Banhine National Park

Gaza Province
Mozambique

Watershed Assessment

African Wildlife Foundation
United States Forest Service International Programs

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1. Introduction

The African Wildlife Foundation (AWF) and the U.S. Forest Service (USFS) International Programs initiated a partnership to protect forest, soil and water resources in critically important African landscapes. USFS is providing technical expertise to better understand the watersheds in selected large-scale conservation landscapes in Africa, AWF's African Heartlands. African Heartlands are large African landscapes of exceptional wildlife and natural value where AWF works with a variety of partners, including local communities, governments and other resource users to conserve wild species, ecological communities and natural processes. Many of the conservation targets that AWF has identified are closely linked to forest and watershed processes. USFS and AWF recognize the benefit of working to address watershed degradation in these globally significant African landscapes.

The watershed analysis process assembles, organizes, interprets, and presents information needed to guide future resource management decisions. A watershed or catchment is an area of land that drains to a common point. The size of the area included in a watershed is arbitrary, however, in the United States a consistent set of commonly used terms that describe relative sizes of geographic areas has been used. For this analysis, the Banhine watershed will include both the Chefu and Changane Rivers and their tributaries, with a downstream boundary where the Changane River intersects the park boundary. This area includes most of the north and northwestern part of BNP and the tributaries outside of the Park that drain into the Park from the north and northwest.

1.1 Project Objectives

The Banhine seasonal wetlands, pans, intermittent flowing channels and other springs and wet areas are identified as important conservation targets in this landscape. The main objective of this project is to conduct a general assessment of these hydrological systems in order to determine the conditions of these watersheds and to characterize threats and subsequent strategies to abate threats to these systems. There currently is a lack of systematically and consistently collected basic information on hydrologic components of these systems such as precipitation, stream flow regime, water rights or abstractions, soil cover conditions, and channel/riparian condition. Another area that needed to be better understood is the relationship between local land use regimes and hydrological conditions and water quality.

1.2 Expected Outputs

It is envisaged that the information collected through this process will be used by all parties involved in management of the park to assist in the following:

- Land use planning and implementation;
- Information to users to adopt appropriate water management methods;
- Enforcement of water laws where necessary;
- Educational campaign targeting upstream users; and

- Information to guide changes in policy and institutional mechanisms for water users rights.

The assessment is expected to result in the following:

- Assemblage of existing data and analyses in order to address key issues and questions related to wetland management..
- General assessment of the wetland hydrology, meteorology, groundwater, soils, and vegetation relationships of the Banhine wetlands; characterize existing watershed conditions of the watersheds that contribute flow to the wetland including attributes such as precipitation, stream-flow, water abstractions, vegetation cover conditions, and channel characteristics.
- Documentation of current wetland conditions compared to a reference condition that can provide a basis for describing desired future condition.
- Understanding and documentation of a general water balance of the wetlands and the contributing catchments, including defining catchment boundaries or contributing areas.
- Further assessment of the relationships between various land-use practices and impacts on the wetland system.
- Definition of vegetation cover type, land-use, soil, and the geologic characteristics of the catchment and how they might influence site hydrologic function.

2. Characterization and Existing Condition

2.1 Banhine Wetland Site Description

The Banhine National Park (BNP) is located at approximately 23° S. 32°30' E in Gaza Province, northeast of the Limpopo River, and is within Mozambique's most semi-arid zone, with approximately 400 mm average annual rainfall, and with a mean annual temperature of 18° C. Geographically, it covers an area of approximately 7,000 km^2. The headwaters of the streams that feed the Banhine wetlands are located in higher elevation areas near the Mozambique-Zimbabwe border northwest of the park. None of these headwater areas are protected lands. BNP was established in 1972 to protect these important wetlands, which support a diverse variety of rare fish species, such as killifish and lungfish, and diverse wildlife species including migratory and other bird species. Despite this parks importance in contributing to biodiversity, it has remained undeveloped since its establishment. The protracted war for independence and civil war from 1962 to the early 1990's led to the decimation of most wildlife populations, and destruction of the parks limited infrastructure.

The BNP is central to and forms an integral part of the Greater Limpopo Transfrontier Conservation Area (TFCA). This TFCA surrounds the Greater Limpopo Transfrontier Park (GLTP) which is comprised of Mozambique's Limpopo National Park and the Kruger National Park in South Africa. Banhine National Park is part of African Wildlife Foundations (AWF) Limpopo Heartland, which includes Zinhave National Park and the Limpopo Transfrontier Reserve, Kruger National Park in South Africa, and Gonareszhou National Park in Zimbabwe. Banhine represents one of AWF's priority conservation targets- the Inland Wetlands. These wetlands are threatened by dry season cultivation around their edges, and the proposed highway through the catchment area.. AWF's conservation goal for the inland wetlands is to maintain their integrity, connectivity, functionality, and biodiversity.

Located within a semi-arid environment, the unique and distinguishing feature of the Banhine National Park is the diverse and ecologically rich Banhine wetland system (Draft Banhine National Park Management Plan, 2006). The Banhine wetland system contains a wide variety of wetland types, including seasonal and ephemeral streams or wetland areas, swamps, and numerous small lakes and pools with varying degrees of water permanence. The variation in the degree of permanence, along with the different sized wetlands, results in a wide range of physical and biological characteristics which combine to create a unique of range of wetland habitat diversity within a largely semi-arid environment.

An alluvial wetland system, Banhine is situated within a small topographic depression located in the Limpopo Catchment, at an elevation of approximately 350 meters above mean sea level. This topographic depression is situated between the Alto Limpopo and Alto Changane plains and filled with thin alluvial deposits carried by the ephemeral streams originating in the Alto Limpopo plains. The headwaters of the Banhine wetland, and the area of the delta that feeds the Banhine wetland have a relatively high stream channel density, reflecting a relatively higher gradient. In contrast, the wetland area has a very low number of surface water streams and low channel network density. A large number of small pans in the upland areas surrounding the wetlands indicate that even in the upland areas there are regions with low amounts of surface runoff due primarily to the relatively flat, even topography.

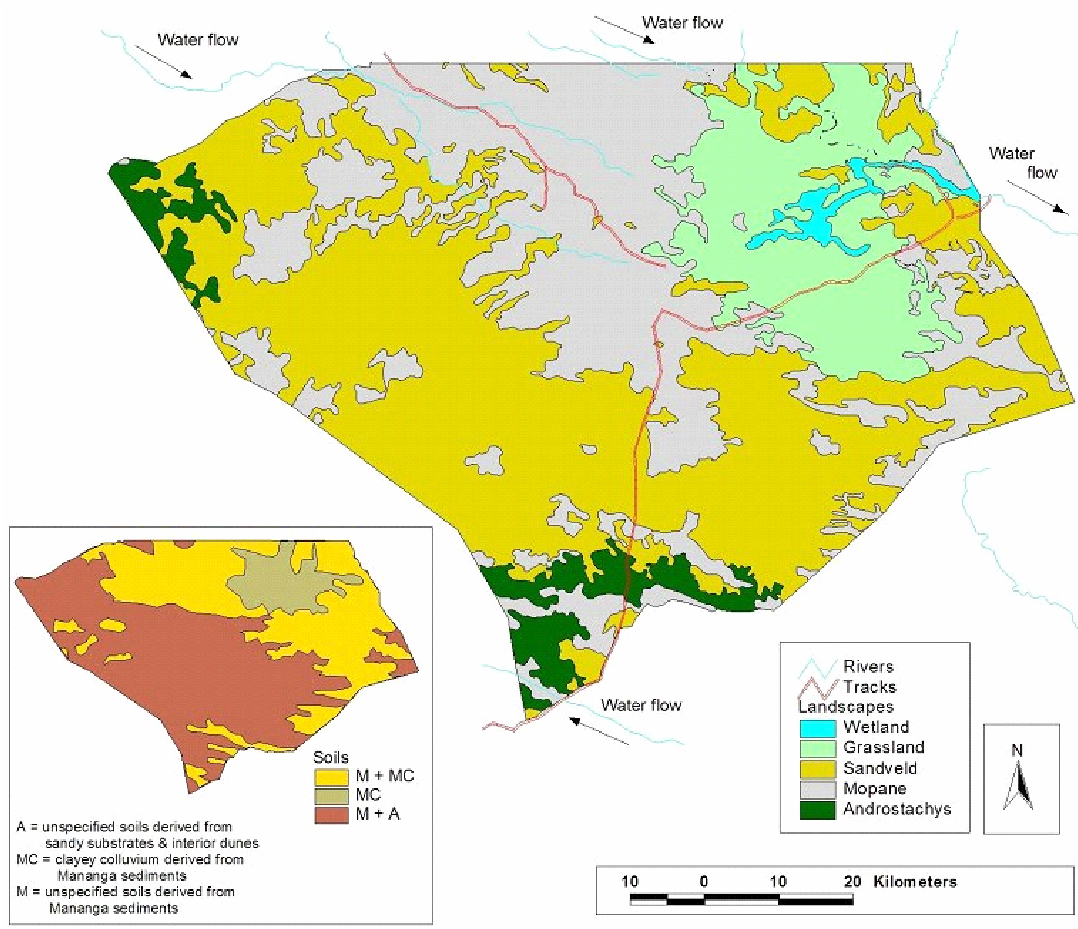


Figure 1. Banhine National Park showing vegetation and soils.

2.2 Climate

BNP has a semi-arid climate, with rainfall occurring principally in the hot and moist summer months, with cooler and drier winters. Most of the year the weather patterns are dominated by clear skies created by a high pressure system that prevails over the southern Africa Plateau from April to September. Northeast and southeasterly winds from the Indian Ocean bring rain from October to March each year. Tropical cyclones originating in the Indian Ocean occasionally bring heavy rainfall to the area. Climate data collected at communities surrounding the BNP from 1960 to 1978 indicate that the average rainfall varies from 584-470 mm annually, with minimum annual rainfall varying from 366 mm at Massangena to 24 mm at Chigubo, near the southeast corner of the park. The total annual precipitation for the Chigubo site best characterizes rainfall within the eastern portion of BNP, which includes the Park headquarters area. Interviews with long-time residents there substantiate that there are occasional sustained drought conditions at that site. The Chicualcula site may best represent precipitation patterns in the headwaters of BNP, and show less drought-prone conditions for the period of record. Annual evaporation at the Chigubo site exceeds one meter, and may best represent evaporation for the Banhine wetlands. Once the wetlands fill, water loss through evaporation is a major factor affecting retention of water in the wetland. The available climate data for the BNP area is summarized in Table 1.

Table 1. Summary of temperature, rainfall, and evaporation for areas surrounding BNP (source Draft BNP Management Plan)

Site	Record	Monthly Avg Temp (C)	Monthly Rainfall (mm)	Mean Annual Rainfall (mm)	Max Annual Rainfall	Min Annual Rainfall (mm)	Mean Annual Evaporation (mm)
Chicualacuala	1961-76	23	42	470	656	189	2228
Massangena	1960-76	25	54	584	928	366	1741
Chigubo	1961-78	ND	52	478	851	24	1122

ND- No data

Extreme rainfall events related to tropical cyclones passing over the area occur infrequently, but are important for filling the wetlands. An atlas for disaster preparedness for Mozambique and the Limpopo basin prepared by the Instito de Gestao de Calimidades, Mozambique suggests that cyclones may reach the BNP area approximately every 12.5 years (Figure 2). These cyclone events will vary in strength and rainfall intensity, and will have varying effects on water levels in the wetland. Interviews with local residents suggest that significant cyclone-related wetland filling events that have led to *outflows from* the wetland have happened twice in the past 25 years. Lesser cyclone events probably partially fill the wetlands, but not to the point of causing outflows.

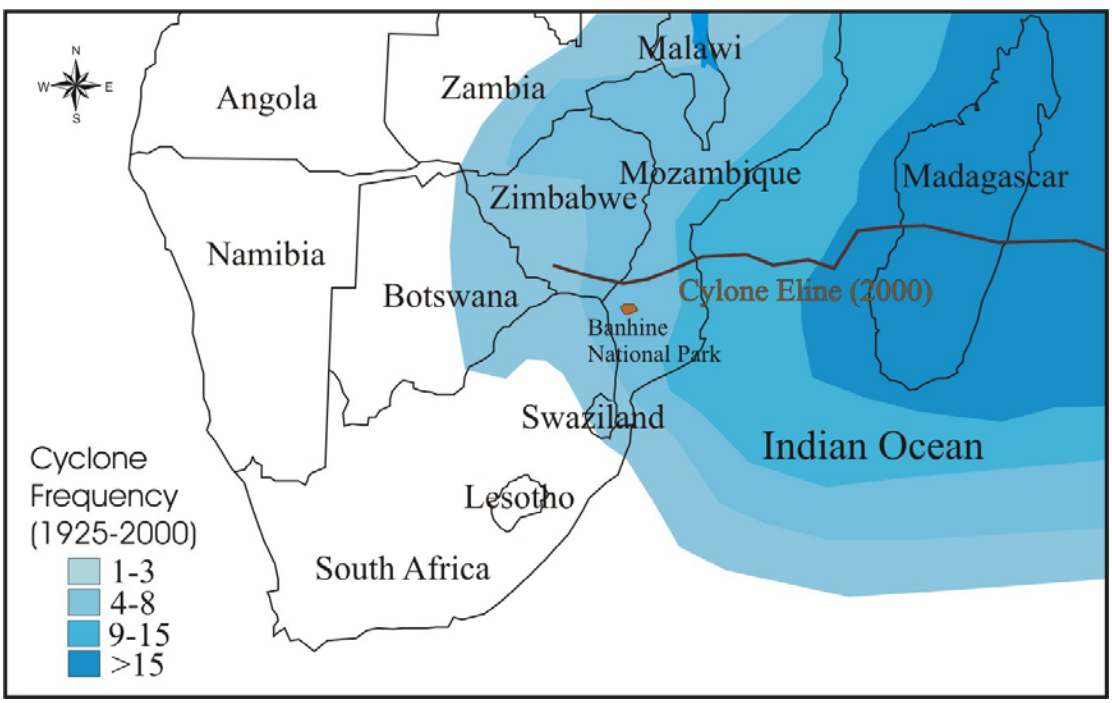
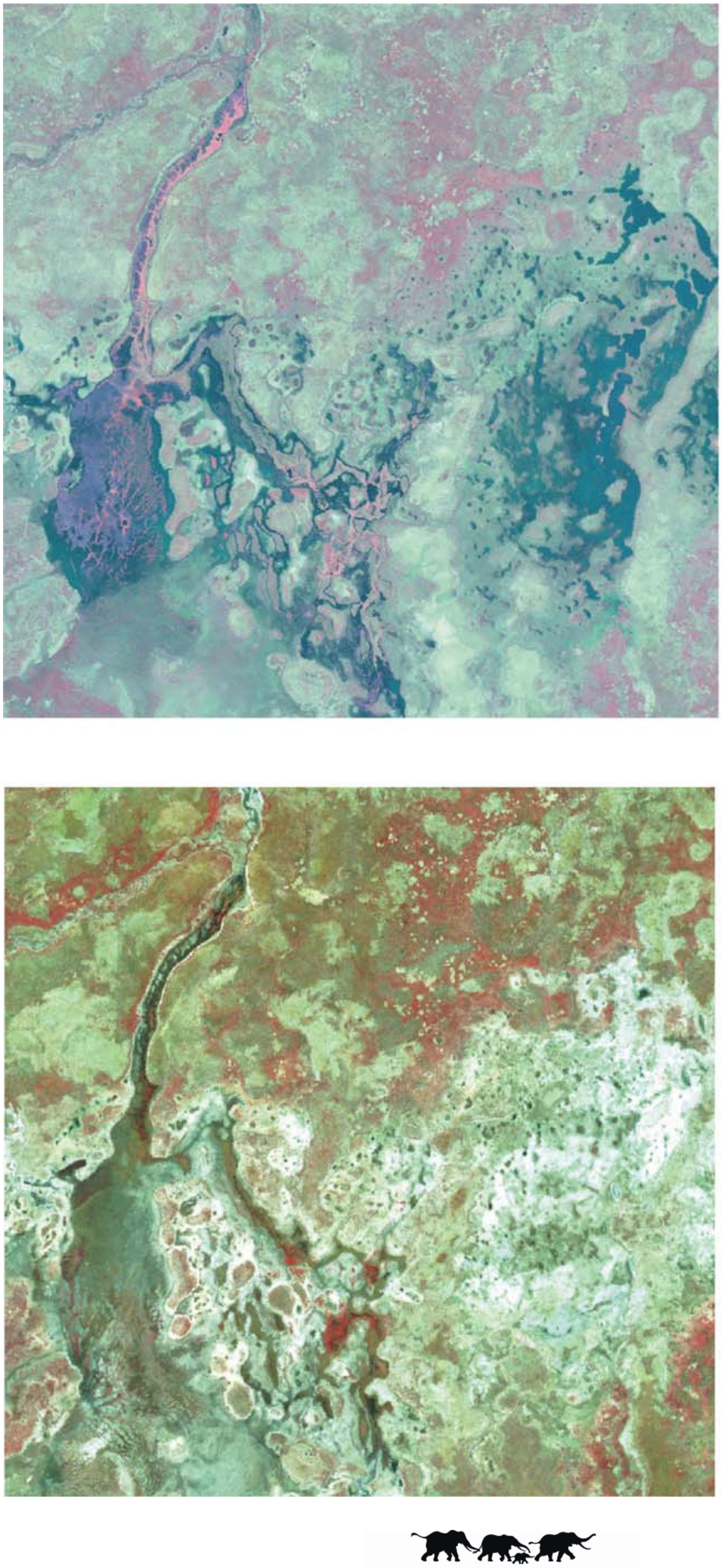


Figure 2. Cyclone frequency in southern Africa. The path of the tropical cyclone Eline is shown. In 2000, Eline caused extensive flooding in Mozambique and filled the Banhine basin with water.

As an example, in 2000 tropical cyclone Eline inundated a large area of Mozambique, including BNP. Eline was a large category 4 storm when it came off the Indian Ocean near Beira (Eline's track is shown on Figure 2). This large cyclone was preceded by 2 weeks of heavy rains and flooding in Mozambique (Dyson 2000 in Smithers et al., 2001). These major storm events filled the wetlands completely, and wetland outflows to the Changane and the Limpopo allowed fish species to migrate upstream into the wetland (Figure 3). As waters receded over the next few years local residents caught those fish that became isolated in the receding waters as water in the wetland evaporated. According to local residents, fish have only been present in the wetland twice in the last 25 years, indicating that the hydrologic connection to downstream rivers is dependent on large and infrequent tropical cyclone events such as Eline.



2000

1990

Figure 3. Landsat images of the Banhine wetland area in 1990 and 2000. These images illustrate the cyclic nature of the Banhine wetlands. In 1990 much of the area is dry pan (whitish areas). In 2000, heavy rains and tropical cyclone Eline have inundated much of the Banhine area (dark areas on 2000 image). Although rare, these extreme weather events are critically important in maintaining wetland functions in Banhine National Park.

2.3 Geohydrology

Sub-surface rock formations underlying the Banhine wetlands are predominantly sedimentary in origin, consisting of terrestrially-derived arkosic sandstones, or marine derived sandy limestones. Each of these is overlain by sandy or clay layers of alluvial of wind-transported origin. Structurally, the wetlands area is a depression situated on the Alto Limpopo Plain where it meets the Alto Changane Plain (Draft BNP Management Plan, 2006). The Alto Limpopo Plain stretches from the Rio dos Elefantes up to the Save River. Sub-surface geology is composed of arkosic sandstones of the cretaceous Sena formation and Lower Tertiary Elefantes formation, and groundwater production is poor. Conglomerate beds and local calcareous facies (near Combomune) form the main water bearing strata, but yields over 3 m^3/h are exceptional.

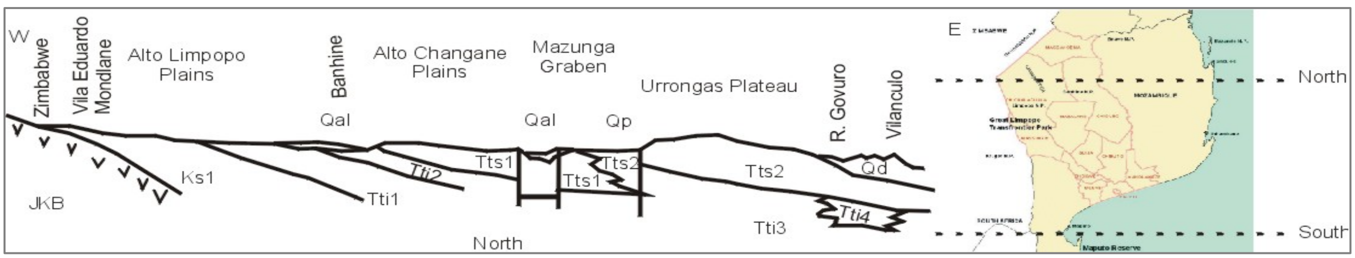


Figure 4. Geological section of the southern Mozambican Sedimentary Basin (source, Draft BNP Management Plan)

Soils in BNP are located on an extensive plain of what are called "Mananga" deposits, which are Pleistocene sediments that form a layer up to 20 m in depth, and often consist of hard, difficult to penetrate and partly sodic clay soils (Dijkshoorn, 2003). Mostly they are covered by a sand layer, which can reach a thickness over 1 meter. These sediments and the soils derived from them are called "Mananga" by local farmers and are typically avoided for cultivation. The parent material of these "Mananga" soils is classified as unconsolidated alluvial. They typically will classify as Haplic Solonetz and Eutric Planosols, and in sandy areas Arenosols.

The BNP draft management plan (2006) indicates that in most of the area the deeper regional groundwater table is found below 60 meters, suggesting the recharge conditions are also poor. Recharge may be poor due to clay soils which underlie the more sandy surface soils throughout much of the wetlands and their headwaters and act to intercept the recharge. The geologic map of Mozambique indicates that this underlying clay soil is exposed in drainages contributing flow to the BNP wetlands, and the numerous pans surrounding the Banhine wetlands and the wetlands themselves indicate the presence of this clay soil mantle at depth. Further evidence for a large area of underlying clay soils acting as a barrier to deeper infiltration is the ability of the wetland to retain water once it is filled, despite relatively low rainfall and high evaporation rates. According to villagers, shallow surface waters may be retained in the wetland for up to five years following a filling event.

Low rates of recharge of the deeper groundwater aquifer restricts the development of groundwater in the area for human or animal use from higher production deeper wells. Low recharge may result from the presence of a clay soil mantle underlying much of the wetland. In much of the wetlands and headwater areas an alluvially derived clay soil mantle exists beneath the sandy surface soils that may also inhibit recharge to the deeper, regional groundwater aquifer, creating a perched aquifer above the regional water table. The clay mantle may be important for allowing shallow groundwater to be directed through the subsurface to the wetland from a much large area surrounding the wetland. Evidence for this type of recharge may best be indicated by the presence of palms and other types of vegetation which are indicative of moist subsurface conditions. Palms are located in areas where shallow groundwater is being transmitted along the clay layer through the soil from areas upslope. As further evidence of a perched aquifer above the deeper regional aquifer, a well dug 3 m in the village of Tchai Tchai near the park headquarters produces fresh water at a relatively shallow depth, and is preferred over the well water at the park headquarters. This water table appears to exist above the clay layer. In the area surrounding the Banhine wetlands there are shallow perched groundwater systems that local people use to create hand dug "wells" a few meters deep and exposing a pools approximately 2 meters across (Draft BNP Management Plan 2006, Marc Stahlmans, personal comm., 2006). These are commonly found in the edge of small pans that are replenished during seasonal storms, and may retain water for long periods even through extended dry conditions. Some of these may have been historically maintained by wild animal use. One of these small "wells" was located during aerial reconnaissance in the main wetland area on what appeared to be a low sand island. At times when the wetland fills, this "well" would likely be flooded.

The Banhine Depression in the centre of the wetland has a thin alluvial cover with shallow groundwater, that can be brackish to saline (up to 33 000 mg/l). The high rates of evaporation that predominate in the area provide the driving force behind high levels of salinization in the depression. The well at the BNP research camp is noticeably salty, and taps the regional groundwater at 50 meters. Water in this well may be recharged by the salty surface waters characteristic in this area (Bills and Da Costa, 2005).

As suggested by the BNP management plan, the groundwater in BNP is highly susceptible to over exploitation, and should only be developed locally for limited use due to low groundwater yields. Water development, especially of the shallow perched aquifer, could have significant impacts by reducing water available for the Banhine wetland (Draft Banhine Management Plan, 2006), and reducing the amount of water available for natural springs and ponds that were observed scattered throughout the wetland area that hold water for longer time periods. In general, with increased wells and human uses of groundwater, smaller ponds and springs could disappear earlier in the year, creating a potential crisis for wildlife species. Further investigation of shallow groundwater sources in and around the wetlands is recommended.

2.4 Watershed Hydrology

2.4.1 Runoff and Streamflow

The surface water hydrology of the wetland is dominated by seasonal runoff that occurs in response to rain season precipitation. The hydrologic response of the upstream tributary channels, the main wetland area and associated smaller pans depends to a large extent on the frequency, magnitude, and duration of rainfall events, and on the antecedent conditions of the watershed. The upper and middle sections of the watershed have well developed channel networks that can deliver water to the wetlands if storms are large enough to generate surface runoff. As discussed in the climate section, cyclones in this area are estimated to occur on average once every 12.5 years, and their intensities and the surface runoff they generate will vary depending on their strength. How much rainfall in the upland areas is required before significant amounts of runoff occur? Do the wetlands fill in response to surface runoff events only, or can streams that flow sub-surface through the stream-bed generate act to fill the wetlands? In certain arid and semi-arid areas throughout the world, channel sub-surface flow is an important physical process. Sub-surface water in arid areas can re-surface locally in response to changes in sub-surface soils or geology, providing a surface water source. How often is surface runoff generated in upland channels that feed the wetlands? Has surface flow in wetland inflow channels only occurred in the filling events in years 1975 and 2000? Or, is surface flow into the wetland more common? Further investigation is recommended into patterns of surface flow frequency into the wetland.

The inputs for the hydrologic cycle for the wetlands also includes rain season rainfall inputs that fall directly into the wetlands, adjacent pans and in the upland areas. Incident rainfall would vary in terms of storm frequency, magnitude, and duration. Some of this incident rainfall would be lost to interception on plant surfaces, and some would reach the soil surface. If the rain fell on a pan or lake bed, it typically would pool there and eventually evaporate or seep into deeper groundwater. However, the ability of the clay soils in the wetlands and surrounding pans to retain water on the surface suggest that little water is transmitted through the clay layer to deeper groundwater aquifers. Once water in upland areas infiltrates into the soil, some percentage will be transpired by plants, and the balance will be available for either recharge to deeper groundwater, or will flow down-gradient along the impermeable clay sub-surface layer to a stream channel, a pan or the Banhine wetland.. If surface flows do not occur, how much do the wetlands fill each year in response to rainfall only? Vegetation in the wetland area suggests that the wetlands fill to some degree year to year (Marc Stahlmans, personal communication, 2006). If the wetlands were completely dry between the major filling event years 1975 and 2000, there would be significant encroachment on the wetlands by adjacent tree species, and other upland plant species. Further investigation is recommended to determine year to year variability of wetland filling linked to normal rainfall only.

Table 2. Variables affecting the surface water balance in Banhine National Park

Banhine National Park Surface Water Balance		
Surface Water Gains	Process	Comment
Surface Flows	Flow down channel networks draining to wetlands from upland areas in watershed	May only flow for brief periods in response to heavy, infrequent rains. Surface flows may only reach wetlands every few years
Rainfall	Rain season precipitation directly filling wetlands. Rainfall infiltrated into soil may from areas surrounding wetlands may drain thru sub-surface soils to wetlands	Intensity, magnitude, and duration varies year to year. Total in park ~400 mm, upland areas ~600 mm. Limited to October-March
Shallow Groundwater	Shallow aquifer perched on clay layer	Water may surface where clay layer near surface. Aquifer re-charged by rain season precipitation, and may not be severely affected by year to year precipitation
Surface Water Losses	Process	Comment
Wetland Evaporation	Direct evaporation from wetland	Estimates for evaporation >2 meters/year
Interception loss	Evaporation from plant leaf surfaces, stems	Estimates from other areas ~10% of rainfall
Transpiration	Shallow groundwater transpired by plants	Woodland areas surrounding wetlands transpire significant amounts of groundwater, grasses and other shallow rooted species less
Groundwater infiltration	Water infiltrates into shallow or deep aquifer	Deeper groundwater may never contribute to springs/seeps, shallow groundwater appears to be important for maintaining surface water

As indicated in the BNP Draft Management Plan (2006) there is no hydrologic data to support any of the conclusions regarding the hydrologic regime of the wetlands or the tributaries that feed the wetlands. Thus, hydrologic variables can only be estimated or modeled based on precipitation data or extrapolations of conditions from other areas with suitable data or similar conditions. The nature of the sub-surface materials comprising the wetland basin, headwater areas, or adjacent to smaller pans can only be estimated also. Several deep soil pits need to be excavated within the wetland and in several areas adjacent to the wetlands to determine the nature and extent of subsurface materials.

The BNP Draft Management Plan (2006) estimated surface runoff for the tributaries into the wetlands using standard techniques that estimate the water balance in the topsoil to generate estimates of recharge and runoff. These estimates were done to develop a preliminary assessment of the hydrologic regime of the wetland, and to determine the frequency of storm events controlling water availability in the wetland. The wetland response to these storm events is very complex. Runoff may completely or partially fill the wetland through surface channel networks, or smaller storms may not generate enough runoff to sustain surface flow, and the wetlands may partially fill with sub-surface flows transmitted through the soil layers above the clay layer that exists in the vicinity of the smaller pans and throughout the wetland. Flow in the major drainages is lost to smaller sand-bed delta distributaries as it nears the wetlands and stream gradient lessens. Surface flow may be lost through infiltration into these sand-bed channels, and sub-surface flows may continue down gradient to the wetland. Thus, surface flows *and* subsurface flows may be important for transmitting water to the wetland. In semi-arid areas of the United States, sand bed channels have been known to have significant subsurface flows that resurface in certain areas depending on the geologic conditions. For the Banhine wetland, the underlying clay layer may act over a much larger area than the wetland itself to transit water down-gradient to the wetlands. The low density of channels, frequency of small pans and low gradients in the middle part of the watershed may indicate that there is a high amount of infiltration into the soil, which may create significant amounts of subsurface flow. Further investigation on the nature of the channels going into the BNP is required to determine watershed function, and this could be accomplished by traversing road systems through the watershed outside of the park. The questions of interest would explore the extent of the hydrologic "contributing area" to the wetland, determine the relative contributions of surface water and groundwater, and determine how water is sustained in the wetland. An associated research question exploring to what extent the clay later acts to retard deeper groundwater recharge would provide valuable knowledge for management.

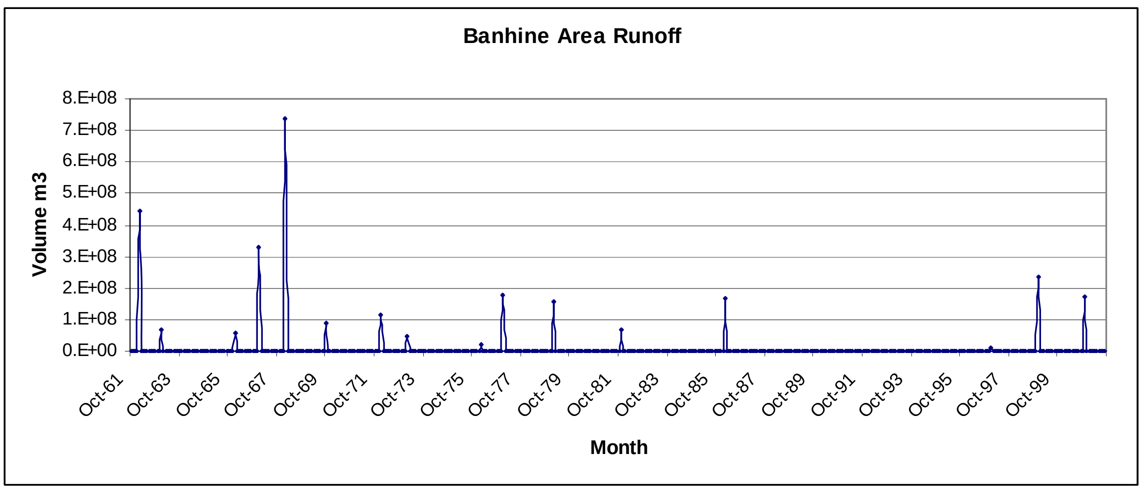


Figure 5. Estimate of Surface Runoff to Banhine Wetlands using the Thorthwaite-Mather method, 1961-2001 (BNP Draft Management Report, 2006).

Storm events that yield significant runoff occur infrequently, and flows are very flashy when they occur, with a steeply rising and falling hydrograph, according to the estimated flow record in Figure 4 (BNP Draft Management Plan, 2006). This flow hydrograph is useful as a first approximation, but the response of the tributaries and the wetland to storm events can only be determined through compilation of data on storm intensity, magnitude, and duration combined with measurements of flows in tributary stream channels and water stage in various parts of the Banhine wetlands. Access to channels during high flow events due to isolated conditions and impassable roads is very difficult, but hydrologic data is critical for understanding water inputs into the wetland. In the absence of flow records, geomorphic and vegetative cues can be used to understand to system hydrologic function. Implementation of hydrometeoric data collection efforts outlined in the BNP Draft

Management Plan (2006) will provide necessary data on precipitation, surface water, and groundwater resources in and adjacent to the wetlands.

2.4.2 Water Quality

Water quality of inflows into the wetland system is influenced by a variety of factors. Sediment can be a source of nutrients to aquatic systems, but if erosion and delivery of sediment is accelerated above background levels, it can have a detrimental effect. Since the majority of the wetland and the upper watershed is nearly pristine and little affected by human land uses, aquatic nutrients and other dissolved solids are probably near background levels in waters entering the wetlands. There is some evidence of significant channel gully-cutting in upland channels near the town of Machaila. If these are extensive, it may influence the delivery of finer sediments to the wetlands. No information on the causes of the gully-cutting are available at this time, and further investigation is recommended. Often, gullies form in response to land uses such as cattle grazing or modifications of the banks and removal of natural vegetation due to streambank farming. No other water quality concerns are apparent.

As indicated in the BNP Draft Management Plan, the abundant aquatic plants and algae present in the smaller pans is indicative of a high level or aquatic nutrients in the smaller pans surrounding the Banhine wetland. As determined by the fish survey (Bills and DaCosta 2005) the high local evaporation rates concentrate dissolved salts as water flows through the wetland towards the outlet.

2.4.3 Wetland Outlet Control

The water elevations in the Banhine Wetlands are controlled by the alluvial fan created by the Changane River at its confluence with the wetland. Figure 6 shows the confluence of the Changane and Banhine wetland. Previous work by Ken Tinley (personal communication, 2006) suggested a hydraulic control on wetland elevation at this location, and suggested that a geologic formation such as a sill may occur there. From our field observations, it appears that the principle feature providing water elevation control, and regulating the outlet of the wetland are sediment deposits from the Changane River, probably deposited during high flow events (Figures 6 - 8).

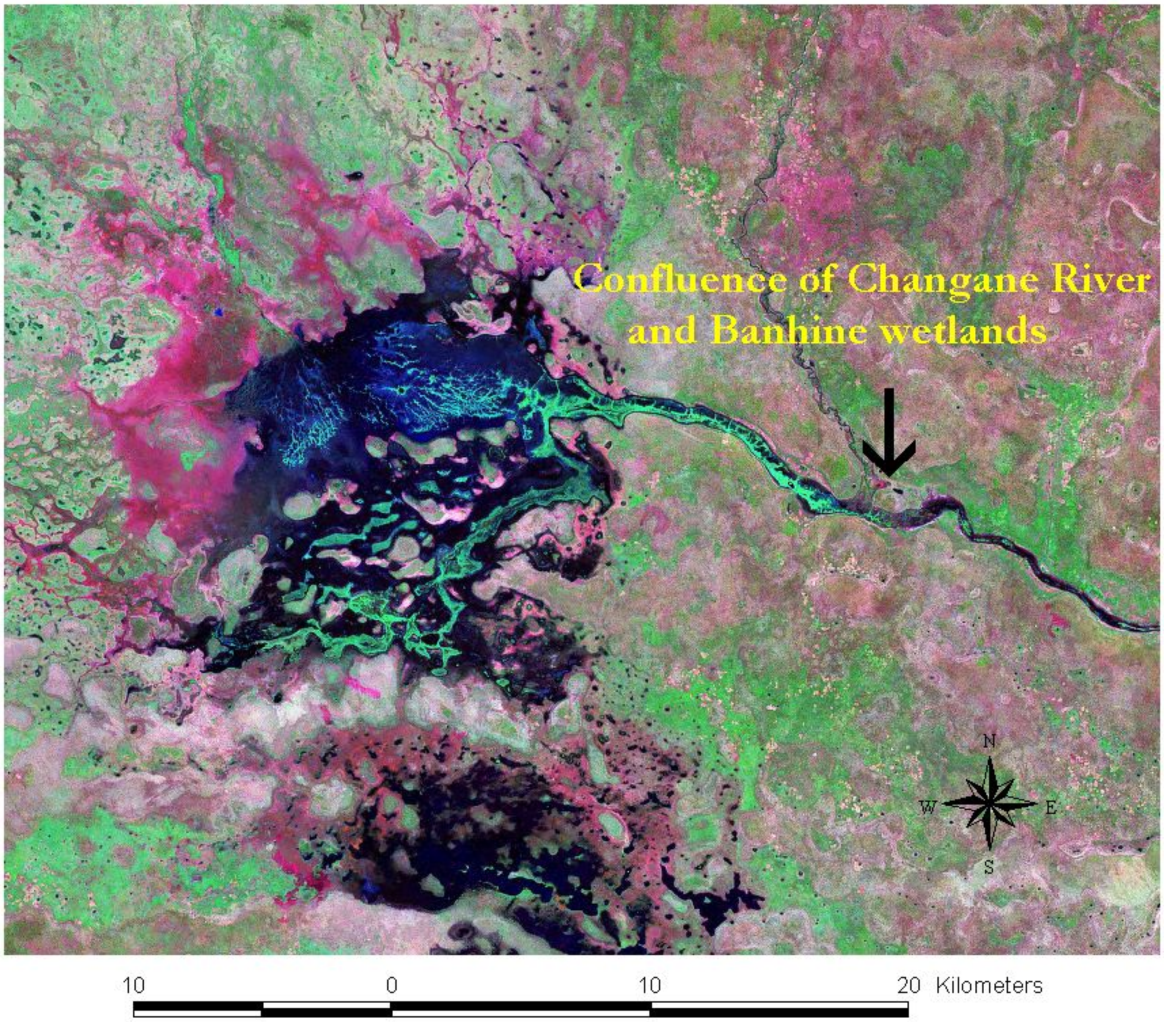


Figure 6. The confluence of the Changane River and the Banhine wetland outlet. The alluvial fan at the confluence is the hydrologic control of the wetland. The image is a Landsat false color composite taken in 2000, when water levels in the wetland were very high due to precipitation from tropical cyclone Eline.

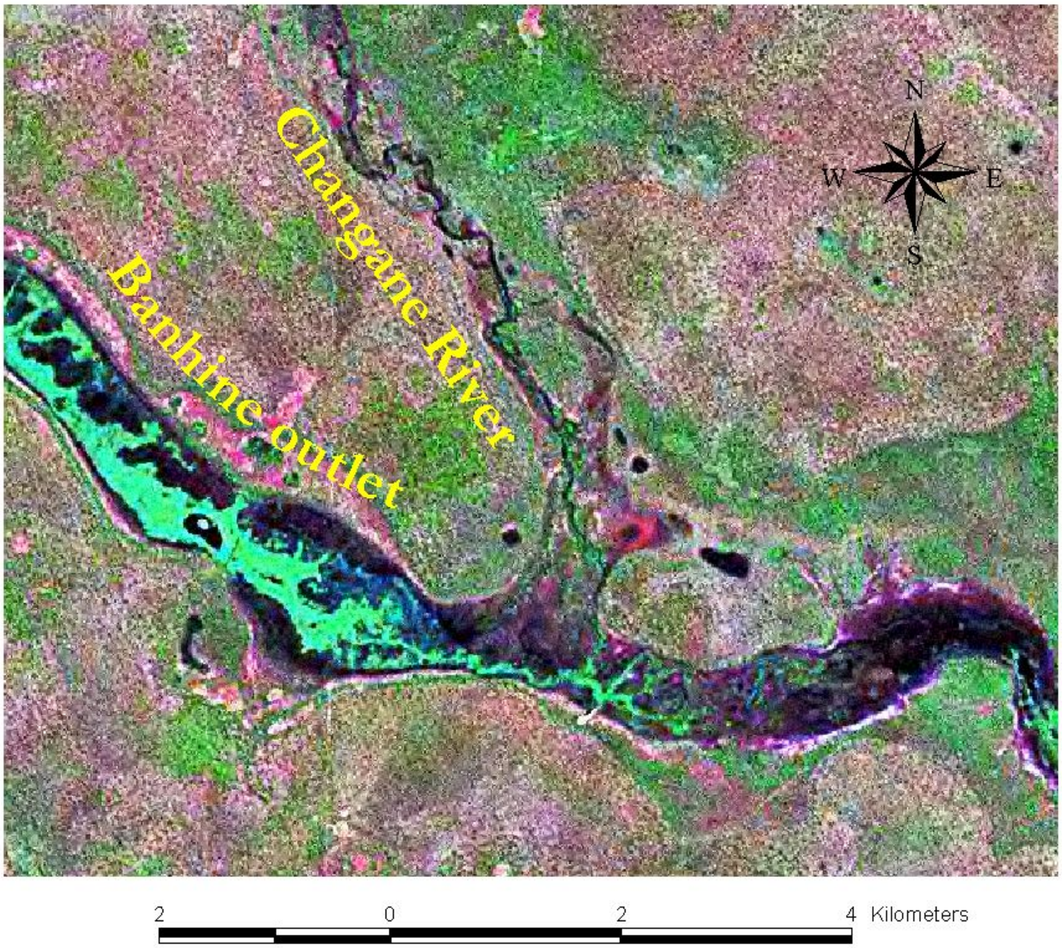


Figure 7. Landsat image of the confluence of the Changane River and the Banhine wetland outlet in 2000. Large outflows from the wetland in that year were the result of the effects of tropical cyclone Eline, which passed directly over the area.

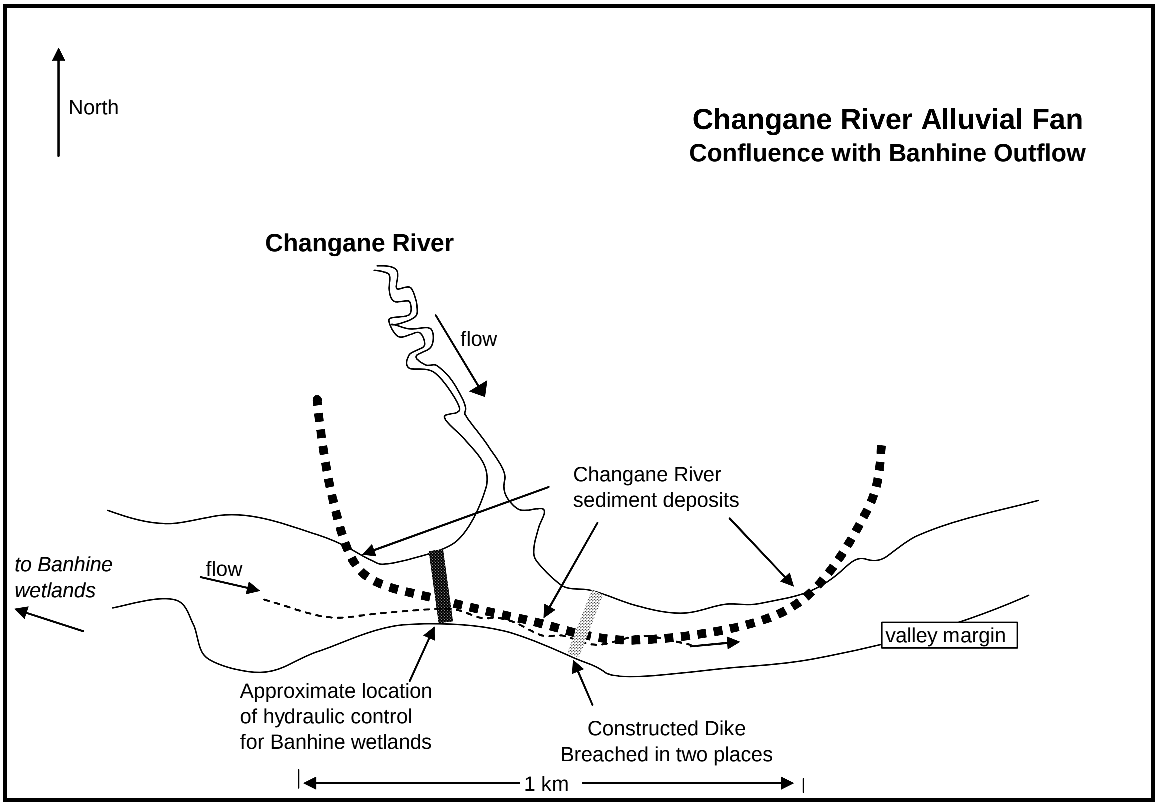


Figure 8. Changane River alluvial fan, and Banhine wetland outlet.

From aerial reconaissance and field observations, it is evident that the Changane River actively transports sand sized bed material to the alluvial fan at its confluence with the wetland outflow channel. In this area, the Changane's distributary channel has shifted over time, and created an extensive fan area of sand and smaller sized particles. As material is deposited, vegetation such as grasses, shrubs, and trees anchor the soils with extensive root systems and help maintain the stability of these relatively fertile alluvial soil deposits during times the wetland discharges flow. The oblique aerial photograph (Figure 8) shows two main lobes of the alluvial fan that have formed over time. The fan is a dynamic feature, and the hydraulic control created by it will shift positions and elevation from time to time in response to wetland outlet flow events. The fan is a broad feature that provides water control and allows fish and other aquatic organisms to pass up and down stream. The control is anchored in place by vegetation, and is very sensitive to land uses that remove or alter native vegetation, such as cattle grazing and farming. This is a favorite area for local villagers to pasture their cattle. Cattle use over time, probably has had a negative impact on the stability of the fan, and increases the likelihood of erosion and channel cutting. As wetland outlet flows increase, they probably transport material from the fan down the wetland outlet channel.

There is a human-created dike just below this fan created by the former rancher at Pio Cabral. It is located just downstream of the alluvial fan at the confluence with the Changane River. This dike is currently breached in two places, and these breaches concentrate streamflows into constricted channels. There is evidence of channel downcutting in each of the breaches. The breaches probably formed during one of the major flooding events in 1975 or 1999. The dike does not currently retain water during flood events. Park management should consider removing this dike, or breaching it in more places to disperse erosive flow energy. Further, the outlet control appears to be outside the park boundary and it is strongly recommended that the confluence area either be included in the park or managed as a separate conservation area. This will insure that the alluvial fan which provides the outlet control for the wetland remains stable over time. It is also recommended that at least a portion of the alluvial fan area be fenced to keep out cattle and other livestock.

Figure 9. Changane River overview of alluvial fan and wetland outlet confluence

The Changane River channels shows distinct signs of an active sediment transport regime, with active sand bars along much of its length (Figure 10). Although we did not survey the gradient, the Changane River appears to have a much higher gradient than the wetland outlet.

Figure 10. The Changane River two kilometers upstream of the confluence with the wetland outlet, showing extensive sand bar formation and evidence of active bedload sediment transport. The channel is approximately 15-20 meters wide at the bankfull elevation

2.4.4 Watersheds and Channel Networks

The watersheds that drain into the Banhine wetlands originate in Zimbabwe or nearby border areas and flow southeasterly to the park through a well-defined network of sand-bed intermittent flow channels. (For the purposes of this report, intermittent flow is flow that occurs in well-defined channels, while ephemeral flow occurs in broad swales with no defined channel) Numerous channels occur in the headwater areas which then converge into a single channel downstream. These confined channels eventually disperse into broad fans of smaller channels as they approach the northern park boundary. These distributary channels form inland deltas that eventually supply water into the wetland and associated pans. The catchment area is illustrated in Figure 11.

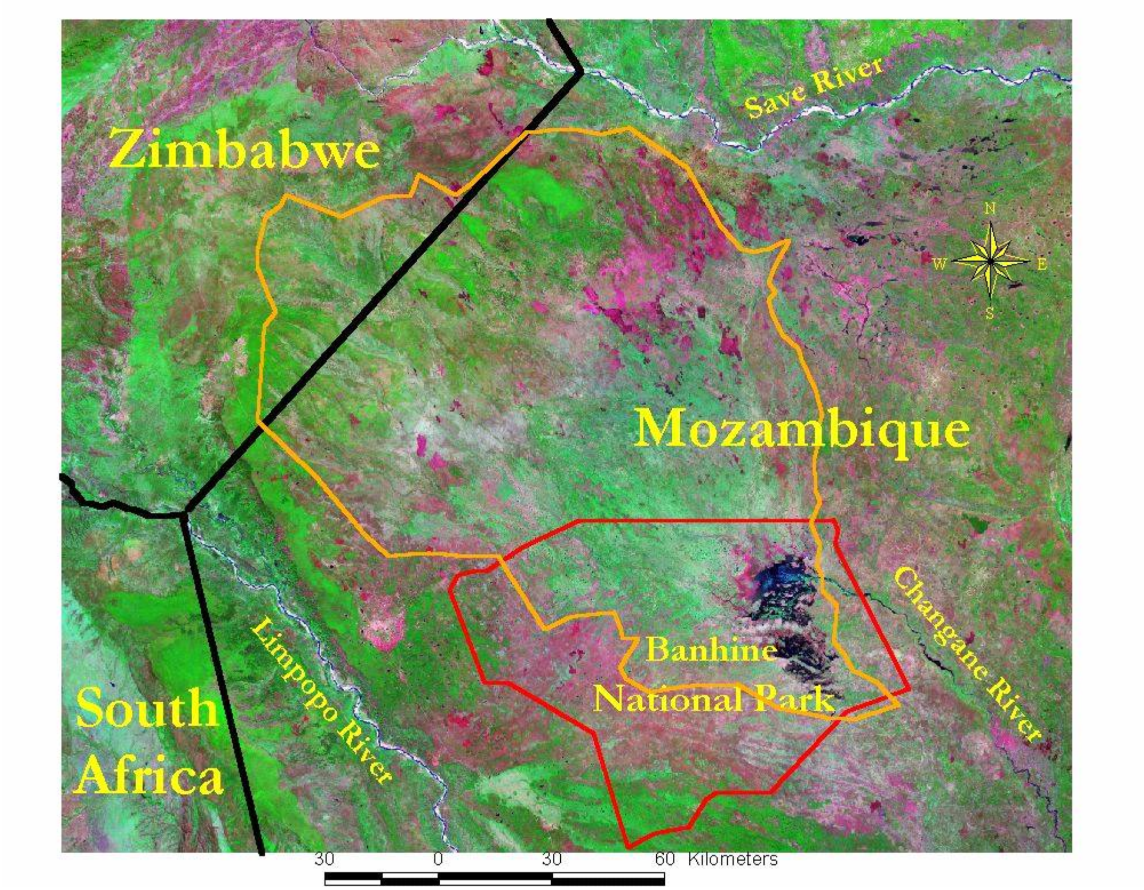


Figure 11. The catchment area of the Banhine wetlands. The catchment boundary is the orange line that extends to the north and west from the wetland. The furthest headwaters extend into Zimbabwe.

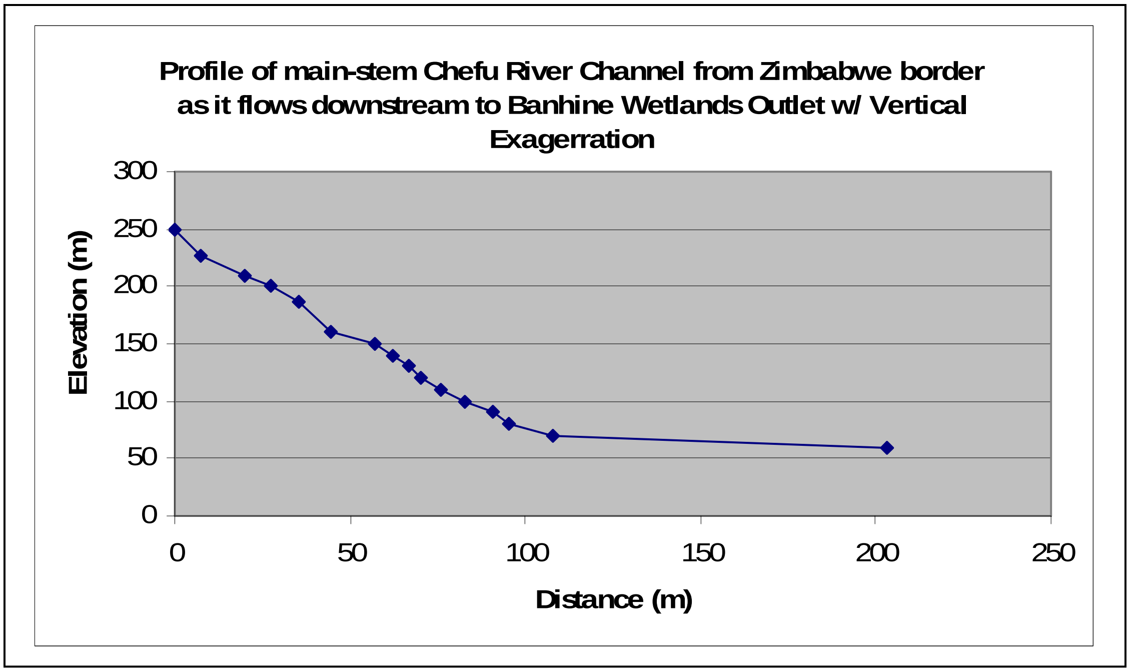


Figure 12. Longitudinal profile of Chefu River from headwaters to wetland outlet at the mouth of the Changane River in Banhine National Park

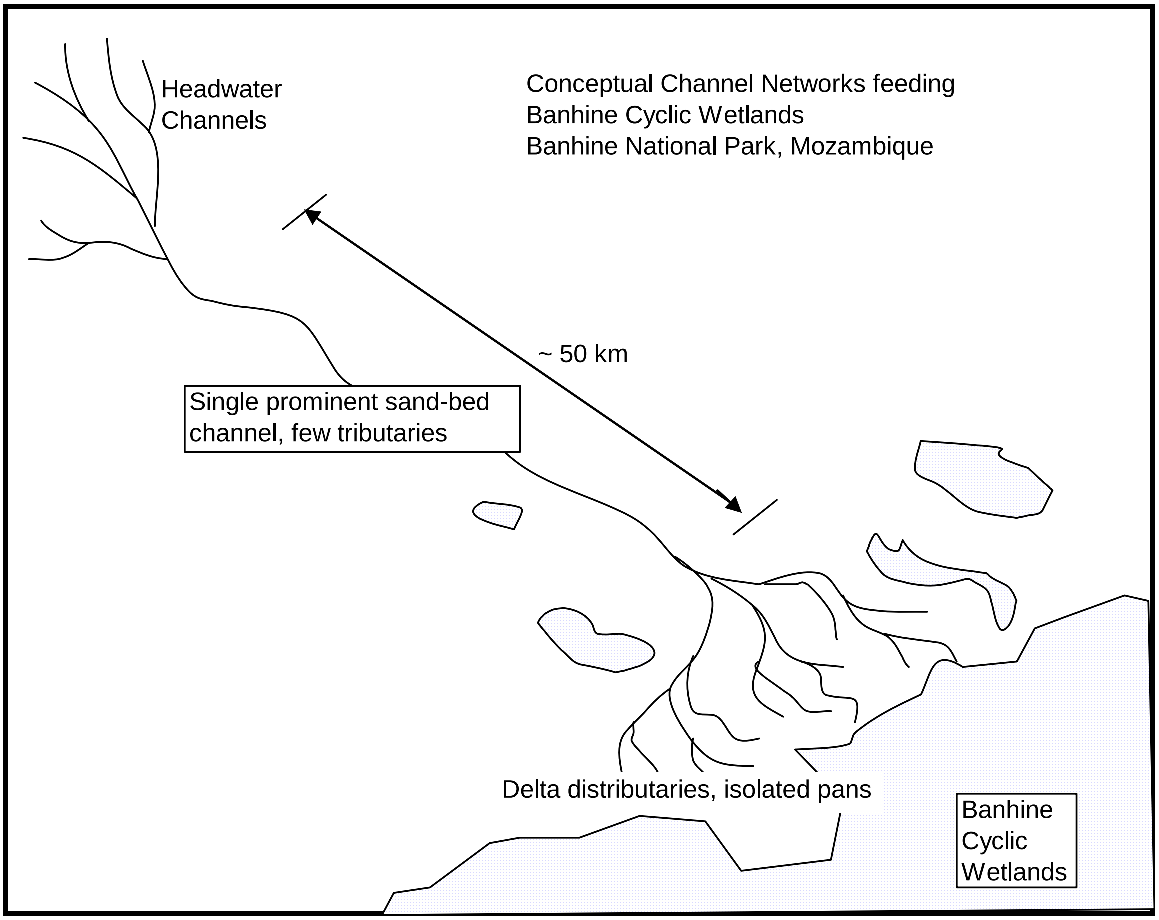


Figure 13. Model of the channel network in the Banhine wetland headwaters and delta.

Water flows in the main upstream channels also deliver sediment to the large network of distributary channels and delta areas on the edge of the wetland From the aerial survey, it was evident that the sand-sized sediments carried by the larger rivers drop out and acculumulate as the channels split and enter the delta areas. Little if any sand-sized particles reach the wetland, although finer particles are likely carried further into the wetland before being deposited. This fine sediment, rich in nutrients, helps increase the productivity of the wetland. The deposition of finer material over time may also be a key to the wetland function by helping to inhibit infiltration. The exception to this is at the mouth of the Changane River, where abundant sand accumulates in the wetland outlet channel and creates an alluvial fan.

2.5 Geology

BNP lies within a sedimentary basin whose axis runs roughly parallel to the present day Mozambique coast. The highest elevation (181 MSL) occurs in the NW section of the park and the area dips in a SE direction. The park is covered principally by sandy soils that overlay a calcrete layer approximately seven meters below the surface. The Banhine wetlands area consists of alluvial deposits transported by intermittent streams originating outside the BNP boundary.

The headwaters of the principal intermittent streams that supply surface water to the Banhine wetlands occur northwest of BNP near Mozambique's border with Zimbabwe. The largest of these intermittent streams is the Chefu River, which originates in the basalts and rhyolites of the Karoo formation in southwestern Zimbabwe near Gonarezhou National Park. Once in Mozambique, these igneous rocks are overlain by the sandstones of the Sena and Elefantes formations in an area known as the Alto Limpopo plain. The Banhine wetlands occur in a basin on the eastern edge of the Alto Limpopo where it intersects with the calcarenites and sandstones of the Mangulane and Mazamba formations.

2.6 Vegetation

To assist in the development of the 2002 BNP Management Plan, Stalmans and Wishart (2005) classified the vegetation of BNP using a combination of field survey and the analysis of LANDSAT satellite imagery (Figure 14). They identified 5 broad landscapes within BNP made up of combinations of 11 distinct plant communities. These landscapes represent broad vegetative groupings based on a combination of environmental factors including topography, soils, hydrology, and the existing natural vegetation pattern.

1. *Wetland landscape*. These areas are the seasonally and cyclically inundated areas of the northeastern portion of BNP. *Phragmites australis/mauritianus* reeds, *Typha capensis* and sedges characterize the vegetation. This important wetlands landscape covers approximately 1% of BNP.

2. *Grassland landscape*. These areas are seasonally inundated areas that surround the wetlands. This landscape occupies approximately 14% of BNP and consists of open grasslands with scattered trees and clumps of brushy vegetation. This landscape has been identified as of critical importance to the resident population of ostrich (*Struthio camelus*).

3. *Mopane landscape*. Occupying approximately 34% of BNP, this landscape occurs mostly in the northern and western portions of the park. Closed canopy woodlands characterize it. The ephemeral streams that supply water to the wetlands occur within the mopane landscape.

4. *Sandveld landscape*. Occupies approximately 47% of BNP, making it the dominant landscape of the park. It occurs principally in the southern and western reaches of BNP and consists of woody species and grasses.

5. *Androstachys (Nsimbitsi) landscape*. This landscape occupies approximately 4% of BNP and represents species-poor woodland areas with a limited understory of grasses.

Eleven different plant communities within the 5 broad landscapes of BNP have also been identified. These communities represent areas of similar environmental conditions where recurring assemblages of grass and woody species occur. A more complete description of the individual plant communities is contained in Stalmans and Wishart (2005).

Using the Ramsar Convention of wetland classification, the following wetland types have also been identified within BNP (Stalmans and Wishart, 2005).

1. Permanent inland deltas (L)
2. Permanent rivers/streams/creeks (M)
3. Seasonal/intermittent/irregular rivers/streams/creeks (N)
4. Seasonal/intermittent freshwater lakes (>8ha) including floodplain lakes (P)
5. Permanent freshwater marshes/pools; ponds (below 8ha), marshes and swamps on inorganic soils; with emergent vegetation water-logged for at least most of the growing season (Tp)
6. Seasonal/intermittent freshwater marshes/pools on inorganic soils; includes sloughs, potholes, seasonally flooded meadows, sedge marshes (Ts)

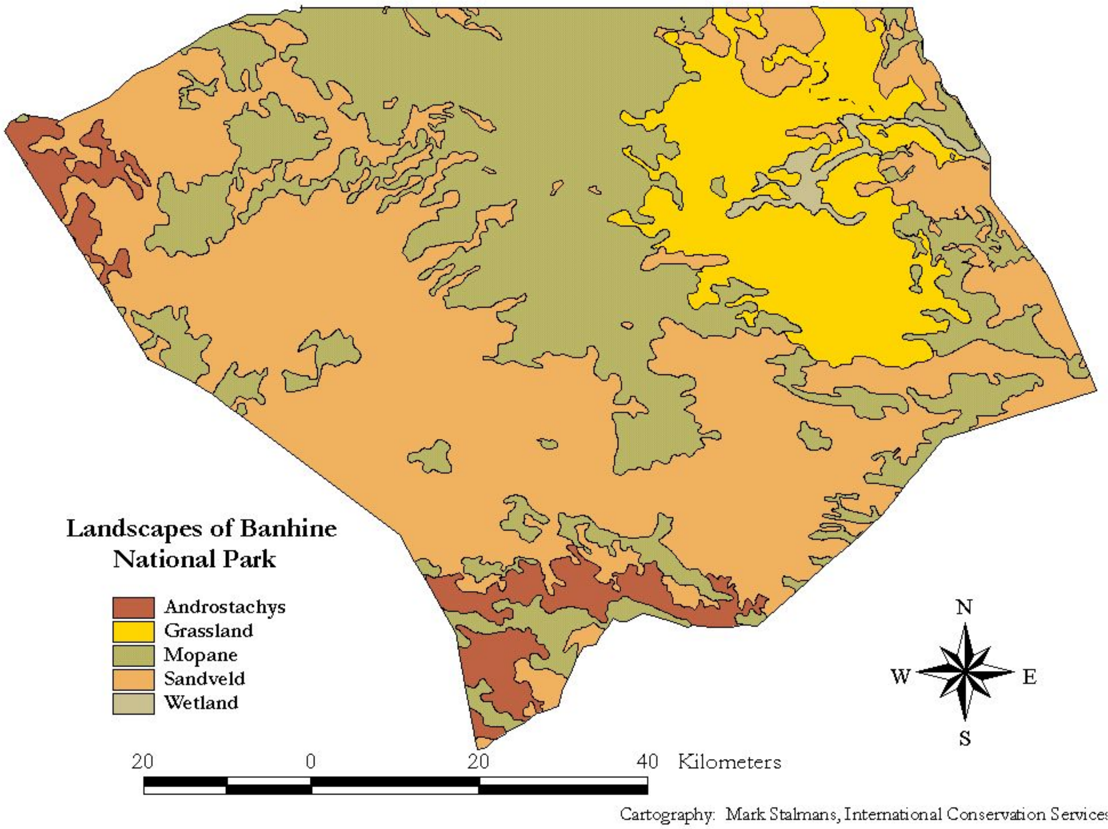


Figure 14. The major landscapes of Banhine National Park.

2.7 Human Land Uses and Impacts

Understanding the patterns of human land use in the Banhine Watersheds is important for developing an integrated approach to sustainable watershed management. There are a variety of land uses currently in the BNP watersheds. This area is semi-arid, with poor soils, low agricultural potential, and is prone to drought conditions (FAO 2004) The FAO indicates that all of BNP and surrounding towns such as Chigubo and Chockwe are at severe risk of drought. Resident human populations in BNP adapt to drought conditions by changing eating habits (reduced meals), intensifying the search for part-time work, intensify fishing and hunting efforts, sell livestock, increase charcoal production, and in the worst case, move the family (FAO, 2004).

Within the park there are scattered communities, subsistence farms, and livestock grazing. Five human settlements are located within the park. Official population estimates are unavailable, but over 2000 people may live within the park. The majority of the human population derives their livelihoods from subsistence agriculture and livestock husbandry. Because of the nature of economic activities, the area is threatened by land degradation as a result of forest removal for agriculture and charcoal production, construction timbers and fuel, high livestock densities (goats and cattle), and bush fires set by poachers. The situation is exacerbated by undefined land tenure rights and growing population density. There is also considerable dependence on non-timber forestry products largely in the form of wild fruits and traditional medicines.

Outside of the park the current effects of subsistence farming, community development, and livestock grazing on water quality and water flows are minimal. However, an increase in the intensity of these land uses can significantly affect sediment outputs and erosion, as well as channel destabilization, either in the form of widening or gullying. Accelerated erosion and sedimentation potentially have detrimental effects on aquatic ecosystem productivity downstream and can cause instability in channels. Roads on the landscape can concentrate runoff and increase sediment production rates from landscapes, and destabilize channels.

Subsistence agriculture is the main source of livelihood for the communities in this landscape. Maize is the dominant crop. The main challenges to agriculture include frequent droughts, lack of draught power, high cost of inputs and limited access to markets. Despite these problems reliance on subsistence cropping is high. Goats, chicken, and cattle seem to be the most common livestock in the area as they are owned, albeit in small numbers, by most local community members.

Fish are not an abundant resource in the BNP area. We observed many fish drying racks along the edge of the Banhine wetland, but they are simply an artifact of the powerful tropical cyclone Eline, which filled the Banhine wetland in 2000. As wetland water levels dropped the local community members used spears and traps to capture the fish that were isolated in shrinking pools. By the time of our field reconnaissance (July 2006) water levels had fallen sufficiently that fish were no longer a significant protein source for the human population. Fish are only occasionally present in the wetland area, following the large precipitation events that fill the wetland and allow outflows sufficient for fish to migrate upstream from permanent water sources. Further proof of the small role of fishing in the Banhine area was evidenced by the lack of watercraft owned by area residents. We observed no boats of any kind in areas surrounding the wetland

Tourism, both consumptive and non-consumptive, has the potential to become an important source of employment for the communities in the Banhine area. The development of the Greater Limpopo Transboundary conservation area has the potential to increase the number of visitors to the area. This initiative, which includes the countries of Mozambique, South Africa, and Zimbabwe, is an ambitious plan to integrate the five National Parks of the transboundary area into a single ecological unit. AWF is working on methods of ensuring that the local communities share in the economic benefits of this initiative. In fact tourism is viewed as having perhaps the best potential for the economic development of the BNP area.

Human impacts to stream channels upstream of BNP corresponded to settlement patterns, primarily since settled areas cause increased soil disturbance and sediment supply, disturb riparian vegetation extent, abundance, and recruitment, and can change runoff patterns and the safe storage and release of surface flows. Safe storage and release of water simply stated means that vegetation and ground cover is adequate to allow for rainfall infiltration, and slows overland flow protecting soils from erosion. Runoff, once it is allowed to infiltrate, can be more slowly metered to streams or groundwater. Most human impacts within the BNP area and in areas upstream of the park consisted of roads, subsistence farms, cleared areas for dwellings, and localized pond or streambank disturbance from gathering reeds or collecting water. Abandoned farms were also a major impact, since from field surveys they appeared to be slow to recover ground cover and are prone to gullying and other erosion. These soil disturbances often lead to erosive surface flow, since with no ground cover runoff tends to be more erosive, and floods tend to be more damagind higher magnitude events..

2.8 **Watershed Condition and Function**

A watershed characterization that describes general meteorological, surface and groundwater, physical and biological, and biophysical processes has been completed. These characteristics set the stage for analyzing relevant factors that directly influence flow, water quality, or the timing of water in the watershed.

Table 3 lists the influential factors that affect the timing, quality, and quantity of streamflow into the Banhine wetlands. A subjective rating based on professional knowledge and field observations of the physical and biological systems within the watershed is provided. Ratings are given as high, moderate, or low depending on their influence on hydrology or water quality.

Table 3. Watershed characterization factors and ratings.

Factors	Flow	Quality	Timing
METEOROLOGY			
Precipitation			
Amount	High	High	High
Duration	High	High	High
Frequency	High	High	High
Air Temperature			
Monthly, Daily, Hourly			
Maximum	High	High	High
Minimum	Low	Low	Low
Evaporation	High	High	High
Wind	High	High	High
SURFACE WATER			
Quantity			
Streams	High	High	High
Floods	High	High	High
Reservoirs	None	None	None
Pans/lakes	High	High	High
DRAINAGE BASIN CHARACTERISTICS			
Watershed Morphometry			
Channel Geometry (cross-section)	High	High	High
Topography (slope, aspect, drainage density)	High	Mod	High
Wetlands/Riparian Areas			
Soils			
Depth	High	Low	High
Infiltration	High	Low	High
Geology (lithology)	High	High	High
Vegetation (upland)	High	Low	Mod
Human Influence			
Domestic stock	High	High	Low
Mining	None	None	None
Roads	Low	Low	Low
Agriculture	Mod	Mod	Mod
Ground-water extraction	High	Mod	Mod
Developed areas	Mod	Mod	Mod

3. Key Issues, Concerns, and Questions

3.1 Overview

Through information gained from field surveys and interviews with park personnel, the team identified and described ecological processes of greatest concern and established the degree to which these processes may be functioning. From this information, the assessment has identified a list of key issues and concerns. Questions for further research were suggested for issues that require additional information.

Characterization of the BNP area was established through a series of activities ranging from field reconnaissance surveys, aerial survey, compilation of secondary data, and digital analysis of spatial data. Through these characterization efforts, the assessment team has concluded that the overall condition and function of wetlands in the BNP indicates the wetlands are in excellent condition. Specifically, observations by the assessment team following field and aerial surveys, combined with the previous work that has been done in the basin, led the team to suggest that the condition ranged from fair to excellent, with an overall rating of excellent. Land conversion to farming, road construction, and other land disturbing activities are still relatively limited. Based on aerial reconnaissance, .most of the upstream rivers that provide water to the Banhine wetlands seem to be in excellent condition. The trend in condition was thought to be stable for the areas we surveyed. However, future population pressure will determine trends since human use was the biggest driver for determining watershed condition.

As progress has been made with partners who are working in the region, it is clear that much information already exists on the current conditions and problems affecting BNP and surrounding areas. Other researchers and institutions have gathered and analyzed data in order to formulate prescriptions and in some cases implementation of resource protection efforts has already commenced. These programs seek to empower local stakeholders to co-manage the natural resources in their area and share both costs and benefits of the land uses practiced.

Furthermore, central government departments with mandates over watershed and/or catchment management exist on the ground, albeit with limited resources. This includes the Mozambique Departments of Water, Natural Resources, and the Ministry of Environment. All these have scattered data and information relevant to watershed management and if pooled together, could be useful reference for assessment and improved management.

3.2 Key Issues and Discussion

A set of key issues has been identified for this watershed analysis that focus on resource issues providing insight into park water resource management. Some of these key issues are broad scale issues that may generally apply throughout BNP, and others are limited to a particular area. Key issues address resource concerns or problems that are unique to the park and its watersheds.

3.2.1 Watershed or catchment condition and land use

There are a variety of land uses currently in the BNP watershed. Within the park there are scattered communities, subsistence farms, and livestock grazing. Five human settlements are located within the park. Official population estimates are unavailable, but up to 2000 people may live within the park. The majority of the human population derives their livelihoods from subsistence agriculture and livestock husbandry. Because of the nature of livelihood economic activities, the area is threatened by land degradation as a result of forest removal for agriculture and charcoal, construction timbers and fuel, high livestock densities, especially goats and cattle, and bush fires set by poachers. The situation is exacerbated by undefined land tenure rights and growing population density.

Outside of the park the extent of subsistence farming and livestock grazing is unknown, but other impacts such as runoff from towns may be having an effect on water flows and water quality. These land uses can have significant effects on sediment outputs and erosion, and can destabilize channels. Increased erosion and sedimentation can have detrimental effects on aquatic ecosystem productivity downstream and can cause instability in channels. Roads on the landscape can concentrate runoff and increase sediment production rates from landscapes. Are land uses both within the park and outside the park having a significant effect on water flows and water quality? Will future development such as road construction, forest cutting, and community development in the upland areas outside the park increase sediment production and change water flows from the upland areas? As settlement rates increase in upland areas outside the park, are there ways to direct settlement to preferred areas?

3.2.2 Precipitation regime and hydrologic cycle

Scant information is available on the magnitude, frequency, and amounts of precipitation at BNP or the upland areas that contribute flow to the wetlands.

How does the precipitation regime in upland areas affect water flows and water storage in the park? What are the characteristics of storms or rainy periods that are likely to cause significant runoff that reaches the parks wetlands? Are the wetlands in the park filled only by upland runoff from larger flooding events such as cyclones, or will a series of smaller events with normal amounts of total precipitation create enough runoff to fill the wetlands? How much do the wetlands fill in response to local rain events? How well developed are drainage networks in the land areas that surrounds the wetlands, in the delta, and in the upland areas that supply runoff to the marsh?

3.2.3 Water balance

Runoff entering the wetlands from major precipitation events and upland floods appears to be slowly metered out of the wetlands over the span of a few years. This "charging" of the wetland system can last for several years after large precipitation and flow events. What is the timing and magnitude of inflows and outflows from the wetland during and for the years following large flood events? What is the expected rate of evaporation and evapo-transpiration and other factors that influence wetland water retention in the wetland? And once it is filled, how long can surface water be expected to be maintained in the wetland? Is there a groundwater connection to the surface water in the marsh? If there is a shallow groundwater connection, how does it vary spatially and temporally? How does the shallow groundwater vary in depth and extent from year to year? How much does the wetland fill each year? How long is water retained and where is it retained each year?

3.2.4 Hydrologic control on wetlands

The Changane River is critically important because the sediment alluvial fan that is created at its confluence with the Banhine wetlands outflow channel acts as the principle hydraulic control on the water elevation within the wetlands. This feature is critical to regulating water levels in the marsh. What are the characteristics of this hydraulic control, and how does it function to regulate water levels? What land use impacts have occurred at the confluence that may influence the stability of the hydraulic control over time? What land use or water regulation exists for the Changane River watershed, how is it implemented, and what plans exist for the future? Is there a way to regulate outflows from the lake and preserve the aquatic, wetland, and terrestrial species that depend on the wetlands? What has been the effect of dikes that were built to retain water in the Banhine wetlands? If flows are regulated by a dam, what will be the trade-offs from an ecological standpoint? What would be the relative benefits and costs of putting in a structure to regulate water outflows? What likelihood would there be that flows would be retained longer in the wetland if a dam was constructed?

3.2.5 Potential threats to wetlands

There are a variety of existing and potential threats to the Banhine wetlands. Activities that increase the rate of sediment production in runoff that enters the wetlands can have a detrimental effect on natural rates of aquatic productivity. Since the wetland acts as a large lake at times, and supports a wide variety of aquatic species, maintaining aquatic productivity is essential for ecosystem health. Activities that can increase sediment production above natural rates are primarily changes in land use within the wetland and its catchment. These, include livestock grazing, construction of roads and buildings, forest clearing, charcoal production, and farming, especially along streambanks. What actions can be undertaken to reduce existing and anticipated impacts?

3.2.6 Water quality

According to a recent water quality survey, water entering the marsh becomes significantly higher in conductivity, which is an indicator of higher total dissolved solids as it flows through the marsh. (Banhine fish survey, 2005). This is probably a result of high evaporation rates in the area. What are the chemical constituents in the water that are becoming more concentrated through evaporation? How do these affect wetland productivity and the spatial extent and abundance of aquatic organisms throughout the wetland? To what degree will more intensive land uses in the upland catchment areas increase the load of dissolved solids in runoff to the wetland? What other types of water quality impacts such as fuel leakage, human sewage, animal wastes, or industrial wastes are impacting the quality of water entering the wetland? What role do drainage networks play in delivering sediment and other types of pollution to the wetland?

3.2.7 Soils

Soils in the study area are closely linked to the regional geology. Two soil maps where obtained during this study, a 1 : 5 000 000 FAO map and the 1:1 000 000 map produced by INIA Departmento del terra Agria Mozambique. A comparison between the two maps was completed. The soil attributes provided by the FAO map were easier for modelling purposes, but the INIA map provides far greater detail – see Figure 1. Soils are described per landtype as defined later in this section.

The deep sands soil type consists of quaternary sands of varying depth that may exceed 30m. These areas are almost flat with a gently undulating landscape. Soil structure and depth follows catenal sequences across this landscape. These soils range in colour from grey through orange to red. The soils have low to medium fertility with the red soils more fertile than the grey and orange. These soils are well drained, but where they are shallow and overlay cretaceouse clays they are characterized by the appearance of numerous small ephemeral pans. Calcrete is common in the area.

The upland areas are dominated by sandy soils while the wetland soils appear to be dominated by silty highly organic clays. In the outlet channel these soils appear to be highly sodic. Do the wetland soils act as a barrier to infiltration of surface water into groundwater creating a perched wetland? How thick are the wetland soil layers? What is the spatial variation of soil types throughout the wetland? Are soils in areas in and near the delta of the Chefu River different than soils near the outlet channel? How stable are the wetland soils, and what kinds of land uses will be detrimental to them? What kind of land uses are detrimental to upland soils, especially in the upland areas where drainage networks are well established?

3.2.8 Groundwater

Well boreholes are commonly used for water supply by communities in the BNP area. The available groundwater supply, the rate of consumption and the capacity to sustain production without significant draw down of water levels is not known. The impact of boreholes on local wetland hydrology is also unknown. Future use of water for irrigation could lead to other problems such as soil erosion or salt buildup (depending on water and soil chemistry) from flood irrigation.

3.2.9 Fisheries resources

The performance of wetland fisheries is correlated to the presence and quality of water and habitat that is in turn influenced by activities within the watershed and discharges from upstream runoff source areas. In the absence of historical data to allow for trends analysis, an understanding of the relationship between fish species life history and wetland hydrology is lacking in the Banhine landscape. There is also a fundamental lack of information on how fish re-populate the wetland once it is inundated. Do fish migrate to the wetlands from the downstream Limpopo River? Do fish spawn in the Banhine wetlands? How long of a period of inundation is needed to allow for spawning of different fish species? What are critical habitats for species such as killifish, or lungfish? What threats are there to fish species that migrate into the marsh when it is inundated? Are there existing or planned blockages to fish migrations downstream of the Banhine wetlands?

3.2.10 Wetland plants and succession

The wetlands in BNP are cyclic, and fill with water in response to large, relatively infrequent precipitation events which in turn affect the growth cycles, species composition, extent, and rate of plant succession of aquatic and riparian plant species. Plants within the cyclic wetland are also affected by annual rains. Certain species of plants may be important as habitat elements for various species, and their populations may expand and contract given the extent to which the wetland fills with water. Recent vegetation mapping (Stalman and Wishart 2005) shows considerable variability in the spatial extent of vegetation. What are the important plants and plant communities that are providing wildlife habitat? What is the rate of succession, and spatial extent of plants or plant communities that have been identified as providing significant habitat for important wildlife species, and support of aquatic, wetland, and terrestrial food webs? What is the extent of exotic plant invasion in the Banhine wetlands?

3.2.11 Small pans and springs

During our aerial survey we observed numerous small ponds and springs, some in upland areas, others in river valleys or pans. What is the spatial pattern and extent of springs in the park? What is the period and magnitude of flow from these springs? How has human land use affected springs?
Pans are depressions that fill in response to rainfall or flooding events. The Banhine wetlands are essentially a pan that covers a very large land area. The Banhine wetland differs from the smaller pans in having both a channelized inflow and an outlet. In BNP, the very low density of channels suggests that smaller pans adjacent to the Banhine wetlands may fill as the wetland fills, and become isolated as the wetland contracts through evaporation, transpiration, and infiltration. Other smaller pans scattered throughout the park appear to fill in direct response to rainfall. Some may be permanent water sources, others are seasonal. What special management emphasis and protection from human impact should these areas receive? What is the response of these smaller pans to normal annual total precipitation, and between year variability in precipitation?

3.2.12 Fire

There was evidence of wildfires in the wetland areas. What percentage of the fires originate naturally as opposed to anthropogenic ignition? For what reasons are anthropogenic fires ignited? What is the extent, frequency, and severity of fires in the upland areas that contribute water to BNP? What are the fire dependant plant species? How do fires in the upland areas influence runoff patterns and sediment supply? Are there opportunities to use fire to enhance wildlife habitat and other ecological processes?

3.2.13 Park expansion

Park expansion is being considered to bring ecologically significant areas currently outside the BNP under contiguous park management. At present there is light anthropogenic land use in the upper watershed, but that is anticipated to change once a proposed new road is constructed. More intensive land uses such as increased farming, timber harvest for log and charcoal production, livestock grazing, and community development are expected. These activities may have an impact on the Banhine wetlands by increasing sediment and nutrient loads downstream above background levels, potential gullying and loss of streambank water storage, outflows of chemical materials or human waste, streambank instability and channel changes, possible changes in streamflows or in the water holding capacity of the soil from timber removal, or changes in springs or natural water sources from groundwater pumping. At this time a more precise picture is needed of additional development would look like in the upper watershed. The potential for significant effects exists, but land uses would have to significantly increase in intensity.

It is strongly recommended that the area near the mouth of the Changane River be included within the BNP. This area is particularly sensitive to disturbance, and provides the hydraulic control for the wetland outlet. Livestock grazing could de-stabilize this area, increasing erosion and decreasing channel stability. Maintaining it within BNP offers more options for management of this area.

Watershed protection is important along streams that flow into the Banhine wetlands. Also, these streams may provide potential migration corridors for wildlife. It was evident that along some of the channels several kilometers south of the community of Machaila there was standing water in stream corridors. **The area south of the roads southeast and southwest in and out of Machaila create a triangle of about 1000 sq km that intersects the BNP boundary near Nenguasauna and Matabule. Significant wetland areas and water sources extend into the triangle and near the Park boundary. It is recommended that this area be further explored for possible addition to the park.** Ground reconnaissance and possible additional over flights are recommended for this area.

4. Summary and Recommendations

The findings of this assessment can be used to help formulate management recommendations that can be implemented with partners and stakeholders working in this ecosystem. AWF will look for partners that are already developing the means to implement management actions that have emerged from this assessment and previous assessments. AWF will also continue compiling and synthesizing existing information and add to it where possible, specifically through increased GIS data synthesis and through the establishment of a monitoring program in the Banhine area.

4.1 Management Recommendations

Specific recommendations for management of the Banhine National Park and surrounding areas are:

- **Formulate land use plans** - There is a lack of coordination in the Banhine area regarding many aspects of natural resource management, especially water resource management. Land use plans, perhaps coordinated on a District basis, are badly needed in order to guide future development. These land use plans should address current and projected uses of water resources in BNP, and address current and projected uses of water in the BNP watershed. Also, it should attempt to identify ecological values associated with water resources in BNP, and provide guidance regarding development and protection of water resources in BNP and the watershed.

- **Evaluate land carrying capacity for humans and wildlife** - The carrying capacity of land resources to support increasing human and wildlife populations in the area needs to be studied extensively and a comprehensive plan developed that addresses these impacts, especially impacts to ground and surface water resources. This is an urgent need due to the relatively low human population densities and the anticipation of future growth in the upland areas draining into the park.

- **Wetland and floodplain conservation plans** – Development of a conservation plan for wetland and riparian management for the Banhine wetland and national park needs to occur. This plan would provide guidelines and, objectives for preserving sustainable human uses as well as the ecology of this important wetland area.

- **Wetland and floodplain farming impacts**- Determine the effects of farming on the wetland and upstream floodplain area, with an emphais on impacts to soil and water budgets. This information would be used to establish policies to manage the in-migration of people, to build ecologically sustainable communities, and to establish sustainable farming practices best suited to the area.

- **Soil and water conservation practices** - Develop suitable soil and water conservation strategies for subsistence and commercial agriculture, emphasizing soil conservation in the upland areas that are the headwater for the Banhine wetland. . Environmental education of the local population and sharing of successful techniques is essential. This could be framed in the manner of soil and water conservation districts utilizing various government resource ministries (e.g. Forestry, Agriculture).

- **Wildfire and controlled fire** - Establish consistent wildfire control and management strategies for the area. This policy would address wildfire suppression strategies, and the use of human controlled or un-controlled fire to achieve ecological objectives. This strategy would attempt to reduce impacts on soil erosion and water budgets to ecologically sustainable levels.

- **Enforcement of conservation laws** - There is a lack of enforcement of conservation laws in BNP such as those laws regulating wetland area farming, forest harvest cutting, and wildlife poaching. Adequate funding and patrolling of the park is essential to protect its resources.

4.2 Data needs

There are several core areas where more information is needed for future park management of water resources within and surrounding BNP.

1. Need better geologic information- More detailed geologic maps, and geologic cross-sections. Better characterization of sub-surface geology is necessary to determine geohydrology.

2. Need more detailed soil maps and characterization for BNP.. It is recommended that soil pits be dug throughout the park, with a goal of a more spatially accurate classification of park soils.

3. Need a precipitation map for the area, and more detail on precipitation magnitude, frequency, and duration at sites within the Park and in the upland areas contributing surface water to the park.

4. Need more detailed information on settlement patterns on river and stream corridors in upland areas draining into the park. It would be useful to have maps showing detailed settlement and agricultural areas, and complete resource surveys to validate assumptions regarding the impacts of land uses. There is a need to explore ways to develop a predictive model for determining future settlement patterns in upland areas upstream of BNP.

5. Need to determine the best flows for fish migration, habitat, and breeding success. Components of this could be:

   - Determining the preferred combination of depth, flow velocity, and habitat for the main fish species.
   - Understanding the life history of the various fish species including preferred habitat at different life stages.
   - Conducting surveys of existing habitat and providing estimates of potential habitat

6. Need information on the streamflow patterns feeding the wetlands. Streamflows are a very important part of the water balance for the wetlands. Stream gages are needed at several locations on streams feeding the wetlands. How do the patterns of streamflows and floods in tributaries to the wetlands affect the extent, rate, and duration of wetland filling, and how do the streamflows affect plant communities, fish, and wildlife?

7. Additional surveys of wetland plant species in Banhine and riparian species along the channels in the upstream areas that contribute flow to the wetland, with a focus on water needs for the various species of vegetation.

9. Need studies on balancing upstream anthropogenic water use with the needs and goals of Banhine wetland mangement, both currently and under future conditions. A community and government sponsored policy is needed to ensure future water needs for all stakeholders.

10. Information on the extent, quality and quantity of groundwater needed for community crops and livestock, and the effects of groundwater extractions on surface waters.

10. Inventory of the springs and vernal pools in the wetlands area to determine spatial density and distribution of water sources for wildlife and humans.

11. Need a topographical survey of the outlet control where the Changane River meets the Banhine wetland. An aerial LIDAR survey to precisely map the topography would greatly benefit the management of land uses within the Banhine wetland area. LIDAR would be a useful tool for surveying topography in the entire park.

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