The results of the PES assessment using the Wetland IHI (DWAF 2007) are given in Table 7-3, with a description of the categories provided in Table 7-1. The PES categories derived concur with the literature, changes observed in regard to the vegetation communities, changes indicated by the hydrological modelling, and observations made in the field. A PES category of D is indicated for the hydrological driver, based on the extreme changes to the flooding regime. Geomorphology is indicated as E and water quality as C/D, although the confidence in the latter is low. The vegetation alteration score is indicated as D/E. The trajectory of change under the current management regime and flooding scenario is strongly negative.

Table 7-2 PES categories derived for the floodplain driving processes and wetland landuse based on the Wetland IHI (DWAF 2007)

Process	Ranking	Weighting	Score	PES Category
DRIVING PROCESSES:		100	3.0	
Hydrology	1	100	2.8	D
Geomorphology	2	80	3.7	E
Water Quality	3	30	2.0	C/D
WETLAND LANDUSE:		80	3.1	
Vegetation Alteration Score	1	100	3.1	D/E

In contrast to the PES, the EIS assessment indicates that the system falls within a Very High category (Table 7-3) because of the range of ecosystem services provided by the floodplain and its pans, some of which are indicated in Figure 7.10 to Figure 7.12. A description of the categories is provided in Table 7-4. The floodplain is thus considered ecologically important and sensitive on a national or even international level. The biodiversity of wetland systems falling within this category are usually very sensitive to flow and systems modifications. The floodplain is also expected to be playing a major role in moderating the quantity and quality of water of a major river, in this case the Pongola.

Examples of some of the vegetation communities described herein are shown in Figure 7.13.

Table 7-3 EIS derived for the floodplain driving processes and wetland landuse based on the Wetland IHI (DWAF 2007)

Summary table from the EIS, Hydro-Functional and Direct Human Benefit assessment sheets	Score (0-4)	Confidence (1-5)
Ecological Importance and Sensitivity	4.0	3.6
Hydro-Functional Importance	3.0	3.3
Direct Human Benefits	2.7	3.0
Overall EIS Category	3.2	3.3

Table 7-4 Rating scale used in the EIS assessment (based on DWAF, 1999a and DWA 2011)

Ecological Importance and Sensitivity categories	Range of Median	Recommended Ecological Management Class
Very high Wetlands and riparian systems that are considered ecologically important and sensitive on a national or even international level. The biodiversity of these wetland is usually very sensitive to flow and systems modifications. They play a major role in moderating the quantity and quality of water of major rivers.	>3 and <=4	A
High Wetlands and riparian systems that are considered to be ecologically important and sensitive. The biodiversity of these wetlands may be sensitive to flow and systems modifications. They play a role in moderating the quantity and quality of water of major rivers.	>2 and <=3	B
Moderate Wetlands that are considered to be ecologically important and sensitive on a provincial or local scale. The biodiversity of these wetlands is not usually sensitive to flow and systems modifications. They play a small role in moderating the quantity and quality of water of major rivers.	>1 and <=2	C
Low/marginal Wetlands that are not ecologically important and sensitive at any scale. The biodiversity of these wetlands is ubiquitous and not sensitive to flow and systems modifications. They play an insignificant role in moderating the quantity and quality of water of major rivers.	>0 and <=1	D

Figure 7.10 Photographs taken at various pans showing fishering activities (November 2014).

Figure 7.11 Photographs of commercial and subsistence agriculture on the floodplain. Pumps are used to support flood irrigation of the commercial lands in particular (November 2014).

Figure 7.12 Photographs taken at various pans showing some of the livestock grazing, mainly on the *C. dactylon* lawns (November 2014).








Figure 7.13 Some of the vegetation communities originally described as occurring on the Pongola floodplain (Furness and Breen 1980; Heeg and Breen 1982): (top row) *Ficus sycomorus forming* the dominant tree species of the *F. sycomorus – Rauvolfia caffra* community located along the levees of the Pongola and Usuthu rivers; (second row) *Acacia xanthophloea* forming the dominant tree species of the *A. xanthophlea - Dyschoriste depressa* community that occurs towards the edge of the floodplain where drier conditions prevail; (third row) *Phragmites australis* which prefers swampy areas on the floodplain and inundated areas of the pans and *P. mauritianus* which prefers river banks, inlet-outlet channels and pan margins where there are fluctuating water levels; (fourth row left) The *Cyperus fastigiatus - Echinochloa pyramidalis* community located on the edge of a pan; (fourth row right) *Cynodon dactylon* lawns that occupy areas that regularly experience alternating inundation and exposure; (fifth row left) Communities of emergent (mainly *C. fastigiatus*) and floating leaved macrophytes (*Nymphaea, Trapa* and *Ludwigia*) in a pan; (fifth row right) Aquatic hydrophytes in seasonally to permanently inundated pans dominated by the water chestnut (*Trapa natans/bispinosa – bottom row left*) and various water lilies (*Nymphea species*). Some exotic hydrophytes such as *Eichornia crassipes* (water hyacinth) was also evident on many of the pans (November 2014).

7.1.2 Fish

Merron et al. (1993b)[9] estimated the percentage by biomass for six major fish species occurring on the Pongola floodplain in descending order of their contribution to the total catch. These were:

i. Mozambique tilapia (Oreochromis mossambicus);
ii. sharptooth catfish (*Clarias gariepinus*);
iii. rednose labeo (*Labeo rosae*);
iv. tigerfish (*Hydrocynus vittatus*);
v. silver catfish (*Schilbe intermedius*);
vi. stripe-tailed robber (*Brycinus imberi*).

However, they found that these proportions changed depending on the flooding regime with *O. mossambicus* dominating fish communities during drought years and in the pans after extended periods of isolation. The larger labeos, tigerfish and silver catfish were only able to recolonize the pans and replenish populations after floods.

Surveys of 24 sites on the Pongola River, its floodplain and adjoining tributaries by Weldrick (1996) between 1993 and 1995 showed considerable variation in the fish assemblage between main channel, tributaries and pans. Mozambique tilapia dominated catches throughout, but the smaller barbs were well represented in littoral seine catches. The numerically most abundant species included: Mozambique tilapia, river goby (*Glossogobius callidus*), East Coast barb (*Barbus toppini*), straightfin barb (*Barbus paludinosus*) and the redbreast tilapia (*Tilapia rendalli*). Flood-dependent species like rednose labeo and tigerfish were present, but only at three of the sites.

Phélines (1973) noted that early floods in November produced only limited breeding, but that floods later in the season (Dec-Feb) caused widespread breeding with minor releases prior to the larger floods stimulating migration and gonad ripening among the flood-dependent species (labeos and tigerfish). Heeg and Breen (1982) later noted that gonadal development peaked during November, but that spawning peaked later in the season between January and February – particularly for rednose labeos, which appeared to spawn only later in the season (Feb-Mar). It seems likely therefore that floods released early in the season do not coincide with other environmental factors such as temperature and photoperiod that cue gonad maturation. Heeg and Breen (1982) also noted that the Ndumo pans (and by implication the pans further downstream in Mozambique) may be important refuges for replenishing breeding stock subject to high fishing mortality in the pans in the more southerly parts of the floodplain.

Since 2000, flow releases from the Jozini Dam have been restricted largely to a single flood in October, with additional floods occurring later in the season only if the dam spills. In

9 Identified during the course of surveys in the mid-1980s.

addition, extensive cultivation of the floodplain has occurred. Attendant with agricultural encroachment has been the degradation of wetland vegetation and the consequent loss of nursery areas for young fish. Fishing continues to be an important subsistence and commercial activity and with increasing numbers of people on the floodplain, fishing pressure is likely to have increased since the 1980s. However, perceptions among fishers are that reduced catches in the pans are due to the lower flows rather than fishing pressure (Jaganyi et al. 2009).

No recent data are available on the fish populations of the floodplain[10]. It can be assumed that the fish community on the floodplain is thus presently dominated by flood-independent species, i.e. the tilapia and small barbs. Larger, flood-dependent species such as tigerfish, rednose labeos and silver catfish are expected to be present, but in relatively low abundances.

Table 7-5 Ecoclassification - fish

Zone	PES
1. Dam to below Mzinyeni	E
2. Mzinyeni to Mthikeni	D
3. Subane to Shalala	D
4. Shalala to Ndumo	D
5. Ndumo	C

7.2 Social status (2014)

Since the construction of Jozini Dam, the socio-economic status of the floodplain has changed from an ecologically-dominated system with the local communities dependent on the natural resources to a cash/subsistence economy.

- The cash economy is driven by the commercial irrigation agriculture immediately downstream of the Jozini Dam in the Mjindi and Makhatini Flats.
- The subsistence economy (or semi-commercial where communities sell their excess production) is driven by activities on the floodplain from Mzinyoni to Ndumo, with the areas around Shalala to Mandlankunzi being more semi-commercial than subsistence. Other activities include fishing in the pans, cattle grazing on the

[10] A results of a recently-completed WRC study on the Pongola Floodplain were not available for this study.

floodplain, harvesting of the natural resources and water abstraction for irrigation, household use and stock watering.

7.2.1.1 Commercial agriculture

Immediately downstream of the dam, the main crops are sugarcane (Figure 7.14), cotton, bananas and mangoes. These crops are irrigated mainly by water piped from Jozini Dam and are not discussed further here.

Figure 7.14 Sugar cane growing in the Pongola Floodplain in Nondabuya

7.2.1.2 Subsistence/semi-commercial agriculture

Downstream of Nondabuya, the activities are semi-commercial/subsistence agriculture, fishing, and harvesting of natural resources. The most widely-cultivated crops are: maize; sweet potato; pumpkins and butternuts; beans and groundnuts.

Further downstream in the Shemula and Ndumo floodplain areas; although maize is still the main crop, chillies are increasingly cultivated (Figure 7.15). The agricultural activity although still subsistence in the central sections of the floodplain, is becoming more commercial with crops such as chillies being grown for markets.

Average field size per household on the floodplain is c. 1 ha according to Lankford et al. (2010). However there are indications that the average size is declining as communities split the areas allocated to them between their family members (T. Tlou, pers comm with communities). The findings of Lankford et al. (2010) were confirmed that households also allocate a small portion of their field (about ¼ ha) to grow a range of short rotation vegetable crops including onions, carrots, cabbage and spinach. These are usually planted between May and June (i.e. after the harvest of the main crops) and harvested in July. Women tend the fields and are more involved in from farming in the floodplain than are men.

Figure 7.15 Chillies under cultivation near Mandlankunzi Pan (November 2014)

7.2.1.3 Cattle grazing

There are competing demands for land for grazing and cultivation, which affects cattle production on the Pongola Floodplain. Cattle graze in more elevated areas of the floodplain, where there is little cultivation, during the farming season. Then, during the winter period, the communities bring their cattle onto the floodplain to access the couch grass (*Cynodon*) lawns where these are available. However because of the changes in the natural flooding regime and excessive cultivation, these *Cynodon* lawns have all but disappeared. This has negatively affected cattle production in the area.

The pans themselves are also important watering holes for cattle (Figure 7.16), although, according to the communities some of the smaller pans dry up during the winter (dry season).

Figure 7.16 Cattle grazing on the shore of the Nemanini Pan (November 2014)

7.2.1.4 Fishing

Nearly half of the households catch fish every week in order to feed the families and earn an income. Fishermen reported earning R2 500 – R4 500 per month from the sale of fish (DWA 2010), but this can be higher at the beginning of the rainy season. According to the study conducted by the DWA, floodplain fisheries yield in the order of 37 kg per ha of floodplain. The Pongola Floodplain yields about 200 tonnes per year. The economic value of fishing translates to approximately R4.5 million per year in local economic contribution and benefits *c*. 6450 households. This figure has substantially increased in recent years.

7.2.1.5 Harvesting of plants

In the 1980 and early 1990s, according to the locals, approximately 72% of the households or 4 500 households on the floodplain were highly dependent on natural resources from the floodplain.

Because of changes in the ecology of the Pongola Floodplains, the dependence on the natural resource as a source of food has been deteriorating with the exception of fishing as discussed above. The plants that were most widely harvested by local households included: reeds (*Phragmites* sp); thatching grass (*Cyperus* sp); bulrushes (*Typha* sp); wild figs (*Ficus* sp), and; water lilies (*Nymphae* sp).

There are still some reeds and bulrushes on the edges of the pans, but it the change in the flood regime and over-harvesting has seen their abundance drop dramatically. Similarly, the thatched grass that used to occur on the floodplains has declined significantly. This is partly because of the change in flooding but also because agriculture has replaced thatching grass. The water lilies are still abundant and are harvested for food by the local communities. The availability of figs, which are also harvested for food, has declined significantly.

7.2.1.6 Water for domestic purposes

With the increasing concentration of communities in the Shemula – Ndumo area, the Pongola River is used as a conduit for water released from the Jozini Dam. This is treated at the Shemula water treatment works to supply the communities in the Shemula scheme area. The current average annual release is 7.3 million m^3/a, or 0.23 m^3/s.

The population in the Pongola Floodplain has increased significantly since 2001, which has increased the demand for potable water. The Pongola River is seen as a source of water supply for the whole of Umhlabuyalingana and Jozini and it is planned that by 2019, a constant 30 million m^3/a will be released downstream of Jozini Dam for treatment and distribution at Jozini and Shemula.

7.2.1.7 Water for crop irrigation

The October flood currently provides the most reliable water for crop irrigation, although some farmers have expressed a desire to have this flood two weeks earlier, in September, so that they can start planting earlier. This is however expected to affect the latter part of the season, when the field are dry particularly when there are no mid- to late-season spills from Jozini Dam. During that time, some farmers pump water from the channel and pans to irrigate their fields.

8 HYDROLOGY

Discharge time-series were provided by Aurecon (Pty) Ltd (DWS 2014a) for naturalised and present day conditions, and for potential future scenarios of water-resource demands from the dam (agricultural, inter-catchment transfers, irrigation and municipal/domestic). These were coupled with four different high flow release patterns for the downstream floodplain. Simulations were based on monthly modelling using the Water Resources Yield Model (WRYM) inherited from the PRIMA IAAP 10 Study (TPTC 2011)[11]. Naturalised monthly discharges were disaggregated for hydrodynamic modelling using historic gauge data from the upstream catchment. For the present day and future scenarios, MODSIM was used to simulate daily releases from Jozini Dam.

The simulated time-series extends from 1951 to 2004, but this period was reduced to the most recent 15 years for hydrodynamic simulations, giving more acceptable run times of the hydrodynamic model of *c*. 24 hours.

The details of the hydrology and the scenario simulations are present in Aurecon (2014a).

[11] TPTC refined streamflows from the Joint Maputo Basin Water Resources Study (JMBRS)

9 HYDRODYNAMIC MODELLING

Heeg and Breen (1982) recognised the need for "*the construction of a hydraulic model of the system, which will establish relationships between river flow and flood levels, and will provide the means for testing the effects of this*[12] *and other engineering alternatives for the optimisation of the use of available water resources*". This "hydraulic model" is the hydrodynamic modelling addressed in this chapter. A more recent study of the Pongola Floodplain by Langford et al. (2010) entitled "*Hydrological modelling of water allocation, ecosystem services and poverty alleviation in the Pongola Floodplain, South Africa*". Their hydrological modelling involved the use of measured "natural river regime" flows[13] and the development of relationships between discharge and flooded area from the previous studies of Phélines et al. (1973), Heeg and Breen (1982) and Basson et al. (2006). The latter, and other historic hydrodynamic models of the floodplain, are discussed in the next section.

9.1 Hydrodynamic models of the Pongola Floodplain

Over the past 42 years, since the commissioning of Jozini Dam, four computational models have been developed to simulate the hydrodynamic behaviour of the downstream Pongola Floodplain, including:

- one-dimensional[14] (1d):
  - Pitman and Weiss (1979), Department of Water Affairs (1987), and Beck and Basson (2003);
- two-dimensional (2d):
  - Basson *et al.* (2006).

The Pitman and Weiss (1979) one-dimensional cell-based model had previously been successfully applied for simulating inundation behaviour in various other floodplains. Limited data were available, however, to calibrate the model for the Pongola Floodplain, and predictions indicated that a peak discharge of 690 m^3/s (100 $10^6 m^3$) filled the downstream pans, whereas a lower peak of 345 m^3/s (50 $10^6 m^3$) did not. The next model developed, by the Department of Water Affairs in 1987, was also cell-based, with stage-storage functions and weir connections between cells. The model was essentially steady-state incorporating Manning's formulation for flow resistance. Whereas the 1979 model excluded a section of the (more confined) Pongola River immediately downstream of Jozini Dam, the entire extent of the floodplain to the Usuthu River confluence was included in the 1987 model. Historic

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[12] refers specifically to inflatable weirs, which were considered a promising solution for increasing floodplain inundation
[13] from station W4H002 at Golela upstream of Jozini Dam, for the period 1929 to 1976
[14] spatial dimensions

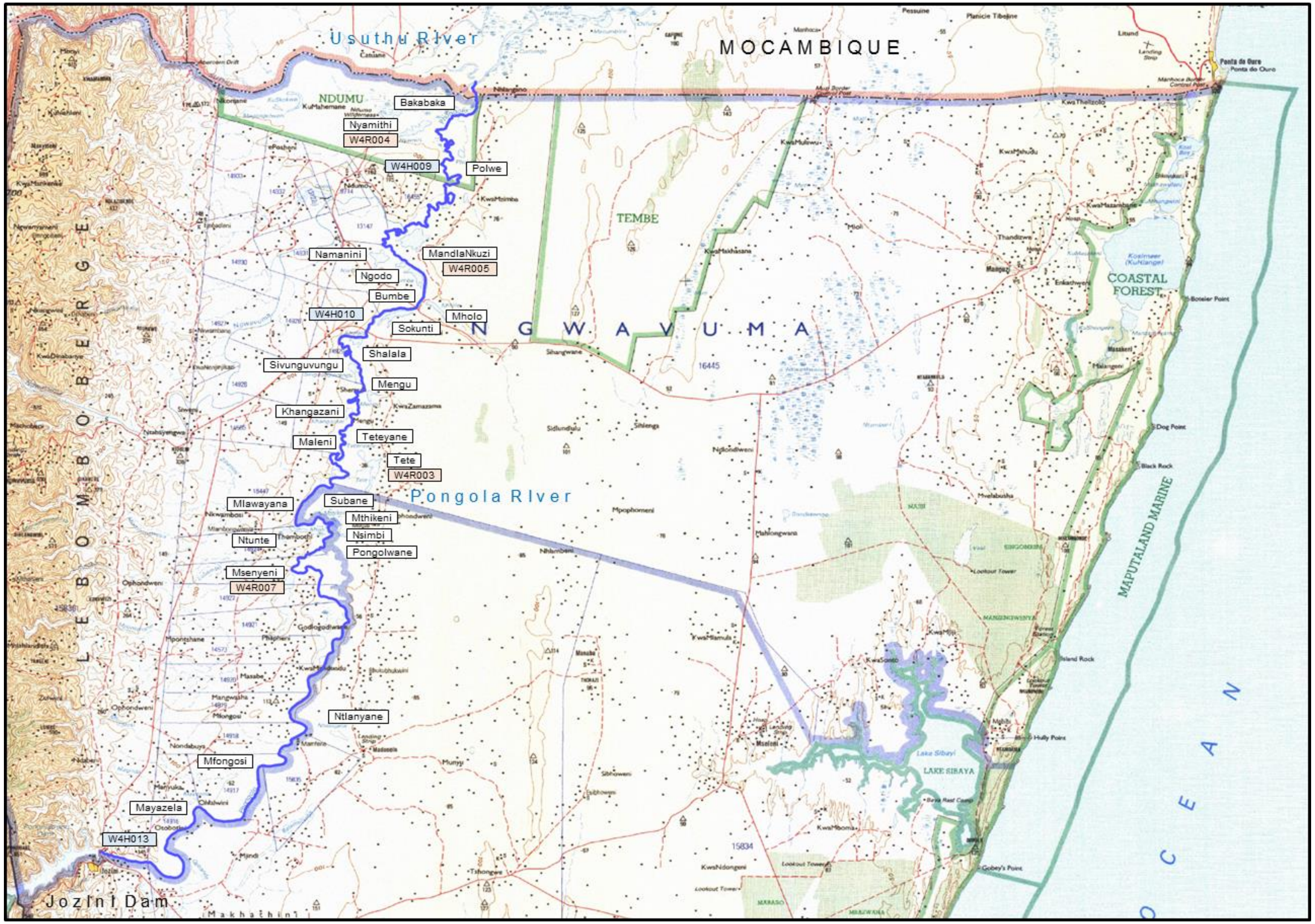

Figure 9.1 Location of the Pongola River and Floodplain in northern KwaZulu Natal showing the position of gauging stations (W4H0x and W4R0x - refer to Table 9-1) and major pans (refer to Table 9-2 and Appendix A).

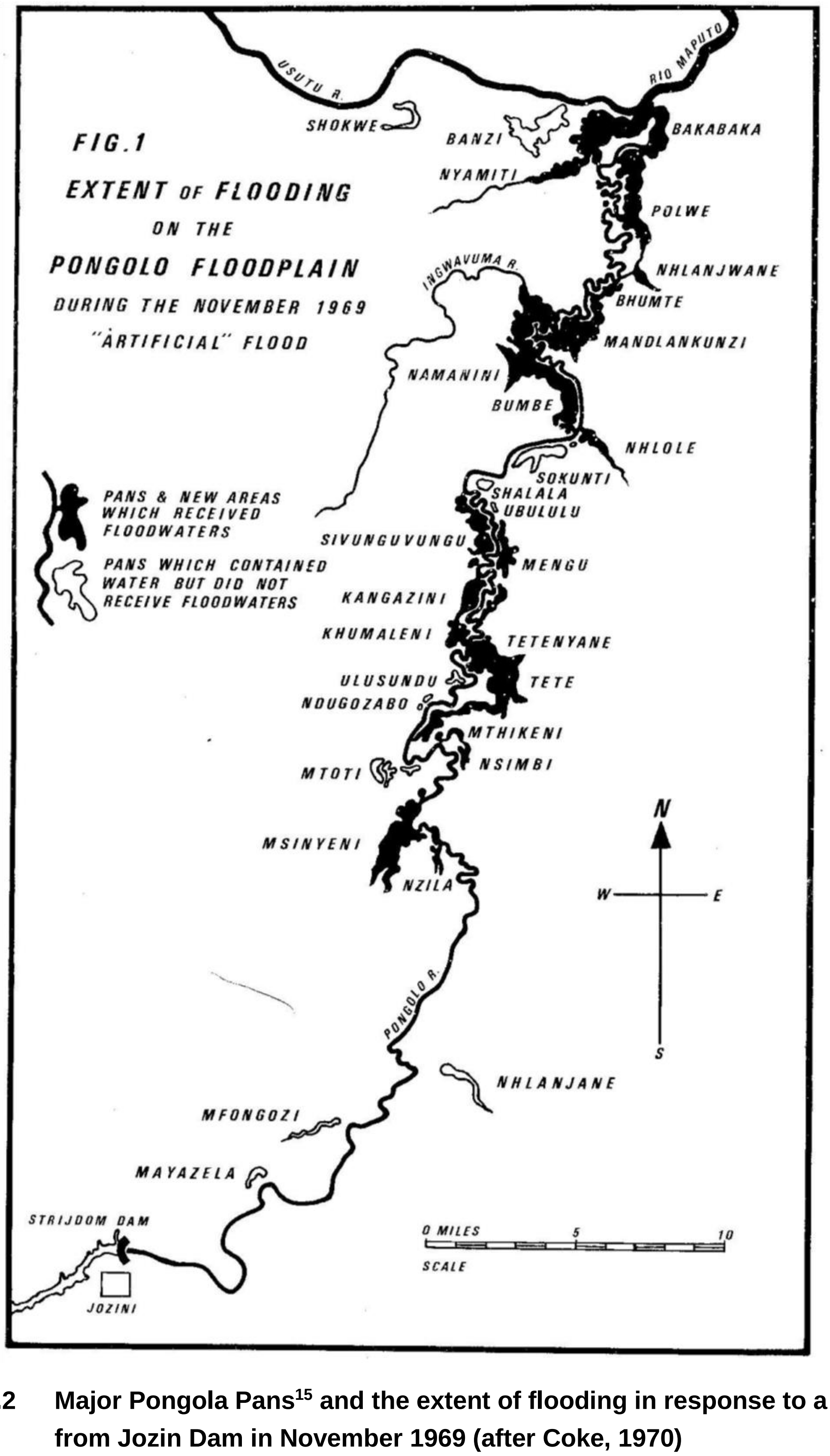

Figure 9.2 Major Pongola Pans[15] and the extent of flooding in response to a release from Jozin Dam in November 1969 (after Coke, 1970)

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15 names and spellings may vary from the more common ones used in this study; Jozini Dam was previously named Pongolapoort Dam and prior to that, Strijdom Dam

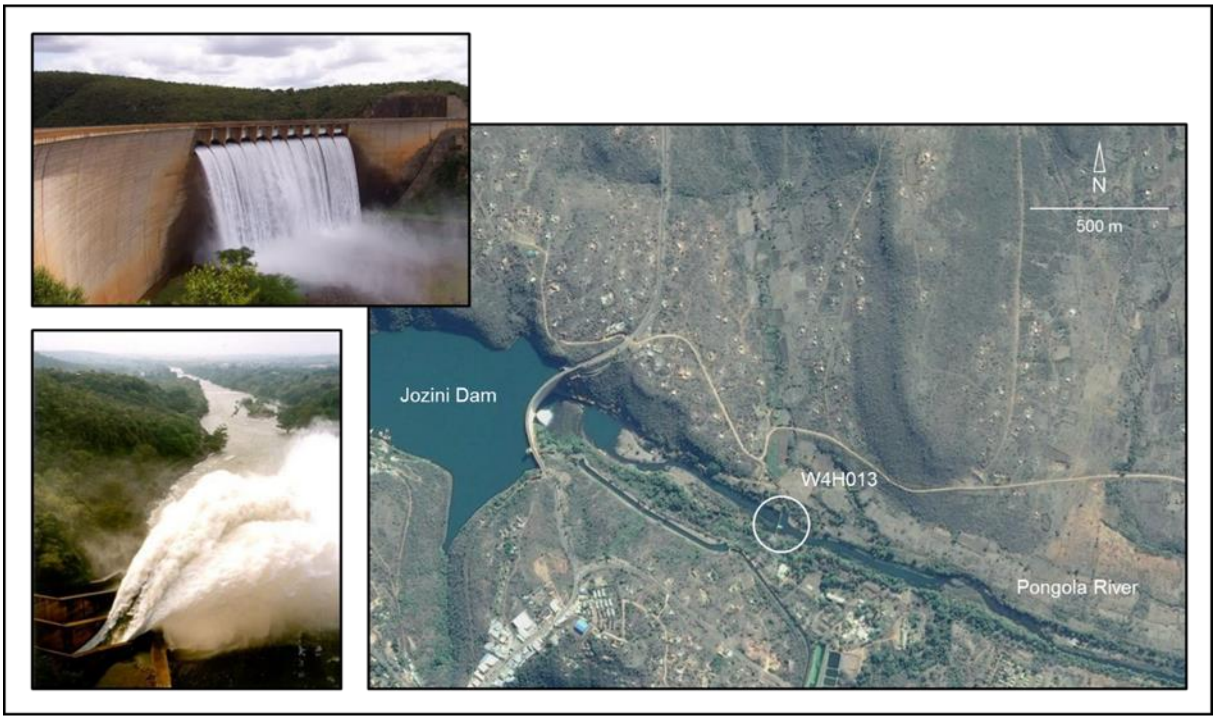

Figure 9.3 Satellite image (GE, July 2013) of the Jozini Dam Wall and downstream Pongola River. The inset photographs show (top) the dam spilling and (bottom, after *Basson et al.* 2006) a managed release. The position of the downstream gauging station (W4H013) is indicated.

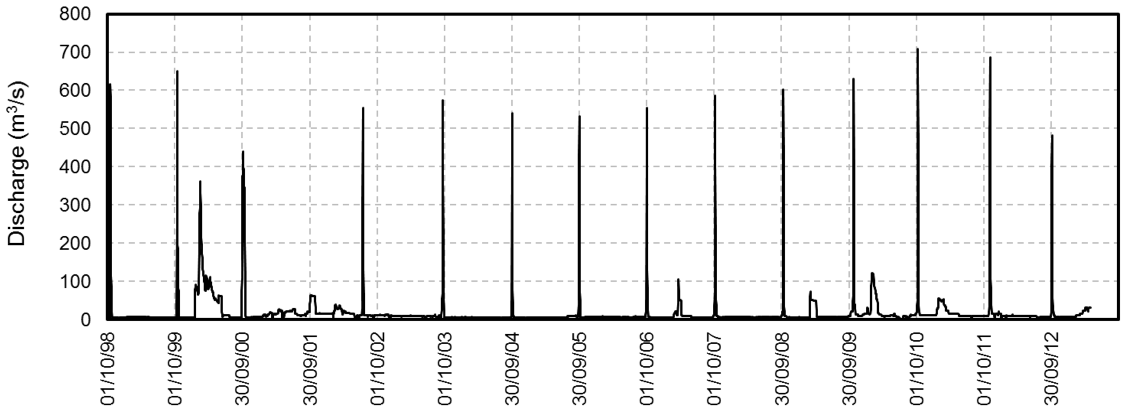

Figure 9.4 Plot of releases from Jozini Dam into the Pongola River gauged at Station W4H013 (refer to Figure 9.3), for the period 1998 to 2012

dam releases and resulting pan levels were used for calibration, but predictions tended to underestimate peaks and overestimate associated lag times by up to a few days. A one-dimensional hydrodynamic model (Mike 11) of the Pongola River and Floodplain was developed sixteen years later by Beck and Basson (2003), under the auspices of a Water Research Commission Project. The model was parameterised with cross-sections at *c.* 500 m intervals along the Pongola River, and hydraulic controls (channels and weirs) provided the connectivity between the active channel and major pans[16] (represented by storage areas). The simulated flood peak was overestimated by *c*. 0.5 m, and travelled through the system too fast by *c*. half a day.

Basson *et al.* (2006) followed-up their 2003 study three years later with linked 1d and 2d models (Mike 11 and 21C, respectively) for the upper[17] and lower Pongola Floodplain, respectively. Initial model setup involved the use of a curvilinear grid with higher spatial resolution covering the river channel. Simulations encountered instabilities that could not be resolved, however, and a rectilinear grid was ultimately used, with the upstream 18 km of the system modelled one-dimensionally using Mike 11. The grid size applied for the 2d analysis was 20 m (laterally) by 50 m (longitudinally).[18] The model was parameterised with topographical data from two sources: digitised cross-sections and contours from 1930's and 1950's maps, and bathymetric surveys during the 2004 release (refer to Section 9.2.2.1). The October 1986 release was used for calibration, and model performance was checked against measured data associated with releases in 1986, 2002 and 2005. Computational time for an event[19] was *c*. 24 hours.[20] Basson *et al.* (2006) give a predictive accuracy of *c*. 0.5 m for pan water levels, and less than one day[21] for the timing of peaks. Water level plots, however, indicate some substantially higher differences of up to *c*. 1.0 m.[22] Discrepancies were attributed to measurement errors and possible geomorphological changes are mentioned in reference to a 2.5 m difference in peak water level for the Msenyeni Pan in 1986. The calibrated model was also used for simulating hydrodynamic behaviour in response to different operational scenarios. These included different hydrograph peaks, volumes and shapes, as well as varying initial pans levels[23]. Key findings were the importance of peak duration and volume on pan inundation and [peak] discharge at the Mocambique Border; the minor influence of initial pan levels on the effectiveness of large-volume releases; and the widespread flooding associated with extreme events. Also noted was the sensitivity of model results to topography, with a vertical accuracy of *c*. 0.3 m suggested for future detailed surveys.

[16] and connections between pans
[17] to 18 km below Jozini Dam
[18] 625000 cells
[19] generally simulated over *c*. one week
[20] This would present difficulties for the present study, where simulations are required for at least a decade.
[21] Ostensibly, not exceeding one day
[22] 1.0 m at Tete (1986, 2005); 0.75 m at Nsimbi (1986); 0.75 m at MandlaNkuzi (2005)
[23] empty, 50% and at maximum retention level

Concomitant with advances in computing technology over the past three decades has been the development of multi-dimensional hydrodynamic models. For spatially extensive, topographically and hydraulically complex systems, such as the Pongola Floodplain, a model with advanced functionality is required. Consideration of available 2d models, both commercial and freeware[24], led to the selection of RMA2 for this study.

9.2 Two-dimensional hydrodynamic modelling using RMA2

9.2.1 Background

RMA2 is a 2d[25], depth-averaged, hydrodynamic model using finite elements, and is based on implicit solutions of the fully non-linear shallow water equations. It was developed by Norton *et al*, 1973 of Resource Management Associates, under contract with the USACE (Wurbs 1994). The model has been extended over the past four decades, and a version (together with pre- (CFGEN) and post-processors which are part of the TABS[26] numerical modelling system) is maintained by the Waterways Experiment Station (WES) Hydraulics Laboratory (Donnel 2011). A commercial version, with licensing, is also available (Resource Modelling Associates, King (2014)) that includes ongoing updates. [27] Pre- and post-processing software for RMA2 includes RMAGEN and RMAPLT, respectively.

RMA2 was one of the first multi-dimensional models widely used for modelling riverine and estuarine applications, and is a first generation hydrodynamics engine. Over the past three decades, a number of new computational engines have been developed, although earlier models such as RMA2 still receive frequent use. It is included in the well-known Surfacewater Modelling Systems (SMS) suite[28], and a selection of recent applications include Bruxer and Thompson (2008), Holtschlag (2009), Yin *et al.* (2010), Sammany and Moustafa (2011), Lee and Julien (2012) and Han (2014).

According to Jones (2011), the main drawbacks of the early computational engines are numerical instability, particularly when the application involves significant wetting and drying and relatively long run times. In this study, the King (2014) version of RMA2 was applied to the Pongola Floodplain, which is characterised by extreme wetting and drying of an extensive floodplain (*c*. 13000 ha)[29] through which a well-defined active channel flows (Figure 9.5 and Figure 9.6). The floodplain contains numerous pans (*c*. 150 pans were

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[24] Freeware models generally have reduced or limited functionality as well as spatial constraints, although more (*eg*. HECRAS v5) are being developed.
[25] and 1d
[26] acronym unknown
[27] as recent as January 2015
[28] http://www.xmswiki.com/xms/SMS:RMA2
[29] Heeg and Breen (1982) reported a floodplain area of 10 000 ha; Basson *et al.* (2006) give a higher value of 13 000 ha; this study, based on the national 25 m Digital Elevation Model (DEM) and aerial photographic coverage, delineated and modelled inundation within a (maximum) floodplain area of

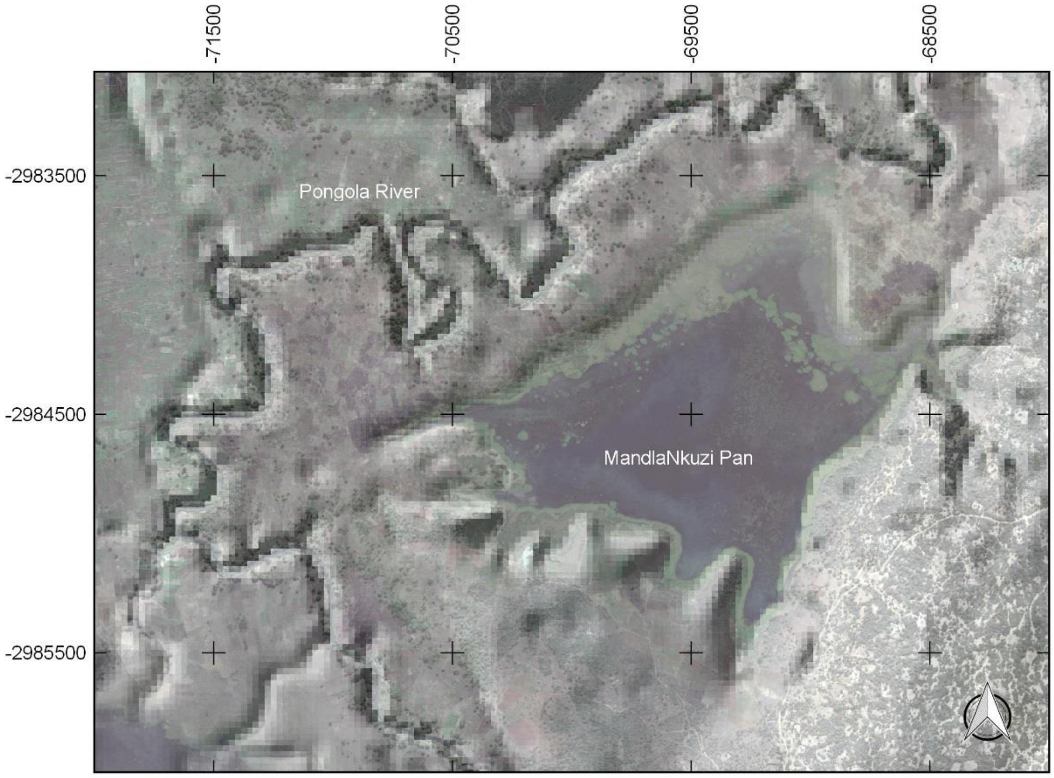

Figure 9.5 Satellite image (GE, August 2013) of the Pongola Floodplain draped over the national 25 m DEM, showing the well-defined meandering active channel (*c*. 15 m wide at this location), the MandlaNkuzi Pan and patchwork of agricultural fields in the floodplain (between the pan and channel). For spatial perspectives, refer to Figure 9.12 and Figure 9.13.

13 100 ha. The latter excludes floodplains and pans that are not directly flooded by the Pongola River (*eg*. Msunduzi and Shokwe).

Figure 9.6 Pongola River, riparian vegetation and agricultural fields in the adjacent floodplain (November 2014)

identified by La Hausse (1987[30]), which are generally connected to the Pongola River through small tributary and paleo channels that breach levees[31] adjacent to the active channel, as illustrated in Figure 9.7 and evidenced in the historic photographs of Figure 9.8. The pans are isolated from surface flow in the river during the low flow season with their water levels falling due to evapotranspiration losses[32]. The hydrodynamic modelling required simulation over a considerable discharge range[33], associated with rapid changes in flow due to managed releases from Jozini Dam under Present Day (PD) operation. Furthermore, simulations were needed for long periods of at least a decade. More commonly, multi-dimensional hydrodynamic models are used to simulate behaviour over much shorter periods such as hours or days, these being generally associated with isolated hydrological events.

Figure 9.7 Levee separating the active channel in the foreground and floodplain pan beyond (November 2014)

30 reproduced in the Appendix as it is the most comprehensive mapping and identification found, and is not readily available
31 naturally developed
32 Seepage losses could also occur, especially for pans located close to the active channel.
33 up to 850 m3/s for Present Day (PD) operation and higher under natural conditions

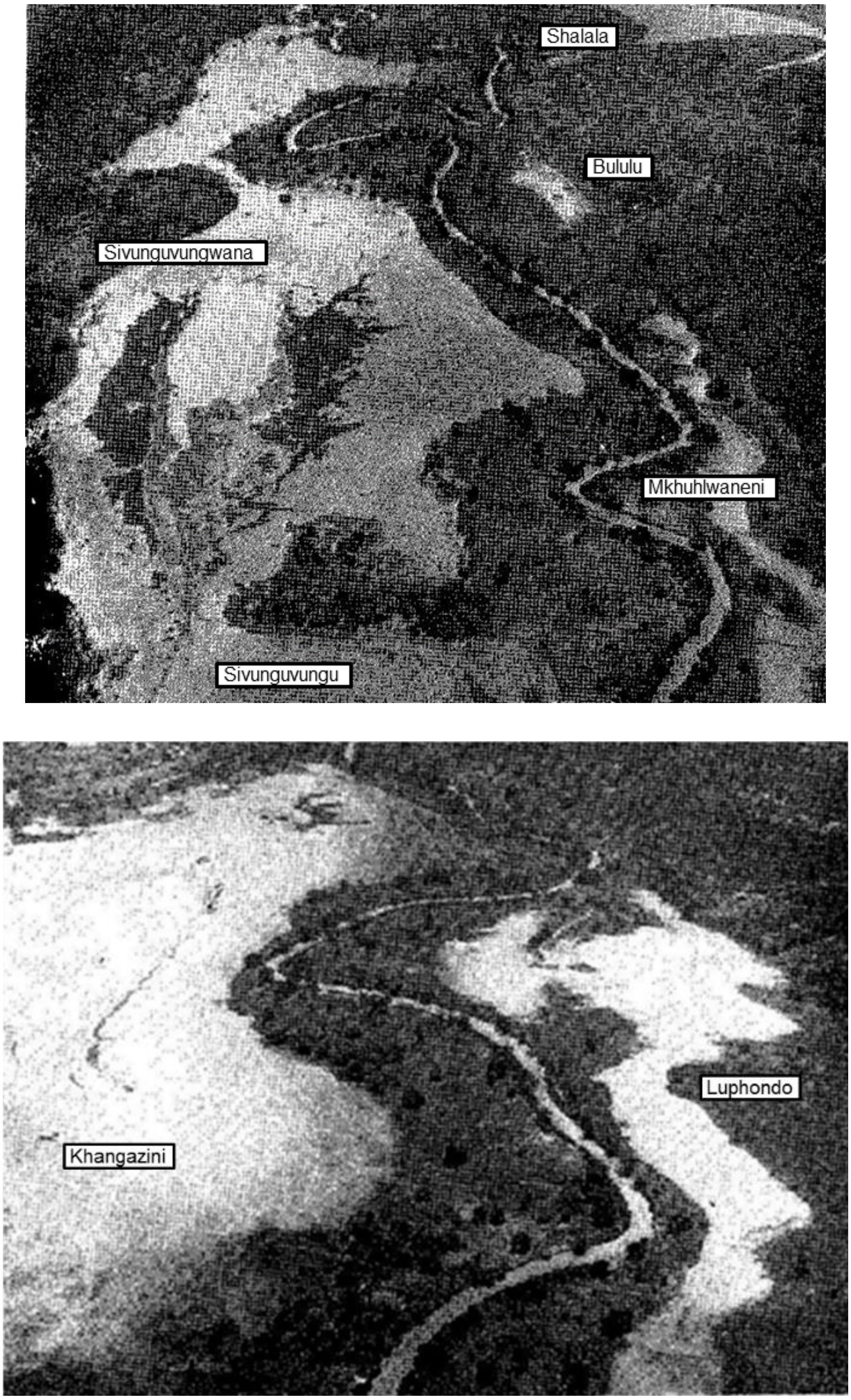

Figure 9.8 Historic aerial photographs taken obliquely looking downstream, showing floodplain inundation resulting from a managed release in November 1969 (*photos* M. Coke, after Phélines *et al*, 1973)

9.2.2 Available data

9.2.2.1 Topographical information

Accurate topographical data is essential to the development of a 2d hydrodynamic model, and two available data sources were used. The first of these is from the bathymetric longitudinal survey of the Pongola River bed carried out for the Basson *et al.* (2006) study. These topographical data were sourced directly from the Department of Water Affairs and Forestry (DWAF)[34], with the bathymetric portion needing to be extracted from the data set which also included floodplain topography. Whereas the Basson *et al.* (2006) study used digitised cross-sections and contours from topographical maps of the 1930's and 1950's, the current project used the national 25-m Digital Elevation Model (DEM)[35] available from National Geo-spatial Information (NGI) (Department of Rural Development and Reform)[36]. The standard error of the DEM is quoted as 1.2 m[37] and 2.5 m in flatter areas (NGI 2011). Figure 9.5 shows a section the floodplain where the active and paleo channels, raised levees, floodplain and the MandlaNkuzi Pan are clearly discernible. Based on such an appraisal of the relative topography, and the results of the Basson *et al.* (2006) study[38], the development of a hydrodynamic model with accuracy suitable for an environmental flow assessment, was deemed worth pursuing.

9.2.2.2 Discharge and stage observations

Available discharge and stage records were obtained from the DWS[39] for gauging stations along the Pongola River and in floodplain pans, and are listed in Table 9-1. Discharge at Station W4H013 is accurately gauged at a compound sharp-crested weir (Figure 9.9), which has been calibrated up to flows of *c.* 850 m^3/s using an Acoustic Doppler Profiler (ADP) (le Roux 2008). At the remaining six stations (examples of which are illustrated in Figure 9.9 and Figure 9.12), local gauge levels are recorded using data loggers, and these are converted to elevations relative to mean sea level (msl). An exception is at the Ndumo Station (W4H009), where levels are relative to the gauge datum. Records were also obtained for two stations along the Usuthu River from the Swaziland Department of Water Affairs.

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34 that performed the survey
35 In this study, synonymous with Digital Terrain Model (DTM). Since the DEM is obtained photogrametrically, the extent to which it represents a Digital Surface Model (DSM) which includes features such as vegetation, is unclear.
36 http://www.ngi.gov.za/
37 σ (one standard deviation)
38 although this study appears to have concentrated on flood peaks associated with individual releases and not extended sequences of floodplain wetting, drying and associated pan isolation from surface flow
39 https://www.dwa.gov.za/hydrology/

Table 9-1 Gauging stations in the Pongola Floodplain

Station Number	Location	Parameter	Location (dms)[40]		Record	
			Latitude (S)	Longitude (E)	from	to
Pongola River						
W4H013	Jozini Dam	Discharge	27 25 22	32 04 49	1983	2014
W4H010	Lake View	Stage	27 02 13	32 15 59	2003	2014
W4H009	Ndumo	Gauge	26 54 21	32 19 28	1975	2014
Pongola Pans						
W4R003	Tete	Stage	27 07 51	32 16 17	2001	2014
W4R004	Nyamithi	Stage	26 53 10	32 18 36	2000	2014
W4R005	MandlaNkuzi	Stage	26 58 38	32 18 36	2000	2014
W4R007	Msenyeni	Stage	27 13 01	32 12 24	2004	2014
Usuthu River						
GS6	Siphofaneni	Discharge	26 41 24	31 40 48	1958	2014
GS16	Usuthu Port	Discharge	26 48 00	32 00 00	1995	2014

Stage: relative to msl

Figure 9.9 Discharge gauging station W4H013 located downstream of the Jozini Dam Wall (refer to Figure 9.3; DWAF 2008).

[40] degrees minutes seconds

Figure 9.10 Stage gauge W4H010 attached to bridge pier at Lake View (M. Kempen, undated).

Figure 9.11 Water level gauge W4H009 (refer to Figure 9.13) in an active channel at Ndumo Game Reserve (M. Kempen, undated).

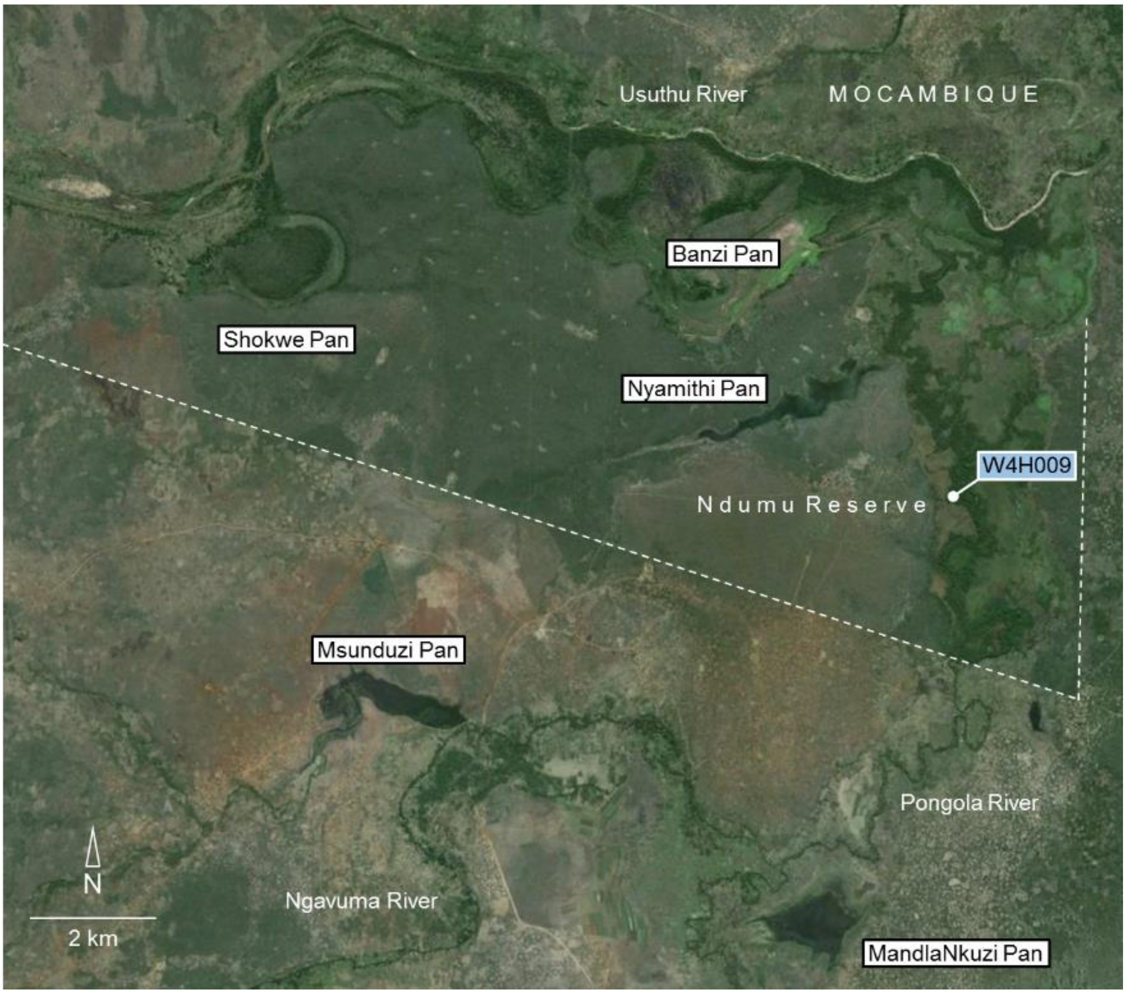
Figure 9.12 Stage gauges at the Tete (top) and MandlaNkuzi (bottom) Pans, and the boats used to access them (*photos* G. Marneweck, November 2014 and M. Kempen (inset, MandlaNkuzi Pan), undated (DWA 2012))

9.2.3 Model setup

The 2d hydrodynamic model developed in this study extends from upstream at the Jozini Dam Wall to the downstream confluence of the Pongola and Usuthu Rivers at the

Mocambique Border (Figure 9.1). It includes all floodplain areas that are directly inundated by flows along the Pongola River. The modelled area therefore excludes the Msunduzi and Shokwe Pans, with the latter associated with flooding along the Usuthu Floodplain (Figure 9.13).

Inundation of the lower Pongola Floodplain (including its pans and wetlands) in the Ndumo Game Reserve [41] is associated not only with flows in the Pongola River, but to a large extent with flows in the Usuthu River. This is clearly illustrated in Figure 9.14, which is a plot of recorded stage levels at two downstream gauging stations in the Pongola River: Lake View (W4H010) and Ndumo (W4H009). The short-duration October releases from Jozini Dam are obvious in the Lake View and Ndumo records, as are the longer-duration wet season releases at Lake View. Wet season releases are not as clearly identifiable, however, in the Ndumo record. Within the Ndumo Game Reserve, wet season inundation is substantially influenced by flows in the downstream Usuthu River.



[41] The Ndumu Game Reserve is a Ramsar site (wetlands of international importance)

Figure 9.13 Satellite image (GE, August 2013) of the lower Pongola Floodplain showing the Pongola and Usuthu Rivers, Ngavuma Tributary, selected pans, Ndumo Game Reserve and Gauge (W4H009).

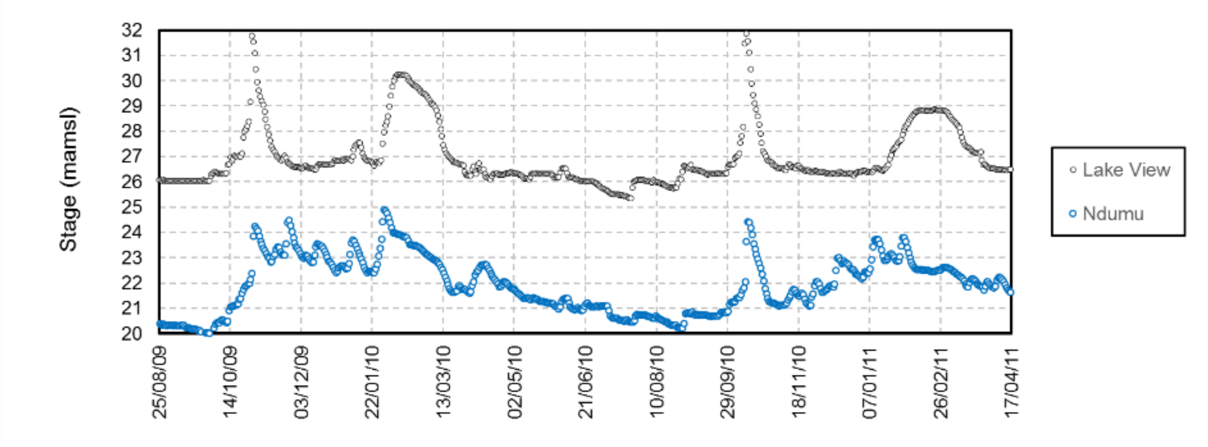


Figure 9.14 Monitored stage fluctuations at Lake View (W4H010) and Ndumo (W4H009) over the period August 2009 to March 2011, showing the influence of the Usuthu River flows in the downstream Ndumo record

9.2.3.1 Digital Elevation Modelling

As mentioned previously, the national (25 m) DEM was used for the Pongola Floodplain. Its spatial resolution is sufficient to allow mapping of the Pongola River by its locally reduced elevation, as illustrated in Figure 9.5. The bathymetric survey of the active channel, however, provides superior accuracy for the channel bed level, and this, together with measurements of channel width were used to characterise the longitudinal bed topography of the river.

9.2.3.2 Construction of a finite-element mesh and associated topographic elevations

The finite-element mesh (Figure 9.15) used in the hydrodynamic modelling was developed using a combination of software specifically coded in this study and Geographic Information Systems (GIS)[42]. The step-wise procedure was as follows:

- The thalweg for the Pongola River was digitised using the national 25 m DEM. This resulted in a channel polyline with 4769 vertices, which was manually smoothened[43] to 1294.
- Channel bed widths were measured using satellite photography, and varied from 50 m immediately downstream of the Jozini Dam Wall to 15 m at the confluence of the

[42] A combination of Quantum GIS (QGIS) (http://www.qgis.co.za/en/site/) and SAGA-GIS (http://www.saga-gis.org/en/index.html) were used.
[43] This was necessary to reduce the mesh density in the channel and by association in the floodplain adjacent to the channel.

Pongola and Usuthu Rivers. Trapezoidal channel cross-sectional shapes were applied, with maximum bank slopes of 45° over bank widths of 7.5 m[44] . In the model setup, levees are positioned adjacent to the river channel banks to allow these features to be included as quadrilateral elements (as for the channel, whereas triangular elements are used to characterise the highly variable floodplain topography, refer to Figure 9.15).[45] Software was developed to automate the setup of channel bed, bank and levee elements (and nodes), based on the channel centre-line position, and widths of the bed, bank and levees.

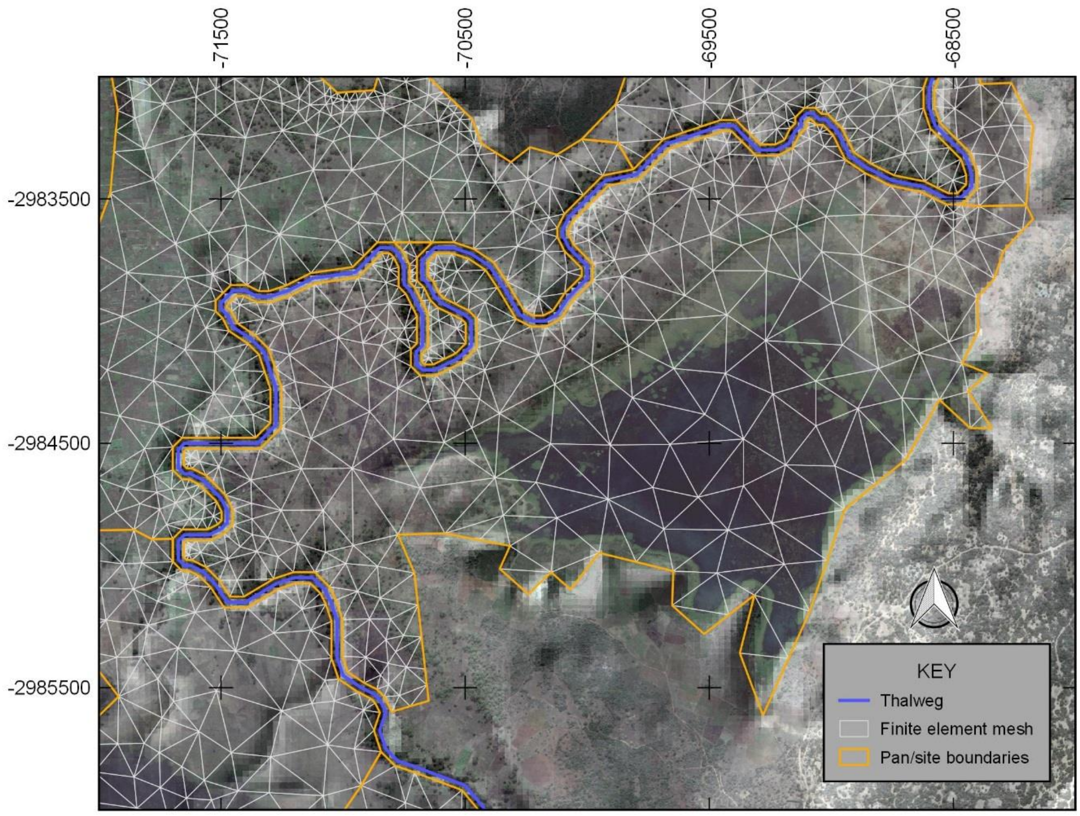


Figure 9.15 Finite element mesh for a section of the Pongola Floodplain shown superimposed on a satellite image (GE, August 2013) which is draped over the national 25 m DEM. The projected Coordinate Reference System (CRS) is Hartebeeshoek94/Lo33.

- The lateral floodplain extents were delineated using maximum recorded stages from the gauging stations (refer to Table 9-1) and the floodplain topography. Meshing of the floodplains was computed in QGIS using the Triangle software developed by

44 *ie*. the maximum channel depth is 7.5 m

45 Advantages of this approach are that it avoids the use of high mesh densities in the floodplain to characterise levee topography, and that these (quadrilateral) elements can receive special treatment in the (RMA2) analysis to act as flow controls. A disadvantage, however, is that the effective conveyance of the channel is artificially reduced.

Shewchuk (undated), available as the Basemesh Plugin for QGIS (Vetsch *et al* 2014). The meshing software produces conforming Delaunay triangles based on the polygon model boundary (floodplain and levee), breaklines used to align[46] mesh segments, holes within the mesh where elements are not required (*e.*g. elevated topographical features that are not flooded), conforming vertices (Steiner points) and restrictions on maximum element areas. The Basemesh software provides output as shapefiles and text files[47].

- Additional software was also developed to merge the quadrilateral elements forming the channel (bed, banks and levees) with the floodplain triangulation from the QGIS-Basemesh (Triangle) programs. The software (developed within this study) also assigns elevations to all nodes in the channel/floodplain mesh as follows:
  - bed elevations for the channel were assigned from the bathymetric survey[48];
  - levee elevations were assigned from the 25 m DEM: the topography within the triangular elements adjacent to the (top of the) channel banks were interrogated for locally elevated topographical features, and these elevations were assigned to the corner nodes forming levee elements; and
  - floodplain elevations were assigned from the 25 m DEM.
- Lastly, the finite-element mesh was written in text format (.rm1) that is loaded into RMAGEN for final RMA2 pre-processing.

9.2.3.3 Boundary and initial conditions

The boundary conditions used in the Pongola Floodplain model include:

- Daily discharge time-series at the upstream Pongola River model boundary, representing naturalised, PD and future scenario conditions.
- As discussed previously in reference to Figure 9.14, inundation of the Ndumo Floodplain is a function of flows in both the Pongola and Usuthu Rivers. For this reason, a rating (or stage-discharge) relationship has been applied at the downstream model boundary in the Usuthu River, immediately downstream of the confluence.
- Daily discharge time-series at the upstream Usuthu River model boundary.
- Daily discharge time-series from tributaries flowing into the Pongola Floodplain.
- Evapotranspiration from open water surfaces.

The elevation difference over the modelled area is *c*. 50 m, and the slope adjustment method in RMA2 was used to compute an initial (restart) condition from which transient (unsteady) simulations commence.

[46] The ability of Triangle and facility in Basemesh to align mesh segments to breaklines is important, since it is allows for mesh refinement in areas of variable topography and also to align mesh segments to flow lines (*c.* defined by contours).
[47] node and element
[48] Bathymetric survey points at variable spacing were assigned to the closest 25 m DEM cell (averaged for multiple assignments); linearly interpolated for missing elevations; and a 10-point centred-moving average used to smoothen the longitudinal variations. These variations were often substantial, ostensibly due to the bathymetric survey not following the channel thalweg during the flood release.

9.2.3.4 Floodplain wetting and drying and maximum retention levels in the pans

The marshing feature in RMA2 has been successfully used to model wetting and drying of the floodplain associated with flooding. Using this feature, when water levels fall below the ground surface, flow occurs in the low porosity groundwater zone. Pans are isolated[49] from surface flow in the river when stages fall below invert levels which are the hydraulic controls determining connectivity between the river and pans. Maximum (pan) retention levels (MRL) are defined by the point of disconnection.

9.2.4 Model calibration and verification

9.2.4.1 Description of calibration process

The model was calibrated using measured stages at the two gauged locations in the river channel (*viz.* Lake View and Ndumo) and from the four pan locations (*viz*. Msenyeni, Tete, MandlaNkuzi and Nyamithi), refer to Table 9-1. Measurement-based data was used as far as possible for model calibration, including daily discharge time-series:

- from Station W4H013 below Jozini Dam, and
- from Stations GS6 or GS16 in Swaziland.

The parameter values for the following variables were determined as part of the calibration:

- flow resistance as a function of depth
- turbulence parameters[50],
- marshing parameters[51],
- depth[52] for element elimination/addition, and
- evapotranspiration.

For the above four pans with continuous water level recorders, MRL were determined from the recession limbs of the stage hydrographs (refer to Figure 9.16), and invert levels were adjusted as part of the calibration procedure.[53] For the remaining pans, MRL were determined by vegetation mapping using high resolution aerial and satellite imagery as well as ground-truthing.[54] The floodplain was delineated into 56 areas (or sites) based mainly on the presence of 30 major named pans from the literature (Phélines *et al*, 1973; Heeg and

[49] In the modelling, this is done by dropping levee-type quadrilateral elements from the solution procedure when water levels fall below ground level. This depth below ground level needs to be small to effectively isolate ponded pans from river flow. Applying this to all floodplain elements, however, resulted in a degree of cyclic behaviour under certain conditions (*c*. steady flows) due to successive (modelled) wetting and drying of elements. This was largely addressed by increasing the effective groundwater depth for floodplain elements.
[50] Smagorinsky turbulence closure was used with $\alpha = 0.2$ and a minimum kinematic viscosity of 1 m^2/s.
[51] Maximum depth of groundwater, depth of transition into flow in the low porosity zone and the associated porosity value (refer to Donnel, 2011; King, 2014)
[52] below ground surface
[53] since the DEM is not sufficiently accurate
[54] G. Marneweck *pers com*

Breen, 1982). The model thus consists of the active channel and 56 adjacent and contiguous floodplain areas, most of which contain well-defined pans (*e.*g. the MandlaNkuzi Pan in Figure 9.15).

The flow resistance values (Manning's n) used in the model were 0.030 and 0.040 for the river channel and floodplain, respectively. These were increased ten-fold to maximum values of 0.30 and 0.40 at ground level for depths below 0.40 m. For levee-type and certain floodplain elements used to isolate floodplain areas from surface water in the river, drying and wetting depths of 0.2 m and 0.1 m, respectively, were used. For the remaining floodplain elements, substantially higher values were used (5 m and 3 m, respectively) to dampen instabilities found to result from cyclical wetting and drying of floodplain elements associated with *c*. steady conditions. The extent to which the hydrodynamic modelling was required to simulate episodic wetting and drying of an extensive floodplain is illustrated by the range of inundation modelled: between *c*. 17[55] and 111 km^2.

The relatively recent three-year period October 2008 to September 2010 was used for model calibration and verification, since it contains six events of varying magnitude: three were artificial end-of-dry season releases of up to *c*. 630 m^3/s (daily average), and the remaining were wet season releases between *c*. 50 m^3/s and 120 m^3/s. The first year was used for calibration and the remaining to assess model performance. This three-year period also provides reliable stage measurements compared with prior and more recent times: the gauging of historical water levels in the floodplain has been challenging for the DWS, due to vandalism of equipment and the removal of fixed stations[56] for agriculture (M. Kempen, *pers com*).

Figure 9.16 shows comparative plots of modelled (calibration and verification) and measured stage hydrographs for the six gauged locations along the Pongola River and in the floodplain pans. Generally, good replications have been achieved in terms of peaks, rising and recession limbs when the river and pans are connected, recession of ponded levels in the pans, and low flow stages in the river. A constant evapotranspiration rate of 4.0 mm is shown to produce satisfactory drawdown results, and is almost identical to the WR2005 annual average of 4.1 mm for this region. For the Tete Pan, the MRL is lower[57] after the October releases than following wet season inundation. A possible reason is due to increased vegetation cover during the naturally wet period, which could act to elevate the effective invert level through higher flow resistance and obstruction of return flow. Measured stage recessions in the pans (Tete, MandlaNkuzi and Nyamithi) all indicate rises in August 2009, which are attributed to inflows from the adjacent catchments and intercepted rainfall[58].

[55] *c*. half this value is water retained in wetland areas of the northern Ndumu Reserve and the balance is made up of pans
[56] required for fixing elevation datums at gauge stations
[57] by *c*. 25 cm
[58] 60.3 mm over two days as measured at Jozini

Flows from adjacent catchments, many of which enter the Pongola River through pans[59], were modelled hydrologically at a monthly time-scale.[60] These estimates appeared to be of insufficient accuracy, however, to be meaningfully applied as pan inflows, and were rather specified as direct river inflows. The modelled and measured low flow stages in the Pongola

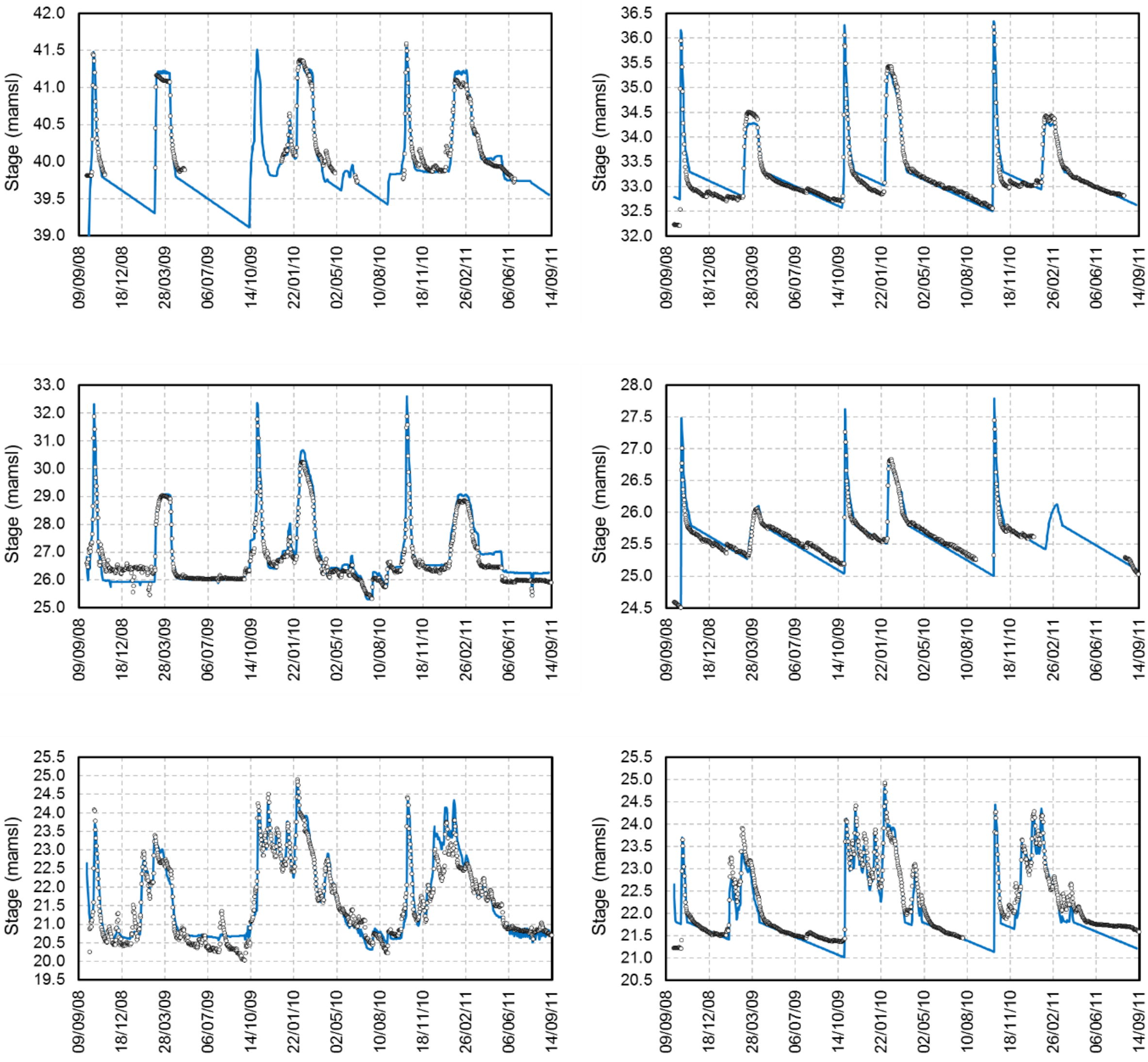


Figure 9.16 Measured (black markers) and modelled (blue-shaded lines) stage fluctuations for the gauged locations along the Pongola River and in the pans: row-wise from top-left to bottom-right: Msenyeni Pan, Tete Pan, Lake View (River), MandlaNkuzi Pan, Ndumo (River) and Nyamithi Pan.

River at Lake View differ by *c*. 0.5 m for the periods December 2008 to March 2009, and after April 2011. These deviations are attributed mainly to temporal changes in the hydraulic

[59] Pans that receive flows from the adjacent catchment (small tributaries or drainage lines) include Mayazela, Mfongozi, Mholo, Mzinyeni, Ntlanyane, Ntunte, Nyamithi, Pongolwane and Tete.
[60] disaggregated to provide a daily time-series

behaviour of the low flow channel. For example, preceding the March 2009 release, a discharge of *c*. 6.3 m^3/s resulted in an average stage of *c*. 26.5 m, whereas following the release, *c*. 7 m^3/s produced a stage *c*. 0.5 m lower.

The RMA2 model was found to run reasonably efficiently: for the 22470 mesh elements in the model[61], the one-year calibration simulation took *c*. 3 hours. The default time-step used in the simulations was *c*. 4 hours, which is targeted at the dry season when changes are gradual: flow is confined to the active channel and the floodplain pans are ponded. Variable time-steps (down to as low as 1 second) were permitted when convergence was not achieved within 10 iterations. Convergence criteria were reasonably severe: 5 mm/s for velocity and 0.1 mm for water surface computations.

The previous studies of Phélines *et al.* (1973), Heeg and Breen (1982) and Basson *et al.* (2006) have all contributed estimates of discharges required to inundate the major Pongola Pans. These values have been used in subsequent studies such as that of Lankford (2010) in the development of relationships between discharge and flooded area. A compilation of these previous estimates, together with those from this study, is provided in Table 9-2. Phélines *et al.* (1973) and Heeg and Breen (1982) provide measurement-based estimates, whilst the more recent studies involved modelling[62]. The estimates of Heeg and Breen (1982) are provided as ranges, since initiation of pan filling was noted not to have occurred at the lower discharge, but took place at the higher value. It is likely that discharge estimates of Heeg and Breen (1982) incorporate previous estimates of Phélines *et al.* (1973), although this is not clear.

Values from the two modelling studies are reasonably similar, although this (RMA2) study indicates generally higher discharges that are closer to those suggested by Heeg and Breen (1982). Exceptions are, however, for the Sokunti and MandlaNkuzi Pans. For the latter, however, initiation of pan filling (from this study) agrees with a gauged steady release. It worth noting that geomorphological changes have taken place since the dam was commissioned.[63] Fluvial modifications have been brought about through dam closure and also the regular October flood releases of almost two decades, whose peaks exceed annual events (close to a 1:5 year return period, Phélines *et al,* 1973). These are likely to have altered the hydraulic behaviour, and differences in discharge estimates, over time, are not unexpected. This, together with modelling uncertainties dictate that the results of this hydrodynamic study, and the broader flow assessment, should it be implemented, needs to be done within a framework of adaptive management that involves monitoring.

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[61] 18456 nodes and up to *c*. 110000 equations
[62] calibrated based on available information at the time
[63] Basson *et al.* (2006) note that for 80 kms analysed, the Pongola River has on average narrowed by 35%, with the greatest changes having taken place closest to the dam wall. They also state that the river bed near the wall has degraded since construction of the dam.

The study of Phélines *et al.* (1973) indicated that flood peaks of *c*. 120 m^3/s with three-day durations would be sufficient to replenish most of the pans. Heeg and Breen (1982) do not specify (peak) discharges *per se*, but identify the pans that require flooding at different times of the wet season (refer to Section 9.2.5.3 for a detailed description). The RMA2 study[64] provides the basis for estimating the releases to achieve Heeg and Breen's (1982) suggested "ecological flow release regime" (e.g. releases of different magnitudes were tested to ensure that the flooded the pans stipulated in Heeg and Breed (1982). Perhaps more importantly (since these discharge-duration estimates existed prior to this study), it allowed changes in hydraulic behaviour, associated with different release patterns (*viz,* scenarios - refer to Section 9.2.5.3), to be quantified.

Table 9-2 Discharges required to inundate major pans of the Pongola Floodplain, from various sources and this study

Floodplain pan[65]	**Discharge (m^3/s)**			
	Phélines *et al*, 1973	Breen and Heeg, 1982	Basson *et al*. 2006	RMA2[66]
Mayazela	430	300		200
Mfongosi	430	300		100
Ntlanyane	430	300	20	200
Msenyeni	15	0-7	20	15
Pongolwane		142-198		50
Nsimbi	85	85-142	40	50
Mthikeni	85	57-85		50
Ntunte		85-142		50
Mlawayana		85-142		40
Subane		57-85		40
Tete	70	28-57	30	30
Teteyane		28-57		30
Maleni	85	57-85	35	50
Khangazani	80	57-85	50	75
Mengu	85	57-85	45	50
Sivunguvungu	80	57-85	40	40
Shalala	100	142-198	50	75
Sokunti	100	28-57	60	75
Mholo		85-142		75
Bumbe	30	7-28		35
Ngodo	30	7-28		35
Namanini	25	7-28	65	35
MandlaNkuzi	80	57-85	70	50
Polwe		57-85		*

[64] and also considering previous estimates, as given in Table 9-2
[65] listed in a downstream progression (south to north)
[66] *ie*. this study

Floodplain pan[65]	Discharge (m³/s)			
	Phélines *et al*, 1973	Breen and Heeg, 1982	Basson *et al*. 2006	RMA2[66]
Nyamithi		57-85		75
Bakabaka		57-85		*

* these are also dependent on Usuthu River flows; the topographical data is too coarse in the lower Pongola (Ndumo Floodplain) to provide reasonable estimates

9.2.4.2 Recent changes in the hydraulic behaviour of the Ndumo Floodplain

The Ndumo Floodplain is characterised by pans, extensive wetlands and riparian forest. Major pans connected to the Usuthu River are the Shokwe and Banzi, whereas those adjacent to the Pongola River are the Polwe, Nyamithi, Bakabaka and Ndwanini. Numerous smaller pans were mapped by La Hausse, 1987 (refer to Section 1.6.1, Appendix). It needs to be re-emphasized that the Ndumo Wetlands and Pans[67] respond to flows in both the Pongola and Usuthu Rivers. Modelling indicates that the Usuthu River's backwater influence during high flows extends upstream[68] of the Ndumo Game Reserve .

Concrete weirs were constructed downstream of the Banzi[69] and Nyamithi[70] Pans and although the latter structure is intact, the Banzi Weir is breached[71]. Associated with this, is the so-called "Lower Usuthu Breach", where this river broke its southern bank diverting flows through the Banzi Pan and into the Pongola River (Figure 9.17). Due to international implications[72], a number of studies have investigated possible causes for the breach and its remediation (Wadeson 2006; Anderson 2009; Basson 2011 and SALOMON LDA 2010 and 2011)[73]. As of November 2014, the Lower Usuthu Breach continued to divert flows through the Banzi Pan.[74] Figure 9.18 shows the incised active channels and riparian forest immediately downstream of the Banzi Pan. A key finding of the geomorphological scoping study of the Lower Usuthu Breach (Wadeson 2006) is the naturally unstable characteristic of the Usuthu River. Frequent channel change was evidenced from paleo channels, but upstream catchment conditions were seen to be responsible for accelerated instability.

The influence of the Usuthu River flows on the Pongola Floodplain is therefore even greater than pre-breach conditions. For this study, however, insufficient topographic data were available during model setup to include the Usuthu River from its breach position to the

[67] An exception is the Shokwe Pan, which is not connected to the Pongola River.
[68] as much as *c*. 4 km (active channel distance) to the KwaBumbe Pan, when the Usuthu River is flooding but not the Pongola River
[69] date unknown
[70] 1983 (Whittington *et al*, 2013)
[71] date unknown
[72] The Usuthu River forms a stretch of the southern border between South Africa and Mocambique.
[73] In August 2005, the Government of Mozambique reported to the Government of South Africa a drastic reduction of flow along the Usuthu River in the Catuane area. They agreed at that time that the pre-breach situation should be restored.
[74] A temporary berm constructed in 2007 was washed away during the next wet season (SALOMON LDA, 2010)

Pongola River confluence.[75] The southern wetlands in the Ndumo Game Reserve have been impacted[76] by the severe reduction in wet season flows (Figure 9.19), and are frequently inundated for only a few days each year during the October release. This impact is expected, since the ameliorating influence of the Usuthu River reduces with increased distance from the Usuthu Confluence.[77] Given the above, it is clear that the future ecological (and potentially, Ramsar) status of the Ndumo Floodplain system depends not only on Pongola River releases, but on limiting the impact of future water resource developments along the Usuthu River in Swaziland.[78]

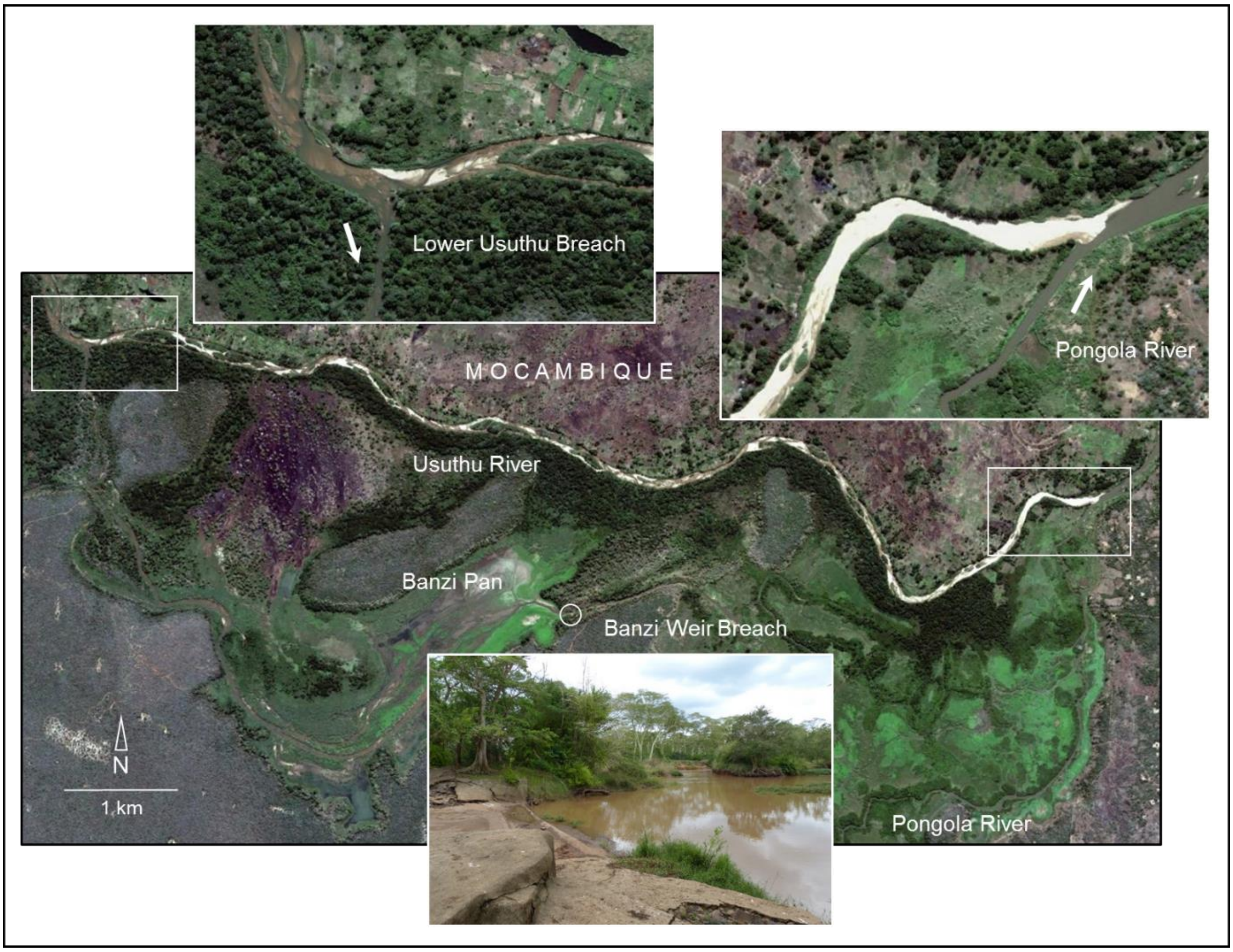

Figure 9.17 Satellite image (GE, August 2013) of the northern Ndumo Game Reserve showing the Lower Usuthu Breach, Banzi Weir Breach, dewatered section of the Usuthu River and return path into the Usuthu River (November 2014).

[75] The existence was found in March 2015 of a LiDAR survey for the Usuthu River and adjacent wetlands and pans in the Ndumu Reserve.
[76] G. Marneweck *pers com*
[77] or post-breach, where the diverted flows enter the Pongola River further upstream
[78] not addressed in this study

Figure 9.18 Active channels in the Ndumo Game Reserve downstream of Banzi Pan, through which the redirected Usuthu River flows. Note the exposed roots of the riparian forest trees (November 2014)

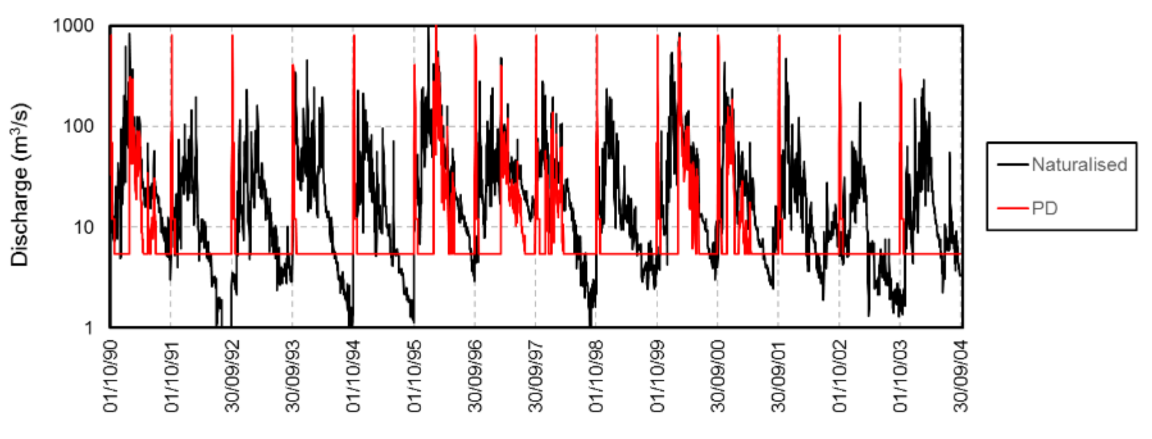

Figure 9.19 Daily discharge time-series under naturalised and PD conditions, plotted for the period October 1990 to September 2004 (logarithmic discharge scale used for ease of comparison)

9.2.4.3 Model refinement

The calibrated RMA2 model was subsequently applied to simulate floodplain response to different management options, and these are presented in Section 9.2.5.3, following. Before discussing these, however, two potential refinements to the modelling are suggested:

- Two-dimensional modelling of topographically and hydraulically complex floodplain system, such as the Pongola, requires an accurate DEM. The national 25 m DEM for the floodplain, augmented with bathymetric survey data for the active channel, was used in this study. Any further sensible improvements to the modelling would require a more accurate floodplain survey, such as that provided by LiDAR. Recently[79], the existence of LiDAR survey data for the Usuthu River and adjacent wetlands and pans[80] was noted, but these post-dated use in this project. The need for a more accurate survey was also recommended by Basson *et al.* (2006) (refer to Section 9.1).
- Monitored stage fluctuations, in response to regulated release patterns for additional major pans would improve calibration. This could be achieved by using temporary (inexpensive) loggers for the duration of dam releases.

9.2.5 Model application

The model was firstly applied to simulate hydraulic behaviour under naturalised conditions as well as for PD operation of Jozini Dam. Essential to these simulations is the provision of discharge time-series.

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[79] March 2015

[80] ostensibly associated with the Lower Usuthu Breach

9.2.5.1 Discharge time-series

Discharge time-series were provided by Aurecon (Pty) Ltd (DWS 2015) for naturalised and PD conditions (Figure 9.19), as well as for potential future scenarios that include all water resource demands from the dam (agricultural, inter-catchment transfers, irrigation and municipal/domestic). These were coupled with four different high flow release patterns for the downstream floodplain (refer to Section 9.2.5.3). Simulations were based on monthly modelling using the Water Resources Yield Model (WRYM) inherited from the PRIMA IAAP 10 Study (TPTC 2011)[81]. Naturalised monthly discharges were disaggregated for hydrodynamic modelling using historic gauge data from the upstream catchment. For PD and future scenarios, MODSIM was used to simulate daily releases from Jozini Dam.

The simulated time-series extends from 1951 to 2004, but this period was reduced to the most recent 15 years for hydrodynamic simulations, giving more acceptable run times of *c*. 24 hours.

9.2.5.2 Post processing RMA2 results for analyses in the DRIFT DSS

The standard output from a RMA2 simulation is a binary results file that may be loaded into RMAPLT for graphical displays and post-processing. The large spatial extent of the Pongola Floodplain, length of record simulated and number of time-series analysed (natural, PD and seven scenarios), meant that it was effective (and necessary) to develop software to automate the post-processing of RMA2 results for further analysis in the DRIFT DSS.

In addition to the binary output file, a results file[82] for selected floodplain nodes was created. For each of the 56 contiguous floodplain sites (which include the major pans in Table 9-2), site-specific 25 m DEM data were generated[83]. These were combined with stage levels to compute 56 site-specific geometric data files, with each containing tabulated relationships between stage and:

- floodplain and pan/s, inundated:
  - volume,
  - area,
  - average depth,
  - area with depth range 0.2 m to 0.6m;
- floodplain, inundated:
  - area;
  - area with depth range 0.2 m to 1.0 m;
- pan/s, inundated:
  - area,
  - average depth,

[81] TPTC refined streamflows from the Joint Maputo Basin Water Resources Study (JMBRS)
[82] in ASCII text format
[83] in xyz and site name format

- area with depth range 1.0 m to 1.5 m,
- area with depth range greater than 1.0 m.

Geometric data relationships were then combined with daily time-series of modelled stages (for selected nodes per site) to generate site-specific time-series for each of the ten parameters listed above. Example excerpts from the results files, which are the hydrodynamic basis for further analyses in DRIFT, are given in Appendix B. Maximum retention levels for the pans provide the vertical delineation between pan and combined pan/floodplain inundation, discussed previously in Section 9.2.4.1. The depth ranges (or classes) used were identified as constituting critical (hydraulic) habitat for indicator vegetation species and/or fish guilds.

9.2.5.3 Scenarios

Seven potential future water use scenarios were constructed and their time-series of daily releases from the Jozini Dam modelled by Aurecon (DWS 2015). These are explained in Section 11.

The hydrodynamic model was used to simulate downstream inundation for each of these seven hydrological scenarios, with tributary and Usuthu River flows maintained at the present day (2014) situation. Post processing of RMA2 results for analyses in DRIFT was as for naturalised and present day conditions (refer to Section 9.2.5.2).

9.3 Ecohydraulics of the river site

No hydraulics were computed for the river site (Pongola River 1). The response curves that were created linked directly to flow. As part of the process of constructing the curves, however, the hydrodynamic model described above was used to determine bankful discharge for the river near Tete Pan.

10 DRIFT INDICATORS

DRIFT makes use of a series of hydrological, hydraulic, ecosystem and social indicators to capture the response to the river ecosystem to flow change. This section lists those used in this EWR assessment, and provides comment on, and reasons for the selection of, each indicator.

10.1 Hydrological and hydraulic indicators

The flow and hydraulic indicators calculated are provided in Table 10-1. The relevant site specific summaries: naturalised and baseline are provided in Sections 13 to 17.

Table 10-1 Flow and hydraulic indicators calculated for the baseline and scenario hydrology

Code	Indicator	Units	River	Floodplain/ pans
Mean annual runoff	Mean Annual Runoff	m^3/s	X	
Dry onset	Dry Season Stage: Onset	weeks	X	X
Dry Min 5d stage	Dry Season Stage: Minimum 5-day	m^3/s	X	X
Dry duration	Dry Season Stage: Duration	days		X
Wet onset	Wet Season onset	weeks	X	X
Wet duration	Wet Season Stage: Duration	days		X
Wet Max 5d stage / Q	Wet Season Stage: Maximum 5-day	m^3/s		X
W/Ann: sum Days (F)		days		X
W/Ann: Freq FP cross (V) thold 0.2-1	Wet: Frequency per season of up- crossings in to 0.2-1 m depth on floodplain	count		X
W/Ann: Days FP depth 0.2-1 (V)	Wet: Number of up-crossings into the 0.2-1 m depth range	count		X
ann: mean Pan area 1-1.5 m	Annual: Mean pan area with a depth between 1 and 1.5 m	m^2		X
ann: mean Duration Oct exp		days		X
annl: mean Onset Oct exp	Annual: Onset of the recession after the 'October' flood	weeks		X
Dry: mean FParea	Dry: Mean floodplain area	m^2		X
Dry: mean Pan area	Dry: Mean pan area	m^2		X
Dry: mean Pan area 1-1.5 m	Dry: Mean pan area with a depth between 1 and 1.5 m	m^2		X
Dry: mean Pan area GT 1m	Dry: Mean pan area with a depth > 1.0 m	m^2		X

Code	Indicator	Units	River	Floodplain/ pans
Dry: mean Pan depth	Dry: mean pan depth	m		X
T1: mean FP & Pan depth	Transitional 1: Mean pan and floodplain depth	m		X
T1: mean FParea	Transitional 1: Mean floodplain area	m^2		X
T1: mean Pan area	Transitional 1: Mean pan area	m^2		X
T1: mean Pan area 1-1.5 m	Transitional 1: Mean pan area with a depth between 1 and 1.5 m	m^2		X
T1: mean Pan depth	Transitional 1: Mean pan depth	m		X
T2: mean FP & Pan depth	Transitional 2: Mean pan and floodplain depth	m		X
T2: mean FParea	Transitional 2: Mean floodplain area	m^2		X
T2: mean Pan area	Transitional 2: Mean pan area	m^2		X
T2: mean Pan area 1-1.5 m	Transitional 2: Mean pan area with a depth between 1 and 1.5 m	m^2		X
T2: mean Pan depth	Transitional 2: Mean pan depth	m		X
W/Ann: Days FP depth 0.2-1 (V)	Annual: Days when the water on the floodplain was between 0.2 and 1 m deep.	days		X
W/Ann: Freq FP cross (V) thold 0.2-1	Annual: Number of up-crossings past a threshold of 0.2 m.	count		X
W/Ann: Frequ connected (F)	Annual: Number of separate connections between river and pan.	count		X
W/Ann: sum Days (F)	Annual: Number of days for which there was water on the floodplain.	days		X
W: FP & P area 0.2-0.6 m	Wet: Area of floodplain and pan with a water depth of between 0.2 and 0.6 m.	m^2		X
W: FP area 0.2-1 m	Wet: Area of floodplain with a water depth of between 0.2 and 1 m.	m^2		X
W: Pan area GT 1m	Dry: Mean pan area with a depth > 1.0 m.	m^2		X
Wet Max 5d stage / Q	Wet: mean stage in pans.	m		X
Wet/Ann: Onset ext FP flooding	Annual/Wet: Onset of floodplain flooding (outside of the pans).	weeks		X
Wet: FP & Pan depth	Wet: Mean pan and floodplain depth	m		X
Wet: mean FP & Pan area	Wet: Mean pan and floodplain area	m^2		X
Wet: Mean FP & Pan vol	Wet: Mean pan and floodplain volume	m^3		X
Wet: mean FP area	Wet: Mean floodplain area	m^2		X
Wet: mean Pan area	Wet: Mean pan area	m^2		X
Wet: mean Pan depth	Wet: Mean pan depth	m		X

10.2 Ecosystem indicators

The ecosystem indicators used in this assessment, and the areas of the floodplain to which they were applied, are listed in Table 10-2.

Table 10-2 Ecosystem indicators used in the DRIFT DSS

Discipline	Indicators	River	Floodplain	Pans
Water Quality	Salinity			x
	Suspended sediments		x	
Geomorphology	Channel capacity	x		
Vegetation	Floating rooted vegetation (*Trapa natans/bispinosa, Nymphaea lotus and N. caerulea*)			x
	Submerged vegetation (*Potamogeton crispus*)			x
	Mixed sedge-grass community (*Cyperus fastigiatus* and *Echinochloa pyramidalis*)		x	x
	Reedbeds (*Phragmites australis*)		x	x
	Reedbeds (*Phragmites mauritianus*)		x	x
	Couch grass lawns (*Cynodon dactylon*)		x	x
	Riparian Tree Communities (*Ficus sycomorus - Rauvolfia caffra / Acacia xanthophloe - Dyschoriste depressa* community)	x	x[84]	
Fish	*Chiloglanis paratus*	x		x
	Oreochromis mossambicus	x		x
	Labeo rosae	x		x
	Hydrocynus vittatus/ Brycinus imberi	x		x
	Tilapia rendalli	x		x

[84] Note: riparian vegetation forms only a small component of the floodplains.

10.2.1 Geomorphology indicators: Comments and reasons for selection

The geomorphological indicator used is channel capacity.

Under current release the annual flood is roughly equivalent to an event with a 1 in 4 year return period on the natural flow regime used in this study[85]. This can be expected to result increased channel capacity relative to natural given the reduction in sediment supply and an annual releases in excess of the natural annual flood. In the past this increased capacity was probably affected through the processes of vegetation encroachment, bank stabilisation and resultant channel deepening (Basson *et al*. 2006). However, the current rate of removal of riparian vegetation is likely to result in destabilisation of the banks, and possibly channel widening, which would also increase channel capacity. The risk associated with this is that, as time goes by, larger flood will be required to fill the pans and flood the floodplain.

In fact, DWS personnel at Jozini Dam report that the release has increased to 800 m3s-1 over the years partly because "the channel has deepened and higher flows are needed to fill pans. Not sure that the effect has been as extreme as the perception [Basson et al. (2006) reported that deepening was not extensive] suggests but it is certainly a possibility.

10.2.2 Vegetation indicators: Comments and reasons for selection

The indicators selected were derived from the review of the literature. In some cases specific information was provided for individual species, especially with respect to *Potamogeton crispus*, on which extensive work had been undertaken by Rogers (1984) and *Cynodon dactylon* (Furness and Breen, 1982, 1985). For others, experience was used to derive the response variables. Each indicator was listed in the literature on the system and areas where these occurred previously could be visited to establish how they had responded to the altered flooding regime the system has experienced since operation of the dam. This assisted with assessing the responses based on the linked indicators for the naturalised versus current day flow regime.

10.2.3 Fish indicators: Comments and reasons for selection

In diverse river systems, it is not feasible or necessary to assess the response of every fish species present in the river to flow change. The ecological guild concept has been used extensively for evaluating the effects of flow changes on diverse river fish communities (Leonard and Orth 1988; Aadland 1993; Welcomme et al. 2006; Baumgartner et al. 2013). Ecological guilds are used to group species according to similar morphological, physiological, behavioural and life history adaptations rather than according to taxonomic relatedness – the assumption being that species with similar adaptations will respond to environmental change and variability in similar ways.

[85] Beck and Basson (2003) report this discharge to be equivalent to a 1:2 year return period but the data provided does not appear to support this.

For the purposes of Pongola EWR assessment, seven fish guilds were selected: (1) flood-dependent - benthic, (2) flood-dependent – pelagic, (3) flood-independent – generalist, (4) flood-independent – vegetation, (5) main channel – rheophilics, (6) main channel – semi-rheophilics and (7) main channel – pool (Table 10-3). A principal species was selected for each indicator guild, e.g. tigerfish was selected for the flood-dependent – pelagic guild, on the basis of its sensitivity to a range of flow-related parameters based on a review of the literature available for the system (Heeg and Breen 1982; Merron et al. 1993a; Merron et al. 1993b; Weldrick 1996). The guild requirements were based mostly, but not wholly, on the requirements of the selected principal species. The parameters considered included timing and frequency of flooding, access to pans, inundation of marginal vegetation and aerial extent and duration of inundation. The use of indicators assumes that if a suite of critical conditions are met for more sensitive species, the requirements for less sensitive species or guilds will be met as well. Only the dry season requirements of the main channel (Pongola) guilds were considered since was is assumed that if wet season requirements of the floodplain were met, the requirements of the main channel would be met as well.

Table 10-3 Fish indicators used in the DRIFT DSS

GUILD	DESCRIPTION	SPECIES
Flood-dependent – benthic	This guild forms an important component of the subsistence fishery. Members of the guild migrate from the main channel onto the floodplains to spawn over the wet season when these become inundated. Numbers decline in the absence of flooding. Includes *Labeos* and *Synodontis* which use benthic or littoral habitats rather than open water pelagic. The mormyrids are sensitive to increasing salinities in the pans over the dry season.	Principal species: Rednose labeo (*Labeo rosae*). Represents: Brown squeaker (*Synodontis zambezensis*), Bulldog (*Marcusenius macrolepidotus*), Churchill (*Petrocephalus catostoma*)
Flood-dependent guild - pelagic	The flood-dependent pelagic guild include important components of the subsistence and recreational fishery. The principal indicator species (tigerfish) has a preference for large open water lagoons and is sensitive to shallow pans with low DO (Mosepele et al. 2009). Spawning for this species is likely on floodplains on inundated vegetation (Smit et al. 2013). Numbers will decline if water depths either in the main channel or pans decline <1m.	Principal species: Tigerfish (*Hydrocynus vittatus*), Represents: silver catfish (*Schilbe intermedius*), spot-tailed robber (*Brycinus imberi*)
Flood-independent - generalist	Flood-independent generalists are able to spawn across a wide range of conditions and for an extended period during the year in the absence of floods. They are tolerant of deteriorating water quality conditions. Mozambique tilapia, the principal indicator species, accounts for up to 90% of fish catches in drought years.	Principal species: Mozambique tilapia (*Oreochromis mossambicus*)
Flood-independent - vegetation	The flood-independent vegetation guild can spawn in the absence of flooding, but is sensitive to marginal and aquatic vegetation changes either for food or habitat. The principal indicator species, the redbreast tilapia are flood-independent, but are sensitive to the drought-related loss of aquatic macrophytes which they feed on and which they use as cover (Merron et al. 1993a).	Principal species: Redbreast tilapia (*Tilapia rendalli*) Represents: southern mouthbrooder (*Pseudocrenilabris philander*), small barbs
Main channel - rheophilic	Main channel riffle guild members like the sawfin suckermouth are found in main channel rapid habitats (Weldrick 1996). The *Chiloglanis* genus is a good indicator of general riffle and rapid habitat condition in the main channel.	Principal species: Sawfin suckermouth (*Chiloglanis paratus*) Represents: Lowveld

GUILD	DESCRIPTION	SPECIES
		suckermouth (*Chiloglanis swierstrai*)
Main channel – semi-rheophilic	This guild includes the tigerfish which is important for the recreational fishery as well as the larger-bodied rheophilic labeos. Adults and juveniles use the main channel for refuge over the dry season. This guild requires access to faster-flowing riffle and rapid habitats for feeding during the dry season, passage between pools (depths > 0.2 m) and enough flow to maintain water quality in the pools.	Principal indicator: tigerfish (*Hydrocynus vittatus*) Represents: leaden labeo (*Labeo molybdinus*), Redeye labeo (*Labeo cylindricus*)
Main channel – pool	Small barbs and other species inhabiting pools and marginal slackwaters in the main channel. Without floodplain refugia over the dry season, the main channel pool community depends on the availability of hydraulic refuges either along the margins of the active channel or in pools. Discharges above natural may result in some loss of hydraulic refuges for this guild by drowning out pool habitats and increasing mean velocities through the channel. The absence of hydraulic refuge would also affect juveniles of all species that had entered the main channel from the floodplain at the beginning of the flood season.	Principal indicator species: Plump barb (*Barbus afrihamiltoni*) Represents: Straightfin barb (*Barbus paludinosus*), Bowstripe barb (*Barbus viviparous*)

10.3 Social indicators

The social indicators used in this assessment, and the areas of the floodplain to which they were applied, are listed in Table 10-4.

Table 10-4 Social indicators used in the DRIFT DSS

Discipline	Indicators	River	Floodplain	Pans
Social	Fishing in pan			x
	Fishing in main river channel	x		
	Drinking water	x		x
	Harvesting of fruits (figs, etc.)	x	x	
	Harvesting of reeds and grasses	x	x	
	Grazing for livestock		x	
	Flood irrigated commercial agriculture		x	
	Perceptions of disease		x	
	Reeds for reed dance		x	

10.3.1 Social indicators: Comments and reasons for selection

The social economic indicators were based on the literature review conducted on the use by the communities of the natural resources in the floodplain. The social economic profile of the Pongola floodplain area indicates that there is significant dependence on the natural resources generated by the floodplain and pans.

The relative isolation and high poverty levels in the area have compounded the dependency of local communities on natural resources from the floodplain (Breen *et al*. 1998). The reasoning behind the indicators selected is as follows:

(i). Floodplain vegetation provides fuel and traditional building materials such as thatch and reeds for the local households, as well as food such as fish and wild plants (Heeg and Breen 1982). Based on the interviews and observations during the site visit, the main focus of this indicator was fruit.

(ii). Fish have always represented a major source of animal protein in the diet of households near the Pongola Floodplain. Many economic activities in the Pongola Floodplain are dependent on the availability of fish after the flood season.

(iii). The traditional reed dances are still practiced, and requires reeds harvested from the floodplain. General indications are that demand is high and these are supply limited.

(iv). Floodplain agriculture is importance to the economy of the region. Much of this activity is dependent both on the flood flows for irrigation and on the fertile soils that are deposited on the floodplain as the water recedes.

(v). The perception among users of the floodplain is that high summer flows and prolonged flooding leads to an increase in diseases such as malaria.

10.4 Weightings

For the ecosystem Overall Integrity values and social well-being, indicators were equally weighted. However, fish biomass was not included as it would have been double accounting.

10.5 Management impacts

There are several non-flow related, anthropogenic pressures on the Pongola Floodplain that are currently negatively affecting the ecological integrity of the system. The two most important of these are:

- Clearing of indigenous vegetation for cultivation.
- Fishing.

The influences of changes in these two pressures were not modelled as part of the scenarios but are provided here because they are useful in the interpretation of the results for the scenarios. The estimated end values (relative to 2014) for the baseline (2014) and naturalised scenarios for the impact of cultivation of the areal extent of key vegetation indicators under two hypothetical future levels (no pressure from cultivation and double pressure from cultivation) are given in Table 10-5. It is expected that the aquatic plants in the pans such as *Potamogeton* (floating rooted vegetation) and *Trapa* (submerged vegetation) are not heavily affected by cultivation, whereas the plants on the floodplains, such as the reeds and the lawn grass are heavily affected by cultivation.

Table 10-5 The estimated end values (relative to 2014) for each of the impact of cultivation of the areal extent of key vegetation indicators under two hypothetical future levels: Removal of current (2014) pressure (no pressure) and doubling of the current (2014) pressure (double pressure) under tow flow scenarios (present day-PD; and natural-Nat).

Indicator	Future levels of cultivation pressure	Baseline (2014)	Naturalised
P australis	No pressure	110	110
	Double pressure	80	80
P mauritianus	No pressure	150	150
	Double pressure	20	80
Cynodon	No pressure	300	300
	Double pressure	20	20
Potamogeton	No pressure	100	100
	Double pressure	100	100
Trapa	No pressure	120	120
	Double pressure	80	80

The estimated end values (relative to 2014) for the baseline (2014) and naturalised scenarios for the impact of fishing pressure of the abundance of key fish indicators under the same two hypothetical future levels are given in Table 10-6. It is expected that flood-independent guilds are not be markedly affected by fishing pressure but that the flood-dependent guilds are affected by fishing pressure.

Table 10-6 The estimated end values (relative to 2014) for the impact of fishing pressure of the abundance of key fish indicators under two hypothetical future levels: Removal of current (2014) pressure (No pressure) and doubling of the current (2014) pressure (double pressure(under tow flow scenarios (present day-PD; and natural-Nat).

Indicator	Future levels of fishing pressure	Baseline (2014)	Naturalised
Flood-independent – generalists and vegetation	No pressure	100	100
	Double pressure	100	100
Flood-dependent – benthic and pelagic	No pressure	120	120
	Double pressure	80	80

11 SCENARIOS EVALUATED

The approach used for the evaluation of the scenarios and establishment of a recommended EWR for the Pongola Floodplain differed from that applied for the river EWRs. This is mainly because it does not make sense to set EWRs exclusively for a range of ecological conditions in the light of:

- the high social dependence on the floodplain;
- the apparent conflict between October irrigation release and the flow requirements of the ecosystem;
- the water supply targets of Jozini Dam, and;
- the need to find a flow regime that optimizes social AND ecological benefits.

Thus, the EWR assessment focussed on evaluation of the predicted impact on the social and ecological attributes of the floodplain, with an eye on the volume of water that would be required from Jozini Dam. Within the budget and time constraints of this project, it was only possible to evaluate natural, present day and seven EWR release scenarios (Table 11-1). This is mainly because of the considerable time required to run each scenario through the hydrodynamic model and post-process the required hydraulic indicators (c. 32 hours per scenario; see Section 8):

Table 11-1 Scenarios evaluated

No.	Scenario name	Code	MAR (MCM)
1	Baseline: 2014 release operations	Base	579.94
2	Naturalised	Nat	1121.67
3	Baseline with adjustments. ‘October’ flood but three weeks earlier in September	Base_Sept	580.68
4	Heeg and Breen (1982) – adjusted to = 250 MCM per annum	HB_250	588.28
5	Heeg and Breen (1982) scenario but with the December flood (see Section 11.3) in October, i.e., same timing as baseline	HB_mod	588.85
6	October flood at 600 m^3s^{-1}, PLUS December and February floods from Heeg and Breen (1982)	HB_R600	582.82
7	October flood at 400 m^3s^{-1}, PLUS December and February floods from Heeg and Breen (1982)	HB_R400	593.79
8	Heeg and Breen (1982) –plus future demands (2040)	HB_modD1	561.16
9	Heeg and Breen (1982) – plus future demands (2040) with water demand management measures	HB_modD2	581.10

Note: The volumetric summaries for all the scenarios INCLUDE the volume of water associated with floods with a return period of 1:2 years and greater. As per RDM convention, the EWRs suggested for the Preliminary Reserve (Section 19) are provided EXCLUDING the volume of water associated with these floods. However, the assumption is that they will occur.

11.1 Baseline: 2014 Release Operations

The 2014 pattern of releases has been in operation since 2000, with the exception that the large October flood release has increased in magnitude from c. 450 to >700 m^3s^{-1} over that time.

For Tete, two baseline scenarios were run: Baseline and an updated Baseline (Base-UpD). The updated Baseline scenario is a re-simulation of Baseline conditions used in preparation of DRIFT response curves because inaccuracies[86] were noted in the original version after it had been applied. Both baseline scenarios were run at all sites to check and demonstrate that here were no major differences between them.

Current releases are designed to fill the pans in Ndumo Game Reserve, but do not necessarily achieve this target. This is mainly because the October release does not coincide with the flooding season in the Usuthu River. When the Usuthu and Pongola Rivers flood simultaneously the water slows down and backs up into Ndumo Game Reserve at the confluence of the two rivers, filling the pans. If the Usuthu River is full when a flood passes down the Pongola River, there is nothing to hold the water in Ndumo Game Reserve. This creates two problems:

- the Ndumo pans only partially fill, and;
- the water velocities in the pans are higher than natural, and result in erosion and the creation of channels in the pans, which further reduces retention.

This phenomenon has resulted in extensive and damaging erosion in Banzi Pan (Figure 4.3) in particular. The erosion is likely to be ongoing as long as the flood releases from Jozini Dam do not coincide with flooding in other parts of the catchment, which means that the situation can be expected to steadily worsen.

The current releases from Jozini Dam at time exceed 700 m^3/s (Figure 11.1). Future lowflow releases will be *c.* 1 m^3/s higher to provide a 30 MCM per annum to Shemula for domestic use.

[86] MODSIM was not reducing the releases when the storage dropped below the sill of the spillway gates. This resulted in overestimated releases when the dam stage is drawn down (e-mail correspondence 18/02/2015, A Sparks, Aurecon SA). Scenario and rectified PD time-series were provided on 27/02/2015.

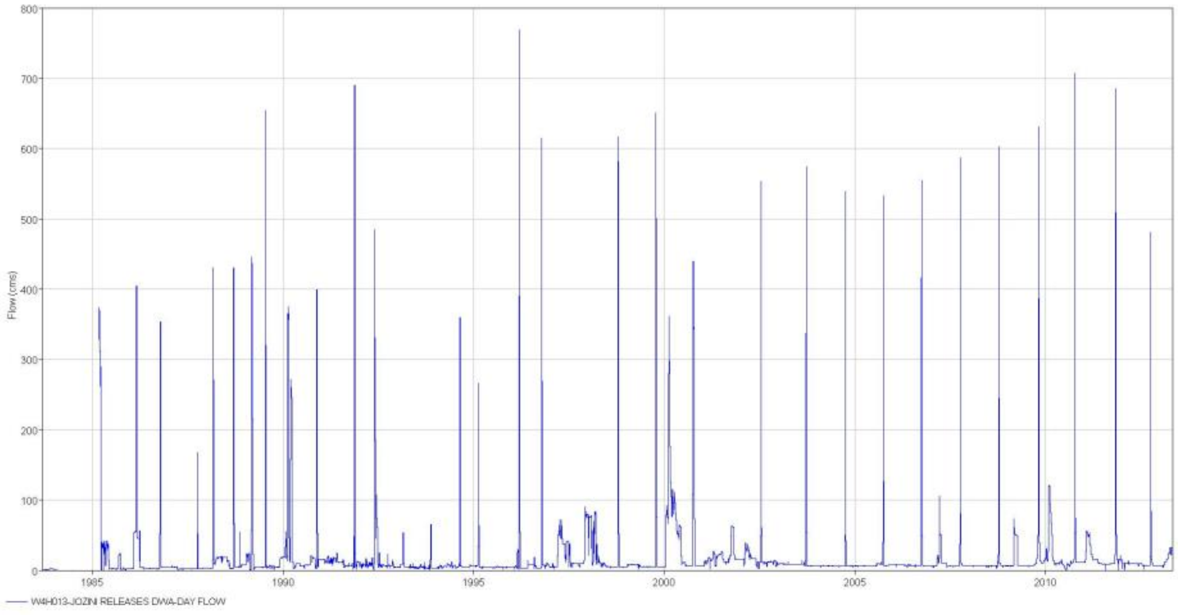


Figure 11.1 Releases from Jozini Dam from 1985-2013

11.2 Baseline 'October' flood but three weeks earlier in September (Code = Base_Sept)

As its name suggests, this scenario is identical to the Baseline, except for the fact that the October release is made two weeks earlier.

11.3 Heeg and Breen (1982; Code = HB_250)

Heeg and Breen (1982) provided detailed recommendations for a release regime from Jozini Dam that would provide some protection to the natural ecosystem and the subsistence users dependent on it. Their recommendations were as follows:

1. Raise to flood all pans in December, hold for three days, drop to normal level to drain and drop flow by two days at 56 m^3s^{-1} flow and four days at 28 m^3s^{-1} flow. This should effect flushing (of saline water from the pans) and allow fish migration.
2. Raise to flood Tete (no date given but we assume this is January), oscillate water level about this point to flood subsistence lands. Such oscillations would probably range between flooding Mthikeni at the highest level and maintaining Namanini-Bumbe-Ngodo complex at lowest flood level.
3. Raise level to flood all pans during February, hold for five days and return to 2 above.
4. Drop to level of Namanini-Bumbe-Ngodo during March. Oscillate about this point, raising to level of Tete perhaps once or twice.

5. Unimpeded flow April-November.

Using the hydrodynamic model developed for this study (Section 8), plus Basson *et al*. (2006), DWS gauging weir and water level recorders, and measurements provided by *inter alia* Heeg and Breen (1982), the discharges corresponding to the requests above are:

1. Raise to flood all pans in December: 150 m^3s^{-1}
2. Raise to flood Tete in January: 50 m^3s^{-1}:
    a. For the oscillations: 35-65 m^3s^{-1}
3. Raise level to flood all pans during February[87]: 150 m^3s^{-1}
4. Drop to level of Namanini-Bumbe-Ngodo during March: 35 m^3s^{-1}.
5. “Unimpeded flow” April-November: c. 2.4 m^3s^{-1}.

“Unimpeded flow” as referred to by Heeg and Breen (1982) was taken as c. 2.4 m^3s^{-1} (from Hughes 2000; for a C category river). In reality, however, current lowflow conditions in the river do not fall below 5.5 m^3s^{-1}. This is because *c*.157 MCM per annum ‘compensation flows’ for Mozambique are released at *c.* 5.5 m^3s^{-1} for most of the year.

According to Heeg and Breen (1982), the above scenarios “*involved 41 MCM of water per annum*”. However, volumetric calculations for the above effective discharges indicate that in fact the scenarios will require in the region of 350 MCM per annum.

For the modelled scenario, however, the requirements were thus so that they used c. 250 MCM as this approximate the current volume of the October flood.

The releases for the Heeg and Breen (1982) scenario, as modelled in this study, can be summarised as:

December:

- Three days at 150 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.
- Two days at 56 m^3s^{-1}
- Four days at 28 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.

January:

- Two days at 50 m^3s^{-1}.
- One day at 35 m^3s^{-1}, followed up one day at 65 m^3s^{-1}. Repeat three times.
- Remaining days at 2.4 m^3s^{-1}.

February:

- Five days at 150 m^3s^{-1}.
- Remaining days at 50 m^3s^{-1}.

[87] This is expected to flood more of the floodplain in Ndumo than would the same discharge in December because flows in the Usuthu River are higher in February than in December.

March:

- Fifteen days at 35 m^3s^{-1}.
- Remaining days at 50 m^3s^{-1}.

11.4 Heeg and Breen (1982) scenario with December requirements moved to October (Code = HB_mod)

The releases for this scenario can be summarised as follows:

October:

- Three days at 150 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.

December:

- Two days at 56 m^3s^{-1}
- Four days at 28 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.

January:

- Two days at 50 m^3s^{-1}.
- One day at 35 m^3s^{-1}, followed up one day at 65 m^3s^{-1}. Repeat three times.
- Remaining days at 2.4 m^3s^{-1}.

February:

- Five days at 150 m^3s^{-1}.
- Remaining days at 50 m^3s^{-1}.

March:

- Fifteen days at 35 m^3s^{-1}.
- Remaining days at 50 m^3s^{-1}.

11.5 October flood at 600 m^3s^{-1} PLUS Heeg and Breen (1982; Code = HB_R600)

The releases for this scenario can be summarised as follows:

October:

- One day at 600 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.

December:

- Three days at 150 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.
- Two days at 56 m^3s^{-1}
- Four days at 28 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.

January:

- Two days at 50 m^3s^{-1}.
- One day at 35 m^3s^{-1}, followed up one day at 65 m^3s^{-1}. Repeat three times.
- Remaining days at 2.4 m^3s^{-1}.

February:

- Five days at 150 m^3s^{-1}.
- Remaining days at 50 m^3s^{-1}.

March:

- Fifteen days at 35 m^3s^{-1}.
- Remaining days at 50 m^3s^{-1}.

11.6 October flood at 400 m^3s^{-1}, PLUS December and February floods from Heeg and Breen (1982; Code = HB_R400)

The releases for this scenario can be summarised as follows:

October:

- Two days at 400 m^3s^{-1}

December:

- Three days at 150 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.
- Two days at 56 m^3s^{-1}
- Four days at 28 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.

February:

- Five days at 150 m^3s^{-1}.
- Ten days at 50 m^3s^{-1}.
- Remaining days at 2.4 m^3s^{-1}.

11.7 Heeg and Breen (1982) – adjusted with the addition of future demands (2040; Code = HB_modD1)

This scenario is based on HB-mod with the addition of future demands (2040) to Zululand and Umkanyakude District Municipalities and Zamakuhle. The additional demands result in an estimated yield deficit of 25 $10^6m^3/a$.

11.8 Heeg and Breen (1982) – adjusted with the addition of future demands (2040), plus WDM (Code = HB_modD2)

This scenario is based HB_modD1 but incorporating water demand management for all users, except the average low flow[88] discharge of 5.45 m^3/s and the high flow release for the floodplain, which is 225 $10^6 m^3/a$.

[88] primarily for obligations to Moçambique.

12 SCENARIO EVALUATION: JOZINI DAM TO UPSTREAM OF MZINYENI

For each scenario, the predicted ecosystem changes in the study pan and its surrounding floodplain are evaluated as:

1. estimated mean percentage change from baseline[89] in the abundance, area or concentration of indicators;
2. the predicted change in Overall Ecosystem Integrity, relative to baseline.

For each scenario, the predicted social changes are evaluated as:

1. estimated mean percentage change from baseline in the abundance, area or concentration of indicators;
2. the predicted change in Overall Well-being, relative to baseline.

Ntlanyane Pan was chosen to represent this section of the floodplain.

12.1 Ntlanyane Pan and Floodplain

12.1.1 Hydrology and hydraulics

The summary flow and hydraulic indicators for Ntlanyane Pan and Floodplain for the scenarios are given in Table 12-1

12.1.2 Ecosystem

12.1.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at Ntlanyane Pan and Floodplain are given in Table 12-2.

The Ntlanyane Pan and Floodplain does not fare well under the HB scenario variations, this is mainly because:

- it requires a relatively high discharge to inundate the floodplain and fill the pan (see Table 9-2), and;
- the HB scenarios include a flooding regime for the whole of the wet season, which means that Jozini Dam will spill less than under baseline.

It is worth nothing, however, that this was not one of the pans that Heeg and Breen (1982) were concerned with when the recommended releases for the floodplain.

[89] Baseline ecological conditions are those estimated in 2014.

Table 12-1 Median values for the flow and hydraulic indicators for Ntlanyane Pan and Floodplain for the scenarios[90]. Codes and units for the indicators are given in Section 10.1.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Dry onset	42.000	22.000	39.00	22.00	22.00	41.00	12.50	22.00	22.00
Dry Min 5d stage	1.00	1.13	1.00	0.41	0.08	0.99	0.89	0.06	0.08
Dry duration	352.00	229.50	352.00	216.50	198.00	352.50	216.00	163.50	201.50
Wet onset	40.000	44.000	37.00	44.00	44.00	40.00	26.00	44.00	44.00
Wet duration	11.00	76.00	11.00	181.00	181.00	8.50	7.00	181.00	181.00
Wet Max 5d stage / Q	3.25	2.82	3.25	1.20	1.08	2.73	1.71	0.90	1.06
ann: mean Duration Oct exp	356.00	0.00	356.00	0.00	0.00	116.50	0.00	0.00	0.00
annl: mean Onset Oct exp	42.00	2.00	39.00	-1.00	-1.00	41.00	-1.00	-1.00	-1.00
W/Ann: Days FP depth 0.2-1 (V)	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
W/Ann: Freq FP cross (V) thold 0.2-1	2.00	1.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00
W/Ann: Frequ connected (F)	1.00	1.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00
W/Ann: sum Days (F)	7.00	9.50	7.50	0.00	0.00	4.00	0.00	0.00	0.00
W: FP & P area 0.2-0.6 m	0.38	0.27	0.28	0.17	0.10	0.31	0.29	0.08	0.10
W: FP area 0.2-1 m	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet/Ann: Onset ext FP flooding	41.00	0.00	38.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet: mean FP & Pan area	2.30	1.11	1.90	0.71	0.56	1.96	1.58	0.46	0.54
Wet: Mean FP & Pan vol	2.95	0.65	2.20	0.49	0.37	2.34	1.51	0.33	0.36
Dry: mean Pan area 1-1.5 m	0.36	0.38	0.36	0.06	0.01	0.36	0.30	0.01	0.01
T1: mean Pan area 1-1.5 m	0.08	0.04	0.32	0.00	0.00	0.38	0.41	0.00	0.00
Wet: mean Pan area 1-1.5 m	0.34	0.13	0.31	0.01	0.01	0.35	0.34	0.01	0.01
T2: mean Pan area 1-1.5 m	0.35	0.11	0.30	0.01	0.01	0.34	0.35	0.01	0.01
Dry: mean Pan area GT 1m	0.54	0.64	0.56	0.06	0.01	0.54	0.36	0.01	0.01
W: Pan area GT 1m	1.37	0.14	1.12	0.01	0.01	1.21	0.87	0.01	0.01
Dry: mean FParea	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
T1: mean FParea	3.10	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00
Wet: mean FP area	0.34	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
T2: mean FParea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[90] Base-UpD. See explanation in Section 11.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Dry: mean Pan area	1.40	1.48	1.41	0.88	0.60	1.40	1.26	0.51	0.60
T1: mean Pan area	1.97	1.03	1.92	0.45	0.01	1.97	1.57	0.01	0.01
Wet: mean Pan area	1.97	1.03	1.89	0.65	0.40	1.95	1.55	0.35	0.39
T2: mean Pan area	1.95	1.09	1.87	0.98	0.91	1.93	1.65	0.87	0.89
Dry: mean Pan depth	0.81	0.88	0.83	0.46	0.29	0.81	0.69	0.24	0.29
T1: mean Pan depth	2.68	0.54	1.17	0.18	0.04	1.33	0.98	0.04	0.04
Wet: mean Pan depth	1.43	0.58	1.16	0.34	0.30	1.20	0.96	0.23	0.28
T2: mean Pan depth	1.19	0.57	1.15	0.48	0.37	1.18	1.03	0.34	0.36
T1: mean FP & Pan depth	1.44	0.54	1.17	0.18	0.04	1.26	0.98	0.04	0.04
Wet: FP & Pan depth	1.26	0.58	1.16	0.30	0.25	1.19	0.96	0.21	0.24
T2: mean FP & Pan depth	1.19	0.57	1.15	0.48	0.37	1.18	1.03	0.34	0.36

Table 12-2 Ntlanyane Pan and Floodplain: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Floating rooted vegetation	0.8	3.9	-7.6	-5.7	1.4	0.5	-8.3	-6.5
Submerged vegetation	2.2	4.8	-12.4	-14.8	6.1	3.6	-17.1	-15.2
Mixed sedge-grass community	-22.2	2.2	-40.6	-38.6	-49.3	-44.8	-47.8	-38.9
Reedbeds (P. australis)	12.9	3.2	11.9	13.5	3.7	2.8	12.2	12.6
Reedbeds (P. mauritianus)	-3.6	5.6	-14.0	-11.0	-23.0	-33.0	-15.6	-11.3
Couch grass lawns	-16.7	2.2	-25.7	-24.5	-28.8	-20.0	-27.6	-24.7
Riparian tree communities	-8.7	0.6	-9.4	-10.4	-6.9	-12.7	-15.5	-10.0
Fish								
Flood-dependent - benthic	8.6	-1.5	-20.0	-19.1	-29.9	-46.9	-38.2	-30.9
Flood-dependent - pelagic	8.6	-1.5	-20.0	-19.1	-29.9	-46.9	-38.2	-30.9
Flood-independent generalists	-19.0	1.8	-30.4	-34.3	-2.6	-17.4	-36.2	-34.7
Flood-independent - vegetation	-18.3	4.9	-33.3	-36.4	-8.2	-19.6	-39.8	-36.8
Fish biomass	10.0	5.9	-13.2	-12.6	-16.5	-29.1	-22.5	-18.0

All of the scenarios assume present day (2014) level of human pressure on the system.

12.1.2.2 Overall ecosystem integrity

The Overall Ecological Integrity for each scenario at Ntlanyane is illustrated in Figure 12.1. Figure 12.1 summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

For Ntlanyane, the results show that all of the scenarios other than the Natural, Baseline and Base_Sept scenarios are expected to worsen ecosystem condition from a D-E category to a E/F category. This is because Ntlanyane will not flood as extensively as it does at present under the lower floods magnitudes and reduced spills comprising the H&B scenarios. The changes in flooded area (Wet Max 5d stage / Q) and onset of flooding (Wet/Ann: Onset ext FP flooding) are clear in Table 12-1.

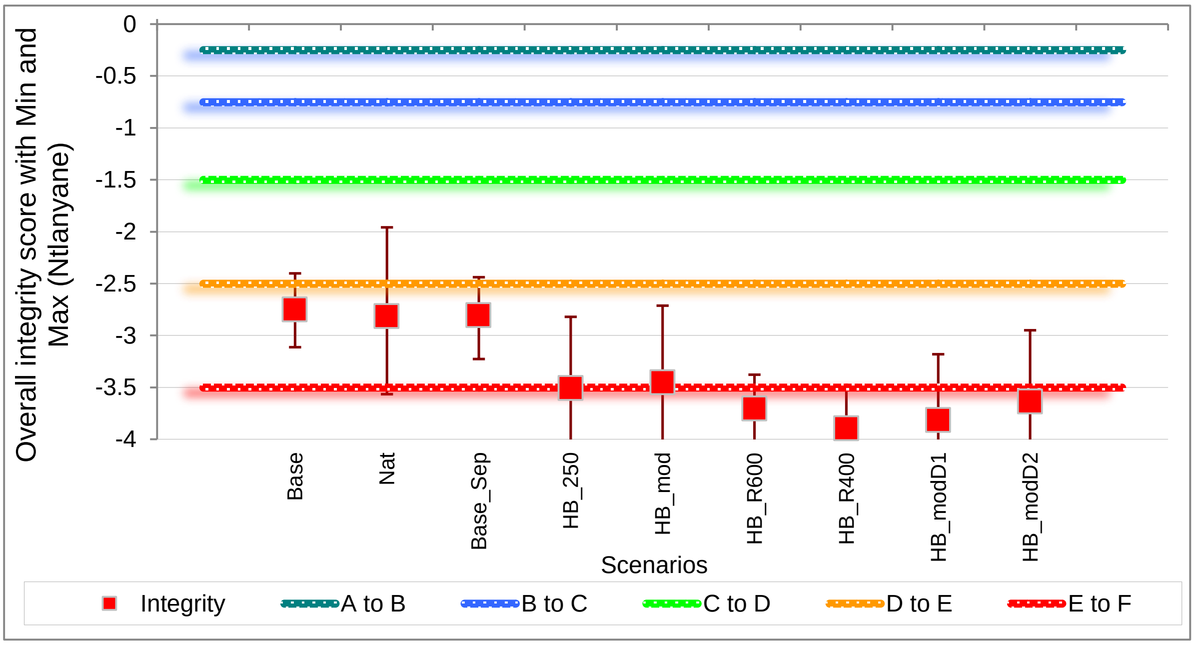


Figure 12.1 Overall ecosystem integrity scores for the scenarios at Ntlanyane. Baseline (2014) integrity is labelled 'Base".

12.1.3 Social

12.1.3.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the social indicators for the scenarios at Ntlanyane Pan and Floodplain are given in Table 12-3.

All of the scenarios assume present day (2014) level of human pressure on the system.

Table 12-3 Ntlanyane Pan and Floodplain: The mean percentage changes (relative to 2014) for the social indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Fishing - pans	6.7	3.9	-6.3	-5.6	-9.7	-16.3	-10.5	-8.1
Drinking water (domestic and livestock)	-19.3	3.3	-31.9	-36.4	1.6	-16.3	-37.7	-37.1
Fuel wood	-4.4	1.7	-4.9	-5.5	-3.2	-6.4	-8.0	-5.3
Fruit harvesting	-1.6	2.8	-1.7	-1.9	-0.8	-2.0	-2.7	-1.8
Reeds and grass harvesting	-0.1	4.8	-7.1	-6.0	-13.5	-13.5	-9.8	-6.3
Livestock grazing	-2.7	5.3	-5.3	-5.2	-5.9	-4.1	-6.1	-5.6
Floodplain recession agriculture	-21.4	4.7	-25.8	-25.9	-23.6	-23.8	-26.9	-25.0
Perceptions on disease regulation	4.4	-1.5	22.1	22.1	19.8	22.4	23.9	22.1

12.1.3.2 Overall well-being

The pattern for overall well-being is similar to that shown for overall ecosystem integrity (vegetation and fish), *viz*. all of the scenarios other than the Baseline and Base_Sept scenarios are expected to worsen well-being (Figure 12.2).

This is being driven by the recession agriculture indicator, and to a lesser extent the availability of drinking water, and (in addition to flood magnitude) is related to the onset of the flooding of the pan and floodplain (**Error! Reference source not found.**).

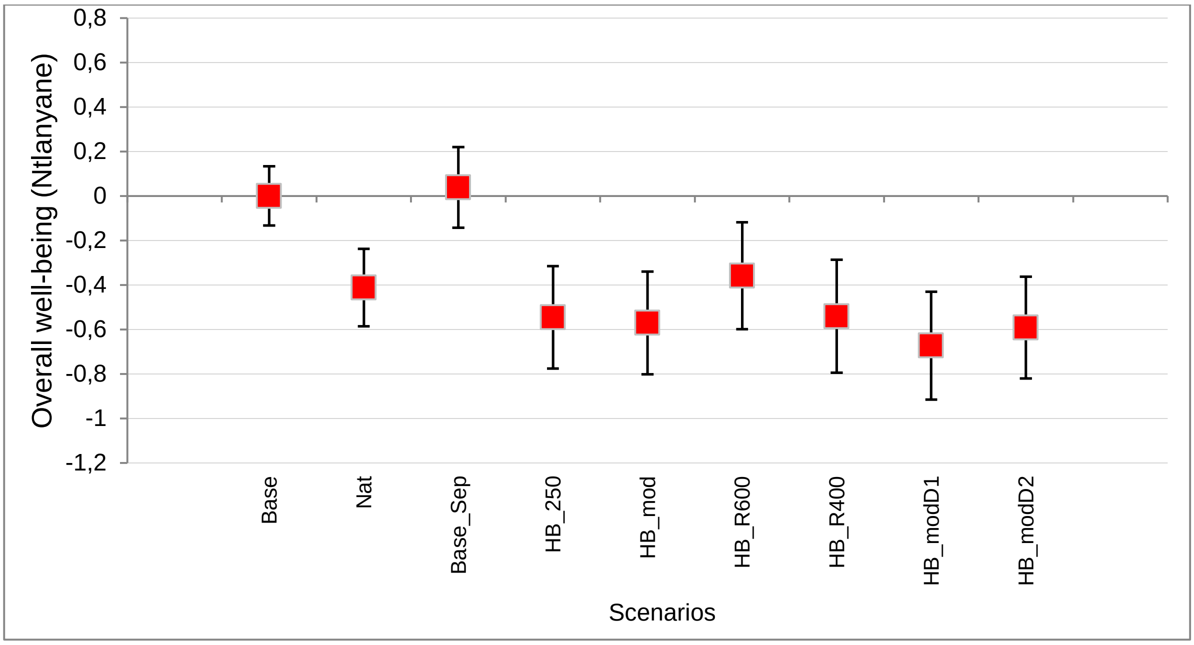


Figure 12.2 Overall well-being scores for the scenarios at Ntlanyane. Baseline (2014) integrity is labelled 'Base

13 SCENARIO EVALUATION: MZINYENI TO MTHIKENI

For each scenario, the predicted changes in the study pans and their surrounding floodplain are evaluated as:

1. estimated mean percentage change from baseline in the abundance, area or concentration of indicators;
2. the predicted change in Overall Ecosystem Integrity, relative to baseline.

For each scenario, the predicted social changes are evaluated as:

1. estimated mean percentage change from baseline[91] in the abundance, area or concentration of indicators;
2. the predicted change in Overall Well-being, relative to baseline.

Mzinyeni Pan and Mthikeni Pan were chosen to represent this section of the floodplain.

13.1 Mzinyeni Pan and Floodplain

13.1.1 Hydrology and hydraulics

The summary flow and hydraulic indicators for Mzinyeni Pan and Floodplain for the scenarios are given in Table 14-4.

13.1.2 Ecosystem

13.1.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at Mzinyeni pan and floodplain are given in Table 16-2.

All of the scenarios assume present day (2014) level of human pressure on the system.

The changes in individual indicators are discussed in more detail in Section 14.1.

[91] Baseline ecological conditions are those estimated in 2014.

Table 13-1 Median values for the flow and hydraulic indicators for Mzinyeni Pan and Floodplain for the scenarios. Codes and units for the indicators are given in Section 10.1.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Dry onset	44.000	14.500	41.00	14.00	14.00	9.00	14.00	14.00	14.00
Dry Min 5d stage	0	0	0.32	0.35	0.59	0.46	0.59	0.59	0.59
Dry duration	338	194	338.00	241.50	180.50	212.00	179.50	180.50	180.50
Wet onset	40.000	43.000	37.00	49.00	40.00	40.00	40.00	40.00	40.00
Wet duration	25.00	138.00	25.50	121.00	182.50	151.00	183.00	182.00	182.50
Wet Max 5d stage / Q	2.91	2.49	2.91	2.77	2.77	2.77	2.77	2.77	2.77
ann: mean Duration Oct exp	156.50	52.00	167.00	151.00	35.00	24.00	25.00	35.00	35.50
annl: mean Onset Oct exp	47.00	29.50	44.00	18.50	46.00	45.00	45.00	45.50	45.50
W/Ann: Days FP depth 0.2-1 (V)	13.00	111.50	13.00	61.00	61.00	40.00	67.00	61.00	61.00
W/Ann: Freq FP cross (V) thold 0.2-1	2.00	4.00	2.00	7.00	7.00	4.50	8.00	7.00	7.00
W/Ann: Frequ connected (F)	1.00	1.00	1.00	1.00	2.00	3.00	2.00	2.00	2.00
W/Ann: sum Days (F)	25.00	132.00	25.50	121.00	137.50	93.50	147.50	136.00	136.50
W: FP & P area 0.2-0.6 m	0.47	0.40	0.24	0.00	0.39	0.37	0.36	0.39	0.39
W: FP area 0.2-1 m	0.47	0.28	0.00	0.00	0.21	0.14	0.11	0.20	0.20
Wet/Ann: Onset ext FP flooding	40.00	44.00	37.00	50.50	50.00	40.00	40.00	50.00	50.00
Wet: mean FP & Pan area	1.44	0.98	0.50	0.01	0.90	0.75	0.72	0.90	0.90
Wet: Mean FP & Pan vol	1.09	0.43	0.10	0.00	0.45	0.27	0.23	0.45	0.45
Dry: mean Pan area 1-1.5 m	0.00	0.06	0.01	0.03	0.03	0.02	0.03	0.03	0.03
T1: mean Pan area 1-1.5 m	0.36	0.00	0.01	0.00	0.16	0.16	0.29	0.23	0.17
Wet: mean Pan area 1-1.5 m	0.05	0.04	0.00	0.00	0.03	0.03	0.02	0.03	0.03
T2: mean Pan area 1-1.5 m	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dry: mean Pan area GT 1m	0.001	0.12	0.03	0.06	0.05	0.04	0.06	0.05	0.05
W: Pan area GT 1m	0.19	0.06	0.00	0.00	0.07	0.03	0.02	0.07	0.07
Dry: mean FParea	0.01	0.55	0.16	0.30	0.27	0.18	0.31	0.27	0.27
T1: mean FParea	1.34	0.00	0.22	0.00	1.66	1.48	1.31	1.56	1.64
Wet: mean FP area	0.95	0.51	0.05	0.00	0.43	0.28	0.25	0.43	0.42
T2: mean FParea	0.07	0.44	0.01	0.00	0.04	0.04	0.03	0.04	0.04
Dry: mean Pan area	0.09	0.38	0.12	0.27	0.30	0.25	0.31	0.30	0.30
T1: mean Pan area	0.48	0.28	0.48	0.01	0.48	0.48	0.48	0.48	0.48
Wet: mean Pan area	0.48	0.46	0.45	0.01	0.47	0.47	0.47	0.47	0.47

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
T2: mean Pan area	0.48	0.48	0.42	0.01	0.45	0.45	0.45	0.45	0.45
Dry: mean Pan depth	0.15	0.61	0.27	0.42	0.40	0.33	0.43	0.40	0.40
T1: mean Pan depth	1.29	0.19	0.32	0.20	1.56	1.40	1.25	1.46	1.53
Wet: mean Pan depth	0.95	0.56	0.22	0.18	0.51	0.39	0.36	0.51	0.51
T2: mean Pan depth	0.24	0.46	0.18	0.14	0.22	0.21	0.21	0.22	0.22
T1: mean FP & Pan depth	0.78	0.19	0.24	0.20	0.91	0.84	0.76	0.86	0.90
Wet: FP & Pan depth	0.58	0.37	0.20	0.18	0.35	0.29	0.27	0.35	0.35
T2: mean FP & Pan depth	0.21	0.31	0.18	0.14	0.20	0.20	0.20	0.20	0.20

Table 13-2 Mzinyeni Pan and Floodplain: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Floating rooted vegetation	1.2	-43.9	-20.0	6.8	-4.3	-8.9	6.7	6.7
Submerged vegetation	18.3	7.4	20.4	18.5	16.3	19.1	18.4	18.5
Mixed sedge-grass community	62.5	7.2	66.2	53.1	44.9	53.7	51.4	53.0
Reedbeds (P. australis)	19.3	-2.2	17.2	19.7	16.2	17.5	19.6	19.6
Reedbeds (P. mauritianus)	42.6	2.9	37.3	47.5	41.2	48.7	47.2	47.6
Couch grass lawns	29.6	-7.2	15.9	20.8	19.4	20.5	20.6	20.7
Riparian tree communities	-42.2	-3.8	-16.1	-28.5	-22.1	-29.8	-27.9	-28.4
Fish								
Flood-dependent - benthic	61.1	0.9	51.5	46.4	41.8	47.2	45.9	46.3
Flood-dependent - pelagic	61.1	1.1	51.5	46.4	41.8	47.2	45.9	46.3
Flood-independent generalists	-3.0	-3.7	1.4	5.0	2.4	5.0	5.0	5.0
Flood-independent - vegetation	5.5	-3.1	8.1	10.6	7.6	10.7	10.4	10.6
Fish biomass	72.7	3.9	61.4	59.8	51.6	61.0	59.0	59.7

13.1.2.2 Overall ecosystem integrity

The Overall Ecological Integrity for each scenario at Mzinyeni is illustrated in Figure 13.1. Figure 13.1 summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

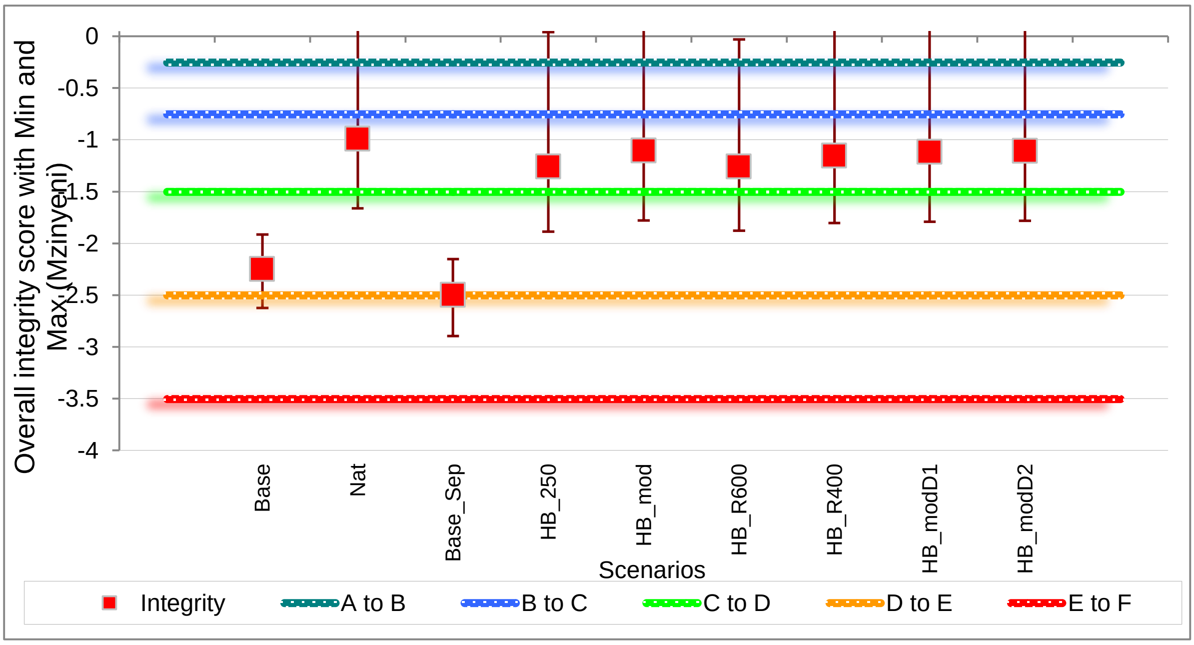


Figure 13.1 Overall ecosystem integrity scores for the scenarios at Mzinyeni. Baseline (2014) integrity is labelled 'Base".

13.1.3 Social

13.1.3.1 Consequences for the indicators used in the DRIFT DSS

The predicted changes for the social indicators are given in Table 13-3. These are discussed in more detail in Section 14.1.

13.1.3.2 Overall well-being

The overall well-being predicted for each scenario is shown in Figure 13.2. These are discussed in Section 14.1.

Table 13-3 Mzinyeni Pan and Floodplain: The mean percentage changes (relative to 2014) for the social indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Fishing - pans	46.8	2.8	38.5	37.8	31.6	38.7	37.1	37.7
Drinking water (domestic and livestock)	11.0	-24.4	10.6	18.8	15.7	18.9	18.7	18.8
Fuel wood	-10.5	0.4	-4.1	-7.3	-5.7	-7.6	-7.1	-7.2
Fruit harvesting	-8.2	2.7	-3.1	-5.3	-3.9	-5.5	-5.1	-5.3
Reeds and grass harvesting	35.1	4.1	34.2	33.7	29.1	33.9	33.3	33.7
Livestock grazing	51.9	-0.7	30.8	40.2	37.4	39.5	39.9	40.1
Floodplain recession agriculture	-5.6	4.4	-15.1	-12.7	-2.2	-11.0	-12.4	-13.3
Perceptions on disease regulation	-58.1	-3.2	-32.1	-33.4	-26.9	-35.5	-32.5	-33.4

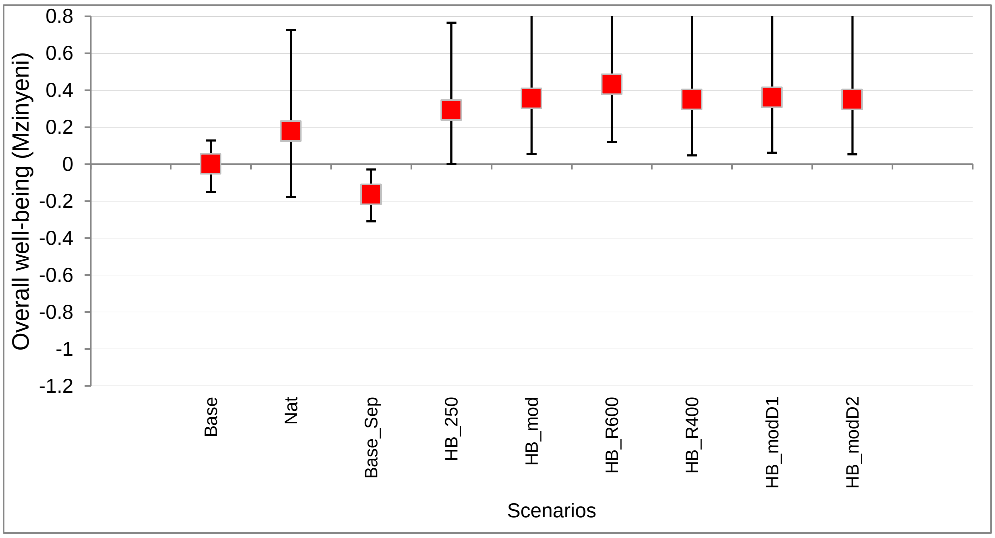


Figure 13.2 Overall well-being scores for the scenarios at Mzinyeni. Baseline (2014) integrity is labelled 'Base'.

13.2 Mthikeni Pan and Floodplain

13.2.1 Hydrology and hydraulics

The summary flow and hydraulic indicators for Mthikeni Pan and Floodplain for the scenarios are given in Table 13-4

13.2.2 Ecosystem

13.2.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at Mthikeni Pan and Floodplain are given in Table 13-5.

All of the scenarios assume present day (2014) level of human pressure on the system.

The changes in individual indicators are discussed in more detail in Section 14.1.

Table 13-4 Median values for the flow and hydraulic indicators for Mthikeni Pan and Floodplain for the scenarios. Codes and units for the indicators are given in Section 10.1.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Dry onset	44.000	10.500	41.00	10.00	10.00	10.00	10.00	10.00	10.00
Dry Min 5d stage	0	0	0.25	0.31	0.56	0.56	0.56	0.56	0.56
Dry duration	340	271	336.50	273.00	210.00	209.00	208.00	210.00	209.00
Wet onset	40.000	45.000	37.00	49.00	40.00	40.00	40.00	40.00	40.00
Wet duration	23.00	75.50	25.00	89.00	153.00	153.50	154.50	153.00	153.00
Wet Max 5d stage / Q	4.52	4.02	4.53	3.16	3.15	3.15	3.16	3.15	3.15
ann: mean Duration Oct exp	280.50	22.00	289.50	183.00	41.00	31.00	35.00	43.00	42.50
annl: mean Onset Oct exp	46.00	27.00	43.00	11.50	45.00	44.00	44.00	44.50	45.00
W/Ann: Days FP depth 0.2-1 (V)	5.00	36.00	5.00	20.00	21.00	20.00	23.00	21.00	21.00
W/Ann: Freq FP cross (V) thold 0.2-1	3.00	6.00	3.00	5.00	6.00	6.00	7.00	6.00	6.00
W/Ann: Frequ connected (F)	1.00	1.00	1.00	1.00	2.00	3.00	2.00	2.00	2.00
W/Ann: sum Days (F)	23.00	75.50	25.00	89.00	113.00	97.50	121.00	111.00	111.50
W: FP & P area 0.2-0.6 m	0.18	0.25	0.29	0.23	0.25	0.27	0.27	0.25	0.25
W: FP area 0.2-1 m	0.07	0.00	0.00	0.00	0.04	0.02	0.01	0.04	0.04
Wet/Ann: Onset ext FP flooding	41.00	44.50	37.50	49.00	40.00	40.00	40.00	40.00	40.00
Wet: mean FP & Pan area	1.18	0.61	0.98	0.40	1.07	1.03	1.02	1.06	1.07
Wet: Mean FP & Pan vol	1.81	0.25	0.71	0.10	0.97	0.83	0.80	0.96	0.97
Dry: mean Pan area 1-1.5 m	0.04	0.17	0.05	0.13	0.15	0.14	0.15	0.14	0.14
T1: mean Pan area 1-1.5 m	0.07	0.00	0.33	0.00	0.00	0.36	0.37	0.00	0.00
Wet: mean Pan area 1-1.5 m	0.24	0.00	0.29	0.00	0.32	0.33	0.33	0.32	0.32
T2: mean Pan area 1-1.5 m	0.31	0.00	0.26	0.00	0.30	0.29	0.28	0.29	0.30
Dry: mean Pan area GT 1m	0.04	0.29	0.11	0.18	0.19	0.20	0.21	0.19	0.19
W: Pan area GT 1m	0.63	0.00	0.29	0.00	0.45	0.38	0.36	0.44	0.45
Dry: mean FParea	0.00	0.07	0.02	0.04	0.03	0.03	0.04	0.03	0.03
T1: mean FParea	0.40	0.00	0.03	0.00	0.45	0.29	0.26	0.45	0.45
Wet: mean FP area	0.21	0.00	0.01	0.00	0.10	0.06	0.05	0.09	0.10
T2: mean FParea	0.02	0.00	0.00	0.00	0.02	0.01	0.01	0.01	0.02
Dry: mean Pan area	0.54	0.87	0.56	0.75	0.82	0.82	0.82	0.82	0.82
T1: mean Pan area	0.97	0.54	0.97	0.43	0.97	0.97	0.97	0.97	0.97
Wet: mean Pan area	0.97	0.61	0.97	0.40	0.97	0.97	0.97	0.97	0.97

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
T2: mean Pan area	0.97	0.61	0.96	0.37	0.97	0.97	0.97	0.97	0.97
Dry: mean Pan depth	0.36	0.81	0.52	0.63	0.66	0.68	0.70	0.65	0.66
T1: mean Pan depth	2.06	0.35	0.77	0.26	2.66	1.50	1.42	2.60	2.64
Wet: mean Pan depth	1.61	0.41	0.73	0.24	0.97	0.84	0.82	0.96	0.97
T2: mean Pan depth	0.75	0.40	0.69	0.22	0.73	0.72	0.71	0.73	0.73
T1: mean FP & Pan depth	1.69	0.35	0.75	0.26	2.23	1.26	1.20	2.18	2.21
Wet: FP & Pan depth	1.41	0.41	0.72	0.24	0.89	0.80	0.78	0.88	0.89
T2: mean FP & Pan depth	0.73	0.40	0.69	0.22	0.72	0.71	0.71	0.72	0.72

Table 13-5 Mthikeni Pan and Floodplain: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move **away** from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move **towards** natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Floating rooted vegetation	-19.6	8.1	-23.3	20.1	20.6	20.8	19.3	20.0
Submerged vegetation	15.8	8.7	17.8	17.2	18.4	17.7	16.6	17.0
Mixed sedge-grass community	44.0	8.6	62.9	47.2	48.6	47.9	45.5	46.8
Reedbeds (P. australis)	8.7	10.3	14.7	27.0	26.8	27.7	26.3	26.8
Reedbeds (P. mauritianus)	34.2	6.7	32.7	46.4	44.3	48.4	44.8	46.3
Couch grass lawns	8.7	9.7	9.7	29.5	29.8	30.6	29.2	29.1
Riparian tree communities	-25.6	-1.6	-24.7	-30.3	-28.9	-31.3	-23.4	-30.1
Fish								
Flood-dependent - benthic	45.8	-0.1	52.6	50.6	51.3	52.7	47.2	45.8
Flood-dependent - pelagic	46.8	-0.2	52.8	50.8	51.4	52.9	47.3	46.8
Flood-independent generalists	1.9	-1.1	-0.5	7.0	7.2	7.2	7.3	1.9
Flood-independent - vegetation	5.0	3.6	3.7	8.3	9.1	8.9	8.7	5.0
Fish biomass	67.0	7.2	73.1	80.5	80.5	83.7	76.6	80.0

13.2.2.2 Overall ecosystem integrity

The Overall Ecological Integrity for each scenario at Mthikeni is illustrated in Figure 13.3. Figure 13.3 summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

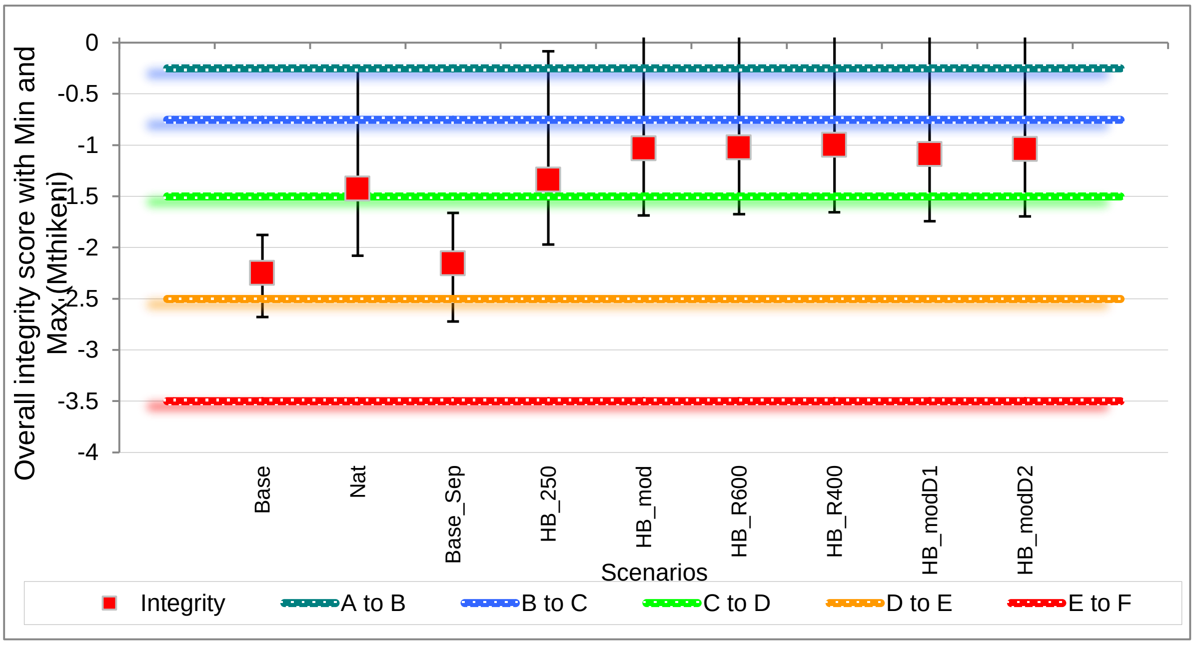


Figure 13.3 Overall ecosystem integrity scores for the scenarios at Mthikeni. Baseline (2014) integrity is labelled 'Base".

13.2.3 Social

13.2.3.1 Consequences for the indicators used in the DRIFT DSS

The predicted changes for the social indicators are given in Table 13-6. These are discussed in more detail in Section 14.1.

13.2.3.2 Overall well-being

The overall well-being predicted for each scenario is shown in Figure 13.4. These are discussed in Section 14.1.

Table 13-6 Mthikeni Pan and Floodplain: The mean percentage changes (relative to 2014) for the social indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Fishing - pans	34.3	3.7	38.2	42.5	42.6	44.3	41.8	42.4
Drinking water (domestic and livestock)	14.6	-0.2	16.3	30.6	30.7	30.8	30.5	30.5
Fuel wood	-8.8	0.4	-8.5	-10.5	-10.1	-10.9	-8.2	-10.5
Fruit harvesting	-4.7	2.1	-4.1	-5.2	-4.8	-5.4	-4.1	-5.2
Reeds and grass harvesting	21.0	6.0	28.3	28.4	28.4	28.8	26.9	28.1
Livestock grazing	6.6	6.8	7.6	22.6	22.8	23.4	22.4	22.4
Floodplain recession agriculture	-9.3	10.2	-4.5	1.4	2.3	-2.6	3.3	0.6
Perceptions on disease regulation	-39.1	-1.4	-35.7	-38.0	-34.2	-39.5	-28.4	-38.0

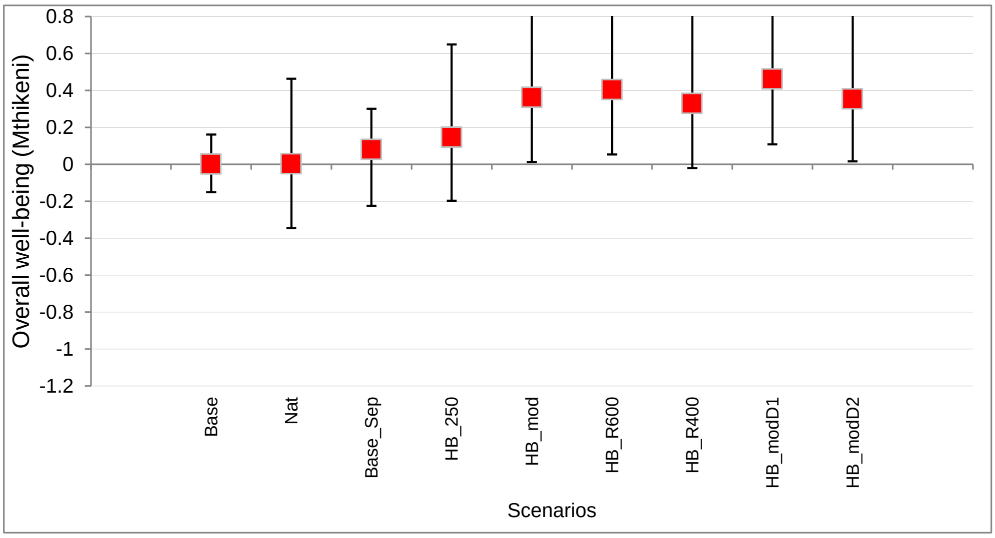


Figure 13.4 Overall well-being scores for the scenarios at Mthikeni. Baseline (2014) integrity is labelled 'Base'.

14 SCENARIO EVALUATION: SUBANE TO SHALALA

For each scenario, the predicted changes in the study pans and their surrounding floodplain are evaluated as:

1. estimated mean percentage change from baseline[92] in the abundance, area or concentration of indicators;
2. the predicted change in Overall Ecosystem Integrity, relative to baseline.

For each scenario, the predicted social changes are evaluated as:

1. estimated mean percentage change from baseline in the abundance, area or concentration of indicators;
2. the predicted change in Overall Well-being, relative to baseline.

Tete Pan, Khangazini Pan and Sivunguvungu Pan were chosen to represent this section of the floodplain.

14.1 Tete Pan and Floodplain

14.1.1 Hydrology and hydraulics

The summary flow and hydraulic indicators for Tete Pan and Floodplain for the scenarios are given in Table 14-1. For Tete, an additional scenario was run because the Present Day hydrology used in the population and calibration of the DRIFT-DSS (see Baseline in Table 14-1) was updated and changed slightly in the subsequent scenario modelling (see Base_UpD in Table 14-1). Both of these were run to check whether the changes made to the hydrology made any appreciable difference to the results from the DSS. The results for Baseline and Base-UpD were almost identical (see Table 12-1 and Section 14.1.2), which meant that the updated baseline could be used as a baseline for the other sites.

14.1.2 Ecosystem

14.1.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at Tete pan and floodplain are given in Table 14-2. With the exception of Base_Sep, all the scenarios result in a considerable improvement in the abundance and or area of most ecosystem indicators. The exceptions are riparian tree communities and fish generalists. The reasons that they are predicted to decline under the scenarios are:

- riparian tree communities benefit from the current low frequency of flooding, and will be reduced with the higher frequency of flooding in the scenarios;

[92] Baseline ecological conditions are those estimated in 2014.

Table 14-1 Median values for the flow and hydraulic indicator for Tete Pan and Floodplain for the scenarios[93]. Codes for the indicators are given in Section 10.1.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2	Base_UpD
Dry onset	43.000	10.500	40.00	9.00	9.00	9.00	9.00	9.00	9.00	43.00
Dry Min 5d stage	0.91	1.36	0.96	1.10	1.35	1.25	1.35	1.35	1.35	0.91
Dry duration	345.00	247.00	345.00	279.00	218.00	216.00	216.00	218.00	218.00	345.00
Wet onset	40.000	44.000	37.00	49.00	40.00	40.00	40.00	40.00	40.00	40.00
Wet duration	18.00	98.00	18.00	84.00	145.00	147.00	147.00	145.00	145.00	18.00
Wet Max 5d stage / Q	4.72	4.48	4.71	4.03	4.03	4.02	4.03	4.03	4.02	4.72
W/Ann: sum Days (F)	18.00	98.00	18.00	70.00	70.50	66.50	87.50	70.00	70.50	18.00
W/Ann: Freq FP cross (V) thold 0.2-1	2.00	3.50	2.00	3.00	3.00	4.00	4.00	3.00	3.00	2.00
W/Ann: Days FP depth 0.2-1 (V)	7.00	37.00	7.00	8.50	8.50	11.50	10.50	8.50	8.50	7.00
ann: mean Pan area 1-1.5 m	0.23	0.66	0.27	1.01	0.28	0.26	0.26	0.28	0.28	0.23
Dry: mean Pan area GT 1m	0.97	1.53	1.12	1.38	1.41	1.40	1.44	1.41	1.41	0.97
W: Pan area GT 1m	2.14	1.16	1.44	1.03	1.68	1.58	1.56	1.68	1.68	2.14
mean Duration Oct exp	306.00	11.00	316.50	29.00	90.00	57.00	58.00	90.00	90.00	306.00
mean Pan area 1-1.5 m	0.23	0.66	0.27	1.01	0.28	0.26	0.26	0.28	0.28	0.23
mean Onset Oct exp	42.00	28.50	39.00	50.00	41.00	41.00	41.00	41.00	41.00	42.00
Dry: mean FParea	0.00	0.14	0.07	0.05	0.04	0.07	0.06	0.04	0.04	0.00
Dry: mean Pan area	1.64	2.08	1.73	1.94	1.97	1.94	2.01	1.97	1.97	1.64
Dry: mean Pan area 1-1.5 m	0.49	0.39	0.49	0.49	0.41	0.46	0.40	0.41	0.41	0.49
Dry: mean Pan area GT 1m	0.97	1.53	1.12	1.38	1.41	1.40	1.44	1.41	1.41	0.97
Dry: mean Pan depth	1.07	1.53	1.22	1.37	1.40	1.39	1.44	1.40	1.40	1.07
T1: mean FP & Pan depth	2.49	1.08	1.48	1.02	2.04	1.88	1.78	2.04	2.03	2.49
T1: mean FParea	2.43	0.00	0.00	0.00	1.56	0.52	0.17	1.56	1.56	2.43
T1: mean Pan area	2.73	1.62	2.09	1.57	2.73	2.73	2.73	2.73	2.73	2.73
T1: mean Pan area 1-1.5 m	0.00	1.03	0.26	1.04	0.34	0.37	0.32	0.34	0.34	0.00
T1: mean Pan depth	3.76	1.08	1.48	1.02	2.89	2.19	1.88	2.89	2.89	3.75
T2: mean FP & Pan depth	1.52	1.21	1.42	0.97	1.45	1.45	1.44	1.45	1.45	1.52
T2: mean FParea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[93] Additional scenario is Base-UpD. See explanation in text.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2	Base_UpD
T2: mean Pan area	2.17	1.74	2.00	1.54	2.04	2.03	2.03	2.03	2.04	2.17
T2: mean Pan area 1-1.5 m	0.25	0.39	0.27	1.00	0.27	0.27	0.27	0.27	0.27	0.25
T2: mean Pan depth	1.52	1.21	1.42	0.97	1.45	1.45	1.44	1.45	1.45	1.52
W/Ann: Days FP depth 0.2-1 (V)	7.00	37.00	7.00	8.50	8.50	11.50	10.50	8.50	8.50	7.00
W/Ann: Freq FP cross (V) thold 0.2-1	2.00	3.50	2.00	3.00	3.00	4.00	4.00	3.00	3.00	2.00
W/Ann: Frequ connected (F)	1.00	1.50	1.00	3.00	4.00	3.00	4.00	4.00	4.00	1.00
W/Ann: sum Days (F)	18.00	98.00	18.00	70.00	70.50	66.50	87.50	70.00	70.50	18.00
W: FP & P area 0.2-0.6 m	0.40	0.21	0.24	0.21	0.31	0.28	0.28	0.31	0.31	0.40
W: FP area 0.2-1 m	0.43	0.00	0.00	0.00	0.06	0.00	0.00	0.06	0.06	0.43
W: Pan area GT 1m	2.14	1.16	1.44	1.03	1.68	1.58	1.56	1.68	1.68	2.14
Wet Max 5d stage / Q	4.72	4.48	4.71	4.03	4.03	4.02	4.03	4.03	4.02	4.72
Wet/Ann: Onset ext FP flooding	41.00	46.00	38.00	49.00	41.00	40.00	40.00	40.50	41.00	41.00
Wet: FP & Pan depth	1.88	1.15	1.44	1.00	1.60	1.55	1.53	1.60	1.60	1.88
Wet: mean FP & Pan area	3.39	1.68	2.03	1.56	2.42	2.26	2.23	2.42	2.42	3.39
Wet: Mean FP & Pan vol	6.73	1.94	2.92	1.55	3.93	3.51	3.43	3.93	3.93	6.74
Wet: mean FP area	0.82	0.00	0.00	0.00	0.09	0.01	0.00	0.09	0.09	0.82
Wet: mean Pan area	2.57	1.68	2.03	1.56	2.33	2.25	2.23	2.33	2.33	2.57
Wet: mean Pan depth	2.32	1.15	1.44	1.00	1.65	1.55	1.53	1.65	1.65	2.32

Table 14-2 Tete Pan and Floodplain: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2	Base_UpD
Vegetation									
Floating rooted vegetation	22.9	8.2	26.5	19.3	18.9	19.5	19.3	19.3	2.9
Submerged vegetation	24.7	5.2	24.2	21.7	21.0	22.4	21.5	21.6	2.1
Mixed sedge-grass community	46.9	11.2	57.9	41.1	36.7	43.0	40.1	41.1	10.4
Reedbeds (P. australis)	23.7	8.0	27.6	24.9	24.3	25.0	24.9	24.9	4.0
Reedbeds (P. mauritianus)	34.5	8.6	24.4	34.5	38.4	35.9	33.4	34.5	7.9
Couch grass lawns	48.4	11.6	64.1	26.6	27.2	29.0	26.4	26.6	3.3
Riparian tree communities	-18.8	-0.9	-16.5	-20.5	-12.6	-21.6	-20.2	-20.5	2.0
Fish									
Flood-dependent - benthic	57.4	3.2	53.2	42.4	41.1	44.4	41.9	42.4	5.6
Flood-dependent - pelagic	61.6	3.2	53.2	42.4	41.1	44.4	41.9	42.4	5.6
Flood-independent generalists	1.4	-0.3	-6.7	-6.2	-2.6	-5.6	-6.2	-6.2	-0.9
Flood-independent - vegetation	17.1	4.6	10.3	7.8	9.0	8.9	7.4	7.7	2.3
Fish biomass	89.0	9.8	72.1	65.4	65.6	67.8	64.5	65.4	89.0

- under baseline conditions, fish generalist have a competitive advantage over species of fish in the other guilds as they are better able to tolerate impacted conditions. They would lose this advantage if flood releases from Jozini Dam better mimicked the natural flow regime, thereby benefiting other fish guilds.

All of the scenarios assume present day (2014) level of human pressure on the system.

The time-series predictions for the vegetation and fish indicators presented in Table 14-2 are provided in Figure 14.1 and Figure 14.2, respectively. This information is only provided for the Tete Pan and Floodplain, as this was the focus site for the DRIFT DSS population and calibration. Thereafter, the relationships developed for Tete were extrapolated to the other sites.

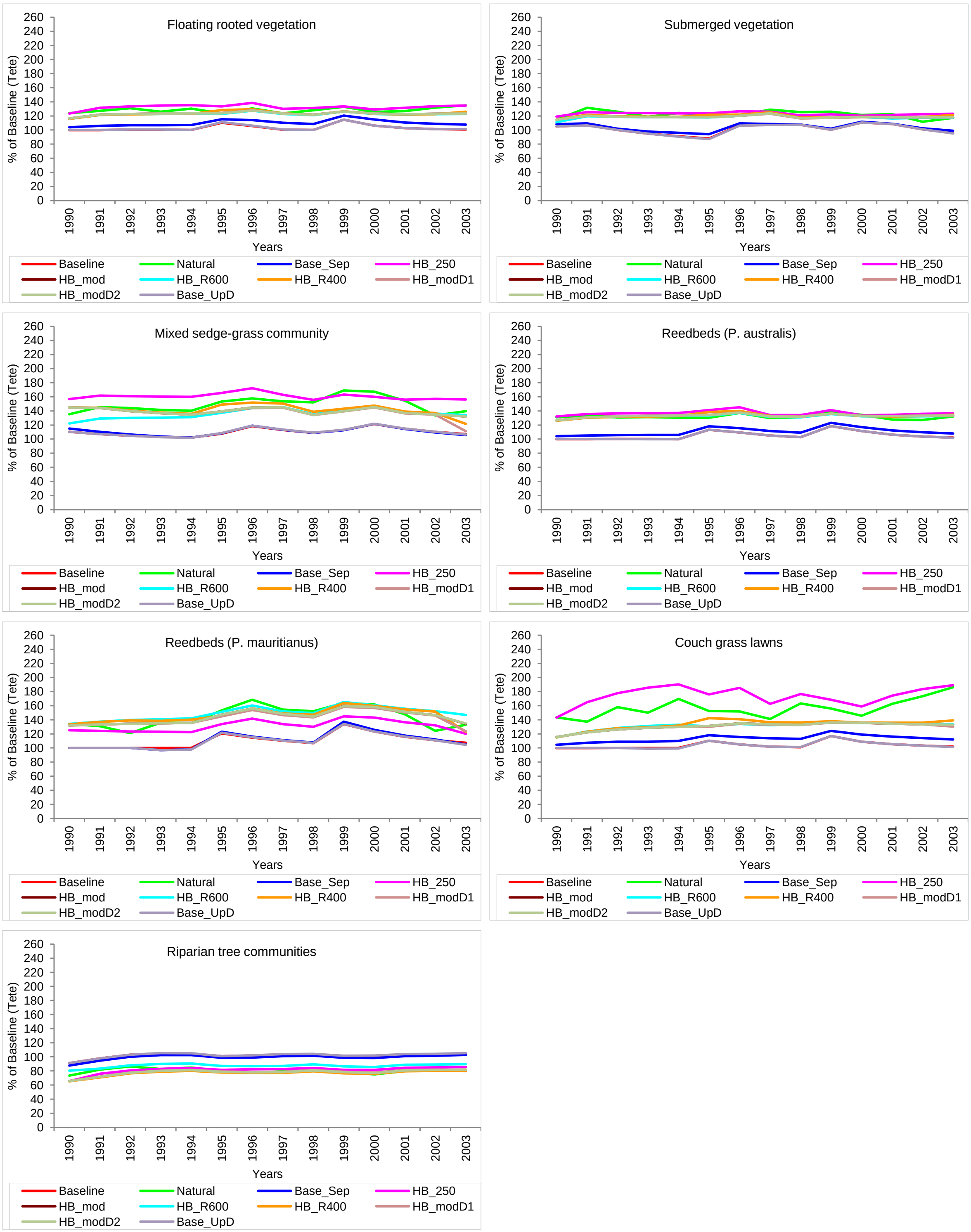
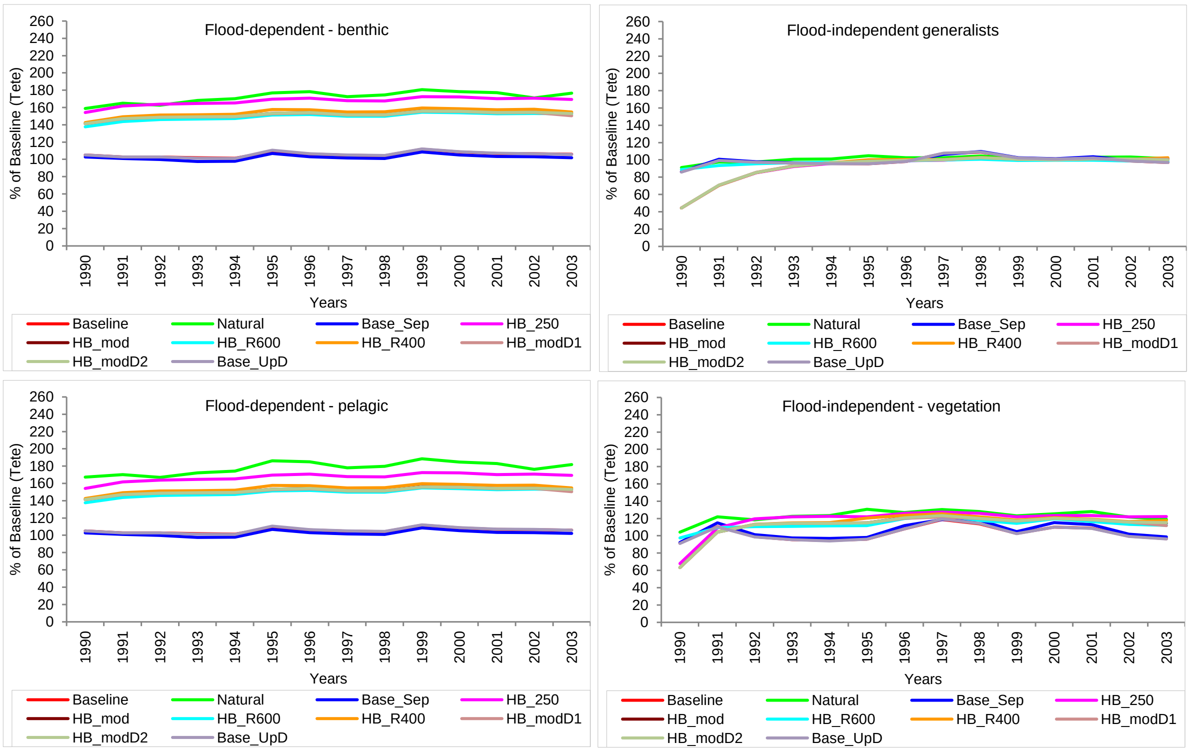


Figure 14.1 Time-series of predicted changes in vegetation indicators at Tete. Scenario lines not visible are hidden by those showing.



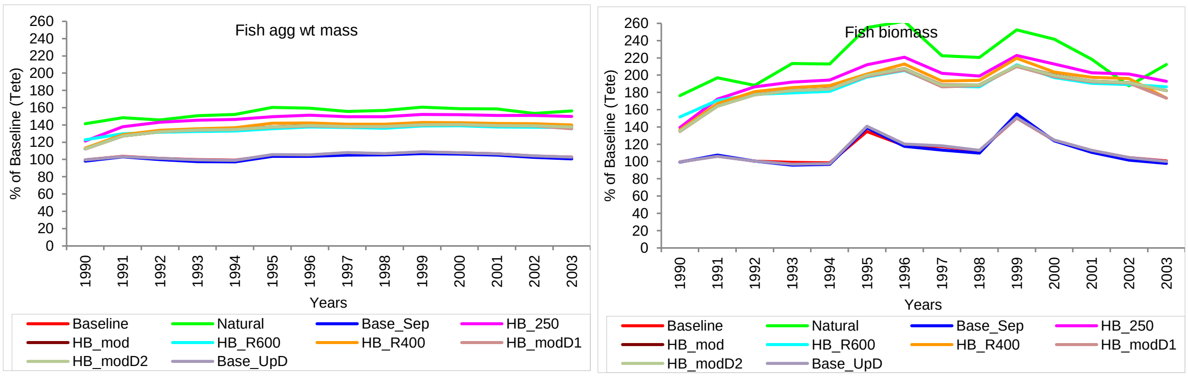


Figure 14.2 Time-series of predicted changes in fish indicators at Tete.

Scenario lines that are not visible in Figure 14.1 and Figure 14.2 are hidden by similar scenario. This is often the case for Baseline (red) and Base-UpD (beige). These two are very similar and so the red line is almost completely hidden by the beige line. The visible line that looks red is in fact the pink line (HB-250).

The period simulated is 1990-2003. Figure 14.1 and Figure 14.2 show the year-on-year changes in each indicator in response to the prevailing conditions. These conditions, derived using the historical flow records (1990-2003), show the predicted response for each indicator, under the condition specified in each scenario, should the same flow conditions be replicated into the future with the exception that the scenarios assume present day (2013) level of human pressure on the system.

The response for the indicators will change if direct human pressures on the system, from activities such as cultivation, grazing of livestock, fishing and harvesting of fruit, change. An estimate of the predicted changes in the outcomes for the naturalised and baseline scenarios should pressure be doubled or halved are given in Section 10.5.

14.1.2.2 Overall ecosystem integrity

The Overall Ecological Integrity for each scenario at Tete is illustrated in Figure 14.3. Figure 14.3 summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

For Tete, the results show that all of the scenarios other than the Baseline, Base_UpD and Base_Sept scenarios are expected to improve ecosystem condition from a D-E category to a C/D category. Given the current level human use of the system it is unlikely that flow alone will be able to improve conditions much beyond a B/C category. There is also very little to differentiate Natural and some of the HB scenarios. Although these differences may well appear if the human pressures on the system were lower, the current situation makes it difficult to resolve them.

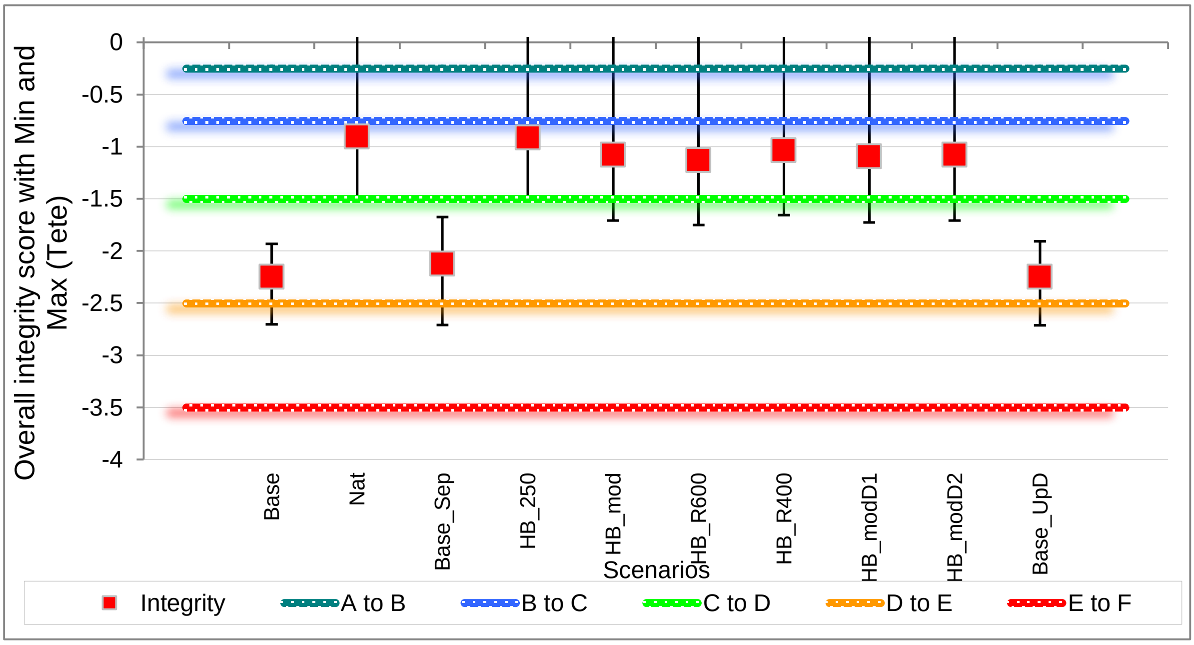


Figure 14.3 Overall ecosystem integrity scores for the scenarios at Tete. Baseline (2014) integrity is labelled 'Base".

14.1.3 Social

14.1.3.1 Consequences for the indicators used in the DRIFT DSS

The predicted changes for the social indicators are given in Table 14-3.

Table 14-3 Tete Pan and Floodplain: The mean percentage changes (relative to 2014) for the social indicators for the scenarios.

Colour coding:
Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.
Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Fishing - pans	53.7	8.4	46.7	45.4	46.0	46.2	44.7	45.3
Drinking water (domestic and livestock)	16.0	-2.2	5.3	12.4	17.0	12.1	12.3	12.4
Fuel wood	-4.6	4.5	-4.1	-5.2	-3.2	-5.4	-5.1	-5.2
Fruit harvesting	-3.7	5.1	-2.3	-3.0	-1.9	-3.3	-3.0	-3.0
Reeds and grass harvesting	34.8	9.5	37.8	34.8	32.5	35.9	34.5	34.7
Livestock grazing	164.5	38.5	206.9	91.8	93.9	99.8	91.1	91.9
Floodplain recession agriculture	-8.1	10.3	-0.2	7.6	8.4	7.2	4.2	7.1
Perceptions on disease regulation	-45.2	-5.4	-18.2	-18.4	-22.2	-19.9	-17.2	-18.3

The results for individual indicators are more variable that those for the ecosystem indicators. The predictions are:

- Fishing in pans is based on and so follows the same trends as fish biomass (Table 14-2).
- Drinking water (domestic and livestock) improves but only slightly for all but three baseline scenarios (Base, Base_UpD and Base-Sept).
- The slight decline predicted for fuel wood and fruit harvesting is related to reduced access
- Reeds and grass harvesting is based on, and so follows the same trends as, reedbeds (Table 14-2).

- Livestock grazing is expected to do much better for Natural and HB_250 mainly because it (1) improves the couch grass and (2) ensures a ready access to water through the summer months.
- As expected floodplain recession agriculture is predicted to benefit most from Base_Sept, which moves the current October flood into September in order to allow earlier planting and multiple harvests. However, it will also be positively affected by some of the HB scenarios that provide the December floods in October.
- Perceptions on disease regulation worsen as the flow regime moves closer towards natural. Whether these perceptions are correct or not, people perceive that frequent flooding and longer durations of standing water on the floodplain increases diseases such as malaria.
- Reeds for reed dance harvesting are based on reedbeds and so follows the same trends (Table 14-2).

14.1.3.2 Overall well-being

The overall well-being follows the same trends as overall ecosystem integrity despite the adverse effects of the HB scenarios on recession agriculture (Figure 14.4).

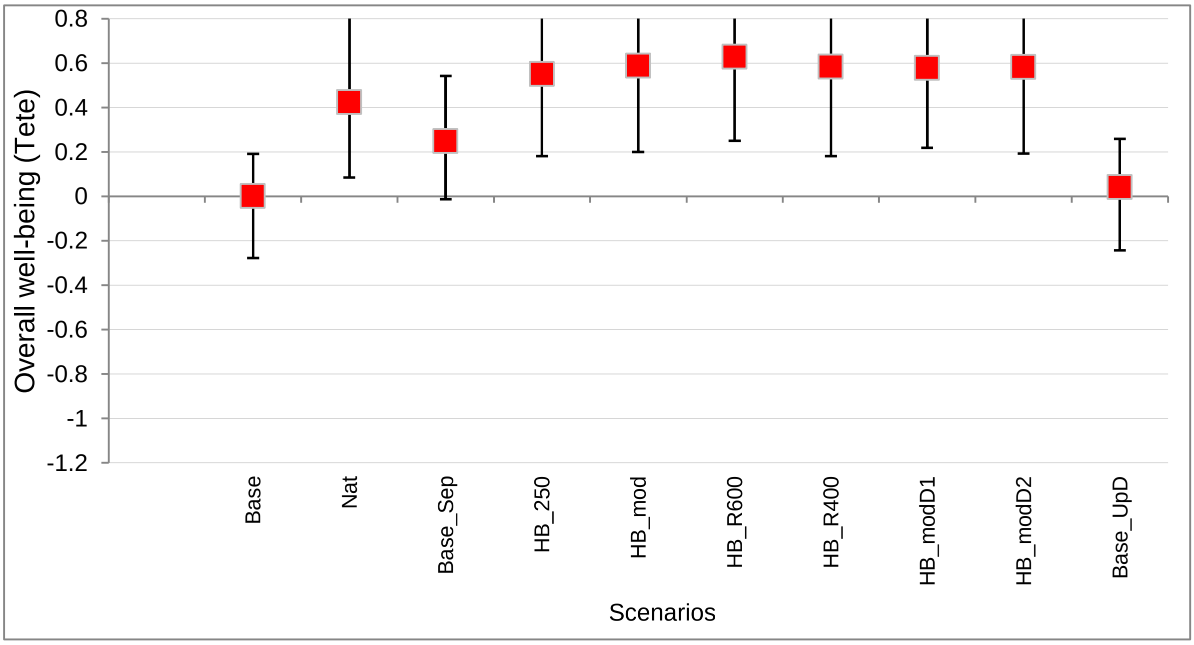


Figure 14.4 Overall well-being scores for the scenarios at Tete. Baseline (2014) integrity is labelled 'Base'.

14.2 Khangazini Pan and Floodplain

14.2.1 Hydrology and hydraulics

The summary flow and hydraulic indicators for Khangazini Pan and Floodplain for the scenarios are given in Table 14-5

14.2.2 Ecosystem

14.2.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at Khangazini Pan and Floodplain are given in Table 14-5.

All of the scenarios assume present day (2014) level of human pressure on the system.

The changes in individual indicators are discussed in more detail in Section 14.1.

Table 14-4 Median values for the flow and hydraulic indicators for Khangazini Pan and Floodplain for the scenarios. Codes and units for the indicators are given in Section 10.1.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Dry onset	43.00	14.00	40.00	9.50	8.00	9.00	9.00	8.00	8.00
Dry Min 5d stage	0.10	0.15	0.15	0.13	0.37	0.38	0.38	0.38	0.37
Dry duration	348.50	298.50	349.00	291.50	230.00	227.00	229.00	230.00	230.00
Wet onset	41.00	46.00	38.00	49.00	41.00	40.00	41.00	41.00	41.00
Wet duration	14.00	41.50	13.50	71.50	132.00	136.00	133.00	132.00	132.00
Wet Max 5d stage / Q	3.40	3.09	3.41	2.19	2.19	2.18	2.19	2.19	2.19
ann: mean Duration Oct exp	308.50	6.00	319.00	60.00	121.00	61.00	60.00	121.00	121.00
annl: mean Onset Oct exp	42.00	46.50	39.00	50.00	41.00	41.00	50.00	41.00	41.00
W/Ann: Days FP depth 0.2-1 (V)	4.00	7.00	4.00	0.00	0.00	0.50	0.00	0.00	0.00
W/Ann: Freq FP cross (V) thold 0.2-1	2.00	3.00	2.00	1.00	1.00	1.50	1.00	1.00	1.00
W/Ann: Frequ connected (F)	1.00	2.00	1.00	2.00	2.00	3.00	3.00	2.00	2.00
W/Ann: sum Days (F)	9.00	34.00	9.00	11.50	11.50	18.50	14.50	11.50	11.50
W: FP & P area 0.2-0.6 m	0.16	0.09	0.18	0.05	0.18	0.18	0.18	0.18	0.18
W: FP area 0.2-1 m	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet/Ann: Onset ext FP flooding	41.00	43.00	38.00	0.00	0.00	2.50	0.00	0.00	0.00
Wet: mean FP & Pan area	0.79	0.20	0.52	0.11	0.57	0.55	0.55	0.57	0.57
Wet: Mean FP & Pan vol	0.93	0.05	0.31	0.02	0.38	0.35	0.34	0.38	0.38
Dry: mean Pan area 1-1.5 m	0.01	0.04	0.02	0.03	0.03	0.04	0.04	0.03	0.03
T1: mean Pan area 1-1.5 m	0.13	0.00	0.08	0.00	0.23	0.18	0.11	0.21	0.22
Wet: mean Pan area 1-1.5 m	0.13	0.00	0.07	0.00	0.11	0.10	0.10	0.11	0.12
T2: mean Pan area 1-1.5 m	0.09	0.00	0.07	0.00	0.09	0.09	0.09	0.09	0.09
Dry: mean Pan area GT 1m	0.01	0.07	0.04	0.04	0.03	0.05	0.05	0.03	0.03
W: Pan area GT 1m	0.36	0.00	0.07	0.00	0.12	0.10	0.10	0.13	0.13
Dry: mean FParea	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
T1: mean FParea	0.35	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01
Wet: mean FP area	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2: mean FParea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dry: mean Pan area	0.24	0.40	0.26	0.35	0.37	0.40	0.40	0.38	0.38
T1: mean Pan area	0.77	0.19	0.53	0.11	0.76	0.66	0.56	0.69	0.71

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Wet: mean Pan area	0.67	0.20	0.51	0.11	0.56	0.55	0.55	0.57	0.57
T2: mean Pan area	0.54	0.18	0.51	0.10	0.54	0.53	0.53	0.53	0.54
Dry: mean Pan depth	0.30	0.51	0.38	0.42	0.44	0.47	0.47	0.44	0.44
T1: mean Pan depth	2.06	0.25	0.61	0.20	0.91	0.77	0.65	0.81	0.84
Wet: mean Pan depth	1.18	0.26	0.59	0.20	0.66	0.64	0.63	0.66	0.66
T2: mean Pan depth	0.62	0.25	0.58	0.19	0.62	0.61	0.61	0.62	0.62
T1: mean FP & Pan depth	1.61	0.25	0.61	0.20	0.90	0.77	0.65	0.81	0.84
Wet: FP & Pan depth	1.01	0.26	0.59	0.20	0.66	0.64	0.63	0.66	0.66
T2: mean FP & Pan depth	0.62	0.25	0.58	0.19	0.62	0.61	0.61	0.62	0.62

Table 14-5 Khangazini Pan and Floodplain: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Floating rooted vegetation	-24.8	-4.2	-21.1	14.8	14.1	10.8	13.0	15.4
Submerged vegetation	13.2	8.2	17.0	14.2	19.5	15.9	12.9	14.6
Mixed sedge-grass community	25.6	-1.3	16.5	17.0	21.2	15.2	10.4	16.5
Reedbeds (P. australis)	5.9	-1.0	10.4	16.2	16.4	15.3	15.4	16.6
Reedbeds (P. mauritianus)	39.4	-0.6	15.1	38.7	44.1	35.1	30.2	38.9
Couch grass lawns	2.7	-6.9	0.7	7.1	10.9	6.9	6.9	7.6
Riparian tree communities	-7.3	-3.7	-2.5	-9.5	-9.7	-8.7	-7.5	-9.4
Fish								
Flood-dependent - benthic	33.9	-4.4	29.5	29.9	36.4	29.6	26.6	29.8
Flood-dependent - pelagic	49.8	-2.9	47.2	46.5	54.9	46.3	42.7	46.3
Flood-independent generalists	2.2	1.0	1.8	6.2	5.6	5.0	5.5	6.4
Flood-independent - vegetation	6.7	1.7	6.0	11.8	12.7	10.4	9.7	11.9
Fish biomass	62.7	5.2	54.3	65.1	75.0	63.2	58.2	65.2

14.2.2.2 Overall ecosystem integrity

The Overall Ecological Integrity for each scenario at Khangazini is illustrated in Figure 14.5. Figure 14.5 summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

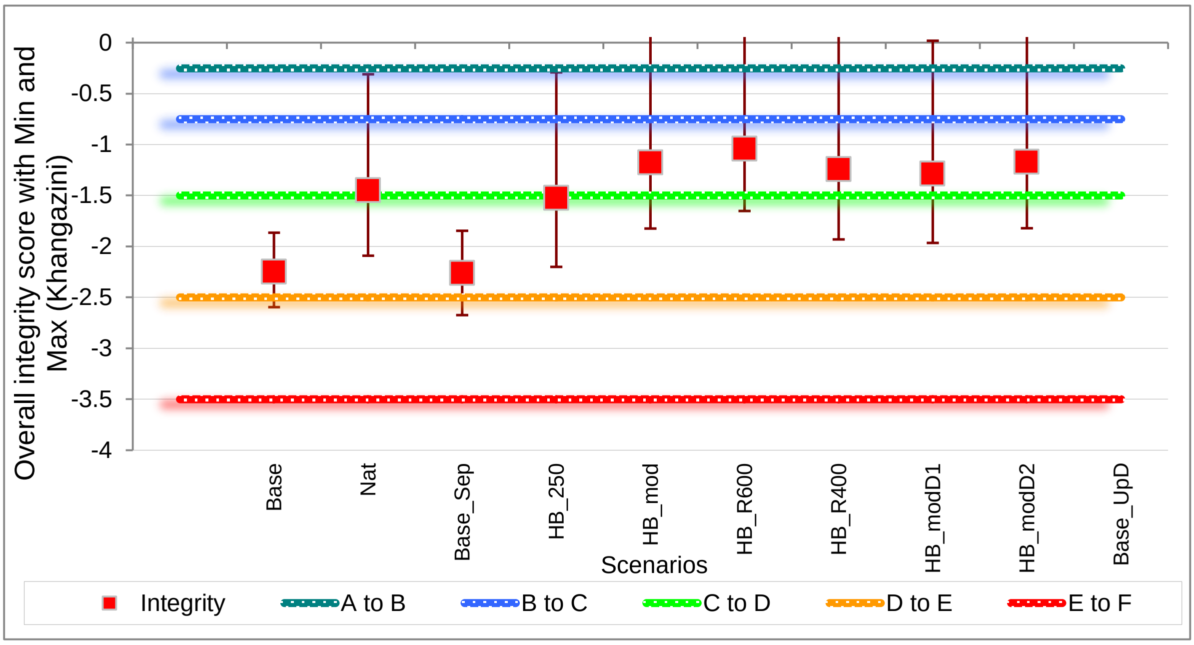


Figure 14.5 Overall ecosystem integrity scores for the scenarios at Khangazini. Baseline (2014) integrity is labelled 'Base".

14.2.3 Social

14.2.3.1 Consequences for the indicators used in the DRIFT DSS

The predicted changes for the social indicators are given in Table 14-6. These are discussed in Section 14.1.

14.2.3.2 Overall well-being

The overall well-being predicted for each scenario is shown in Figure 14.6. These are discussed in Section 14.1.

Table 14-6 Khangazini Pan and Floodplain: The mean percentage changes (relative to 2014) for the social indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Fishing - pans	43.1	4.1	36.7	46.5	53.3	45.3	41.8	46.6
Drinking water (domestic and livestock)	-19.3	3.3	-31.9	-36.4	1.6	-16.3	-37.7	-37.1
Fuel wood	-4.4	1.7	-4.9	-5.5	-3.2	-6.4	-8.0	-5.3
Fruit harvesting	-1.6	2.8	-1.7	-1.9	-0.8	-2.0	-2.7	-1.8
Reeds and grass harvesting	-0.1	4.8	-7.1	-6.0	-13.5	-13.5	-9.8	-6.3
Livestock grazing	-2.7	5.3	-5.3	-5.2	-5.9	-4.1	-6.1	-5.6
Floodplain recession agriculture	-21.4	4.7	-25.8	-25.9	-23.6	-23.8	-26.9	-25.0
Perceptions on disease regulation	4.4	-1.5	22.1	22.1	19.8	22.4	23.9	22.1

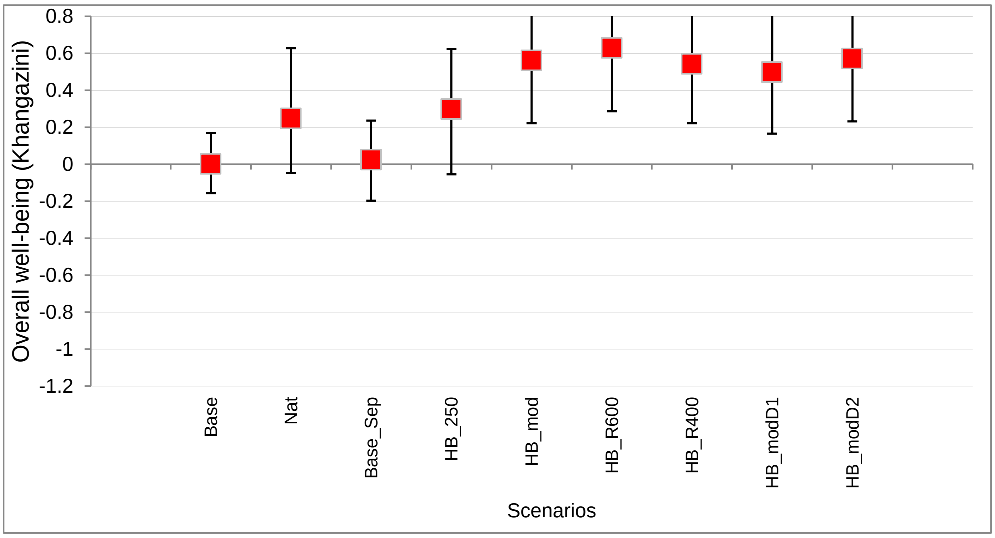


Figure 14.6 Overall well-being scores for the scenarios at Khangazini. Baseline (2014) integrity is labelled 'Base'.

15 SCENARIO EVALUATION: SHALALA TO NDUMO BORDER

For each scenario, the predicted changes in the study pans and their surrounding floodplain are evaluated as:

1. estimated mean percentage change from baseline[94] in the abundance, area or concentration of indicators;
2. the predicted change in Overall Ecosystem Integrity, relative to baseline.

For each scenario, the predicted social changes are evaluated as:

1. estimated mean percentage change from baseline in the abundance, area or concentration of indicators;
2. the predicted change in Overall Well-being, relative to baseline.

Shalala Pan, Sokunti Pan, Namanini Pan and Mandlankuzi Pan were chosen to represent this section of the floodplain.

15.1 Shalala Pan and Floodplain

15.1.1 Hydrology and hydraulics

The summary flow and hydraulic indicators for Shalala Pan and Floodplain for the scenarios are given in Table 15-1

15.1.2 Ecosystem

15.1.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at Shalala Pan and Floodplain are given in Table 15-2.

All of the scenarios assume present day (2014) level of human pressure on the system.

The changes in individual indicators are discussed in more detail in Section 14.1.

[94] Baseline ecological conditions are those estimated in 2014.

Table 15-1 Median values for the flow and hydraulic indicators for Shalala Pan and Floodplain for the scenarios. Codes and units for the indicators are given in Section 10.1.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Dry onset	42.00	12.00	39.00	8.50	8.50	8.50	8.50	8.50	8.50
Dry Min 5d stage	0.23	0.36	0.26	0.18	0.41	0.43	0.42	0.41	0.41
Dry duration	351.00	293.50	351.00	295.00	232.50	229.00	233.00	233.00	233.00
Wet onset	41.00	46.00	38.00	6.00	41.00	40.00	49.00	41.00	41.00
Wet duration	12.00	51.50	12.00	30.50	129.00	134.00	71.00	128.50	128.00
Wet Max 5d stage / Q	3.90	3.55	3.90	2.50	2.47	2.46	2.50	2.47	2.48
ann: mean Duration Oct exp	307.50	5.00	318.00	0.00	0.00	60.50	59.00	6.00	5.00
annl: mean Onset Oct exp	42.00	46.50	39.00	7.50	8.50	41.00	50.00	7.50	8.50
W/Ann: Days FP depth 0.2-1 (V)	4.00	12.50	4.00	2.00	2.00	2.00	2.00	2.00	2.00
W/Ann: Freq FP cross (V) thold 0.2-1	2.00	3.00	2.00	2.00	2.00	2.50	2.00	2.00	2.00
W/Ann: Frequ connected (F)	1.00	1.00	1.00	2.00	2.00	3.00	2.00	2.00	2.00
W/Ann: sum Days (F)	12.00	33.50	12.00	17.00	41.00	97.50	53.50	45.00	42.50
W: FP & P area 0.2-0.6 m	0.08	0.18	0.06	0.28	0.07	0.07	0.06	0.07	0.07
W: FP area 0.2-1 m	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet/Ann: Onset ext FP flooding	41.00	45.00	38.00	6.00	6.00	7.00	6.00	6.50	6.00
Wet: mean FP & Pan area	0.82	0.43	0.58	0.38	0.60	0.61	0.51	0.61	0.61
Wet: Mean FP & Pan vol	1.49	0.22	0.65	0.12	0.70	0.72	0.45	0.71	0.71
Dry: mean Pan area 1-1.5 m	0.12	0.14	0.12	0.12	0.17	0.16	0.14	0.17	0.17
T1: mean Pan area 1-1.5 m	0.00	0.00	0.29	0.00	0.18	0.12	0.24	0.18	0.35
Wet: mean Pan area 1-1.5 m	0.10	0.00	0.33	0.00	0.19	0.17	0.20	0.18	0.18
T2: mean Pan area 1-1.5 m	0.21	0.00	0.39	0.00	0.24	0.18	0.26	0.22	0.21
Dry: mean Pan area GT 1m	0.13	0.19	0.14	0.15	0.19	0.21	0.18	0.19	0.19
W: Pan area GT 1m	0.55	0.00	0.41	0.00	0.43	0.43	0.27	0.42	0.43
Dry: mean FParea	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
T1: mean FParea	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet: mean FP area	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2: mean FParea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dry: mean Pan area	0.46	0.50	0.46	0.47	0.50	0.51	0.50	0.50	0.50
T1: mean Pan area	0.67	0.43	0.58	0.39	0.61	0.65	0.50	0.58	0.56
Wet: mean Pan area	0.65	0.43	0.58	0.38	0.60	0.61	0.51	0.60	0.61

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
T2: mean Pan area	0.59	0.43	0.57	0.37	0.59	0.60	0.50	0.59	0.59
Dry: mean Pan depth	0.67	0.90	0.71	0.72	0.82	0.85	0.81	0.81	0.81
T1: mean Pan depth	4.15	0.47	1.13	0.32	1.17	1.25	0.87	1.12	1.08
Wet: mean Pan depth	2.02	0.52	1.12	0.31	1.17	1.17	0.89	1.17	1.17
T2: mean Pan depth	1.15	0.50	1.11	0.29	1.14	1.16	0.88	1.15	1.15
T1: mean FP & Pan depth	3.24	0.47	1.13	0.32	1.17	1.25	0.87	1.12	1.08
Wet: FP & Pan depth	1.68	0.52	1.12	0.31	1.16	1.17	0.89	1.17	1.17
T2: mean FP & Pan depth	1.15	0.50	1.11	0.29	1.14	1.16	0.88	1.15	1.15

Table 15-2 Shalala Pan and Floodplain: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Floating rooted vegetation	-26.1	10.9	-31.7	18.7	17.7	12.9	14.9	18.1
Submerged vegetation	10.4	6.2	9.7	13.6	15.9	17.4	13.2	13.6
Mixed sedge-grass community	7.8	1.1	-24.4	-20.9	-16.0	0.5	-21.3	-20.0
Reedbeds (P. australis)	8.8	10.4	0.6	20.1	20.6	21.0	19.6	19.5
Reedbeds (P. mauritianus)	11.4	0.7	-8.2	0.4	4.8	0.9	3.0	2.7
Couch grass lawns	2.6	23.7	-7.3	20.9	21.2	21.9	19.3	20.9
Riparian tree communities	-10.4	1.5	-1.4	-8.4	-7.7	-7.0	-6.4	-7.4
Fish								
Flood-dependent - benthic	23.1	2.7	-3.4	16.8	28.0	34.0	17.6	17.6
Flood-dependent - pelagic	19.4	2.6	-6.0	15.0	25.5	30.9	15.6	15.7
Flood-independent generalists	-8.1	1.2	-7.7	-2.4	-2.9	-3.2	-4.5	-2.6
Flood-independent - vegetation	-3.6	6.0	-9.3	0.6	0.8	2.4	-1.4	0.4
Fish biomass	26.5	7.0	-4.2	21.3	32.5	36.0	21.1	26.5

15.1.2.2 Overall ecosystem integrity

The Overall Ecological Integrity for each scenario at Shalala is illustrated in Figure 15.1. Figure 15.1 summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

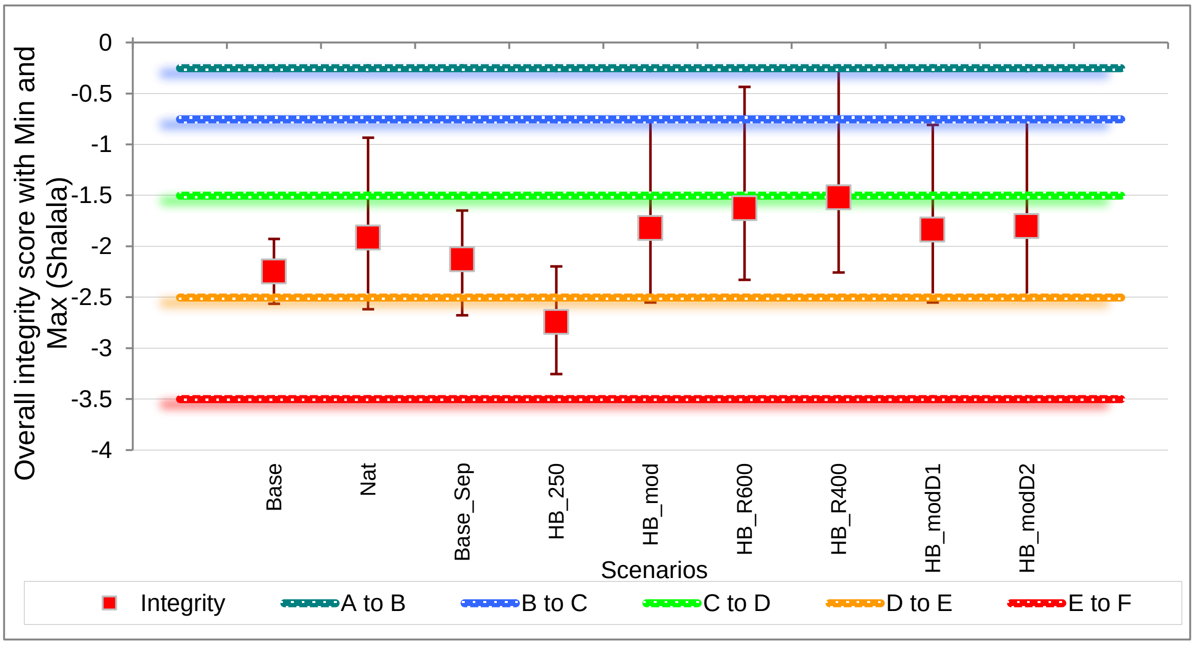


Figure 15.1 Overall ecosystem integrity scores for the scenarios at Shalala. Baseline (2014) integrity is labelled 'Base".

15.1.3 Social

15.1.3.1 Consequences for the indicators used in the DRIFT DSS

The predicted changes for the social indicators are given in Table 14-3. These are discussed in Section 14.1.

15.1.3.2 Overall well-being

The overall well-being predicted for each scenario is shown in Figure 15.2. These are discussed in Section 14.1.

Table 15-3 Shalala Pan and Floodplain: The mean percentage changes (relative to 2014) for the social indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Fishing - pans	15.6	3.6	-9.4	8.3	15.4	18.4	8.2	9.2
Drinking water (domestic and livestock)	-5.6	-0.8	-6.8	15.1	11.9	10.9	8.9	14.9
Fuel wood	-9.2	1.1	-1.7	-8.1	-7.5	-6.9	-6.4	-7.3
Fruit harvesting	-4.7	2.7	0.7	-2.7	-2.3	-2.0	-1.7	-2.2
Reeds and grass harvesting	5.7	2.6	-11.6	-7.2	-3.2	2.5	-6.8	-5.6
Livestock grazing	9.0	59.3	-1.6	51.8	54.0	56.4	48.6	52.6
Floodplain recession agriculture	-12.4	10.3	-8.4	-8.8	-1.6	-7.2	-8.1	-7.7
Perceptions on disease regulation	-19.2	-1.0	6.1	6.6	6.0	6.6	7.0	6.7

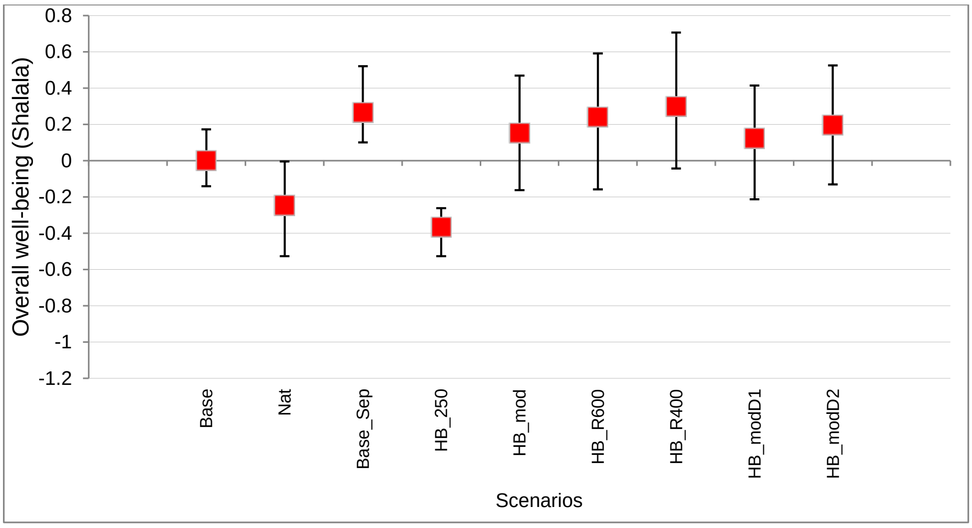


Figure 15.2 Overall well-being scores for the scenarios at Shalala. Baseline (2014) integrity is labelled 'Base'.

15.2 Sokunti Pan and Floodplain

15.2.1 Hydrology and hydraulics

The summary flow and hydraulic indicators for Sokunti Pan and Floodplain for the scenarios are given in Table 15-4.

15.2.2 Ecosystem

15.2.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at Sokunti Pan and Floodplain are given in Table 15-5.

All of the scenarios assume present day (2014) level of human pressure on the system.

The changes in individual indicators are discussed in more detail in Section 14.1.

Table 15-4 Median values for the flow and hydraulic indicators for Sokunti Pan and Floodplain for the scenarios. Codes and units for the indicators are given in Section 10.1.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Dry onset	42.5	10.5	39.0	9.5	9.0	9.5	9.5	9.0	9.0
Dry Min 5d stage	1.5	1.5	1.5	1.6	1.8	1.8	1.8	1.8	1.8
Dry duration	350.5	304.0	350.5	283.0	219.5	216.5	221.0	220.5	220.0
Wet onset	41.0	46.0	38.0	6.0	41.0	40.0	49.0	41.0	41.0
Wet duration	12.5	46.5	12.5	32.0	140.0	144.5	82.0	139.5	139.5
Wet Max 5d stage / Q	5.3	5.0	5.3	3.7	3.7	3.7	3.7	3.7	3.7
ann: mean Duration Oct exp	295.5	51.5	291.0	32.5	89.0	34.0	35.0	89.5	87.5
annl: mean Onset Oct exp	44.5	15.5	41.5	12.0	45.0	44.0	12.0	46.0	45.5
W/Ann: Days FP depth 0.2-1 (V)	7.0	17.0	7.0	4.0	4.0	5.0	4.0	4.0	4.0
W/Ann: Freq FP cross (V) thold 0.2-1	2.0	3.0	2.0	2.0	2.0	3.5	2.0	2.0	2.0
W/Ann: Frequ connected (F)	1.0	1.0	1.0	1.5	2.0	3.0	2.0	2.0	2.0
W/Ann: sum Days (F)	12.5	46.5	13.0	32.0	57.5	88.0	53.5	57.0	58.5
W: FP & P area 0.2-0.6 m	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
W: FP area 0.2-1 m	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet/Ann: Onset ext FP flooding	41.0	45.0	38.0	6.0	6.0	40.0	6.5	6.5	6.0
Wet: mean FP & Pan area	1.4	0.9	1.1	0.9	1.1	1.1	1.0	1.1	1.1
Wet: Mean FP & Pan vol	3.8	1.5	2.2	1.4	2.3	2.2	1.8	2.3	2.3
Dry: mean Pan area 1-1.5 m	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
T1: mean Pan area 1-1.5 m	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wet: mean Pan area 1-1.5 m	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
T2: mean Pan area 1-1.5 m	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dry: mean Pan area GT 1m	0.8	0.9	0.8	0.8	0.8	0.9	0.8	0.8	0.8
W: Pan area GT 1m	1.0	0.8	0.9	0.8	0.9	0.9	0.8	0.9	0.9
Dry: mean FParea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T1: mean FParea	1.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Wet: mean FP area	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
T2: mean FParea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dry: mean Pan area	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
T1: mean Pan area	1.1	0.9	1.1	0.9	1.0	1.1	1.0	1.0	1.0
Wet: mean Pan area	1.1	0.9	1.1	0.9	1.1	1.1	1.0	1.1	1.1

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
T2: mean Pan area	1.1	0.9	1.1	0.9	1.1	1.1	1.0	1.1	1.1
Dry: mean Pan depth	1.6	1.9	1.7	1.8	1.9	1.9	1.9	1.9	1.9
T1: mean Pan depth	5.3	1.5	2.0	1.5	1.8	2.5	1.8	1.8	1.9
Wet: mean Pan depth	3.2	1.6	2.0	1.5	2.2	2.1	1.8	2.1	2.2
T2: mean Pan depth	2.1	1.6	2.0	1.5	2.1	2.1	1.8	2.1	2.1
T1: mean FP & Pan depth	3.5	1.5	2.0	1.5	1.8	2.3	1.8	1.8	1.9
Wet: FP & Pan depth	2.6	1.6	2.0	1.5	2.1	2.1	1.8	2.1	2.1
T2: mean FP & Pan depth	2.1	1.6	2.0	1.5	2.1	2.1	1.8	2.1	2.1

Table 15-5 Sokunti Pan and Floodplain: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Floating rooted vegetation	17.6	8.5	16.6	20.0	20.2	20.8	19.7	19.2
Submerged vegetation	15.6	6.0	18.0	20.4	21.3	24.3	19.6	20.4
Mixed sedge-grass community	23.2	-1.6	33.5	35.3	39.2	54.7	33.3	35.2
Reedbeds (*P. australis*)	18.4	8.4	17.5	25.4	25.4	24.3	24.3	24.0
Reedbeds (*P. mauritianus*)	12.7	2.2	0.7	19.8	24.5	8.5	16.1	16.6
Couch grass lawns	21.3	13.4	20.9	26.4	29.7	22.3	27.6	25.1
Riparian tree communities	-12.1	-1.9	-15.3	-17.4	-18.1	-16.3	-16.0	-16.7
Fish								
Flood-dependent - benthic	26.5	1.3	19.9	37.4	41.8	45.8	34.5	35.4
Flood-dependent - pelagic	30.6	1.6	20.1	37.9	42.4	45.8	34.8	35.7
Flood-independent generalists	-1.3	0.4	-12.2	-10.5	-10.5	-10.5	-11.0	-10.5
Flood-independent - vegetation	7.0	4.0	2.5	6.0	7.0	7.5	5.1	5.8
Fish biomass	37.1	6.3	20.1	50.5	55.0	52.9	46.4	47.4

15.2.2.2 Overall ecosystem integrity

The Overall Ecological Integrity for each scenario at Sokunti is illustrated in Figure 15.3. Figure 15.3. summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

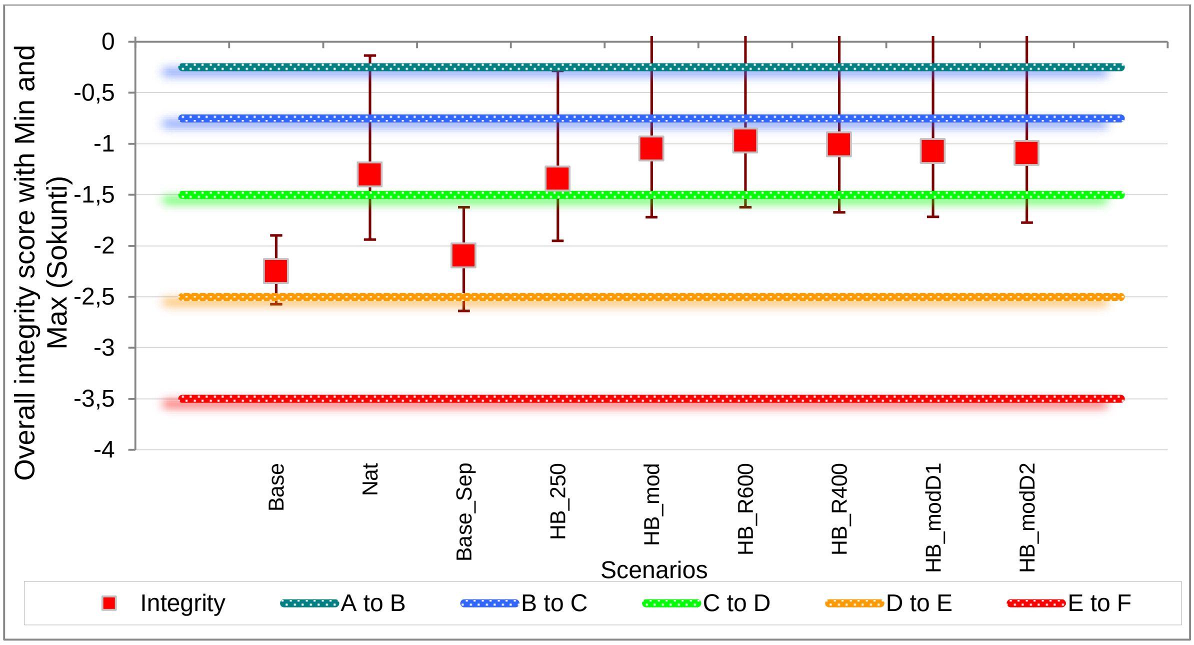


Figure 15.3 Overall ecosystem integrity scores for the scenarios at Sokunti. Baseline (2014) integrity is labelled 'Base".

15.2.3 Social

15.2.3.1 Consequences for the indicators used in the DRIFT DSS

The predicted changes for the social indicators are given in Table 15-6. These are discussed in Section 14.1.

15.2.3.2 Overall well-being

The overall well-being predicted for each scenario is shown in Figure 15.4. These are discussed in Section 14.1.

Table 15-6 Sokunti Pan and Floodplain: The mean percentage changes (relative to 2014) for the social indicators for the scenarios.

Colour coding:

Orange: move **away** from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move **towards** natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Fishing - pans	26.2	5.1	13.8	35.7	37.7	34.4	32.1	32.8
Drinking water (domestic and livestock)	6.4	5.9	4.1	9.7	9.1	8.0	8.1	9.6
Fuel wood	-3.0	1.4	-3.9	-4.4	-4.6	-4.2	-4.1	-4.3
Fruit harvesting	-2.9	1.9	-2.6	-3.1	-3.3	-2.8	-2.7	-2.9
Reeds and grass harvesting	16.8	3.2	19.8	26.3	28.6	30.2	24.6	25.5
Livestock grazing	36.9	23.3	37.0	46.6	52.4	39.2	48.6	43.8
Floodplain recession agriculture	-13.4	9.9	-8.3	-7.8	5.1	-6.3	-8.3	-8.3
Perceptions on disease regulation	-12.4	-1.3	-0.9	-0.8	-1.9	-0.4	0.1	-0.3

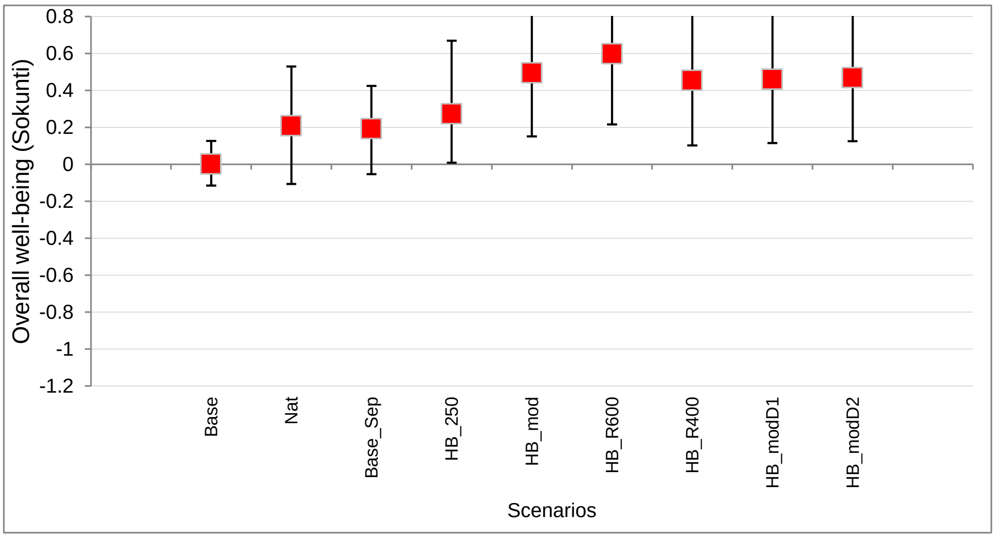


Figure 15.4 Overall well-being scores for the scenarios at Sokunti. Baseline (2014) integrity is labelled 'Base'.

15.3 Namanini Pan and Floodplain

15.3.1 Hydrology and hydraulics

The summary flow and hydraulic indicators for NamaniniPan and Floodplain for the scenarios are given in Table 15-7

15.3.2 Ecosystem

15.3.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at Namanini Pan and Floodplain are given in Table 15-8.

All of the scenarios assume present day (2014) level of human pressure on the system.

The changes in individual indicators are discussed in more detail in Section 14.1.

Table 15-7 Median values for the flow and hydraulic indicators for Namanini Pan and Floodplain for the scenarios. Codes and units for the indicators are given in Section 10.1.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Dry onset	43.00	17.00	40.00	9.00	9.00	9.00	9.00	9.00	9.00
Dry Min 5d stage	0.12	0.41	0.15	0.26	0.50	0.41	0.51	0.50	0.50
Dry duration	347.00	251.00	347.00	283.00	221.00	220.00	220.00	221.00	221.00
Wet onset	41.00	44.50	38.00	49.00	41.00	40.00	40.00	41.00	41.00
Wet duration	16.00	95.50	16.00	80.00	141.00	143.00	142.50	141.00	141.00
Wet Max 5d stage / Q	3.58	3.27	3.57	2.78	2.77	2.78	2.79	2.77	2.77
ann: mean Duration Oct exp	306.50	11.50	317.00	58.00	120.00	60.00	58.00	119.00	120.00
annl: mean Onset Oct exp	42.00	8.50	39.00	50.00	41.00	41.00	50.00	41.00	41.00
W/Ann: Days FP depth 0.2-1 (V)	6.00	17.50	6.00	3.50	3.50	4.50	3.50	3.50	3.50
W/Ann: Freq FP cross (V) thold 0.2-1	2.00	3.50	2.00	2.00	2.00	2.50	2.00	2.00	2.00
W/Ann: Frequ connected (F)	1.00	2.00	1.00	4.00	3.00	4.00	5.00	4.00	3.50
W/Ann: sum Days (F)	13.00	81.50	13.00	43.50	37.00	41.50	50.50	38.00	36.50
W: FP & P area 0.2-0.6 m	0.15	0.32	0.20	0.42	0.19	0.20	0.20	0.19	0.19
W: FP area 0.2-1 m	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet/Ann: Onset ext FP flooding	41.00	46.00	38.00	6.00	6.00	7.00	6.00	6.00	6.00
Wet: mean FP & Pan area	1.35	0.68	0.95	0.57	1.04	1.01	0.98	1.04	1.05
Wet: Mean FP & Pan vol	2.26	0.32	0.78	0.19	1.02	0.92	0.84	1.02	1.03
Dry: mean Pan area 1-1.5 m	0.06	0.21	0.06	0.18	0.22	0.19	0.22	0.22	0.22
T1: mean Pan area 1-1.5 m	0.07	0.00	0.44	0.00	0.24	0.23	0.26	0.24	0.24
Wet: mean Pan area 1-1.5 m	0.27	0.00	0.41	0.00	0.42	0.43	0.43	0.41	0.42
T2: mean Pan area 1-1.5 m	0.45	0.00	0.39	0.00	0.43	0.42	0.42	0.43	0.43
Dry: mean Pan area GT 1m	0.06	0.35	0.14	0.24	0.27	0.25	0.29	0.27	0.27
W: Pan area GT 1m	0.94	0.00	0.41	0.00	0.55	0.50	0.46	0.55	0.55
Dry: mean FParea	0.00	0.02	0.01	0.00	0.00	0.01	0.01	0.00	0.00
T1: mean FParea	0.33	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00
Wet: mean FP area	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2: mean FParea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dry: mean Pan area	0.60	0.96	0.66	0.84	0.88	0.86	0.90	0.88	0.88
T1: mean Pan area	1.33	0.65	0.97	0.59	1.31	1.33	1.21	1.31	1.31
Wet: mean Pan area	1.21	0.68	0.95	0.57	1.04	1.01	0.98	1.04	1.04

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
T2: mean Pan area	0.97	0.69	0.94	0.56	0.96	0.96	0.96	0.96	0.96
Dry: mean Pan depth	0.41	0.86	0.54	0.69	0.74	0.72	0.76	0.74	0.74
T1: mean Pan depth	2.81	0.43	0.84	0.35	1.38	1.73	1.21	1.37	1.39
Wet: mean Pan depth	1.71	0.46	0.82	0.33	0.96	0.90	0.86	0.96	0.96
T2: mean Pan depth	0.85	0.48	0.80	0.31	0.83	0.82	0.82	0.83	0.83
T1: mean FP & Pan depth	2.43	0.43	0.84	0.35	1.38	1.59	1.21	1.37	1.39
Wet: FP & Pan depth	1.56	0.46	0.82	0.33	0.95	0.90	0.86	0.96	0.96
T2: mean FP & Pan depth	0.85	0.48	0.80	0.31	0.83	0.82	0.82	0.83	0.83

Table 15-8 Namanini Pan and Floodplain: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Floating rooted vegetation	-18.5	6.4	-25.1	19.4	19.9	18.8	19.5	19.5
Submerged vegetation	17.5	7.5	20.2	20.2	19.5	20.8	20.0	20.2
Mixed sedge-grass community	30.3	-2.1	53.6	36.3	31.2	38.2	35.9	36.2
Reedbeds (P. australis)	9.9	5.0	12.2	21.9	22.2	22.0	21.9	22.0
Reedbeds (P. mauritianus)	19.7	0.5	2.7	10.0	13.7	9.9	9.5	9.9
Couch grass lawns	8.7	9.4	5.1	24.3	26.2	24.1	23.8	24.4
Riparian tree communities	-18.0	-5.8	-13.7	-17.3	-8.0	-17.5	-16.9	-17.3
Fish								
Flood-dependent - benthic	44.6	-4.4	43.4	34.9	33.8	36.6	34.0	34.6
Flood-dependent - pelagic	47.0	-4.3	43.5	35.2	34.2	36.9	34.3	34.9
Flood-independent generalists	14.4	-2.1	6.3	16.5	20.7	14.7	16.4	16.5
Flood-independent - vegetation	13.2	-2.2	10.5	17.2	18.6	16.8	16.9	17.0
Fish biomass	66.6	2.0	53.9	56.0	60.3	56.7	55.0	55.6

15.3.2.2 Overall ecosystem integrity

The Overall Ecological Integrity for each scenario at Namanini is illustrated in Figure 15.5. Figure 15.5 summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

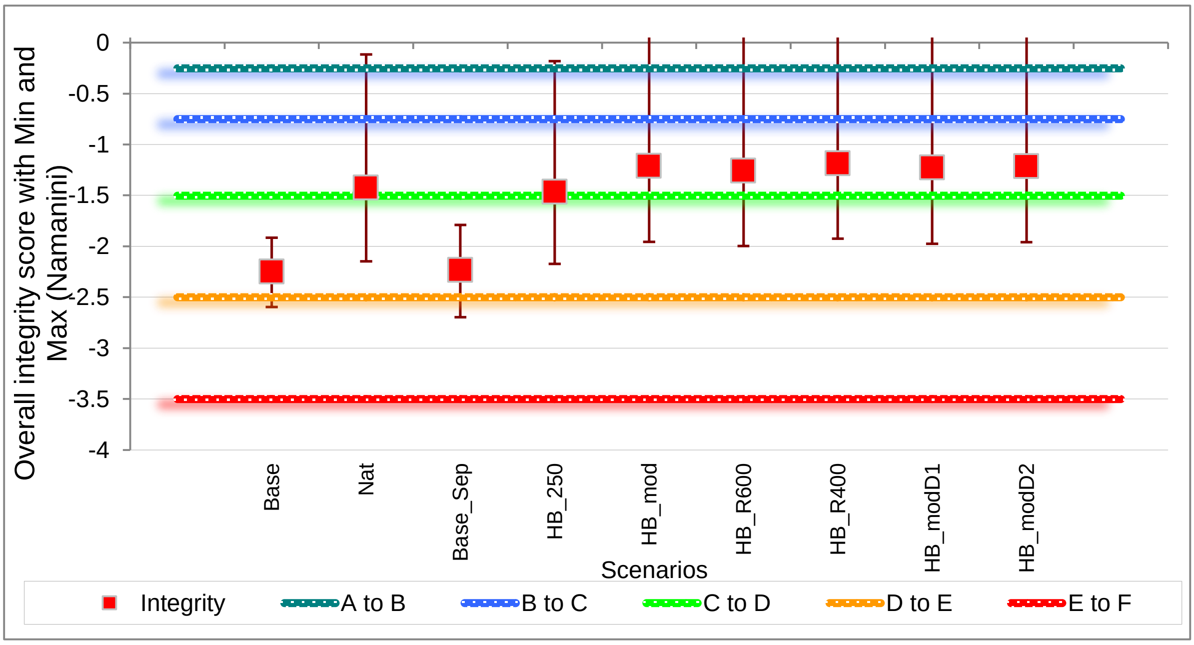


Figure 15.5 Overall ecosystem integrity scores for the scenarios at Namanini. Baseline (2014) integrity is labelled 'Base".

15.3.3 Social

15.3.3.1 Consequences for the indicators used in the DRIFT DSS

The predicted changes for the social indicators are given in Table 15-9. These are discussed in Section 14.1.

15.3.3.2 Overall well-being

The overall well-being predicted for each scenario is shown in Figure 15.6. These are discussed in Section 14.1.

Table 15-9 Namanini Pan and Floodplain: The mean percentage changes (relative to 2014) for the social indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Fishing - pans	39.4	3.8	34.8	36.7	37.8	36.9	36.4	36.5
Drinking water (domestic and livestock)	17.1	-4.2	13.4	24.4	25.7	22.6	24.4	24.3
Fuel wood	-4.5	-0.7	-3.4	-4.4	-1.8	-4.4	-4.3	-4.4
Fruit harvesting	-3.6	0.7	-1.9	-2.6	-0.5	-2.7	-2.5	-2.6
Reeds and grass harvesting	21.8	0.1	28.4	26.3	24.3	27.0	26.0	26.3
Livestock grazing	21.9	22.4	13.0	60.5	65.2	60.3	58.9	60.7
Floodplain recession agriculture	-11.2	9.1	-4.8	-5.4	-1.0	-5.0	-5.3	-5.4
Perceptions on disease regulation	-33.3	0.1	-3.6	-2.9	-6.1	-3.0	-1.8	-2.8

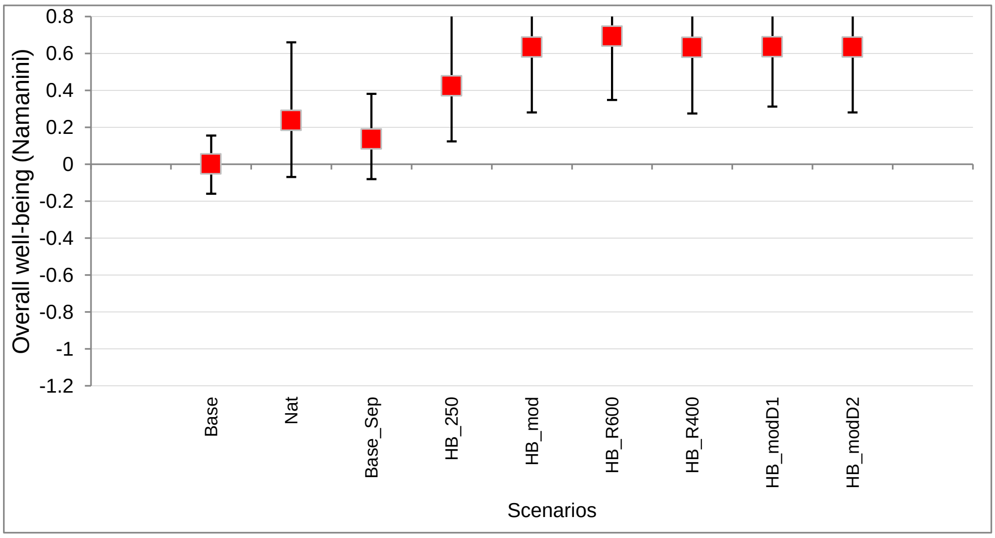


Figure 15.6 Overall well-being scores for the scenarios at Namanini. Baseline (2014) integrity is labelled 'Base'.

15.4 MandlaNkuzi Pan and Floodplain

15.4.1 Hydrology and hydraulics

The summary flow and hydraulic indicators for MandlaNkuzi Pan and Floodplain for the scenarios are given in Table 15-10

15.4.2 Ecosystem

15.4.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at MandlaNkuzi Pan and Floodplain are given in Table 15-11.

All of the scenarios assume present day (2014) level of human pressure on the system.

The changes in individual indicators are discussed in more detail in Section 14.1.

Table 15-10 Median values for the flow and hydraulic indicators for MandlaNkuzi Pan and Floodplain for the scenarios. Codes and units for the indicators are given in Section 10.1.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Dry onset	44.00	13.50	41.00	10.00	10.00	10.00	10.00	10.00	10.00
Dry Min 5d stage	0.52	0.74	0.56	0.61	0.85	0.85	0.70	0.85	0.85
Dry duration	339.50	281.00	339.50	312.50	218.00	214.00	278.00	218.00	218.50
Wet onset	41.00	46.00	38.00	6.00	6.00	41.00	48.50	6.00	6.00
Wet duration	24.00	69.00	23.50	25.00	25.50	148.00	82.00	25.50	25.50
Wet Max 5d stage / Q	3.17	3.09	3.18	2.47	2.47	2.48	2.50	2.46	2.47
ann: mean Duration Oct exp	361.00	7.50	360.50	0.00	0.00	0.00	0.00	0.00	0.00
annl: mean Onset Oct exp	42.00	6.50	39.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
W/Ann: Days FP depth 0.2-1 (V)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W/Ann: Freq FP cross (V) thold 0.2-1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
W/Ann: Frequ connected (F)	1.00	1.00	1.00	1.00	1.00	3.00	0.00	1.00	1.00
W/Ann: sum Days (F)	24.00	69.00	23.50	25.00	25.50	103.00	0.00	25.50	25.50
W: FP & P area 0.2-0.6 m	0.13	0.10	0.07	0.12	0.07	0.07	0.10	0.07	0.07
W: FP area 0.2-1 m	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet/Ann: Onset ext FP flooding	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet: mean FP & Pan area	2.32	1.97	2.09	1.93	2.03	2.12	1.94	2.03	2.03
Wet: Mean FP & Pan vol	4.41	1.84	3.17	1.44	2.61	3.48	1.61	2.61	2.57
Dry: mean Pan area 1-1.5 m	0.69	0.72	0.68	0.93	1.13	0.76	0.78	1.13	1.13
T1: mean Pan area 1-1.5 m	0.29	0.16	0.13	0.00	1.51	0.09	0.17	1.50	1.55
Wet: mean Pan area 1-1.5 m	0.11	0.10	0.15	0.00	1.77	0.12	0.02	1.40	1.71
T2: mean Pan area 1-1.5 m	0.13	0.09	0.18	0.00	1.82	0.15	0.00	1.67	1.60
Dry: mean Pan area GT 1m	0.96	1.67	0.97	1.43	1.61	1.67	1.50	1.61	1.60
W: Pan area GT 1m	2.01	1.09	1.91	0.00	1.85	1.93	0.02	1.84	1.84
Dry: mean FParea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T1: mean FParea	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet: mean FP area	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2: mean FParea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dry: mean Pan area	1.97	2.08	2.02	2.02	2.03	2.05	2.04	2.03	2.03
T1: mean Pan area	2.75	1.95	2.09	1.94	1.98	2.23	1.95	1.98	1.98
Wet: mean Pan area	2.30	1.97	2.09	1.93	2.03	2.12	1.94	2.03	2.03

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
T2: mean Pan area	2.09	1.96	2.08	1.92	2.03	2.09	1.94	2.03	2.03
Dry: mean Pan depth	0.95	1.40	1.04	1.18	1.22	1.33	1.26	1.21	1.21
T1: mean Pan depth	2.80	0.87	1.57	0.79	1.00	1.92	0.87	0.99	1.00
Wet: mean Pan depth	1.89	0.94	1.52	0.75	1.28	1.64	0.83	1.28	1.27
T2: mean Pan depth	1.56	0.89	1.48	0.70	1.25	1.52	0.79	1.24	1.23
T1: mean FP & Pan depth	2.50	0.87	1.57	0.79	1.00	1.92	0.87	0.99	1.00
Wet: FP & Pan depth	1.87	0.94	1.52	0.75	1.28	1.64	0.83	1.28	1.27
T2: mean FP & Pan depth	1.56	0.89	1.48	0.70	1.25	1.52	0.79	1.24	1.23

Table 15-11 MandlaNkuzi Pan and Floodplain: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Floating rooted vegetation	8.0	3.7	-7.8	18.8	13.9	0.8	16.3	19.2
Submerged vegetation	20.3	6.3	15.5	21.2	21.2	21.6	20.5	21.4
Mixed sedge-grass community	27.0	2.4	16.4	30.6	20.8	24.1	28.7	30.6
Reedbeds (*P. australis*)	18.6	5.7	10.2	19.7	19.4	15.6	18.2	19.6
Reedbeds (*P. mauritianus*)	10.4	2.6	4.6	4.9	12.0	5.9	3.8	4.4
Couch grass lawns	11.2	4.9	6.5	16.3	10.5	7.4	13.8	16.0
Riparian tree communities	-14.4	-2.1	11.2	-12.8	-3.2	5.8	-12.4	-12.5
Fish								
Flood-dependent - benthic	34.0	-6.0	14.6	24.2	33.0	5.0	22.6	23.9
Flood-dependent - pelagic	34.1	-6.7	15.5	24.4	34.3	5.8	22.6	24.0
Flood-independent generalists	-4.6	0.6	-0.1	-5.8	-0.6	-0.5	-6.3	-5.5
Flood-independent - vegetation	5.5	3.7	5.0	5.6	7.6	6.9	4.5	5.8
Fish biomass	44.9	0.4	20.6	30.5	48.6	12.6	28.1	30.0

15.4.2.2 Overall ecosystem integrity

The Overall Ecological Integrity for each scenario at MandlaNkuzi is illustrated in Figure 15.7. Figure 15.7 summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

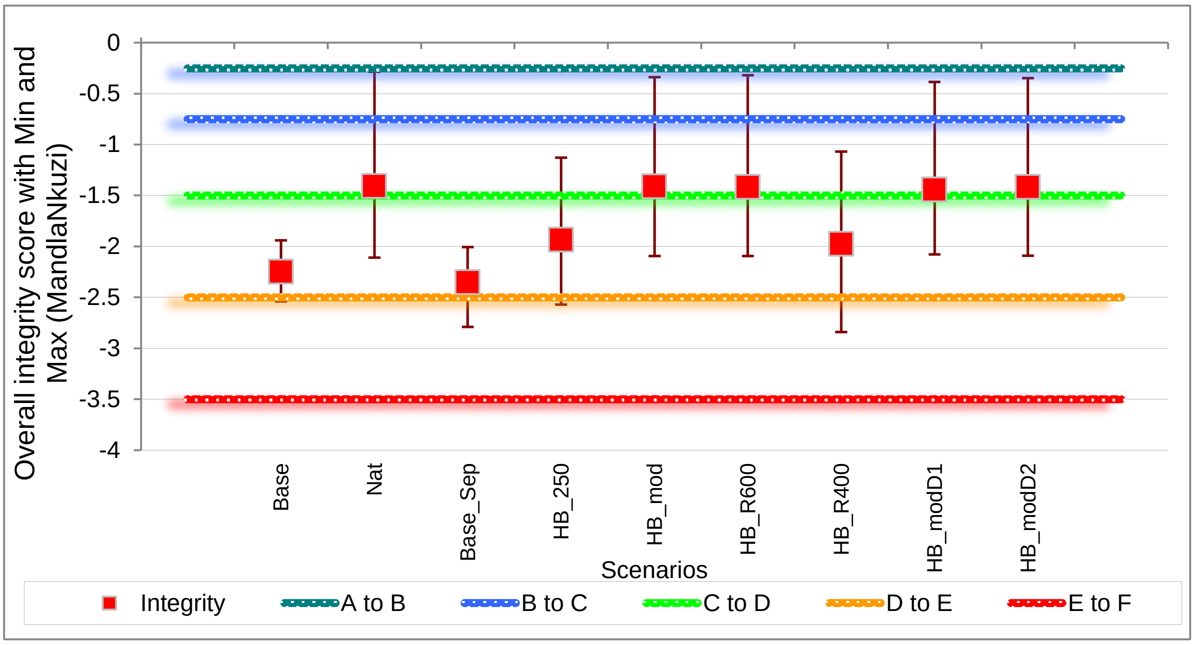


Figure 15.7 Overall ecosystem integrity scores for the scenarios at MandlaNkuzi. Baseline (2014) integrity is labelled 'Base".

15.4.3 Social

15.4.3.1 Consequences for the indicators used in the DRIFT DSS

The predicted changes for the social indicators are given in Table 15-12. These are discussed in Section 14.1.

15.4.3.2 Overall well-being

The overall well-being predicted for each scenario is shown in Figure 15.8. These are discussed in Section 14.1.

Table 15-12 MandlaNkuzi Pan and Floodplain: The mean percentage changes (relative to 2014) for the social indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Fishing - pans								
Drinking water (domestic and livestock)	6.2	3.2	7.9	13.5	17.8	11.7	10.7	12.6
Fuel wood	-4.2	1.1	22.0	-4.0	0.1	11.9	-3.8	-3.9
Fruit harvesting	-1.6	2.8	11.7	-1.4	2.1	7.7	-1.2	-1.3
Reeds and grass harvesting	21.1	3.7	12.4	22.2	18.1	17.3	20.9	22.1
Livestock grazing	23.7	10.9	13.0	32.4	20.5	14.5	27.6	31.8
Floodplain recession agriculture	-8.6	13.0	-9.3	-8.9	-8.9	-9.8	-9.8	-8.9
Perceptions on disease regulation	-13.3	5.9	6.7	6.7	6.7	9.1	9.1	7.5

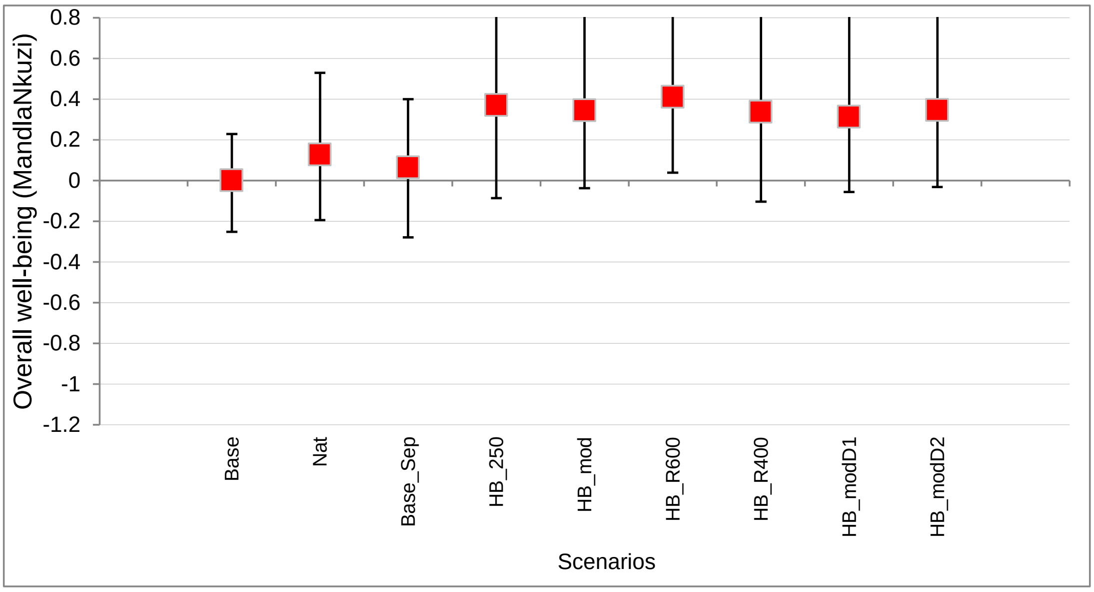


Figure 15.8 Overall well-being scores for the scenarios at MandlaNkuzi. Baseline (2014) integrity is labelled 'Base'.

16 SCENARIO EVALUATION: NDUMO

For each scenario, the predicted changes in the study pans and their surrounding floodplain are evaluated as:

1. estimated mean percentage change from baseline[95] in the abundance, area or concentration of indicators;
2. the predicted change in Overall Ecosystem Integrity, relative to baseline.

Nyamithi Pan and Bakabaka Pan were chosen to represent this section of the floodplain. Hydraulically these two areas are more like wetlands alongside the river than floodplain pans separated from the active channel. This means that it is neither possible nor relevant to calculate separate pan and floodplain parameters. So all the hydraulic parameters for these two areas were calculated for the pan and floodplain combined.

Social indicators were not computed for Ndumo Game Reserve, as the primary purpose of the area is conservation.

16.1 Nyamithi Pan and Floodplain

16.1.1 Hydrology and hydraulics

The summary flow and hydraulic indicators for Nyamithi Pan and Floodplain for the scenarios are given in Table 16-1

16.1.2 Ecosystem

16.1.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at Nyamithi Pan and Floodplain are given in Table 16-2.

All of the scenarios assume present day (2014) level of human pressure on the system.

The changes in individual indicators are discussed in more detail in Section 14.1.

[95] Baseline ecological conditions are those estimated in 2014.

Table 16-1 Median values for the flow and hydraulic indicators for Nyamithi Pan and Floodplain for the scenarios. Codes and units for the indicators are given in Section 10.1.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Dry onset	21.00	12.00	19.50	17.50	16.00	13.50	16.00	16.00	16.00
Dry Min 5d stage	0.86	0.38	0.94	0.63	0.56	0.64	0.64	0.56	0.56
Dry duration	203.00	236.50	182.50	230.50	221.00	249.00	211.00	220.00	221.50
Wet onset	42.00	45.50	38.00	46.50	41.50	46.50	45.00	41.50	41.50
Wet duration	89.50	119.50	100.00	130.00	130.50	113.00	131.50	131.50	130.00
Wet Max 5d stage / Q	3.91	3.78	3.90	3.89	3.84	3.92	3.91	3.82	3.84
ann: mean Duration Oct exp	50.00	104.00	67.00	73.50	21.00	18.50	11.00	20.50	17.50
annl: mean Onset Oct exp	45.00	27.00	42.00	19.00	19.50	19.50	19.50	19.50	19.50
W/Ann: Days FP depth 0.2-1 (V)	22.00	61.50	35.00	64.00	67.50	44.00	67.00	68.00	67.50
W/Ann: Freq FP cross (V) thold 0.2-1	5.00	4.00	6.00	5.50	5.00	4.50	5.50	5.00	5.00
W/Ann: Frequ connected (F)	1.00	0.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00
W/Ann: sum Days (F)	72.50	119.50	83.00	130.00	130.50	98.50	125.00	131.50	130.00
W: FP & P area 0.2-0.6 m	0.06	0.06	0.07	0.09	0.07	0.07	0.08	0.07	0.07
Wet/Ann: Onset ext FP flooding	41.00	45.50	38.00	46.00	25.50	46.00	46.00	25.50	25.50
Wet: mean FP & Pan area	1.43	1.46	1.38	1.42	1.41	1.41	1.42	1.41	1.41
Wet: Mean FP & Pan vol	2.88	3.08	2.32	2.65	2.64	2.56	2.64	2.62	2.63
T1: mean FP & Pan depth	2.18	0.79	1.33	0.72	0.69	0.79	0.76	0.69	0.69
Wet: FP & Pan depth	1.95	2.07	1.65	1.83	1.82	1.78	1.82	1.81	1.82
T2: mean FP & Pan depth	1.34	1.35	1.34	1.34	1.34	1.34	1.34	1.34	1.34

Table 16-2 Nyamithi Pan and Floodplain: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Floating rooted vegetation	-9.5	8.3	-2.4	-4.8	-5.0	-3.4	-5.7	-4.9
Submerged vegetation	3.7	4.9	4.7	2.1	2.5	4.3	1.6	2.0
Mixed sedge-grass community	28.1	5.9	18.5	10.0	12.5	18.5	6.2	9.7
Reedbeds (P. australis)	5.2	8.9	8.1	6.1	5.9	7.5	5.3	5.9
Reedbeds (P. mauritianus)	21.8	11.6	16.7	15.5	12.2	18.2	13.1	15.4
Couch grass lawns	-5.1	11.0	0.4	-4.0	-3.5	-0.8	-5.1	-4.4
Riparian tree communities	-3.3	-9.7	-1.0	0.2	2.0	-1.1	0.0	0.3
Fish								
Flood-dependent - benthic	22.8	8.6	21.8	15.3	17.3	22.5	13.7	15.1
Flood-dependent - pelagic	24.0	8.3	23.2	16.0	17.3	23.5	14.2	15.7
Flood-independent generalists	-9.8	-1.6	0.5	0.1	0.6	0.0	0.0	0.0
Flood-independent - vegetation	-6.8	2.0	2.3	0.5	1.4	2.0	-0.2	0.3
Fish biomass	24.6	11.1	28.2	20.9	21.2	28.8	18.6	20.5

16.1.2.2 Overall ecosystem integrity

The Overall Ecological Integrity for each scenario at Nyamithi is illustrated in Figure 16.1. Figure 16.1 summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

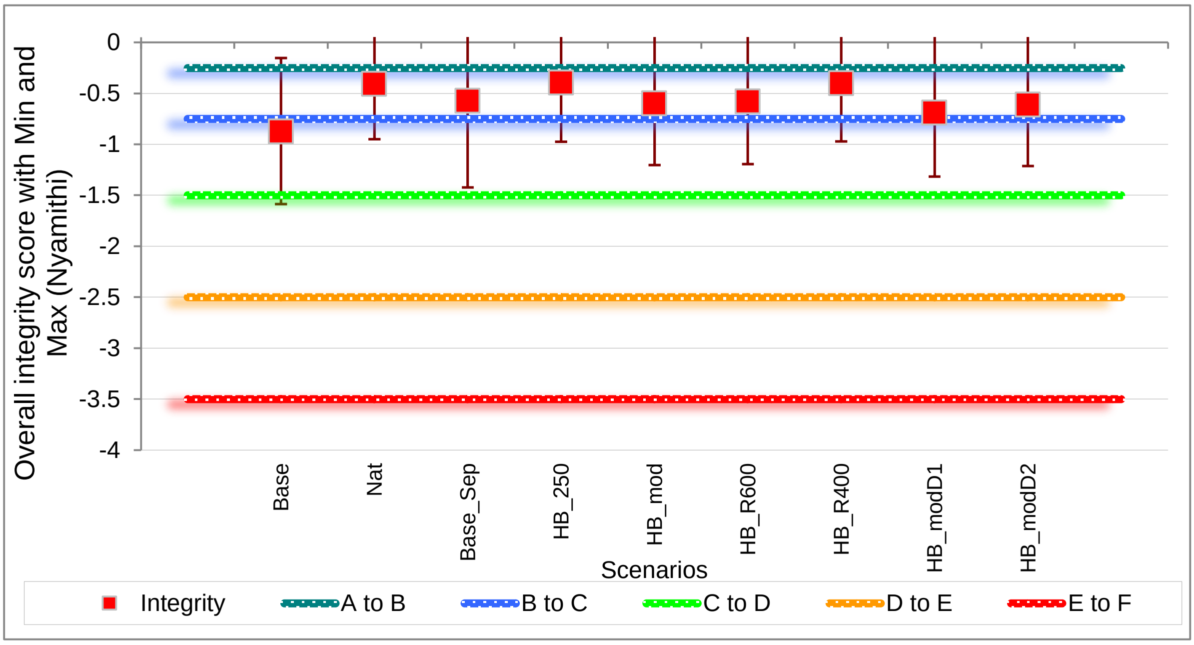


Figure 16.1 Overall ecosystem integrity scores for the scenarios at Nyamithi. Baseline (2014) integrity is labelled 'Base".

16.2 Bakabaka Pan and Floodplain

16.2.1 Hydrology and hydraulics

The summary flow and hydraulic indicators for Bakabaka Pan and Floodplain for the scenarios are given in Table 16-3

16.2.2 Ecosystem

16.2.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at Bakabaka Pan and Floodplain are given in Table 16-4.

All of the scenarios assume present day (2014) level of human pressure on the system.

The changes in individual indicators are discussed in more detail in Section 14.1.

Table 16-3 Median values for the flow and hydraulic indicators for Bakabaka Pan and Floodplain for the scenarios. Codes and units for the indicators are given in Section 10.1.

	Baseline	Natural	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_modD1	HB_modD2
Dry onset	24.50	10.00	23.00	16.50	16.50	12.50	16.50	16.50	16.50
Dry Min 5d stage	2.31	0.29	2.42	2.19	2.31	2.31	2.31	2.31	2.31
Dry duration	191.00	300.50	170.00	181.00	166.50	178.50	166.50	166.50	166.50
Wet onset	41.00	43.50	38.00	47.50	42.50	42.00	46.50	42.50	42.50
Wet duration	127.00	63.00	162.00	154.50	168.50	153.00	154.50	168.50	168.50
Wet Max 5d stage / Q	6.44	4.80	6.43	6.42	6.37	6.45	6.44	6.35	6.37
ann: mean Duration Oct exp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
annl: mean Onset Oct exp	42.00	46.50	39.00	50.00	41.00	41.00	50.00	41.00	41.00
W/Ann: Days FP depth 0.2-1 (V)	4.00	7.00	4.00	0.00	0.00	0.50	0.00	0.00	0.00
W/Ann: Freq FP cross (V) thold 0.2-1	2.00	3.00	2.00	1.00	1.00	1.50	1.00	1.00	1.00
W/Ann: Frequ connected (F)	2.50	0.00	3.00	2.50	3.00	3.00	2.50	3.00	3.00
W/Ann: sum Days (F)	9.00	34.00	9.00	11.50	11.50	18.50	14.50	11.50	11.50
W: FP & P area 0.2-0.6 m	0.35	0.49	0.81	0.71	0.73	0.70	0.70	0.73	0.73
Wet: mean FP & Pan area	10.19	9.84	9.36	9.39	9.55	9.56	9.52	9.55	9.55
Wet: Mean FP & Pan vol	27.76	24.00	16.55	18.47	18.75	18.84	18.89	18.76	18.74
T1: mean FP & Pan depth	2.48	0.79	1.22	0.73	1.22	1.60	1.22	1.20	1.22
Wet: FP & Pan depth	2.66	2.36	1.74	1.90	1.93	1.94	1.93	1.93	1.93
T2: mean FP & Pan depth	1.49	1.90	1.48	1.53	1.53	1.52	1.53	1.51	1.53

Table 16-4 Bakabaka Pan and Floodplain: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Floating rooted vegetation	-3.2	2.5	7.4	7.0	6.1	7.3	7.0	7.0
Submerged vegetation	-5.7	-0.1	10.4	9.0	7.7	10.8	9.0	9.0
Mixed sedge-grass community	-1.7	2.8	21.2	16.9	16.5	22.2	16.9	16.9
Reedbeds (P. australis)	-2.8	3.9	8.3	7.9	7.1	8.4	7.9	7.9
Reedbeds (P. mauritianus)	-10.4	6.9	6.9	8.8	8.1	7.3	8.8	8.8
Couch grass lawns	-16.0	2.0	4.3	5.4	5.0	4.7	5.4	5.4
Riparian tree communities	11.2	-4.0	-4.4	-7.3	-6.2	-6.4	-7.3	-7.3
Fish								
Flood-dependent - benthic	-18.8	1.2	19.1	17.1	15.6	20.7	17.1	17.1
Flood-dependent - pelagic	-18.2	1.2	19.9	17.6	16.1	21.8	17.6	17.6
Flood-independent generalists	-23.5	1.7	-0.8	-1.1	-0.3	-0.8	-1.1	-1.1
Flood-independent - vegetation	-21.7	3.8	4.1	3.3	3.9	4.3	3.3	3.3
Fish biomass	-15.3	14.5	28.7	27.3	25.5	31.1	27.3	27.3

Natural scenario scored poorly for Bakabaka. The reasons for this are not entirely clear but are probably related to the shorted duration of the wet season in the natural flow regime (see Table 16-3.

16.2.2.2 Overall ecosystem integrity

The Overall Ecological Integrity for each scenario at Bakabaka is illustrated in Figure 16.2. Figure 16.2 summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

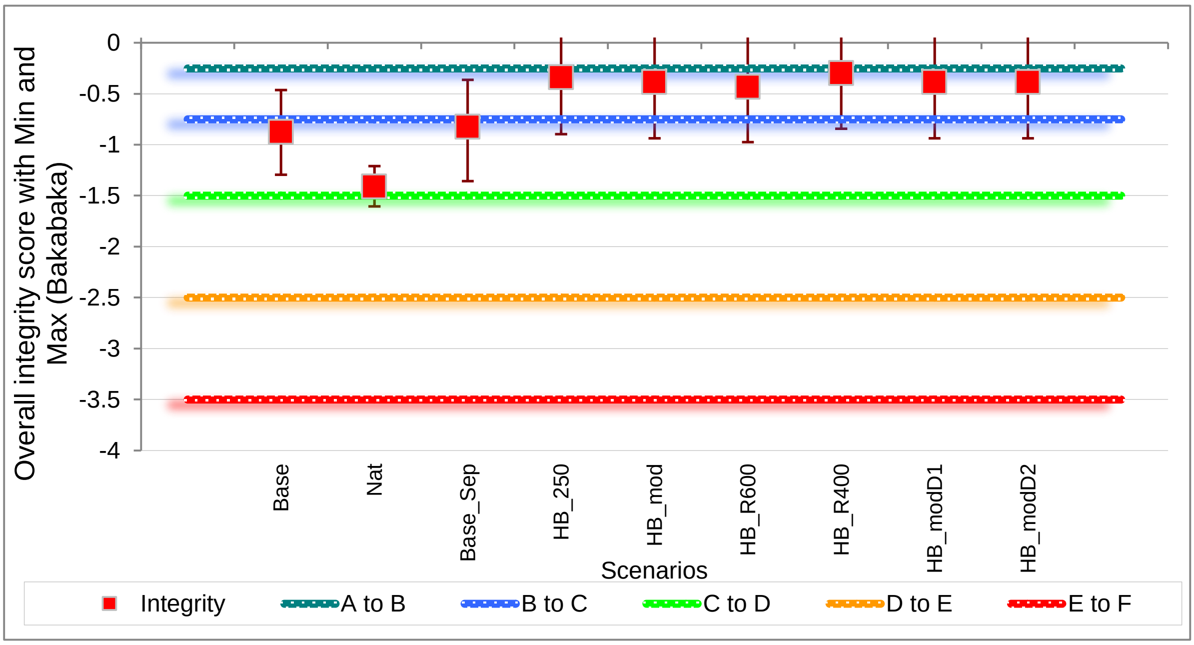


Figure 16.2 Overall ecosystem integrity scores for the scenarios at Bakabaka. Baseline (2014) integrity is labelled 'Base".

17 SCENARIO EVALUATION: PONGOLA RIVER

For each scenario, the predicted changes in the study pans and their surrounding floodplain are evaluated as:

1. estimated mean percentage change from baseline[96] in the abundance, area or concentration of indicators;
2. the predicted change in Overall Ecosystem Integrity, relative to baseline.

For each scenario, the predicted social changes are evaluated as:

1. estimated mean percentage change from baseline in the abundance, area or concentration of indicators;
2. the predicted change in Overall Well-being, relative to baseline.

17.1 Hydrology

The summary flow indicators for the Pongola River for the scenarios are given in Table 17-1

Table 17-1 Median values for the flow indicators for Pongola River for the scenarios. Codes and units for the indicators are given in Section 10.1.

	Base	Nat	Base_Sep	HB_250	HB_mod	HB_R600	HB_R400	HB_mod D1	HB_mod D2
Mean annual runoff	11.78	30.83	11.78	12.50	12.50	12.06	13.58	12.50	12.50
Dry onset	42.00	14.00	39.00	11.50	8.00	11.50	11.50	8.00	8.00
Dry Min 5d Q	5.45	2.86	5.45	5.45	5.45	5.45	5.45	5.45	5.45
Dry duration	348.00	210.00	348.00	283.00	222.00	222.00	222.00	222.00	222.00
Wet onset	40.00	43.50	37.00	48.00	40.00	48.00	48.00	40.00	40.00
Wet duration	12.00	103.50	12.00	78.00	139.00	78.00	78.00	139.00	139.00
Wet Max 5d Q	383.16	240.41	383.16	130.00	130.00	130.00	130.00	130.00	130.00

17.2 Ecosystem

17.2.1 Individual indicators used in the DRIFT DSS

The mean percentage changes (relative to baseline) for the ecosystem indicators for the scenarios at Pongola River are given in Table 17-2.

All of the scenarios assume present day (2014) level of human pressure on the system.

[96] Baseline ecological conditions are those estimated in 2014.

Table 17-2 Pongola River: The mean percentage changes (relative to 2014) for the vegetation and fish indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Reedbeds (P. mauritianus)	0.0	-3.8	0.0	0.0	0.0	0.0	0.0	0.0
Riparian tree communities	-2.0	-22.6	-3.5	-9.4	-26.0	-9.3	-9.4	-26.2
Fish								
Main channel - rheophilic	0.0	-4.1	0.0	0.0	0.0	0.0	0.0	0.0
Main channel - semi rheophilic	0.0	-0.5	0.0	0.0	0.0	0.0	0.0	0.0
Main channel - pool	0.2	5.7	0.2	0.2	0.2	0.2	0.2	0.2

17.2.2 Overall Ecosystem Integrity

The Overall Ecological Integrity for each scenario at Pongola River is illustrated in Figure 17.1. It summarises the individual results for the indicators into an assessment of the general ecosystem condition that is expected to result from the different release options represented by the scenarios.

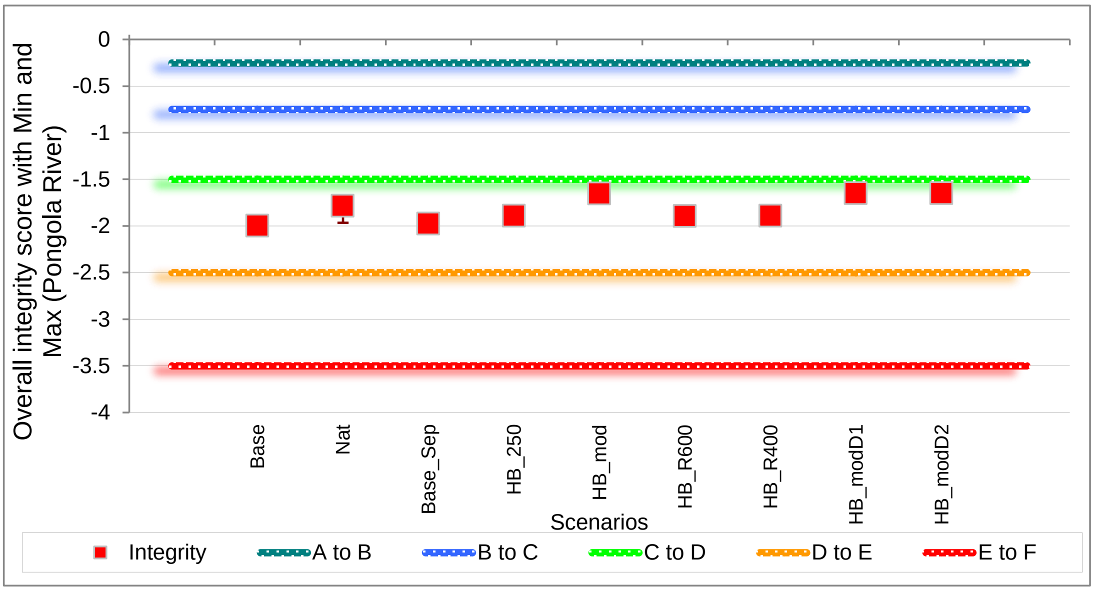


Figure 17.1 Overall ecosystem integrity scores for the scenarios at Pongola River. Baseline (2014) integrity is labelled 'Base".

17.3 Social

17.3.1 Consequences for the indicators used in the DRIFT DSS

The predicted changes for the social indicators are given in Table 17-3.

Table 17-3 Pongola River: The mean percentage changes (relative to 2014) for the social indicators for the scenarios.

Colour coding:

Orange: move away from natural relative to baseline. Light = 30-50%. Dark = >50%.

Green: move towards natural relative to baseline. Light = 30-50%. Dark = >50%.

	Natural	Base_Sep	H&B_250	H&B_mod	H&B_R600	H&B_R400	H&B_modD1	H&B_modD2
Vegetation								
Fishing - river	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Fuel wood	-2.2	-24.9	-3.9	-10.3	-28.7	-10.2	-10.3	-28.8
Fruit harvesting	-0.8	-9.4	-1.4	-3.8	-10.7	-3.8	-3.8	-10.8
Reeds and grass harvesting	0.0	-3.5	0.0	0.0	0.0	0.0	0.0	0.0

17.3.1.1 Overall well-being

The overall well-being predicted for each scenario is shown in Figure 17.2. These are discussed in Section 14.1.

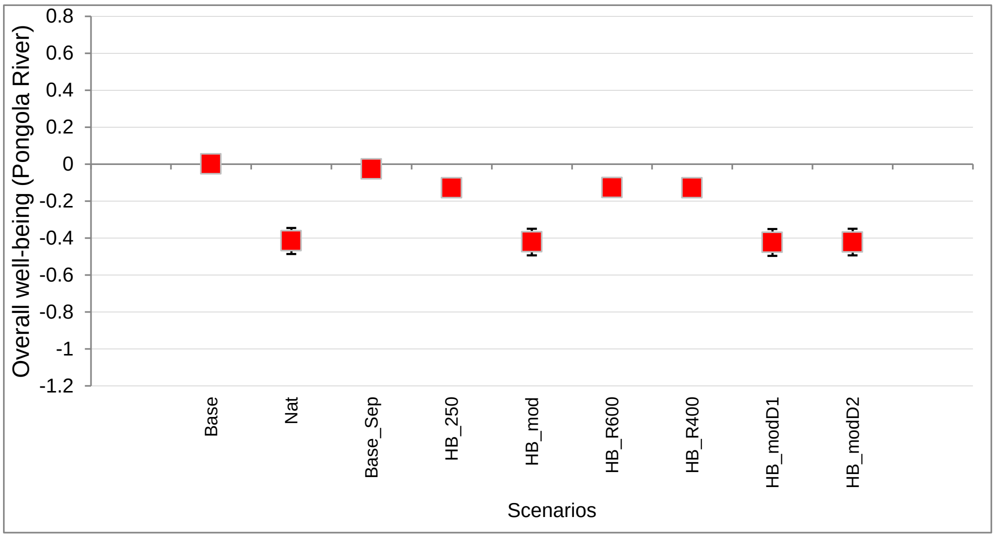


Figure 17.2 Overall well-being scores for the scenarios at Pongola River. Baseline (2014) integrity is labelled 'Base'.

18 SCENARIO EVALUATION – WHOLE FLOODPLAIN

This section summarises the information in Sections 12 to 17 for the floodplain as a whole.

Figure 18.1 and Figure 18.2 show all the individual overall integrity and overall well-being plots, respectively, presented in the previous sections side by side. This allows for a quick perusal of the overall predicted condition for each scenario at each site.

In general, the two scenarios that yield the best ecosystem outcomes overall are HB_mod and HB_600. This is borne out in the average Overall Integrity plot for the whole floodplain (Figure 18.3), which shows that, in terms of the predictions generated in the study, HB_mod, HB_600 and HB_modD2 will approximate the natural condition in the floodplain as a whole, while HB_400 and HB_modD1 are not significantly lower than the top scoring three scenarios. The average predicted ecological condition for all five of these scenarios is a C/D category. Obviously, this will vary between pans, with Ntlanyane being in the poorest condition (D/E category) and the pans in Ndumo Game Reserve (Nyamithi and Bakabaka) being in the best condition (Category A/B). The human pressure on the pans outside of the Ndumo Game Reserve means that the average condition of these (excluding Ntlanyane) is expected to be C-category, i.e., approximately one full category higher than under the 2014 baseline Jozini Dam release regime.

The scenario that yields the best social outcomes overall is HB_600, and as is the case for the ecosystem, HB_mod, HB_400, HB_modD1 and HB_modD2 offer then next best outcomes (Figure 18.4).

The spatial distribution of the pans and their ecological condition for each of the scenarios is shown in Figure 18.5 to Figure 18.9. In these the slightly different configurations achieved with each of the scenario is evident. For instance, HB_600 returns the best result for Sokuthi (C Category) and Ntlanyane (Category D/E), whereas HB-mod returns the best result for Nyamithi (B category) and for Tete (C Category).but one of the worst results for Shalala (E Category). Certainly the HB_250 scenario offers considerable <u>ecological</u> benefit for Tete and Nyamithi.

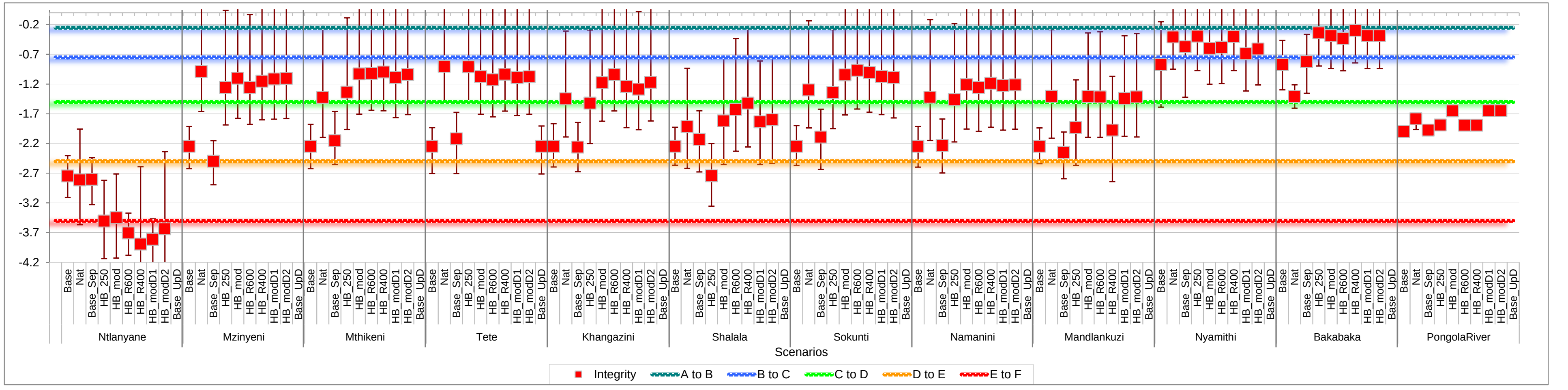


Figure 18.1 Combined overall integrity plots for all sites.

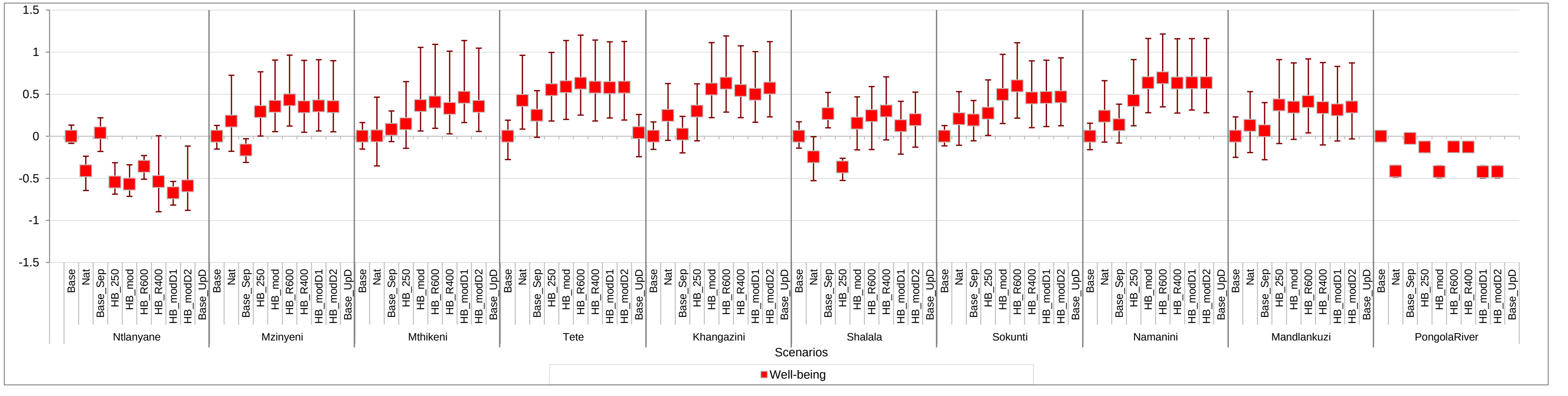


Figure 18.2 Combined overall well-being plots for all sites.

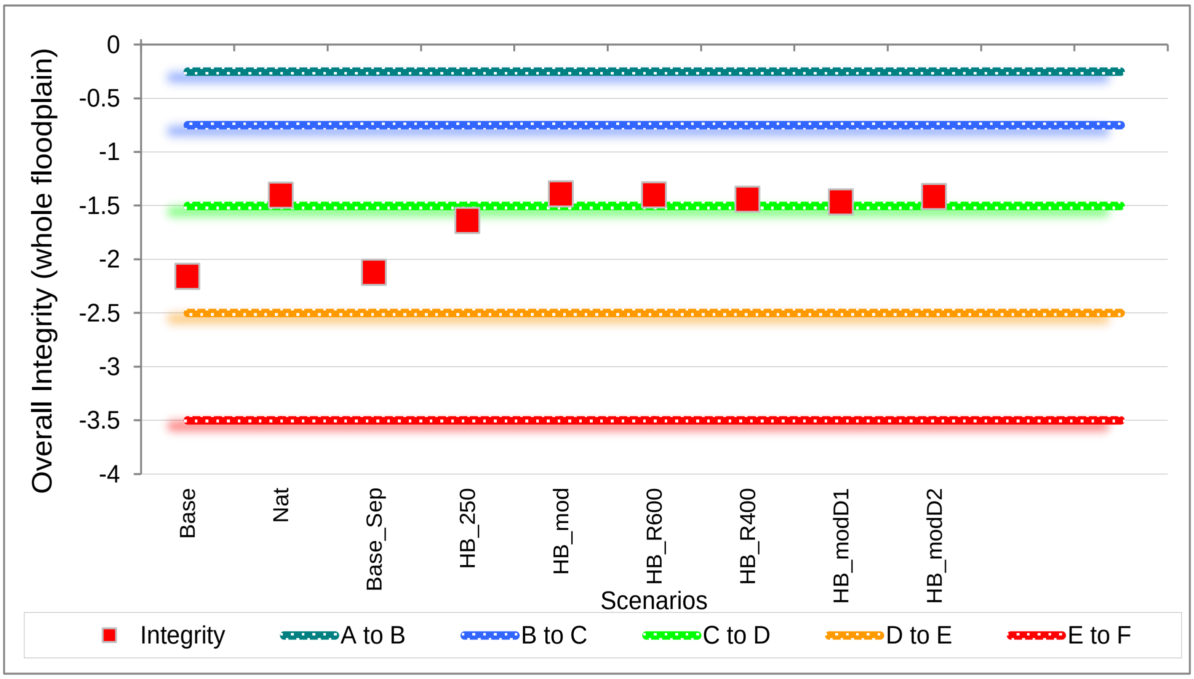


Figure 18.3 Integrity for the whole floodplain, based on the combined overall integrity scores for each site

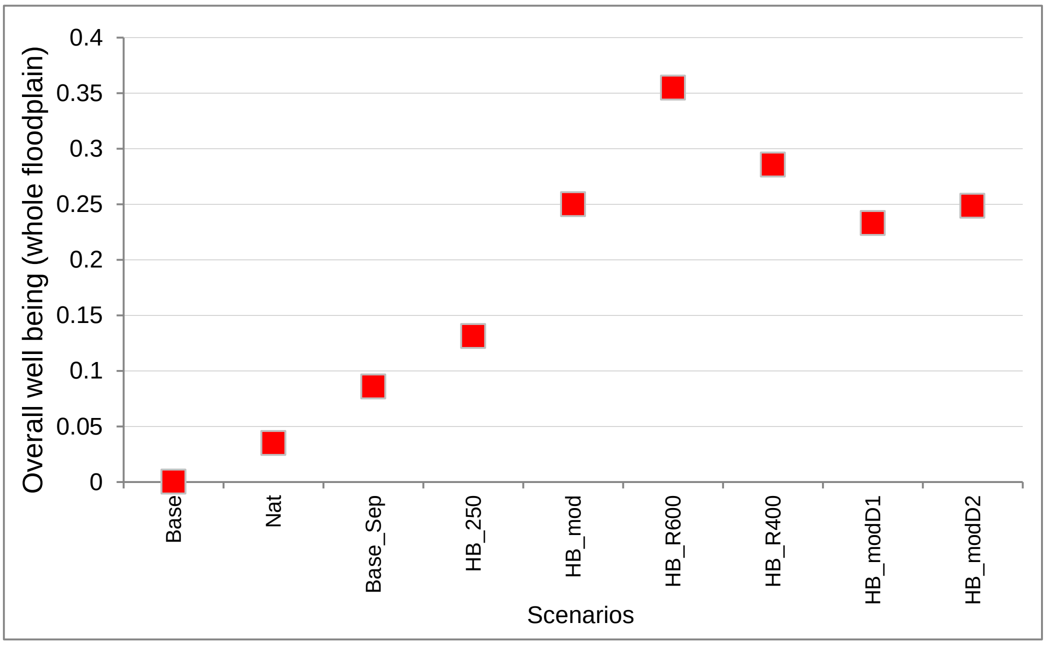


Figure 18.4 Well-being for the whole floodplain, based on the combined well-being scores for each site.

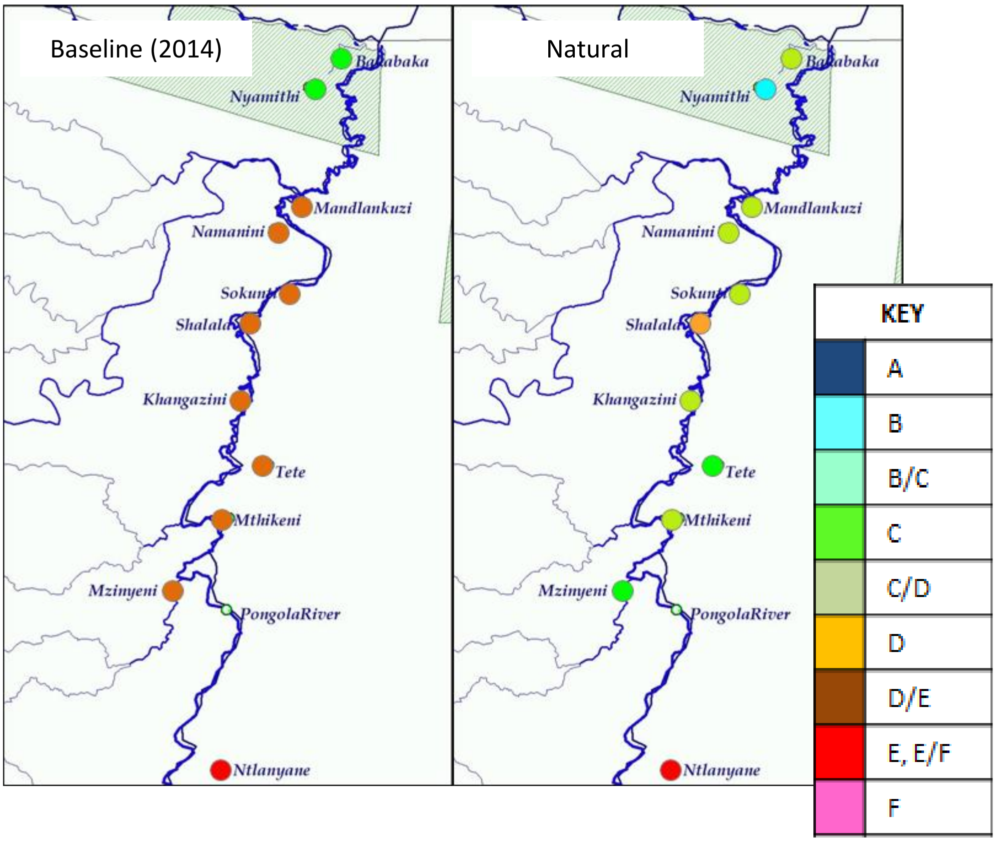


Figure 18.5 Estimated ecological condition for the study pans for the Baseline (2014) and Natural scenarios.

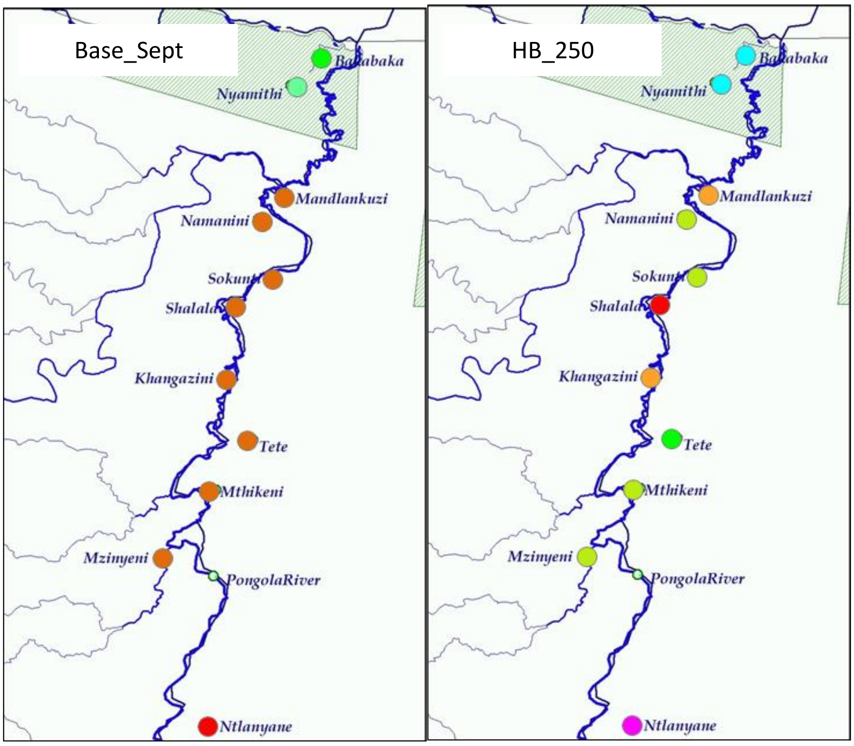


Figure 18.6 Estimated ecological condition for the study pans for the Base_Sept and HB_mod scenarios (see key in Figure 18.5).

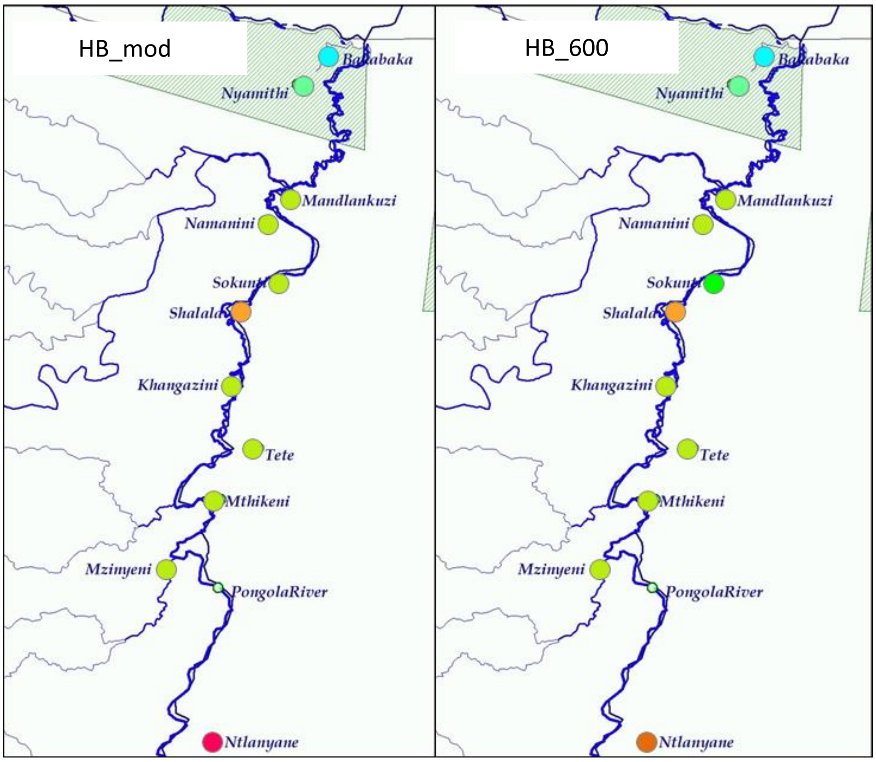


Figure 18.7 Estimated ecological condition for the study pans for the HB_mod and HB_600 scenarios (see key in Figure 18.5).

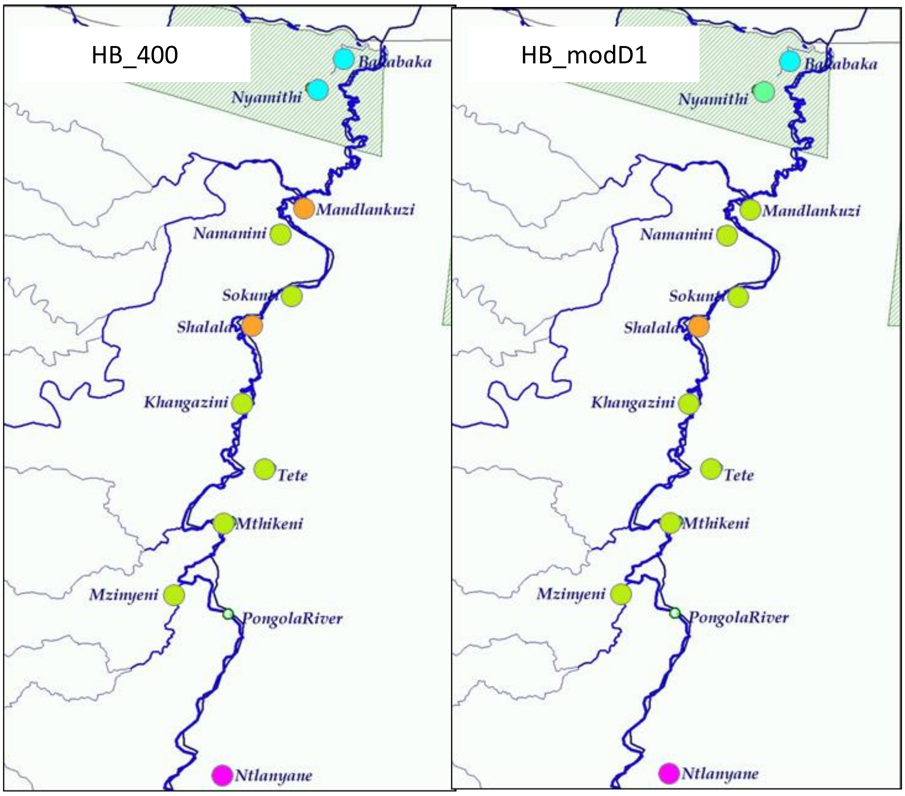


Figure 18.8 Estimated ecological condition for the study pans for the HB_400 and HB_modD1 scenarios (see key in Figure 18.5).

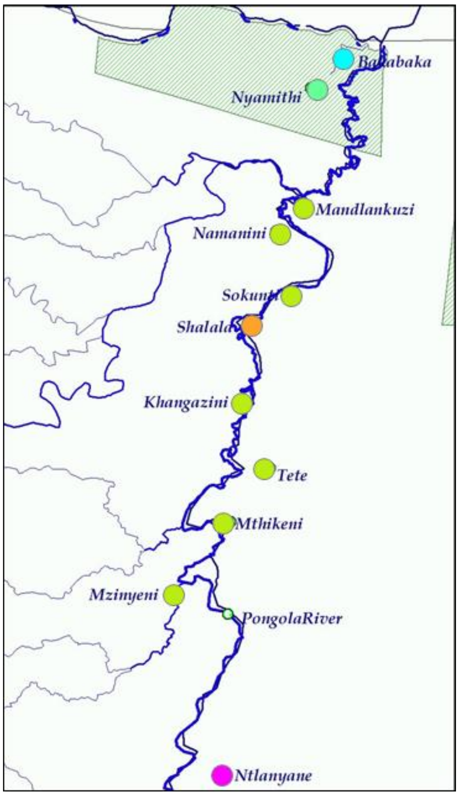


Figure 18.9 Estimated ecological condition for the study pans for the HB_modD2 scenario (see key in Figure 18.5).

The volumes of the releases associated with each of these scenarios are as follows:

Baseline:	579.94 MCM
Natural:	1121.67 MCM
Base-Sept:	580.68 MCM
HB_250:	588.28 MCM
HB_mod:	588.85 MCM
HB_600	582.82 MCM
HB_400	593.79 MCM
HB_modD1	561.16 MCM
HB_modD2	581.10 MCM.

HB_600 was selected as the **recommended release scenario** (see Section 19), as it represents the best outcome for the ecosystem and social aspects combined. However, this is flexible within the constraints of the HB scenarios, and possibly other scenarios that may be revealed through additional scenario analysis (see Section 20).

19 RECOMMENDED RELEASE SCENARIO

HB_600 was selected as the **recommended release scenario** as it represents the best outcome for the ecosystem and social aspects combined.

The releases for this scenario can be summarised as follows:

October:

- One day at 600 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.

December:

- Three days at 150 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.
- Two days at 56 m^3s^{-1}
- Four days at 28 m^3s^{-1}
- Remaining days at 2.4 m^3s^{-1}.

January:

- Two days at 50 m^3s^{-1}.
- One day at 35 m^3s^{-1}; followed by one day at 65 m^3s^{-1}. Repeat three times.
- Remaining days at 2.4 m^3s^{-1}.

February:

- Five days at 150 m^3s^{-1}.
- Remaining days at 50 m^3s^{-1}.

March:

- Fifteen days at 35 m^3s^{-1}.
- Remaining days at 50 m^3s^{-1}.

The volume of these releases is 582.82 MCM per annum. The ecological category for each of the pans is given in Table 19-1.

Table 19-1 Ecological Categories for the pans associated with HB-600

Pan	REC
Ntlanyane	D/E
Mzinyeni	C/D
Mthikeni	C/D
Tete	C/D
Khangazini	C/D
Shalala	D
Sokunti	C
Namanini	C/D
Mandlankuzi	C/D
Nyamithi	B/C
Bakabaka	B

20 DISCUSSION AND WAY FORWARD

Releases from Jozini Dam affect the whole Pongola Floodplain, but not all parts are affected equally. Thus, any decisions with respect to the release regime should consider the configuration of different effects in the various parts of the floodplain.

Similarly, releases affect all users of the floodplain, but again, not equally. Releases that are designed to support one sector will often prejudice another, particularly if they affect the natural environment negatively. Indeed, ecological considerations on the floodplain are mainly important in so far as they support people's livelihoods. There is no doubt that the baseline (2014) releases, designed to assist agriculture, are negatively affecting fishing and grazing. The results of this study suggest that a better designed release regime could considerably aid fishing and grazing and need not necessarily prejudice agriculture, particularly in the October timing of the main flood event is maintained.

Importantly, there is anecdotal evidence to support the redistribution of the release in accordance with a pattern similar to the recommended release scenario (HB_600). In wet years, when the Jozini Dam spills (mimicking the distribution in HB-600), agricultural and fish yields are reportedly better than in years where this does not occur (T. Tlou, per obs.).

We are confident that, if implemented, the recommended release scenario will yield a better overall outcome for all users and for the ecosystem as a whole than does the baseline (2014) scenario. We are not as confident that it is the optimal solution for the floodplain, as negotiations, and indeed monitoring and adaptive management, may well result in some refinement. Thus, as mentioned previously, we feel there is both scope for and merit in further optimisation based on the analysis of additional release scenarios for Jozini Dam. Whether this is done as part of the Classification Process or as part of an adaptive management strategy, or both, is open to debate. Certainly, we would favour whichever of the options hastens implementation of a more user-friendly flow release regime at Jozini Dam.

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Appendix A. FLOODPLAIN PANS MAPPED AND NAMED BY LA HAUSSE (1987)

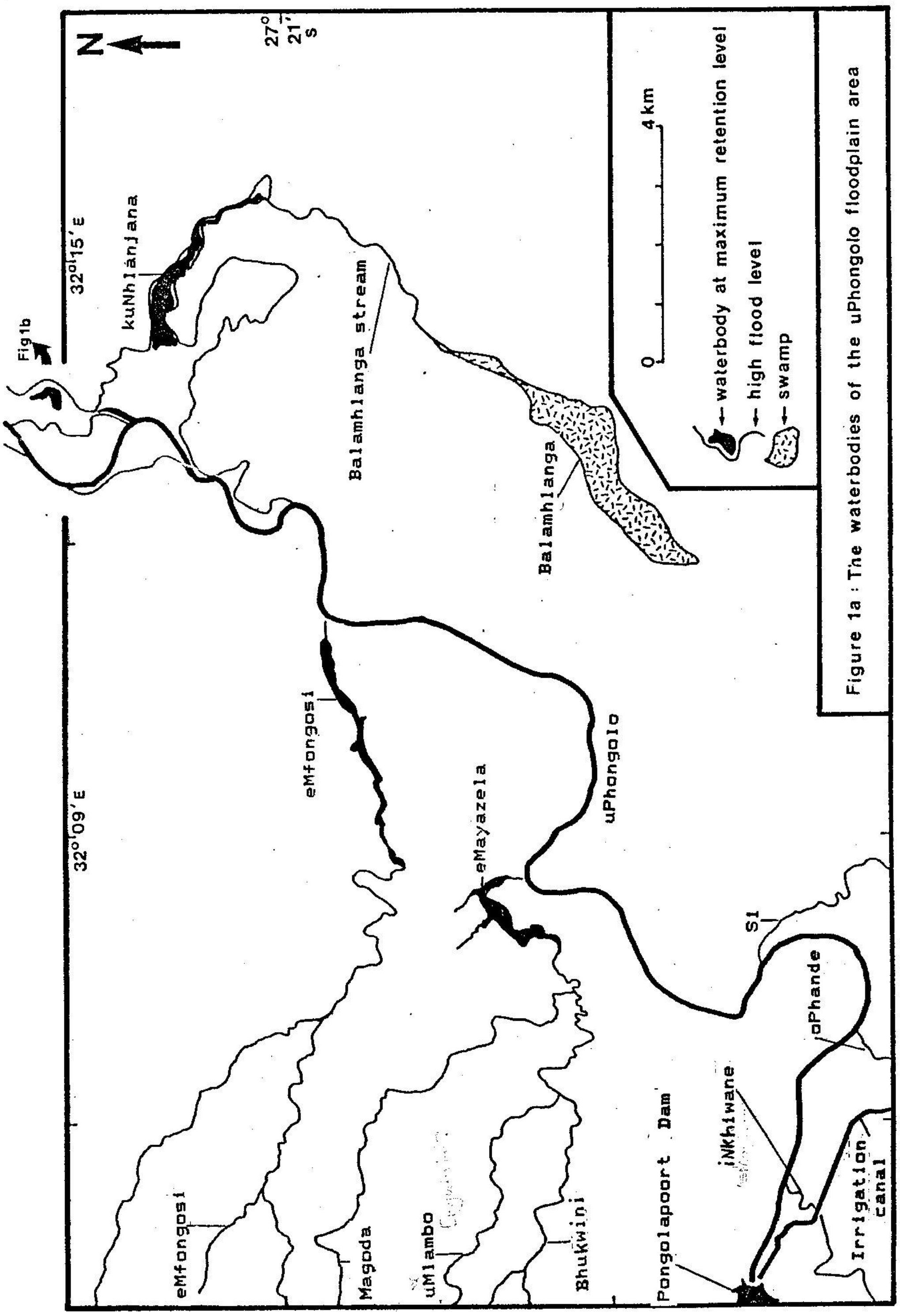


Figure 1a : The waterbodies of the uPhongolo floodplain area

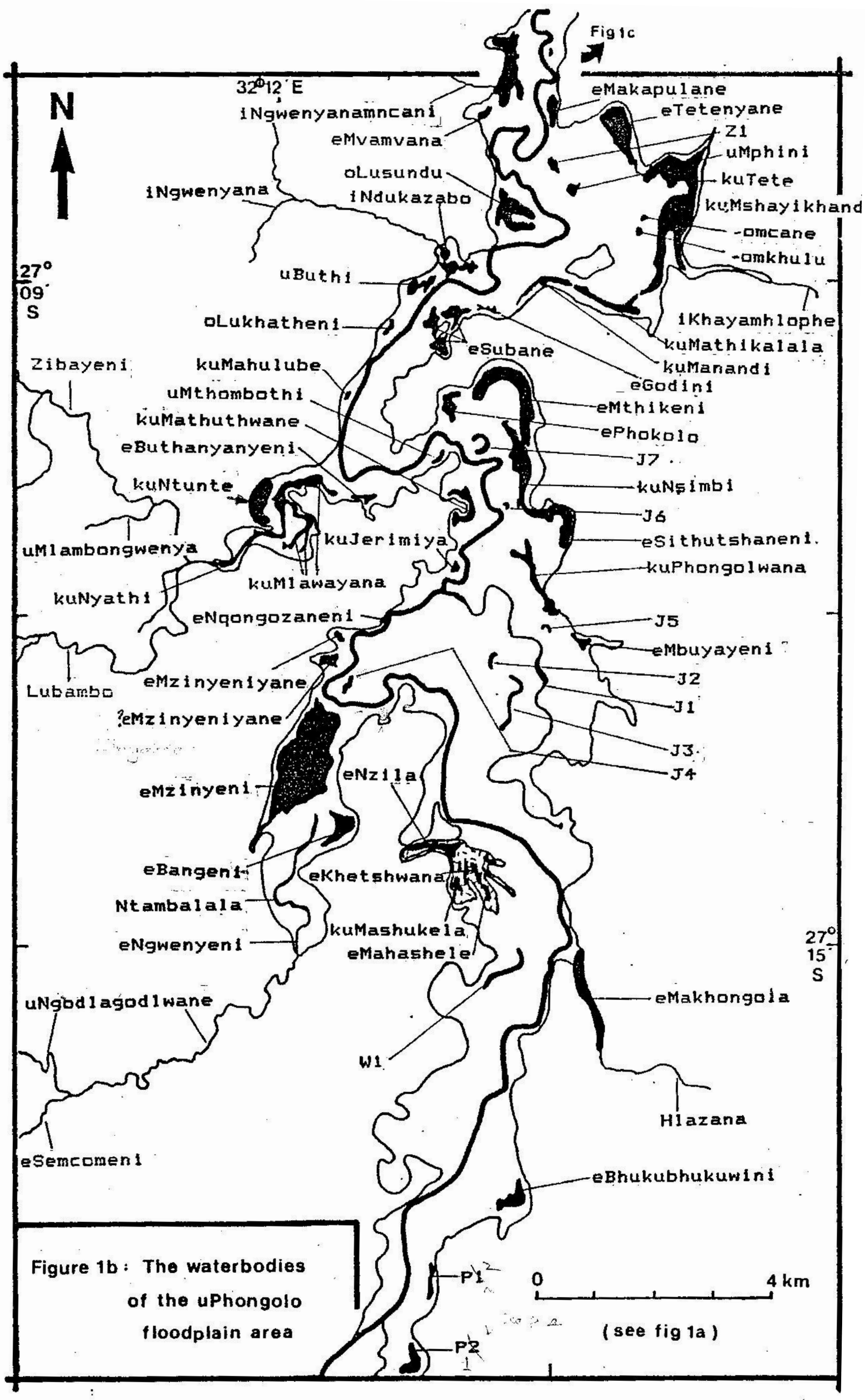


Figure 1b : The waterbodies of the uPhongolo floodplain area

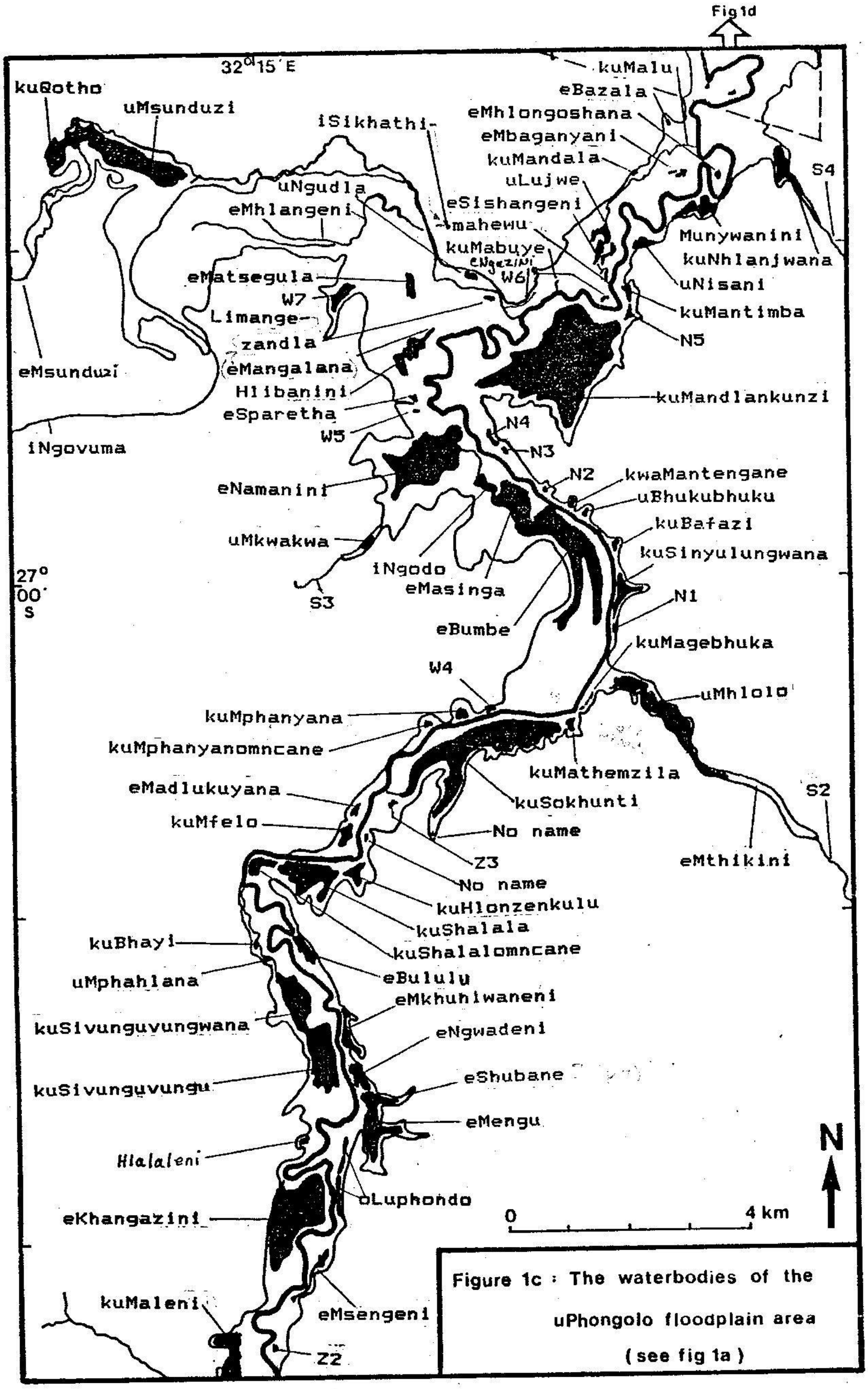


Figure 1c : The waterbodies of the uPhongolo floodplain area (see fig 1a)

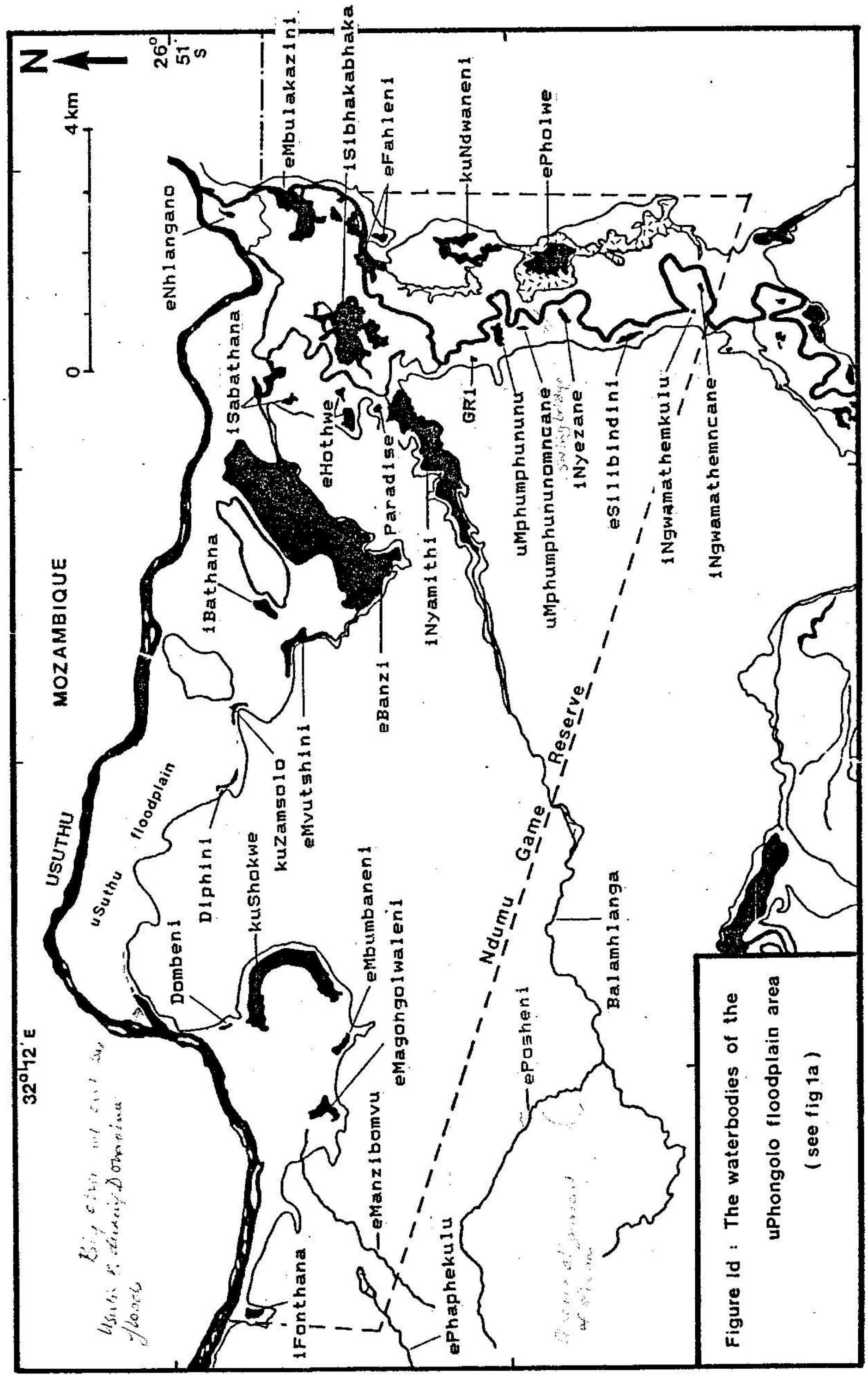


Figure Id : The waterbodies of the uPhongolo floodplain area (see fig 1a)

Appendix B. EXAMPLE OF POST-PROCESSING RESULTS

Appendix Table 1 Examples of results files for Tete (floodplain and pan): geometric file (Tete.geo) and daily timeseries file (Tete_ts.txt) for PD conditions

Tete.geo

Parameters(#=col):
1=Stage
Floodplain & pan/s: 2=Vol 3=Area 4=Av.depth
Floodplain: 5=Area
Pan/s: 6=Area 7=Av.depth
Pan/s area in depth range: 8=1.0-1.5m
Pan/s area in depth range: 9=1.0+m
Floodplain & pan area in depth range: 10=0.2-0.6m
Floodplain area in depth range: 11=0.2-1.0m
Pan/s edge level: 34.00
Max. area of pan/s: 2.731
Units: Stage & edge level: mamsl, Av.depth: m, Area: km^2, Vol: Mm^3
113[1]

31.21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31.30	0.067	0.866	0.077	0.000	0.866	0.077	0.000	0.000	0.000	0.000
31.40	0.159	0.964	0.165	0.000	0.964	0.165	0.000	0.000	0.000	0.000
31.50	0.258	1.030	0.251	0.000	1.030	0.251	0.000	0.000	0.866	0.000
31.60	0.364	1.089	0.334	0.000	1.089	0.334	0.000	0.000	0.964	0.000
31.70	0.475	1.143	0.416	0.000	1.143	0.416	0.000	0.000	1.030	0.000
31.80	0.592	1.194	0.496	0.000	1.194	0.496	0.000	0.000	1.089	0.000
31.90	0.715	1.251	0.571	0.000	1.251	0.571	0.000	0.000	0.277	0.000
32.00	0.842	1.313	0.642	0.000	1.313	0.642	0.000	0.000	0.230	0.000

etc.

Tete_ts.txt

Parameters(#=col):
1=dd/mm/yyyy
2=Stage
Floodplain & pan/s: 3=Vol 4=Area 5=Av.depth
Floodplain: 6=Area
Pan/s: 7=Area 8=Av.depth 9=Area in depth range 1.0-1.5m 10=Area in depth range +1.0m
Floodplain & pan/s: 11=Area in depth range 0.2-0.6m
Floodplain: 12=Area in depth range 0.2-1.0m
Units: Stage: mamsl, Av.depth: m, Area: km^2, Vol: Mm^3
5145[1]
(rows below extracted from 5145 daily values)

03/10/1990	32.43	1.45	1.52	0.95	0.00	1.52	0.95	0.98	0.98	0.22	0.00
04/10/1990	32.61	1.74	1.61	1.08	0.00	1.61	1.08	1.10	1.10	0.19	0.00
05/10/1990	33.01	2.42	1.85	1.31	0.00	1.85	1.31	0.28	1.32	0.22	0.00
06/10/1990	36.10	13.09	5.20	2.52	2.46	2.73	3.80	0.00	2.73	0.37	0.86
07/10/1990	36.30	14.16	5.36	2.64	2.63	2.73	4.00	0.00	2.73	0.34	0.76
08/10/1990	36.00	12.55	5.11	2.45	2.38	2.73	3.70	0.00	2.73	0.40	0.97
09/10/1990	35.72	11.15	4.87	2.29	2.14	2.73	3.42	0.00	2.73	0.49	1.09
10/10/1990	35.50	10.14	4.66	2.17	1.93	2.73	3.20	0.00	2.73	0.60	1.17
11/10/1990	35.32	9.32	4.46	2.09	1.73	2.73	3.02	0.19	2.73	0.61	1.16
12/10/1990	35.18	8.70	4.28	2.03	1.55	2.73	2.88	0.35	2.73	0.58	1.05
13/10/1990	35.00	7.96	3.99	2.00	1.26	2.73	2.71	0.52	2.73	0.56	0.96
14/10/1990	34.68	6.76	3.54	1.91	0.80	2.73	2.38	0.42	2.38	0.43	0.51
15/10/1990	34.29	5.46	3.00	1.82	0.27	2.73	1.99	0.33	2.04	0.43	0.08
16/10/1990	34.03	4.72	2.76	1.71	0.03	2.73	1.73	0.29	1.86	0.39	0.00

[1]number of data rows, Av = average, mamsl = metres above mean sea level, Vol = volume

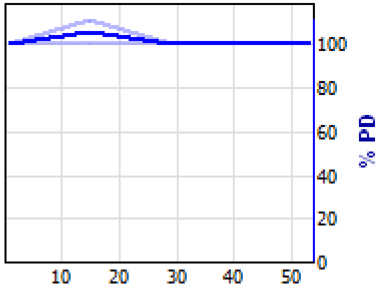
Appendix C. MOTIVATIONS FOR VEGETATION RESPONSE CURVES

The response curves below are for Tete Pan and Floodplain

<table>
<tr><td colspan="2">Floating rooted vegetation (Trapa natans/bispinosa, Nymphaea lotus and N. caerulea)</td></tr>
<tr><td>Response curve</td><td>Explanation</td></tr>
<tr><td>

☑ Dry onset [D season]

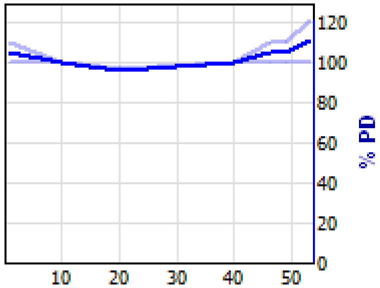
<table>
<tr><th>Desc</th><th>cal week</th><th>Y</th></tr>
<tr><td>Min</td><td>1.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>15.00</td><td>0.200</td></tr>
<tr><td></td><td>29.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>43.00</td><td>0.000</td></tr>
<tr><td></td><td>46.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>49.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>53.00</td><td>0.000</td></tr>
</table>



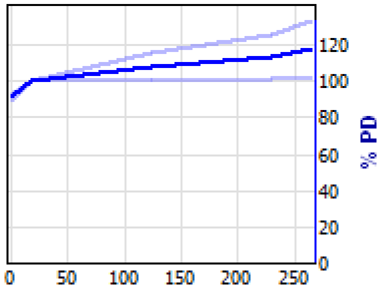
</td><td>These species generally require permanent inundation. However they are able to survive seasonal drying over the winter months but in all cases respond to inundation over the summer months between November and March.</td></tr>
<tr><td>

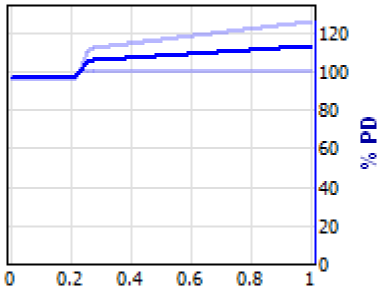
☑ Wet onset [F season]

<table>
<tr><th>Desc</th><th>cal week</th><th>Y</th></tr>
<tr><td>Min</td><td>1.00</td><td>0.100</td></tr>
<tr><td>MinPD</td><td>10.00</td><td>0.000</td></tr>
<tr><td></td><td>20.00</td><td>-0.200</td></tr>
<tr><td>Median</td><td>40.00</td><td>0.000</td></tr>
<tr><td></td><td>46.00</td><td>0.050</td></tr>
<tr><td>Max PD</td><td>49.00</td><td>0.100</td></tr>
<tr><td>Max</td><td>53.00</td><td>0.800</td></tr>
</table>



</td><td>These species generally require permanent inundation. However they are able to survive seasonal drying over the winter months but in all cases respond to inundation over the summer months between November and March. Reproduction is predominantly via vegetative growth and the production of drought resistant seeds and propagules. Antecedent conditions are thus important as this largely determines the production of the drought resistant seeds and vegetative propoagules. Extended dry periods especially over the summer months would therefore largely determine the response of the species in the wet years that follow. Ideally the wet onset should start between October to November and even as late as December in order for these species to complete their life cycles and for maximising productivity. The species are however able to tolerate later inundation but the later into the summer season the shorter the period they have for completion of their life cycles and for the production of fruits and vegetative propagules. The species are largely dormant over the dry season months from May to September although the Nymphaea may flower over the dry season as long as there is enough surface water of the right depth.</td></tr>
</table>

<table>
<tr><td colspan="2">Floating rooted vegetation (Trapa natans/bispinosa, Nymphaea lotus and N. caerulea)</td></tr>
<tr><td>Response curve</td><td>Explanation</td></tr>
<tr><td>
Wet duration [F season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.519</td></tr>
<tr><td>MinPD</td><td>18.00</td><td>0.000</td></tr>
<tr><td></td><td>18.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>18.00</td><td>0.000</td></tr>
<tr><td></td><td>124.00</td><td>0.500</td></tr>
<tr><td>Max PD</td><td>230.00</td><td>1.000</td></tr>
<tr><td>Max</td><td>264.50</td><td>1.250</td></tr>
</table>


</td><td>The wet season duration should extent from early summer (October) through to the end of March in order for these species to complete their life cycles and for maximising productivity. Trapa generally flowers in late summer following summer inundation. Inundation should be of suficient length to support the production of fruits and vegetative propagules to enable these species to survive dry periods should they occur. Reproduction is predominantly via vegetative growth and the production of drought resistant seeds and propagules so it is estimated (based on anecdotal evidence and observations from other similar aquatic macrophytes) that the duration of inundation should be at least 150 days for these species to flourish. The species are largely dormant over the dry season months from May to September although the Nymphaea may flower over the dry season as well as long as there is enough surface water of the right depth.</td></tr>
<tr><td>
Wet: mean Pan area 1-1.5 m [F season]
<table>
<tr><th>Desc</th><th>km2</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-0.200</td></tr>
<tr><td>MinPD</td><td>0.21</td><td>-0.174</td></tr>
<tr><td></td><td>0.22</td><td>-0.087</td></tr>
<tr><td>Median</td><td>0.23</td><td>0.000</td></tr>
<tr><td></td><td>0.25</td><td>0.100</td></tr>
<tr><td>Max PD</td><td>0.28</td><td>0.250</td></tr>
<tr><td>Max</td><td>1.00</td><td>1.000</td></tr>
</table>


</td><td>These species generally thrive where water depth is greater than 1 m although they can occur in shallower zones. There is expected to be an upper depth limit range for these species but based on anecdotal evidence and field observations they generally do not occur where water depth exceeds 1.75 m.</td></tr>
</table>

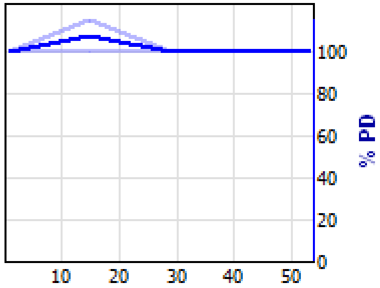
Submerged vegetation *(Potamogeton crispus)*

Response curve	Explanation

Response curve

☑ Dry onset [D season]

Desc	cal week	Y
Min	1.00	0.000
MinPD	15.00	0.500
	29.00	0.000
Median	43.00	0.000
	46.00	0.000
Max PD	49.00	0.000
Max	53.00	0.000



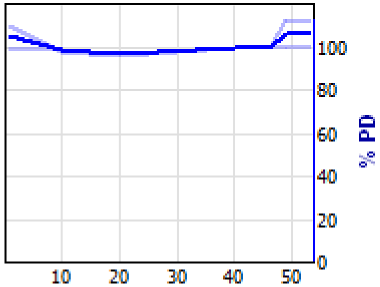
Explanation

This species requires permanent inundation. However they are able to survive seasonal drying via the production of drought resistant vegetative propagules and achenes (Mitchell and Rogers 1985).

Response curve

☑ Wet onset [F season]

Desc	cal week	Y
Min	1.00	0.100
MinPD	10.00	-0.100
	20.00	-0.200
Median	40.00	0.000
	46.00	0.000
Max PD	49.00	0.300
Max	53.00	0.200



Explanation

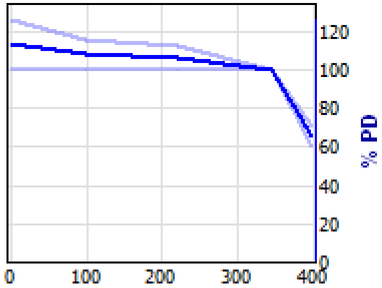
According to Rogers and Breen (1980), a drop in water temperature to 25ºC in autumn stimulates the germination of turions (vegetative propagules of *P. crispus*) and seasonal regeneration which increases until the winter minimum temperature of 15ºC. Germination is thus staggered over a period of 3 to 4 months (April to July) thereby increasing the chance of plant establishment if flooding is late and continues into Autumn or Winter). Young plants have the ability to remain dormant for up to 3 months under poor light conditions (Mitchell and Rogers 1985).

Submerged vegetation *(Potamogeton crispus)*

Response curve | **Explanation**

Dry duration [D season]

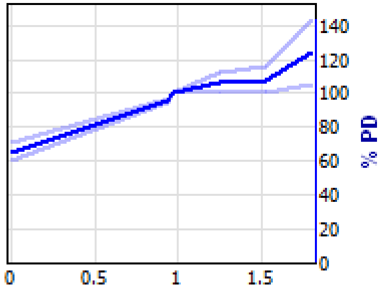
Desc	days	Y
Min	0.00	1.000
MinPD	97.00	0.500
	221.00	0.250
Median	345.00	0.000
	345.50	-0.008
Max PD	346.00	-0.020
Max	397.90	-2.000



Propagule production is usually during winter and spring (Mitchell and Rogers 1985) and is highly seasonal. Achenes (a fruit containing a seed) of *P. crispus* require drying and rewetting for germination and thus during the wet period the achene bank increases with rewetting after a drought stimulating germination (Mitchell and Rogers 1985). This persistent seedbank strategy is a mechanism to ensure survival of long term aseasonal drought conditions. Between the months of May to November the pans must have standing water to a depth of at least 1 m for this species to flourish (Mitchell and Rogers, 1985). Individual plants have a short life span (4 to 5 months; Rogers, 1984). Since germination is staggered over a period of 3 to 4 months, the population can be replaced at least once in a season (Rogers, 1984) in the pans with the population being present for 6 to 8 months of the year during the dry season.

Dry: mean Pan area GT 1m [D season]

Desc	days	Y
Min	0.00	-2.000
MinPD	0.90	-0.300
	0.94	-0.250
Median	0.97	0.000
	1.25	0.250
Max PD	1.52	0.500
Max	1.80	1.500



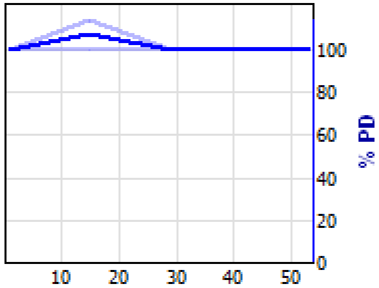
For optimal productivity of the species a pan depth range starting at 1.5 m in May and decreasing to 1 m during November is suggested by Mitchell and Rogers (1985).

Mixed sedge-grass community *(Cyperus fastigiatus and Echinochloa pyramidalis*

Response curve | **Explanation**

☑ Dry onset [D season]

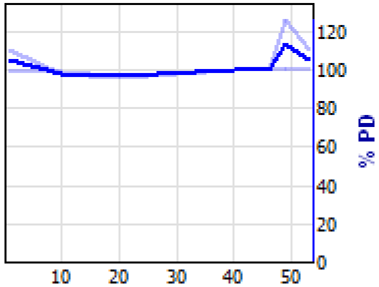
Desc	cal week	Y
Min	1.00	0.000
MinPD	15.00	0.400
	29.00	0.000
Median	43.00	0.000
	46.00	0.000
Max PD	49.00	0.000
Max	53.00	0.000



These species generally respond to intermittent inundation and seasonal saturation. They are able to survive seasonal drying over both the summer and winter months. Intermittent inundation of the floodplain and pan edges and in the flood recession areas during the summer months between October and March are expected to be the key drivers.

☑ Wet onset [F season]

Desc	cal week	Y
Min	1.00	0.050
MinPD	10.00	-0.100
	20.00	-0.200
Median	40.00	0.000
	46.00	0.000
Max PD	49.00	1.000
Max	53.00	0.100



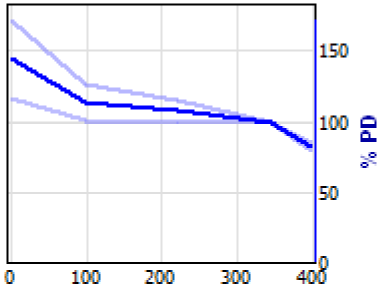
Growth starts at the onset of the rains but the stature would depend on the extent, magnitude and frequency of flooding/inundation. The main growth period would be during the summer months between October and March. Wet onset from early to mid-summer is expected to be better than late summer onset as early inundation would ensure enough time for the species to complete their life cycles and re-allocate resources to the underground storage organs (rhizomes) before the onset of the winter (by the end of April).

Mixed sedge-grass community *(Cyperus fastigiatus and Echinochloa pyramidalis*

Response curve

Dry duration [D season]

Desc	days	Y
Min	0.00	2.000
MinPD	97.00	1.000
	221.00	0.500
Median	345.00	0.000
	345.50	0.000
Max PD	346.00	-0.010
Max	397.90	-1.000



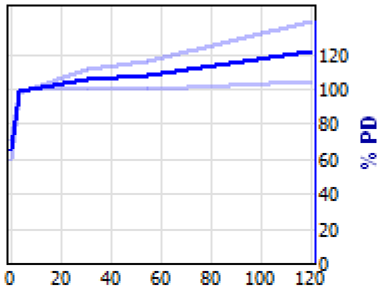
Explanation

Ideally the wet onset should start between October to November and even as late as December in order for these species to complete their life cycles and for maximising productivity. The species are however able to tolerate later inundation as they normally occur in areas that experience fluctuating inundation throughout the summer season due to flood pulses which normally would have occurred under naturalised flows. However they would still require enough time between the onset of flooding and the start of the dry period for completion of their life cycles and more importantly for re-allocation of resources to underground storage organs (rhizomes). The species are largely dormant over the dry season months from May to September. Where grazing is heavy and drainage slightly more rapid following the floods, *E. pyramidalis* may form a mosaic with *C. dactylon*. (Furness and Breen 1980). Extensive prolonged drying (dry periods) would be detriental to these species as continual desiccation would result in the depletion of the rhizome banks reducing the ability of the species to respond and recover during future floods.

Response curve

W/Ann: Days FP depth 0.2-1 (V) [F season]

Desc	days	Y
Min	0.00	-2.000
MinPD	0.00	-2.000
	3.50	-0.100
Median	7.00	0.000
	30.50	0.200
Max PD	54.00	0.500
Max	120.00	1.400



Explanation

Favours wetter conditions than *P. mauritianus* and grows in standing water in the pans as well as along the margins of the main channel and in wetter zones of the seaonally inundated parts of the floodplain (Heeg and Breen, 1982). Prefers full summer inundation. These species generally thrive where water depth is less than 1 m although they can occur in deeper zones for short periods. A common depth range on the floodplain and around the edges of the pans is thus expected to be 0.2 to 1 m. The species normally occur in areas that experience fluctuating levels of inundation throughout the summer season due to flood pulses which normally would have occurred under naturalised flows. Theoretically, the more events that cross the threshold and inundate these areas, the better would be the response of this community and higher productivity and more vigorous growth would be expected.

<table>
<tr><td colspan="2">Reedbeds (Phragmites australis)</td></tr>
<tr><td>Response curve</td><td>Explanation</td></tr>
<tr><td>
Wet onset [F season]
<table>
<tr><th>Desc</th><th>cal week</th><th>Y</th></tr>
<tr><td>Min</td><td>1.00</td><td>0.050</td></tr>
<tr><td>MinPD</td><td>10.00</td><td>0.010</td></tr>
<tr><td></td><td>20.00</td><td>-0.200</td></tr>
<tr><td>Median</td><td>40.00</td><td>0.000</td></tr>
<tr><td></td><td>46.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>49.00</td><td>0.600</td></tr>
<tr><td>Max</td><td>53.00</td><td>0.100</td></tr>
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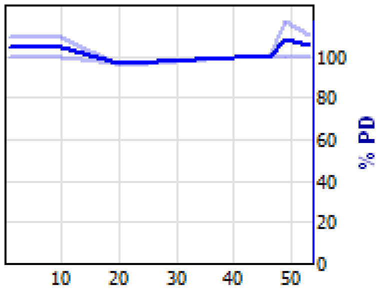
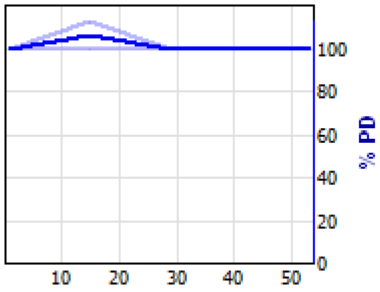
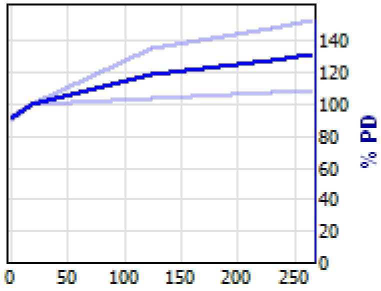


</td><td>This species prefers permanent inundation. It is however able to survive seasonal drying over the winter months but in all cases responds to inundation over the summer months between October and March. Reproduction is predominantly via vegetative growth. Extended dry periods especially over the summer months would therefore largely determine the response of the species in the wet years that follow as it would be dependent on the rhizome biomass remaining. Ideally the wet onset should start between October to November and even as late as December in order for this species to complete its life cycle and for maximising productivity. This species is generally dormant over the dry season months from May to September.</td></tr>
<tr><td>
Dry onset [D season]
<table>
<tr><th>Desc</th><th>cal week</th><th>Y</th></tr>
<tr><td>Min</td><td>1.00</td><td>0.000</td></tr>
<tr><td>MinPD</td><td>15.00</td><td>0.300</td></tr>
<tr><td></td><td>29.00</td><td>0.000</td></tr>
<tr><td>Median</td><td>43.00</td><td>0.000</td></tr>
<tr><td></td><td>46.00</td><td>0.000</td></tr>
<tr><td>Max PD</td><td>49.00</td><td>0.000</td></tr>
<tr><td>Max</td><td>53.00</td><td>0.000</td></tr>
</table>


</td><td>This species prefers permanent inundation. It is however able to survive seasonal drying over the winter months. Extended dry periods especially over the summer months would therefore largely determine the response of the species in the wet years that follow as it would be dependent on the rhizome biomass remaining. Ideally dry onset should not occur before the end of summer.</td></tr>
</table>

☑ Wet duration [F season]

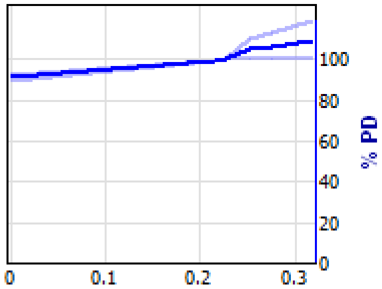
Desc	days	Y
Min	0.00	-0.500
MinPD	18.00	0.000
	18.00	0.000
Median	18.00	0.000
	124.00	1.300
Max PD	230.00	1.600
Max	264.50	1.700



Favours wetter conditions than *P. mauritianus* and grows in standing water in the pans as well as along the margins of the main channel and in wetter zones of the seaonally inundated parts of the floodplain (Heeg and Breen, 1982). Prefers full summer inundation.

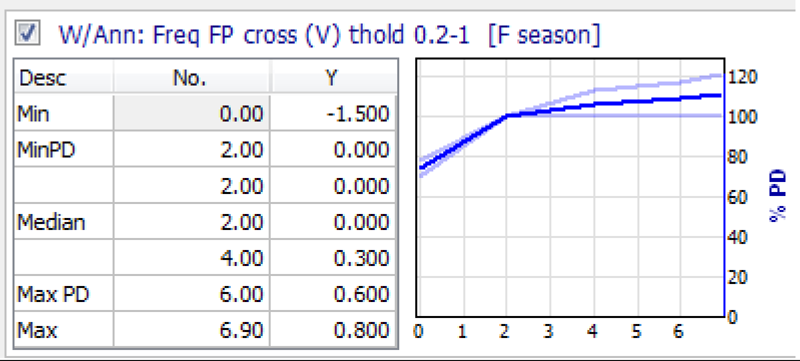
☑ Wet: mean Pan area 1-1.5 m [F season]

Desc	km2	Y
Min	0.00	-0.500
MinPD	0.21	-0.043
	0.22	-0.022
Median	0.23	0.000
	0.25	0.100
Max PD	0.28	0.300
Max	0.32	0.700



This species generally does not occur in water deeper than 1.5m for extended periods. It is however expected to flourish in standing water within a depth range of 1 to 1.5 m for extended periods. It is assumed that the larger the pan area exposed to a depth range of 1 to 1.5m, the more opportunity there is for this species to take advantage of the wetter conditions during the wet season and the higher the productivity of this species.

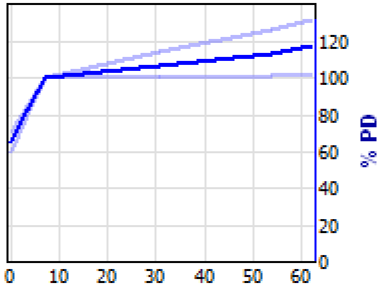
Reedbeds *(Phragmites mauritianus)*	
Response curve	**Explanation**
Wet duration	Favours slightly drier conditions than *P. australis* and generally prefers sites where there is water movement such as the edges of the river banks that experience intermittent inundation and areas above the maximum retention level in the pans (Heeg and Breen 1982).
(see figure below)	As this species prefers intermittent inundation, it is assumed that the higher the frequency of floods that cross the floodplain threshold of 0.2 to 1 m during the wet season, the more opportunity there is for this species to flourish, particularly in the areas above the maximum retention levels in the pans. It is not expected to occur in water deeper than 1 m for extended periods. It is expected to flourish in areas where the water depth fluctuates between 0.2 and 1 m with intermittent drying between flood events.



Desc	No.	Y
Min	0.00	-1.500
MinPD	2.00	0.000
	2.00	0.000
Median	2.00	0.000
	4.00	0.300
Max PD	6.00	0.600
Max	6.90	0.800

W/Ann: Days FP depth 0.2-1 (V) [F season]

Desc	days	Y
Min	0.00	-2.000
MinPD	0.00	-2.000
	3.50	-1.000
Median	7.00	0.000
	30.50	0.400
Max PD	54.00	1.000
Max	62.10	1.200



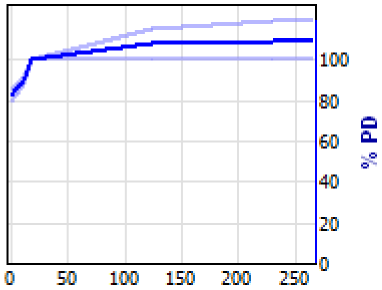
This species is expected to thrive in areas where the depth range of flowing water is between 0.2 and 1 m for at least 90 days in the wet season.

Couch grass lawns *(Cynodon dactylon)*

Response curve	Explanation

Wet duration [F season]

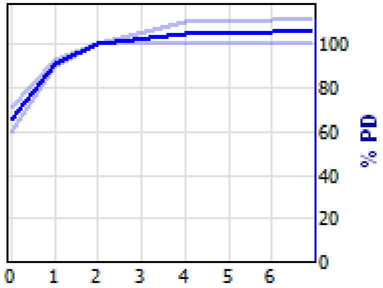
Desc	days	Y
Min	0.00	-1.000
MinPD	5.00	-0.800
	10.00	-0.600
Median	18.00	0.000
	124.00	0.500
Max PD	230.00	0.700
Max	264.50	0.700



This species survives inundation as viable rhizomes and shoots even though the latter lose their leaves following inundation (Heeg and Breen 1982). This species can tolerate periods of submergence of up to 150 days (Furness and Breen 1980). Inundation should persist for at least 28 days for the aquatic phase to benefit (Furness and Breen 1982). As the plants are exposed to increasing water stress, productivity decreases. However this species is extremely tolerant of extended periods of dry conditions following exposure and of submergence.

W/Ann: Freq FP cross (V) thold 0.2-1 [F season]

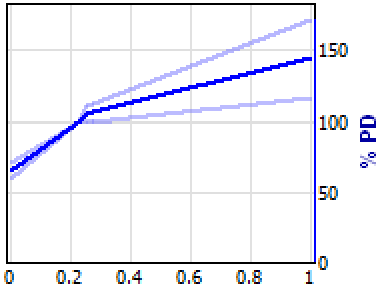
Desc	No.	Y
Min	0.00	-2.000
MinPD	1.00	-0.500
	2.00	0.000
Median	2.00	0.000
	4.00	0.100
Max PD	6.00	0.200
Max	6.90	0.200



This species extends from below the maximum retention level to above the high flood level and is found on gently sloping areas that become exposed gradually as the flood waters recede (Heeg and Breen 1982).This species rapidly responds following re-exposure as the flood waters recede. The interval between consecutive periods of inundation should exceed 25 days (Furness and Breen 1982).

Wet: mean Pan area 1-1.5 m [F season]

Desc	km2	Y
Min	0.00	-2.000
MinPD	0.21	-0.100
	0.22	-0.010
Median	0.23	0.000
	0.25	0.100
Max PD	0.28	0.300
Max	1.00	2.000



This species responds rapidly following re-exposure as the flood waters recede (Heeg and Breen 1982) and flood events of this magnitude are expected to inundate more of this habitat and increase productivity.

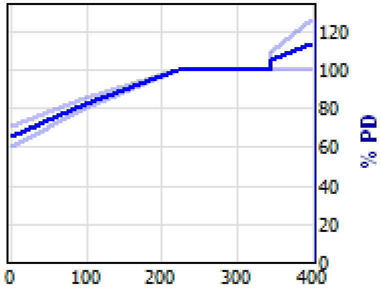
Riparian Tree Communities *(Ficus sycomorus - Rauvolfia caffra / Acacia xanthophloe - Dyschoriste depressa community)*	
Response curve	Explanation

Riparian Tree Communities *(Ficus sycomorus - Rauvolfia caffra / Acacia xanthophloe - Dyschoriste depressa community)*

Response curve | **Explanation**

Dry duration [D season]

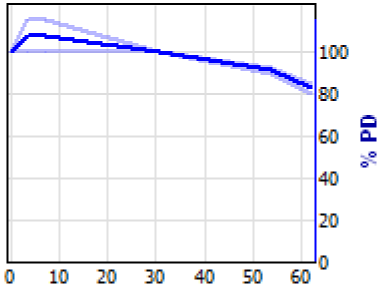
Desc	days	Y
Min	0.00	-2.000
MinPD	97.00	-1.000
	221.00	0.000
Median	345.00	0.000
	345.50	0.000
Max PD	346.00	0.020
Max	397.90	1.000



Under normal flooding conditions these communities are infrequently flooded (Heeg and Breen 1982) and prefer drier conditions. They can tolerate intermittent flooding for short periods.

W/Ann: Days FP depth 0.2-1 (V) [F season]

Desc	days	Y
Min	0.00	0.000
MinPD	0.00	0.000
	3.50	0.500
Median	7.00	0.500
	30.50	0.000
Max PD	54.00	-0.500
Max	62.10	-1.000



Flooding duration is normally short (Heeg and Breen 1982). *A. xanthophloe* along the edge of the pans may succumb during periods of high pan levels for extended times (Heeg et al. 1980). During periods where floods cross the floodplain threshold many times in one season, it is likely to stress the riparian trees as they would be exposed to extended periods of inundation.

Appendix D. MOTIVATIONS OF FISH RESPONSE CURVES

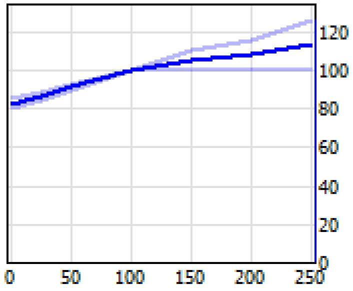
The response curves below are for Tete Pan and Floodplain

Flood-dependent benthic

Response curve | **Explanation**

Submerged vegetation [D season]

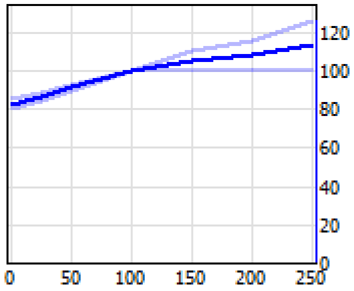
Desc	%Base	Y
Min	0.00	-1.000
MinPD	25.00	-0.800
	50.00	-0.500
Median	100.00	0.000
	150.00	0.100
Max PD	200.00	0.500
Max	250.00	1.000



Potamogeton crispus is an indicator of general productivity levels on the floodplain early in the wet season. Senescence at the end of the dry season increases the availability of nutrients driving primary and secondary productivity which translates to a stronger fish year class due to increased food availability for recruits (Heeg and Breen 1982).

Mixed sedge-grass community [F season]

Desc	%Base	Y
Min	0.00	-1.000
MinPD	25.00	-0.800
	50.00	-0.500
Median	100.00	0.000
	150.00	0.100
Max PD	200.00	0.500
Max	250.00	1.000



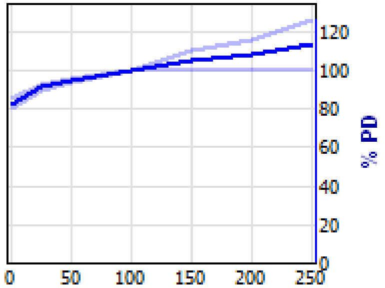
Emergent mixed grass sedge meadow and reedbeds important nursery area for young fish, providing vegetative cover for larvae and juveniles in this guild. Reduced availability and inundation leads to increased vulnerability to predation on young fish. Inundation of sedges also assumes inundation of *Phragmites* reedbeds (Heeg and Breen 1982).

Flood-dependent benthic

Response curve	Explanation

Couch grass lawns [F season]

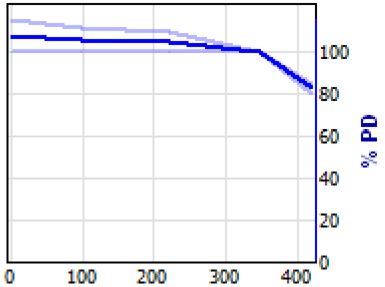
Desc	%Base	Y
Min	0.00	-1.000
MinPD	25.00	-0.500
	50.00	-0.300
Median	100.00	0.000
	150.00	0.100
Max PD	200.00	0.500
Max	250.00	1.000



Couch grass lawns are a predictor of general productivity levels on the floodplain later in the wet season. Die-off towards the end of the wet season increases the availability of nutrients driving primary and secondary productivity over the flood season which translates to a strong fish year class due to increased food availability for young-of-the-year (Heeg and Breen 1982).

Dry duration [D season]

Desc	days	Y
Min	0.00	0.500
MinPD	97.00	0.250
	221.00	0.088
Median	345.00	0.000
	345.50	0.000
Max PD	346.00	-0.003
Max	419.75	-1.000



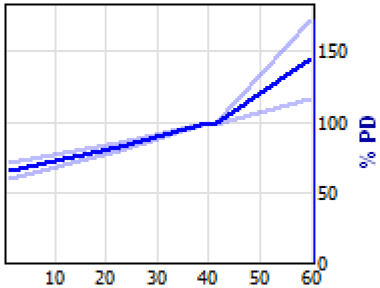
An extended dry season reduces habitat availability for floodplain-dependent fish, water quality deteriorates (DO, turbidity, conductivity), inter- and inter-specific competition together with predation increases, as does fishery mortality (Weldrick 1996).

Flood-dependent benthic

Response curve	Explanation

Wet onset [F season]

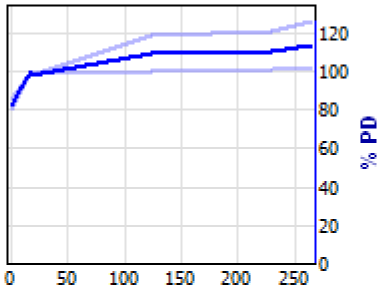
Desc	cal week	Y
Min	1.00	-2.000
MinPD	1.00	-2.000
	22.50	-1.000
Median	40.00	0.000
	40.50	-0.100
Max PD	41.00	-0.100
Max	59.80	2.000



The flood-dependent benthic guild depends on the onset of the wet season coinciding with increasing temperatures over spring which triggers gonad maturation (Merron et al. 1993). An early onset to the wet season will coincide with low temperatures and spawning and migratory cues will be mismatched with flow conditions. A delay of the wet season onset beyond week 49 will delay migratory and gonadal maturation cues.

Wet duration [F season]

Desc	days	Y
Min	0.00	-1.000
MinPD	9.00	-0.500
	18.00	-0.100
Median	18.00	0.000
	124.00	0.700
Max PD	230.00	0.800
Max	264.50	1.000



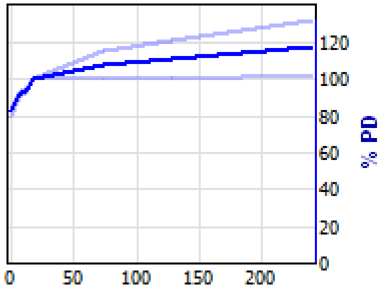
Longer duration of the wet season results in longer time on the Floodplain for feeding, growth and development of juvenile flood-dependent guilds which translates to larger fish and a stronger year-classes (Heeg and Breen 1982, Welcomme 2001). A longer duration wet season is considered to be a good predictor of a moderate recession slope enabling fish to move from the floodplain back into the pans or main channel at the start of the dry season.

Flood-dependent benthic

Response curve	Explanation

W/Ann: sum Days (F) [F season]

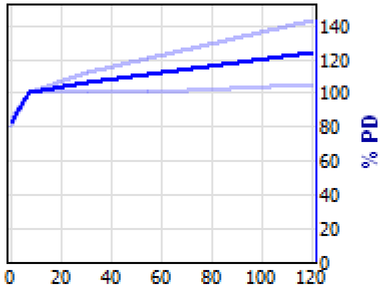
Desc	days	Y
Min	0.00	-1.000
MinPD	7.00	-0.500
	12.50	-0.300
Median	18.00	0.000
	73.00	0.500
Max PD	128.00	0.800
Max	239.20	1.200



The number of days the pans are connected to the main channel increases the number of opportunities for flood-dependent guilds to access the floodplain and pans for spawning and feeding. This leads to increased opportunities for growth, development and reproduction. Towards the end of the wet season, the number of opportunities for fish to leave the floodplain are also increased.

W/Ann: Days FP depth 0.2-1 (V) [F season]

Desc	days	Y
Min	0.00	-1.000
MinPD	0.00	-1.000
	3.50	-0.500
Median	7.00	0.000
	30.50	0.300
Max PD	54.00	0.800
Max	120.00	1.500



x axis = max 120. The number of days depths in the floodplain are between 0.2-1 m translates to the total amount of wetted habitat available to the flood-dependent benthic guild over the wet season for spawning, feeding, growth and development. Less inundation will increase inter- and intra-specific competition resulting in reduced growth and mortality of young fish. During flooding there is a large nutrient pulse from allochthonous material, terrestrial plant matter, detritus, animal faeces, nutrients – indirect effects on fish through productivity (Heeg and Breen 1982, Welcomme 2001). The relationship is expected to be direct and proportional.

Flood-dependent pelagic

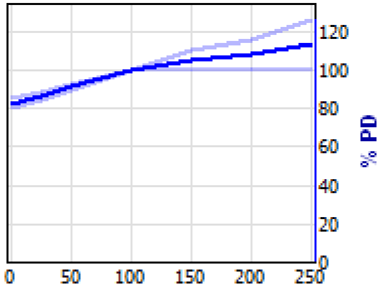
Response curve	Explanation

Flood-dependent pelagic

Response curve / **Explanation**

☑ Submerged vegetation [D season]

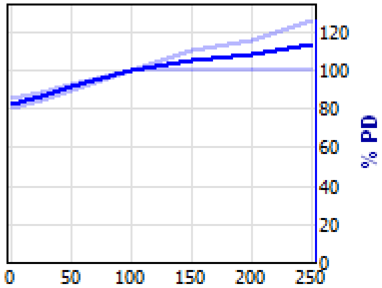
Desc	%Base	Y
Min	0.00	-1.000
MinPD	25.00	-0.800
	50.00	-0.500
Median	100.00	0.000
	150.00	0.100
Max PD	200.00	0.500
Max	250.00	1.000



Potamogeton crispus is an indicator of general productivity levels on the floodplain early in the wet season. Senescence at the end of the dry season increases the availability of nutrients driving primary and secondary productivity which translates to a stronger fish year class due to increased food availability for recruits (Heeg and Breen 1982).

☑ Mixed sedge-grass community [F season]

Desc	%Base	Y
Min	0.00	-1.000
MinPD	25.00	-0.800
	50.00	-0.500
Median	100.00	0.000
	150.00	0.100
Max PD	200.00	0.500
Max	250.00	1.000



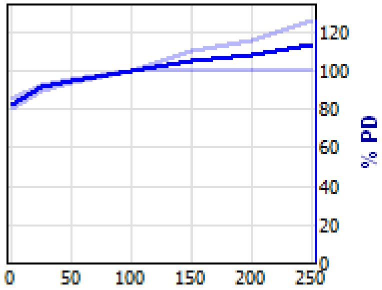
Emergent mixed grass sedge meadow and reedbeds important nursery area for young fish, providing vegetative cover for larvae and juveniles in this guild. Reduced availability and inundation leads to increased vulnerability to predation on young fish. Inundation of sedges also assumes inundation of phragmites reedbeds (Heeg and Breen 1982).

Flood-dependent pelagic

Response curve | **Explanation**

☑ Couch grass lawns [F season]

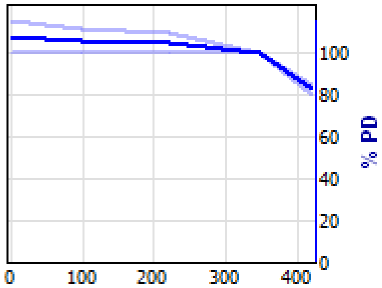
Desc	%Base	Y
Min	0.00	-1.000
MinPD	25.00	-0.500
	50.00	-0.300
Median	100.00	0.000
	150.00	0.100
Max PD	200.00	0.500
Max	250.00	1.000



Couch grass lawns are a predictor of general productivity levels on the floodplain later in the wet season. Die-off towards the end of the wet season increases the availability of nutrients driving primary and secondary productivity over the flood season which translates to a strong fish year class due to increased food availability for young-of-the-year (Heeg and Breen 1982).

☑ Dry duration [D season]

Desc	days	Y
Min	0.00	0.500
MinPD	97.00	0.250
	221.00	0.088
Median	345.00	0.000
	345.50	0.000
Max PD	346.00	-0.003
Max	419.75	-1.000



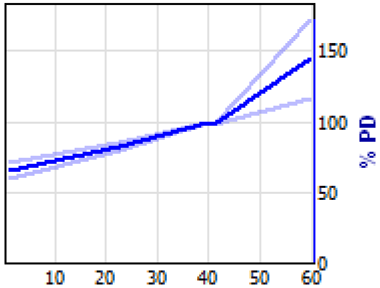
An extended dry season reduces habitat availability for floodplain-dependent fish, water quality deteriorates (DO, turbidity, conductivity), inter- and inter-specific competition together with predation increases, as does fishery mortality (Weldrick 1996).

Flood-dependent pelagic

Response curve	Explanation

Wet onset [F season]

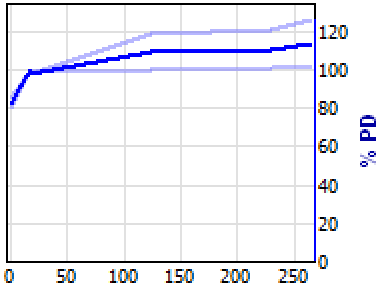
Desc	cal week	Y
Min	1.00	-2.000
MinPD	1.00	-2.000
	22.50	-1.000
Median	40.00	0.000
	40.50	-0.100
Max PD	41.00	-0.100
Max	59.80	2.000



The flood-dependent pelagic guild depends on the onset of the wet season coinciding with increasing temperatures over spring which triggers gonad maturation (Merron et al. 1993). An early onset to the wet season will coincide with low temperatures and spawning and migratory cues will be mismatched with flow conditions. A delay of the wet season onset beyond week 49 will delay migratory and gonadal maturation cues.

Wet duration [F season]

Desc	days	Y
Min	0.00	-1.000
MinPD	9.00	-0.500
	18.00	-0.100
Median	18.00	0.000
	124.00	0.700
Max PD	230.00	0.800
Max	264.50	1.000



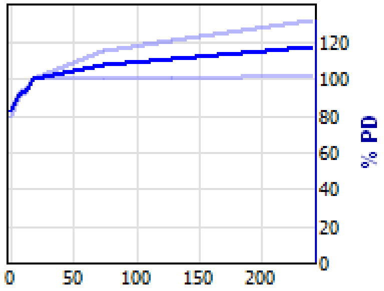
Longer duration of the wet season results in longer time on the Floodplain for feeding, growth and development of juvenile flood-dependent guilds which translates to larger fish and stronger year-classes (Heeg and Breen 1982, Welcomme 2001). A longer duration wet season is considered to be a good predictor of a moderate moderate recession slope enabling fish to move from the floodplain back into the pans or main channel at the start of the dry season.

Flood-dependent pelagic

Response curve	Explanation

W/Ann: sum Days (F) [F season]

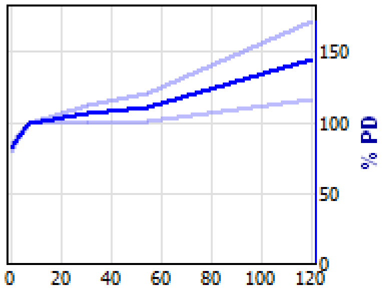
Desc	days	Y
Min	0.00	-1.000
MinPD	7.00	-0.500
	12.50	-0.300
Median	18.00	0.000
	73.00	0.500
Max PD	128.00	0.800
Max	239.20	1.200



The number of days the pans are connected to the main channel increases the number of opportunities for flood-dependent guilds to access the floodplain and pans for spawning and feeding. This leads to increased opportunities for growth, development and reproduction. Towards the end of the wet season, the number of opportunities for fish to leave the floodplain are also increased.

W/Ann: Days FP depth 0.2-1 (V) [F season]

Desc	days	Y
Min	0.00	-1.000
MinPD	0.00	-1.000
	3.50	-0.500
Median	7.00	0.000
	30.50	0.300
Max PD	54.00	0.800
Max	120.00	2.000



x axis = max 120. The number of days depths in the floodplain are between 0.2-1 m translates to the total amount of wetted habitat available to the flood-dependent pelagic guild over the wet season for spawning, feeding, growth and development. Less inundation will increase inter- and intra-specific competition resulting in reduced growth and mortality of young fish. During flooding there is a large nutrient pulse from allochthonous material, terrestrial plant matter, detritus, animal faeces, nutrients – indirect effects on fish through productivity (Heeg and Breen 1982, Welcomme 2001). The relationship is expected to be direct and proportional and more pronounced than the flood-dependent benthic guild since these fish have a preference for clear, open water lagoons (Mosepele et al. 2009).

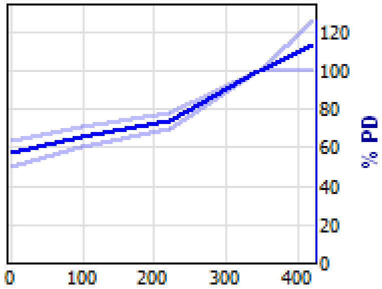
Flood-independent generalist

Response curve	Explanation

Flood-independent generalist	
Response curve	Explanation
See response curve below	Flood-independent generalists (e.g. O. mossambicus) are able to exploit a wide range of environmental conditions. However, they benefit from an extended dry season since they nest-guarders which are not dependent on flooding to trigger spawning and they are tolerant of deteriorating water quality conditions in pans during drought years (Merron et al. 1993). They will also be released from competition and predation by species intolerant of these conditions.

Dry duration [D season]

Desc	days	Y
Min	0.00	-2.500
MinPD	97.00	-2.000
	221.00	-1.500
Median	345.00	0.000
	345.50	0.000
Max PD	346.00	0.000
Max	419.75	1.000

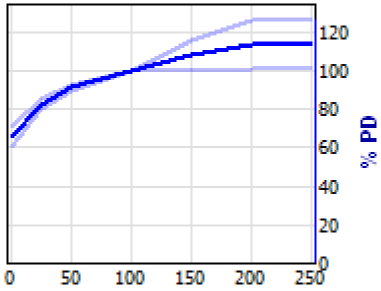


Flood-independent vegetation

Response curve	Explanation

Submerged vegetation [T1 season]

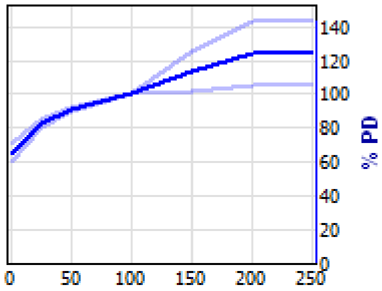
Desc	%Base	Y
Min	0.00	-2.000
MinPD	25.00	-1.000
	50.00	-0.500
Median	100.00	0.000
	150.00	0.500
Max PD	200.00	1.000
Max	250.00	1.000



Potamogeton crispus is a indicator of general productivity levels on the floodplain. Senescence at the end of the dry season increases the availability of nutrients driving primary and secondary productivity over the flood season which translates to a strong fish year class due to increased food availability (Heeg and Breen 1982). The vegetation is also an important source of food for opportunistic macrophytic browsers in this guild e.g. T. rendalli.

Mixed sedge-grass community [F season]

Desc	%Base	Y
Min	0.00	-2.000
MinPD	25.00	-1.000
	50.00	-0.500
Median	100.00	0.000
	150.00	1.000
Max PD	200.00	1.500
Max	250.00	1.500



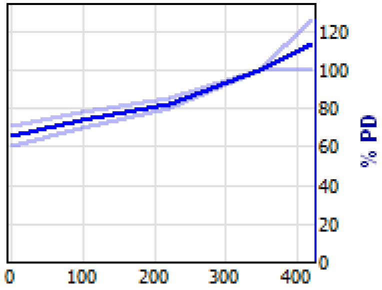
Flood-independent vegetation guild members like T. rendalli are opportunistic macrophytic browsers and Echincloa pyramidalis is an important component of its diet (Weyl and Hecht 1998, Heeg and Breen 1982). No inundation or low production of this sedge would reduce food availability and therefore growth and development of juvenile and adults of this species over the flood season. Sedges also provide cover for juvenile fish.

Flood-independent vegetation

Response curve

Dry duration [D season]

Desc	days	Y
Min	0.00	-2.000
MinPD	97.00	-1.500
	221.00	-1.000
Median	345.00	0.000
	345.50	0.000
Max PD	346.00	0.000
Max	419.00	1.000



Explanation

Flood-independent vegetation guild (e.g. T. rendalli) benefit from an extended dry season since they are not dependent on flooding to trigger spawning (Merron et al. 1993). They will also be released from competition and predation from species intolerant of an extended dry season. The response is not expected to be as strong as flood-independent generalists.

References:

Heeg, J. and Breen, C.M. 1982. Man and the Pongolo floodplain. South African National Scientific Programmes Report No. 50. A report of the Committee for Inland Water Ecosystems National Programme for Environmental Sciences 56. Council for Scientific and Industrial Research, Pretoria. 117 pp.

Merron, G.S.; Bruton, M.N. and la Hausse de Lalouviere, P. 1993. Implications of water release from the Jozini dam for the fish and fishery of the Phongolo floodplain, Zululand. Southern African Journal of Aquatic Sciences, 19: 34-49.

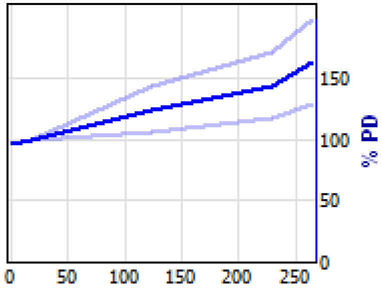
Weyl, O.L.F. and Hecht, T. 1998. The biology of Tilapia rendalli and Oreochromis mossambicus (Pisces: Cichlidae) in a subtropical lake in Mozambique. South African Journal of Zoology, 33: 178-188.

Fish biomass

Response curve	Explanation

Wet duration [F season]

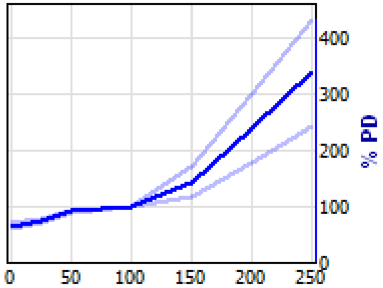
Desc	days	Y
Min	0.00	-0.200
MinPD	9.00	-0.087
	18.00	0.000
Median	18.00	0.000
	124.00	1.500
Max PD	230.00	2.000
Max	264.50	2.300



Explanation: Increased duration of floodplain inundation increases the amoung of time young-of-the-year spend on the floodplain feeding and growing leading to a stronger year-class, larger fish before they move off the floodplain and higher biomass (Welcomme 1975, Welcomme 2001).

Fish agg wt mass [All seasons]

Desc	%Base	Y
Min	0.00	-2.000
MinPD	25.00	-1.500
	50.00	-0.500
Median	100.00	0.000
	150.00	2.000
Max PD	200.00	3.000
Max	250.00	3.500



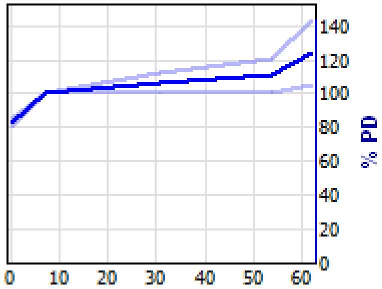
Explanation: Weighted sum from Fish agg wt

Fish biomass

Response curve

W/Ann: Days FP depth 0.2-1 (V) [F season]

Desc	days	Y
Min	0.00	-1.000
MinPD	0.00	-1.000
	3.50	-0.500
Median	7.00	0.000
	30.50	0.300
Max PD	54.00	0.800
Max	62.10	1.500



Explanation

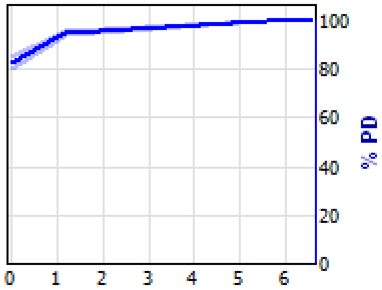
The number of days depths in the floodplain are between 0.2-1 m translates to the total amount of wetted habitat available to the fish on the floodplain over the wet season for spawning, feeding, growth and development. More habitat available reduces competitive interactions, shelter for individual fish (Halls and Welcomme 2004)

Main channel rheophilics

Response curve

Dry Min 5d stage [D season]

Desc	m3/s	Y
Min	0.00	-1.000
MinPD	1.00	-0.400
	1.20	-0.300
Median	5.57	0.000
	5.64	0.000
Max PD	5.71	0.000
Max	6.56	0.000



Explanation

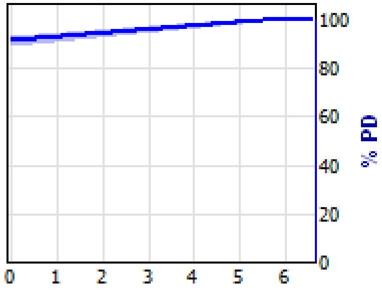
The main channel riffle guild is dependent through the dry season on flowing water over a gravel/cobble substrate. It has been assumed these conditions will be met at minimum 5 day discharge of 1.3 m3/s. Anything lower than this would reduce the quantity and quality of riffle habitats and therefore its suitability for this guild.

Main channel semi-rheophilics

Response curve

☑ Dry Min 5d stage [D season]

Desc	m3/s	Y
Min	0.00	-0.500
MinPD	5.47	0.000
	5.52	0.000
Median	5.57	0.000
	5.64	0.000
Max PD	5.71	0.000
Max	6.56	0.000



Explanation

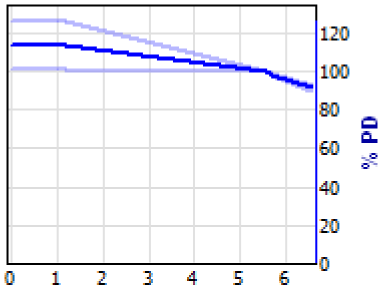
Through the dry season, large rheophilic cyprinids and characids (e.g. L. marequensis and H. vittatus) require passage through shallow riffles and runs and some flow to maintain water quality in pools. Productivity in shallow fast-flowing riffles areas needs to be maintained for drift feeding juveniles and adults belonging to this guild.

Main channel pool

Response curve

☑ Dry Min 5d stage [D season]

Desc	m3/s	Y
Min	0.00	1.000
MinPD	1.00	1.000
	1.20	1.000
Median	5.57	0.000
	5.64	-0.050
Max PD	5.71	-0.100
Max	6.56	-0.500



Explanation

The main channel pool community depends on the availability of hydraulic refuges either along the margins of the active channel or in pools. A discharge in excess of 5 m3/s will result in some loss of hydraulic refuges for this guild by drowning out pool habitats and increasing mean velocities through the channel.

Appendix E. MOTIVATIONS FOR SOCIAL RESPONSE CURVES

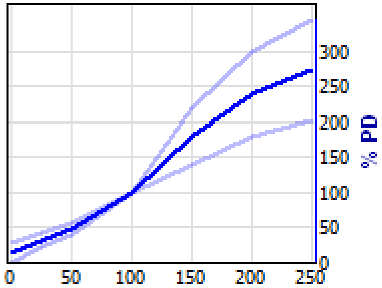
The response curves below are for Tete Pan and Floodplain

Fishing in pans

Response curve

Fish biomass [F season]

Desc	%Base	Y
Min	0.00	-5.000
MinPD	25.00	-3.900
	50.00	-3.000
Median	100.00	0.000
	150.00	2.500
Max PD	200.00	3.000
Max	250.00	3.200



Explanation

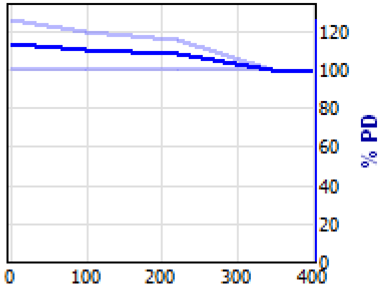
Significant demand for fishing as a source of protein. Any increase in fish abundance will result in a similar increase in fish catches. Therefore there will be a positive impact on the social wellbeing of the households in the floodplain. Increase in fish increases with additional floods in January February.

Drinking water

Response curve

Dry duration [D season]

Desc	days	Y
Min	0.00	1.000
MinPD	97.00	0.750
	221.00	0.500
Median	345.00	0.000
	345.50	0.000
Max PD	346.00	-0.020
Max	397.90	-0.050



Explanation

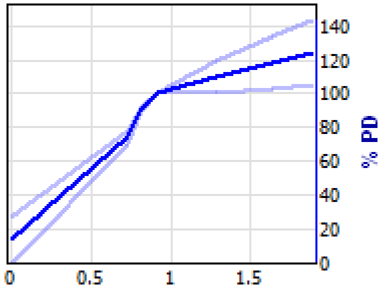
As the dry duration lengthens the impact on availability of water for drinking is negatively affected.

Drinking water

Response curve

Dry Min 5d stage [D season]

Desc	m3/s	Y
Min	0.00	-5.000
MinPD	0.73	-1.500
	0.82	-0.500
Median	0.91	0.000
	1.28	0.750
Max PD	1.64	1.250
Max	1.89	1.500



Explanation

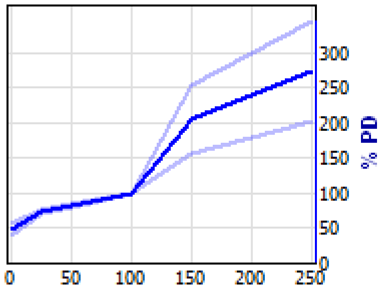
The depth of water in the pans will provide access to water for cattle drinking. Domestic use of water for cooking & washing increases with availability. The lower the depth of water declines livestock due to livestock mortalities resulting from general water shortages and mud trapping.

Harvesting of fruits (figs, etc.)

Response curve

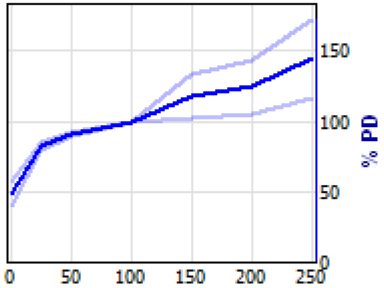
Riparian tree communities [F season]

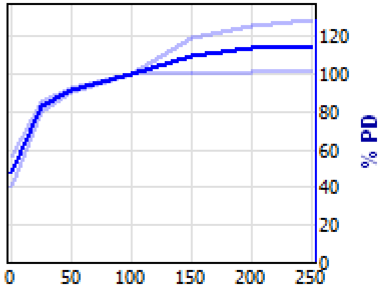
Desc	%Base	Y
Min	0.00	-3.000
MinPD	25.00	-1.500
	50.00	-1.000
Median	100.00	0.000
	150.00	2.750
Max PD	200.00	3.000
Max	250.00	3.200



Explanation

Harvesting of fruits in the floodplain as a source of food is prevalent in the Pongola. If the riparian tree communities increase from present day, harvesting of the fruits will increase.

<table>
<tr><th colspan="2">Harvesting of reeds and grasses</th></tr>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>
Mixed sedge-grass community [D season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-1.000</td></tr>
<tr><td></td><td>50.00</td><td>-0.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>1.250</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>1.500</td></tr>
<tr><td>Max</td><td>250.00</td><td>2.000</td></tr>
</table>


</td><td>The mixed sedge grass is important for thatching, construction, mats and crafts. Increase in abundance of the sedge communities will increase harvesting with increase in harvesting.</td></tr>
<tr><td>
Reedbeds (P. australis) [D season]
<table>
<tr><th>Desc</th><th>%Base</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>-3.000</td></tr>
<tr><td>MinPD</td><td>25.00</td><td>-1.000</td></tr>
<tr><td></td><td>50.00</td><td>-0.500</td></tr>
<tr><td>Median</td><td>100.00</td><td>0.000</td></tr>
<tr><td></td><td>150.00</td><td>0.710</td></tr>
<tr><td>Max PD</td><td>200.00</td><td>1.000</td></tr>
<tr><td>Max</td><td>250.00</td><td>1.100</td></tr>
</table>


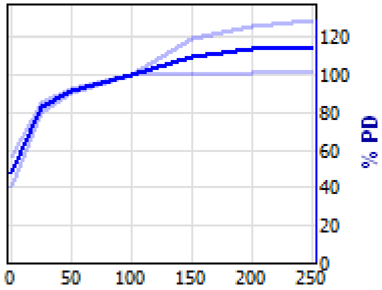
</td><td>Demand for reeds increases with availability for harvesting. It is used for construction. However the demand is dwindling because of the modern dwellings being built in the Pongola Floodplain.</td></tr>
</table>

Harvesting of reeds and grasses

Response curve

Reedbeds (P. mauritianus) [D season]

Desc	%Base	Y
Min	0.00	-3.000
MinPD	25.00	-1.000
	50.00	-0.500
Median	100.00	0.000
	150.00	0.710
Max PD	200.00	1.000
Max	250.00	1.100



Explanation

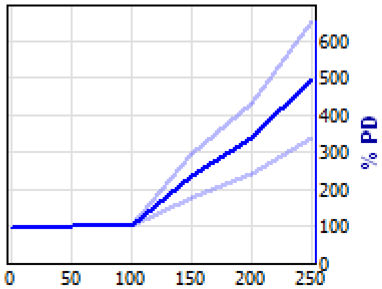
Demand for reeds increases with availability for harvesting. It is used for construction. However the demand is dwindling because of the modern dwellings being built in the Pongola Floodplain.

Grazing for livestock

Response curve

Couch grass lawns [F season]

Desc	%Base	Y
Min	0.00	-0.050
MinPD	25.00	-0.020
	50.00	0.000
Median	100.00	0.000
	150.00	3.000
Max PD	200.00	3.500
Max	250.00	4.000



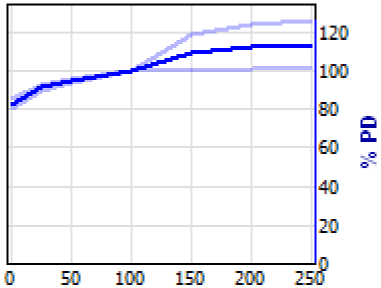
Explanation

An increase in *Cynodon* lawns will see an increase in the quality of livestock and in grazing area. The livestock abundance is however limited by land that is converted to farming.

<table>
<tr><th colspan="2">Flood irrigated commercial agriculture</th></tr>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>

Submerged vegetation [F season]

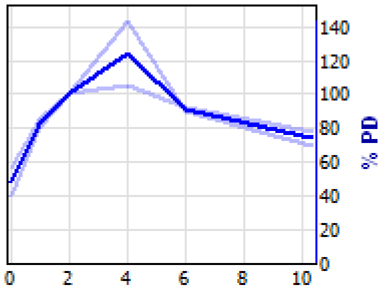
Desc	%Base	Y
Min	0.00	-1.000
MinPD	25.00	-0.500
	50.00	-0.300
Median	100.00	0.000
	150.00	0.700
Max PD	200.00	0.900
Max	250.00	1.000



</td><td>Significant demand for commercial agriculture. Commercial irrigation starts at the end of the October beginning of November. An increase in the submerged vegetation will increase the nutrients and enrich the soils in the floodplain. This will have a positive impact on productivity.</td></tr>
<tr><td>

W/Ann: Freq FP cross (V) thold 0.2-1 [F season]

Desc	No.	Y
Min	0.00	-3.000
MinPD	1.00	-1.000
	2.00	0.000
Median	2.00	0.000
	4.00	1.500
Max PD	6.00	-0.500
Max	10.35	-1.500



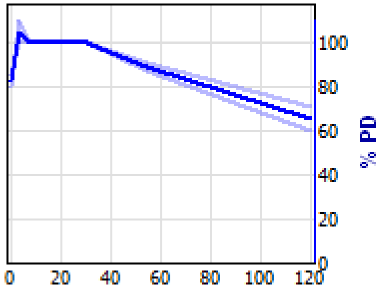
</td><td>The frequency of the floods inundating the floodplain has an effect on the commercial agricultural activity in the system. The more floods released will result in limited time for the waters to recede in time for planting season.</td></tr>
</table>

Flood irrigated commercial agriculture

Response curve

W/Ann: Days FP depth 0.2-1 (V) [F season]

Desc	days	Y
Min	0.00	-1.000
MinPD	0.00	-1.000
	3.50	0.100
Median	7.00	0.000
	30.50	0.000
Max PD	54.00	-0.600
Max	120.00	-2.000



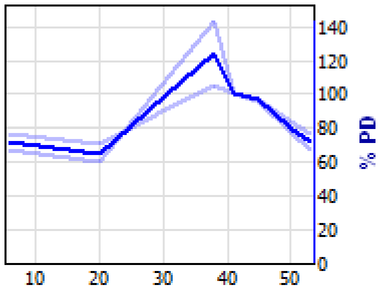
Explanation

The more days the floodplain is submerged the shorted the time available for growing crops. Ideally, the duration of flood releases should be limited to enable the water to recede in time for planting to take place.

Response curve

Wet/Ann: Onset ext FP flooding [F season]

Desc	week	Y
Min	6.00	-1.600
MinPD	20.00	-2.000
	38.00	1.500
Median	41.00	0.000
	45.00	-0.200
Max PD	50.00	-1.100
Max	53.00	-1.600

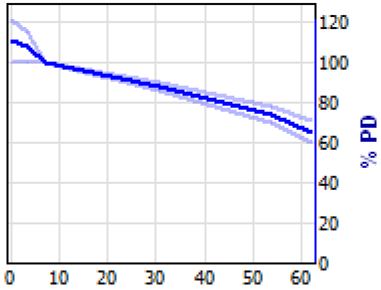


Explanation

Week 20 - too early for agriculture. low production. Week 38 - optimal to allow for floods to recede in time for onset of farming season. Week 43 will have negligible drop in production. Week 48 will also be a little late for exposure before the normal season. Week 52 will be very late and will reduce production per ha in April/ May harvest of maize.

Perceptions of disease

Response curve	Explanation

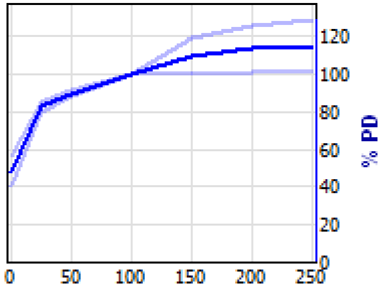
<table>
<tr><th colspan="2">Perceptions of disease</th></tr>
<tr><th>Response curve</th><th>Explanation</th></tr>
<tr><td>
W/Ann: Days FP depth 0.2-1 (V) [F season]
<table>
<tr><th>Desc</th><th>days</th><th>Y</th></tr>
<tr><td>Min</td><td>0.00</td><td>0.800</td></tr>
<tr><td>MinPD</td><td>0.00</td><td>0.800</td></tr>
<tr><td></td><td>3.50</td><td>0.500</td></tr>
<tr><td>Median</td><td>7.00</td><td>0.000</td></tr>
<tr><td></td><td>30.50</td><td>-0.700</td></tr>
<tr><td>Max PD</td><td>54.00</td><td>-1.500</td></tr>
<tr><td>Max</td><td>62.10</td><td>-2.000</td></tr>
</table>
</td>
<td>The perception among users of the floodplain is that high summer flows and prolonged flooding leads to an increase in diseases such as malaria</td></tr>
</table>

Reeds for reed dance

Response curve | **Explanation**

Reedbeds (P. australis) [D season]

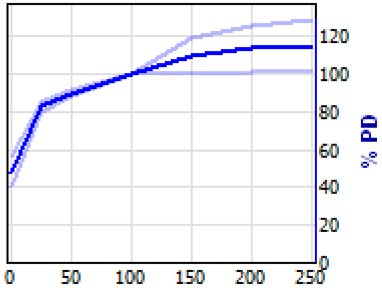
Desc	%Base	Y
Min	0.00	-3.000
MinPD	25.00	-1.000
	50.00	-0.600
Median	100.00	0.000
	150.00	0.700
Max PD	200.00	1.000
Max	250.00	1.100



Reed harvesting for reed dance is important during August / September. Increase in human population increases the demand for the reeds.

Reedbeds (P. mauritianus) [D season]

Desc	%Base	Y
Min	0.00	-3.000
MinPD	25.00	-1.000
	50.00	-0.600
Median	100.00	0.000
	150.00	0.700
Max PD	200.00	1.000
Max	250.00	1.100



Reed harvesting for reed dance is important during August / September. Increase in human population increases the demand for the reeds.