MGOBEZELENI

THE LINKAGES BETWEEN HYDROLOGICAL AND ECOLOGICAL DRIVERS

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

The ecological dependencies on the hydrological system of coastal environments, with its many feedbacks are highly complex and not well understood. The terrestrial environment controls the hydrological system. To investigate the linkages between the hydrological and ecological drivers in this project, the hydrological system was quantitatively analysed using field measurements and numerical modelling techniques.

The Mgobezeleni catchment comprises low-lying paleodunes with interdunal depressions that are aligned with the coastline. These were incised by fluvial processes to form the main streams feeding into Lakes Mgobezeleni and Shazibe upstream of the estuary. Highly permeable soils induce rapid infiltration that limits the surface runoff processes. Consequently, groundwater storage dominates the hydrological system in the Mgobezeleni catchment, which has a profound influence on the surface water dynamics. The groundwater recharge, storage and discharge are the important processes that need to be quantified to establish an understanding of the hydrological dynamics and water budgets. A conceptual hydrogeological model was developed based on published regional groundwater studies and geological investigations in the catchment. A conceptual hydrological model of the surface water features was developed from field studies in the catchment. A (quasi) three-dimensional transient numerical groundwater model based on the conceptual models was developed, calibrated and applied to assist in understanding the Mgobezeleni hydrology, hydraulics and solute transport.

The model parameters for recharge and aquifer hydraulic properties were calibrated by equating the simulated discharge in strategic stream sections and the groundwater storage (water table elevation) with measured values during a 10-year simulation period. The simulated streamflow in the main streams feeding into the lakes was in close agreement with measured values and the water pressure head (elevation) was generally closer than 1 m of the measured levels for all the boreholes. The simulated water level elevation in Lake Mgobezeleni from the water balance model was generally within 0.2 m of the measured levels. It is proposed that the model was sufficiently accurate and reliable to assess the hydrology of the system and evaluate the different natural and anthropogenic impacts on the water resources of the system.

Nearly fifty-five percent of the catchment rainfall infiltrates the soil surface to replenish the groundwater storage after accounting for evapotranspiration processes in the soil surface layers. This effective recharge and the hydraulic properties (conductivity and storage coefficient) of the aquifers and the drainage boundaries (streams, lakes estuary and ocean) control the groundwater storage and the depth to the water table.

The Mgobezeleni hydrogeology is dominated by three main aquifers comprising the unconfined Kwambonambi Formation with relatively high hydraulic properties that overlies the semi-permeable Kosi Formation that creates a leaky type aquifer overlying the deeper Uloa Formation with its relatively high permeability. The Uloa Formation forms the deepest semi-confined aquifer overlying the Cretaceous bedrock. Nweze (2015) mapped the hydraulic properties and spatial distribution of these aquifer units across the central region of the study area.

Approximately 7,000 Mm^3 of groundwater is stored in the primary aquifer above the bedrock (Cretaceous sediments) for the Mgobezeleni catchment assuming an average depth of ~70 m. This groundwater discharges into the streams, lakes and estuary as baseflow to balance the net recharge and any change in storage. Streamflow measurements and lake water level measurements were used to calibrate the infiltration rate assuming that the groundwater storage was in balance between the inflows (recharge) and outflows (streamflow).

The average annual recharge to the Mgobezeleni catchment over the ten year simulation period from 2004 to 2015 under the current land use conditions was estimated to be approximately 31 Mm^3 $year^{-1}$ and an average annual loss to evapotranspiration of 80 Mm^3 $year^{-1}$. The annual net loss to the aquifer is approximately 49 Mm^3 $year^{-1}$ (>1 mm day^{-1}). This has depleted the aquifer storage and consequently the baseflow into the rivers. This is equivalent to an average drawdown of about 10 mm over the entire catchment for the study period. In reality, there would be a greater drawdown along the ridges and plantations with compensating lower drawdown along the drainage boundary. However, this loss of storage would be reflected in the average discharge to the streams and lakes.

The locations of all production boreholes in the Sodwana region were identified and assumed to provide an average household water use of 30 Ml $month^{-1}$ (30 m^3 $month^{-1}$) with the exception of lodges where the consumption was assumed to be 300 Ml $month^{-1}$ (300 m^3 $month^{-1}$). The boreholes were configured in the model to abstract groundwater from the Uloa Formation at depths generally greater than 20 m. An average abstraction rate of 7000 m^3 $month^{-1}$ or approximately 0.1 Mm^3 $year^{-1}$ from the Sodwana boreholes was equivalent to less than 1% percent of the average net recharge and is unlikely to impact seriously on the groundwater system.

The impact of the plantations on the hydrology was evaluated by comparing the current land use simulations with the assumed natural conditions represented by replacing ALL the plantations and woodlots with grasslands in the numerical models. The mass balance model under commercial plantations and subsistence woodlots was calibrated and the Mgobezeleni catchment area estimated to be on average 101 Mm^2 from the digitised groundwater flow patterns. The catchment area did vary by over 15 Mm^2 between wet and drier periods during the simulation period. In comparison, the catchment area for the grassland conditions, estimated by assuming all plantations were replaced by grasslands, was 91 Mm^2. There was a simulated reduction in the average catchment area of nearly 10 Mm^3 between the current landuse and the grassland conditions because the drawdown due to the plantations induced a cone of depression that extended the recharge zone further west of Mbazwana. This ten percent increase in Mgobezeleni catchment area under plantations compensated for the significant reduction in the recharge due to the interception and evapotranspiration rate of the plantations.

The model predicted a net water loss from the catchment under current land use conditions of 48 Mm^3 $year^{-1}$ for the period from 2004 to 2015. Under grassland conditions, this net loss is estimated to be approximately 45 Mm^3 $year^{-1}$. This equates to water use by the plantations of over 3 Mm^3 $year^{-1}$ for the Mgobezeleni catchment. This cumulative loss from recharge over the ten-year simulation period was approximately 67 Mm^3. In comparison, the estimated abstraction by boreholes in the Sodwana area is less than 0.1 Mm^3 $year^{-1}$.

Under natural conditions, prior to the population settlement that has taken place since the early 1960s following the introduction of forestry and tourism, the catchment soils and groundwater were oligotrophic with nitrogen and phosphorus concentrations at about 0.05 and 0.02 µg l^{-1} respectively. These values were similar in the water in Lakes Mgobezeleni and Shazibe and the Mgobezeleni Estuary. As a result of both the population increase and the introduction of water-borne sewage systems and pit latrines, quantities of nitrogen and phosphorus are being washed down into the groundwater. This has elevated the levels of these nutrients to values well above the desirable ecological values, but so far, the acceptable drinking water standard levels have not been reached. Groundwater flow to the lakes has elevated the nutrient levels in those systems but the growth of aquatic vegetation has reduced the levels to below the values measured in the groundwater. The nutrient concentration of water from the lakes to the estuary was reduced due to mixing with seawater with the result that the concentrations of nitrogen and phosphorus are only slightly higher than acceptable levels.

An assessment of the ecological status of the open water bodies was undertaken by examining the microalgal populations. Considerably elevated numbers of microalgae were counted in water samples from Lake Mgobezeleni. Similar samples from Lake Shazibe and the estuary revealed lower numbers. The reason for the differences is likely due to in the type of vegetation in the two lakes, with Lake Shazibe being dominated by macrophytes rather than microalgae. The microalgae in the estuary were more normal but species diversity of the microphytobenthos was noticeably lower than expected. The dominant microalgae in Lake Mgobezeleni were cyanophytes with the toxic species *Microcystis aeruginosa* the dominant. The identification of *Microcystis* was confirmed by Next Generation Sequencing technology to analyse the 16 S rRNA gene sequences. Cyanophytes were present in both Lake Shazibe and the Mgobezeleni Estuary but in much lower numbers. In the case of the estuary, the reduced numbers are likely due to the lake water flowing through a large swamp where some filtration might be occurring. The dilution of the lake water by seawater is also a likely cause of the lower numbers in the estuary water.

Measurements of the macronutrients in the groundwater and surface water features showed similar composition. This was assumed to indicate the conceptual view that the surface water resources were very heavily dependent on the groundwater system.

Particle tracking techniques illustrated the pathway of surface contaminants released from residential sites across the region. The majority of pathways from the Mbazwana region were travelling toward Lake Shazibe and its feeder streams. The majority of the contaminant pathways from the Sodwana Village Dwellings were released directly into Lake Shazibe and Lake Mgobezeleni during the ten-year simulation period. The model indicated that the particles released from the surface of the saturated zone did not penetrate into the deeper aquifers. Both lakes function as flow-through systems. The model indicated that the groundwater discharge into the lakes was less than the outflow to the downstream aquifer. Hence, those groundwater contaminants that were not bound up in the lakes were likely to be released downstream.

The Mgobezeleni Estuary enters the Indian Ocean at Sodwana Bay where the offshore Agulhas Current flows southwards but inshore there is a wind-driven longshore drift moving from south to north transporting sediments that build the sand berm that closes the estuary mouth and controls its opening and closing. This is one of the most important drivers of estuary dynamics. The currents at the estuary mouth are affected by the Jesser Point reef. The estuary usually exits into the bay to the north of that reef but at times it has moved southwards to exit over the rocks. The dominant angle of wave attack is from the south-east which creates a 'log-spiral' coastline shape. The Maputaland coast is a sediment-rich coastline with sediments brought into the sea by the Tugela and Mfolozi Rivers. As well as the coast-parallel movements of the sand, there is also a pattern of movement normal to the sea as sand is washed onto the beach. From there it is moved by the wind either inland to build the tall vegetated coastal dunes, or up and down the beach.

There is a seasonal pattern to the sand movement. Most beach erosion occurs in winter and it is possible that the casuarina trees planted at Jesser Point are altering the amount of sand available to the beach at the outlet of the estuary. The marine tides influence the hydrodynamics of the estuary. At times, wave overwashing may add sufficient water to breach the estuary.

A survey of the soils was conducted by the Natural Resources team of the KZN Department of Agriculture, Environment Affairs and Rural Development. A total of 192 soil points were assessed and a soils map was generated using a predictive soils mapping algorithm. The soils map shows that over half of the catchment area is dominated by deep, sandy and dystrophic soils. Wetland soils were mapped as a soil complex that covered 12% of the area. For all the samples measured the pH is acidic. The origin of the sand is aeolian and has little variability.

The Mgobezeleni Catchment is part of the Maputaland Centre of Endemism that is recognised for its diversity in plant and animal species with a number endemic to the Maputaland Coastal Plain. Many of the species are tropical with many Afrotropical species reaching the southernmost limit of their range here.

In much of the catchment the water table is too deep to have a significant influence on the plants growing above it. The vegetation is shaped by frequent burning, grazing and the influences of small-scale agriculture. Along the coast, the dryland vegetation consists of tall dune forests merging into coastal forests further inland. Where fire, small-scale agriculture and grazing have prevented forest formation, there is grassland. The coastal grasslands of the Maputaland coastal plain are characterised by a very large proportion of woody plants and forbs and are rich in legumes. A survey was undertaken by the KZN Department of Agriculture, Environment Affairs and Rural Development to determine veld condition and a landcover map was produced.

The watercourses are one of the noteworthy features of the Mgobezeleni Catchment. They often have a predominantly north-south orientation indicating that the position of the watercourses is fixed by the dune formations of the area. Vegetation types include streams at the lowest point with sedge swamp or swamp forest higher than riparian forest and finally coastal forest or coastal grassland. These habitats are in narrow linear bands that run the length of the watercourses. Many wetlands in coastal Maputaland and especially those in the Mgobezeleni Catchment contain peat deposits that have accumulated over a long period. The peat swamps occur where the gradient of the watercourses flattens out and widen. The peat-forming process is still ongoing and the two lakes are still gaining organic material. The peat deposits cover an area of 441 ha and the volume of peat within in the catchment is estimated as 6.66 million m^3.

The swamp areas were/are severely impacted by small-scale agriculture resulting in a loss of swamp forest and sedge swamp. The subsistence multi-cropping is rapidly changing to be commercial mono-crop farming. This results in a decomposition of peat as it dries. This peat has low water permeability and so loss of peat is likely to lower the groundwater table. Management intervention is required to reduce drainage and prevent drying of peat. There is also a need to contain the agriculture to a sustainable level. Small-scale subsistence farming where there is intercropping can be tolerated but it is necessary to set a limit to the proportion of the peat swamps that can be under cultivation at any one time. Within the iSimangaliso Park, there should be no cultivation at all.

Because the lakes have very stable water levels, they both have an abundance of associated vegetation – on the shoreline, emergent, and, especially in the case of Lake Shazibe, as submerged plants. They both have clear, light brown-stained water. Although they are both in sand basins, they have a considerable quantity of accumulated organic material on the bed of the lake. This is the case throughout Lake Shazibe, and only in the deeper parts and vegetated fringes of Lake Mgobezeleni. The lakes are set in wide palaeo-basins with sandy substrata and both have the trajectory to become filled with peat. Lake Shazibe is much further along this trajectory than Lake Mgobezeleni.

The socio-economic study was a requirement of the Water Research Commission as a component of funding approval. There is a single tarmac road running from Mbazwana to the Mgobezeleni Estuary. All other roads are sandy and during dry weather these quickly become usable only with 4x4 vehicles. Despite this, transport by private taxis is available, but was mainly observed to operate on the tarmac section during dry conditions.

The area from Mbazwana to the estuary is outside the border of iSimangaliso Wetland Park and forestry. It supports many tourist accommodation facilities that are needed for the many thousands of tourists who visit the area annually. These businesses likely provide a large proportion of the cash-flow into the area, if not the largest portion. Other economic activities include small businesses in the form of building suppliers, food, banking, clinics, schools and fuel outlets. Tourism and forestry are the core of the economy and form an attraction for persons and their families to move into the area. This increase in the population is identified by the number of buildings that are under construction. New residents build their own accommodation which initially is fairly rustic but the people soon begin making cement building blocks with the intention of constructing superior facilities. A survey of the population showed that the great majority of the black population consider themselves to be local.

Local householders receive their water supply from different sources, namely a piped supply from the Mbazwana Municipality, local boreholes, rainwater, tanker transported water or water purchased from neighbour's boreholes. The municipal supply pipeline appears to be over-extended with the result that flow is inadequate because many householders using the tap-water system feel that they are only receiving about half of their water requirements.

Analyses of the tapwater showed it to be of acceptable quality. Very few of the residents with commercial accommodation facilities receive piped water and most are dependent on private boreholes that supply an adequate amount of clean clear water of high quality with N and P concentrations well within the SANAS water quality standards.

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- Zikhali Traditional Authority
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- SAFCOL for access to the Mbazwana Plantation
- DWS (access to pumping station and water filtering & processing)

PUBLICATIONS AND PRESENTATIONS

Bate G (2014) Lecture to Probus, Estcourt, KwaZulu-Natal.

Bate G (2014) Presentation at ALLWET summer school, Mbazwana.

Bate G (2016) Presentation to Local council and community, Mbazwana/Sodwana. March.

Bate GC (2015). The influence of a rural community on the quality of the ground, lake and estuary water in northern KwaZulu-Natal. South African Society of Aquatic Scientists Annual Conference, Champagne Sports and Leisure Resort, KwaZulu, June 2015

Bate GC, Dorrington R and Mkhwaknazi M (2016). Water quality in northern Maputaland. South African Society of Aquatic Scientists Annual Conference, Kruger National Park, July 2016. Oral accepted. Venkatachalam S, Nunes M, Nqowana T, Balfour A, Hilliar S, Bate G and R Dorrington (2016). Molecular analysis of cyanobacterial diversity in Northern Maputoland: Assessing the potential for the production of harmful cyanotoxins. South African Society of Aquatic Scientists Annual Conference, Kruger National Park, July 2016. Oral accepted.

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Bate, Guy, Ricky Taylor, Bruce Kelbe, Millicent Mhkwanazi (2014). The influence of a growing human rural population on the trophic status of a small but important estuary in Northern KwaZulu-Natal, South Africa. Presentation to the Royal Society of South Africa, University of KwaZulu-Natal, Pietermaritzburg campus, South African.

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Bate, Kelbe & Taylor (27 May 2013). Presentation of the project. Inception meeting – WRC

Kelbe BE (2014) Hydrology, water quality and contaminant transport. Our current level of knowledge. Presentation at ALLWET summer school, Mbazwana

Kelbe BE (2014) Mgobezeleni Estuary Hydrodynamics Presentation at ALLWET summer school, Mbazwana

Kelbe BE (2014) Mgobezeleni Hydrology. Presentation at ALLWET summer school, Mbazwana

Kelbe BE (2015) Review W70 and W31/32 SFRA study. Presented to DWS, Durban.

Kelbe BE, Grundling A and Price J (2016) Modelling water-table depth in a primary aquifer to identify potential wetland hydrogeomorphic settings on the northern Maputaland Coastal Plain, KwaZulu-Natal, South Africa. *Hydrogeology Journal* **24** (1) 249-265.

Kelbe B and Taylor R. (2014). Threatened water resources; Maputaland Coastal Plain studies. Symposium on Contemporary Conservation Practice. Midmar, November 2014.

Mkhwanazi M and Bate G (2014) Hydrocensus and population. Presentation at ALLWET summer school, Mbazwana

Ricky Taylor, Bruce Kelbe, Guy Bate, Jean Simonis and students. (13 May 2014). The Mgobezeleni Estuary and its catchment. Presented to local people (especially diving community) at Sodwana.

Ricky Taylor, Guy Bate & Bruce Kelbe and about 20 affiliates (Feb 2015). The Hydrology and Ecology of the Mgobezeleni Catchment and Estuary. Presentation to the EKZNW 'BioBlitz' team, Sodwana.

Ricky Taylor, Guy Bate & Bruce Kelbe. (June 2015). Trajectories of change in the Mgobezeleni wetlands: A conceptual understanding. SASAqS Symposium, Drakensberg.

Ricky Taylor, Guy Bate, Bruce Kelbe & Jean Simonis (25 June 2014) The Mgobezeleni Catchment Study: an integrated hydrology-ecology study in the Mozambican Coastal Plain. Presentation to SASAqS, Thaba N'chu.

Taylor RH (1 July 2014). The Mgobezeleni Catchment Study – Ecological Aspects. WRC Annual Review.

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Taylor RH (14 Oct 2014) Overview of the study area. Presentation at ALLWET summer school, Mbazwana

Taylor RH (14 Oct 2014) Vegetation of the catchment. Presentation at ALLWET summer school, Mbazwana.

Taylor RH (9 Sept 2013) Estuaries – the interface between rivers and the sea. Lecture to UniZulu Honours students, UniZulu.

Taylor, R (in press) Dynamics of the macrophytic vegetation of the Mgobezeleni estuary and floodplain in northern KwaZulu-Natal. *South African Journal of Botany*.

Taylor, R (7 October 2015). Mgobezeleni Catchment study: the linkages between hydrological and ecological drivers. *WRC Annual Review*. Pretoria.

UZ STUDENT INVOLVEMENT

Exposure of hydrology students to real-world problems and field experiments as part of WRC Project K5/2259

The UNIZULU educational process of preparing hydrology students to assist the country with a future of limited water resources and the human impact on these resources has become very important. The past teacher-based, theory-orientated lectures with limited practicals is not working and together with educational research suggests immediate correction. For this reason, the Department of Hydrology staff were very happy to become involved in the WRC Project: K5/2259 – Linkages between the hydrodynamic and biological drivers of the Mgobezeleni Catchment that started in April 2013.

The student involvement in the project started even before the WRC Project was initiated with the groundwater exploration, siting and drilling of monitoring boreholes for DWS in the Mgobezeleni Catchment. This also involved the siting, drilling and pump fitting for two community production boreholes in the same area. Our involvement in the WRC Project has improved the quality of our instruction from a student perspective, and secondly contributed to a much-improved professional preparation of candidate hydrologists, in terms of their abilities to transfer knowledge to new contexts, to frame and solve novel problems, and to work collaboratively in new environments. This process was greatly enhanced by the participation and involvement of the principle researchers: Prof Guy Bate, Prof Bruce Kelbe and Dr Ricky Taylor. These researchers took responsibility for the Hydrology Hon. Research projects. Three to five students were allocated to each of the researchers as mentors through the proposal writing and research process. The process was repeated for the three consecutive years of the project.

Our hydrology students needed both the teaching/learning of facts and principles as well as the teaching/learning of skills and procedures. These skills were largely obtained through watching experts (principle WRC researchers) and through the actual doing part with practice and trial and error during fieldwork in Sodwana. Critical to the success of their learning was the active participation in their learning! These fieldtrips to the Project area had both a research focus and a strong basis in discovery learning.

The Table below provides a historic summary of the graduate student developments that took place prior to and over the full extent of the WRC Project. The table provides overview of just how important and successful the project and researcher's involvement with the students had been.

Jean Simonis

24 March 2016

Year	Hon.	MSc	PhD	Post -Doc		Comments
2011	3	1			a)	Exploration & drilling of DWS monitoring boreholes
					b)	MSc project (A Nweze): CHARACTERIZATION OF THE HYDROSTRATIGRAPHIC UNITS OF SODWANA AREA USING THE ELECTRICAL RESISTIVITY METHOD
2012	6				a)	Fitting of community water pumps: Ntshongwe & Manaba.
					b)	Installation of UNIZULU weather station at Sodwana
					c)	Poster and Oral Presentations at the 15th WATERNET & 16th SANCIAHS Hydrology Symposiums
					d)	ARC/ALLWET/Munich Technical University Summer School: Sodwana Presentations
					e)	Enrolment of all Hon. students as interns (Learning Academy) at DWS
2013	7				a)	Involvement of 3 WRC Project researchers as mentors in Hon. Research Projects
					b)	Modelling lecture series presented by Prof B Kelbe
					c)	ALLWET/UNIZULU Research Agreement & Summer School
2014	13	2	1	1	a)	PhD project (M Mkhwanazi): THE HYDROCHEMICAL CHARACTERIZATION OF THE MGOBEZELENI CATCHMENT
					b)	MSc project (G Makwela): SPATIAL AND TEMPORAL DYNAMICS OF THE BEACH BERM THAT CONTROLS THE MGOBEZELENI ESTUARY, SODWANA BAY, RSA
					c)	Post-Doc Project (A Ugbenyen): BIOFLOCCULATION- POTENTIAL OF MICROORGANISM FROM MGOBELEZENI ESTUARY
					d)	MSc project (J Dafel): PRODUCTION OF BIOFLOCCULANT FROM MARINE BACTERIA AND ITS APPLICATION IN THE TREATMENT OF COAL WASH PLANT FINES
					e)	NRF/ARC/ALLWET (Summer School in October 2014)
2015	13		1		a)	PhD Project (T Selepe): MOLECULAR IDENTIFICATION OF PREVIOUSLY ISOLATED PANTOEA SPECIES, ASSESSMENT AND CHARACTERISATION OF ITS BIOFLOCCULANT PRODUCING POTENTIAL IN COMPARISON WITH TRADITIONAL FLOCCULANTS FOR INDUSTRIAL WASTE WATER TREATMENT
					b)	Submission for examination of Dafel's and Nweze's theses
2016					a)	Submission of an abbreviated report to the Mbazwana Tribal Authorities & Sodwana Community presentation (Prof G Bate)
					b)	Successful examination of 2 MSc (Dafel's and Nweze's theses)
TOTAL	42	3	2	1		

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- **Bend**: A position of a LT logger in the Mgobezeleni Estuary about 250 m from the mouth (See figure 25 – Bend LTC)
- **Berm**: The ridge of marine sand that forms at the mouth of the estuary causing it to close
- **Berm LTC**: The position of the LTC logger at the end of the old Berm in the swamp about 500 m upstream of the Mgobezeleni Estuary
- **Bridge**: The bridge over the Mgobezeleni Estuary near the mouth (Also Sodwana Bridge) where an LTC logger was positioned
- **C**: Carbon
- **DEM**: Digital Elevation Model
- **DWS**: The National Department of Water and Sanitation. This includes previous departments of Water and Forestry (DWAF) and Water Affairs (DWA)
- **EDX**: Energy dispersive x-ray
- **Estuary**: Refers to the Mgobezeleni Estuary that flows to the sea at Jesser Point, Maputaland, South Africa
- **Forests**: Naturally occurring area covered chiefly by a variety of trees, woody vegetation and undergrowth. Swamp Forest, dune forests, etc….
- **Geohydrology**: refers to the hydrological features that interact directly with the groundwater system. This includes all the drainage boundaries generally perceived as surface water features
- **GUI**: Graphical User Interface
- **Ha**: Hectare
- **HSU**: Hydrostratigraphic Unit
- **Hydrogeology**: refers to the geological properties and features that have a direct influence on the hydraulic of the groundwater system
- **Lat**: Latitude
- **Long**: Longitude
- **LTC loggers**: Water level, electrical conductivity and temperature loggers
- **m**: metre
- **M**: Mega (10^6)
- **m^{-2}**: Per square metre
- **MAP**: Mean Annual Precipitation
- **mBToC**: metres below Top of Case
- **Mg l^{-1}**: Milligrams per litre
- **ml**: millilitre (1 thousandth of a litre)
- **Ml**: Megalitre
- **Mm^3**: Million cubic metres
- **mRL**: The elevation in metres above a Relative Level. Two known datum are used, WGS84 and Cape that do not give the same elevation values for the coastline in the study area. The Mean Sea Level (MSL) is also unknown in relation to these datum so all elevation values were referred to a common relative datum.

- **NH_4-N**: Nitrogen in the ammonium form
- **NMMU**: Nelson Mandela Metropolitan University
- **NO_3-N**: Nitrogen in the nitrate form
- **NO_2-N**: Nitrogen in the nitrite form
- **Nox-N**: Oxidised nitrogen
- **P**: Used as the abbreviation for phosphate measured.O-P : Ortho-phosphate
- **pH**: Measurement of acidity
- **Pers. Com**.: Personal communication
- **Plantations**: An area, farm or estate comprising a monoculture grown for commercial purposes.
- **Ramsar**: Convention on Wetlands. Named after the city of Ramsar in Iran, where the Convention was signed in 1971.
- **SANS 241**: South African National Standards No 241
- **SEM**: Scanning electron microscopy
- **SRTM**: Shuttle Radar Topography Mission: Elevation data (WGS84)
- **TDS**: Total Dissolved Solids
- **Thalweg**: the thalweg is a line drawn to join the lowest points along the entire length of a stream bed or valley in its downward slope
- **TIN**: Triangular Irregular Network
- **TMS**: Table Mountain Sandstone
- **TSS**: Total suspended solids
- **$\mu g\ l^{-1}$** : Micrograms per litre
- **yr^{-1}** : per year
- **UKZN**: University of KwaZulu-Natal
- **UNIZULU**: University of Zululand
- **WGS84 Datum**

DEFINITIONS: WIKIPEDIA ENCYCLOPEDIA

- A **piezometer** is either a device used to measure liquid pressure in a system by measuring the height to which a column of the liquid rises against gravity, or a device which measures the pressure (more precisely, the piezometric head) of groundwater [1] at a specific point. A piezometer is designed to measure static pressures, and thus differs from a pitot tube by not being pointed into the fluid flow.
- A **borehole** is a narrow shaft bored in the ground, either vertically or horizontally that is constructed for many different purposes, including the extraction of water, other liquids (such as petroleum) or gases (such as natural gas), as part of a geotechnical investigation, environmental site assessment, exploration, temperature measurement, as a pilot hole for installing piers or underground utilities, for geothermal installations, or for underground storage of unwanted substances.

PLACE NAMES

Jesser Point	-27.539	32.681
Lake Mgobezeleni	-27.531	32.659
Lake Shazibe	-27.507	32.664
Lake Sibaya	-27.355	32.687
Mbazwana	-27.480	32.583
Mgobezeleni (Mngobezeleni) Estuary	-27.541	32.678
Qondwane	-27.	32.
Sangweni Pan	-27. 585	32. 629
Sodwana Bay	-27.534	32.679
Thungwini	-27.482	32.649
Tolla se Gat (Tolla's Crossing)	-27.485	32.658

CHAPTER 1. INTRODUCTION

The Zululand Coastal plain is a region where there are strong linkages between the terrestrial, the aquatic, the ecological and the marine environments. Nearly the entire coastal margin from the Mfolozi Estuary to the Mozambique border is a proclaimed nature reserve due to its national and international importance. All the estuaries in this region are amongst the most important breading grounds for the marine ecology in southern Africa (Turpie et al*.,* 2002). The form and function of these estuaries are very diverse and range from the very large St Lucia system to the much small Mgobezeleni estuary. While considerable research was conducted on the St Lucia system (Perissinotto et al., 2013) its sheer size inhibits detailed investigation of the driving forces that link the different water resources to the terrestrial, ecology and marine environment. The Mgobezeleni estuary drains a small surface water catchment that is strongly dependent on the groundwater system. Within this catchment are lakes and wetlands that feed the estuary creating a direct linkage between the groundwater and the marine environments. The size of the Mgobezeleni system is ideal for a concerted investigation of the driving forces and limiting factors that link the terrestrial, aquatic, ecological and marine environments in a single research project/program.

A large proportion of the Mgobezeleni groundwater catchment lies within the proclaimed nature reserve. In 2011, the Mgobezeleni Catchment area was the focus of a considerable amount of development because of 99-year land-lease agreements organised by the local chief. These agreements are being taken up at financial rates that are below current market rates and "holiday homes" are being constructed at a rapid rate. In addition to residential buildings, there is also an assortment of small enterprise businesses arising, such as hotels, resorts, mechanical workshops, stores and associated infrastructure.

The soils in the area are largely of dune sand origin and highly permeable to water. Pollutants such as oils, petrol and diesel as well as the plethora of household chemicals that are routinely discharged into sewage systems or directly onto the soil are likely finding their way into the groundwater system. In addition, localised agriculture is being undertaken in the form of home gardens, small-scale agriculture and orchards. There is also commercial forestry in the area. Because the topography is relatively flat, there are a number of vlei areas, many of which have well developed peat. Peat is good for water retention but if the water table drops for a few years, it can decompose and loose its water retention capacity.

There are two main lakes in the area, namely Lake Mgobezeleni and Lake Shazibe that supply water to the Sodwana tourism facilities. These lakes are situated very close to a relatively densely populated area that is expanding rapidly. Both these lakes are relatively low lying (<5 mMSL) and with the possibility of future sea level rise and the incidence of increased storms, cyclones and droughts, information is urgently needed on the stability of the water supplies and the capacity of the aquifer to supply the future development that is likely to increase rapidly in the near future. In addition to the matter of estimating the supply of bulk water, there is a need to measure any changing water quality in the area in the light of the increasing discharge of septic tank effluent into the groundwater.

The mouth of the Mgobezeleni Estuary used to support mangroves that were very old and tall but which have died because of some unknown ecological disturbance. The flow channel from the lakes to the estuary is an area of important wetland forest vegetation. In the light of the recent loss of mangroves, it is important to assess the stability of all the wetland vegetation in order to propose management scenarios. To do this the proposal was to undertake an assessment of the groundwater, lake water and estuary water with the aid of a computer model that will enable to enhance current knowledge of the hydroecology of the system, examine scenarios of future under conditions of increased development, water quality, climate change and seawater rise.

1.1 AIM

The Overarching aim: To investigate the hydrology and hydrology-dependent ecology of the Mgobezeleni catchment, its wetlands and its estuary. To achieve this aim, the following objectives were considered.

1.2 OBJECTIVES

Objective 1: To create conceptual and numeric models of the surface and groundwater dynamics of the Mgobezeleni catchment and estuary to establish the detailed hydrodynamic behaviour of the catchment.

Objective 2: To create a conceptual model of the hydrochemical dynamics of the system and its export of nutrients to the marine environment to understand the salt and water dynamics of the estuary and how these can be controlled by management (e.g. the estuary breaching policy).

Objective 3: To develop a conceptual model linking the hydrology and ecology through the identification of the drivers of the different wetland types. This will allow us to establish the sensitivity of these wetlands to human induced impacts on water quality, geohydrology, and estuary management regime.

Objective 4: To identify and quantify human-induced inputs especially those that lower the water table or alter nutrient levels – that will enable an understanding of the impact of increasing urbanisation in the catchment on the physical environment and its goods and services.

Objective 5: To train young scientists in the study of integrated hydro-biological systems.

CHAPTER 2. STUDY AREA

The Maputaland Coastal Plain has highly permeable soils and low-lying terrain with many wetlands that are dominated by the groundwater dynamics (Kelbe et al., 2016). In these environments, the bulk of the rainfall impinging on the topographical surface will follow a preferential subterranean pathway through the groundwater system rather than the conventional hillslope pathways ((Beven, 2001) to the surface water resources (wetlands, rivers, lakes and the Ocean). The groundwater dynamics are considered the main hydrological drivers of the system in this study.

Groundwater can flow over great distances in different aquifers that can transcend topographical divides (hillslope catchment). Consequently, it is necessary to incorporate all the hydrological features that contribute to the flow dynamics of the groundwater system. This study involves the establishment of the hydrological drivers that affect the ecology of the Mgobezeleni system that comprises a network of streams, lakes, wetlands and the estuary. However, the hydrological system driving the ecological functions of the system involves processes that extend well beyond the margins of the ecological system. Consequently the study area (the groundwater catchment) for the hydrological system is significantly larger than the ecological regime in this study.

2.1 LOCATION

The domain for the hydrological study area is dependent on the spatial scale of the controlling processes that affect the main hydrological features. The groundwater dynamics relies on the hydraulic gradient rather than the topographical gradient to transport the water and solutes to lower discharge boundaries such as the rivers, lakes, wetlands and ocean that are primary features of interest in this study. Consequently, the hydrological catchment (groundwater recharge zone) is defined more by the groundwater divides (water table ridges) than the surface topography. Hence, it is necessary to consider a much larger study area than the conventional surface catchment in these environments for the hydrological study.

The groundwater divides formed by the water table ridges are dynamic features that can move under prevailing geohydrological conditions caused by floods, drought and anthropogenic impacts. The groundwater ridge will be created by the groundwater recharge, hydraulic properties of the aquifers and the hydraulic characteristics of the drainage boundaries. The hydraulic properties of the geological formations are considered stationary but the discharge through drainage boundaries can vary with the rise and fall of the water table. Consequently, it is important in groundwater studies to incorporate all the external boundaries that can influence the water table profile forming the water table divide of the study area. The main areas of concern in this project are the internal boundaries comprising the Mgobezeleni lakes and feeder streams that ultimately drain into the estuary and Ocean. The external boundaries extended from the Indian Ocean shoreline in the east to the Mbazwana River in the west and from Lake Sibaya in the north to the Mkuze swamplands in the south (Figure 1). The section between the Mbazwana River and the feeder stream to Lake Sibaya is considered to be a distant no flow boundary.

Since the groundwater divide is a dynamic feature that requires considerable resources to determine from field measurements, it is more pragmatic and cost effective to derive it from a calibrated and validated transient numerical model that is described in subsequent chapters.

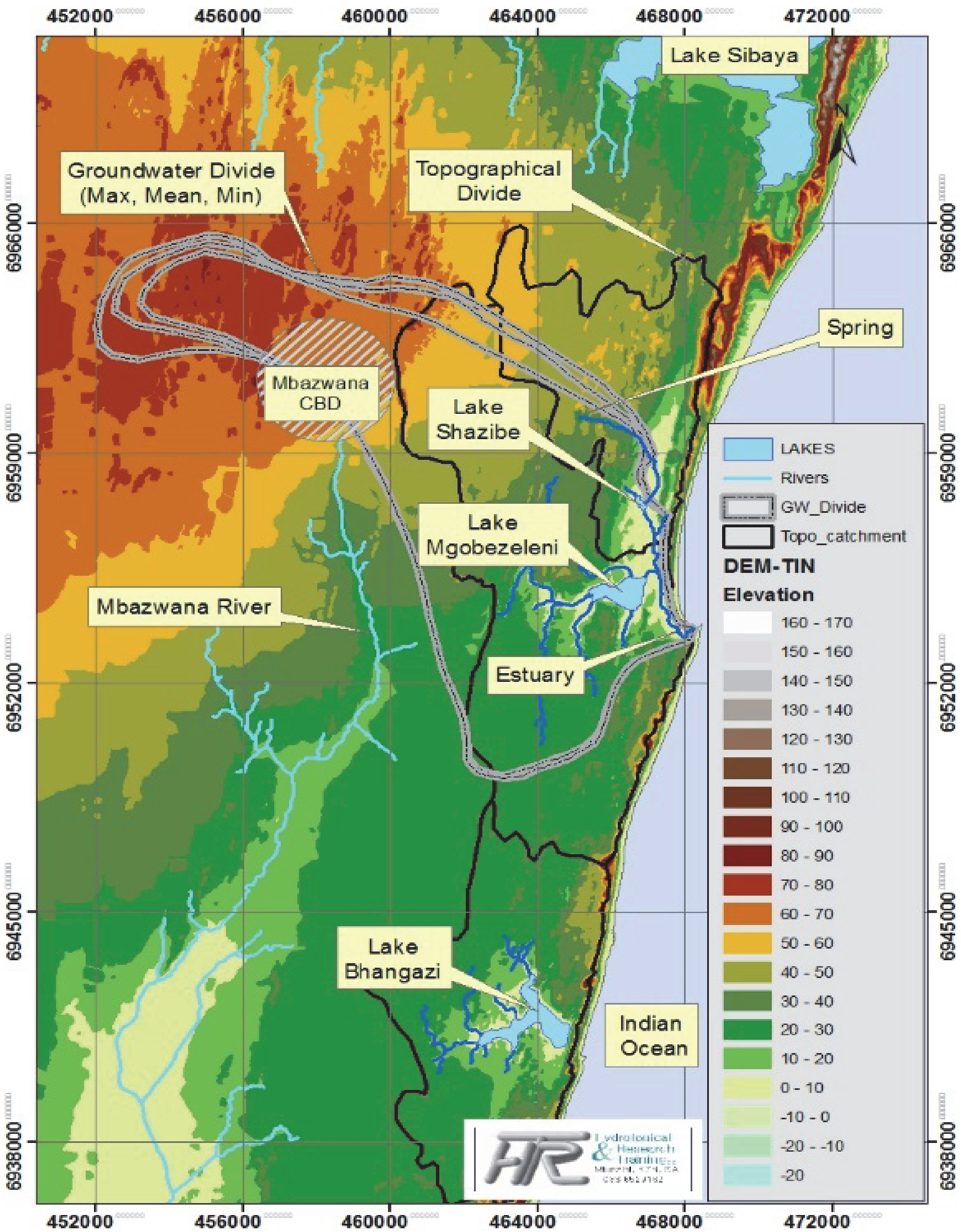


Figure 1. The main topographical drainage features (rivers, lakes and Ocean) forming the domain of the hydrological study area. The groundwater catchment (grey polygons) and the topographical catchment (black polygons) are shown for the Mgobezeleni outlet.

The groundwater recharge catchment for the Mgobezeleni estuary created by the groundwater ridge (divide) under various geohydrological (wet and dry) and current land use conditions are shown in Figure 1 (described in subsequent chapters) for a direct comparison with the topographical (hillslope) catchment created by the surface ridges that is also shown in Figure 1. The delineation of the groundwater catchment involves the establishment of a suite of conceptual models of the hydrogeology and geohydrology that form the basis of the numerical models. The development of these models and their subsequent calibration and validation requires considerable fieldwork and hydrological monitoring covering the extended study area shown in Figure 1. This section covers, the data collection, monitoring and conceptual modelling of the various water resources of the hydrological study area.

2.2 CLIMATE AND WEATHER

The study area lies on the east coast of South Africa in the sub-tropics where the weather is controlled by the Indian Ocean anticyclonic circulation and migrating low-pressure systems (Kelbe, 1982; Garstang et al., 1987). In winter, the rainfall is mainly derived from forced convection associated with the cold fronts migrating up the east coast under the influence of the mid-Atlantic cyclonic activity in the southern oceans (Kelbe, 1988). In summer, the upper atmosphere becomes more unstable with the prevailing jet stream that often leads to the formation and propagation of large free convective storm that occasional produce hail. These large storms may also be triggered by the cold fronts emanating from the mid-latitudes and propagating across southern Africa in both summer and winter. Consequently, the weather patterns have a strong annual cycle with generally more rainfall in summer (Oct-Mar) than the winter months (Apr-Sep). The daily rainfall distribution for Sodwana Bay from 1998 to 2014 is shown in Figure 2.

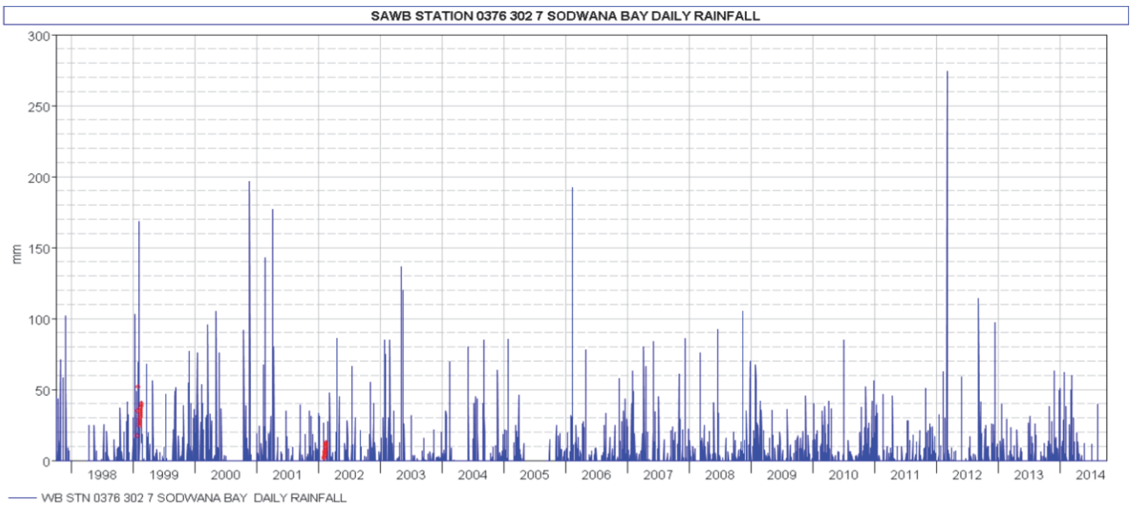


Figure 2. The daily rainfall for SAWB Station 0376 3027 at Sodwana Bay. The red symbols indicate missing values.

The cumulative rainfall series from Sodwana and Mbazwana show a difference of about 255 mm year^{-1} for the period from 2000 to 2015 (Figure 3). The 15-year mean for Sodwana is 1066 mm and for Mbazwana is 811 mm. This rainfall gradient between the coast and hinterland is similar to the Maputaland region (Kelbe et al., 2016).

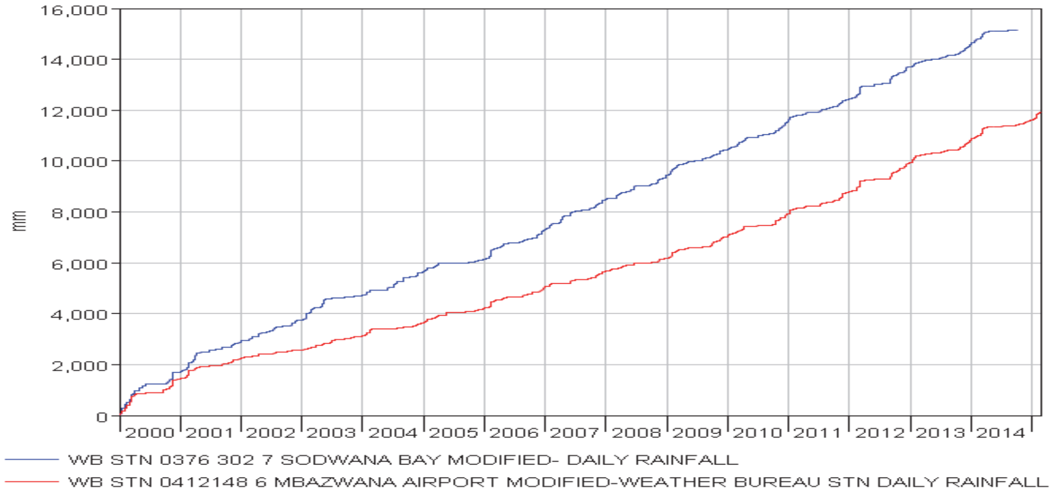
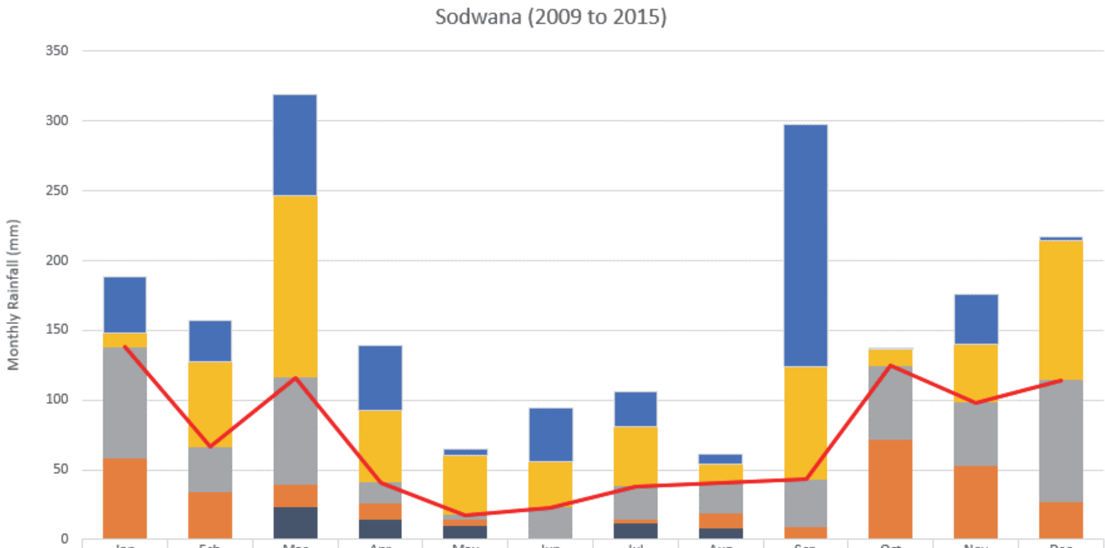


Figure 3. The cumulative daily rainfall series for Mbazwana (inland station) and Sodwana (coastal station) from 2000.

Although the monthly rainfall is highly variable, the rainfall shows an annual cycle with approximately 2-3 times more rainfall in the summer months compared to the winter months (Figure 4). However, the rainfall distribution shows large peaks in March and September when cyclonic weather system can produce extreme rainfall events. The rainfall series shown in Figure 2 does not capture the very large cyclonic event in 1984 when Cyclones Domoina and Imboa stuck within days of each other producing



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	40.3	29.3	72.525	46.35	4.5	38.625	25.575	7.125	173.4	0.825	36.375	2.1
Q3	10	61.2	131.025	51.7	42.7	32.625	42.375	13.125	81.05	12.225	41.275	100.45
Med	79.5	32.5	76.825	15.125	3.675	22.125	24.125	21.75	34.1	52.825	45.85	87.175
Q1	58.5	34	16.125	11.625	4.125	1.125	2.625	10.5	9.15	71.625	52.5	27.075
Min	0	0	23	14	10	0	11.5	8.5	0	0	0	0
Med	138	66.5	115.95	40.75	17.8	23.25	38.25	40.75	43.25	124.45	98.35	114.25

Figure 4. The box plot of monthly rainfall variability for Sodwana.

rainfall of over 500 mm in several days (Kovac et al., 1985). A deep upper-level cut-off low-pressure system also produce torrential rainfall in September 1987 although this system struck further south (van Bladeren and Burger, 1989).

The University of Zululand established an automatic weather station in 2009 at Sodwana that recorded hourly values of rainfall, screen temperature and humidity, wind speed & direction, solar radiation and soil moisture. These measurements were used to calculate the potential evaporation rate using the Penman model.

The hourly temperature fluctuation in the radiation shield at 2 m height from October 2012, to 2015 for the Sodwana Bay Lodge automatic weather station are shown in Figure 5 illustrating the seasonal trends. The Mean daily temperature is 21°C with a daily range in temperature of approximately 15°C, a minimum of 5°C and a maximum of 36°C.

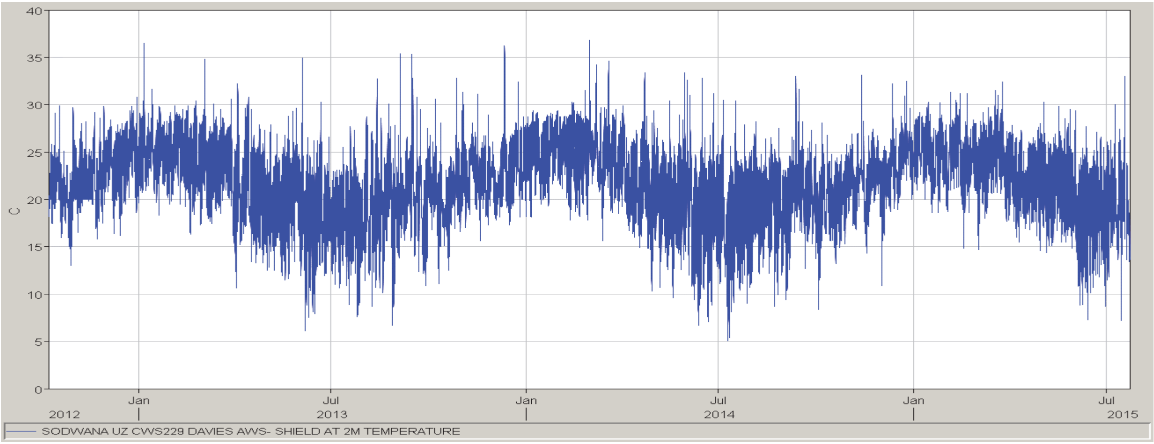


Figure 5. The mean hourly temperature (°C) measurements for the Automatic Weather Station at Sodwana Bay Lodge from October 2012 to July 2015.

The hourly measurements of relative humidity in the radiation shield at 2 m height from October 2012 to July 2015 for the Sodwana Bay Lodge Automatic weather station are shown in Figure 6. The average hourly humidity is 82% with a daily range of about 24% (SD=12%). The very high humidity at night often creates near saturated conditions to provide plant available water, particularly in the low lying swamp areas.

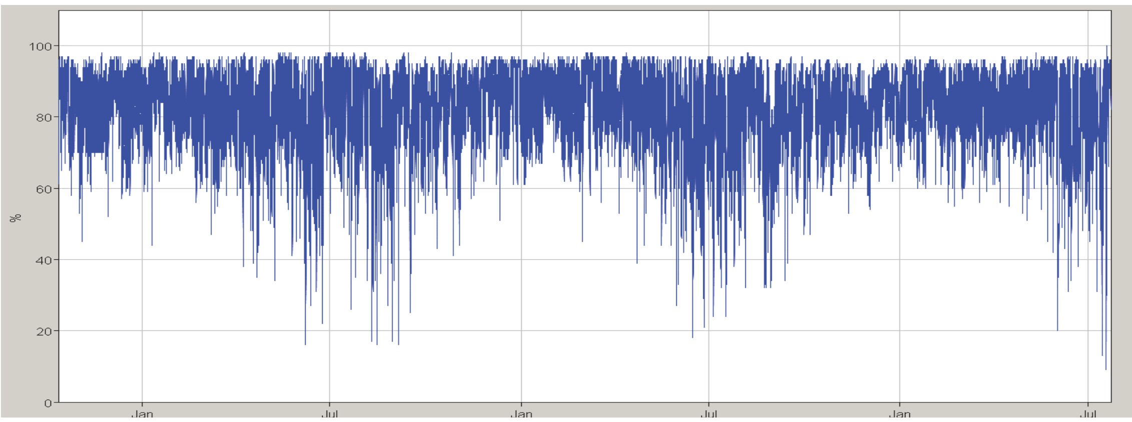


Figure 6. The mean hourly relative humidity measurements from the automatic weather station at Sodwana Bay Lodge from October 2012 to July 2015.

The hourly solar radiation measurements (Figure 7) together with the corresponding hourly temperature, relative humidity (dew point temperature) and wind speed were used to calculate the hourly potential (Penman) evaporation rate for the Sodwana site (Figure 8).

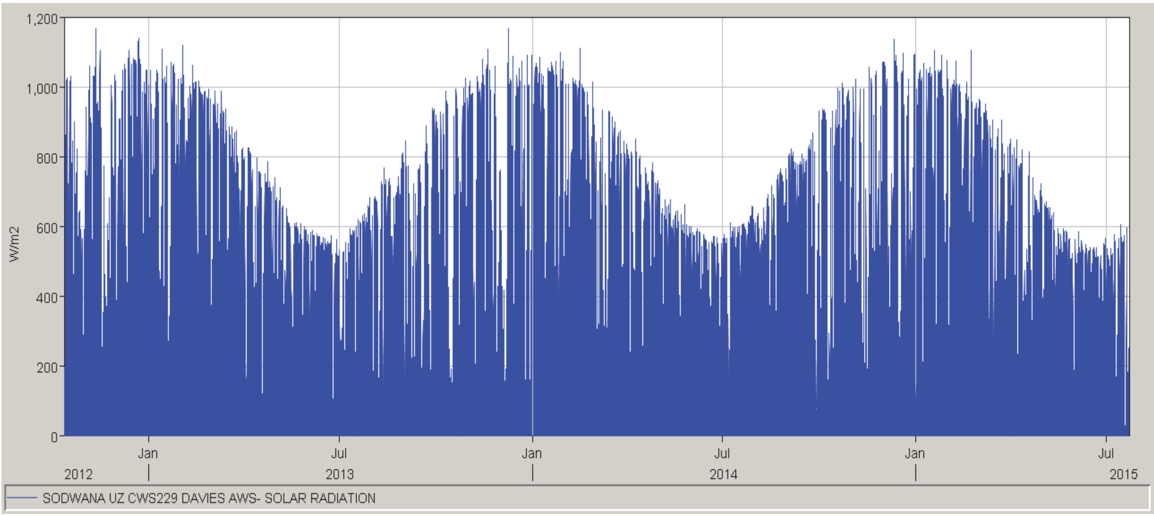


Figure 7. The measured solar radiation (W m^{-2}) for the Automatic Weather Station at Sodwana Bay Lodge from October 2012 to July 2015.

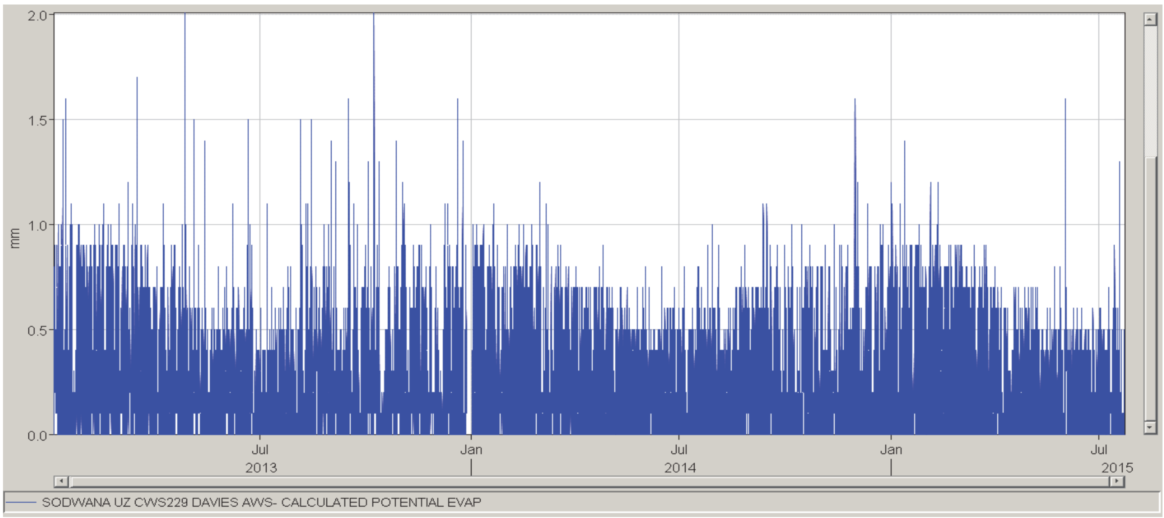


Figure 8. The calculated potential evaporation rate (mm hr^{-1}) from the solar radiation, temperature, humidity and wind speed measurements at the automatic weather station at Sodwana Bay Lodge from October 2012 to July 2015.

The average monthly wind speed and wind direction derived from the accumulated and averaged values over hourly intervals are shown in Figures 9 and 10 for the period from 2012 to 2015. The average monthly wind speed varies from 0.6 m s^{-1} to 2 m s^{-1} over the three years of measurements although the hourly values reached velocities of over 7 m s^{-1} with a mean of 1.4 m s^{-1} and a standard deviation of 1.4 m s^{-1}. However, the frequency distribution of wind speed for three years of monitoring (Figure 10) indicates that most days had average wind speeds of less than 1 m s^{-1}.

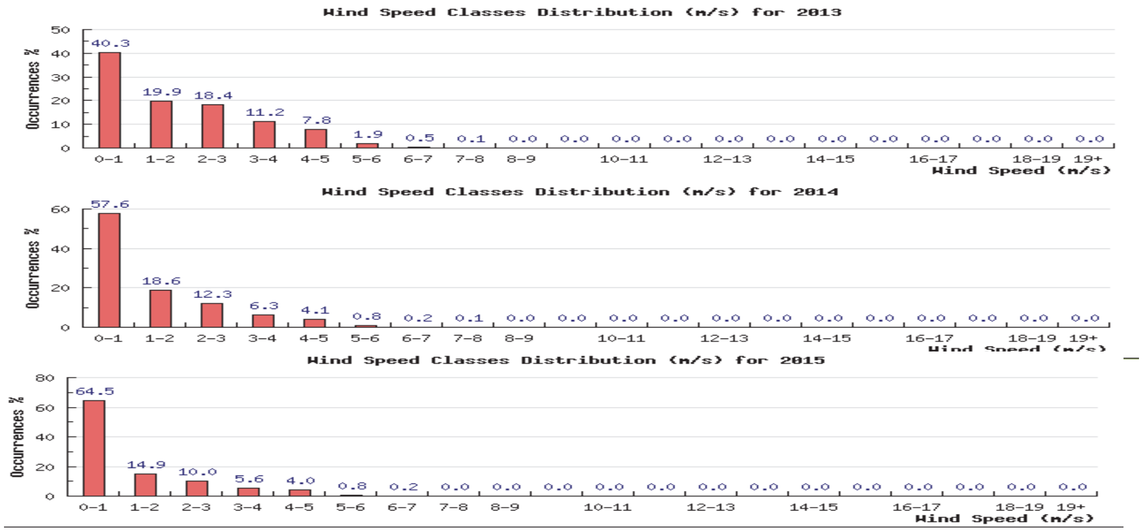


Figure 9. The Wind speed Class distribution for 2013 to 2015 for Sodwana Bay Lodge.

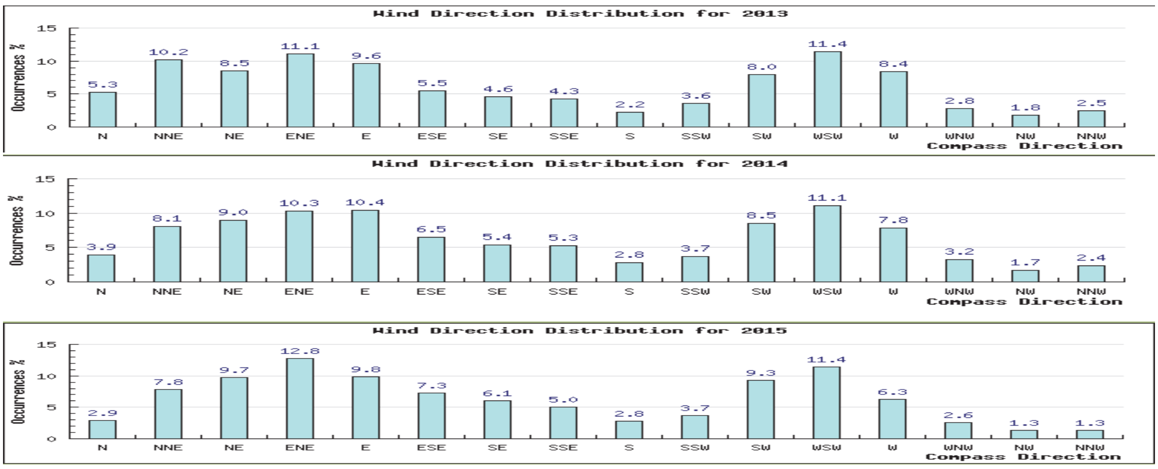


Figure 10. The average monthly wind direction distribution from 2013 to 2015 at Sodwana Bay Lodge.

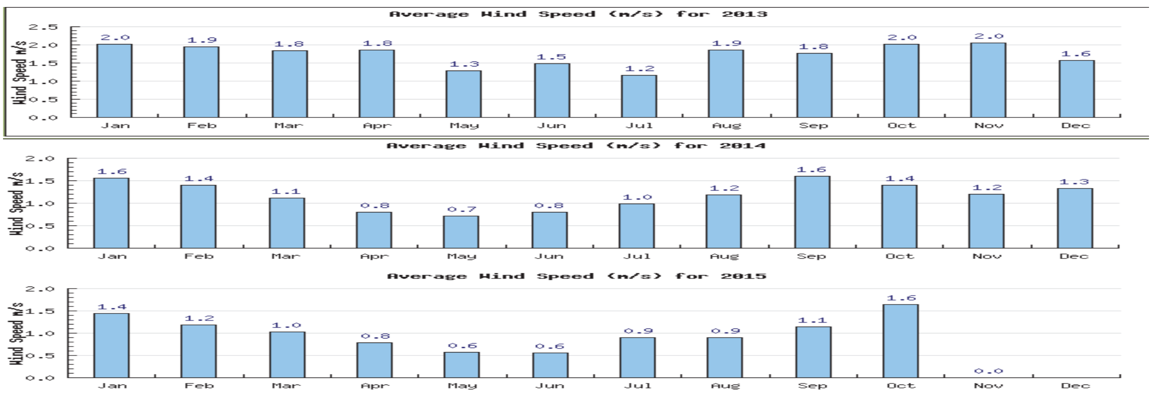


Figure 11. The average monthly wind speed at Sodwana Bay Lodge.

The prevailing (average hourly) wind direction was generally NNE to E (39%) or SW to W (27%) over the three seasons as shown in Figure 10. The wind regime plays a crucial role in the sediment dynamics of the mouth as discussed later in the report.

2.3 GEOLOGY

The study area forms part of the Maputaland Coastal Plain that is characterised by a sequence of sediments overlying consolidated rocks of Jurassic basalts and rhyolitic rocks that generally slope to the east at an angle of about 3 degrees (Botha, 2015; Botha et al., 2013). During the Cretaceous Period much of the area was below sea level during periods of transgression (Figure 12), creating a hydrogeological unit of claystone and siltstone with very low hydraulic conductivity and storativity. This stratigraphic unit (Zululand Group) behaves as an aquiclude with residual brackish water, and forms the base of the regional aquifer for this study. Overlying the Zululand Group are unconsolidated to partially consolidated sedimentary deposits formed by a succession of marine, alluvial and aeolian processes (Worthington 1978; Meyer and Godfrey 1995; Kelbe et al., 2013; Botha et al., 2013) with varying combinations of sand, silt and clay (Figure 13). The strata have sufficiently different hydraulic properties to form several hydrogeological units that create both unconfined and partially confined (leaky type) aquifers in some location that may occur in the study area. A schematic of the proposed hydrostratigraphic sequence for the Maputaland Coastal region was adapted from Kelbe et al. (2016) as shown in Figure 12.

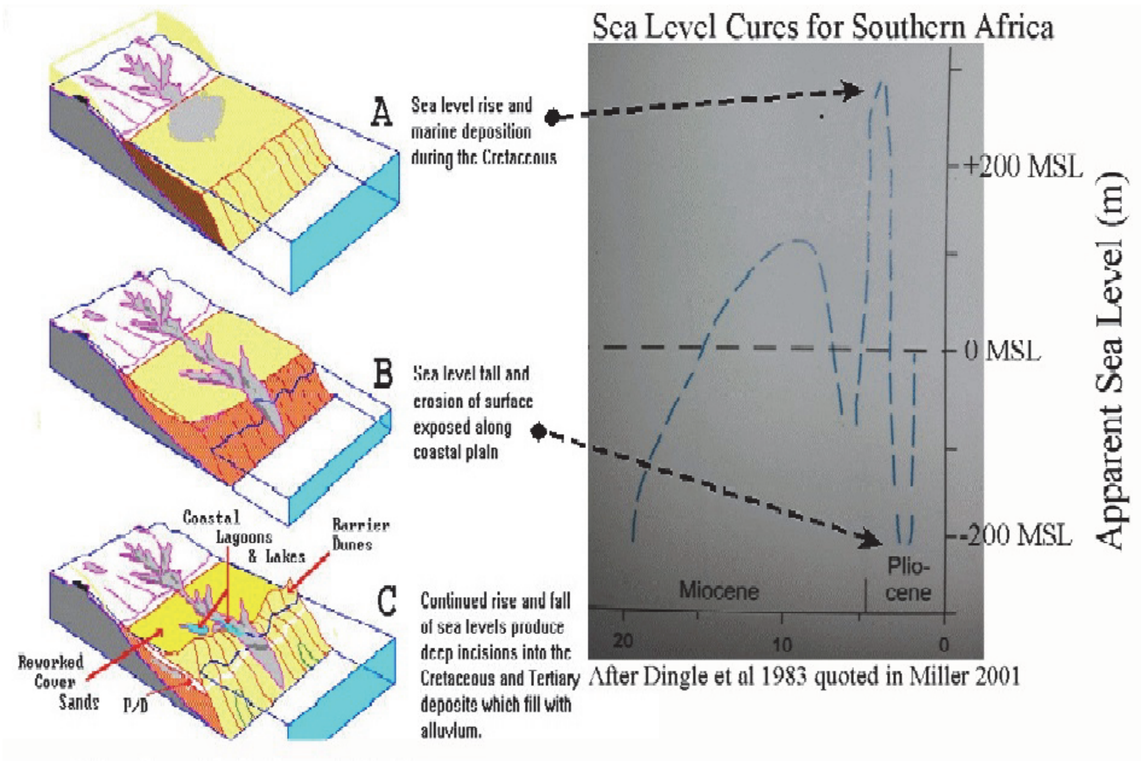


Figure 12. A schematic diagram of the deposition and erosion along the Maputaland Coastal plain (left) during marine regression and transgression (right).

2.3.1 Miocene-Pliocene Unit (Layer 3)

The lowest part of this primary porosity aquifer (*Mio-Pliocene* sediments) consists of karst-weathered calcarenites with intercalated mudstone beds (Maud and Botha 2000) often referred to as the Uloa Formation (Figure 13). This hydrostratigraphic unit (HSU) (stratigraphic layer with assumed uniform hydraulic properties) is generally overlain by sedimentary units with finer grained, less permeable sediments creating a leaky type aquifer (Todd 1980).

Along sections of the Maputaland costal margin, this overlying unit comprises an extensive layer of *Middle to Late Pleistocene* marine, estuarine clay, silt and sand comprising the Port Durnford Formations. These sediments generally have lower hydraulic conductivities and storativities than the underlying Uloa Formation, forming a partially confined leaky aquifer that is hydraulically connected to the Indian Ocean in places (Kelbe and Germishuyse 2010). However, recent drilling (Scharpers, 2012, Appendix II) indicate the absence of the Port Durnford in the study area and further north (Kelbe et al., 2015).

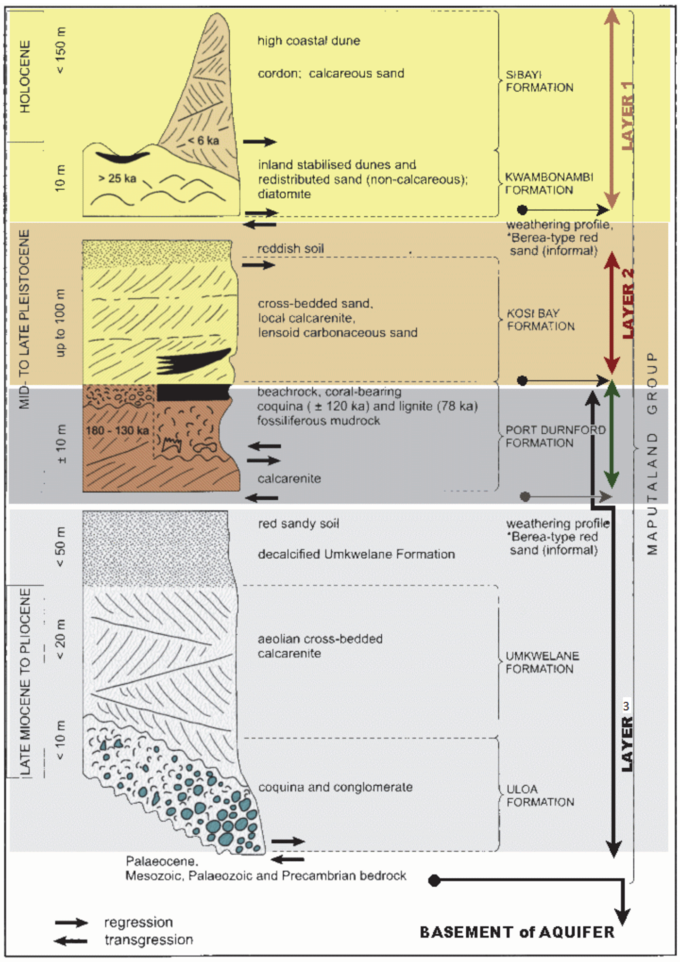


Figure 13. A vertical schematic of the Maputaland Group and adapted from Botha (as referenced in Miller, 2001) for the basis of the conceptual hydrogeological model for the study area.

2.3.2 Pleistocene Unit (Layer 2)

Overlying the extensive *Middle to Late Pleistocene* sediments are younger porous and more permeable sandy formations of *Late Pleistocene* to *Holocene* age. These layers form the Kosi Bay Formation that covers an extensive area from the coast to the western interior. Separating the Kosi and older formations are interspaced bands of lignite and red sands.

2.3.3 Holocene Unit (Layer 1)

The uppermost, youngest *Holocene* sediments (Sibaya Formation) and the reworked sands of the Kwambonambi Formation covering a large section of the study area have relatively high hydraulic conductivity and drain rapidly (DLP 1992). The Sibaya generally occurs in the high frontal dunes above the phreatic zone (DLP 1992) and plays little role in groundwater movement.

In an attempt to identify the stratigraphy of the region and provide long term monitoring of water levels in the different aquifers, eight deep boreholes were installed in the study area by Jeffares and Green (Scharpers, pers comm) for the Department of Water Sanitation (DWS). The drillings from these boreholes were logged and captured by Jeffares & Green (Scharpers. Unfortunately, most of these boreholes were not drilled sufficiently deep to intersect the basement formed by the upper surface of the Cretaceous mudstone. However, Nweze (2015) has conducted a geophysical survey of the central study area using electrical resistivity to identify stratigraphic horizons at the boreholes and then extrapolate these along east-west and north-south transects.

2.3.4 Aquifer Basement boundary

The base of the primary aquifer is considered the top of the St Lucia Formation (Cretaceous). This facies has not been mapped for the region so it was necessary to use available information to derive the surface contours. The basement elevation was presented by Miller (2001) for Lake Sibaya in the northern section of the study area. Additional elevation contours of the Cretaceous were taken from the Geological Survey maps for the section along the foothills of the Lebombo Mountains where it is exposed. Unfortunately the monitoring boreholes do not appear to have intersected the basement but Nweze (2015) has derived transects of the basement for the central study area using geophysics.

A DEM of the basement elevation profile was derived from these data and is presented in Figure 14. There is a deep paleochannel underlying Lake Sibaya that descends to over 130 m below sea level and another channel under Lake Mgobezeleni / Shazibe that is deeper than 50 m below sea level.

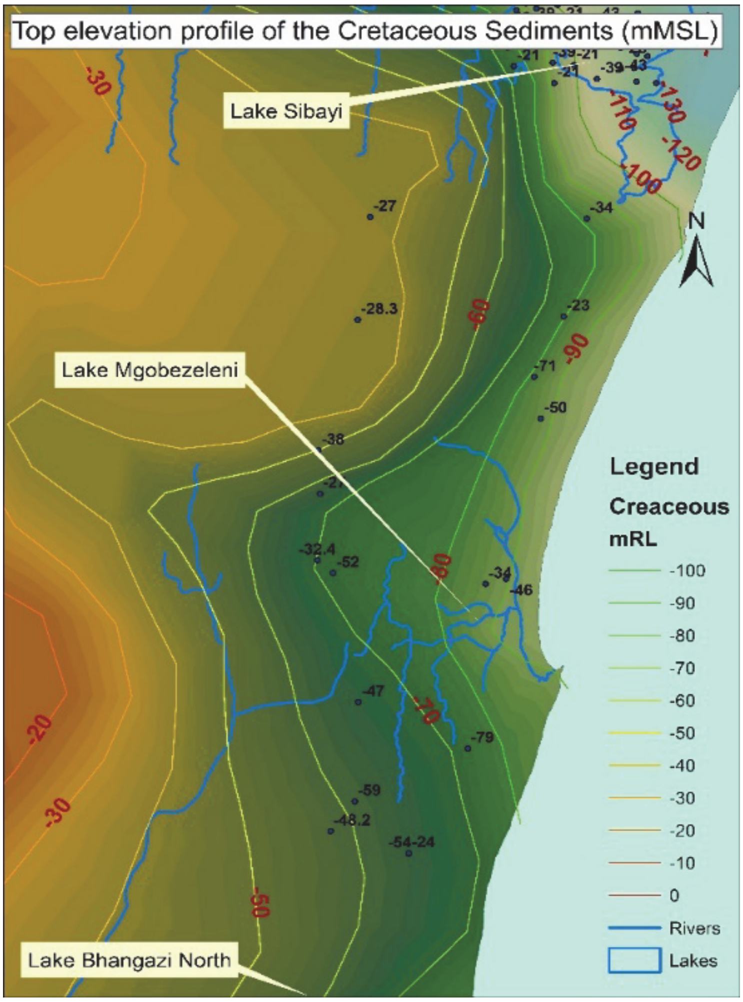


Figure 14. The inferred base of the primary aquifer formed by the top of the Cretaceous bed rock.

2.3.5 HSU Boundaries

The spatial and vertical extent of the primary aquifers formed by the three main Hydrostratigraphic Units was derived from the geophysical survey by Nweze (2015) who identified three principle facies: the Kwambonambi/ Kosi Bay interface; the Kosi-Bay/Uloa interface and the Uloa/St Lucia interface. The basement rock was reported to slope at 3-5^{o} from west to east. The elevation profile of the bottom of the Kosi Bay and Kwambonambi Formations were extrapolated at 4^{o} to cover the entire study area. It was necessary to adjust the vertical profiles of these facies where they exceeded the height of the surface topography described below, particularly along the incised alluvial valleys. The stratigraphic profile was reduced to a minimum thickness of 5 m below the topographical surface using the Groundwater Vistas numerical model GUI interface to create the spatial dimensions of the three main aquifers described in the model development in Chapter 4.

2.4 GEOMORPHOLOGY

In this groundwater-dominated system, the hydrology is controlled more by the hydraulic gradient than by the topographic gradient (hillslope). Consequently, it is only necessary to define the elevation of the drainage boundaries that will largely determine the hydraulic gradient (groundwater profile) and the discharge into the surface water resources. However, it is also necessary in this study to simulate the evapotranspiration from deep-rooted vegetation. This will require a reliable estimate of the topographical profile that will determine the rooting depth of vegetation and the subsequent water lost to evapotranspiration.

The elevation profile of the greater study area was created from 5 m contours provided by the Dept. of Survey and Mapping. The SRTM data set was also considered in estimating the vertical elevation of specific features for the model development and calibration. The SRTM data are reported to have an Absolute Height Error of 5.6 m for Africa (Farr et al., 2007). While the estimated vertical resolution of the SRTM data is better than 6 m in general, the surface features that are measured do not always coincide with the ground surface. For areas with extensive vegetation cover, the radar return is a function of the vegetation height, structure and density (Carabajal and Harding, 2006). Hence, the SRTM data is likely to be in error for the areas with dense, tall vegetation that occur along many of the prominent drainage lines and particularly the estuary. The SRTM data is also based on the WGS84 datum that is not the same as the survey data and needed to be transformed for this study. Consequently, the SRTM data was not used except for the extraction of exposed water surface targets used in the model calibration as described in a subsequent chapter.

The 5 m contours were not adequate to define the profile of the valley bottom from the lake outlets to the estuary mouth. Consequently, 1 m contours of this estuary section were estimated from the outline of the river channel and visual inspection of the flood plain as elaborated further in subsequent text.

The Triangular Irregular Network (TIN) generated from the 5 m contour and supplements with the bathymetric survey for Lake Mgobezeleni and the assumed depth contours for Lake Shazibe is shown in Figure 1.

2.5 SURFACE WATER RESOURCES

The surface water resources covering the main hydro-ecological study area include several coastal lakes, perennial streams and rivers, the estuary at Sodwana and a groundwater spring (Figure 15). The main focus of the study are restricted to the catchment areas feeding into the Mgobezeleni and Shazibe lake systems and the estuary. The Mbazwana River forms a tributary of the Mkuze River that drains into Lake St Lucia and forms an external boundary for the groundwater model. Lake Bhangazi North has not been included in the study but also formed one of the external drainage boundaries.

Various monitoring sites were established to assist in the quantification and interpretation of the hydrology for the study area and to support the development, calibration and verification of a water balance model. The main hydrological monitoring sites are described in the various sections below.

2.5.1 Drainage Network

The streams in the study area are generally aligned along a north-south orientation, parallel to the inter-dune depressions. The streams feeding into the lakes generally have a very different profile when compared to the streams draining from the lakes though a very low gradient swamp. With one notable exception (the groundwater spring), the headwaters of the lake feeder streams have fluctuating flows associated with the changing water table profile. These upper reaches will have flow during wet periods and may have no flow during extended periods of dry conditions while the lower reaches will be perennial.

The main tributary feeding Lake Shazibe is fed from a headwater spring (Photograph 1) and is likely to flow continuously throughout the year, even under extended dry period such as 2014. The flow in this stream at the Tolla se Gat road crossing (Photograph 2) appears to flow at all times and was measured on several occasions.

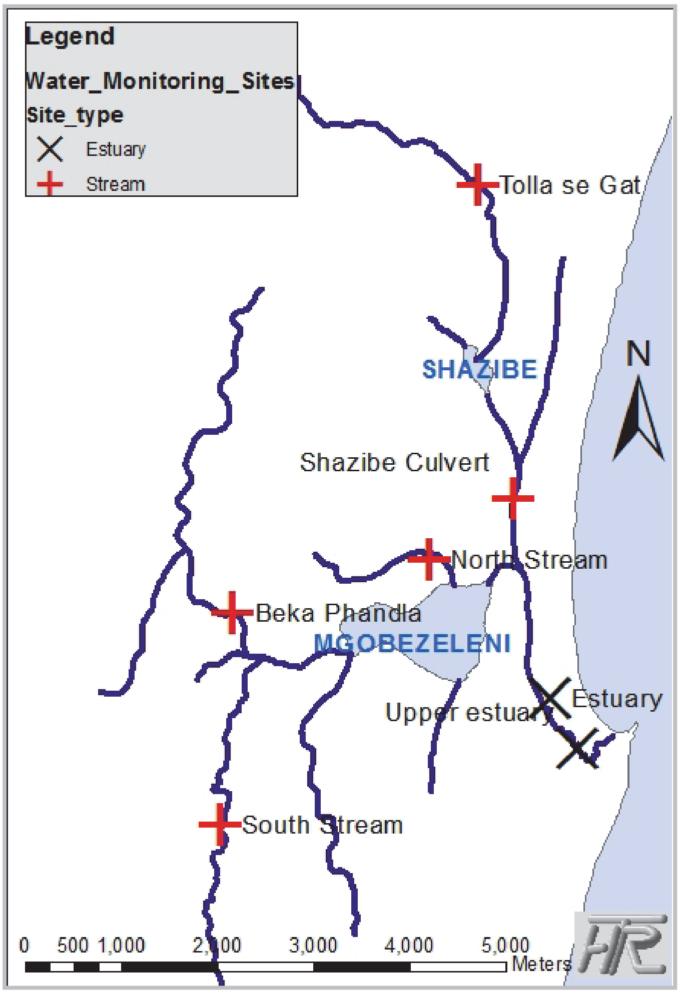
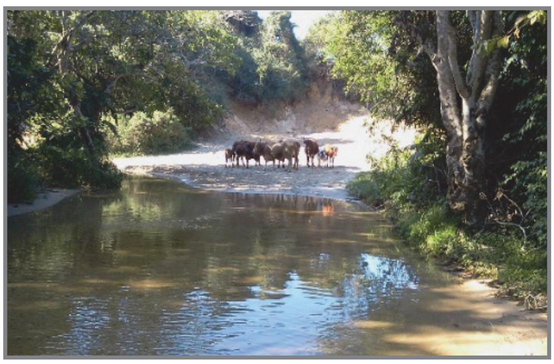


Figure 15. The stream network and the flow monitoring sites (red cross).

Photograph 1. Spring at the head water of the stream flowing into Lake Shazibe



Photograph 2. The road crossing at Tolla se Gat monitoring side on the stream feeding into Lake Shazibe.

The stream draining Lake Shazibe does not appear to have a well-defined channel but flows through a wide swamp (Photograph 3) until it crosses the Sodwana road culverts (Photograph 4) where it appears to flow in a more regular channel with a sandy bed overlying thick peat. The only suitable site for flow monitoring was identified at the road culvert.

The channel downstream of the confluence of the lake outflows is well defined with a depth of approximately 1 m and a width that is approximately 5 m although it is covered by tree branches that will impede flow (Photograph 5). No suitable flow-gauging site was identified between Lake Mgobezeleni and the mouth. Several of the feeder streams into Lake Mgobezeleni were channelised (Photograph 6) and were used for flow monitoring.

Discharge measurements were also conducted on the south stream (Photograph 7) and the north-canalised stream section (Photograph 8) feeding into Lake Mgobezeleni.

Photograph 3. Photographs of the stream channel below Lake Shazibe

Photograph 4. The stream channel draining Lake Shazibe just downstream of the road culvert

Photograph 5. The main channel below the confluence of the lake outflow streams about 3 km upstream of the mouth.

Photograph 6. The canalised stream channel feeding into Lake Mgobezeleni at the Bheka Pandla monitoring site.

Photograph 7. The channel used for streamflow monitoring on the south stream.

Photograph 8. The canalised northern stream section draining into Lake Mgobezeleni used for flow monitoring

2.5.2 Lake Mgobezeleni

Lake Mgobezeleni is a freshwater lake that is fed by groundwater-dominated streams of a perennial nature that are underlain by deep peat deposits with very little sediment production. The lake drains into a very low gradient stream channel (see Photograph 5) that forms part of the Mgobezeleni Estuary. The lake also receives and discharges groundwater along much of its shoreline, acting as a "flow through" drainage boundary for the primary aquifer.

The bathymetry of the lake was surveyed by Prof Simonis (*pers com*) in 2014 at the points shown in Figure 16. The survey points were corrected to the lake level elevation (DWS monitoring site), extrapolated to the lake shoreline using Kriging (Figure 17A), and incorporated into the DEM. The DEM was then used to derive a relationship for the volume-depth and area – depth shown in Figure 17B.

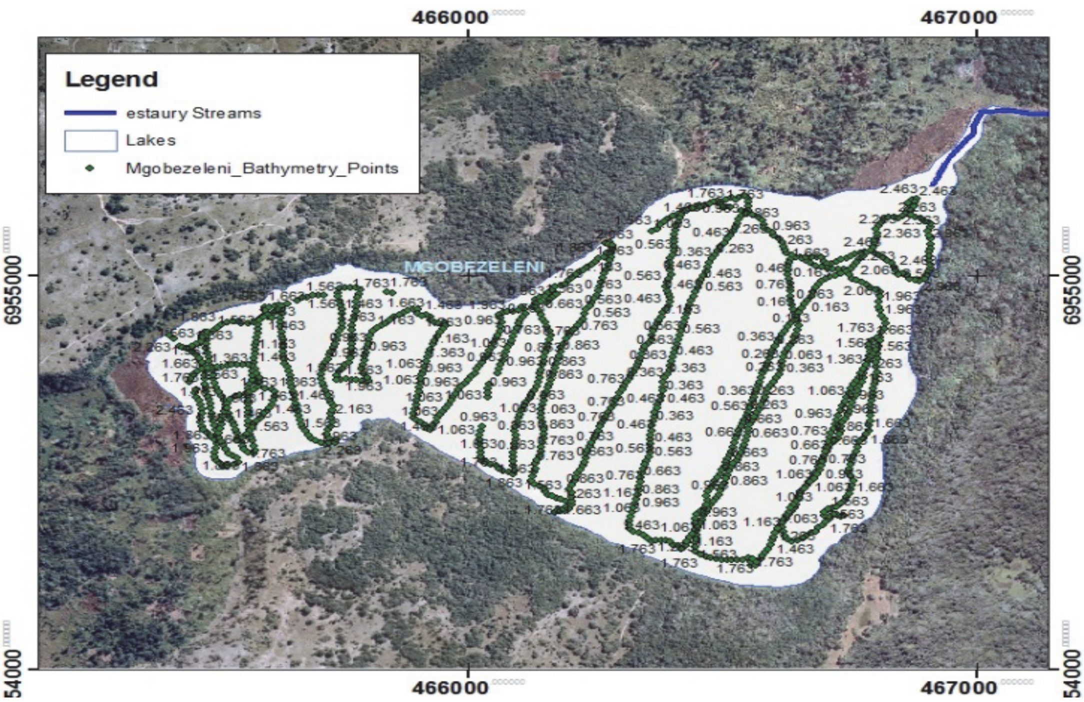


Figure 16. The bathymetric survey conducted by Prof Simonis. Elevation points are in units of mRL (mMSL).

The water level elevation in Lake Mgobezeleni was monitored by DWS since February 1991 (Figure 18). The water level measurements were faulty since 2011 and it was necessary to install a logger in 2014 for this project. The DWS measurements were corrected in 2014 but still show unreliable measurements since March 2015 when compared to the logger readings.

Lake Mgobezeleni reached a high water level elevation of 4.43 mRL in 1991 with general levels above 3.4 mRL (Figure 18). Since 2002, the lake level has generally fluctuated between 3.2-3.5 mRL. The series average between 1991 and 2010 was 3.34 mRL with a minimum of 3.16 mRL in 2010 and a maximum of 3.69 mRL (Table 1). Since 2011, the lake water level measurements are too unreliable to include in the statistics.

There is some concern about the very high water level in 1991 but the measurements do show the typical storm hydrograph characteristic features. However, the erratic jumps in water level from 2011 to 2014 (blue graph) indicate instrument errors and were discarded.

The decade long period with above average water level followed by the decade long period with below average water level shown in Figure 18 may be direct consequences of the well document 18-year cycle in the regional rainfall (Tyson, 1980; Tyson et al., 1975; Dyer, 1979; Kelbe, 1982).

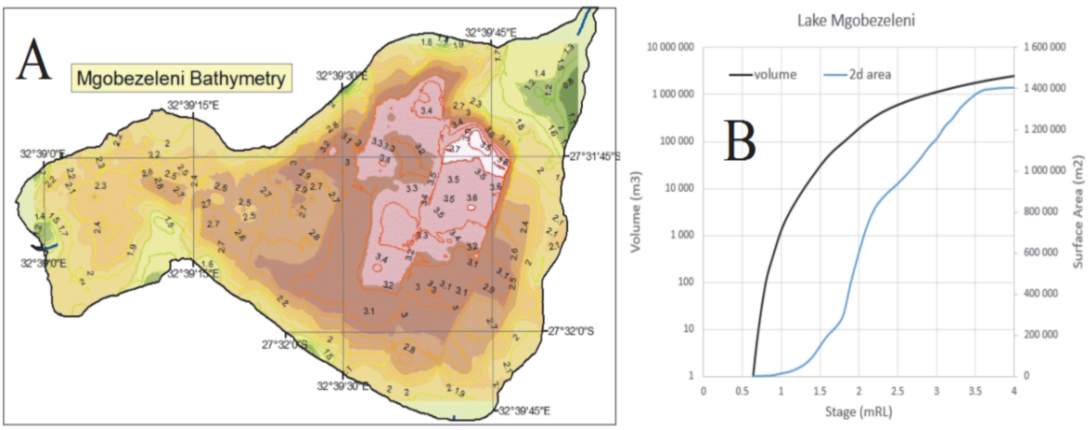


Figure 17. (A) The extrapolated bathymetric profile of Lake Mgobezeleni (contour map) and (B) the rating curve of surface area (m^2) and volume (m^3).

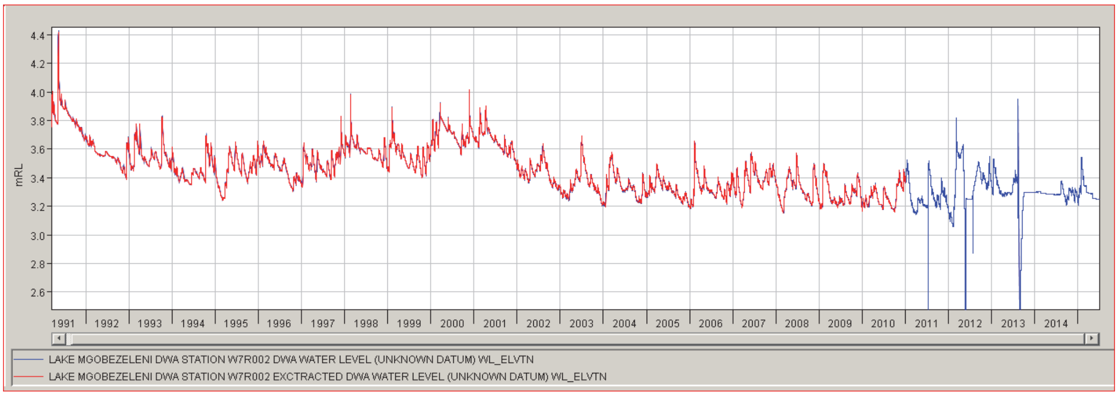


Figure 18. The hourly water level elevation measurements for Lake Mgobezeleni (*Source DWS*:Hydrology:Stn W7R002).

Table 1. Basic statistics for Lake Mgobezeleni Water level elevation from 1991 to 2010.

Statistic	Pre-2002	2002-2010	Post 2010
Mean	3.61	3.34	3.30
#	14058	368421	193520
Maximum	4.43	3.69	3.95
Minimum	3.24	3.16	1.94
STD	0.096	0.091	0.13

The depth duration curve for daily water level elevation series is shown in Figure 19.

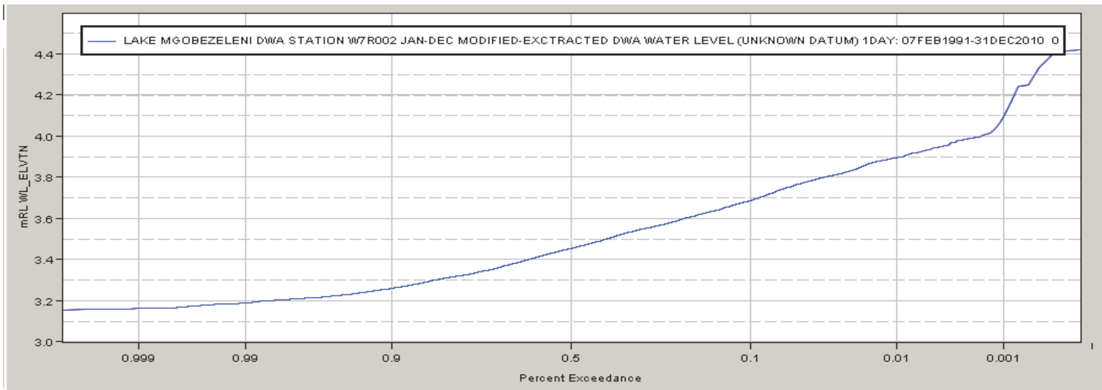


Figure 19. The daily depth duration curve for Lake Mgobezeleni derived from the 20 year record from 1991 to 2010.

2.5.3 Lake Shazibe

Lake Shazibe has not been monitored in the past and the bathymetry has not been surveyed. An attempt to survey the lake was unsuccessful. The exact shoreline of the lake is uncertain. It was established from fieldwork that the fringe vegetation seen from the aerial photograph in Figure 20 (taken January 2016) forms a substantial floating mass along the western margin of the lake. It is assumed that much of the eastern margin also comprises a large floating mass of vegetation.

Figure 20. Aerial photograph showing Lake Shazibe and the surrounding swamp vegetation – January 2016.

2.5.3.1 Shazibe streams

Lake Shazibe is fed by one main stream that originates from a groundwater spring in the deeply incised river valley approximately 4 km upstream. The river flows strongly across the road at Tolla se Gat (where *ad hoc* discharge measurements were taken using inserted rectangular cross-section – Photograph 9) and then it flows through the low lying canalised wetland area to the north of the lake.

The outflow from the lake does not appear to follow any well-defined channel but seeps through the floating vegetation into the swamp where there is also no clearly defined channel (Photograph 10). Ultimately, the outflow appears to were dammed by the construction of the Sodwana road where the stream flows through two road culverts before converging with the outflow from Lake Mgobezeleni. The western culvert has become blocked and all the flow is through the eastern culvert pipes where further *ad hoc* measurements were taken (Photograph 11).

Continuous water level and temperature measurements were monitored at Tolla se Gat and just upstream of the road culvert (Figure 21). The streamflow at Tolla se Gat was higher than the measured flow at the road culvert on nearly all occasions with the exception of the large storm in February 2015 (Table 2).

Table 2. The measured flow rates ($m^3\ s^{-1}$) at the Tolla se Gat road crossing and the road culvert.

Date	Culvert	Tolla se Gat
23 Jul 13, 13:00	0.053	0.061
02 Jun 14, 13:30	0.027	0.051
24 Jan 15, 11:48	0.038	0.054
09 Feb 15, 14:40	0.074	0.045

Unfortunately, the water level logger at Tolla se Gat was vandalised so there is only a short monitoring record that corresponds to the water level record at the culvert. The water level response to rainfall events at Tolla se Gat was smaller than the water level changes at the culvert following several rainfall event but this may be due to the channel characteristics. However, the storm hydrographs at Tolla se Gat after significant rainfall events show a rapid recession that did not occur at the road culvert (Figure 21) illustrating the significant difference in flow characteristics upstream and downstream of Lake Shazibe. The recession hydrograph at Tolla se Gat fell rapidly after the 45 mm rainfall event while the stream at the culvert continued to rise for several days after the event. The continual rise in water level after the storm event downstream of Lake Shazibe is interpreted as a groundwater recharge condition that does not occur further upstream of Tolla se Gat. This is discussed in more detail in a subsequent section.

Photograph 9. The road culvert used to measure streamflow in the stream from Lake Shazibe.

The water level record for the culvert from July 2014 is shown in Figure 22. There was a significant increase in water level elevation of 25 cm at the culvert following a large storm of nearly 100 mm on 09 Feb 2015. The measured streamflow (Table 2) following the large rainfall event in February 2015 was 0.07 $m^3\ s^{-1}$ (~6000 $m^3\ day^{-1}$) which was significantly higher than the measured flow on 24 January 2015 of 0.04 $m^3\ s^{-1}$ (~3000 $m^3\ day^{-1}$). The recession curve for this larger storm continued for over a month before the water level reached the pre-storm levels, and then continued to drop for another month. This illustrates the very large water storage capacity of the Shazibe Resource (lake and groundwater).

Photograph 10. The strong flow at the Tolla se Gat road crossing where several flow and water level measured were taken until the piezometer was vandalised.

Photograph 11. The undefined river course below Lake Shazibe where water level measurements were taken.

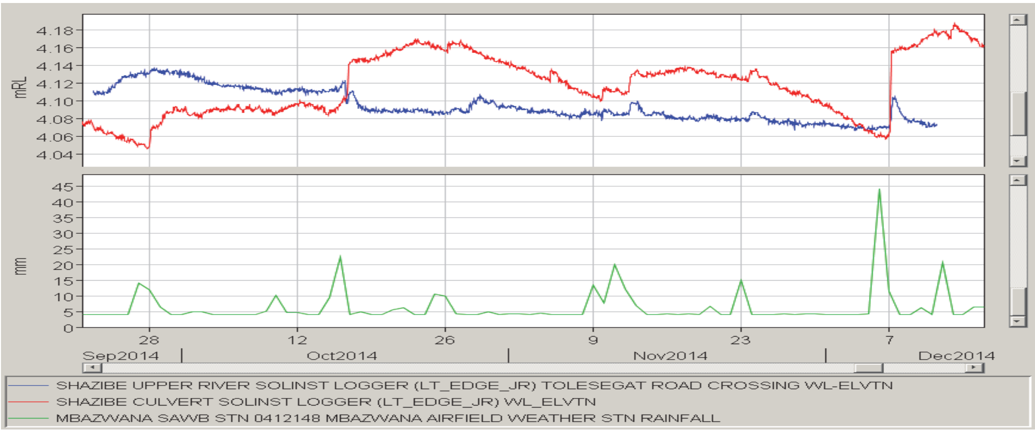


Figure 21. The normalised (same starting value) water level (m – arbitrary datum) at Tolla se Gat and culvert (upper graph) and the corresponding period daily rainfall at Mbazwana (lower graph)

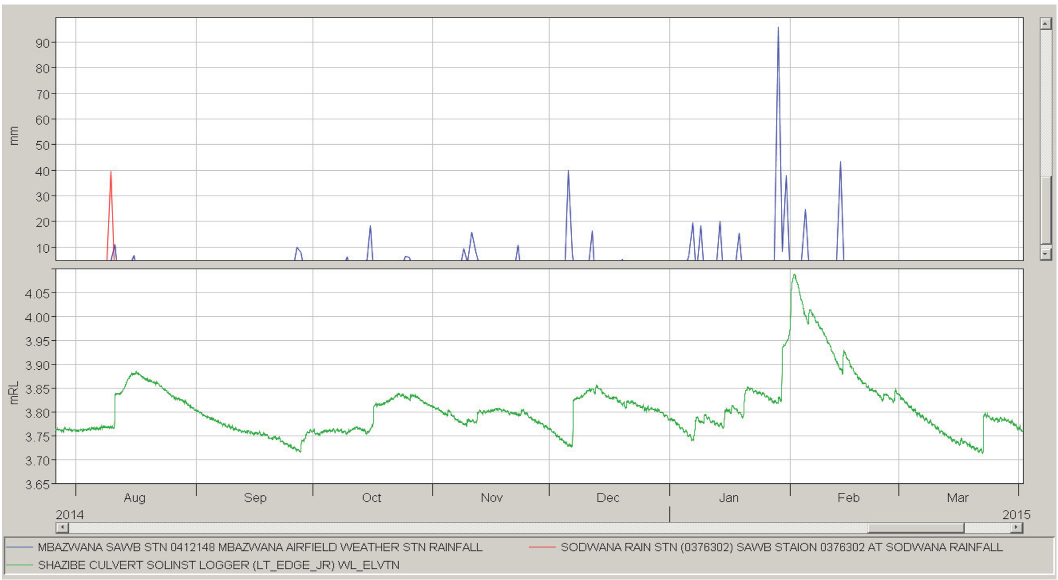


Figure 22. The measured water level (m) and rainfall at the Shazibe stream culvert showing the direct response in outflow from Lake Shazibe due to significant storm events.

It is uncertain if all the flow from Lake Shazibe passes through the road culvert because of the extensive peat formation upstream, downstream and possibly beneath the culvert/road crossing. There is some evidence for a rapid water level response in the peat formation near the estuary mouth that may indicate groundwater flow beneath the culverts. This may partially explain the lower flow rates at the culvert compared to the Tolla se Gat measurements upstream of the lake (Table 2).

2.5.3.2 Lake Shazibe

A water level logger was installed at the old wooden jetty in Lake Shazibe in early 2014 but was stolen in June 2014. A replacement was subsequently installed (04/Mar/2015) along the shoreline in a sunken metal pipe anchored to the sand bed. Neither of the two sites was surveyed, and their respective datums are unknown. A third water level logger was installed in a monitoring borehole next to the production boreholes in Sodwana Bay Lodge. This monitoring borehole is about 50 m from the edge of Lake Shazibe.

None of these monitoring sites were surveyed to the required elevation accuracy. Consequently, the datums for all these monitoring sites were established using a common datum relative to other sites. To adjust the water level measurements for Lake Shazibe to a common datum, the water level measurements from the logger sites along the stream toward the estuary were used to establish high and low conditions where the system may were linked in some way.

The water level series from Lake Shazibe for the two sites in the lake were first adjusted to correspond with the water level measurements at the Shazibe road culvert downstream of the lake for the corresponding periods as shown in (Figure 23). Neither of these two sites were surveyed so the absolute elevation of the series is unknown and the elevation error is significant so all the analysis is on relative changes rather than absolute elevation. The average head for the lake is estimated to be about 20 cm higher than the corresponding head at the culvert based on the hydraulic slope derived from specific peak water level conditions described above. The peaks in water levels for the two monitoring sites shown in Figure 23 are generally associated with rainfall events and illustrate the significant water storage in the lake system.

It was established from field observations that there was a constant runoff through the culvert draining downstream of Lake Shazibe into the Mgobezeleni system up to middle of October 2015 when the water level dropped to below the base of the culvert (Figure 23). The water level upstream of the culvert dropped from ~3.7 mRL to ~3.1 mRL during October 2015. The water level in Lake Shazibe also dropped to a low of about 3.6 mRL (Figure 23). This would imply the Lake Shazibe water level elevation is marginally higher than the water level at the road culvert. Based on these assumptions it is estimated that the elevation of the water level measurements at the culvert and Lake Shazibe are at least 0,5 m higher than Lake Mgobezeleni.

There is a high correlation between the water level in the lake and at the culvert from 2014 up to the time; the culvert ran dry in October 2015. Consequently, the water level in the culvert does provide an estimate of the lake level between June 2014 and Mar 2015 when the logger in the lake was stolen.

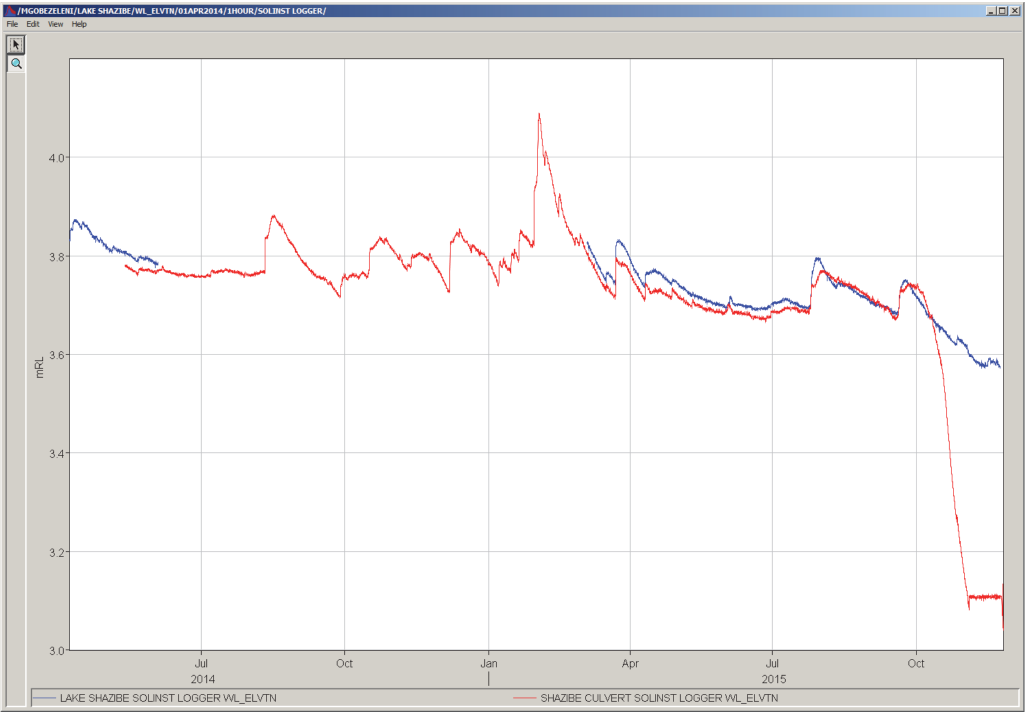


Figure 23. The measured water level at two sites (blue) adjusted to correspond to the level series for the culvert (red).

2.5.4 Downstream of the Lakes

The estuary channel is defined, for the purpose of this project, as the channel and floodplain section from the mouth to the confluence of the two streams draining Lake Mgobezeleni and Lake Shazibe (Figure 24). The stream channel cuts through a dense layer of peat forming the floodplain that appears to be hydraulically connected to the water level in the main channel. The estuary water level and salinity fluctuations are controlled by the flow of water into the system from the catchment but buffered by the two lakes and from the sediment dynamics of the mouth linked to the marine environment. The establishment of a conceptual and numerical model of this system requires information and monitoring of the marine, channel and floodplain components. This section outlines the data collection and conceptual model of the controlling features to support the numerical modelling of the hydroecology.

The stream channel from Lake Shazibe and Lake Mgobezeleni converge just downstream of the road culvert and then flow in a channel within the swamp forest that is covered by numerous tree

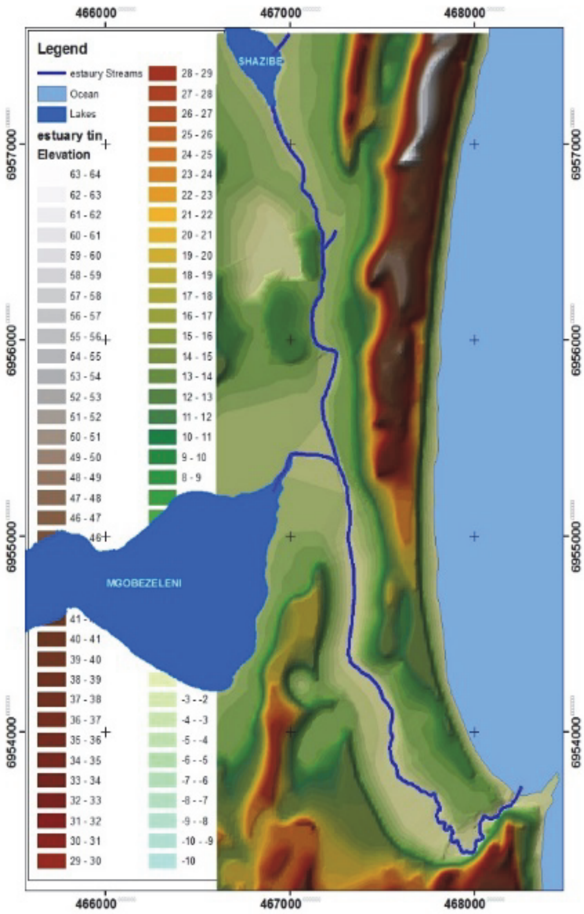


Figure 24. The derived elevation contours for the topographical surface defined by the top of the dune and peat deposits forming the geomorphological setting for the drainage network from both lakes to the Ocean.

branches (Photograph 12) to emerge at the mouth 3.5 km downstream of the confluence. The dimensions of the channel were difficult to measure due to the difficulty of access and the swamp forest vegetation that intrudes into the channel in most sections.

An attempt was made to establish the topographical profile of the stream network draining from both lakes to investigate the hydrodynamics of the system. Since it was extremely difficult to locate and follow the channel in the dense swamp forest, the channel path was derived from a visual inspection of aerial photographs and the 5 m contours infilled with 1 m contours along the river valleys (Figure 24).

Photograph 12. The main channel downstream of the confluence from both lakes showing the numerous tree trunks that cross the channel.

Water level elevation and temperature were measured at several sites along the length of the channel between the mouth and the confluence using Level and Temperature (LT) loggers. Several sites near the mouth were also monitored for changes in salinity (Electrical Conductivity) using LTC loggers. Figure 25 shows the location of the monitoring sites and Table 3 gives details of the loggers.

Table 3. The type and position of monitoring in the estuary. The distance is upstream from the bridge

Logger	Distance (m)	Logger	Frequency	Piezometer
Bridge	0	LTC	5/15	Perforated pipe
Bend	267	LT/LTC	15	Channel bed
Berm	460	LT/LTC	15	Perforated pipe
Lower channel	1450	LTC	60	Perforated pipe
Mid channel	~2000	LT	60	Channel bed
Upper channel	~2750	LT	60	Perforated pipe
Culvert	~3700	LT	60	Perforated pipe

The first logger was installed on the channel bed in 2013 (courtesy HR&TS cc) at the “Bend” just upstream of the mouth Two additional piezometers with loggers were installed in July 2013 at the “Bridge” and “Berm” sites shown in Figure 25.

The logger at the “Bend” site was placed on the bed of the outer bank and secured to a tree about 265 m upstream of the bridge. The logger may have moved and was not always placed at exactly the same position so it was necessary to match the first and last water level reading after each download to eliminate discontinuities by assuming the water level had not changed between the two readings taken 15 minutes apart. The initial reading up to October 2013 was not pressure compensated.

Figure 25. The water monitoring sites along the Mgobezeleni estuary channel. Aerial photographs from KWZ Wildlife.

By October 2013 all the project loggers were installed in temporary piezometers in the channel with the exception of one approximately three quarters of the way to the confluence (subsequently removed). In September 2014, several LT loggers were replaced with LTC loggers to included Electrical Conductivity measurements at those sites near the estuary mouth (see Figure 25). Initially, the loggers at the mouth (Bridge) recorded changes in water level, temperature and salinity at 5 m intervals but this was changed to 15-minute intervals from 15 February 2015 (Table 3). An additional LT logger was installed in a 6 m deep piezometer in the swamp floodplain (peat) about 50 m from the main channel and 10 m from the main road.

The "Bend" logger has taken almost uninterrupted water level and temperature measurements every 15 minutes since 26 July 2013 and salinity measurements since 22 September 2014 (Figure 26). During this period, the mouth has breached or partially breached on about 24 occasions over a 24-month period (Figure 26). However, the breaching intervals are not regular, with breaching periods of days (Figure 26). The dynamics of these breaches are described in a latter chapter.

It has not been possible to survey the logger position to the required accuracy (<1 cm) because of the very dense and inhospitable vegetation cover. Nor has it been possible to measure the Mean Sea Level

Elevation. Consequently, it was necessary to use measured peaks and troughs in the water level elevation of the different traces to derive the best estimate of a common datum referred to as the **Relative Level (mRL).**

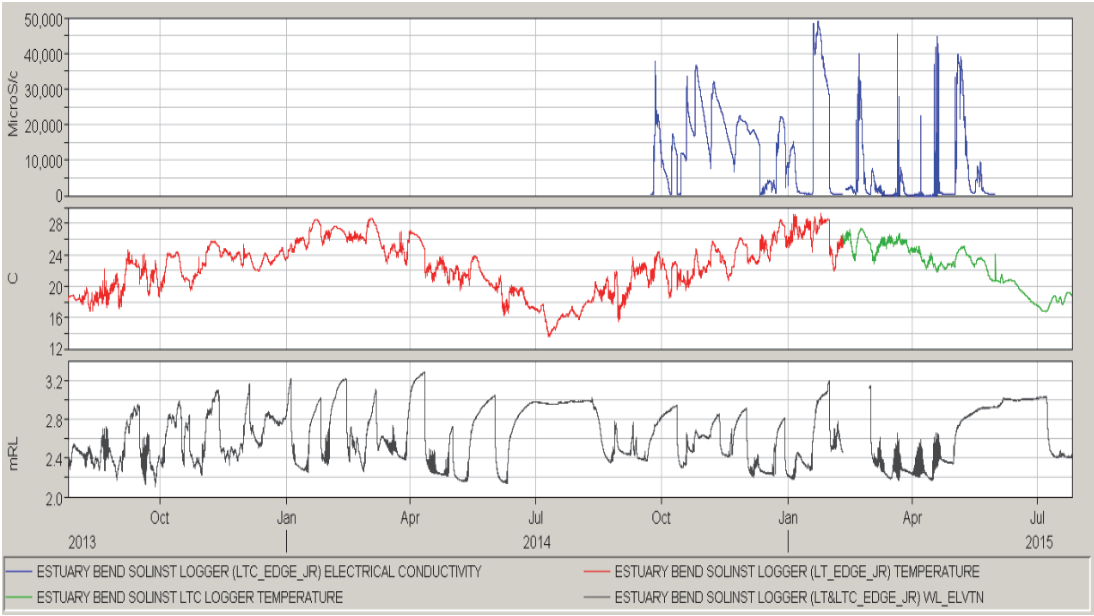


Figure 26. The logger series for the electrical conductivity (top), water temperature (middle) and water level elevation (bottom) at the bend site about 256 m upstream of the bridge.

The water level elevation during mouth closures reached a peak height of 3.27 mRL at the bridge on 10 April 2014 before it was breached. Prior to the breaching, the mouth showed a continual rise that was also evident in the lake logger series (Figure 27) that could not be associated with any rainfall event. After the breeching, the subsequent drop in water level at the mouth (and all the other logger sites in the estuary) was also observed in the logger series in Lake Mgobezeleni (but at a much-reduced rate). While a rapid rise in water level in the lakes and estuary following a significant rainfall event is expected, a drop in water level in the lake below pre-storm conditions is unlikely to occur. A similar recession following a rainfall event in August 2014 also suggested that the lake and mouth water level were almost at the same elevation. Since there was significant outflow of approximately 0.48 $m^3 s^{-1}$ at the bridge prior to breaching from the estuary when the mouth was closed, it is assumed that there was a small hydraulic gradient between the lake and the mouth that was sufficient to sustain this flow rate through the channel and floodplan. The estuary channel was estimated to be about 5 m wide on average with a flow depth of approximately 1 m when the mouth was closed – giving an hydraulic radius of about 0.7 assuming that the flood plain does not contribute to the flow. Assuming a Manning's Roughness of 0.05 for a channel with numerous roots, it is estimated that the slope of the water surface under these flow conditions will be approximately 0.15 m for the 3 km channel between the stream confluence and the mouth. Consequently, it is estimated that the water level in Lake Mgobezeleni was about 15 cm higher than the water level at the mouth prior to the mouth breach on 14 April 2014. All the intermediate logger series were adjusted using the same hydraulic gradient (Table 4). The logger series for the adjusted water level elevation (mRL) are shown in Figure 27. The Monitoring series show a fairly regular sequence of mouth closures followed by breaches that are discussed in detail in the subsequent sections.

Table 4. The calculated water level at peak height for mouth closure at monitoring points along the channel. The estimated height was used to adjust the data series to a common datum (mRL).

Monitoring site	Distance (m)	Max WL above bridge (m)
Bridge	0	0
Bend	267	0.013
Berm	460	0.023
Central channel	1450	0.073

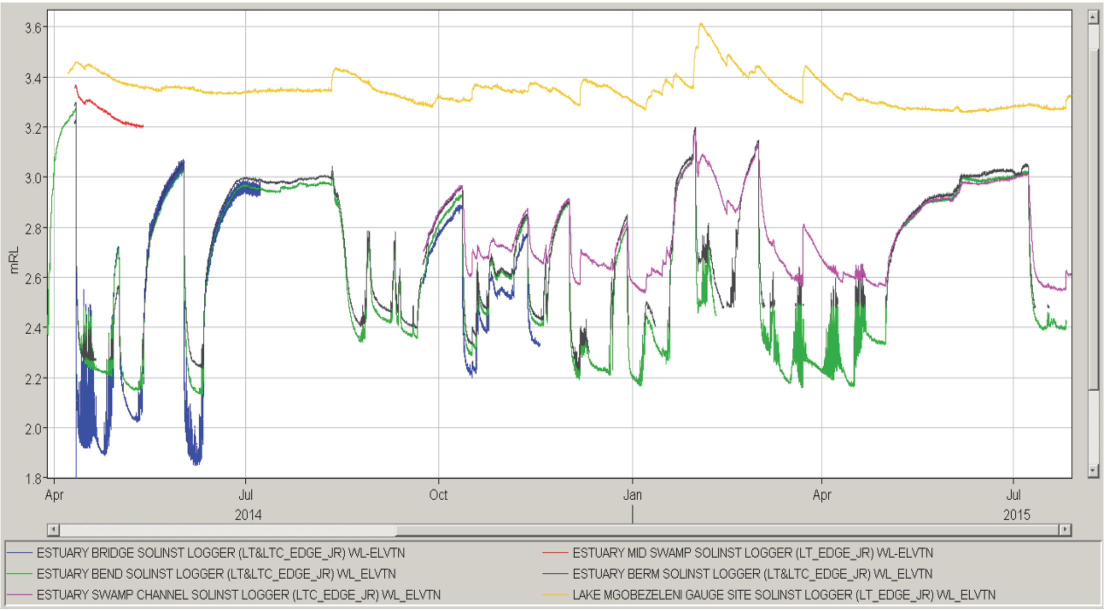


Figure 27. The water level elevation for sites along the channel upstream of the bridge toward Lake Mgobezeleni. The datum for each site was adjusted to synchronise the peak water level at the precise time of the mouth breach in May 2014 as described in the text.

2.5.4.1 Floodplain (peat/swamp)

Two piezometers were installed on the 23 September 2014 in the main channel and the adjacent flood plain about 30 m apart and approximately 1.5 km upstream of the bridge. Both monitored water level and temperature while the one in the main channel also monitored EC (salinity). It was not possible to survey the piezometers so the water level elevation of both sites were adjusted vertically to correspond with the peaks as described above. The water level elevation and salinity series are shown in Figure 28. The water level in BOTH the main channel and the flood plain responded equally to the changes in the mouth water level conditions. The water level measurements show that;

1. This section of the main channel experienced tidal fluctuation during April and May 2015 for 1.5 km upstream of the bridge that correspond with the tidal series at the three sites closer to the mouth (See locations in Figure 27).

2. The two series, shown in Figure 28, for the channel and floodplain indicate that the water level in the flood plain did not show the spring tides but it generally dropped lower under the flood plain than it dropped in the main channel during the tidal surges in the main channel.

The water level elevation for floodplain shows a regular fluctuation during mouth closure when the water level is relatively static that may be attributable to the evaporation and evapotranspiration from the swamp forest.

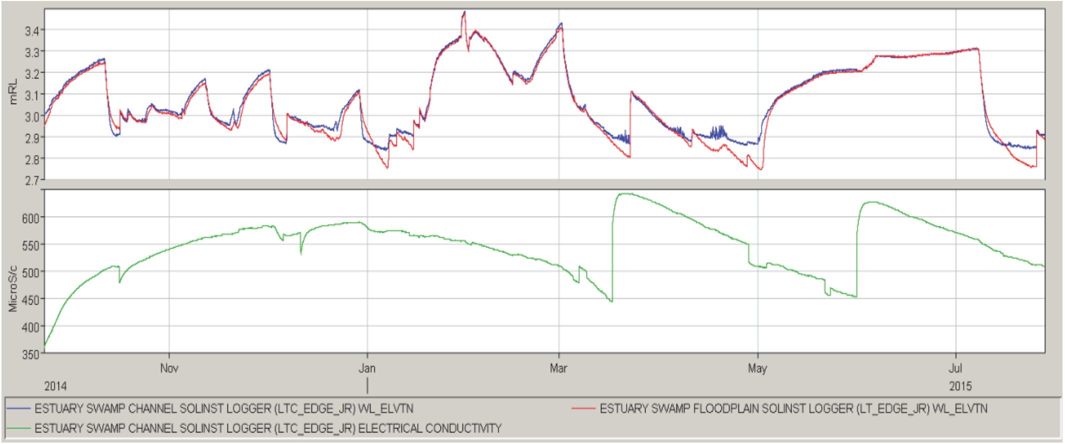


Figure 28. The hourly measurements of water level elevation (mRL) and Salinity (µs cm^{-1}) at a location about 1.5 km upstream of the bridge in the main channel and the adjacent floodplain.

2.5.4.2 Channel profile and flow dynamics

Water level monitoring was conducted in the estuary to establish the hydrodynamics of the mouth during the various stages of the mouth closing and breaching. The causes of the mouth closure and breaching and the ecological significance are described in a subsequent chapter. The bathymetric profile and flow dynamics are presented in the next section.

The water level monitoring and discharge measurements data indicates that there is substantial outflow from the lakes and surrounding floodplain that will influence the mouth dynamics. To establish the source and sinks in the system, the bathymetric profile of the lower channel section below the confluence of the outlets from both lakes was derived from 5 m elevation contours and from estimated elevation contours of the river channel and flood plain/peat that was digitised from aerial photographs. The bathymetric profile of the estuary and floodplain surface topography was mapped from the mouth to the confluence of the two streams draining the lakes.

It was established that the flood plain comprises a deep decaying layer of rotting vegetation (peat) that appears to have very high hydraulic conductivities as illustrated by the very rapid water level responses to changing water level in the channel described earlier in the text. Consequently, this flood plain is expected to act as an extension of the river channel with significantly modified hydraulic properties (conductivity and storage). The depth of the peat layer below the surface was determined by R Taylor across the main section of the flood plain close to the logger-monitoring site (Figure 29). A transect of (1) the surface elevation and (2) depth of the peat (elevation) across the section AA' (shown in Figure 29) is presented in Figure 30. It was assumed this transect is a typical representation of the entire floodplain peat deposit from the confluence to the bridge at the mouth.

The difference between these surface and subsurface (bottom of the peat) contours was used to derive the estimated volume of peat between the confluence of the stream and the mouth.

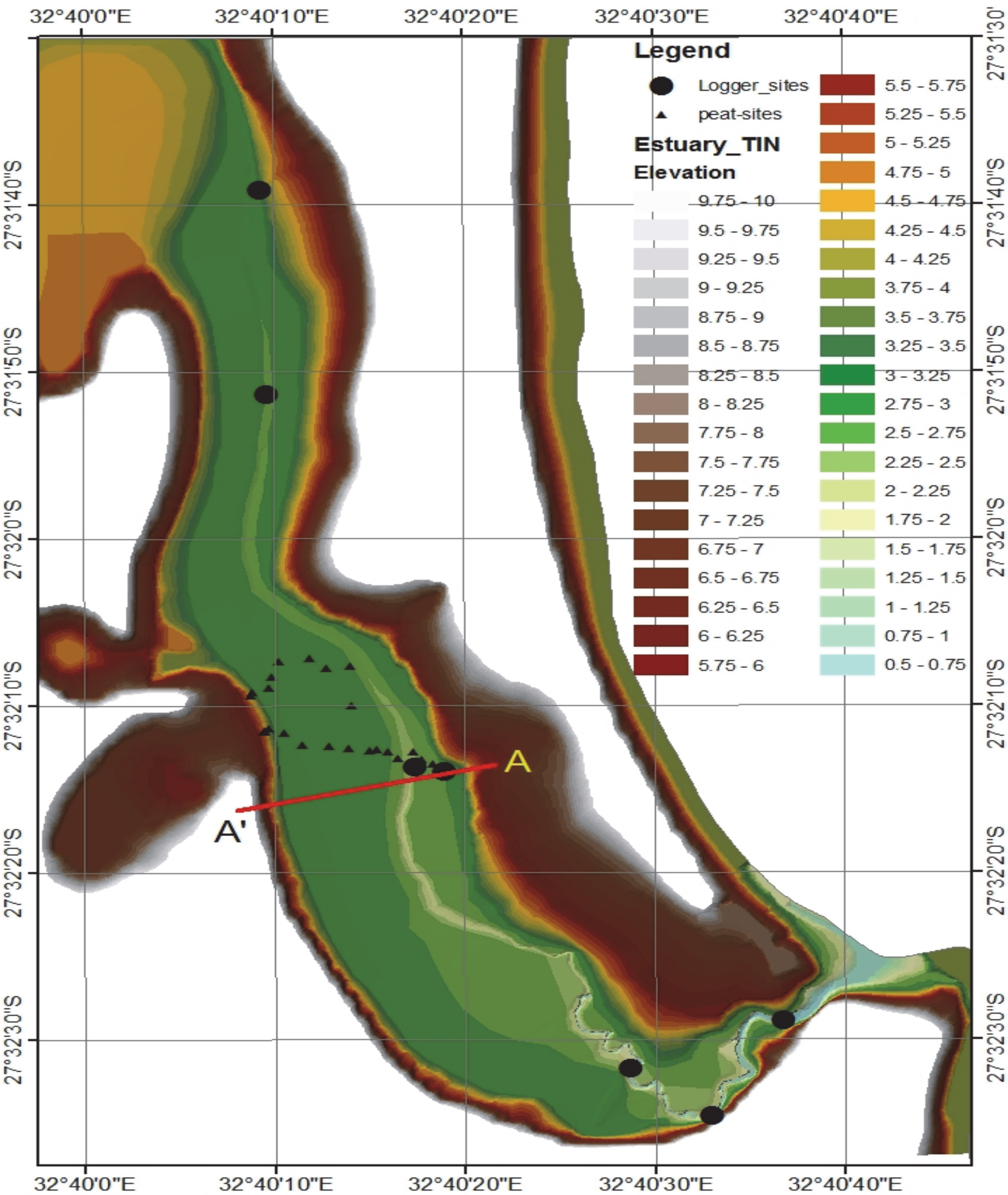


Figure 29. The TIN for the river section below the confluence generated from 5 m contours and estimated contours of the channel and flood plain from aerial photographs. Peat profile from RH Taylor.

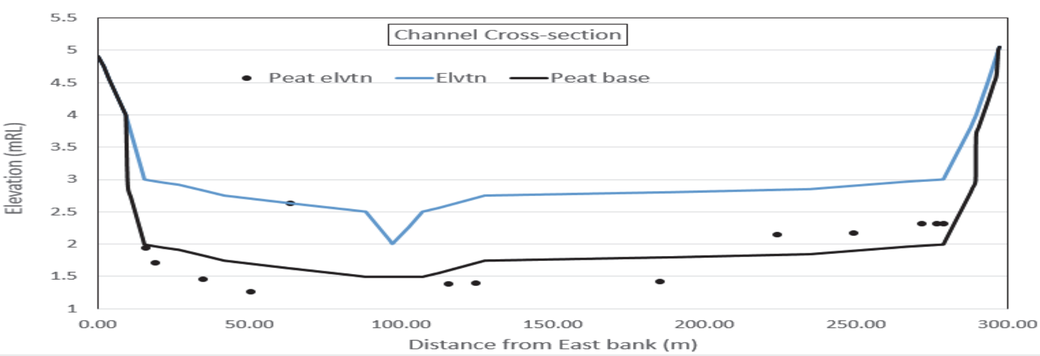


Figure 30. The surface elevation across the AA' transect midway up the channel with the estimated peat base profile and peat core measurements (from RH Taylor).

The estimated volume and surface area of the estuary mouth and main channel for increased depths of inundation were derived from the DEM and plotted in Figure 31. The initial slow rise in the volume and area of inundation represents the main channel, most of which is assumed to lie below 2.5 mRL. There is an abrupt increase in both the area and volume of inundation at 2.5 mRL when the rising waters start to inundate the floodplain. The volume and area relationship above 3.5 mRL does not include the back flooding of Lake Mgobezeleni and its surrounding area are likely to have happened based on the corresponding changes in water level discussed earlier. The difference between the two volumes curve represents the increasing volume to peat above the indicated datum. This volume would contain water in relation to the hydraulic properties of the peat.

As the water in the stream between the mouth and the confluence rises on mouth closure, it appears to flood both the channel and the swamplands (flood plain) as shown by the water level traces in Figure 32. However, there is a distinct change in the rate of increase in the water level in the system for at least 500 m upstream of the mouth as illustrated in Figure 31. The rise in water level does not show an abrupt change that would illustrate a stage when the channel would overflow onto the flood plain but rather a general increase that would support the concept of a wide channel with a highly porous swampy mat that was also filling at the same rate as the channel.

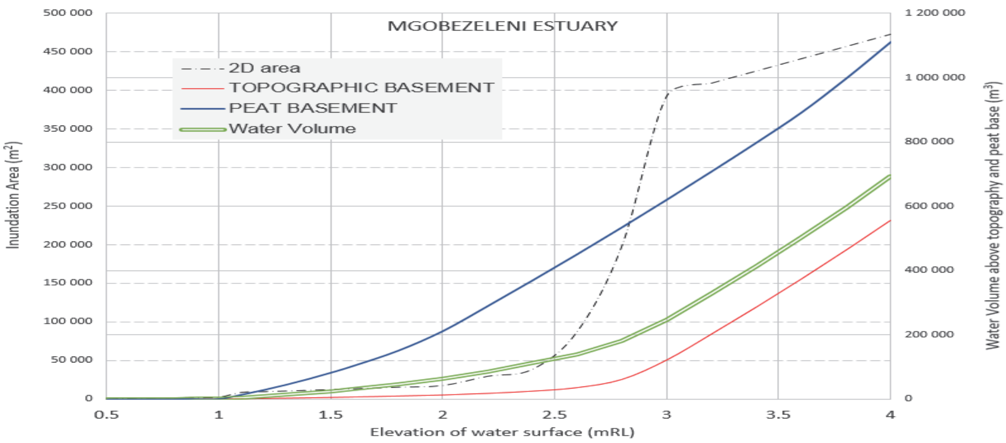


Figure 31. The derived relationship between the depth of inundation (water level elevation) in the estuary and the surface area (m^2) of the portion of the channel and flood plain that are exposed (dashed line). The solid lines represent the change in the water volume above the peat basement (blue line) and the topographical surface formed by the channel and surface of the flood plain (red line). The double line represents the volume of water stored above the peat base assuming that the peat has a porosity of 25%.

2.5.4.3 Tidal Surges following mouth breach.

The general characteristic of the tidal pulses for several hundred metres upstream of the mouth Berm are illustrated in Figure 33 during the strong tidal interaction during March and April, 2015. The water level recession following the mouth breaching on 1 March 2015 at about 18:30 appears to continue unabated for two weeks to a base level of about 2.18 mRL after 16 days with some overtopping from spring tides superimposed on the recession curve (Peak 1 in Figure 33). Following the minimum water level of 2.1 mRL after the initial breach, it rise prior with the spring tides to an average level of about 2.3 mRL (Peak 2), which is also recorded further upstream (Figure 32). This was attributed to partial mouth closure during spring tides. However, there appears to be a partial opening of the mouth during the second spring tide that allowed the water levels to drop to about 2.16 mRL. The base level then abruptly rises towards the end of the spring tide, presumably due to partial closure of the mouth before it again recedes to almost the same elevation about two weeks later. The slight rise in the base level is repeated for the third spring tide but the mouth starts to close completely on the fourth and fifth spring tides (Figure 33A).

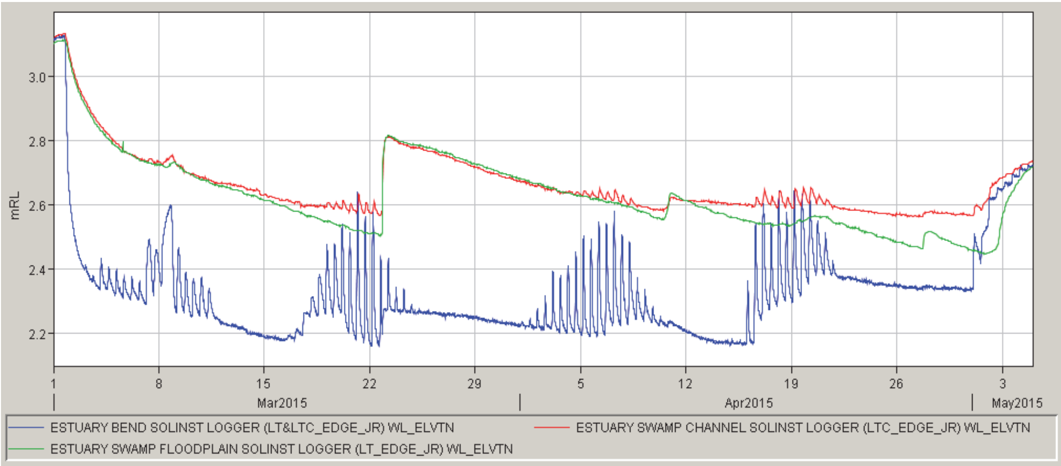


Figure 32. The water level elevation (mRL) for the piezometers at 0.25 km and 1.5 km upstream of the bridge for the two month period with strong tidal interaction from 1 Mar 2015 to 1 May 2015.

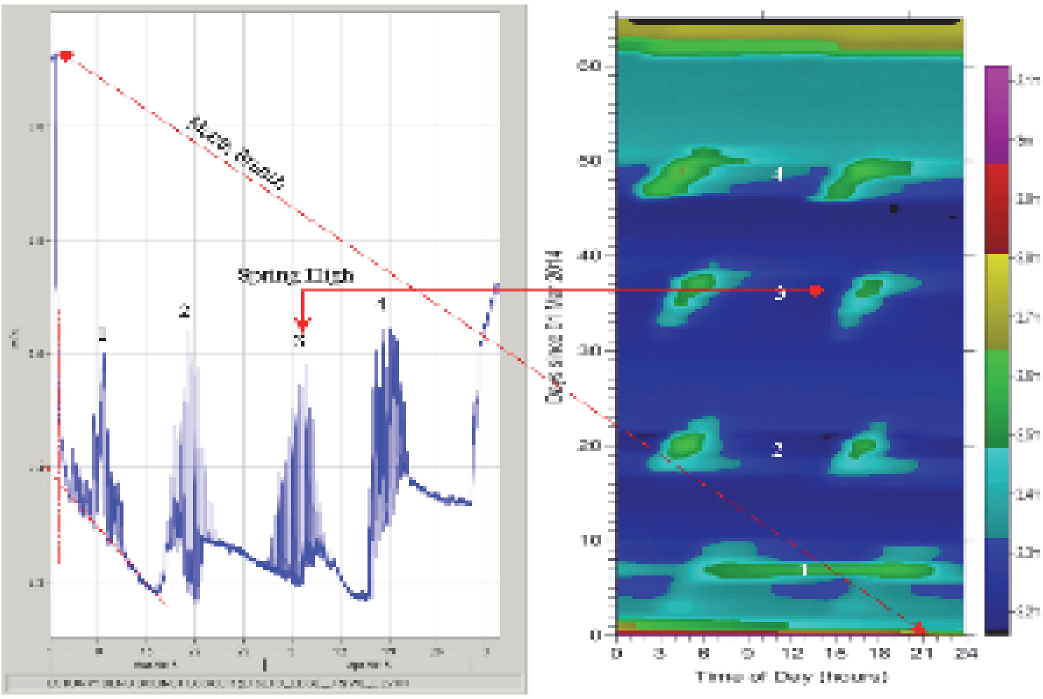


Figure 33. The changes in water level elevation at the Bend site 250 m upstream of the bridge (Left). The map on the right frame shows the same sequence of changes in water level elevation plotted for time against days since 01/03/2015.

The twice-daily tidal action in the estuary is clearly shown in the time map in Figure 33B for the second and third spring tides with only partial mouth closure. The tidal interaction during the spring tides immediately following the initial breach of the mouth on 1 March 2015 is modified by the substantial drainage from the main channel and upstream lakes. The second and third spring tidal cycles show the typical impact of seawater overtopping into a partially closed mouth. This is followed by increasing mouth closure during the fourth and fifth tidal cycles.

2.5.4.4 Mouth Breach Case Study

The breaching of the mouth causes a substantial volume of stored water in the channel and flood plain to be released as a large wave that reached its peak discharge at the bridge about 01h50 after the initial breach at the mouth (Figure 34). The channel and floodplain upstream of the bridge released over 60,000 m^3 over the initial 3h30 hours. During this period, there was a significant drop in water level of approximately 0.75 m at the 250 m (Bend) and 500 m (Berm) monitoring sites upstream of the bridge over the 24-hour period immediately after the breaching event (Figure 35). However, the water level at 3.0 km upstream of the main channel in the mid-section showed a very small recession of about 5 cm for the same 24-hr period following the breaching event (Figure 35).

Subsequent monitoring of the channel and floodplain (Figure 32) indicated that the water level drops significantly after natural breaching events (Figure 32) albeit at a much slower rate beyond 1 km upstream. It is assumed that the water level drop following the breaching event on 11 April 2014 would were approximately 0.45 m in the channel and slightly less in the floodplain (0.4 m) over the 24 hr period.

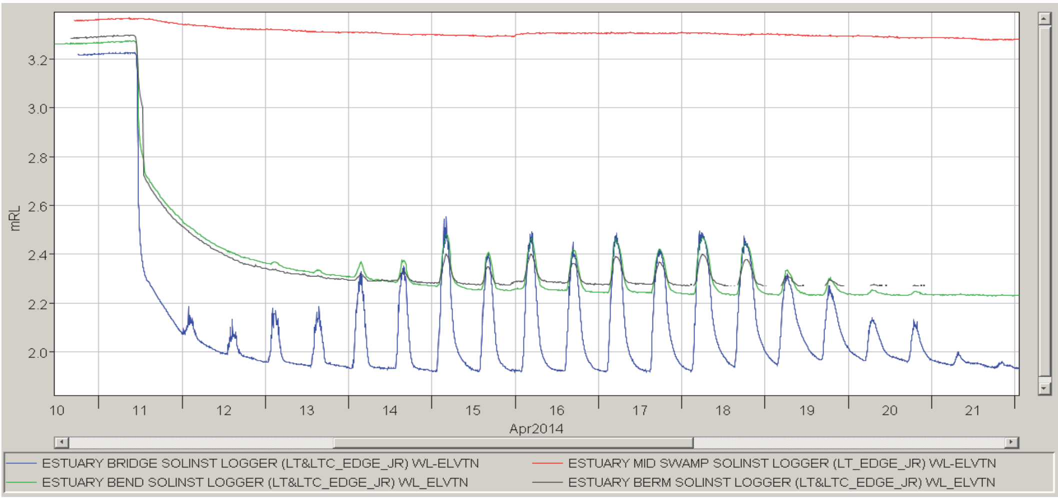


Figure 34. The measured water level response to the mouth breaching event on the 11 April 2014 for the 1.5 km channel section upstream of the bridge.

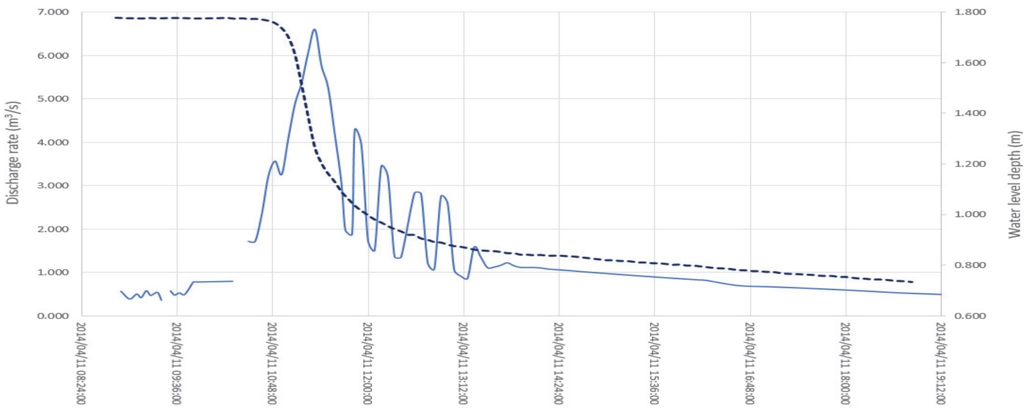


Figure 35. The measured discharge rates under the road bridge during the mouth breach on 11 April 2014. The dashed line shows the measured water level depth above the bed (m) and the solid line is the measured flow rate ($m^3 s^{-1}$) through the left and right box culvert. The flow rate was extrapolated over a full 24 hour period using the same recession rate as the water level.

Assuming wedge storage of 1 m over 2 km (2000 m^2), and a channel width of 5 m, the breaching event would have released 10,000 m^3 over the initial 24 hr period. However, there was a corresponding release from the floodplain that is approximately 100 times wider than the channel and approximately the same bed elevation. Based on the Depth: Volume relationship shown in Figure 31, the drop in water level from 3.0 to 2.0 mRL (Figure 35) would have released close to 200,000 m^3 from the channel and floodplain. This would have drained an area of approximately 300,000 m^2 assuming the entire floodplain had the same porosity as the monitoring site at 1 km upstream.

The length of the beach berm before the breach on the 14 April 2014 was ~300 m. The water level elevation was 3.2 mRL. The width of the beach berm from the estimated mid-tide shoreline to the estuary shoreline was approximately 40 m. The measured discharge prior to the breaching event was determined as 6000 m^3 day^{-1}. Assuming this flow all drained out through the beach berm, then it is estimated that the hydraulic conductivity of the beach berm sands was about 300 m day^{-1}.

2.5.4.5 Estuary salinity dynamics

A visual inspection of the flow of water under the Sodwana Bridge on several occasions indicated that there were situations where the water in the lower layers was flowing in the opposite direction (upstream) to the water flowing in the upper layers probably due to density differences. This was attributed to the influx of seawater when the mouth was partially closed and there was only a very slow outflow of freshwater. Consequently, it was important to conduct the EC measurements at the appropriate depths in the channel. This was not always possible at all the monitoring sites.

The EC logger at the mouth was placed in a short piezometer attached to the old Gauge Plate on the western side of the bridge. This side of the bridge was significantly shallower than the eastern side due to natural scour on the outer bend of the approaching channel. The logger managed to capture the salinity changes about 100 m upstream of the mouth but may have missed some of the early shallow influx due to its elevated position. The EC measurements were conducted at 5-minute intervals but this rapidly led to overflow of the logger memory and some data was lost during the monitoring period.

Salinity monitoring along the estuary at four sites for 1.0 km upstream from the bridge commenced in September 2014 (see Figure 25 for the locations). At the bridge, the logger was installed at the base of the piezometer on the western bank to monitor the salinity changes in the lower layers. At the Bend site 250 m upstream, the logger was placed on the outer bank of the channel at a shallow depth of about 20 cm that monitored the upper flow regime. At the Berm site the logger was installed in a piezometer that was pushed into the central channel but not properly secured and became exposed under certain conditions giving false conductivity readings. The logger at 1.5 km was installed in a piezometer secured in the channel and the logger placed on the bottom. Since the saline water would travel in the lower layers under laminar flow conditions due to density differences, the position of the logger needs to be considered in the analysis of the salinity measurements from these four loggers.

The loggers were not calibrated for electrical conductivity so the readings are considered to represent relative changes and not absolute salinity values. There were logger failures that have caused several gaps with missing data for all the sites. The complete records for the four sites are shown in Figure 36. There is no significant intrusion of saline water to the mid-channel monitoring sites at 1 km upstream.

The loggers clearly show that the seawater influx and overtopping is sufficient to push seawater over 500 m upstream of the mouth following spring tides when the mouth is open or partially open. However, the salinity measurements at 1500 m upstream only showed a very small signal that ranged between 450 and 650 µs cm^{-1} between July 2014 and November 2015, although this was significantly higher than freshwater outflow. A typical salinity graph following the closing and opening of the mouth is shown in Figure 37. The seawater penetrates very rapidly for over 500 m upstream but does not reach the mid-channel sections at 1000 m. There is a slower recession along the main channel but it appears that there is some residual salinity along near the bend that may be due to entrapment is some sections of the channel.

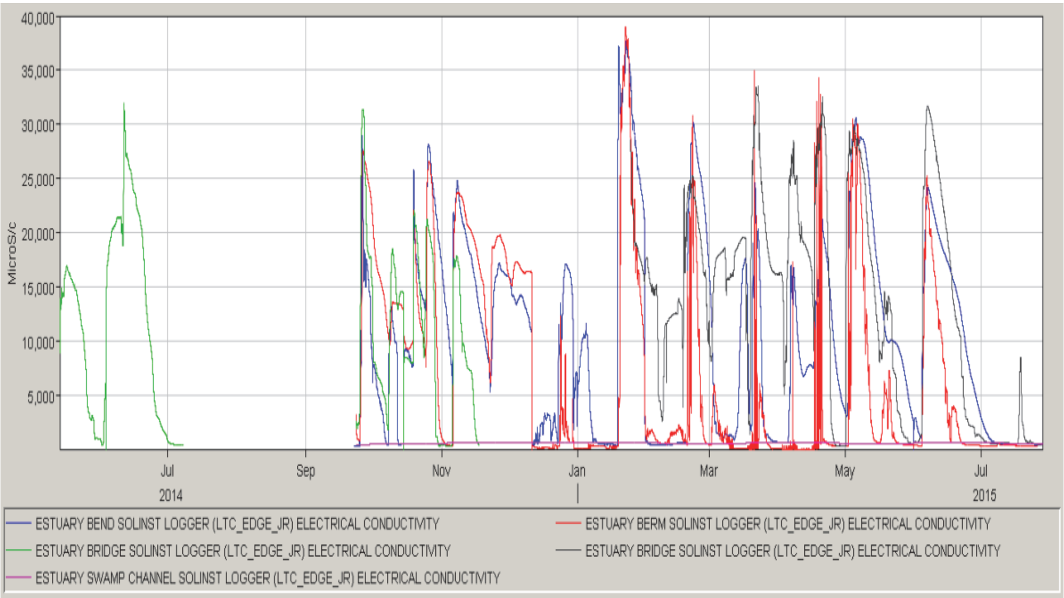


Figure 36. The complete 5 min and 15 min record of electrical conductivity for the estuary monitoring sites.

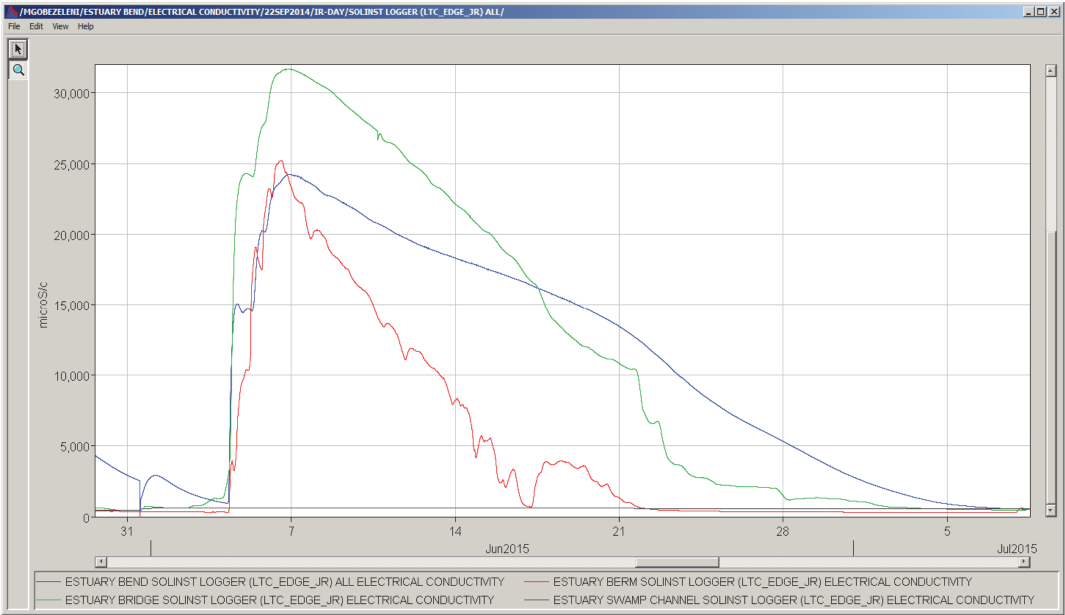


Figure 37. The salinity graph for the monitoring sites at the bridge, bend, berm and mid-channel representing a typical conditions following the breaching and subsequent closure of the mouth.

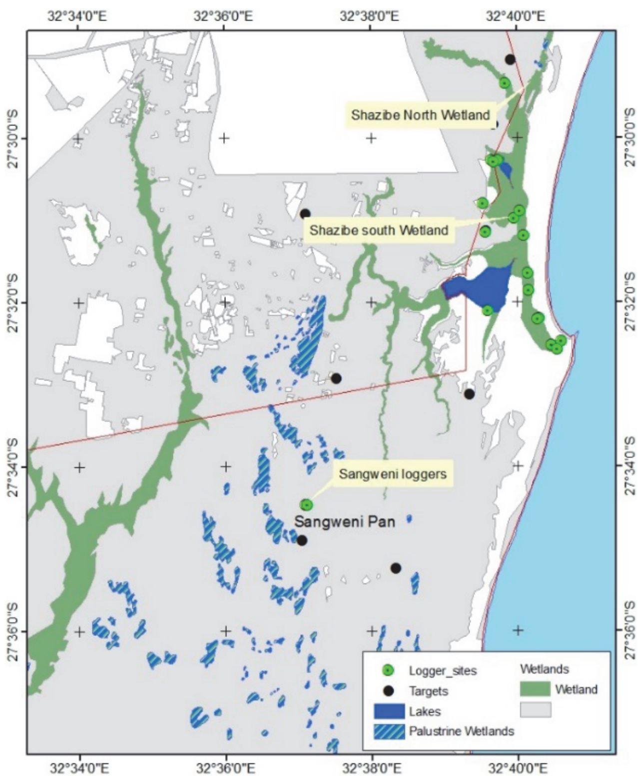


Figure 38. The map of the distribution of wetlands in the study area (*Source*: Ezemvelo KZN Wildlife) and the position of wetland monitoring and survey sites.

2.5.5 Wetlands

The study area has an abundance of riverine, lacustrine, estuarine and palustrine wetland areas. The hydrology of these systems is associated with their spatial and temporal flow characteristics. The riverine, estuarine and lacustrine systems were described above. This section describes the main palustrine (isolated) systems that are generally static in nature and controlled almost entirely by the groundwater profile.

The distribution of the palustrine wetlands in the study area were mapped in Figure 38. These are mainly in the southern part of the catchment within the iSimangaliso Park and along the drainage lines in the north and west. The vast majority of these wetlands are directly associated with the shallow fluctuating regional water table in interdunal depressions.

Photograph 13. The wetland formed in a shallow depression to the north of Lake Shazibe.

Starting in the north of Lake Shazibe, there are a number of pans along the topographical depression to the east of the Shazibe River formed by interdunal depressions (Photograph 13). There are some drains along the southern edge of these pans but there does not appear to be a direct channel draining toward Lake Shazibe.

A transect of the peat profile across this pan was surveyed and discussed in another section. No water level measurements were taken in this wetland.

Just to the south of Lake Shazibe and to the west of the swamp and stream channels draining to the estuary lies a wetland that was monitored for water level and temperature. The piezometer elevation has not been surveyed accurately so the water level elevation was compared to the water level elevation in the Shazibe stream piezometers. The series were compared by setting the starting values to a common value to create the normalised series in Figure 39 that show the fluctuations in the swamp "channel" between the Lake Shazibe and the culvert and the piezometers in the swamp to the west of the "channel'. The Swamp channel is assumed to be flowing from Lake Shazibe while the wetland shows the fluctuation in wetland storage due to incident rainfall. Also shown in Figure 39 is the head variation for SOD006, at 30 m depth approximately 750 m to the south representing the deeper groundwater changes associated with the same recharge events.

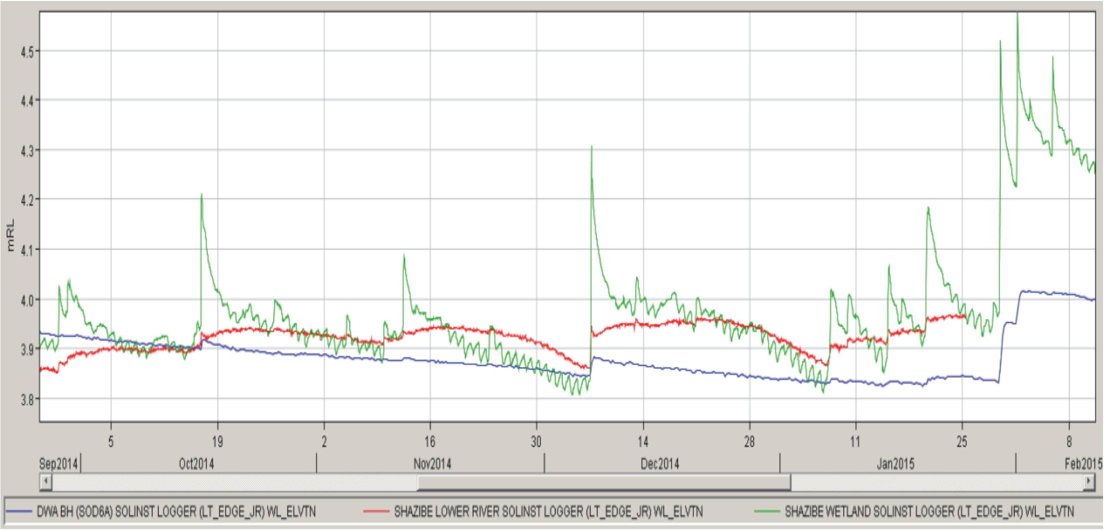


Figure 39. The normalised (same starting values) water level fluctuations in the wetland and adjacent stream just south of Lake Shazibe. Note the water level elevations have not been surveyed and are not based on any specific datum at this stage.

To the south of Lake Mgobezeleni lies the Sangweni Pans. Two shallow piezometers horizontally separated by 3 m were installed in these wetlands at depths of 2 and 6 m to monitor the relative changes below and above the peat layer at the site shown in Figure 38. The measured depths (m) over the past 12 months at both sites are shown in Figure 40. The piezometric head below the peat layer dropped continuously during the dry period by nearly 1 m from May 2014 to January 2015. The water level then rose by less than 1 m by March 2015 but has again dropped the same amount by August 2015. By the end of May, the water level in the upper peat layer had dropped below the logger so it is unknown to what extent the peat dried out during the drought period.

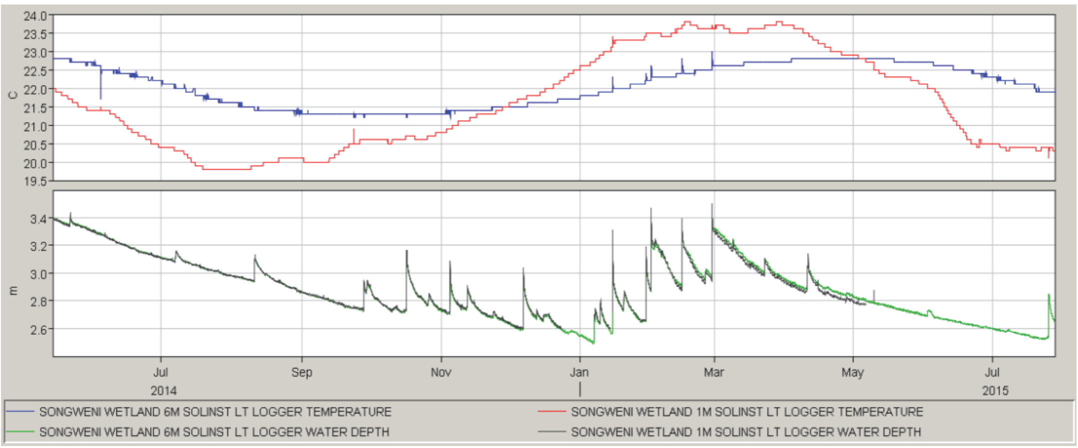


Figure 40. The water level (lower graph) and temperature fluctuation at 2 m and 6 m depths in the Sangeweni Pan. Note the water level elevation has not been surveyed and is not based on any specific datum at this stage.

There were several rainfall events during the monitoring period that produced a direct response in the piezometer water level. The water level hydrograph in both the peat and underlying sandy layer showed the typical rapid rise in water level followed by the multiphase recession limb associated with different hydrological processes. While the rapid rise in water level in the shallow piezometer (1 m) is due to the rainfall recharging the peat layer, the rapid but smaller rise in the water level in the deeper piezometer may be due to both recharge storage and the weight of additional storage in the overlying burden. However, the recession limb for both hydrographs show identical curves once the initial storage has receded that suggest that the peat layer is fairly permeable and will support the rapid recharge to the lower layers. A similar conclusion was proposed for the estuary where the peat floodplain responded equally fast to changes in water level in the main channel.

2.6 GROUNDWATER

Borehole logs for the study area have identified the main aquifer units (Scharpers, 2013) based on the provisional lithostratigraphy for coastal KwaZulu-Natal (Botha, 1997) shown in Figure 13. The unconsolidated geological formation forming the main aquifers in the study area were described above, mapped by Nweze (2015), and then extrapolated to cover the model domain for the study area in this project (Figure 14). The Sibaya and Kwambonambi Formations are assumed to comprise the upper, unconfined primary aquifer. Underlying the Kwambonambi lies the (leaky) Kosi Bay aquifer with high fines content that partially confines the lower aquifer comprising the Uloa/ Umkwelane Formations. These unconsolidated aquifer units overlying the partially consolidated and assumed impervious mudstone/siltstone of the St Lucia Formation that general slopes at about 3-5^{o} toward the Indian Ocean.

The inland stabilised paleodunes forming the study area are highly permeable sands that result in very little surface runoff with the exception of wetlands and surrounding landscapes with very shallow water table that occur mainly to the south of Lake Mgobezeleni. Consequently, it is assumed that the effective rainfall will infiltrate and percolate into the groundwater in significant quantities resulting in substantial groundwater storage. The groundwater storage will subsequently be released into the drainage zones at slow rates creating a continual baseflow in the receiving streams, lakes and wetlands.

Numerous boreholes provide groundwater to local businesses and residential properties in the Sodwana area. Prof Bate has located most of the boreholes and sampled the water for nutrients the results of which are described in the next chapter.

There are two long-term monitoring boreholes in the study area at Mbazwana and just south of Lake Mgobezeleni (SOD 2). Eight additional monitoring sites were established by DWS in 2012 as part of the National Groundwater Monitoring program. Two of these sites (SOD 5 and SOD 6) have three separate monitoring boreholes in the Uloa, Kosi Bay and Kwambonambi Formations. The other sites have monitoring boreholes in the Uloa Formation. Most of the boreholes (Table 5) were fitted with continuous water level logging equipment by DWS and the water level is measured manually at periodic intervals (dip meter). Unfortunately, two of the shallow boreholes at SOD6 were blocked by termite nests and need to be recovered.

Table 5. The details of the DWS monitoring Boreholes.

ID	NGB #	X	Y	Depth	ToC		
SOD 1		27.484	32.6653	43?	42.2		42.2
SOD 2	KZN120029	27.51555	32.61839	56	40	37.767	
SOD 3	KZN120030	27.5868	32.61761	56	34.00	31.246	49.77
SOD 4A	KZN120031	27.32929	32.27528	61	39	30.478	57.58
SOD 4B	KZN120030	27.32929	32.27528	21	39	30.478	
SOD 5A	KZN120033	27.49729	32.66138	49	25	22.043	25.36
SOD 5B	KZN120034	27.49729	32.66138	49	25.00	22.043	
SOD 5C							
SOD 6A				49			39.26
SOD 6B	KZN120036	27.51886	32.65954	17	20	11.5	16.87
SOD 6C				40			
SOD 7	KZN120038	27.55204	32.65586	46	33.00	23.75	
SOD 8A	KZN1200040	27.58737	32.63893	52	32.00	31.927	7.4
SOD 8B				50			
BH27				51			31.7
SIB 1A	KZN120042	27.29521	32.71204	46	41.00	41.24	42.7
SIB 1B	KZN120043	27.29521	32.71204	46	41.00	41.24	
SIB 2	KZN120044	27.41373	32.60626	60	43.00	34.89	59.12
MBAZWANA	047900	-27.45295	32.63238				
SOD 1 SODWANA BAY	2732DA00010	-27.55046	32.66143	43?		25.723	

All of the early continuous OTT water level measurements have not been rectified and cannot be used for this project. However, all the instruments were replaced and appear to be working properly but there are still some uncertainties regarding the elevation of the Top of Casing (ToC) for some boreholes so it has not been possible to convert the depth reading to water level elevation relative to the common datum being used in the project (mRL) for these boreholes. A Solinst levelogger was installed in SOD6 (deep) borehole in early 2015.

The water level elevation (piezometric head in mRL) for the DWS boreholes were captured in the project database and used as head targets in the groundwater model calibration. The piezometric head series for the DWS monitoring boreholes are shown in the following figures.

There was a general decline in the groundwater elevation over the past 15 years at Mbazwana and Sodwana Bay (Figure 41) although it appears that the drop in water level near the coast has stabilised at current levels. However, there was a drop of 3 m at Mbazwana. If the drop in water level at Mbazwana Forest Station can be associated with the same trends at Mtubatuba presented by Brites (2013) then it is likely that the decline was continuing for many years prior to the start of measurements due to the plantations in the area.

The manual dipper reading of depth from Top of Case (mBToC) to the water level using a standard dip meter (dipper) were taken at irregular intervals since 2012. The data series NORMALISED to a common starting value are shown in Figure 42. The data series show an apparent seasonal fluctuation in water level and a general trend over the past three years. The water level ELEVATION (mRL) rises during the summer season and falls during winter in direct response to the rainfall cycle. However, there was a marginal INCREASE in water level elevation (drop in Depth to the water table) over the past few years despite of drought conditions but it is not statistically significant.

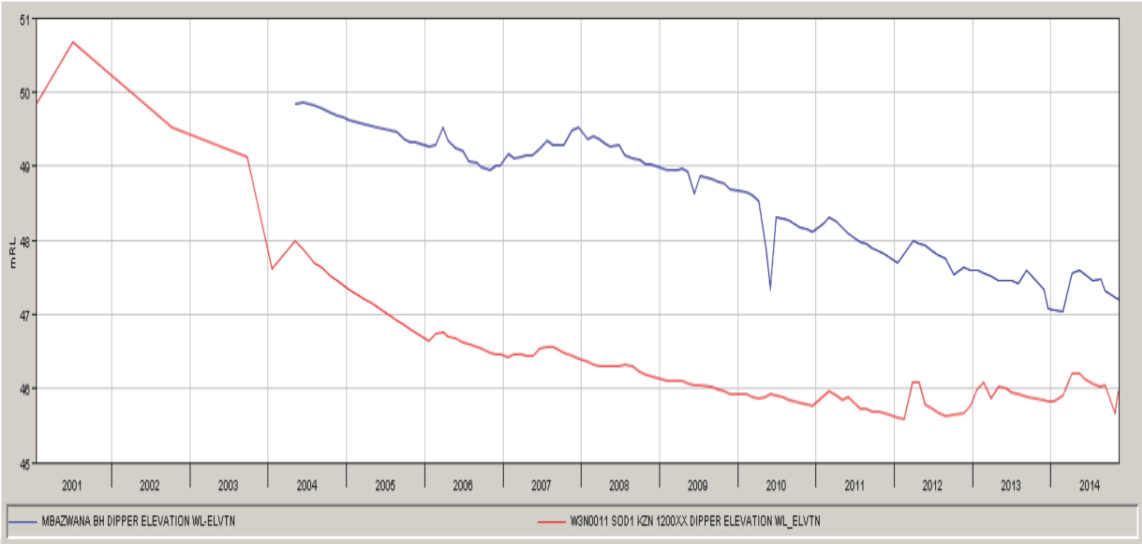


Figure 41. The measured water level ELEVATION (mRL) at Mbazwana () and Sodwana Bay (W3N0011) since 2004 and 2001 respectively. The series have been NORMALISED relative to a common starting elevation. The decline in water level for Mbazwana is approximately 1 mm day^{-1}.

2.7 MARINE ENVIRONMENT

The estuary enters the Indian Ocean at Sodwana Bay. Here the sea is warm and clear. Although the offshore Agulhas Current moves rapidly southwards, in the inshore environment there is a wind-driven longshore drift moving predominantly from south to north. It transports the sediments that accumulate to build the sand berm that closes the estuary mouth. This sand berm, to a large extent, controls the opening and closing regime of the estuary and is one of the most important drivers of the estuary dynamics.

The currents at the estuary mouth are affected by the Jesser Point reef. The estuary usually exits into the sea into the bay to the north of the point, but at times will move southwards to exit over the rocks.

The dominant angle of wave attack is from the southeast. At Jesser Point, the coastline changes angle and has a concave shape where radius of curvature becomes greater with increasing distance from this headland (Figure 43). Meeuwis (1982) described how the headlands of the Maputaland coast refract waves creating a ‘log-spiral’ coastline shape. In doing so it affects both the steepness of the beach and the sorting of sand grains – the coarsest being nearest the reef.

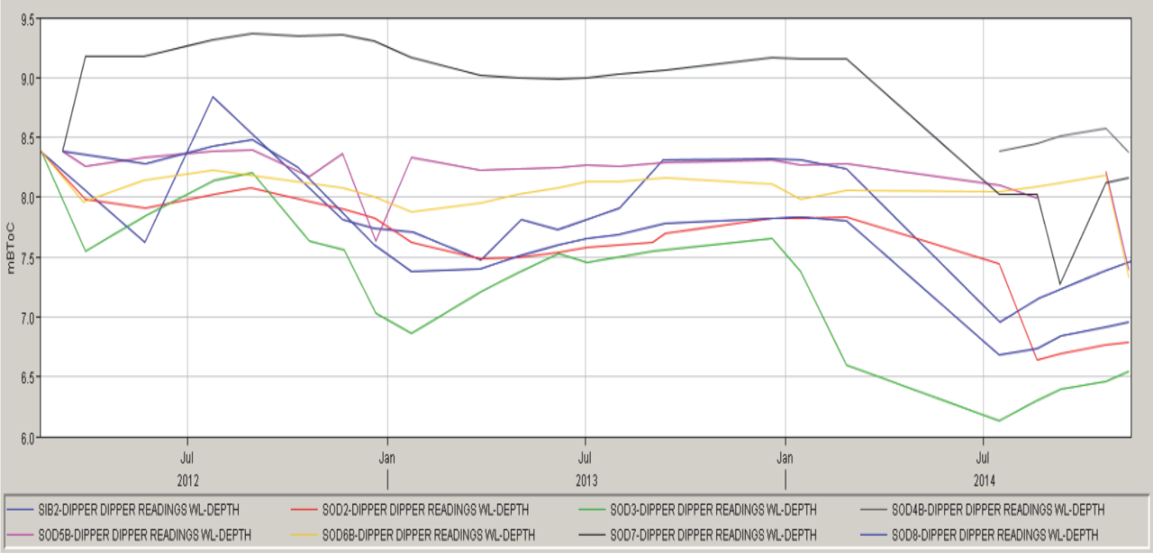


Figure 42. The measured DEPTH from the ToC to the water level in the new DWS monitoring boreholes (SOD2-SOD8).

The Maputaland coast is a sediment-rich coastline. The sediments are brought into the sea by the Tugela and Mfolozi Rivers and then work their way northwards. As well as the coast-parallel movements of the sand, there is also a pattern of movement normal to the sea as sand is washed onto the beach. Here it is then moved by the wind either inland to build the impressively tall vegetated coastal dunes, or up and down the beach.

Figure 43. The wave crests have been marked in white on this photograph. They show the refraction of waves by Jesser Point. This drives the erosion pattern on the beach which has formed the 'log-spiral' curve of the bay to the north of the reef. It is these waves that have shifted the estuary outlet northwards as seen in this photo.

There is a seasonal pattern to the sand movements. In winter most beach erosion occurs. The sea tends to be rougher and the angle of attack of the waves more from the south. The eroded sand is reworked by wave action and is taken into the nearshore zone. The sand on the beach works its way northwards in pulses. Large sections of the intertidal rocks can be exposed for several months at a time; then smothered in sand for a further few months as a pulse moves northwards.

When sand being moved by wind along the beach reaches a point where there is a change in beach orientation it bypasses the point by taking a 'short cut'. However, at Sodwana this bypass system was hindered by the Jesser Point casuarina trees planted in the 1950s to 1960s to stabilise the 'drift-sands'. It has not been the intention of this project to provide a sand budget. However, it is possible that the casuarina trees were altering the amount of sand available to the beach at the outlet of the estuary.

The sea level could not be measured for the Mgobezeleni site so it was necessary to obtain tidal data for Richards Bay. The hourly tidal data for Richards Bay were obtained from NOAA: UH SEA LEVEL CENTER/NATIONAL OCEANOGRAPHIC DATA CENTER and plotted in Figure 44 for the period from 2013 to 2015.

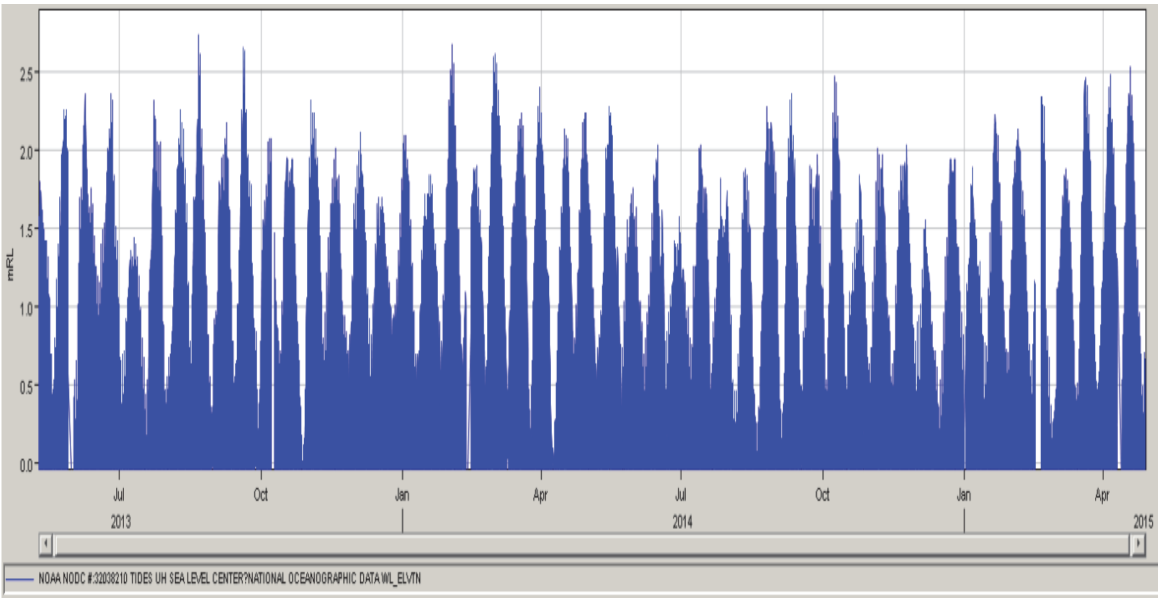


Figure 44. The hourly tidal range above Mean Sea Level for Richards Bay from <UH SEA LEVEL CENTER/NATIONAL OCEANOGRAPHIC DATA CENTER>

The marine tides have a large influence on the hydrodynamics of the estuary. At Sodwana, the tides are semi-diurnal with a maximum range of a little over 2 m. Waves carrying seawater may enter the estuary. This is dependent the level of the tides, the severity and angle of wave action, the height and width of the beach berm and whether the mouth is closed, constricted or open. At times, wave over washing may add sufficient water to breach the estuary. At other times, wave action causes a breach by eroding the seaward slope of the beach berm. This is particularly susceptible to erosion when the beach sand was wetted by the movement of groundwater flow through the sand of the berm. The dynamics of the beach berm are the topic of an MSc study currently being conducted by G Makwela, Department of Hydrology, University of Zululand.

The marine tides may be enhanced by storm conditions that cause the tides to be much larger than the predicted tides.

2.8 SOILS

A survey of the soils was conducted by the Natural Resources team of the KZN Department of Agriculture, Environment Affairs and Rural Development. Figure 45 shows the points where they sampled soils and from where soils were collected for laboratory analyses. A total of 192 soil points were assessed by using a hand-auger, to a depth of 2.5 m. At each point, the soil was classified to its Soil Form (Soil Classification working Group, 1991). From some of these points 46 soil samples sent for detailed lab analyses.

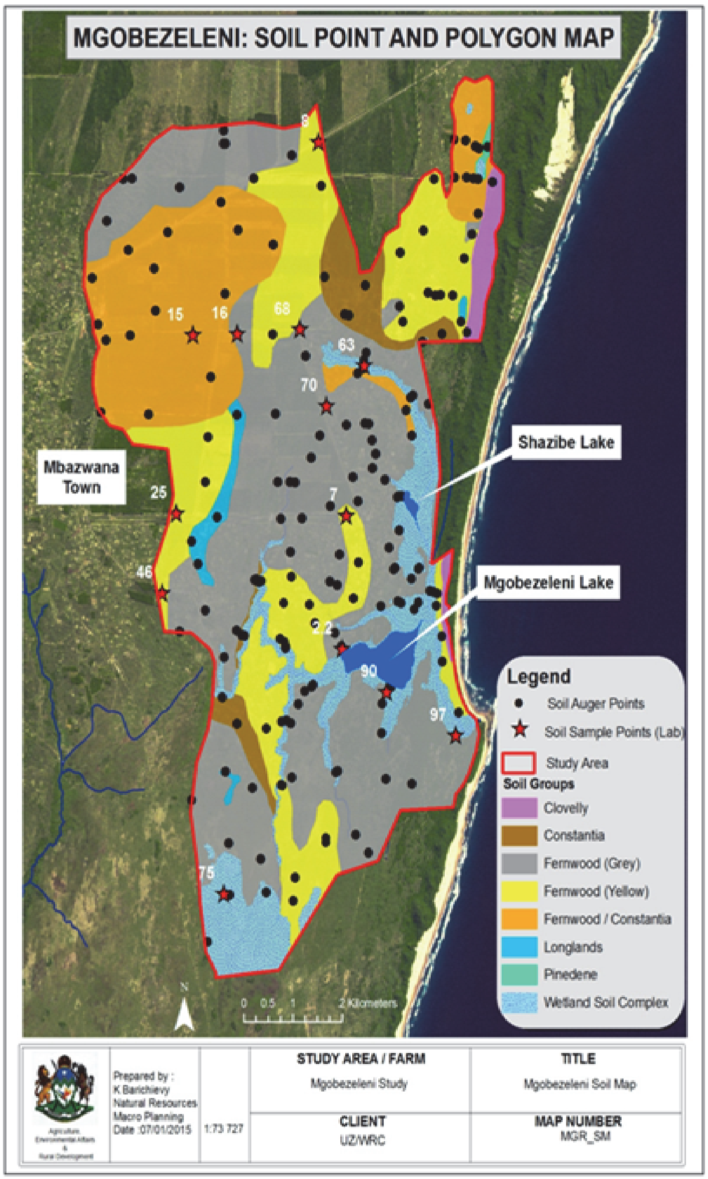


Figure 45. Map of the study area showing soil sampling and classification points and the generated map showing the soil forms (Atkinson & Barichievy, 2015).

A soils map (Figure 45) was then generated using a predictive soils mapping algorithm (which, *inter alia*, takes into account slope, elevation and a topographic wetness index). This work is being incorporated into a larger-scale soils mapping project which aims to have an improved understanding of the spatial soil dynamics, identify soil limitations to agriculture and improved land management in the Maputaland coastal plain (Atkinson & Barichievy, 2015) (See Appendix I).

From the soils map we see that 64% of the catchment area is dominated by deep, sandy and dystrophic soils – being either the grey or the yellow Fernwood Soil Form. Wetland soils were mapped as a soil complex that covered 12% of the area. They comprise of the Champagne, Katspruit, Kroonstad and Longlands forms. (Figure 46). For all the samples measured the pH is acidic, ranging from 3.18 to 6.55 (mean = 4.5).

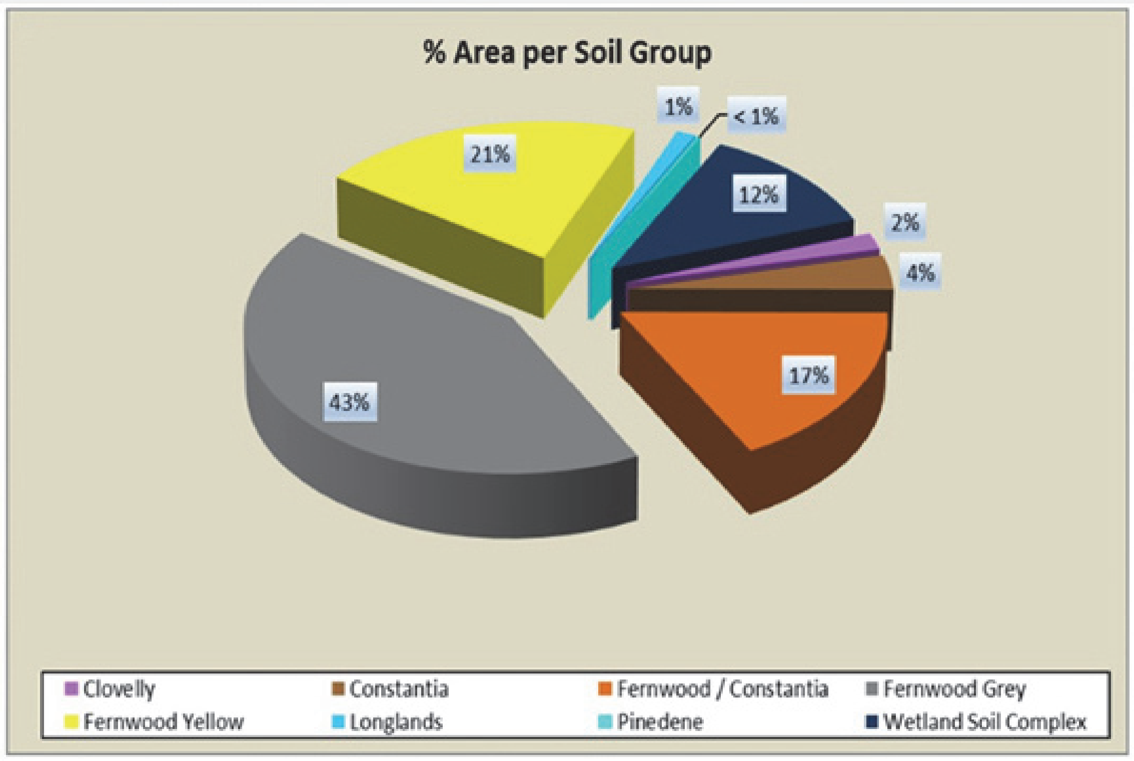


Figure 46. Proportion of soil groups in the catchment. (Atkinson & Barichievy, 2015).

Grain size was not measured from these samples. As the origin of the sand is aeolian, one would not expect very much variability.

Water permeability in the soils is the hydrological property of importance when describing the replenishment of groundwater by rainfall. An Honours project by Mnyango (2014) measured permeability, which he showed to be high.

2.9 ECOLOGY

The Mgobezeleni Catchment is part of the Maputaland Centre of endemism (Van Wyk, 1996). It is an area recognised for its diversity in plant and animal species, of which a number are endemic to the Maputaland Coastal Plain. Many of the species are tropical in nature, with many Afrotropical species reaching the southernmost limit of their range here.

Like the rest of the Maputaland Coastal Plain, the Mgobezeleni Catchment consists of wind-blown deposits of sand that have originated in the sea. This sand is well drained forming a large sand aquifer. In much of the catchment area, the water table is too deep to have a significant influence on the plants growing above it. Moving inland from the sea, the sands are older and rainfall is less. The resulting gradients are expressed in different vegetation zones, which were described by Moll (1980). The Mgobezeleni Catchment is within the zones that are closest to the coast.

In the Maputaland Coastal Plain the main determinants that control plant growth are the subtropical temperatures and absence of frost; the high rainfall – averaging about 1000 mm but having a large year-to-year variability; the young well-leached sandy soils with no rocks and little clay – they have a low nutrient status and are generally acidic. The vegetation is shaped by frequent burning, grazing and the influences of small-scale agriculture.

Along the coast, the dryland vegetation consists of tall dune forests merging into coastal forests further inland. Where fire, small-scale agriculture and grazing have prevented forest formation there is grassland. The coastal grasslands of the Maputaland coastal plain are characterised by a very large proportion of woody plants and forbs and are rich in legumes. A large proportion of the biomass of these grasslands is underground, as many of the plants have thickened roots, bulbs and other underground storage organs. This may be an adaptation to the frequent fires that affect the vegetation. As a result, there is a rich below-the-surface ecosystem, which supports many burrowing reptiles, insects, moles and other animals.

As part of this study, we requested a survey be done to determine veld condition. This was conducted by Keith (2016) of the Natural Resources and Macro Planning Unit, Department of Agriculture and Rural Development (See Appendix II). She produced a landcover map (Figure 47) based on the 2011 aerial photographs and the vegetation map done by Ian Felton (unpublished EKZNW map). This map shows the commercial pine and eucalypt plantations in the north, the central area where there are high densities of human habitation and the southern and eastern parts of the catchment, which are relatively undisturbed.

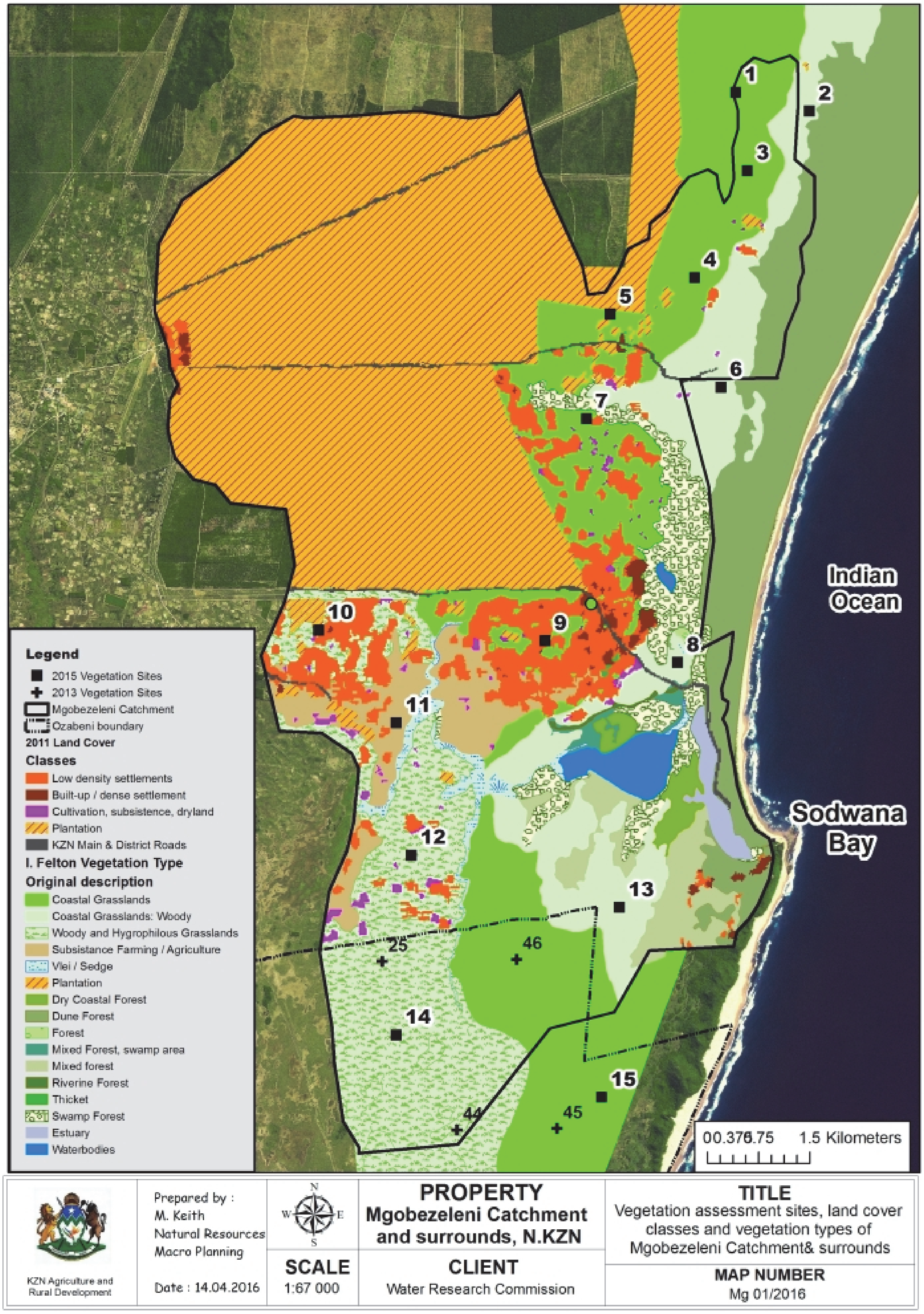


Figure 47. Landcover in the Mgobezeleni Catchment (map by M Cole; Natural Resources and Macro Planning, Department of Agriculture and Rural Development. The numbers indicate sites where detailed veld assessments were conducted.

2.10 LANDUSE

The study area was emerging from a pastoral community (Photograph 14) to a more developed system with the establishment of commercial forestry, peri-urban centres and ecotourism establishments (Photograph 15). The water needs and availability of these different communities varies considerably. The many, large ecotourism lodges require substantial quantities of water to service the needs of guest which is almost inevitably obtained from deep boreholes (Photograph 16) or from rainfall harvesting (Photograph 17). The local community rely heavily on Municipal water that is provided through standpipes along most access routes although some of the more affluent ones have installed boreholes.

Photograph 14. Cattle kraal in Sodwana

Photograph 15. Tourist lodge in Sodwana

Photograph 16. Monitoring production borehole

Photograph 17. Rainfall harvesting

The spatial distribution of human settlements in the Sodwana area were captured from Google Earth and plotted in Figure 48. Also shown in Figure 48 is the groundwater catchment for the Mgobezeleni estuary and lakes as represented by the simulated groundwater divide described in a subsequent chapter. Many of the human settlements between the state plantations and the Mbazwana stream do not fall into the Mgobezeleni catchment. Similarly, most of the Mbazwana CBD and the peri-urban settlements further to the west fall outside the catchment.

The land use types have a direct impact on the interception of rainwater leading to a direct reduction that varies according to the land use type. In urban and peri-urban environment, there is often a significant amount of rainfall harvesting for human needs. However, much of this water is released back into the environment as part of the waste stream. Vegetation will intercept rainwater and allow a proportion of it to be evaporated as part of the interception loss that will also depend on the storage capacity of the vegetation canopy, the atmospheric evaporative demand and rainfall intensity. Estimates of the interception potential of various land use types were determined by Clulow et al. (2014) for many of the land use types in the region.

The evapotranspiration rate for the different vegetation types depends on their age, morphology and rooting depth. The dominant vegetation types in the study area are listed in Table 6 together with their estimated potential evaporation rate at maturity and possible rooting depth identified from the literature.

The land use types in the groundwater catchment (recharge zone) for the Mgobezeleni Estuary is shown in Figure 49. Nearly half the catchment under commercial afforestation is classified as a StreamFlow Reduction Activity (SFRA) that is likely to have a significant impact on the water resources of the system.

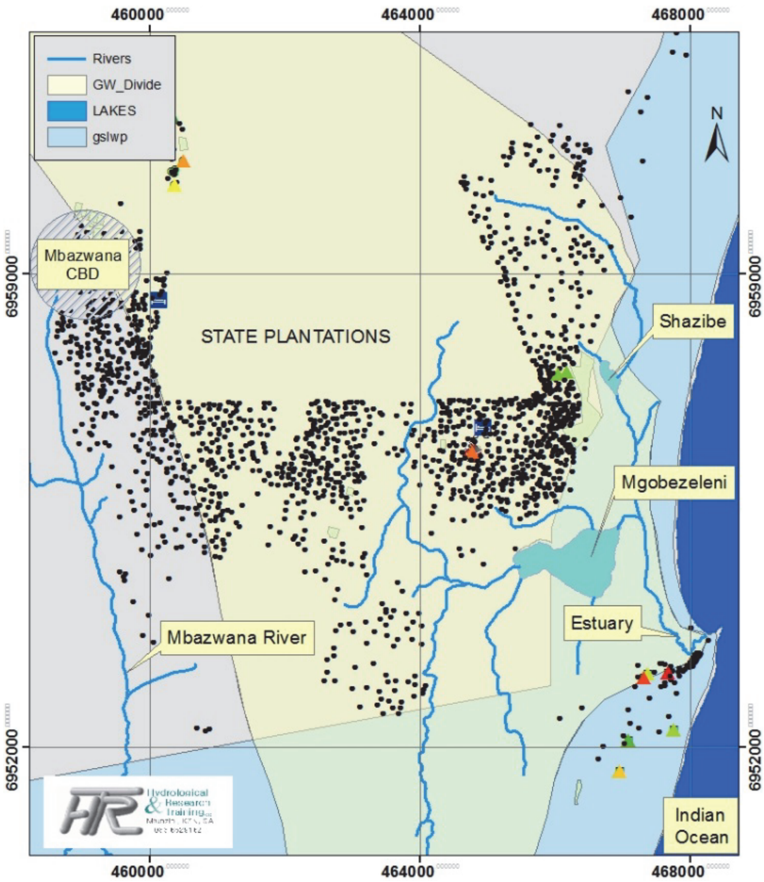


Figure 48. The spatial distribution of human settlements in the Mgobezeleni catchment.

Table 6. Dominant vegetation types and hydrological factors regulating evaporation.

Vegetation types	Potential Evap (% EP)	Max rooting depth
Grasslands	0.5	2
Eucalyptus plantations	1.2	30
Pine plantations	0.8	10
Swam forest	0.7	5
Dune forest	0.4	10
Wetlands	0.7	1

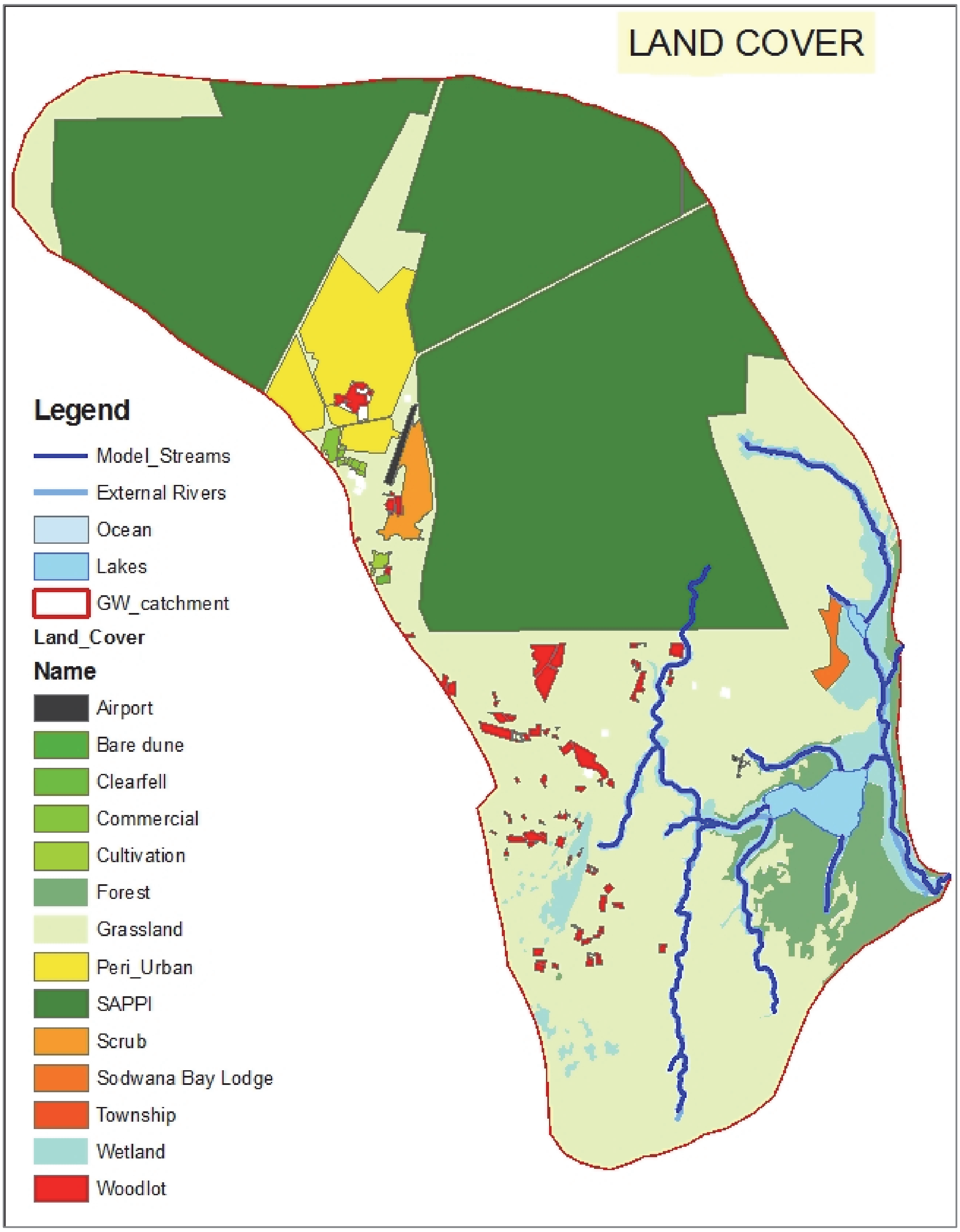


Figure 49. The Land use types for the Mgobezeleni Groundwater Catchment (*Source*: Ezemvelo KZN Wildlife).

CHAPTER 3. WATER QUALITY

The Mgobezeleni Catchment is located in an area where because the soils are sandy and unconsolidated, domestic effluents pose adverse impacts on the groundwater quality. This is especially because the subsurface aquifer is shallow and there is a growing population. The area is rural but the houses are mostly of a high standard having either an internal or external sewage system. However, there is no formal municipal sewage removal system in operation with the result that the dissolved minerals in the effluent is easily able to reach the aquifer. These minerals flow in the groundwater down the slope and enter the wetlands near the coast.

The catchment is very small, likely one of the smallest catchments on the Maputaland Coastal Plain with a large number of species found along the coast from St Lucia to Kosi Bay, a distance of some 170 km. It is typical of much of the area with a number of very valuable systems such as the Mgobezeleni Estuary, Lake Mgobezeleni, Lake Shazibe and peatlands in the watercourses that have a species biodiversity of international importance. A part of the catchment (study area) lies within the iSimangaliso Wetland Park World Heritage Site. The Mgobezeleni Estuary falls under the RAMSAR Convention, which illustrates its international importance. The aquatic ecosystems in the area provide valuable services to local as well as visiting communities. In the wetlands, crop cultivation is being undertaken and also provides grazing for cattle and natural livestock. Water is supplied from Lake Mgobezeleni to the Ezemvelo KZN Wildlife accommodation and office facilities and boreholes are accessing groundwater for both local residents and tourists. These groundwater resources are extremely important to the large tourism industry that exists because of a flourishing recreation facility that provides the most important tropical diving and fishing activity along the KwaZulu-Natal north coast. The Mgobezeleni Estuary functions as a most important recruitment facility for marine fishes and the marine environment, being the only recruitment estuary along a 180 km stretch of coastline.

The local population is greatly dependent economically on the annual influx of tourists who utilise the large and growing number of accommodation facilities, which require toilet facilities of a high standard. These are mainly of the flushing kind employing septic tanks for the initial treatment of the effluent. These systems are largely conservative of the mineral elements contained in human effluent with the result that they, and especially nitrogen and phosphorus (N and P) being very soluble in water, flow down towards and enter the groundwater. All this groundwater flows towards the surrounding aquatic ecosystems, which under natural conditions had evolved under a very low mineral status. The concern that follows the increase in the local population together with the impact of high nutrient inflows as a result of tourists is what the impact will be on the ecology of these important catchment resources.

There are not many natural freshwater lakes and water bodies in South Africa and most of them occur along the Maputaland coastal plain. Their ecological structures and functions are influenced by the interaction of both marine and fresh groundwater. Because of the regional high temperatures, these mostly shallow lakes have no clear pattern of temperature stratification with the result that most of the mixing between upper and lower water is the result of wind. Water temperatures range from 27 to 24^{O}C in summer and 19 to 24^{O}C in winter. The area is classified as subtropical.

The local municipality abstracts water from Lake Sibaya and pumps it to a water treatment facility in the town of Mbazwana before distributing it via a pipeline to some of the residents in the catchment. This implies that it is not only water from rainfall that reaches the catchment. However, the volume of this water from Lake Sibaya is very small by comparison with the volume that enters annually via rainfall. The water quality from Lake Sibaya is low in both nitrogen and phosphorous with the result that there will be very little effect on the total N and P entering the catchment. Although the freshwater in Lake Sibaya is low in N and P, it is brack because of a high chloride concentration. This high chloride concentration is attributed to recent cyclic salt input from the sea or from fossils sources in the Tertiary sand of the underlying basin. Salinity in Lake Sibaya is about 0.6% with chloride concentration of 135 mg l^{-1} (Allanson and van Wyk 1969).

The coastal sands, on which these northern lakes lie, are generally oligotrophic. The phosphorus levels in the water are consistently quite low with a total phosphorus concentration below 30µg l^{-1}. The nutrient levels are higher in the smaller and shallow lakes than in the large deeper ones, and higher in isolated water bodies than in interconnected systems.

Considering that the Mgobezeleni catchment is supplied with water mainly by rainwater, the question that arises is the amount of nitrogen and phosphorus that might be imported into the catchment via this rainfall. Herut et al. (1999) measured nutrient input in the SE Mediterranean area and found the concentrations were in the order of 0.28 g N m^{-2} and 0.009 mg P m^{-2} with some of the N arriving from desert dust. If these data are converted to concentration in an area with 1000 mm rain p.a. indicate an input of 0.28 and 0.009 mg l^{-1}. Subsequent work by Herut (2002) showed that dry deposition was up to 2.5 times higher than wet deposition. Cornell et al. (1995) have shown that nutrients from atmospheric sources have increased as a result of anthropogenic activities but their data showed no correlation between PO_4, NO_3 and NH_4, which indicates a non-marine origin. Their values for wet nutrient fluxes were ~0.009 g m^{-2} yr^{-1} of P and 0.364 g m^{-2} yr^{-1} of total N. Mignon and Sandroni (1999), on the other hand, showed that P input from atmospheric sources had a high variability in the concentration between 0.05- 4.4 umol.l^{-1} (0.003-0.14 mg l^{-1}). The more bioavailable sources of P arrived from incineration with the higher values associated with the incinerators burning biomass.

Weinmann (1955) in Zimbabwe measured 3.2 and 4.3 mg N l^{-1} in two different seasons and Bate and Gunton (1982) who measured ~2.2 mg N l^{-1} at Nylsvlei. In the latter study, NH_4-N constituted 77% and NO_3 23%. Unfortunately, P was not measured in either of these studies because its relative importance to aquatic systems was not considered. The relevance of all these foregoing data is that although rainfall can provide high concentrations of N to the soil, the N content in rain-fed groundwater is about 100 times lower under non-pollutant conditions. This in turn implies that the natural vegetation takes up most of the N that falls in rain. However, when sewage is drained below the reach of vegetation roots, the content in groundwater is high.

Peiqiang Hou et al. (2012) found that nitrogen deposition in Beijing, China was mainly in the dissolved form whereas dry deposition was the main form of P. In that area the content of total N was 7.69 mg l^{-1}, while dissolved N was 6.54 mg l^{-1}. Total P was 0.044 mg l^{-1}, and dissolved P was 0.016 mg l^{-1} with N:P ratios of 174.8 and 408.8 in the dissolved fraction. This indicates that the majority of P arrives as particulate P. This Chinese study showed data that was much higher than Singapore that had TN values of 1.05 mg l^{-1}, Connecticut USA 1.2 mg l^{-1} but lower than Wuhan China which had 3.07-4.39 mg l^{-1} in their rainwater. It does illustrate the effect of industrialization and the anthropogenic effect. There will certainly not be a similar effect at Mgobezeleni where atmospheric inputs are likely very low but development and the anthropogenic effect is clearly growing.

An interesting example was given by Howard-Williams and Thompson (1985) in quoting Hejny (1973); "The swamps associated with the complex fishpond ecosystems in Czechoslovakia, which were under human management since about the 13th century, are now apparently threatened by modern hydrological and agricultural projects. The floodplain soils of the lower Nile Valley and Delta have supported large human populations for 6000 years. Only late twentieth century technology has destroyed or damaged the natural system. The fact that such systems, which were under Man's active management for so long, are now threatened by his own activities makes one appreciate immediately similar dangers in other areas. This is particularly true for wetlands of the tropics, where man has until recently either ignored or 'reclaimed' them".

In the motivation for Project K5/2259, the proposal had a component that identified the Mgobezeleni Catchment area as the focus of a considerable amount of development because of long-term land-lease agreements organised by the local Traditional Authority. These agreements were being taken up at financial rates that were believed to be below the market rates prevailing in many other parts of South Africa. The result was that expansion was not confined exclusively to the local population but that "holiday homes" were being constructed at a fairly rapid rate. Support for this expansion observation was the presence of cement building blocks being used both in new construction or standing in piles waiting to be delivered to building sites. This frequent observation initiated the realisation that there appeared to be a fairly rapidly increasing population in the area.

In addition to private residential buildings, there were also an assortment of small enterprise businesses arising, such as hotels, bed and breakfast resorts, camping resorts and shops. It was clear in the early stages of the project that these facilities would require associated infrastructure in the form of garages, mechanical workshops and a local municipal infrastructure. The belief was that the municipality would provide all the usual services, which would include the reticulation of water and the removal of household and commercial waste. However, because there appeared to be no municipal sewage system, the project identified that human waste was likely being disposed of in sewage systems on the properties where people were living, working and visiting. This identified the need to examine the groundwater quality because some of the water being used for human consumption was coming from boreholes. It is important to understand that the water being used by the community is either from the municipal water reticulation system or from private boreholes. This is because there are no other sources of water available other than the lakes (Sibaya, Mgobezeleni and Shazibe). As stated previously in this report there are no rivers entering the catchment and the only form of water replenishment is rainfall. This being so, the effect of disposing sewage waste into the ground and withdrawing water from the ground was worthy of investigation.

Because there is a central water distribution system derived from Lake Sibaya administered by the local authority, it was necessary to analyse samples from a wide assortment of sources. These included samples from the abstraction pool at Lake Sibaya and other potential sources, i.e. Lake Mgobezeleni, Lake Shazibe, tap water, borehole water, rainwater, roof water and locally stored water acquired from one or more of the foregoing sources. The need to examine this latter source arose during the sampling process when observations showed that some of the houses connected to the Mbazwana authority pipeline had such low pressure in the taps that the householders would allow the water to run under very low pressure into plastic drums. Residents indicated that the flow was continuous, day and night, in order for them to obtain sufficient water for their daily needs.

Students studying for their Honours degrees in hydrology at the University of Zululand were used exclusively to sample water from the local community, while the research team collected samples from the commercial community (accommodation facilities, restaurants and businesses) and from the estuary, the two lakes as well as the valley streams. The reason for this division of labour was to ensure that both communities were addressed in their own language and could have the collection purpose clearly explained to them. We realised early on that there was suspicion about the reason for the presence of unknown persons travelling around the area asking questions. This sampling component was linked to the socio-economic part of the study (see later).

Water samples were collected into newly purchased bottles (500 ml) and each was rinsed twice with the water being sampled. Only new bottles purchased from the same source were used throughout the project. After filling, the bottles were capped with lids that could not be removed without breaking the seal. Each bottle was labelled using a permanent marker. The marked bottle was identified with a number and the geographical location of the sample was allocated with coordinates using a hand-held Garmin GPS (global positioning system). This allowed the water quality to be identified with a map reference. The person allocated the collecting task always collected the samples personally. Bottles were never left for local persons to make the collection other than in the case of rainwater. In the case of rainwater, there was no alternative and in most cases, rainwater samples were rejected as likely having suspect results. All samples collected on a particular occasion (sample trip) were sent to the same accredited water analysis laboratory where the concentration of nitrogen as nitrate, nitrite, ammonium and phosphate (as orthophosphate) was assessed. The purpose of analysing only for nitrogen (N) and phosphate (P) was related to the primary purpose, namely to assess the effect of sewage disposal into the soil and groundwater.

Three different accredited analysis laboratories were employed. The choice was mostly based on ease of delivery of the samples. While we were aware of the differences in concentration that can occasionally be returned by different laboratories analysing “split samples”, the levels of difference were relatively unimportant in this survey because the purpose was to detect whether N and P pollution was present in the water bodies, rather than to determine the absolute levels. We were confident that SANAS accredited laboratories were capable of producing results adequate for our purposes. The three laboratories used were Talbot and Talbot (Pietermaritzburg), Mhlathuze Water (Richards Bay) and Yanka Laboratories (Middelburg, Mpumalanga). All three laboratories produced acceptable results and the final choice was based on accessibility after sampling.

The assessment of whether water from any source was or was not polluted is based on two sets of standards. These two standards are the South Africa National Standard (SANS 241) for Drinking Water 2011 (Class 1 limits) and the ecological standard (South African Water Quality Guidelines, Volume 7 – Aquatic Ecosystems).

According to the SA standards, inorganic nitrogen is seldom present in high concentrations in unimpacted surface waters. This is because inorganic nitrogen is rapidly taken up by aquatic plants and converted into proteins and other organic forms of nitrogen in plant cells. In South Africa, inorganic nitrogen concentrations in unimpacted, aerobic surface waters are usually below 0.5 mg N l^{-1} but may increase to above 5-10 mg N^{-1} in highly enriched waters. Oxidized forms of inorganic nitrogen usually occur under natural conditions (e.g., mineral salts derived from rocks and soil, not due to man's activity), or due to seepage from sewage systems and leaching of organic and inorganic fertilizers from soil. The acceptable drinking water range of nitrate + nitrite concentrations is < 10 mg $l^{-1,}$ while the acceptable range for ammonia is 0-1.0 mg l^{-1}.

Using the data reported by de Villiers and Thiart (2007) we accepted the lower levels of nitrogen and phosphate for ecological water as 0.05 mg l^{-1} of N and 0.01 mg l^{-1} of P respectively.

3.1 ESTUARY WATER QUALITY

In July 2013, the estuary water was sampled at two sites. The one was in the upper estuary, possibly at the limit of salinity influence (-27.541860: 032.674340) while the other was at the bridge crossing the estuary (-27.541356: 32.667700). The water quality at the upper estuary site was ortho-phosphate P 0.00 mg l^{-1}. Unfortunately, there was no value returned for nitrate-N. A further sample collected from the estuary at the bridge returned values of nitrate+nitrite N of 0.09 mg l^{-1} and ortho-phosphate P of 0.008 mg l^{-1}, illustrating that the water quality was of a high standard from an environmental perspective and could be considered oligotrophic from the perspective of that single parameter (water quality). Furthermore, the ratio of N:P :: 10:1.

In February 2014, estuary water collected from the bridge site (E2) was analysed with the results shown in Table 7.

The data in Table 8 indicate that while the levels of N and P were slightly elevated, the extent was not large but the N:P ratio was about ~1.3:1. In June 2014, the estuary water was re-sampled at the bridge-crossing site (E2). The quality at that time showed nitrate-N 0.11 mg N l^{-1}, nitrite-N 0.01 N l^{-1}, and ammonium–N 0.12 mg N l^{-1} giving a total N concentration of 0.24 mg N l^{-1}. Unfortunately, ammonium N had not been assayed in 2013 hence a comparison of total N between the two dates is not possible. The difference in the nitrate-N values between the two dates suggests that the contents at the different dates were not likely to be significantly different.

Table 7. Results of water analyses from site E2 Mgobezeleni Estuary.
(Analysis by Mhlathuze Water in February, 2014).

Sample site	Nitrate as N (mg l^{-1})	Ammonia as N (mg l^{-1})	Total Phosphate (mg l^{-1})
E2 Bridge	0.12	0.05	0.09

The data in Tables 8 and 9 suggest that there was no appreciable N or P pollution in the estuary. The pH of the water (approx. 7) indicates that the samples were of fresh water rather than seawater which has a pH of ~ 8.0-8.2.

The results of all the estuary water analyses (2013-2015) indicates that there was no serious pollution in the estuary water, but that values for nitrogen and phosphate were likely at times to be slightly elevated above a desirable ecological level.

Table 8. Results of estuary water analyses from site E2 (Estuary) – June 2015 (Analysis results from Yanka Laboratories, Middelburg, Mpumalanga).

Depth	pH	Ammonium-N	NOx-N	Nitrite-N	O-Phosphate
0	6.78	<0.45	<0.35	<0.01	<0.03
0.25	7.1	<0.45	<0.35	<0.01	<0.03
0.5	7.02	<0.45	<0.35	<0.01	<0.03
1	7.04	<0.45	<0.35	<0.01	<0.03

Table 9. Analysis of water samples from the estuary sites in July 2015. (Analysis results from Yanka Laboratories, Middelburg, Mpumalanga).

SAMPLE DESCRIPTION	EST 11 Surface	EST 1 Surface	EST 2 Surface	EST 1 West Surface	EST 2 West Bottom	EST 22 (01) Bottom	EST 221 (02) Bottom	EST 2 Bottom
Remarks	Clear	Clear	Clear	Clear	Brown	Clear	Clear	Clear
pH (Laboratory)	7.49	7.26	7.19	7.04	6.93	7.22	7.17	7.17
Total Dissolved Solids	236	258	258	259	265	230	229	252
Suspended Solids (TSS)	10.0	<0.4	2.00	8.00	194	20.0	26.0	<0.4
Turbidity	11.5	3.77	6.56	4.59	72.9	7.72	9.31	9.34
Ammonia	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45
Nitrate + Nitrite (TN)	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35	<0.35
Nitrite	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ortho Phosphate	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03

3.2 ESTUARY BLACK WATER

The term "black water" is used interchangeably by engineers and scientists for primary sewage effluent and river water that is black or has a brown discolouration. In the context of this review, the term is used exclusively in respect of discoloured river water. Rivers with black water are usually very oligotrophic, i.e. with a very low content of dissolved minerals and often have no measurable water hardness (www1).

3.3 BLACK WATER ESTUARIES IN SOUTH AFRICA

Whitfield et al. (1983) described the river water flowing into the Swartvlei system of the Western Cape as being stained dark brown by dissolved organic matter leached from the vegetation of the catchment area with a low electrolyte concentration and an acid pH (pH 4-5). They described the dissolved organic matter as "humic matter" with a concentration of 60-80 mg l^{-1}, and which precipitated out in the estuary at salinity above 17.5 psu, provided the pH was above 8.0. This latter observation may indicate that in contact with seawater (pH ~8) the humic matter either is decolourised or is diluted to the point where the "brown colour" is no longer visible. This humic acid when precipitated was considered likely to represent a significant import of organic matter into the estuary. Rivers flowing into the Swartvlei system include the Wolwe, Hoërkrool and the Karatara rivers. The dissolved organic matter of the Wolwe River was only about half that of the Karatara and Hoërkrool Rivers. Concentrations of nutrients in river water flowing into Swartvlei were given by Howard-Williams and Allanson (1978b) as soluble phosphate 6 µg l^{-1} (0.006 mg l^{-1}) during normal flow. From these observations, it is possible to conclude that the concentration of "humic matter" in river water is a factor controlled by some feature of the environment where the river rises and/or through where it flows.

Black water is a common feature of rivers in the Western Cape along the south coast of South Africa but not so common along the west coast or the east coast. Much of the literature on this black water phenomenon was provided in the estuary "Green Books" produced by the CSIR in Stellenbosch. In this series, the water in the rivers above the estuary head was described. The most westerly river on the south coast where black water was identified is the Buffels (Wes). This is in False Bay and was described by Heineken et al. (1982).

Some estuaries in False Bay have not been reported to have this stained water. These include Silvermine (Heineken 1982), where the reservoir water had a pH of 4.9. Storm water addition probably accounts for the absence of black water reports, i.e. there is no "natural water" flow any more. There are no reports of black water in the Zeekoei or Eerste estuaries (Grindley, 1982). It is possible that, because the area, which is now Cape Town, was populated for so long, anthropogenic sources of nutrients have raised the pH of the surrounding soils and the "pristine" decaying vegetation no longer exists. However, Morant (Pers. Com.) maintained that the Eerste River is a black water system in the Jonkershoek but is nutrient enriched on its way to the sea and loses its tea colour in the process.

Other estuaries in False Bay supplied by rivers with black water include the Sand, the Lourens and the Rooiels. The Sand River (i.e. Sandvlei) receives water that has its origin in Table Mountain sandstone that imparts a special character to both the vegetation and the dissolved solids in the water, which is soft, peat-stained and slightly acid (Morant and Grindley 1982). In the case of the Lourens Estuary, (Heineken et al., 1982) reported transparent brown water with a pH of 6.0-7.0. This was considered typical of water drained from catchments dominated by Table Mountain Group sandstones (TMS) and the brown colouration was considered as probably due to humic acids leached out of the decaying vegetation (King et al., 1979).

The Buffels (Oos) Estuary (Heineken et al., 1982) has the brown peat-stained acid water, which also drains from a TMS-dominated catchment (van Wyk 1959). In the case of the Rooiels, which was considered to be ecologically healthy, Heineken (1982) reported it to have brown peat-stained water in 1958, 1978, 1979 and 1981 while the pH was 6.4-6.5 and the salinity 24-28 psu. Some estuaries in False Bay have not been reported to have this stained water. These include Silvermine (Heineken 1982), where the reservoir water had a pH of 4.9. There are no reports of black water in the Zeekoei or Eerste estuaries (Grindley, 1982). It is possible that, because the area, which is now Cape Town, was populated for so long, anthropogenic sources of nutrients have raised the pH of the surrounding soils and the "pristine" decaying vegetation no longer exists. However, as stated before, Morant (Pers. Com.) maintains that the Eerste River is a black water system in the Jonkershoek but is nutrient enriched on its way to the sea and loses its tea colour in the process. This latter consideration is important in the case of the Mgobezeleni Estuary, which receives water enriched by sewage effluent.

In the Bot/Kleinmond system, which is just east of False Bay there is no mention of brown/stained water. Even the Swart River, one of the tributaries despite the name, was noted as being unstained by humic acids (Heydorn and Tinley, 1980). It is possible that this river also has changed under the influence of anthropogenic input.

Black water was identified by Morant (1983) in the Groot Brak Estuary. "The water throughout the estuary was clear but in the upper reaches heavy-staining ("black-water") limited light penetration (Secchi disc reading of 0,6 m during the November 1981 survey). From the foregoing, it might be concluded that under South African conditions, black water flowing into estuaries is mainly a phenomenon occurring in the Western Cape region caused by the decomposition of vegetation in areas with the dominant geology of Table Mountain Sandstone (TMS), and producing water with a low pH. However, Morant P. (Personal Communication, email 19/03/2013) considered that "blackwater systems are not unique to TMS and the SW Cape". In agreement with this and with specific reference to the Mgobezeleni Estuary, Begg (1978) stated, “The pH in the estuary is said to be 7.0 with an alkalinity of 78.1 mg l^{-1}. The water colour is dark brown – being typical of the humate staining from swamps above the estuary”. With reference to the Kosi system, Begg (1978) referred to McNae (1968) who emphasized that the dark colour of the river and lake water was due to its having risen from leached acid sands over which peat drainage had given rise to the "humate staining". The term “acid sands or acid soils" is often associated with material low in fertility. An example of this is soils produced from Table Mountain Sandstone (TMS). Soils derived from TMS are both low in plant mineral nutrients and the pH is often low (~4-5). In the case of the Mgobezeleni sands, which, being aeolian and heavily leached, should also have a low pH, but actually show an almost neutral pH (7.06; SD 0.60; Range 6.64-7.49; n=51).

From the foregoing, it appears that the black water in Mgobezeleni is the result of humic and fulvic acids that leach from the peat that accumulated in the drainage lines leading to the lakes and estuary. Sposito (2008) maintained, "the structural complexity of soil humus has thus far precluded making a simple list of component solids". He continued to state that the two most investigated humic substances are humic acid and fulvic acid. Where humic acid has the general formula of $C_{185}H_{191}O_{90}N_{10}S$ and fulvic acid has the general formula $C_{186}H_{245}O_{142}N_9S_2$. In the case of the black water in Swartvlei, Whitfield et al. (1983) reported that the concentration of dissolved organic matter was 60-80 mg l^{-1}. A sample of Mgobezeleni Estuary water analysed by an accredited laboratory in 2013 reported a dissolved organic matter concentration of 17.4 mg.l^{-1}, which is only about 25% of the concentration measured in Swartvlei. Despite this apparently low value, the water in the estuary appears very black (Figure 50).

Figure 50. Aerial view of the black water in the Mgobezeleni Estuary (Source: G Nanni).

A water sample was collected from the estuary using an articulated extended aluminium tube. Before entering the water, the tube was initially blocked to prevent water entering and was allowed to sink to the sediment surface. The tube was then unblocked and water and sediment was allowed to enter under hydrostatic pressure. The water so collected was placed in a 500 ml bottle using a number of tube-samples until it was full. Photograph 18 shows how the sample, that was originally totally black, separated within 20 minutes into its component parts. Of interest is the light colouration of the supernatant by comparison with the dark colour of the estuary water as photographed from the air (Figure 50).

One of the estuary sampling points was from the road bridge. Looking down from the edge into the water, its appears completely black. Despite this appearance, a secchi disc can be seen when resting on the bottom at a water depth of 1.7 m and the conclusion is that the water is fairly clear but with a lower layer of black sediment overlying the sandy sediment.

Photograph 18. Sample of water from the Mgobezeleni Estuary showing the settled components. Top – water discoloured by humic/fulvic acids; Upper bottom – layer of fine organic particles; Lower bottom layer of sand.

A conclusion from the foregoing data is that the concentration of black "humic and fulvic acids" is lower in the Mgobezeleni Estuary water than in the case of Swartvlei water (60-80 mg l^{-1}) because the dissolved organic carbon in Mgobezeleni Estuary water was measured as 17.4 mg C l^{-1}. (Note the difference in units between the Swartvlei data and these data. Swartvlei was a measure of dissolved organic matter whereas the Mgobezeleni data refers to dissolved organic carbon).

The question arising is what the black sediment in the estuary might be and hence samples were subjected to microscope observation and energy-dispersive X-ray spectroscopy (EDX) analysis, which is an analysis technique used for the elemental analysis or chemical characterisation of a sample. This analysis technique was employed using equipment from the Scanning Electron Microscopy equipment from the Microscopy Unit at the University of Natal in Pietermaritzburg. Particle samples were first examined using a light microscope. Figure 51 shows a light-brightfield micrograph of a black particle from the estuary. Because these images did not permit identification of what the particles were composed they were subsequently examined by EDX analysis with SEM.

In an attempt to identify the black particulate matter from the estuary samples from various positions were subjected to scanning electron microscopy with EDX (See Figure 52).

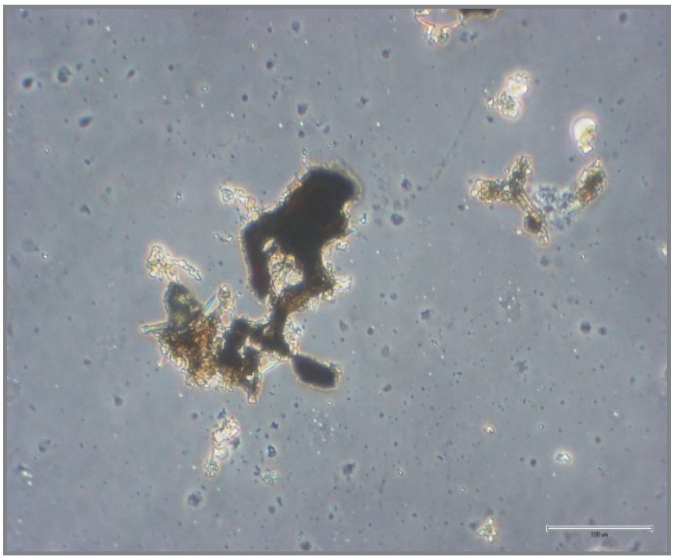


Figure 51. Brightfield image of peat fragments collected from the bottom of the estuary. (Photo: S Naidu, UKZN).

Energy-dispersive X-ray spectroscopy (EDS, EDX, or XEDS), sometimes-called energy dispersive X-ray analysis (EDXA) or energy dispersive X-ray microanalysis (EDXMA), is an analytical technique used for the elemental analysis or chemical characterization of a sample. It relies on an interaction of some source of X-ray excitation and a sample. Its characterization capabilities are due in large part to the fundamental principle that each element has a unique atomic structure allowing unique set of peaks on its X-ray emission spectrum (Goldstein 2003). The elemental analysis provided by the EDX x-ray spectrum is shown in Figure 53.

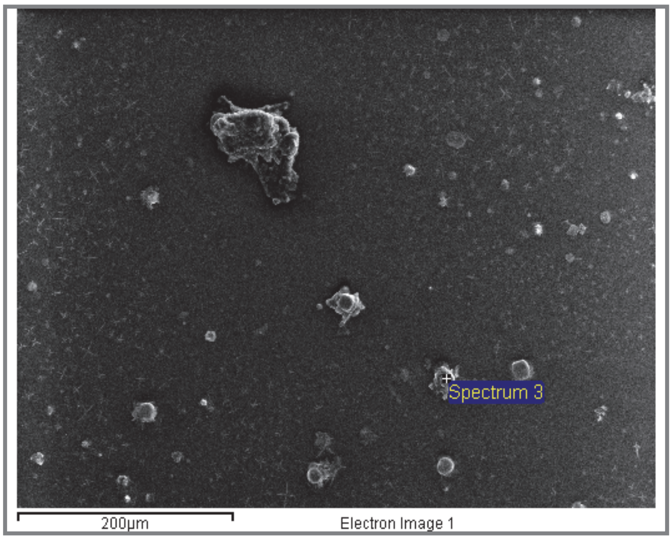


Figure 52. Scanning electron microscope image of black (peat) fragments collected from the bottom of the estuary (Note scale) (Photo: S Naidu, UKZN).

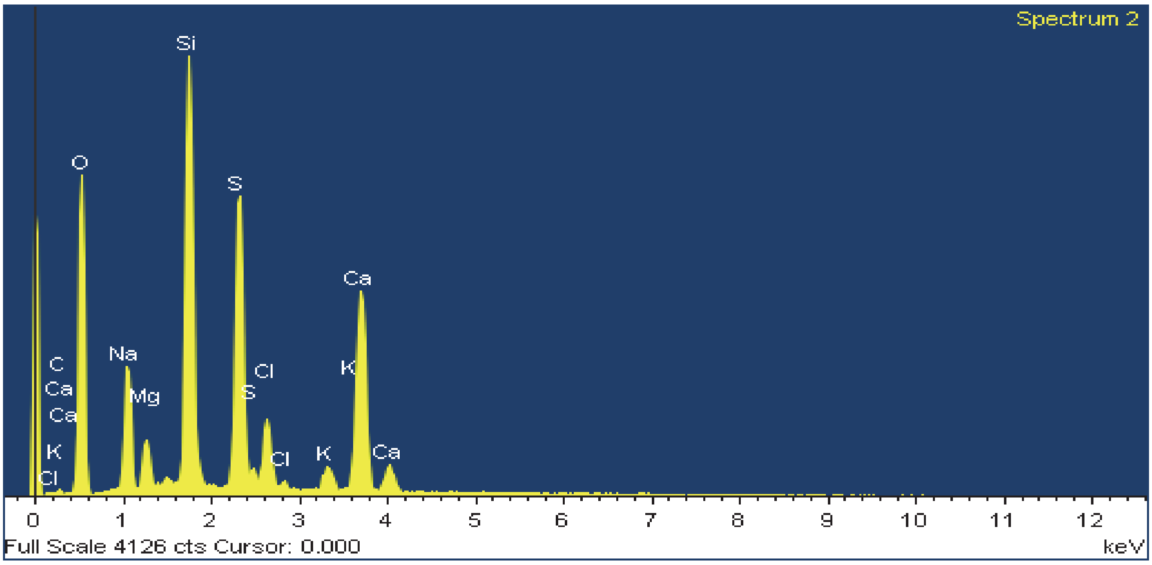


Figure 53. EDX elemental analysis report of the estuary particle (Site 3 Spot 2) from Figure 52 above.

The data in Table 10 indicate that the sum of Carbon and Oxygen (Organic matter) is greater than 50% and that the likelihood of the particles being organic matter is high. The likely major source of this organic matter would be peat of which there is a large amount in the catchment.

Table 10. Elemental analysis of a particle from the Mgobezeleni Estuary (Figure 53) showing the weight proportions as a percentage by weight.

Element	Weight %
C K	3.78
O K	48.68
Na K	6.01
Mg K	1.82
Si K	12.98
S K	11.52
Cl K	3.14
K K	1.18
Ca K	10.89
Total %	100

3.4 LAKE WATER QUALITY

The quality of the water in the lakes is of interest in the Mgobezeleni catchment because it is close to the end of the water flow from rainfall input through the soil after interacting with all the factors in the soil, to its output into the sea. After the water has flowed into the lakes, biotic and abiotic factors take control and influence the quality that eventually flows through a large swamp area into the Mgobezeleni Estuary. Within the lakes, light and temperature interact with microbes (microalgae and bacteria) and macrophytes that respond to the nutrients (N & P) to produce the visible product that is the lakes ecosystem that is the water quality and vegetation.

When lakes have a water supply that is low in mineral nutrients, the vegetation is usually sparse both in the water column and in the shallow margins. If the water flowing into the lakes has an elevated supply of plant nutrients, the result is usually an increase in productivity in the form of plant growth and animal biomass. If the nutrient concentration in the water rises beyond a certain level, the system changes and the species change together with biomass that usually increases. Many of the changes at this level are invisible to the naked eye but can be detected microscopically as a change in species or the number of species. These changes (rate and type) are also affected by temperature. In cold regions, lake water can “turn over” in winter when the surface water cools to less than the deep water. This in effect causes the warm deep water to rise above the cold surface water. In sub-tropical and tropical regions this does not occur and the response to low levels of nutrient enrichment are different. In the case of the lakes in the Mgobezeleni catchment, the sub-tropical environment likely results in them behaving more like water bodies in other tropical regions than many of the lakes and impoundments in South Africa.

Because no rivers flow into the Mgobezeleni catchment the initial soil water quality is that of the rainfall. Part of the rainwater flows below the root systems of the terrestrial vegetation and in doing so, some of the nutrients brought in by the rain are extracted. The proportion of nutrients so extracted depends on the rainfall intensity, the vegetation type and the time that the water takes to percolate beyond the root system. However, as the water passes through the soil it also takes up nutrients that are deposited there by other systems. In the case of the Mgobezeleni catchment, these other nutrients are mostly waste matter of human and domesticated animal origin. In natural systems unpolluted by human activities, animals and plants create a balance where animals consume the plant nutrients, grow on them and excrete them. The animal biomass is limited by the amount of plant biomass and the growth of new vegetation is limited by the amount of available excreted nutrient. This is the case even under conditions of high animal biomass. Hence, it seems reasonable to assume that most of the animal excretion that occurs onto the soil surface does not enter the groundwater. However, when excreted matter is deposited below the root zone, it is necessary to assume that most of those nutrients enter the groundwater that eventually flows into the streams and lakes. Once again, in the specific case of Mgobezeleni, much of the human waste is discarded through latrine systems that concentrate the nutrients and takes them below the rooting zone of the vegetation. This identifies toilets as a source of pollution and the degree of pollution as dependent on the number of people in the catchment. This is quite different to "natural" systems where nutrients are recycled and distributed widely and their concentration in turn limit the number of animals depositing N and P.

3.4.1 Lake Mgobezeleni

Lake Mgobezeleni receives its water from groundwater seepage as well as from streamflow (see hydrology and ecology sections). Because of this, both stream water and groundwater were sampled so that those sources could be compared with water quality in the lake.

Because of its geographical position in the area, access to the lakes was difficult and only 4x4 vehicles could be used. Similarly, because of launching difficulties only light craft could be used. Canoes, kayaks and inflatable canoes were used depending on availability, which meant that a crew of only one or a maximum of two could be deployed to undertake the sampling. Vessels of this type are very susceptible to wind conditions and there were occasions when sampling could not be undertaken because of the weather. In addition, all the sampling stations had to be visited on the same day so that the water was representative of the day, the position and the depth at that time. The sampling procedure involved letting a stoppered weighted 'collecting' bottle (pop-bottle) over the side of the canoe to a measured depth after which a sharp jerk on the rope was required to remove the stopper. This bottle then had to be withdrawn and the sample bottle rinsed twice with the water collected. The weighted pop-bottle was then returned to the sample depth and a further sample collected. The pop-bottle had a volume of 750 ml that meant that one sample was used to wash the sample bottle and one used to collect the 500 ml sample. The sample had to be labelled after collection because we found that relabelled bottles could not be located quickly enough in the cramped conditions of a canoe. When two persons made up the crew, one was required to sample while the other maintained geolocation. Samples were collected just below the surface (0 m), at 0.5 m and every 0.5 m to the bottom at the sample sites shown in Table 12. If the collecting bottle reached, the bottom of the lake no sample was collected because there would be contamination from the organic sediment. A summary of all the water quality analyses for Lake Mgobezeleni is shown in Table 11.

Table 11. Summary of Lake Mgobezeleni average water quality analyses for the period 2013-2015.

Date	Depth (m)	Nitrate	Nitrite	Ammonium	O-Phosphate	Site	
July 2013	0.0	0.00	ND	ND	0.00	-27.53507	32.66022
February 2014	0.0	<0.08	ND	<0.05	0.11	-27.53507	32.66022
June 2014	0.0	0.07	0.01	0.12	0.01	-27.53507	32.66022
"	0.5	0.37	0.01	0.2	0.01	-27.53507	32.66022
"	1.0	0.03	0.01	0.03	0.01	-27.53507	32.66022
July 2015	0.0	<0.35	<0.01	<0.45	<0.03	-27.53507	32.66022
Mgobezeleni 1 Outlet	0.0	0.44	0.03	0.04	0.01	-27.52777	32.66192
Mgobezelen 2	0.0	0.07	0.01	0.01	0.01	-27.52977	32.56861
Mgobezelen 3	0.0	0.33	0.01	0.1	0.01	-27.53206	32.65973
Mgobezelen 4 Jetty	0.0	0.28	0.01	0.14	0.01	-27.53415	32.66029
Average all sites	0.0	0.20	0.01	0.09	0.01	-	-

Ratio of Total N: P: 15:1. (C/f Redfield ratio ~16:1)

3.4.2 Lake Shazibe

In Tables 12 and 13, data at different positions (Figure 54) and depths is presented. The data from 2.0 m depth were quite different from those at the other depths and hence for the calculation of the N: P ratio were ignored. The N: P ratio for the other three depths was ~7:1. The phosphate value of 6.6 mg l^{-1} is very suspicious and may be the result of an analytical error. However, the value of ammonium N from the same site was also unusually high and with two unusual values from the same sampling, the data were retained. The retention of these data is based on the geolocation of the sampling site that is close to a heavily populated resort.

Figure 54. Sites where water samples were collected from Lake Shazibe.

Table 12. Results of chemical analysis of Lake Shazibe (Site 1) water on 3 June 2014. (mg l^{-1})

Depth (m)	Nitrate-N	Nitrite-N	Ammonium-N	Phosphate	Total N
0.0	0.15	0.01	0.100	0.010	0.26
0.5	0.40	0.01	0.050	0.070	0.46
1.0	0.11	0.01	0.050	0.010	0.17
2.0	0.09	0.00	1.34	6.610	1.43

Table 13. Results of chemical analysis of Lake Shazibe water in October 2014 (mg l^{-1})

Site	Nitrate	Nitrite	Ammonium	O-P
Shazibe 1 Outlet	0.51	0.01	0.06	0.01
Shazibe 2	0.32	0.01	0.03	0.01
Shazibe Opposite jetty	0.17	0.01	0.09	0.02
Shazibe 3	0.21	0.01	0.06	0.01
Shazibe jetty	0.19	0.01	2.44	0.01
Shazibe 4 inlet	0.15	0.01	-	0.01

Data collect in 2015 from Lake Sibaya (Table 14) and the open water sites (Table 15) also shows that nitrate nitrogen was elevated but phosphate was also low.

The N: P ratio in Shazibe from the 2014 samples indicate that phosphate was likely a limiting factor for the growth of microalgae._The data from Lake Sibaya indicate the highest values recorded in the area for nitrite.

Table 14. Results of chemical analysis of Lake Sibaya water in June 2015

Site	Location	pH	Ammonia	NO_3	NO_2	OP
Sibaya (1)	-27.41966	7.49	<0.45	<0.35	0.10	<0.03
Sibaya (2)	32.69674	7.62	<0.45	<0.35	0.38	<0.03

Table 15. Analysis of water samples collected from various catchment sites July 2013. (Nox = Total oxidised nitrogen - Nitrate + Nitrite); OP = Ortho phosphate).

Site	Lat	Long	NO_3	$P0_4$
Lake Banghazi 2	-27.64955	32.63342	0.09	0.00
Tatatabeni stream	-27.54893	32.63672	0.01	0.01
Estuary Swamp	-27.54186	32.67434	0.00	0.00
Swamp stream	-27.53702	32.67136	0.10	0.00
Peat stream	-27.52903	32.63824	0.00	0.04
Peat stream	-27.52391	32.65872	0.37	0.05
Culvert	-27.52000	32.66841	0.00	0.00
Tolla se Gat	-27.48881	32.66398	0.23	0.00
Tolla se Gat	-27.48881	32.66398	0.18	0.01
Stream Vegetable Garden	-	-	0.55	0.01
		Mean	0.14	0.01
		n	12	12
		STDev	0.17	0.02

3.4.3 Open and stream water quality

In 2013, samples of open stream water were analysed for Nitrate+Nitrite and Orthophosphate. The results are shown in Table 15.

These data illustrate P but that interference in the form of gardening and animals causes these contents to increase. In the case of the vegetable garden in a peat valley, the relatively high values of N and P are likely the result of fertiliser additions (probably cattle dung as indicated in the section on socio-economics).

3.4.4 Tap water quality

The quality of the tap water is taken from samples collected directly from taps in private households. This is water abstracted from Lake Sibaya and pumped to the Mbazwana Municipal Water Works where it was treated, pumped to storage tanks and reticulated via the municipal pipeline to the various areas served by the system.

The data in Table 16 show that the quality in the tap water supplied to the local community is well within the drinking water standards set out by SANAS 2011 (www.dwa.gov.za), even though the nitrate and orthophosphate levels are elevated with respect to desirable environmental standards (NO_3^- 0.05, P 0.02 mg l^{-1}). The geographical location of the tap water collection sites is not shown because it is irrelevant, all having emanated from the single Lake Sibaya source.

3.4.5 Borehole water quality

The assessment of groundwater quality was undertaken by collecting water samples from boreholes (DWS, private or commercial). The 500 ml samples were treated in the same manner with prewashing as described for the estuary and lake water. As soon as possible after collection, the samples were dispatched to the analytical laboratory (usually less than two days). Sampling commenced in 2013 and continued until 2015.

Table 16. Results of tap water analyses of major chemical determinands collected in 2014 from private households in the Mbazwana area.

Results from tap water samples collected in June 2014 (Mg l^{-1})					
NO_3^-	NO_2^-	NH_4^+	Total N	O-P	
2.54	0.01	0.06	2.61	0.01	
0.18	0	0.05	0.23	1.24	
0.18	0.01	0.05	0.24	2.62	
0.18	0	<0.045	0.23	4.61	
0.21	0	<0.045	0.26	0.17	
0.21	0	<0.045	0.26	-	
0.23	0	<0.045	0.28	0.48	
0.53	0	0.05	0.58	1.52	
0.53	0.00	0.05	0.59	1.52	Average
<11	<0.9	<1.5	-	-	SANAS (Mg l^{-1})

Water from private sources, houses, bed and breakfast establishments, camping grounds and communal boreholes were mostly collected directly from the borehole pump on site but where this was not possible, i.e. if the borehole was sealed and the water pumped into storage tanks, samples were collected from the tap/s connected to the relevant storage facility.

In 2013, we had difficulty in collecting from some households because there was suspicion about the purpose of the survey. However, when word from the Traditional Authority reached the householders they gave us a lot of assistance and became interested in the purpose of the collection. While this made collection very easy, it did increase the time taken for the collection. In 2014 and 2015, the samples were collected by hydrology Honours students from the University of Zululand who were dressed in T-shirts that displayed where they were from and that the collection was a research matter. In those latter two years, the students were also collecting socio-economic data from the same households, so although the time spent at each household was extended there was a doubling up of data being collected. The householders, mainly women during the day, appeared to enjoy the interaction with the students with the result that a considerable amount of information was collected on the general water situation at the time.

Collection of water in 2013 was difficult in the sense that we were unable to determine where boreholes were located. As mentioned previously, the black community were suspicious because we were asking “unusual” questions and particularly because the questions were being asked by unknown white people.

In retrospect, even the white community were suspicious because any questions relating to the location of boreholes were deflected with vague responses such as "...there are quite a few ..." but when asked about actual locations there were very few definitive responses, and some of those questioned were openly hostile and some refused to allow us to take samples. The result is that there were relatively few borehole samples collected during the 2013 field trips and the emphasis was placed more on the collection of samples from the estuary, the streams and the lakes.

Table 17. Borehole water quality data collected during 2013

Lat	Long	NO_3	$P0_4$
-27.52938	32.64508	0.15	0.10
-27.52674	32.65163	3.94	0.00
-27.52455	32.64118	2.80	0.00
-27.51833	32.65429	0.22	0.05
-27.51778	32.65379	4.70	0.00
-27.51769	32.65372	0.66	0.00
-27.51317	32.62103	1.59	0.00
-27.51300	32.64475	0.14	0.00
-27.51090	32.62023	0.00	0.04
-27.50945	32.62622	0.12	0.05
-27.48412	32.66535	0.00	0.08
-27.48393	32.66150	0.27	0.09
-27.48318	32.65951	1.86	0.00
-27.48286	32.65981	2.15	0.00
	Mean	1.33	0.03
	n	14.00	14.00
	St dev	1.57	0.04

Average N:P:: 39:1

The data in Table 17 indicate considerable variability for N and P from the 2013 sampling, as might be expected, but that the levels are well within SANAS drinking water standards (www.dwa.gov.za).

3.4.6 Borehole water quality 2014

The data collected in 2014 from black residential properties were largely undertaken by honours students from the University of Zululand, while the white (mostly commercial) areas were visited by the WRC research team. The procedure at that time was to provide each group of students (male and female mixed) with an area to cover. This area was made up of a map showing a series of tracks taken from Google Earth and printed on an A4 sheet of paper (Figure 55).

The students were expected to follow the track shown and interview all the householders at each of the properties on each side of the track, if they were in at the time. They were required to ask questions on socio-economic issues (see section on socio-economics) take a borehole or tap water sample and collect the geographical coordinates so that the data could be analysed on a geographical basis.

Figure 55. Example of the track-map provided to students who were required to collect water samples during their June 2014 field trip.

During the 2014 collection there were unfortunately some coordinate transcription errors with the result that some data had to be eliminated. However, in the end, 36 water usable quality data sets were collected during this period. The students were required, as part of their honours project requirements, to complete a report on the process and results collected during their field trip.

3.4.7 Borehole water quality June 2015.

Water quality samples were collected by honours students from the Department of Hydrology as part of their final project for the degree. These students were collecting socio-economic data at the same time with the result that the total number of samples was relatively low (Table 18). Only a single site had an ortho-phosphate value > 0.03 hence no N: P ratio could reasonably be calculated.

Table 18. Water quality data collected during June 2015.

Coordinates	Coordinates	Nitrate	Nitrite	NOx	Ammonium-N	Ortho Phosphate
-27.51523	32.58603	0.590	<0.01	0.590	<0.45	<0.03
-27.51153	32.58647	0.590	<0.01	0.590	<0.45	<0.03
	32.58498	0.400	<0.01	0.400	<0.45	<0.03
	32.58498	0.570	<0.01	0.570	<0.45	<0.03
-27.46883	32.58551	0.510	<0.01	0.510	<0.45	<0.03
-27.46370	32.58339	0.580	<0.01	0.580	<0.45	<0.03
	32.58133	<0.35	<0.01	<0.35	<0.45	<0.03
-27.46790	32.58658	0.550	<0.01	0.550	<0.45	<0.03
-27.54230	32.55861	<0.35	<0.01	<0.35	<0.45	<0.03
-27.54230	32.55861	0.470	<0.01	0.470	<0.45	<0.03
-27.53693	32.55063	0.570	<0.01	0.570	<0.45	<0.03
-27.55507	32.53623	<0.35	<0.01	<0.35	<0.45	<0.03
-27.55507	32.53623	0.630	<0.01	0.630	<0.45	<0.03
-27.48735	32.57452	0.480	<0.01	0.480	<0.45	<0.03
-27.52191	32.64617	0.600	<0.01	0.600	<0.45	<0.03
-27.50926	32.64880	0.550	<0.01	0.550	<0.45	0.060
-27.50300	32.58948	0.590	<0.01	0.590	<0.45	<0.03
-27.50397	32.58914	0.570	<0.01	0.570	<0.45	<0.03
-27.50606	32.58784	<0.35	<0.01	<0.35	<0.45	<0.03
-27.52529	32.64302	3.21	<0.01	3.21	<0.45	<0.03
	Mean	0.72	-	0.72	-	0.060
	Stdev	0.67	-	0.67	-	-
	n	16.00	-	16.00	-	1.00

3.4.8 Borehole water quality July 2015.

Having been unsuccessful on previous field trips to identify and locate organisations undertaking borehole drilling prior to 2015, a concerted effort was made in July 2015. This search yielded two contractors one of whom was Mr. W. Clark who was very active at the time drilling at numerous sites throughout the Mbazwana area.

Figure 56. Image of Mgobezeleni drill rig operated by Mr. W Clark.

Mr Clark was kind enough to take us to many of his past clients to whom he explained the purpose of our study. As a result of his assistance, we were able to collect the coordinates of a number of boreholes. At the same time, he provided us with some information collected during the drilling operations (Figure 56). These included date drilled, borehole depth, depth to water and the depth to the Port

Durnford layer (paleo peat layer). The data from the July 2015 water samples and their analysis are shown in Table 19.

Table 19. Water quality data collected from boreholes in July 2015.

Coordinates	Coordinates	Ammonia	NO_3	Nitrite	Nitrate+Nitrite	Ortho Phosphate
-27.54122	32.67706	<0.45	<0.35	<0.01	<0.35	<0.03
-27.54138	32.67689	<0.45	<0.35	<0.01	<0.35	<0.03
-27.54841	32.66585	<0.45	<0.35	<0.01	<0.35	0.10
-27.51996	32.66845	<0.45	<0.35	<0.01	<0.35	<0.03
-27.51579	32.65530	<0.45	4.71	<0.01	4.71	<0.03
-27.51579	32.65530	<0.45	4.89	<0.01	4.89	<0.03
-27.51850	32.65021	<0.45	2.21	<0.01	2.21	<0.03
-27.51574	32.65221	<0.45	<0.35	<0.01	<0.35	<0.03
-27.51224	32.65372	<0.45	8.48	<0.01	8.48	<0.03
-27.50992	32.65563	<0.45	<0.35	<0.01	<0.35	<0.03
-27.51473	32.65836	<0.45	<0.35	<0.01	<0.35	0.05
-27.50930	32.65187	<0.45	4.59	<0.01	4.59	<0.03
-27.52038	32.64957	<0.45	3.73	<0.01	3.73	<0.03
-27.52431	32.64553	<0.45	0.92	<0.01	0.92	<0.03
-27.52307	32.64238	<0.45	4.11	<0.01	4.11	<0.03
-27.52533	32.64177	<0.46	3.33	<0.01	3.33	<0.03
-27.53270	32.64201	<0.45	<0.35	<0.01	<0.35	0.10
-27.51617	32.64382	<0.45	5.82	<0.01	5.82	<0.03
-27.51248	32.64449	3.73	0.44	<0.01	0.44	<0.03
-27.51248	32.64475	<0.01	<0.35	<0.01	<0.35	<0.03
-27.51300	32.64475	<0.03	<0.35	<0.01	<0.35	<0.03
-27.51300	32.64475	<0.45	<0.35	<0.01	<0.35	<0.03
-27.51214	32.65654	<0.45	4.08	0.01	4.09	<0.03
-27.51528	32.65812	<0.45	3.18	<0.01	3.18	<0.03
-27.46877	32.59524	<0.45	20.00	<0.01	20.00	<0.03
-27.46773	32.59361	<0.45	3.58	<0.01	3.58	<0.03
-27.47357	32.59364	<0.45	5.39	<0.01	5.39	<0.03
-27.49629	32.58332	<0.45	0.60	<0.01	0.60	<0.03
-27.52478	32.60655	<0.45	<0.35	<0.01	<0.35	<0.03
-27.51276	32.64048	<0.45	5.45	0.02	5.47	<0.03
-27.52921	32.64834	<0.45	5.39	<0.01	5.39	<0.03
-27.52943	32.64819	<0.45	5.32	<0.01	5.32	<0.03
-27.51074	32.65516	<0.45	4.79	<0.01	4.79	<0.03
-27.51074	32.65516	<0.45	2.12	<0.01	2.12	<0.03
-27.51074	32.65516	<0.45	0.74	0.06	0.80	<0.03
-27.51188	32.65871	<0.45	1.88	0.05	1.93	<0.03
-	-	<0.45	<0.35	0.01	<0.35	0.05
-27.49909	32.66131	<0.45	<0.35	0.01	<0.35	0.10
-27.51511	32.65800	<0.45	1.06	<0.01	1.06	<0.03
-27.47357	32.59364	<0.45	4.98	<0.01	4.98	<0.03
-27.52932	32.64806	<0.45	0.92	<0.01	0.92	<0.03
	Ave	-	4.17	0.03	4.18	0.08
	STDev	-	3.74	0.02	3.74	0.03
	Count	1	27	6	27	5

Samples of water sent to Yanka Laboratories in Middelburg were analysed for a number of chemical constituents in addition to nitrogen and phosphorus and these data in Tables 20 and 21 show the average values from different sources.

Table 20. Additional water quality data supplied by Yanka Laboratories during the analysis of borehole water samples.

Component	Mean BH	STDev	n	CV%	Mean Drums	STDev	n	CV%
Acidity	2.41	1.77	20	73.50	2.72	0.15	3	5.50
Bicarbonate Alkalinity	73.83	54.23	20	73.45	44.07	63.28	3	143.5
Conductivity. Lab	54.74	29.42	20	53.75	42.83	30.56	3	71.3
pH Lab	7.37	0.70	20	9.47	7.17	0.39	3	5.40
Total Hardness	76.44	52.10	20	68.16	50.20	52.44	3	104.4
Ca Hardness	39.22	30.18	20	76.94	22.14	31.15	3	140.7
Mg Hardness	37.21	22.01	20	59.15	28.06	21.63	3	77.0
TDS	274.9	152.1	20	55.3	207.13	152.2	3	73.4
TSS	4.86	2.73	7	56.29	-	-	3	-
Lab Temp.	21.00	0.00	20	0.00	21.00	0.00	3	0.00
Turbidity	8.44	17.98	20	213.0	3.92	4.69	3	119.6
Calcium	21.00	0.00	20	0.00	21.00	0.00	3	0.00
Chloride	111.8	54.21	20	48.47	93.19	49.19	3	52.7
Magnesium	9.04	5.34	20	59.15	6.81	5.25	3	77.1
Potassium	8.53	3.96	20	46.46	6.58	4.11	3	62.4
Sodium	67.83	34.68	20	51.13	53.56	34.68	3	64.8
Silicon	12.89	3.31	20	25.65	12.83	2.25	3	17.5
Sulphate	15.13	10.75	20	71.05	10.25	11.94	3	116.4
Aluminium	0.11	0.15	19	134.9	0.34	0.50	3	145.6

Water from the boreholes appears to be relatively uniform as indicated by the value of the CV percentage. This is the case for all the components except turbidity and aluminium. The pH values are remarkably uniform. Comparing the mean values for borehole water and that of the estuary gives further evidence for the freshness of the profile.

The estuary water appears to be uniform. This is despite the fact that the four samples were collected at depths of 0, 0.25, 0.5 and 1.0 m. This suggests that the almost the entire profile of water in the estuary becomes fresh at times. The pH of the surface water was 6.78 while that of the water at 1.0 m was 7.04. Bearing in mind that seawater normally has a pH of ~ 8.2 the indication is that the water was relatively fresh throughout the profile. The average borehole water value for chloride (Table 21) was 112 mg l^{-1} whereas that for the estuary was only a bit higher at 167 mg l^{-1}, indicating only a slight seawater contamination.

Table 21. Additional chemical characteristics of Water from the Mgobezeleni Estuary as well as water from the Mbazwana Water Treatment Works

Component	Estuary mean	STDev	n	CV%		Raw plant	Final plant
Acidity	2.80	0.20	4.00	7.26		2.25	0.54
Bicarbonate Alkalinity	61.80	0.33	5.00	0.53		117.00	117.00
Conductivity. Lab	70.10	14.39	6.00	20.53		76.10	78.40
pH Lab	6.99	0.14	7.00	2.02		7.50	7.96
Total Hardness	92.48	14.35	8.00	15.51		113.22	112.79
Ca Hardness	36.78	3.27	9.00	8.89		63.39	62.96
Mg Hardness	55.70	11.09	10.00	19.91		49.83	49.83
TDS	343.91	73.79	11.00	21.46		385.31	400.74
TSS	-	-	12.00	-		<0.4	<0.4
Lab Temp.	21.00	0.00	13.00	0.00		21.00	21.00
Turbidity	1.22	0.20	14.00	16.40		1.09	0.95
Calcium	14.73	1.31	15.00	8.89		25.39	25.22
Chloride	166.87	43.23	16.00	25.91		148.40	158.60
Magnesium	13.53	2.69	17.00	19.91		12.10	12.10
Potassium	7.07	1.19	18.00	16.78		11.19	11.46
Sodium	92.13	20.80	19.00	22.58		93.29	98.43
Silicon	10.30	0.08	20.00	0.79		14.50	14.70
Sulphate	12.44	4.68	21.00	37.64		24.70	24.60
Aluminium	0.03	0.01	22.00	33.29		0.04	0.06

Water quality data from a hand-dug pit along the shoreline of Lake Shazibe is shown in Table 22.

Table 22. Additional chemical characteristics of water from Lake Shazibe and water from a hand-dug pit in a peat swamp.

Component	Mean L Shazibe	STDev	n	CV%		Eskom Swamp 1	Eskom Swamp 2
Acidity	1.64	0.61	4.00	37.07		3.41	2.67
Bicarbonate Alkalinity	86.65	36.24	5.00	41.82		4.80	4.60
Conductivity. Lab	58.33	22.08	6.00	37.86		21.50	21.30
pH Lab	7.35	0.13	7.00	1.79		6.13	5.86
Total Hardness	89.92	25.60	8.00	28.47		20.13	18.42
Ca Hardness	51.18	11.60	9.00	22.67		4.52	3.56
Mg Hardness	38.74	14.00	10.00	36.14		15.61	14.87
TDS	287.83	119.60	11.00	41.55		101.81	99.82
TSS	-	-	12.00	-		698.00	774.00
Lab Temp.	21.00	0.00	13.00	0.00		21.00	21.00
Turbidity	1.34	0.40	14.00	29.61		944.00	892.00
Calcium	20.50	4.65	15.00	22.67		1.81	1.42
Chloride	115.76	40.14	16.00	34.68		50.08	49.48
Magnesium	9.41	3.40	17.00	36.14		3.79	3.61
Potassium	7.20	5.05	18.00	70.10		3.90	3.90
Sodium	69.96	30.67	19.00	43.84		27.65	27.17
Silicon	12.53	2.63	20.00	20.98		8.89	8.67
Sulphate	12.77	13.78	21.00	107.92		11.15	11.04
Aluminium	0.06	0.02	22.00	40.03		0.48	0.39

3.5 DISCUSSION WATER QUALITY

The primary objective driving the measurement of water quality in the Mgobezeleni catchment was set out in the proposal submitted to the Water Research Commission in 2012. With reference to the water quality component, the proposal stated, "*With increasing development in the Mgobezeleni area, both formal and informal, and the use of septic tanks for sewage disposal, there will be an increase in the nutrient content of the groundwater*". In this context was it necessary to identify the levels of nitrogen and phosphate in unpolluted groundwater. There are two sources of information to answer this question. The first source is the publication of De Villiers & Thiart (2007) who found that the lowest levels of N and P in South African rivers over a protracted period of years was 0.05 mg N l^{-1} and 0.01 mg P l^{-1}. These were the levels chosen for this project as the likely minimum levels in the Mgobezeleni groundwater. The second source of information comes from the actual N and P levels measured from borehole samples. Some samples showed nitrate values of 0.03 mg N l^{-1}, nitrite at less than 0.01 mg N l^{-1}, ammonium at 0.05 mg N l^{-1} and phosphate at 0.02 mg N l^{-1}.

The "natural" low values of N and P in the boreholes were not the only important values because part of the study was to identify the upper limits for use as drinking water and general home use. These values are published standards available in the South African National Accreditation System (SANS 241:2011) and are:

Ammonium-N (NH_4^+) <1.5 mg N l^{-1}: (UK 0.5 mg N l^{-1})
Nitrate-N (NO_3) < 11.0 mg N l^{-1}. (UK <50.0 mg N l^{-1})
Nitrite-N (NO_2) <0.9 mg N l^{-1}. (UK <0.5 mg N l^{-1}).

These limit values are essentially the same as those specified in the USA http://water.epa.gov/drink/contaminants/index.cfm. Interestingly, there is no specified limit for phosphate in drinking water either in South Africa, the USA or the UK. https://www.thameswater.co.uk/your-account/7486.htm.

In the data for 2015 the average value of nitrate-N in boreholes was 4.18 mg N l^{-1} while nitrate + nitrite was only 4.19 (most boreholes registered zero to very low nitrite values; average 0.02, n=5). These nitrate values are acceptable for drinking water but are very high compared to acceptable environmental standards. The data for phosphate, however, show that there is generally a low phosphate content 0.08 mg P l^{-1} (n=5) but this is higher than desirable for the ecology with respect to the water flowing into Lake Mgobezeleni. The ratio N:P in the groundwater is therefore about 50:1.

With the source of water to the lakes being from groundwater, it is of interest to note the quality of the water in Lake Mgobezeleni and the estuary collected at the same time, Table 23.

Table 23. Open water quality N and P sampled in June 2014 (Analysis – Mhlathuze Water).

Description	Nitrate as N	Ammonia as N	Total Phosphate
Estuary Water (E2)	0.12	0.05	0.09

Comparison of the concentrations of both these elements indicates that the open water values are lower by an order of magnitude (or more in the case of phosphate). The interpretation at this time was that N and P was being taken up by aquatic vegetation under open water conditions because the latter organisms had light available for photosynthesis. An explanation for this residual nitrogen in the open water systems might be the Redfield Ratio, which for microalgae approximates 16:1::N:P (*Redfield A.C., (1934*) or 20:1 (Sterner et al., 2008.) In Table 23 the N:P ratio is approximately 10:1.

3.6 MICROALGAE REPORT

Natural processes and anthropogenic inputs largely determine the quality of surface water in a particular region (Kazi et al., 2009). In the case of the lakes Mgobezeleni and Shazibe, anthropogenic inputs are mostly from groundwater that was impacted by sewage effluents discharged from houses and which has seeped into the groundwater and in turn flowed downwards towards the lakes, the estuary and the sea. The important effluents identified in the groundwater in this catchment (see section on Water Quality) are Nitrate-nitrogen (NO_3-N), Nitrite-N (NO_2-N), Ammonium-N (NH_4-N) and Ortho-phosphate (OP).

The purpose of the study on microalgae was that these organisms react quickly to inputs of nitrogen and phosphorus into open water bodies that are open to receive sunlight. They respond quickly because they are small, mostly in the micrometre range, absorb light, grow, and reproduce by splitting each cell into two. Hence, unlike large plants they react quickly to perturbations that influence them by producing many similar cells or by slowing down their rate of cell division. Microalgae generally respond to increases in nitrogen and phosphorus concentrations by growing faster. There are, however, many different kinds of microalgae in a single water body and when the nutrient conditions change, some species grow faster than others do. In this way, a small amount of N and P entering an open water body will likely alter the whole microalgal population including biomass and species dominance. This is measurable as an increase in the total microalgal population. However, when the N and P concentration increases beyond a certain level, some species grow faster than others and the microalgal population structure changes. With this feature in mind and knowing that the groundwater had been polluted as a result of sewage discharge into the sandy soil of the catchment, an investigation was initiated into the dominant microalgal populations in the lakes and estuary.

Water samples (500 ml) were collected from the Mgobezeleni Estuary, Lake Mgobezeleni, Lake Shazibe and Lake Sibaya. The samples were sent to an analytical laboratory for chemical analysis (see Water Quality section). Further samples were used to determine the biomass using chlorophyll-*a* (Chl *a*) as the determinant and the different groups of microalgae were identified microscopically.

In the Resource Directed Measures for Estuaries Programme of the Department of Water and Sewage there is a requirement that the different major types of microalgae are identified and enumerated respectively. This procedure was introduced for the investigation into the ecological status of the Mgobezeleni Estuary and the lakes.

3.6.1 Identification of the major phytoplankton groups

Water samples (500 ml), one from 0.5 m below the surface and from each 1 m depth to the bottom were collected using a pop-bottle from each of four sites for phytoplankton identification. Each sample was preserved with 1 ml of 25% glutaraldehyde and 1 drop of Rose Bengal solution. Thereafter the samples can be kept for a protracted period (days to weeks) in the dark and in a cool location before being examined microscopically. A 100 ml sub-sample of this preserved water was settled for 24 hours before being reduced to 10 ml by carefully siphoning off the upper 90 ml. The cells were left again to settle for 24 hours before being further reduced to 3 ml using a disposable Pasteur pipette. This reduced volume was transferred to 2 x 1.5 ml microfuge tubes and sent by post to the Nelson Mandela Metropolitan University, Botany microscope laboratory where the microalgal groups were identified using a Zeiss IM 35 inverted microscope at a magnification of x630. Cells were counted for each sample and were classified according to different microalgal groups; i.e. flagellates, diatoms, dinoflagellates, cyanophytes and chlorophytes. Cell density was calculated using the formula:-

$$\text{Cells ml}^{-1} = ((\pi r^2)/A) \times C/V$$

Where: r = radius of the examination chamber
A = Area of each objective frame (mm^2)
C = number of cells in each frame
V = volume of the settled sample (ml).

In the case of this study, the number of plankton cells counted was:

This was done to normalise the data for comparison with other studies. The preparation of samples for the identification of the epipelic diatom communities was performed as described by Bate et al. (2013).

Phytoplankton biomass was measured in both the estuary and in Lake Mgobezeleni as follows:

$$\text{Counts l}^{-1} = \frac{\text{No. cells counted} \times 33443}{\text{No frames viewed} \times 100}$$

A 500 ml water sample was filtered through a GFC filter and the filter pad was placed in a 50 ml glass bottle with 95% Ethanol (4111 Merck). The bottle and contents were kept in the dark and refrigerated until it could be analysed in the Plant Physiology laboratory at the University of KwaZulu-Natal in Pietermaritzburg.

In the laboratory, the extracted chlorophyll was refiltered under suction and placed in a spectrophotomer cuvette before the absorbance was read at 665 nm. After being mixed with 2 drops of 0.1 N HCl absorbance was again read at 665 nm and the reading recorded. The biomass was calculated using the equation of Hilmer (1990), derived from Nusch (1980):

$$\text{Chlorophyll a biomass } (\mu g\ l^{-1}) = (E_{b665} - E_{a665}) \times 29.6 \times (v/(V \times L))$$

Where: E_{b665} = absorbance at 665 nm before acidification
E_{a665} = absorbance at 665 nm after acidification
v = volume of solvent used for the extraction (ml)
V = volume of the sample filtered (l)
L = path length of the spectrophotometer cuvette (cm)
29.6 = a constant calculated from the maximum acid ratio (1.7) and the specific absorption coefficient of chl a in ethanol (82g l^{-1} cm^{-1})

3.6.2 Measurement of microphytobenthic biomass

A 20 mm ID core each from inter-tidal and sub-tidal sediment was collected where it could be reached at each estuary site. The sample was collected by pushing the corer into the sediment. The sediment core was then pushed slowly and carefully out of the top of the corer from the bottom using a suitable plunger. Great care is needed to prevent water above the sample in the corer from washing away the surface of the sediment core, and 10 mm of the core was cut off and placed in a 50 ml glass sample bottle. A second core was taken a short distance away from the first site and placed in the same bottle, i.e. 2 x 10 mm cores in each bottle. The sample bottle was then be placed in a dark cold box and placed in a freezer as soon as possible and the frozen samples returned to the UKZN laboratory in Pietermaritzburg.

Chl a biomass (mg m^2) = $(E_b - E_a) \times 29.6 \times (V/A) \times 1000$
Where: E_b & E_a = sample absorbance measured using the spectrophotometer at 665 nm before and after the addition of 0.1N HCl.
29.6 = constant calculated from the maximum acid ratio (1.7) and the specific absorption coefficient of chl a in ethanol (82 g l^{-1} cm^{-1})
V = volume of ethanol used to extract the pigment (ml)
A = the basal area of the sample in mm^2
1000 = Conversion factor for µg mm^{-2} to mg m^{-2}.

In the laboratory, 30 ml Merck ethanol 4111 was added to each glass sample bottle and the chlorophyll a allowed to extract in a cool dark place for ~6 hours. After extraction, the liquid was refiltered through a GFC filter under vacuum and the filtrate read in a spectrometer at 665 nm. After the reading, 2 drops of 0.1N HCl was added and a further reading taken at 665 nm.

The chlorophyll a concentration was determined from the absorbance readings using the modified equation of Nusch (1980):

The bathymetry of the Mgobezeleni Estuary was measured at 31 positions. All of these positions were on the landward side of the bridge. The mean depth was 1.01 m (SD 0.28 m). The surface water on the east side of the Sodwana bridge had a salinity of 2.5 while at 1 m depth it was 27.6 and the Secchi depth was >1.0 m. At the surface, the dissolved oxygen was 6.72 mg l^{-1} while at 1 m it was 2.65 mg l^{-1}. Surface water pH was 6.97 while at 1 m depth it was 7.68 indicating the presence of seawater below the freshwater. The biomass of phytoplankton are shown in Table 24.

The data (Tables 24 and 25) indicate that the chlorophyll concentrations were in the ranges of low to medium as assessed for estuaries by Snow and Adams (1998). The secchi disc values also indicated clear water indicative of a good trophic status. However, some of the data in Tables 26 and 27 are not quite as positive.

Table 24. Phytoplankton microalgal biomass (Chlorophyll a µg l^{-1}) in the Mgobezeleni Estuary in February 2014. (Biomass value interpretation after Snow and Adams, 2008).

Site	0 m	0.5 m	1.0 m	2.0 m
E1	3.70 (Med)	3.26 (Low)	2.07 (Low)	-
E2	0.74 (V. low)	0.44 (V. low)	1.33 (Low)	-
E3	3.70 (Med)	1.78 (Low)	0.89 (V. low)	0.15 (V. low)
E4	0.74 (V. low)	1.04 (Low)	0.15 (V. low)	-
Ave	2.22 Low	1.63 Low	1.11 Low	0.15 (V. low)

Table 25. Microphytobenthic microalgal biomass (Chlorophyll a mg m-2) in the Mgobezeleni Estuary in February 2014. (Biomass value interpretation after Snow and Adams, 2008)

Site	Intertidal		Sub-tidal	
1	0.14	Low	1.43	Low
2	5.06	Low	5.06	Low
3	3.04	Low	1.71	Low
4	19.40	Medium	2.51	Low
5	6.91	Low	2.68	Low

Samples of water flowing into the head of the estuary were collected and analysed by Talbot Laboratories, Pietermaritzburg in 2013. The results (see Water Quality section) showed that both nitrogen and phosphate concentrations were low. Water samples were collected later at the same sites and sent to the Mhlathuze Water laboratory in Richards Bay for analysis. The results of that analysis (see Water Quality section) also showed that the values of N and P in the water column were low.

At the time that water was collected for biomass, samples were also collected for the enumeration of the estuary benthic diatom population. The estuary data are shown in Table 26 and those for a single site in Lake Mgobezeleni in Table 27.

Table 26. Dominant diatom species found in the intertidal and subtidal reaches of the Mgobezeleni Estuary at four sites in the estuary. (E1 – east of the bridge; E2-4 – west of the bridge).

Site	No. spp	Cells counted	Dominants	Comments
E1 (Intertidal)	17	125	*Amphora exigua* Gregory = 60%	
E2 (Intertidal)	28	84	*Achanthes delicatula* (Kutzing) Grunow = 24%	Very thin sample
E3 (Intertidal)	10	140	*Diploneis elliptica* fo. (Kutz) Cleve = 70%; *Hantzschia distinctepuncta* Hustedt = 17 %	
E4 (Intertidal)	24	112	*Amphora strignosa* Hustedt = 17%; *Caloneis aequatorialis* Hustedt = 15%.	No definite dominant.
E1 (Subtidal)	19	178	*Achananthidium minutissima* (Kutzing) Czarnecki = 60%;	
E2 (Subtidal)	26	74	*Achanthes delicatula* (Kutzing) Grunow = 13%	Very thin sample
E3 (Subtidal)	19	131	*Achnanthes minutissima* Kutzing = 28%; *Amphora coffeaeformis* (Agardh) Kutz =23%;	
E4 (Subtidal)	14	120	*Navicula tenelloides* Hustedt = 83%	Very thin sample

Table 27. Dominant diatom species found in the subtidal reaches of Lake Mgobezeleni at the jetty site.

Site	No. spp	Cells counted	Dominants
Jetty Shallow	7	110	*Aulacoseira ambigua* (Grunow) Simonsen= 90%
Jetty Deep	9	140	*Aulacoseira ambigua* (Grunow) Simonsen= 85%

In the case of the estuary microphytobenthos the trophic status as indicated by species diversity (i.e. frequency >3% of the total population) was fairly normal for an estuary (See Bate and Smailes, 2013), but the diversity in the lake was very low, i.e. 85-90% comprising a single species (*Aulacoseira ambigua*) with only 7-9 species in total. The diatom species present in the microphytobenthos of the estuary were those species commonly found in an earlier survey of South African estuaries by Bate and Smailes (2013). The dominant diatom in Lake Mgobezeleni had not been found in any estuary surveyed because it is a fresh water species. However, Poister et al. (2012) maintained that the species is a common freshwater planktonic centric diatom that responds to higher temperature and light intensity than other members of the genus. Perhaps an important point noted by Poister et al. (2012) was the ability of this diatom to respond to phosphate and which through subsequent settlement out of the water column, can move quantities of phosphate out of the water column into the sediment.

The differences between the lake water and the estuary water were also shown during the process of filtering for the biomass assessments. When the estuary water was filtered using Whatman GFC filters, 500 ml passed through under gravity easily, however when the lake water was filtered it was only possible to get 150 ml to pass through even though a vacuum pump was employed. This meant that further investigations were required to determine the cause.

In September 2014, four water samples were collected from each of the two lakes at 0.5 m below the surface. In the case of both lakes, one of the water samples collected was from a point closest to the outlet stream leading to Mgobezeleni Estuary. This choice was because the main interest at the time was in the quality of water flowing towards Mgobezeleni Estuary because the "normal black water" of the estuary had changed to a green-yellow following a breach to the sea.

Each of the collected water samples was treated with 1 ml 25% glutaraldehyde and one drop of Rose Bengal stain and the contents of 100 ml samples of this lake water was settled for 24 hours and then gravity-reduced in two steps to 3 ml by removing the upper 97 ml. Samples were sent to Mrs. Pat Smailes in the Botany Department at NMMU for cell count analysis. One sample from Lake Mgobezeleni was later sent to Anatoliy Levantes at North West University (Botany Department) for the identification of a species with which Mrs. Smailes was unfamiliar. The results of the initial cell counts are shown in Table 28.

The data in Table 28 show that there were more flagellates than diatoms in the water columns of both lakes Shazibe and Mgobezeleni, but that the diatom population was similar in both systems. The high flagellate numbers are likely a reflection of a relatively high dissolved organic matter content in the water column. Dinophytes were present in relatively low numbers in Lake Shazibe but in much higher numbers in Lake Mgobezeleni likely indicating a difference in the water column chemistry between the two lakes. The big difference between the lakes is reflected in the large numbers of "single cell" cyanophytes compared to the "chain cyanophytes". There were about 25 times more "single cell" cyanophytes in Lake Mgobezeleni than in Lake Shazibe. However, these "single cell" species included a number of Chlorophytes (green) algae that were present but were included in the initial count.

Table 28. Phytoplankton cell counts (-1) from water samples collected from Lake Shazibe (S) and Lake Mgobezeleni (M) in September 2014. (Samples sent to NMMU). (To see the location of the collection sites – refer to Figure FFF in the Water Quality section)

Site	No. of frames	Flagellates	Diatoms	Dinophytes	Cyanophytes (chains)	Cyanophytes (single cells)	Total
S1	23	200	196	9	217	283	904
S2	46	204	70	9	61	187	530
S3	38	195	89	16	158	168	626
S4	72	139	31	14	0	97	281
Σ	179	738	386	48	436	735	2341
M1	5	560	60	174	98	5652	6544
M2	3	300	133	290	120	6232	7075
M3	5	160	60	316	84	3368	3988
M4	3	200	133	463	34	3241	4071
Σ	16	1220	386	1243	336	18493	21678

In order to identify the abundant "single cell" species, specimens were sent to North West University where Dr Anatoliy Levantes identified the two most dominant species as *Aphanocapsa planktonica* (G.M. Smith) Komarek et Anagnostidis (smaller coccoid cells in colonies surrounded by mucilage) and *Aphanothece* cf. *elabens* (Brebbison in Meneghini) Elenkin, (bigger elongated cells in colonies surrounded by mucilage) (Figure 57 and 58).

Other non-dominant algae in the sample included *Merismopedia punctata* Meyen (Cyanophyte), *Pseudoanabena galeata* Bocher (Cyanophyte), *Ankistrodesmus fusiformis* Corda et Korschikoff (Chlorophyte), *Scenedesmus falcatus* Chodat (Chlorophyte), *Scenedesmus quadricauda* (Turp.) Breb. (Chlorophyte), *Cosmarium phaseolus* Ralfs (Chlorophyte), *Staurastrum tetracerum* Ralfs (Chlorophyte). However, of these species the two cyanophytes *Aphanocapsa* and *Aphanothece* were by far the most dominant (Figure 59). *Aphanocapsa* was also more abundant than was *Aphanothece*. This is an interesting finding because although much attention was given to the presence of cyanophytes in freshwater impoundments in South Africa, there were no previous reports of their presence in natural lakes. Despite the water quality of both these lakes and Lake St. Lucia having been monitored (Perissinotto et al. 2013) the microalgal content was overlooked. A strong orange coloured bloom in St Lucia was observed by Taylor and Bate (pers. com.). This was later identified by Perissinotto et al. (2013) as a species of *Cyanothece*. Neither *Aphanocapsa* nor Aphanothece were identified in samples from St Lucia. A. planktonica has not been reported before in RSA (Oosthuizen 2012).

According to Paerl (2000), *Aphanocapsa planktonica* cells are 2-3µ in diameter and occur in oligo- to eutrophic lakes in North America, Europe and temperate zones. On the other hand, *Aphanothece* spp are unicellular solitary pico-planktonic species some of which are capable of nitrogen fixation. While it was not possible for Dr Levantes to be certain about the latter species, he considered it to be comparable to *Aphanothece elabens*. The importance of these identifications is that most references are consistent in that they are organisms that produce mucilage and, being cyanophytes, they can produce toxins.

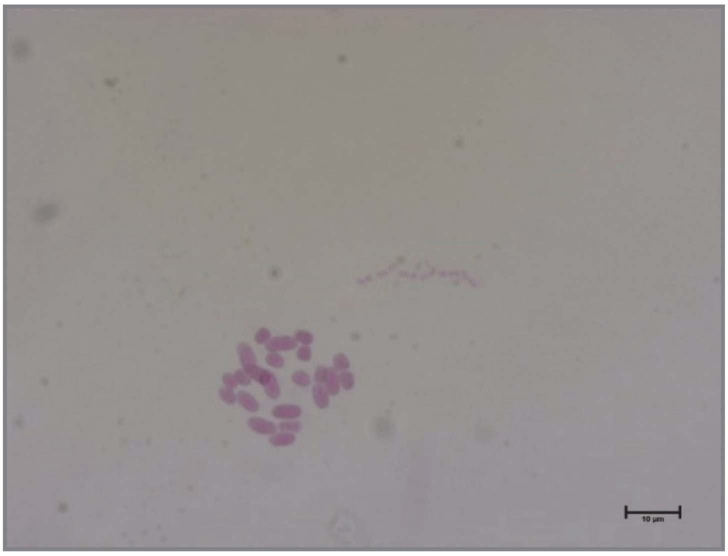


Figure 57. Brightfield image of tiny (1µm Ø) *Aphanocapsa planktonica* cells clumped into groups in a sheath of mucus in a sample of water from Lake Mgobezeleni. (Image: Mr. Subs Naidu, Microscopy Unit, University of KwaZulu-Natal, Pietermaritzburg).

The position of these two species in the Cyanobacteria was described by Clercin (2012) as follows:

Cyanobacteria

• Chroococcales – Solidary or colonial coccoid "blue-greens", never form true filaments

They include the genera: *Aphanocapsa, Aphanothece, Chroococcus, Coelosphaerium, Gloeocapsa, Gloeothece, Gomphosphaeria, Hyella, Merismopedia, Microcystis, Pleurocapsa, Synechococcus, Woronichinia*

Figure 58. Brightfield image of tiny (1µm Ø) *Aphanocapsa planktonica* cells clumped into groups in a sheath of mucus in a sample of water from Lake Mgobezeleni. (Image: Mr. Subs Naidu, Microscopy Unit, University of KwaZulu-Natal, Pietermaritzburg).

• Oscillatoriales – Filamentous colonies, no heterocyst- and akinete-formation

• Include: *Homeothrix, Limnothrix, Lyngbya, Oscillatoria, Phormidium, Planktothrix, Plectonema, Pseudanabaena, Schizothrix, Spirulina, Trichodesmium*

• Nostocales – Filaments forming heterocysts and akinetes, but never true branches

• Include: Anabaena, Anabaenopsis, Aphanizomenon, Calothrix, Cylindrospermun, Cylindrospermopsis, *Gloeotrichia, Nostoc, Rivularia, Scytonema*

• Stigonematales

– Filaments forming heterocysts and true branches • Include: *Brachytrichia, Desmosiphon, Fischerella, Hapalosiphon, Stigonema*

Having identified these two cyanophytes in the lakes within the Mgobezeleni catchment the opportunity was taken to examine the status of the water source being used to supply the Mbazwana Municipality as tap water. To this end, water samples were treated as before and taken to the microscopy unit in the Botany Department at NMMU. There, the following image was captured showing both *A. planktonica* and *A.* c/f *elabens* to be present (Figure 60).

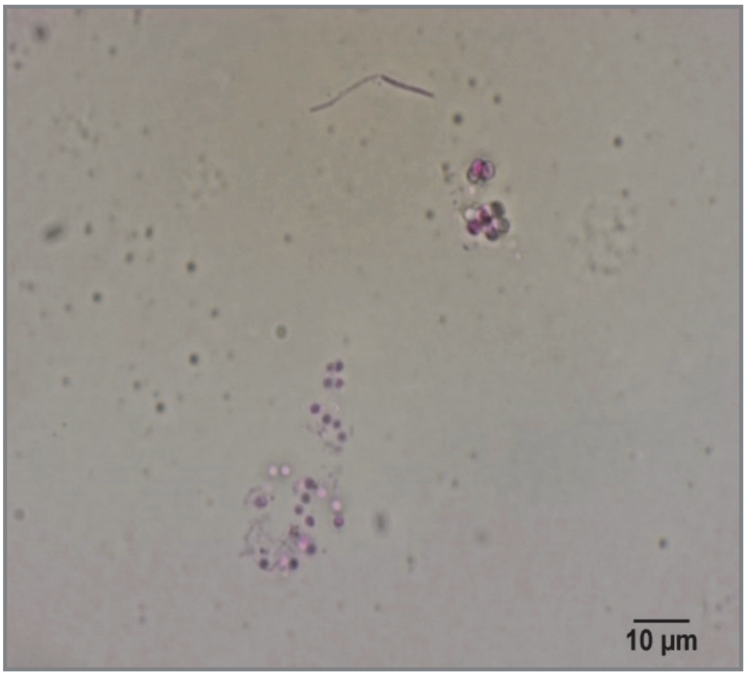


Figure 59. Brightfield image of both *A. planktonica and A. c/f elabens* in a sample of water collected from the bridge over the Mgobezeleni Estuary. (Image: Mr. Subs Naidu, Microscopy Unit, University of KwaZulu-Natal, Pietermaritzburg).

Drews and Weckesser (1973) stated that "some cyanobacteria (cyanophytes) excrete slime or mucilage which becomes dispersed around the organism....". This appears to be the case in Lake Mgobezeleni where not only was it impossible to gravity or hand-pump filter more than 125 ml water but, according to M. Pieters (*Pers. Com*.), the management of the water supplies to the EKZN Wildlife accommodation centre is difficult because of water filtration problems. While much of the foregoing may be largely a water supply problem, it seems that undesirable ecological conditions in the estuary are likely to follow if the nutrient enrichment of the lakes continues. The lake water flows into the estuary and, although it flows through a swamp, the cyanophytes are not being completely filtered out and have reached the estuary. A sample of estuary water was also subjected to microscopic examination and showed that *A. planktonica* was indeed present.

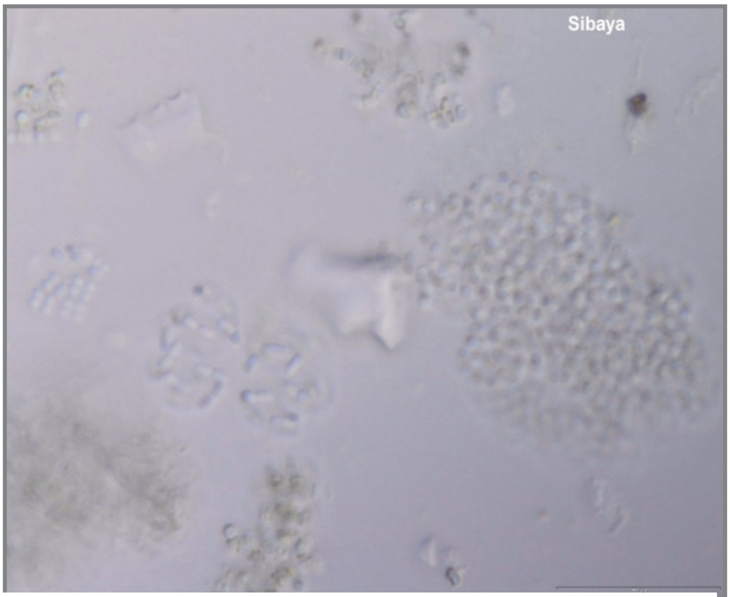


Figure 60. Differential Interference Contrast image of both *A. planktonica and A. c/f elabens* in a single sample of water collected within 1 m of the inlet pipe taking water to the Mbazwana Treatment works. (Photo: Mrs. P. Smailes, Department of Botany, NMMU).

The Mgobezeleni Estuary is important to the ecology of the northern KwaZulu-Natal coast because it is the only one between St Lucia Estuary and Kosi Bay, a distance of ~170 km. In 2014/15 it appeared outwardly to be very similar to the condition that it was in at the time it Begg (1987) described it. The estuary is still shallow, ~2.0 m at the deeper sites; the salinity data show that it is typical of an estuary with respect to its salinity profile both vertically and horizontally. The estuary breaches naturally fairly often during the summer rainy season but less so in the winter, however, it is artificially breached especially during the holiday season when sport fishermen need to access the beach in order to launch their boats. In addition to sport fishermen there is an important diving and diver-training facility at Sodwana that also brings large numbers of tourists to the area annually (See Socio-economic report). Despite the apparent normality, the appearance of cyanophyte microalgae must be considered as a factor in the lowering of the trophic status of the Mgobezeleni Estuary, Lake Mgobezeleni and Lake Shazibe.

The estuaries in South Africa were rated (Turpie et al., 2002; 2012) in terms of a conservation importance score calculated on the basis of size, zonal type rarity, habitat importance and biodiversity importance. In terms of that rating, the Mgobezeleni Estuary was given an importance score of 53 compared to other regional estuaries such as St. Lucia (96.6), Kosi (96.9), and Mfolozi (91.1).

On the basis of the score in Table 29 alone, this estuary does not seem particularly important, but it lies within the iSimangaliso Wetland Park and its habitat importance was given a score of 100. It is the only estuary between St Lucia and Kosi a distance of about 170 km in a most important marine fishery area.

Table 29. Components of the conservation score awarded to The Mgobezeleni Estuary by comparison with other South African estuaries (Turpie et al., 2002).

Rank	Estuary	Size	Habitat importance	Zonal type rarity	Biodiversity importance	Conservation importance
117	Mgobezeleni	20	100	70	72	53

The Resource Directed Measures programme of DWS involves assigning a final management class (MC) to an estuary on the basis of its ecological reserve category (ERC) and other socio-economic criteria. The ERC is determined on the basis of the health and importance of an estuary. The MC is an expression of society's desired future state of health of the system, and determines the quantity and quality of water that needs to be allocated to the estuarine reserve, a higher reserve being associated with a healthier system. In the case of the Mgobezeleni Estuary, despite it's having been allocated a conservation importance score of 53, it has protected area status (Turpie et al., 2002; Table 1) which results in its having an overall importance (EIR) of A, indicating that it should be protected with an Estuarine Reserve Category of A or BAS.

Having followed the principles involved in the classification of the Mgobezeleni Estuary as having an REC of A, the question arises whether, because it is in a protected area, the management should fall to "best attainable state" in view of the increasing population in the catchment which will almost certainly have the long term result of increasing the N and P flow into the groundwater, which will flow eventually into the estuary. At present, the ecological status of the estuary from the perspective of N and P, secchi disc and microalgae might well be considered to be an A, but there seems to be a diminishing likelihood that this will be sustainable and that management will increasingly accept a BAS unless some management action in the catchment area is implemented to stop seepage from latrines into the groundwater. At present the most attainable solution would be the implementation of sewage disposal using conservancy tanks with disposal into the dunes at a site that will take the nutrients directly out to sea, but as a well filtered solution high in N and P.

The importance of reducing the N and P flow into the lakes and then to the estuary is that in static surface waters, especially in the tropics and sub tropics cyanophytes become the dominant microalgal flora. The cyanophytes are a group of non-flagellated photosynthetic bacteria that can make up a large component of both the planktonic and benthic microalgal community. They can be important in that under certain conditions (including anaerobic), they can utilise gasses such as hydrogen sulphide in order to grow. Some species are able to fix nitrogen and can become important under conditions where the water column is oligotrophic. Certain species of cyanophytes can produce toxins, which are able to be harmful if present in high concentration.

Many of the bloom-forming algae are cyanobacteria some of which can potentially produce toxins that may have harmful effects on aquatic and terrestrial life. Some species of cyanobacteria, as well as some diatoms, chrysophytes and other types of algae, can produce taste and odour compounds, which can impart off-flavours to fish or make drinking water taste unpleasant. In addition to problems related to their bloom-forming properties, there is the problem of their growing and accumulating mucous into a protective layer around a colony of cells. This aspect was examined microscopically under the light or scanning electron microscope at the University of Natal. Preserved and stained samples of water previously identified as containing cyanophyte cells were viewed microscopically as follows depending on requirements. The process was undertaken by Mr. S. Naidu in the microscopy Department at the University of KwaZulu-Natal, Pietermaritzburg.

***Methods*:**

(1). Scanning Electron Microscopy

Microscope slide cover slips or Nuclepore polycarbonate membrane filters (0.1µm pore size) were mounted onto SEM aluminium stubs with double-sided carbon tape. A drop of the sample was placed on the cover slip/membrane and allowed to air dry. These samples were then coated with gold, using an Eiko Ion Sputter Coater. Scanning electron imaging was performed on the Zeiss EVO LS15 SEM, under high vacuum, at 5 kV. Subsequent imaging was performed at various magnifications (up to 6340x).

(2). Bright field light viewing:

A drop of the sample was placed on a microscope slide, mounted with a cover-slip and viewed under bright field mode. Imaging was performed at various magnifications using an

Olympus AX70 Compound Fluorescent microscope with a Nikon DS-Ri1 camera. Image Processing – NIS Elements.

(3). Phase Light viewing:

A drop of the sample was placed on a microscope slide, mounted with a cover-slip and viewed under phase mode. Imaging was performed at various magnifications using an Olympus BH2 Compound Phase microscope with a JVC KY-F1030 Camera. Image Processing was by Auto-Montage.

Figure 61 shows how a filter, and very likely a sand filter also, would clog with the mucous and cyanophyte cells. The image shows the effect of the mucous in preventing the 1µm diameter cells from passing through the much larger pores of the filter. This is an existing problem at the EKZN Wildlife Sodwana Camp where water is drawn from Lake Mgobezeleni and pumped into a holding tank. From the holding tank, the water is pumped to a settlement tank where chemicals are added to cause the microalgal particles to coagulate and settle into a sludge-trap. This sludge is then discharged and the water chlorinated before being pumped into a final holding tank from where it is distributed to the camp residents and visitors.

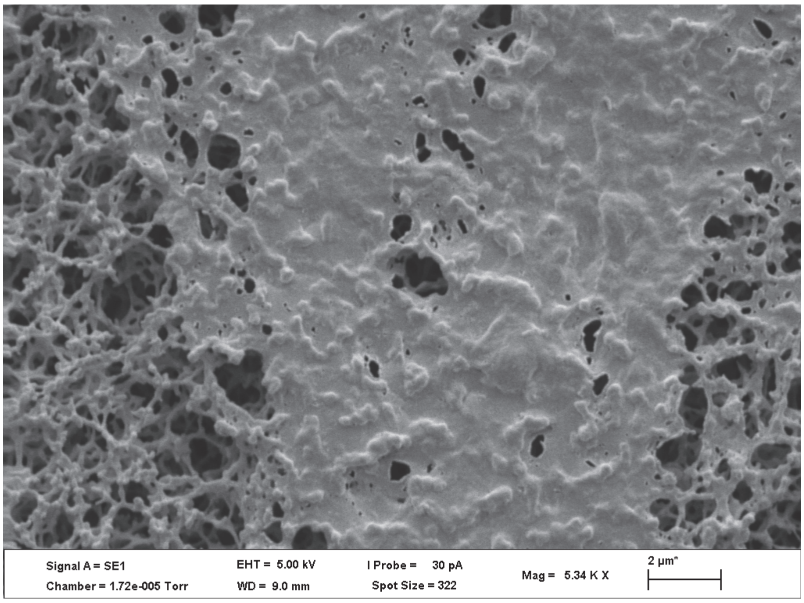


Figure 61. Scanning electronic microscopic image of the mucous in which cells of *A. planktonica accumulate*. (Image: Mr. Subs Naidu, Microscopy Unit, University of KwaZulu-Natal, Pietermaritzburg.

The water that is pumped from Lake Mgobezeleni is from a point known as “the Jetty” – (-27.535022 032.660233). The pipe intake is at the bottom of the lake where it presumably draws in sediment and rotting plant material. Previously, the intake pipe used to be held off the bottom with a floatation device but this is no longer used. No reason for this change in the position of the inlet was provided. However, the previous operator had retired soon before the site visit and that may were the reason.

Van Ginkel (2011) stated that “Cyanobacterial blooms and their effects are symptoms of increasing eutrophication. They are widespread, frequent and typically seasonal”. Many cyanobacterial genera produce one or more of a range of cyanotoxins (WHO, 1999) and many are associated with taste and odour problems encountered by water treatment works (Wnorowski 1992; Swanepoel et al., 2008). The ingestion of water containing high concentrations of cyanobacterial toxin (in drinking or in recreational waters) presents a risk to human and animal health (Pouria et al., 1998; WHO, 1999; Botes et al., 2004). The increasing frequency of cyanobacterial blooms in South African impoundments and rivers is a cause for concern. Since 1990 the research focus, internationally and nationally, has shifted to expanding knowledge of the driving forces behind cyanobacterial blooms and cyanotoxin production. Toxic cyanobacterial blooms are a threat to the supply of safe drinking water in large parts of South Africa (Van Ginkel, 2004), especially in areas where water purification is minimal or not fully functional (Van Ginkel and Conradie, 2001).

Van Ginkel (2011) referred to the amount of phosphate in the water as an index to the eutrophication status of the water concerned. Those data consider a P-concentration of ≤ 0.015 mg l^{-1} to indicate a “negligible” potential eutrophication status. She also considered a P concentration of 0.015- ≤ 0.047 to indicate a small eutrophication potential status; 0.047-≤ 0.130 to indicate a moderate eutrophication potential while > 130 mg l^{-1} would suggest a serious potential for eutrophication (See Table 30).

Water analyses of the two lakes indicates that the present potential for cyanophyte eutrophication potential is low but with continual input of sewage waste into the groundwater plus the potential for an increase in the resident population, this is a problem that will require serious attention with the passage of time, because Oberholzer et al. (2009) have shown that a eutrophication process (potentially) caused by a high urine and faecal load resulting from an unusually high hippopotamus population density in the Nhlanganzwane Dam, Kruger National Park, South Africa, triggered a chain of events characterised by an increase in the growth of primary producers (*Microcystis aeruginosa).* This increase in *M. aeruginosa* biomass was followed by bio-intoxication incidents in wild animals. This situation seems surprisingly similar to the situation in Lake Mgobezeleni.

Cyanophytes or cyanobacteria are often considered to be algae in South Africa whereas they are actually autotrophic bacteria. They are also responsible for many of the Harmful Algal Blooms (HABs) that cause ecological, economical and public health concerns in waterways, through the production of cyanotoxins. Based on surveys carried out in the USA waters, the most commonly identified cyanotoxins are microcystins, cylindrospermopsin, anatoxins and saxitoxins. (http://www.epa.gov/nutrient-policy-data/cyanobacteriacyanotoxins).

Microcystins are the most widespread cyanobacterial toxins in the USA and can accumulate in aquatic animals including fish. Microcystins primarily affect the liver (hepatotoxin), but can also affect the kidney and reproductive system. Microcystins are produced by *Anabaena* sp., *Fischerella* sp., *Gloeotrichia* sp., *Nodularia* sp., *Nostoc* sp., *Oscillatoria* sp., *Microcystis* sp, and *Planktothrix* sp. fortunately, none of these foregoing species was identified in the Sodwana lakes system but there was a fish-kill in 2014. Specimens of dead fish from the estuary were examined but no cause was identified. Other cyanotoxins include Cylindrospermopsin (liver and kidney damage), Anatoxin (very little information available) and Saxitoxins that are representative of a large toxin family referred to as the Paralytic Shellfish Poisoning (PSP) toxins.

Some species of cyanobacteria produce toxins that affect animals and humans. People may be exposed to cyanobacterial toxins by drinking or bathing in contaminated water. The most frequent and serious health effects are caused by drinking water containing the toxins (cyanobacteria), or by ingestion during recreational water contact. Disease due to cyanobacterial toxins varies according to the toxin and to the type of water or water-related exposure such as drinking or skin contact. Humans are affected with a range of symptoms including skin irritation, stomach cramps, vomiting, nausea, diarrhoea, fever, sore throat, headache, muscle and joint pain, blisters of the mouth and liver damage. Swimmers in water containing cyanobacterial toxins may suffer allergic reactions, such as asthma, eye irritation, rashes, and blisters around the mouth and nose. Animals, birds, and fish can also be poisoned by high levels of toxin-producing cyanobacteria.

(http://www.who.int/water_sanitation_health/diseases/cyanobacteria/en/).

According to one report (Clercin (2012), the impacts associated with cyanophyte blooms include oxygen depletion in the water, fish kills, degradation of recreational resources socio-economic impacts, property value impacts, limitation of recreational uses, taste and odour in drinking water MIB (musty) Geosmin (earthy smell) and they can affect both pets and humans and both *Aphanocapsa* and *Aphanothece* may produce hepatoxins that can disrupt the proteins that are used for liver function.

https://engineering.purdue.edu/watersheds/webinars/BGAlgae/2012-10-23 N_Clercin.pdf

Cloern et al. (2015) stated “evidence has accumulated over a period of two decades that the human population has transformed landscapes, chemistry of the atmosphere and oceans and biological communities from the top to the bottom of food webs. Measurements over time contain information that has become essential for understanding environmental change, for establishing policies to conserve resources and sustain processes vital for humanity, for measuring the effectiveness of those policies through adaptive management and for anticipating changes that will unfold under different scenarios of climate change and continued global population and economic growth”. Those authors maintained, “The human population is concentrated along coastlines where we expect signals of anthropogenic changes to be particularly strong”.

Cloern et al. (2015) quote (Carpenter & Bennett, 2011 and De Vries et al., 2013), “Explosive growth of the human population and its activities on land have altered global patterns of element cycling, and recent assessments are that increased flows of nitrogen (N) and phosphorus (P) from land to sea have exceeded planetary boundaries – thresholds beyond which we can anticipate unacceptable consequences for humanity”. This seems to be the case in South Africa and the evidence at Mgobezeleni, including the measurements of nitrogen and phosphorus in the groundwater as well as the identification of cyanophytes in three natural lakes is also a strong indication that the local and holiday populations at Mgobezeleni and Sodwana have considerably altered the natural state of the area in historic times and, indeed, in contemporary times when we read the accounts of relatively recent workers like Begg (1987). This factor must be a large component of the socio-economic impact on the area.

According to van Ginkel (2011), high nutrient concentrations are the result of cultural and natural influxes of nutrients, where cultural eutrophication is related to anthropogenic activities – human, social and economic activities. She stated that “In theory, this form of eutrophication is controllable, because people can take measures to minimise the impact of their activities . . .” which include accelerated population growth and associated settlement patterns, which is what is happening in the Mgobezeleni catchment where cultivation is occurring in peat deposits with the associated effects on both water retention in the catchment and nitrogen and phosphorus additions to the natural flow. She considered that it was clear that South Africa was facing widespread problems related to eutrophication, most of them associated with the larger metropolitan areas and the dams on which those areas rely for their water supplies. She considered that the main reasons for viewing eutrophication of freshwater resources as a serious problem was because it threatens our ability to supply sufficient and safe drinking water to an increasing population.

The following table (Table 30) appeared in van Ginkel (2011).

Table 30/...

Table 30. The classification system used by the Department Water Affairs to classify the National Eutrophication Monitoring.

Programme sites regarding their trophic status and eutrophication potential statistics (DWAF, 2002)					
Statistic	Unit	Current trophic status:			
Mean annual		0 < x ≤ 10	10 < x ≤ 20	20< x ≤ 30	>30
chlorophyll a	µg/ℓ	Oligotrophic (low)	Mesotrophic (moderate)	Eutrophic (significant)	Hypertrophic (serious)
		Current nuisance value of algal bloom productivity:			
% of time					
chlorophyll	%	0	0<x≤8	8<x ≤50	>50
a > 30 µg/ℓ					
	Potential for algal and plant productivity:				
Mean annual total	mg/ℓ	x ≤ 0.015	0.015 <x≤ 0.047	0.047 <x≤ 0.130	>0.130
phosphorus		negligible	moderate	significant	Serious

The data in Table 30 presented by van Ginkel (2011) suggests that phosphorus is the limiting nutrient for the production of cyanophytes in South African dams, yet Lewis et al. (2011) reported that algae excrete phosphatases at their cell surface and into the surrounding water, which allows them to assimilate phosphorus derived from the cleavage of phosphorus from organic matter. The data presented by van Ginkel (2011) refers to total phosphorus, which would include organic phosphorus. This must be important in the eutrophication process, because Lewis et al. (2011) quoted Reynolds et al. (2006) as reporting that algae can take up 10 or more times than the minimum amount of P needed for the synthesis of their own protoplasm. It seems that they store the excess phosphorus as polyphosphate (Healey 1973). Thus, toward the end of the growing season, most of the phosphorus in the upper water column of lakes is incorporated into algal biomass, except in lakes that are so strongly polluted with P as to exceed algal capacity for P uptake. This latter situation does not seem to apply to the Sodwana lakes system, but it is possible that the measure of phosphorus in the water column may not necessarily be the only criterion for algal proliferation if "luxury consumption" has occurred.

The work undertaken in South Africa on N and P pollution and the cyanophyte problem that follows was undertaken on dams rather than on natural lakes. The pollution in dams mostly arises from water flowing to them in rivers polluted mainly from municipal water treatment works rather than groundwater flow from rural populations (Rae et al., 1999; Van Ginkel, 2004 Van Ginkel et al., 2006; 2010). This means that the problems presented by an ever-increasing population in the rural areas of Maputaland on sandy soils where relatively unsophisticated sewage systems predominate have received little or no attention by the Department of Water and Sewage despite the huge size of this population (STATSSA 2011).

Messineo et al. (2009) reported that anatoxin-a ANA-a concentrations were found in the scums of Italian lakes. ANA-a is one of the toxins reportedly resulting from the presence of *Aphanocapsa* sp. Concentrations of ANA-a were found to vary from 115.1 ng g^{-1} to 12.13 µg g^{-1} in Spino Lake. They reported that cyanotoxin poisoning in humans was mainly caused by three toxic groups: microcystins (MCYSTs), cylindrospermopsin and anatoxin-a (ANA-a). ANA-a is a potent neurotoxic alkaloid and it is perhaps one of the most powerful cyanobacterial toxins (Carmichael, WW. 1994).

Earlier work in South Africa concluding that phosphorous may be the determining factor in the increased incidence of cyanophyte blooms should be considered in the light of recent results of work in France by Pitois et al. (2014). These workers, while accepting the relationship between eutrophication and cyanobacterial blooms, noted that Paerl et al. (2011) also consider the influence of meteorological parameters in the form of climate change to be a potential factor in the increase in cyanobacterial frequency. They noted that some recent review articles indicate that in hotter environments, cyanobacteria could have an advantage over other planktonic taxa and that health issues associated with cyanobacterial toxin occurrences could become more prevalent as a result of global warming. In Brittany, France, they project that increasing temperatures, rainfall and global radiation will increase the incidence of cyanobacteria blooms. In that study, *Planktothrix* and *Woronichinia* accounted for 15.5-16% of the total biovolume whereas *Microcystis, Aphanocapsa, Aphanothece* and *Aphanizomenon* accounted for 9-11%. They also noted that those species plus *Anabena* accounted for 76% of the total cyanobacterial biovolume. In Britany, they identified three dominant areas:

While these authors suggest that climate change might result in changes in cyanophyte distribution patterns on a regional scale, their pattern seems to be the reverse of any pattern that might exist in South Africa, unless the dominance of *Aphanothece/Aphanocapsa* is an association of a higher “less sunny” (higher rainfall) Maputaland compared to the Highveld of South Africa.

1. Colder wetter less sunny dominated by *Aphanothece/Aphanocapsa* and *Woronichinia,*
2. Hotter drier sunny area dominated by *Microcystis* and *Anabena*,
3. An intermediate, transitional area associated with *Aphanizomenon* and *Planktothrix.*

In the published literature in South Africa on cyanophytes, there was no mention of either *Aphanocapsa* or *Aphanothece* as being a problem in any of the dams studied. There was the one account of *Cyanothece* in Lake St Lucia (Muir and Perissinotto (2011). The question that arises is whether the absence of previous reports is the result of the similarity between the taxa or whether *Aphanocapsa, Aphanothece, Cyanothece* and *Microcystis* are truly being geographically separated

One further comment of relevance by Pitois et al. (2014) to this Mgobezeleni study is that the similarity between the genera *Aphanocapsa* and *Aphanothece* caused them to bulk the counts of the two. This great similarity, caused by small shape changes within the species was also a feature of the identifications undertaken at Mgobezeleni.

3.7 LAKE MGOBEZELENI CYANOBACTERIUM

This sections covers a report by Rhodes University (Venkatachalam et al., 2016) requested by the team.

The increasing incidence of cyanobacterial blooms in Southern African aquatic systems is raising considerable concerns about the potential for these microorganisms to contaminate potable water with toxic secondary metabolites. Recently cyanobacterial species with the potential to produce cyanotoxins were identified in cyanobacterial blooms in Lakes Shazibe and Mgobezeleni. This has raised concern about the potential health risk to communities using this water for domestic agricultural and recreational purposes. The aim this project was to provide information on the diversity of cyanobacterial taxa in the water column of water bodies in the Maputaland system, focussing on Lake Shazibe and Lake Mgobezeleni but also including Lake Sibaya and the Mgobezeleni Estuary. We used Next Generation Sequencing (NGS) technology to analyse the 16 S rRNA gene sequences of bacterial communities in the water column. The data indicate a persistent cyanobacterial bloom in Lake Mgobezeleni, which includes cyanobacterial taxa closely related to species that are known to produce cyanotoxins. Most notably, a dominant species was *Mycocystis aeruginosa*, which produces the hepatotoxin, mycocystin. This microorganism was also detected in the Mgobezeleni Estuary while other potential cyanotoxin producers were detected in all four water bodies, but at lower levels. The results of this study highlight the importance of identifying water systems at risk of experiencing cytotoxic cyanobacterial blooms and the need to monitor such vulnerable systems to ensure the safety of surrounding communities.

3.7.1 Background

The incidence of cyanobacterial blooms in Southern African aquatic systems has been well documented (Oberholzer et al., 2005; Ibelings & Chorus, 2007) including a bloom of a toxin-producing *Microcystis* species that resulted in game fatalities in the Kruger National Park (Oberholzer et al., 2009). Recently, there has been a substantial increase in cyanobacterial blooms due to eutrophication of freshwater systems raising considerable concerns about the potential for these microorganisms to contaminate potable water with toxic secondary metabolites (Mathews et al., 2015).

There have been several reports of cyanobacterial blooms (*Cyanothece* species) in lake St Lucia (Muir & Perissinotto, 2011; du Plooy et al., 2015). Most recently the presence of *Aphanocapsa* and *Aphalotheca* species has been microscopically identified in samples collected during cyanobacterial blooms in Lakes Shazibe and Mgobezelene in the north of the wetlands system (Bate, unpublished, personal communication). Of concern is the presence of *Aphanocapsa* species, since members of the genus are known to produce hepatotoxic microcystins (Ibelings & Chorus, 2007) that pose a health risk to communities using this water for domestic agricultural and recreational purposes.

There is thus an urgent need to determine the extent of cyanobacterial diversity in these water systems and to establish their potential for the production of toxins that are a risk to human and animal health (Briand et al., 2003; Corbel et al., 2014). The aim of this study was to use molecular methodologies to identify cyanobacterial taxa in lakes Sibaya, Shazibe and Mgobezeleni and to assess their potential to produce harmful cyanobacterial toxins.

3.7.2 Methodology

3.7.2.1 Site description

Two sets of samples were collected for this study from water bodies in the Maputaland system (Figure 62). The first was collected from Lake Mgobezeleni on November 24th, 2015 while a second set of samples was collected from Lake Sibaya (-27.419648 032.696750), Lake Shazibe (-27.504574 032.662382), Lake Mgobezeleni (-27.535117 032.660216) and the Mgobezeleni Estuary (27.541350 032.676939) on January 26th 2016.

3.7.2.2 Sample collection

Five hundred millilitres of water was collected from each sampling site, and transported to Rhodes University by courier within 3 days of sampling at room temperature. Microbial biomass was collected by filtration of between 50-100 ml of the water samples through 0.22µm filters which were submerged in RNA-Later and stored as described in Matcher et al. (2011).

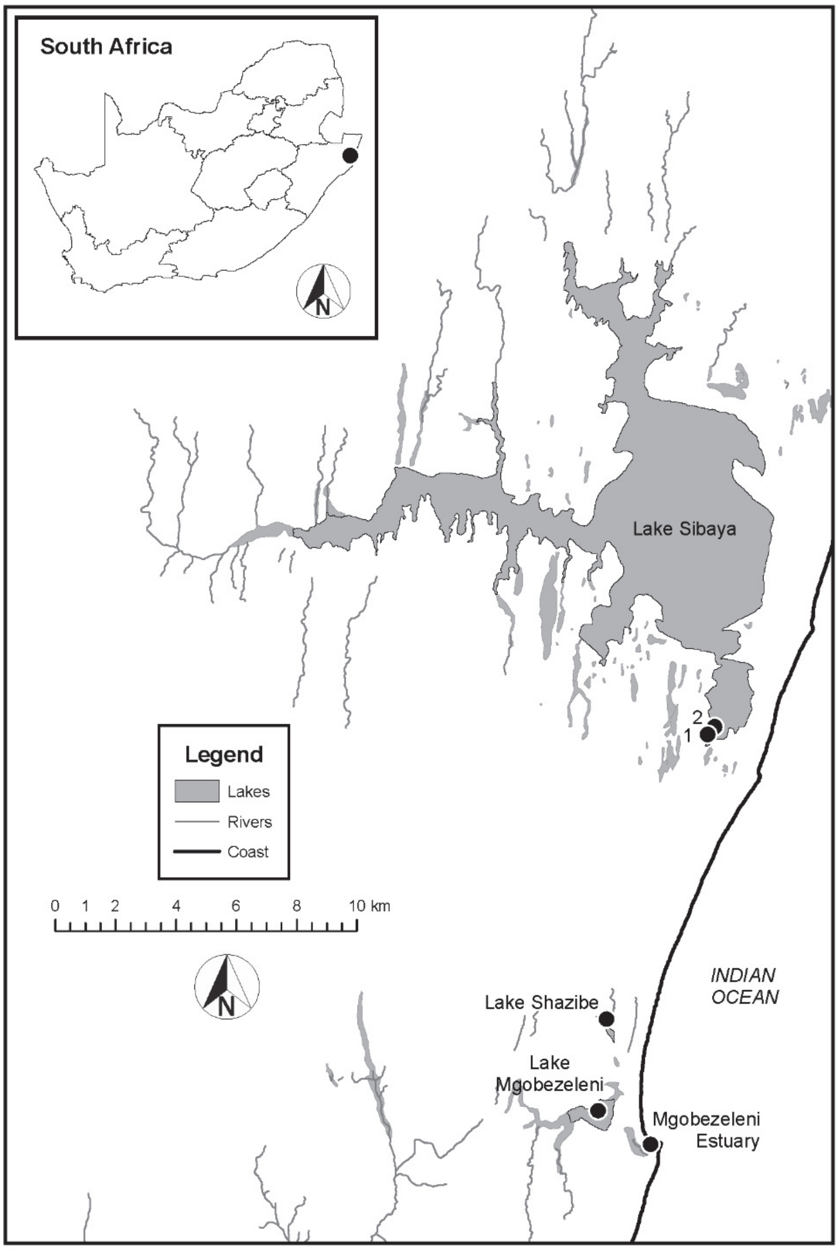


Figure 62: Map depicting the geographical location of sample sites. Map supplied by Ian Meiklejohn.

3.7.2.3 Amplicon library preparation and sequencing

Total DNA was extracted using the PowerWater DNA Isolation kit (MoBio Laboratories) and the hypervariable regions 4 and 5 of the 16S rRNA gene was amplified using the primer pair E517F (5'-CAGCAGCCGCGGTAA-3') and E969-984 (5'-GTAAGGTTCYTCGCGT-3') with MID tags added. The PCR reaction volumes included ~10 ng gDNA in a final volume of 25 µL in X1 PCR buffer, 0.3 µM of each primer, 300 µM dNTPs and 0.5 units of high fidelity KAPAHiFi Hotstart DNA Polymerase (KAPA Biosystems). The cycling parameters used were : 98°C for 5 min (1 cycle); 98°C for 45 s, 45°C for 45 s, 72°C for 1 min (5 cycles); 98°C for 45 s, 50°C for 45 s, 72°C for 1 min (20 cycles) and a final extension at 72°C for 5 min. The resultant amplicon products were purified from a 1% agarose gel using a PCR and Gel purification kit (BioLine) and then sequenced using the GS Junior. Titanium Sequencer as per the manufacturer's specifications (454 Life Sciences, Roche).

3.7.2.4 Computational analysis

Analysis of the sequence reads was done as outlined in Matcher et al. (2015). In brief, sequence curations and quality control was done using GS Junior software (Roche) and Mothur (Schloss et al., 2009). Chimeras were detected and removed from the dataset using UChime (Edgar et al., 2011) and Mothur. Classification of sequence reads was done using The Naïve Bayesian classifier algorithm against the Silva 16S rRNA database (Quast et al., 2013). Phylogenetic trees were constructed using Mega6 (Tamura et al., 2013).

3.7.3 Results

A total of 41061 454 sequence reads (Table 31), with an average length of 450 nucleotides spanning the V4-V5 region of the bacterial 16S rRNA gene sequence, were analysed for this study. The primers used to generate 16S rRNA amplicon libraries also amplify the V4-V5 region of the chloroplast genome, which can be used as a proxy for algal vs cyanobacterial abundance in the samples. In Lake Mgobezeleni and Lake Shazibe the cyanobacteria appear to be the dominant photosynthetic microorganisms, while algae are more abundant relative to the cyanobacteria in Lake Sibiya and the Lake Mgobezeleni Estuary (Table 31). While this is a crude measurement of relative abundance, the dominance of cyanobacteria over algae in Lake Mgobezeleni is supported by morphological studies conducted by Bate and Mhkwanazi (personal communication).

Table 31: Summary of the assignment of 16S rRNA sequence reads generated by pyrosequencing of the amplicon libraries

Samples	No of 454 reads	After curation	Total bacterial reads analysed	Cyanobacteria	Chloroplast (algae)	OTUs (Species)
Lake Mgobezeleni November 2015	3194	3154	ND	1623	85	ND
Lake Mgobezeleni January 2016	9293	9169	5084	1939	20	5187
Mgobezeleni Estuary January 2016	13188	11842	9310	522	656	9638
Lack Sibaya January 2016	2110	2077	1563	265	238	1650
Lake Shazibe January 2016	13273	12879	11192	1522	249	11528

A phylogenetic classification of the sequence reads was used to characterise bacterial diversity (at the phylum level) in the water samples. Reads representing bacteria belonging to the Bacteroidetes phylum were present in significant levels (12.6 to 40% of the total number of reads) in all four water bodies (Figure 63) with Lake Mgobezeleni and its associated estuary containing the highest levels of Bacteroidetes compared to that of the remaining lakes. A large proportion of the bacterial assemblage present in Lake Mgobezeleni samples collected in November 2015 and in January 2016 was represented by Cyanobacteria, with over 37% of the total bacterial reads being assigned to this phylum (Figure 63). In contrast, while cyanobacteria are present in Lake Sibaya and Lake Shazibe, a much larger representation of Actinobacteria and Verrucomicrobia were found in these two lakes.

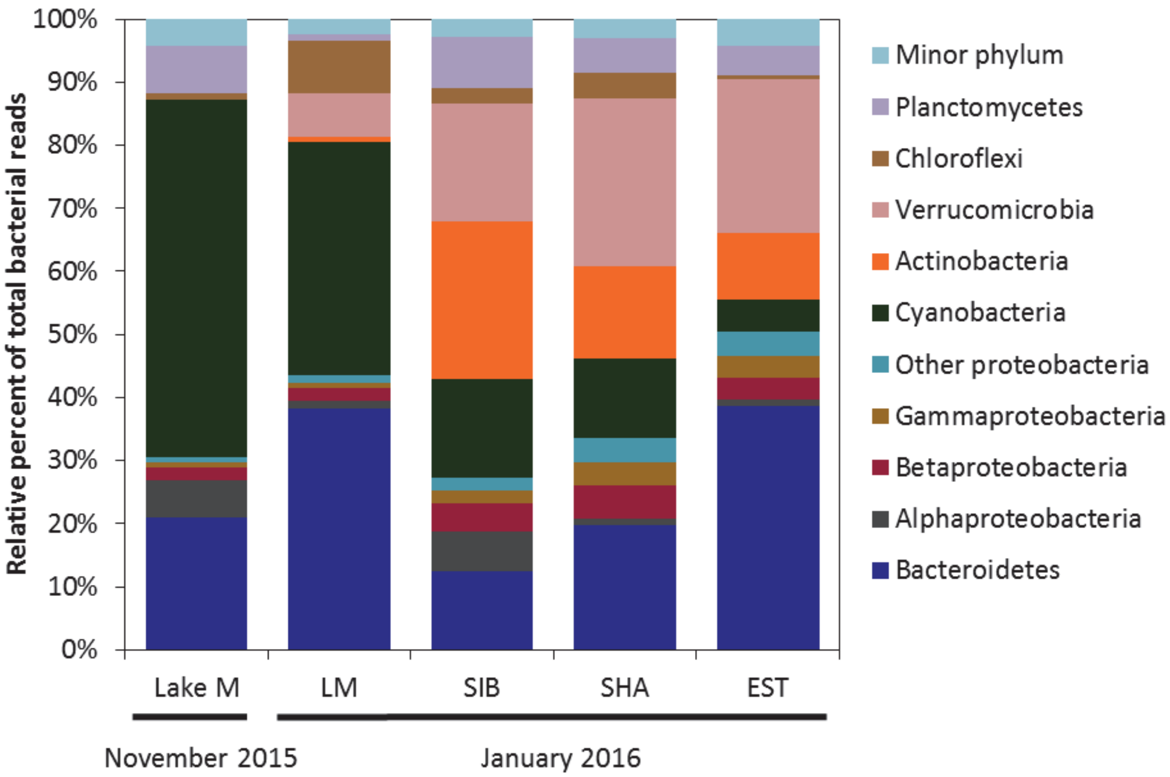
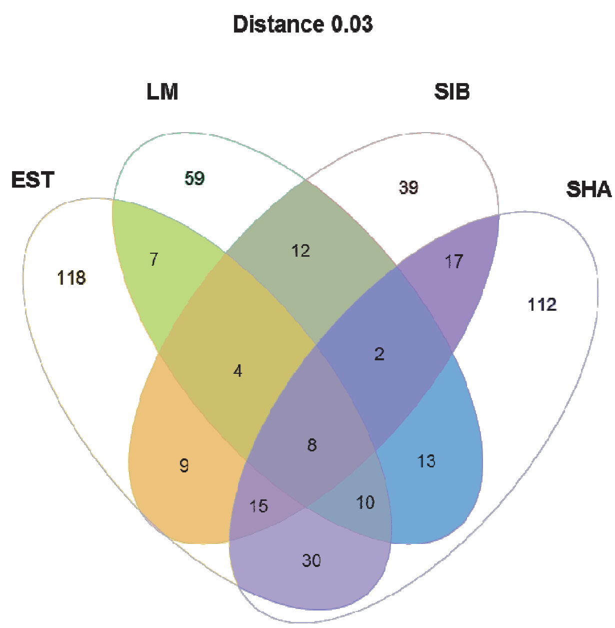


Figure 63: ***Phylogenetic classification of 16S rRNA gene sequence reads.*** **Bacterial 16S rRNA gene sequences were classified to the level of phylum and subclass (in the case of the Proteobacteria) from sequence datasets generated from metagenomic samples of Lake Sibaya (SIB), Lake Shazibe (SHA), Lake Mgobezeleni (LM) and the Mgobezeleni estuary (EST) all collected on the 26th January 2016. Lake Mgobezeleni (Lake M) was also sampled on 24th November 2015 (Lake M).**

To characterise the dominant bacterial taxa in the water samples, an analysis of the operational taxonomic units (OTUs) was conducted. A distance of 0.03 (i.e. 97 % sequence identify between reads), which is generally accepted as the point at which the majority of bacterial species can be differentiated from one another, was used. In other words, OTU analysis at a distance of 0.03 functions as a proxy for identifying species as not all bacterial species can be identified to the level of species due to incomplete databases for comparative purposes.

Overall, Lake Shazibe and the Mgobezeleni Estuary appear to support almost 40% higher levels of species diversity than lakes Sibaya and Mgobezeleni in terms of OTU abundance (Figure 64). Over 50% of these OTUs identified in Lake Shazibe, Lake Mgobezeleni and the Mgobezeleni Estuary were found to be unique to their particular body of water (Figure 64). By contrast, only 26.8% of the OTUs identified in Lake Sibaya were unique to this lake which showed the most overlap of OTUs with Lake Shazibe with 42 OTUs common between these two lakes. Lake Shazibe had the greatest overlap in OTUs with the Mgobezeleni Estuary with over 30% of Lake Shazibe OTUs occurring in the estuary as well (Figure 64). Lake Mgobezeleni and Lake Sibaya exhibited greatest commonality with respect to OTUs with 22.6% to 24.5% of their OTUs found in the corresponding lake. While this analysis does provide a good indication of common species within the microbial communities of the water samples, care must be taken when interpreting the results. Specifically, the representation of data using Venn diagrams does not take into account the total bacterial load (abundance) within water bodies. Therefore, an alternative, more robust comparative indicator was used to identify the dominant OTUs within each system.



	EST	LM	SIB	SHA
EST	201			
LM	29	115		
SIB	36	26	106	
SHA	63	33	42	207
Total	329	203	210	345

Figure 64: ***Venn diagram depicting the distribution of OTUs in the water samples.*** **Lake Sibaya (SIB), Lake Shazibe (SHA), Lake Mgobezeleni (LM) and the Mgobezeleni Estuary (EST). The datasets were subsampled to an even size to avoid representational bias due to differences in dataset sizes. OTUs were determined at a distance value of 0.03.**

In general, the species diversity in Lake Mgobezeleni was lower than that of the other water bodies, with ten OTUs accounting for almost 90% of the total number of sequence reads obtained for the sample. In the other samples, the top ten OTUs accounted for between 40-50% of the reads. The low diversity in Lake Mgobezeleni is a strong indicator of an impacted water body. The only OTU found to be present in significant numbers in all four bodies of water was OTU1 (Figure 65). A sequence comparison (BLAST analysis) of the consensus reads for OTU1 against GenBank (repository for 16S rRNA gene sequences) returned a 99% identity match with a cyanobacterial *Cyanobium gracile* isolate (Table in Figure 64). Not surprisingly, the remaining dominant OTUs in the estuary differ from those found in the lakes which is most likely a reflection of the marine influence. When considering the dominant OTUs found in the lakes themselves, only two OTUs were found to occur in more than one of the lakes. Specifically, OTU2 occurred in both Lake Mgobezeleni and Lake Sibaya whilst OTU7 was found in significant numbers in both Lake Sibaya and Lake Shazibe (Figure 65, 66). Thus, while all three lakes do have many OTUs in common, the OTUs which are dominant in each of these water bodies are very different.

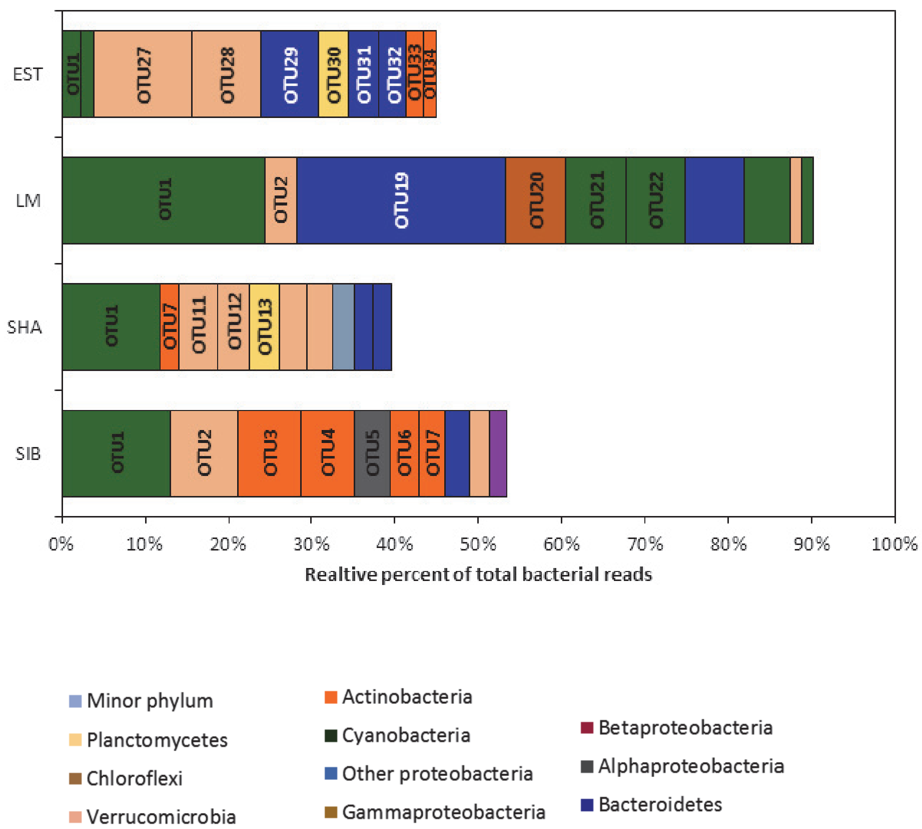


Figure 65: ***Abundance profiles of the dominant OTUs*. Lake Sibaya (SIB), Lake Shazibe (SHA), Lake Mgobezeleni (LM) and the Mgobezeleni Estuary (EST). Abundances are represented as the percentage representation of each OTU relative to the total number of bacterial reads.**

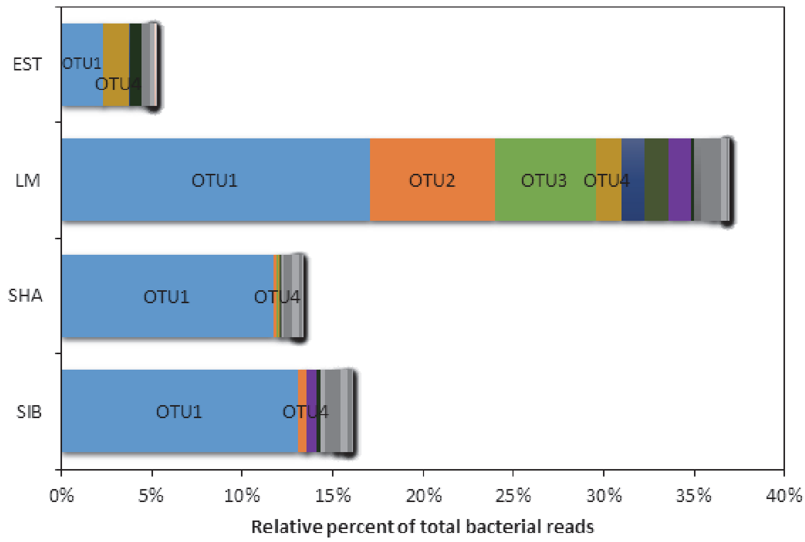


Figure 66: ***Abundance profiles of the Cyanobacterial OTUs.*** **Lake Sibaya (SIB), Lake Shazibe (SHA), Lake Mgobezeleni (LM) and the Mgobezeleni Estuary (EST). Abundances are represented as the percentage representation of each OTU relative to the total number of bacterial reads.**

Primary productivity in ecosystems is a critical component of ecosystem functioning. In aquatic ecosystems this is carried out by algae (eukaryotic) and photosynthetic bacteria of which cyanobacteria dominate. A comparison of the chloroplast (algal) vs 16S rRNA cyanobacterial reads higher relative abundance of algae in Lake Sibaya and the Mgobezeleni Estuary, whereas the cyanobacteria are the dominant photosynthetic microorganisms in Lake Shazibe and Lake Mgobezeleni (Table 31). As observed previously, OTU1, a cyanobacterial species, was found to be dominant in all of the study sites and other than in Lake Mgobezeleni, the cyanobacteria in the water columns of the remaining sites is almost exclusively comprised of this single OTU1 (Figure 66). Lake Mgobezeleni has a wider range of dominant cyanobacterial OTUs with OTU2 and OTU3 being the most dominant. Identification of these two OTUs by sequence comparison to known databases (e.g. GenBank) indicated that they belong to the genera *Nostoc* and *Prochlorothrix* respectively (Table 32).

Whilst cyanobacteria play a crucial role in primary productivity in aquatic ecosystems, they do on occasion have negative impacts. Not only can cyanobacteria form blooms which result in anoxia of water bodies, but several species of cyanobacteria also produce toxins which have serious health implications. These toxins include hepatotoxins, neurotoxins and dermotoxins (Briand et al., 2003). With respect to the cyanobacteria identified in this study, OTU4 has a 99% sequence identity with the neurotoxin producing *Microcystis aeruginosa* whilst OTU15 has a 98% identity with another toxin producing cyanobacterial species, *Nodularia spumigena* (Table 32).

Table 32. Classification of the most dominant cyanobacterial OTUs in each of the lakes by BLAST analysis against the Genbank database.

	Relative abundance(%) of OTUs				Closest match to sequences deposited in Genbank (as determined by BLAST analysis)	Identity (%)
OTU	**SIB**	**SHA**	**LM**	**EST**		
OTU1	8.76	9.26	13.74	2.09	*Cyanobium gracile* strain PCC 6307	99
OTU2	0.28	0.09	5.62	0.00	*Nostoc azollae* PCC0708T	96
OTU3	0.04	0.10	4.44	0.00	*Prochlorothrix hollandica* PCC 9006T	95
OTU4	0.00	0.04	1.14	1.30	*Microcystis aeruginosa* NIES-843T **	99
OTU5	0.00	0.03	1.02	0.11	*Gloeothece membranacea* sPCC 6501T	92
OTU6	0.00	0.01	1.12	0.00	*Trichocoleus desertorum* sATA4-8-CV2	91
OTU7	0.36	0.01	1.00	0.00	*Trichocoleus desertorum* ATA4-8-CV2	91
OTU8	0.16	0.03	0.14	0.53	*Synechococcus rubescens* SAG 3.81T	97
OTU9	0.00	0.07	0.31	0.03	*Cyanobium gracile* strain PCC 6307T	96
OTU10	0.12	0.03	0.29	0.03	*Stanieria cyanosphaera* sPCC 7437T	94
OTU11	0.00	0.01	0.00	0.23	*Pleurocapsa* sp. PCC 7327	95
OTU12	0.04	0.01	0.17	0.05	*Synechocystis* sp. PCC 6803	94
OTU13	0.00	0.11	0.00	0.00	*Oscillatoria nigro-viridis* s PCC 7112	86
OTU14	0.00	0.08	0.00	0.00	*Calothrix* sp. PCC 6303 PCC 6303T	94
OTU15	0.28	0.00	0.06	0.00	*Nodularia spumigena* strain PCC 73104 **	98
OTU16	0.00	0.06	0.00	0.00	*Cyanobacterium aponinum* strain PCC 10605	86
OTU17	0.00	0.01	0.11	0.00	*Desulfosporosinus youngiae* strain JW/YJL-B18	86
OTU18	0.00	0.05	0.00	0.01	*Syntrophothermus lipocalidus* strain DSM 12680	86
OTU19	0.00	0.00	0.00	0.07	*Cyanothece* sp. PCC 8801 **	95
OTU20	0.16	0.01	0.03	0.00	*Cyanobacterium aponinum* strain PCC 10605	98
OTU21	0.00	0.01	0.08	0.00	*Synechocystis* sp. PCC 6803	99
OTU22	0.00	0.00	0.11	0.00	*Gloeobacter violaceus* strain PCC	90
OTU23	0.00	0.00	0.02	0.05	*Synechocystis* sp. PCC 6803	96
OTU24	0.00	0.04	0.00	0.00	*Hassallia andreassenii* strain CCALA 954	98
OTU25	0.00	0.02	0.05	0.00	*Gloeobacter violaceus* strain PCC 7421	90

** Potentially toxin producing strains of cyanobacteria (Briand et al., 2003). SIB: Lake Sibaya SHI: Lake Shazibe; LM: Lake Mgobezeleni; EST: Lake Mgobezeleni Estuary. Shading indicates species identification of OTUs

Cyanobacteria are known to remain dormant in water systems long after events resulting in blooms, being present at low levels in the water system and sediment where they have the potential to respond rapidly to recurring environmental impacts conducive for their growth. We therefore looked at the phylogenetic relationship of all the cyanobacterial OTUs found in the water samples to identify those related to groups with the potential for cyanotoxin production. Overall, a broad range of cyanobacterial species were present in the water samples (Figures 67 & 68) but a large number of OTUs fell within the Order Synechococcales (Figure 68). In addition to OTUs 4 and 15, a third OTU (OTU19) clustered with a *Cyanothece* species known to be a toxin producer (Figure 67). Interestingly, there have been reports of recent, prolonged blooms of a *Cyanothece* species in Lake St Lucia (Muir et al., 2011; du Plooy et al., 2015). Since there is no direct connection between Lake St Lucia and the water bodies investigated in this study, the co-occurrence of this cyanobacteria belonging to this genus may be coincidental rather than related.

Figure 67. Phylogenetic relationship between overall cyanobacterial OTUs (Figure 67) and those OTUs classified within the Order Synechococcales (Figure 68).

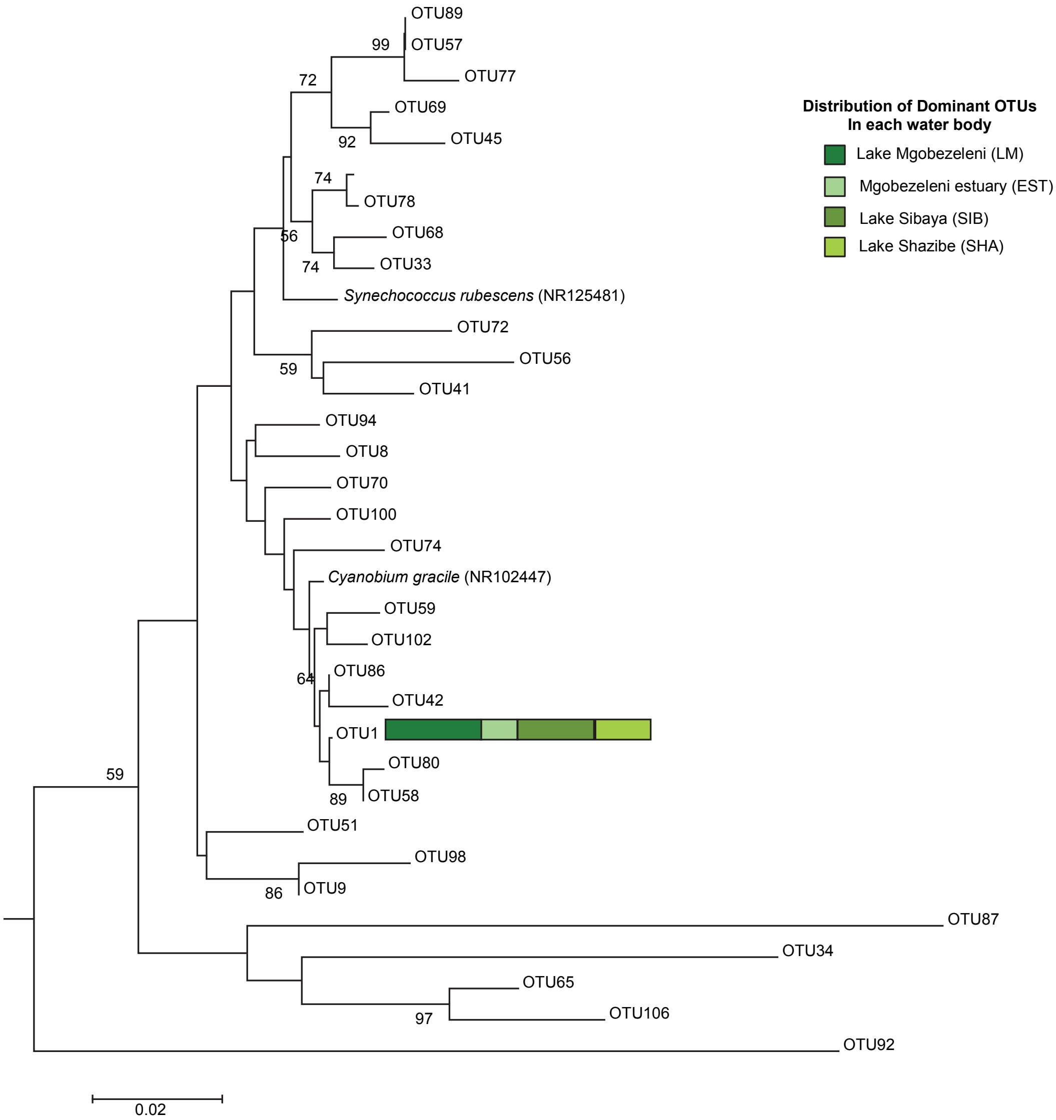


Figure 68. Neighbour-joining phylogenetic tree of the 16S rRNA gene sequences from the dominant Cyanobacteria belonging to the order Synechococcales from Lake Sibaya (SIB), Lake Shazibe (SHA), Lake Mgobezeleni (LM) and the Mgobezeleni estuary (EST). *Methanococcus thermolithotrophicus* DSM 2095 was used as the outgroup. Bootstrap values (expressed as percentage of 1,000 iterations) greater than 50% are given at nodes. The scale bar represents 0.05 substitutions per alignment position in the tree. Shaded boxes represent the relative abundance of dominant OTUs in each of the four water systems with OTU1 accounting for just under 14% of the total reads in the Lake Mgobezeleni sample.

3.7.4 Discussion

The aim of this project was to provide information on cyanobacterial diversity in water bodies in the Maputaland system (Lake Mgobezeleni and Lake Sahzibe) recently observed to experience cyanobacterial blooms. The Mgobezeleni Estuary was included because it is fed by Lake Mgobezeleni and we took advantage of the availability of a water sample to include Lake Sibaya in the study as well.

The experimental approach was to use next generation sequencing (NGS) technology to analyse the 16S rRNA gene sequences of bacteria in water samples. This approach provides high resolution molecular information on bacterial taxa that is several orders of magnitude higher that morphological identification of cyanophytes. In particular, the NGS 16S rRNA data enables the identification of less abundant taxa and depending upon the data volume, can be used to identify "rare" and dormant taxa. Previous studies had shown the presence of *Aphanocapsa* and *Aphalotheca* cyanophytes in Lakes Shazibe and Mgobezekhelele (Bate, personal communication). We did not detect any 16s rRNA reads corresponding to species from these genera. This may indicate that the bloom caused by these species has been superseded by new cyanobacterial species or that species currently present in the water are morphologically similar.

While all four water bodies are dominated by the same Cyanobium gracile strain, (OTU1), the overall microbial communities found in the water columns are quite distinct in terms of diversity and community structure. The relatively low species diversity observed in Lake Mgobezeleni is suggestive of an anthropogenically impacted system resulting in a significant cyanobacterial bloom. Of concern is the observation that a Microcystis aeruginosa strain has been persistently dominant in Lake Mgobezeleni between 24 November 2015 and 26 January 2016. This organism is known to produce mycrocystin, a hepatotoxic compound which poses serious health risks for to humans and animals if ingested. These cyanotoxins can persist in the sediment of contaminated water bodies and in plants irrigated with contaminated water for considerable lengths of time, posing a long term risk to local communities (Briand et al., 2003; Corbel et al., 2014).

What is the potential for future cyanobacterial blooms with the potential for cyanotoxin production? In addition to Microcystis aeruginosa which was detected in Lake Shazibe, Lake Mgobezeleni and in the estuary, a further three potential toxin-producing cyanobacterial taxa, based upon their taxonomic relatedness to species known to produce cyanotoxins, were identified in all four water bodies. However, the majority of cyanobacterial species present in the water column are essential unclassified i.e. there are no known related species currently described in the public databases. These unclassified OTUs fall into two clusters that likely represent completely new cyanobacterial families with a completely unknown capacity for the production of bioactive secondary metabolites that may or may not be cytotoxic.

3.7.5 Conclusions

The results of this study highlight the importance of identifying water systems at risk of developing cytotoxic cyanobacterial blooms and the need to monitor such vulnerable systems to ensure the safety of surrounding communities. The data raise important issues for further study:

1. ***The development of robust methodologies for assessing vulnerable systems.*** We recommend the use of NGS to characterise dormant cyanobacterial taxa resident in the sediment that have arisen from past blooms and have the potential to rapidly respond to favourable environmental conditions.

2. ***The need to determine the toxin-producing potential of the large number of unclassified cyanobacterial taxa***. We recommend the molecular (NGS) route since many of these bacterial species may not be easy to culture and if they can be cultured, the conditions may not be conducive the production of secondary metabolites.

3.8 INORGANIC WATER QUALITY

The University of Zululand students undertook a water quality-monitoring program using an AquaPro instrument. The sample sites are shown in Figure 69 and the average physical properties for all the boreholes sampled are given in Table 33 and the surface water resources in Table 34. The pH was in the range 5.44-7.52 for the groundwater while the surface water had a smaller range of 6.26 to 7.76. The TDS was very similar for both the surface and groundwater sites (97-402 mg l^{-1}) with generally slightly higher salinity values for the surface water. The similarity for all measured macro-constituents for the surface and groundwater supports the conceptual model that the system is groundwater dominated.

Water samples were also collected from the boreholes and surface water features shown in Figure 69 and sent to Mhlathuze Water laboratory for analysis of the major ions. Unfortunately, there was insufficient sample to conduct TDS on all samples. The plot of the concentrations for all the sites are group into surface and groundwater sites in Figure 70. Groundwater samples were taken directly from the borehole with one exception. The relative concentration for the groundwater and surface water samples are shown in Figure 71.

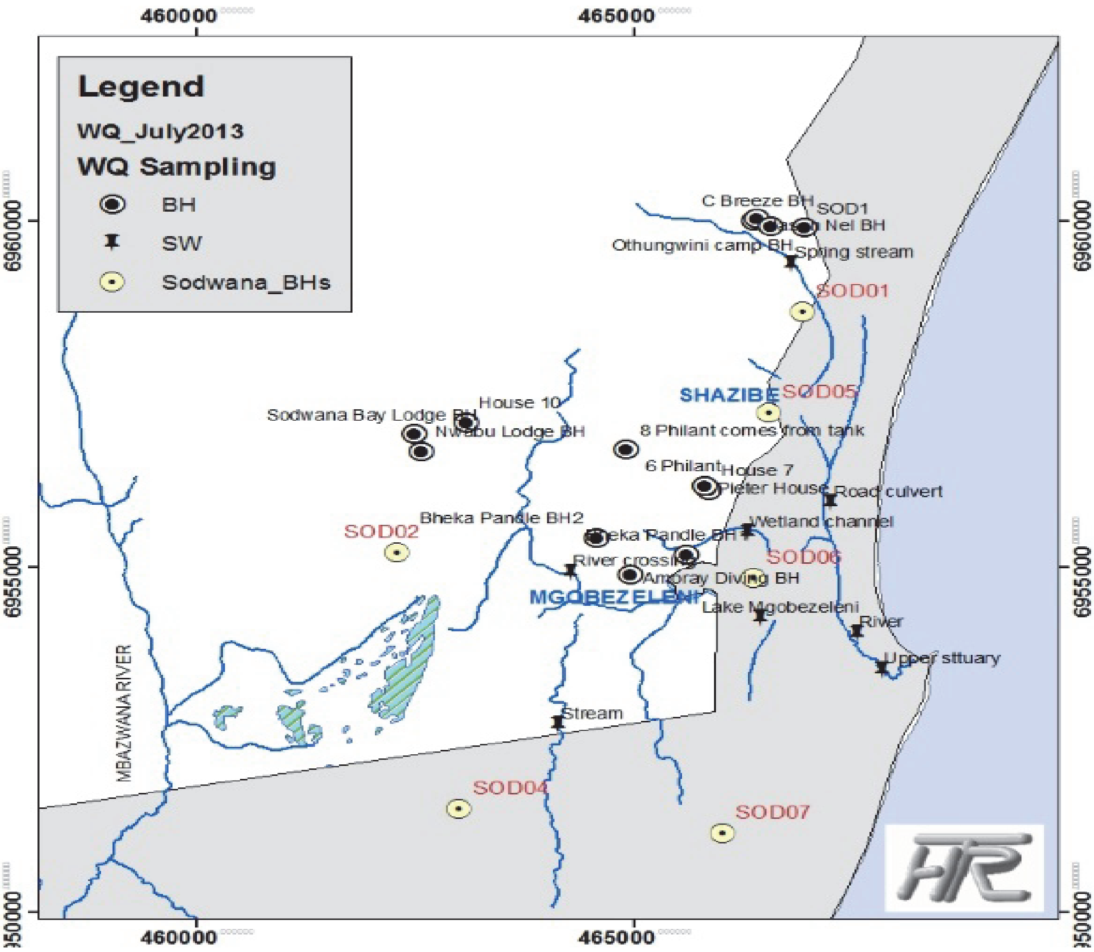


Figure 69. The water quality sampling sites.

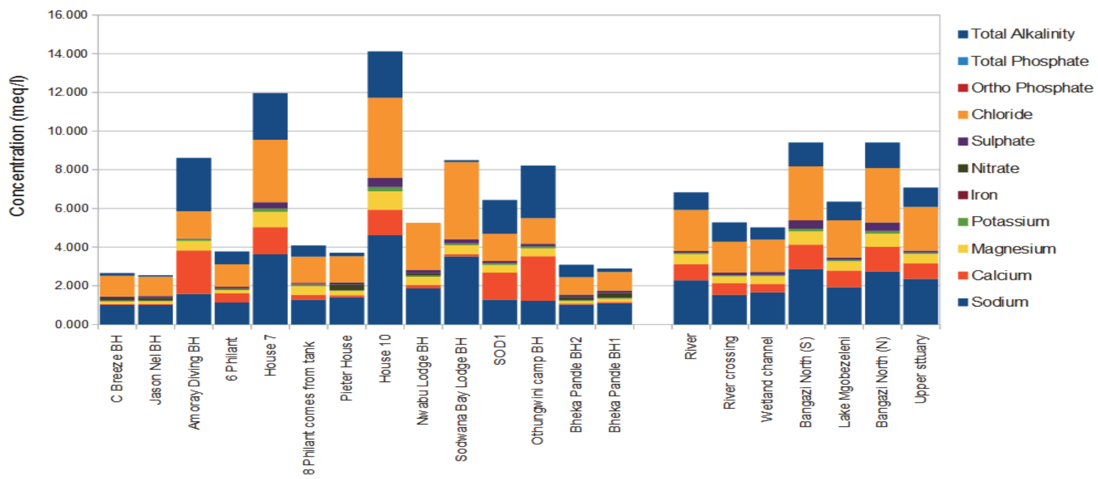


Figure 70. Bar chart of the major cations and anions for all the surface and borehole water samples.

A piper plot of these data in Figure 72 show that the groundwater at SOD 1 and Othungwini Lodge in the north are group with Amoray Lodge in the south as Calcium dominated regions (Open Squares in Figure 72), However, there is not clear separate grouping of the surface water samples (*red crosses*) and the deep groundwater (*blue squares*).

Table 33. The physical properties of surface and borehole water across the main study area using an AquaPro.

BH	Turb (NTU)	pH	ORP	DO	TDS (mg l^{-1})	Salinity (ppt)
SOD1 Monitoring Borehole	0.00	7.03	179.10	0.00	256	0.19
SOD2 Monitoring Borehole	0.00	7.52	94.90	0.00	377	0.29
SOD3 Monitoring Borehole	0.10	5.98	150.90	0.00	113	0.08
SOD4 Monitoring Borehole	1.70	7.34	84.90	0.00	282	0.21
SOD5 Monitoring Borehole	0.00	6.06	197.60	0.00	222	0.17
SOD6 Monitoring Borehole	0.00	7.12	146.10	0.00	259	0.19
SOD7 Monitoring Borehole	0.00	6.39	93.50	0.00	223	0.17
SOD8 Monitoring Borehole	0.00	6.65	184.00	0.00	364	0.28
BH27 Monitoring Borehole	0.00	6.21	222.10	0.00	331	0.25
Bheka Phandla Borehole	8.90	4.82	230.50	0.00	97	0.07
Bheka Phandla Borehole	1.40	5.50	209.60	0.01	106	0.08
C Breeze Borehole	3.60	5.44	155.70	0.00		
J Nel Borehole	0.00	5.64	199.20	0.00		
Othungwini Borehole	0.00	7.26	139.70	0.00	253	0.19
Lake Bhangazi	0.00	7.00	138.80	0.00	390	0.30
Lake Bhangazi	0.00	6.45	95.60	0.00		
Lake Bhangazi	0.00	7.19	90.80	0.00	402	0.30
Lake Mgobezeleni Gauge	5.00	7.76	137.80	0.00	270	0.20
Road culvert stream	5.90	6.26	99.60	0.00	315	0.24
Downstream culvert	5.90	6.33	91.10	0.00	318	0.24
Spring stream	4.70	6.57	62.20	0.00	224	0.17
Stream	2.90	6.28	97.50	0.00	162	0.12

Table 34: Chemical constituents analysed in both surface and groundwater samples.

Ion	Units	Groundwater	Surface water	Ratio
Sodium as Na	mg l^{-1}	45.09	44.66	1.01
Calcium as Ca	mg l^{-1}	16.51	13.79	1.20
Magnesium as Mn	mg l^{-1}	5.12	5.28	0.97
Potassium as K	mg l^{-1}	3.26	2.67	1.22
Iron as Fe	mg l^{-1}	0.310	0.082	3.78
Chloride as Cl	mg l^{-1}	70.75	67.24	1.05
Sulphate as SO_4	mg l^{-1}	7.39	9.01	0.82
Bicarbonate as HCO_3	mg l^{-1}	57.42	43.89	1.31
Nitrate as NO_3	mg l^{-1}	0.99	0.64	1.55
Phosphate PO_4	mg l^{-1}	0.030	0.007	4.29
Total dissolved Sub	mg l^{-1}			

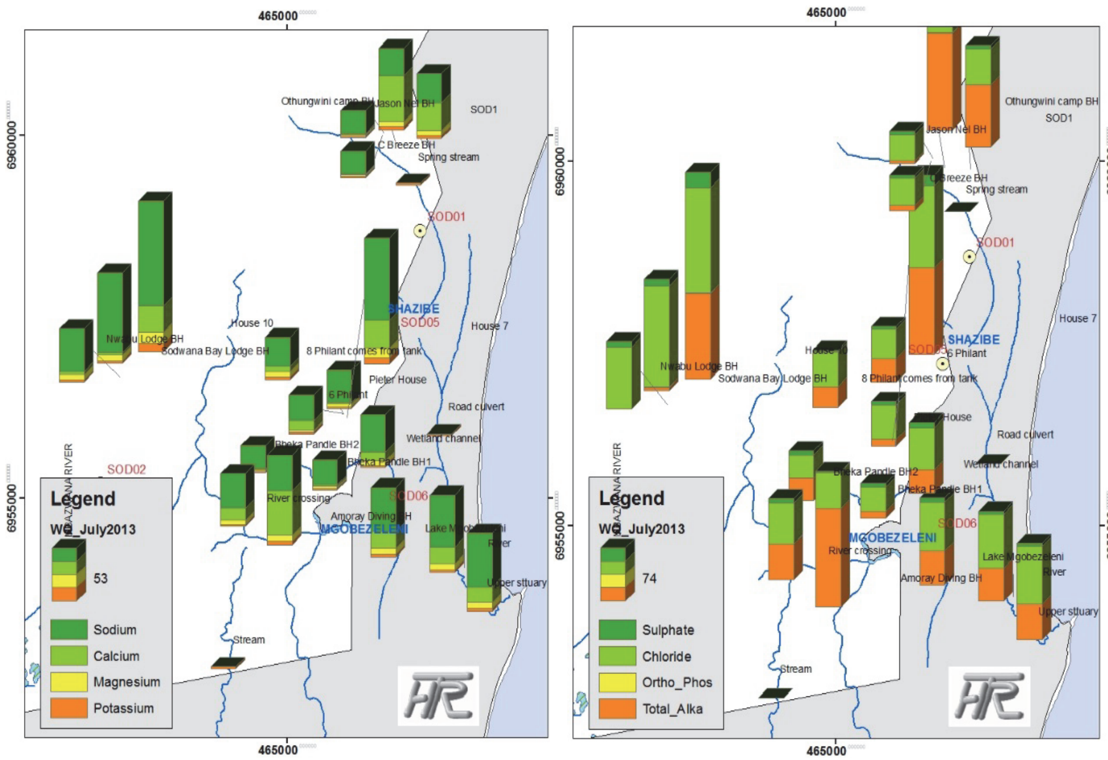


Figure 71. The relative concentrations of the anions and cations.

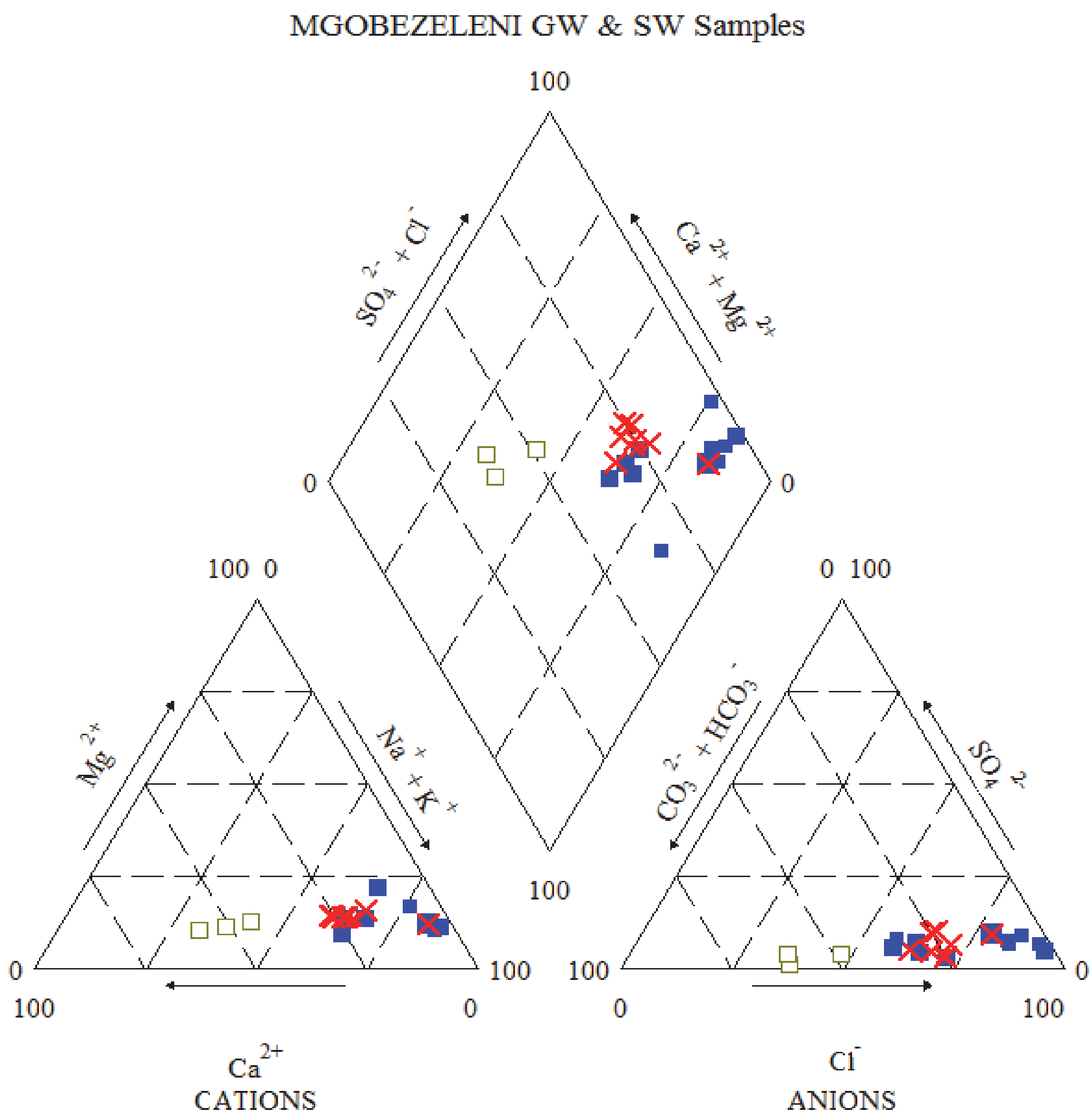


Figure 72. A Piper plot of the surface (red cross) and the groundwater samples (squares) for the samples sites in Figure 13.

CHAPTER 4. HYDROLOGY AND HYDRODYNAMICS of MGOBEZELENI CATCHMENT

It is not feasible to measure the groundwater fluxes and derive the flow velocities without considerable financial and logistic support. The most pragmatic method of deriving these variables is through the development, calibration and validation of appropriate mathematical (numerical) models of the system based on a well-grounded conceptual model formed from sound physical principles and field measurements. This section gives a short summary of the approach and methods used.

The numerical model was developed to provide a comprehensive understanding of the hydrology of the Mgobezeleni system and to provide reliable estimates of the driving variables to assist in evaluating the hydroecology of the system. To achieve this it is necessary to:

- Establish a detailed profile of the water table elevation and its variability to evaluate the hydrological influence on wetlands and drainage features such as streams, lakes, estuary and the ocean shoreline,
- Establish the water level elevations and discharge as well as their variability in the main drainage boundaries (streams, lakes and wetlands) that will directly influence the ecology of these water resources,
- Determine the flow pathways to evaluate sources and sinks of solutes in the system, and
- Enable impact studies of anthropogenic processes.

This report presents the hydrology of the study area as part of an investigation into groundwater and surface water interactions. It was established above that the surface water features (streams, lakes and wetlands) are controlled by the groundwater dynamics. Consequently, the hydrological system was studied using a suite of numerical models that simulate the entire hydrodynamics of the controlling processes that include the infiltration, evapotranspiration, percolation and groundwater flow that discharges into the rivers, lakes, estuary and the coastline.

In hydrological terms, the catchment refers to the land surface that demarcates the full extent of the area capturing the source of water entering the system. This is generally derived from the "best" available topographic elevation profile (Digital Elevation Model) for hillslope-dominated systems. However, in geohydrological systems, the catchment boundary is formed by the groundwater ridge that defines the flow direction rather than the topographical ridges. In the Mgobezeleni system, these two catchment areas have very different boundaries that need to be differentiated in these studies where the sources and sinks of water quantity and quality are the important issues.

An understanding of the hydrology and hydrodynamics requires data and information on the storage and transport of water between the various water resources over different temporal and spatial scales. In this study, the measurement of water storage in the surface and groundwater resources was initiated to achieve the needs of the project. The flow of water in rivers and estuary that transports water between some of the resources was also measured. However, there are large gaps in the monitoring and measurement of the necessary flows between all the resources that are required for a complete water balance study and the determination of the hydrodynamics of the system. Hence, it was necessary to adapt other techniques to support and complement the field measurements. The most pragmatic and cost effective approach is through the development and application of numerical models of the system built on an evolving conceptual model of the hydrology and hydrodynamics.

4.1 HYDROLOGICAL DATA REQUIREMENTS

The surface topography is derived from 5 m contours from the Department of Survey and Mapping as described earlier. In this study, it is necessary to derive the groundwater gradient across the model domain by selecting appropriate external drainage boundaries beyond the catchment area of the main study site (Figure 1). The Mbazwana River formed the western external boundary and the Indian Ocean the eastern boundary. The external boundary between the Mbazwana River and the Lake Sibaya rivers was defined as a no-flow boundary to the west of Mbazwana. Lake Sibaya and Lake Bhangazi systems (lakes and rivers) formed the northern and southern boundaries.

The development of the groundwater model required spatial and temporal data for the recharge (rainfall), evaporation (land use and DEM), and hydrogeological features. The rainfall series was obtained from SAWB and the UZ automatic weather station at Sodwana Bay Lodge and daily rainfall at Mbazwana and Ezemvelo KZN Wildlife office in Sodwana Bay as described in Section 2.2. The evaporation data for the past three years was extracted from the UZ AWS (T, Td, Radiation, and Wind speed) using the Penman model as described in Section 2.2.

The groundwater hydrology (geohydrology) is driven by the hydraulic gradient in the saturated zone unlike surface hydrology that is controlled primarily by the topographical surface (hillslope gradients). The information requirements for the hydrogeology are described in the next section.

4.2 HYDROGEOLOGY

A conceptual model of the hydrogeology described in Section 2.3 was developed from many published studies in the region (Kelbe et al., 2015; Kelbe et al., 2010; Botha et al., 2010; DLP, 1992; Worthington, 1978; Været et al., 2009), limited borehole logs and a concurrent geophysical survey (MSc by Nweze, 2015).

The primary aquifer is conceived to be the unconsolidated sediments deposited during the post-Cretaceous period following sea level changes during periods of regression and transgression, forming paleochannels aligned with major drainage channels (Figure 12). Several Hydrostratigraphic Units (HSU) were described along the Maputaland coastal plain (Botha et al., 2010), some of which were identified in the study area (Schapers, peers com) during borehole development. The information and data available for the study area were described in Section 2.3.

The vertical profile of the three primary aquifers comprising the main groundwater units were described above in Section 2.3 (Figure 13). The spatial distribution of the Hydrostratigraphic Units (HSU) with assumed uniform hydraulic properties were derived from published maps for the upper unconfined aquifer (Figure 73). The spatial distribution of the HSUs for the deeper aquifers are unknown and were derived from calibrations with the numerical model described in subsequent sections.

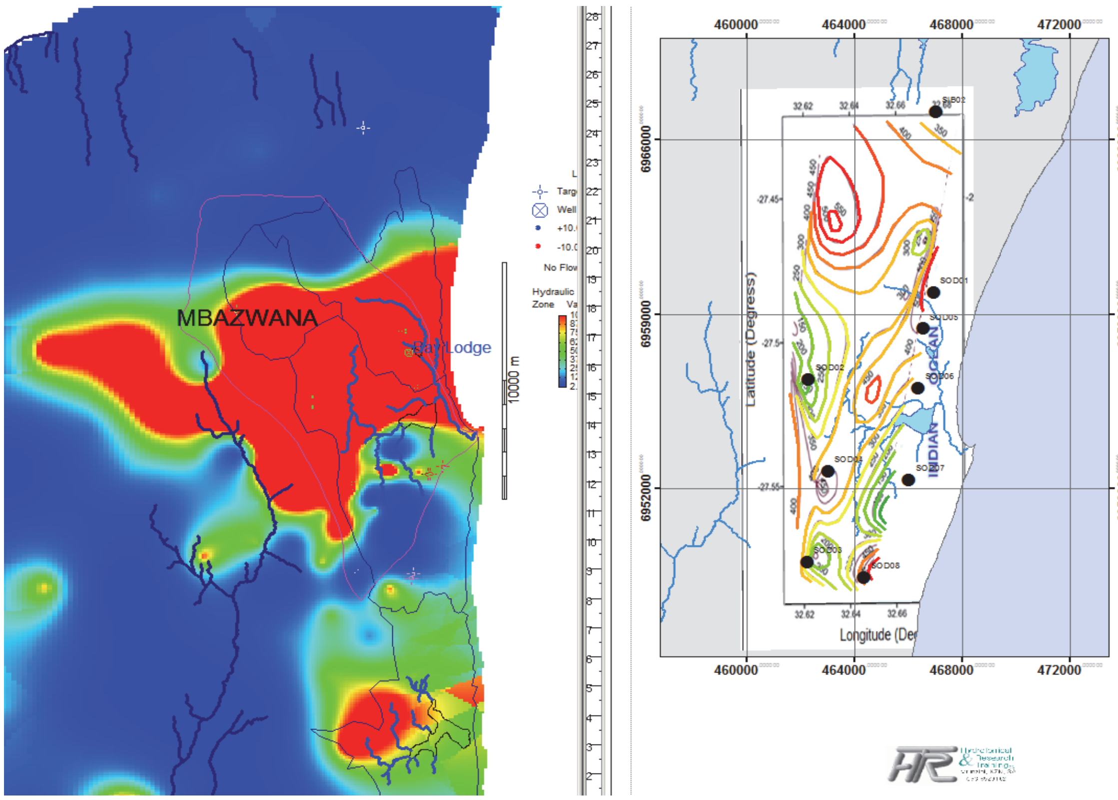


Figure 73. The derived base of the primary aquifer from borehole logs (Left) and the geophysical study by Nweze (2015) (right).

The schematic illustration in Figure 12 and 13 illustrates the main HSU identified in the region. This conceptual model was used by Nweze (2015) to map the vertical profile of the Kwambonambi, Kosi Bay and Uloa Formations for the Sodwana Study area. These units were extrapolated to the external boundaries by assuming a general gradient of 3^{o} from west to east in the numerical model. The base of the primary aquifer (upper surface of the Cretaceous mudstone) was derived from surveys along the coastal margin at Lake Sibaya, Nweze geophysical survey and borehole logs from NGA (DWS) shown in Figure 73.

4.3 NUMERICAL GROUNDWATER MODELLING

The numerical model was required to simulate the water table profile and variability, the discharge rates in all the important boundaries including the streams, lakes and Ocean, the hydrological pathway from source (recharge) to sink (discharge boundaries including evaporation), and anthropogenic impacts. This required a model that could simulate the groundwater dynamics and its interaction with surface water features. It would also need to provide the transport mechanism for particle tracking studies. There are several models (such as Mike SHE and FEFLOW) that could accomplish these requirements but ultimately MODFLOW 2005 (Harbaugh, 2005) was selected for the groundwater dynamics with the latest suite of accompanying packages for linking the groundwater and surface water interactions.

4.3.1 <u>Geomodel configuration</u>

The numerical groundwater model was compiled as a transient, 3-layer configuration on a 100 m by 100 m finite grid in MODFLOW 2005 with its suite of accompanying packages that link the shallow unconfined aquifer to the recharge and discharge zones (streams, lakes, ocean and boreholes). The bottom layer representing the Uloa Formation lies above the impervious bedrock and is semi-confined by the overlying middle layer representing the leaky Kosi Bay Aquifer. The top layer represents an unconfined aquifer comprising the Sibaya and Kwambonambi Formations.

The geological map of the region (Figure 74) was used to create the HSU zones in the surface layer and the initial hydraulic properties of these units were assumed from published studies in the region (Kelbe et al., 2015; DLP, 1992; Worthington, 1978; Været et al., 2009). The hydraulic properties were adjusted during calibration process to derive the final estimates of the hydraulic conductivity and storage coefficient. The Kwambonambi Formation was configured as an unconfined layer. The Kosi Bay Formation was configured as an unconfined layer with variable transmissivity while the Uloa Formation was configured as the lower, confined layer. A cross-section from west to east through the model domain showing the assumed profile of the hydrostratigraphic layers is shown in Figure 75.

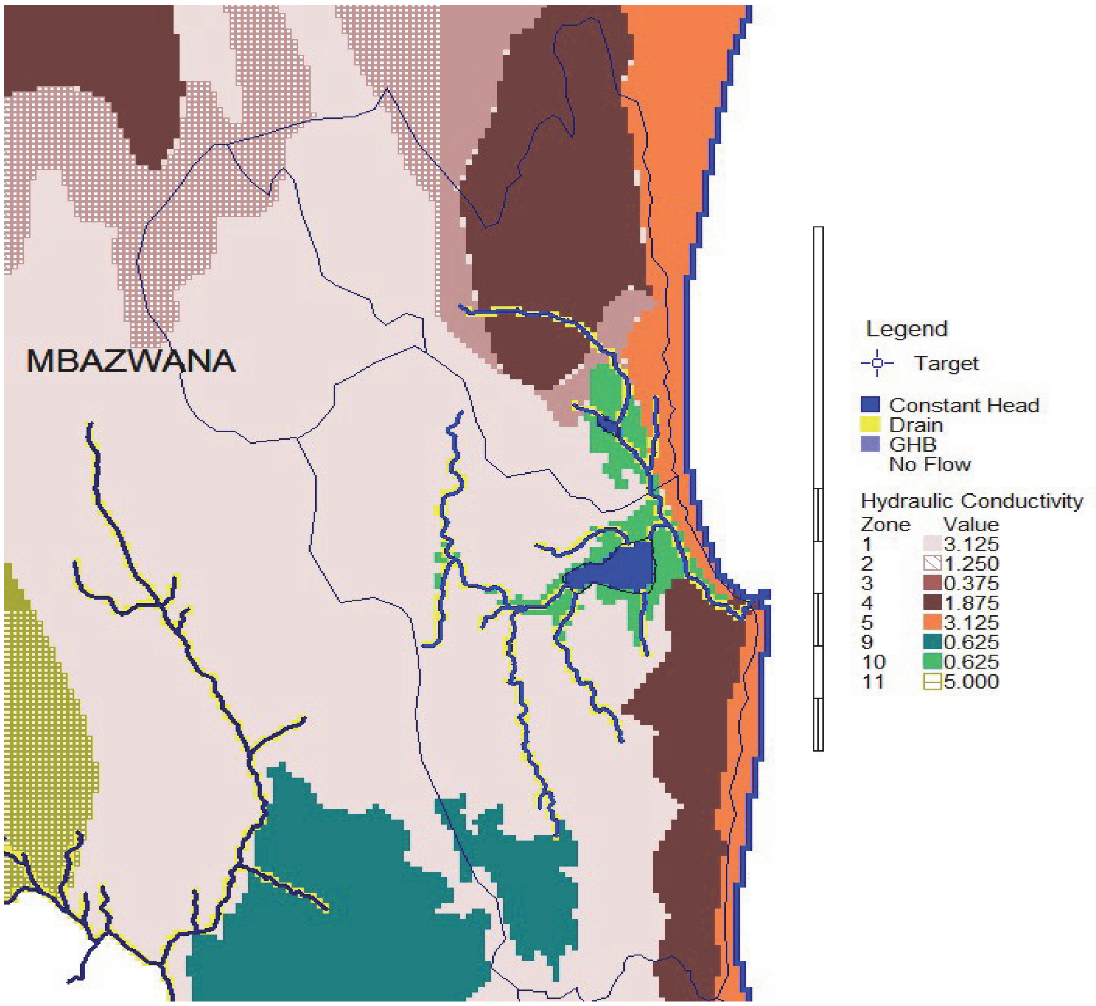


Figure 74. The spatial distribution of the geological units in the upper aquifer derived from the published geological maps by the Geological Society of SA.

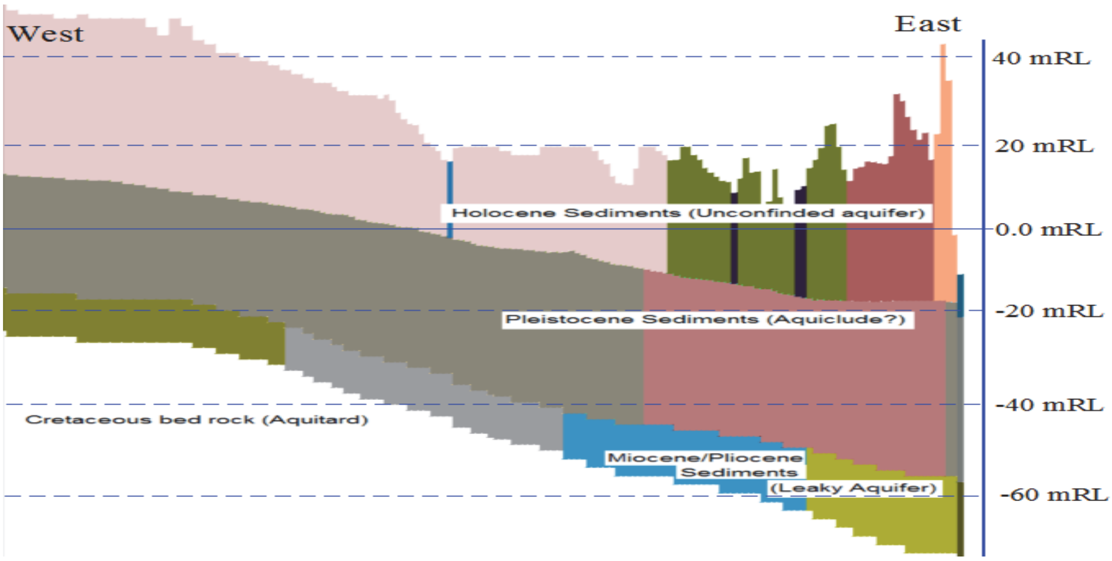


Figure 75. A vertical transect through the model from west to east illustrating the three layers comprising different HSUs.

4.3.2 Hydromodel Configuration

4.3.2.1 Vertical flux boundaries

The infiltration across the model domain is derived from the effective rainfall after subtracting interception losses based on the vegetation type (using a Leaf Area Index). The recharge (percolation) to groundwater storage is derived from the infiltrate rate after evaporation/transpiration losses in the unsaturated zone were satisfied using the Unsaturated-Zone Flow (UZF) Package (Niswonger et al., 2006). The UZF also allows for surface runoff to streams and lakes when the infiltration rate is exceeded. The vertical unsaturated flow is based on the kinematic-wave approximation of a wetting front represented by leading and trailing waves (Smith and Herbert, 1983). UZF further assumes uniform hydraulic properties for the different soil conditions (Figure 74).

The water content in the soil profile is depleted according to the ET demand and soil moisture content. If the water table elevation is within the rooting depth and the ET demand is not met by the unsaturated zone, then the ET is extracted directly from the groundwater. UZF package simulates the infiltration and evaporation rates from the unsaturated zone and the evaporation from the groundwater in contact with the vegetation. The package requires the specification of the effective rainfall, the evaporative demand and rooting depth for each landuse type (Figure 76).

It is assumed that the inflow to groundwater minus the outflow would equate to the change in storage for the model domain (mass balance principles). Under average hydrological conditions, the change in storage is assumed negligible and the inflow (infiltration minus evaporation) should equal the outflow through the streams, lakes, boreholes and seashore. To establish a reliable (calibrated) recharge rate for the model under average hydrological conditions, the effective rainfall (infiltration rate) was adjusted systematically in the steady state model to achieve acceptable correspondence between the measured and predicted runoff at the river monitoring sites while maintain an acceptable correlation between the measured and predicted groundwater storage. This was evaluated in the transient model.

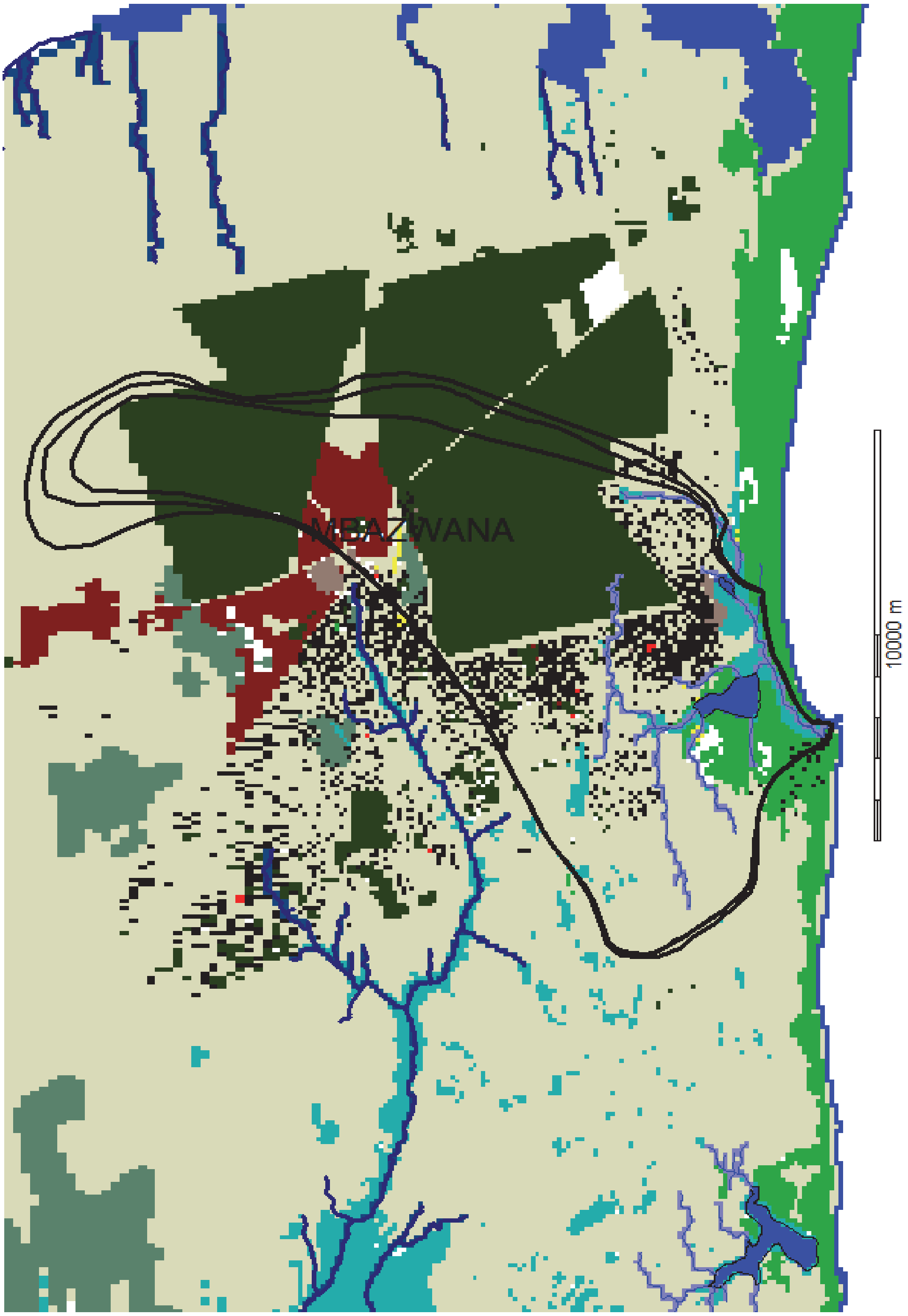


Figure 76. The current landuse pattern for the model domain.

4.3.2.2 External Boundaries

The Indian Ocean shoreline was configured as a constant head boundary with an elevation of 0 mRL and a concentration of 35,000 $g^{-1} m^{3}$. Lake Sibaya and Lake Bhangazi were configured as specified head boundaries. Lake Sibaya water level elevation was extracted from DWS database. No water level measurements are available for Lake Bhangazi so it was assumed that the lake water level was 6 mRL. The Mbazwana River (external boundary) was configured as a head dependent boundary using the SRT package in MODFLOW.

4.3.2.3 Internal stream boundaries

All the internal streams were configured as head dependent boundaries using the SFR1 package (Prudic et al., 2004). The hydraulic conductivity in the stream beds of the rivers where there was no indication of underlying peat deposits were assumed to be controlled by the underlying sandy aquifer. The stream and lakebed sediments where there appeared to be a significant peat layer, the hydraulic conductivity were initially set to be one order of magnitude lower than the surrounding aquifer. However, there are indication that some of the peat may be highly permeable as discussed in the estuary section. Consequently, the stream and lakebed hydraulic properties were subsequently adjusted during the model calibration.

The model uses Manning's equation to route flow down a sloping stream channel of specified width and streambed roughness. The slope of the streambed was derived from the DEM for each stream segment (cell). The streambed roughness was assessed visually and values derived from <http://www.engineeringtoolbox.com/mannings-roughness-d_799.html>. The stream bed roughness for these streams decreases with increasing stream order on the assumption that the stream channel becomes more regular with less grass and more sand substrate until the higher order streams reach the swampy areas where the stream channel losses its shape. It was assumed that the streambed width increases linearly from 1 m in headwaters of first order streams.

4.3.2.4 Lakes

The water balance for both lakes were configured in MODFLOW using the LAK3 package (Merritt and Konikow, 2000). The LAK3 package used the computed streamflow, the interactive groundwater fluxes derived from Darcy's Law and the direct contributions from rainfall, evaporation and surface flow from the UZF package to calculate the lake water balance. At the head of the stream where the outflow channel emerges from the lake, the depth of flow is computed by the model SFR1 package as the difference between the lake stage and the top of the streambed elevation.

4.4 MODEL CALIBRATION AND EVALUATION

It is not possible to derive all the model parameters from direct or indirect measurements so it is necessary to modify the driving variable and controlling parameters to achieve the best agreement between the variables that are directly affected by these controlling parameters in a process called parameter calibration. Unfortunately, the hydrological system is extremely complex with many feed backs/forwards controlled by a multitude of parameters that can provide exactly the same results using different combinations of parameters. Consequently, this study attempted to limit the number of parameter values by adopting the following procedure.

4.4.1 Sensitivity Analysis

A sensitivity analysis was performed on the recharge parameters and the aquifer hydraulic properties to eliminate insensitive parameters from the calibration process.

The model was found to be sensitive to the recharge rate, evaporation rate and the rooting depth of the commercial forestry near Mbazwana. It was establish that similar parameter values for the grassland and commercial forestry resulted in excessive streamflow into Lake Shazibe relative to Lake Mgobezeleni. To achieve the best fit to the flow into Lake Shazibe (at Tolla se Gat) and Bheka Phandla it was necessary to induce lower recharge and/or high evaporation from the Shazibe catchment that was dominated by commercial plantations.

The initial model comprised 15 zones of uniform hydraulic properties representing the different HSUs. A sensitivity analysis indicated that a smaller set of these zones were sensitive to reduction of the residual error between the measured and simulated head values. All the parameters that created a minor response to changes in the residual values (Figure 77) were excluded from the calibration.

4.4.2 Calibration Process

The water balance between the fluxes (recharge & discharge) through a storage unit (aquifer or lake) must balance the change in storage (as illustrated in Figure 78). Consequently, the first requirement was to balance the recharge with the discharge through measurable drainage boundaries under steady state conditions when the change in storage is zero. Most of the recharge to the groundwater is derived from rainfall after accounting for interception losses.

The simulated discharge into the streams and lakes were calculated at suitable locations to enable the adjustment of the recharge and aquifer parameters to achieve an agreement between the measured and simulated flow rates. The infiltration rate (effective rainfall) and evaporation parameters were systematically adjusted together with the storage parameters to achieve the acceptable correlation between the discharge and storage (water level).

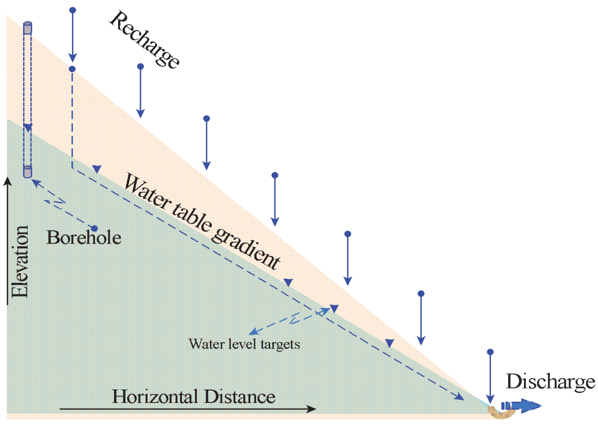


Figure 77. A schematic of the groundwater parameters involved in the recharge calibration process.

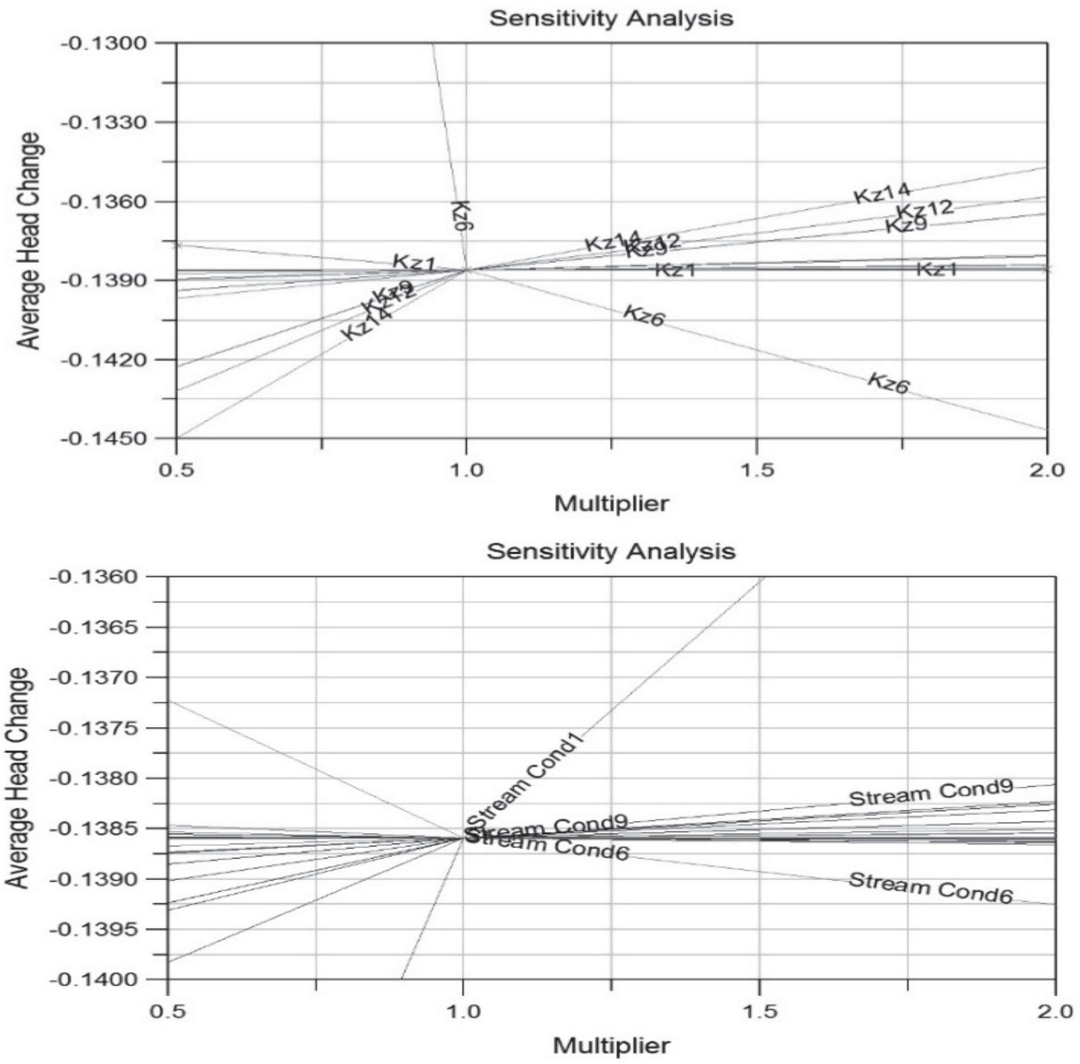


Figure 78. The sensitivity analysis of selected model parameters.

These procedures were repeated in an iterative process when additional data became available during the ongoing fieldwork and conceptual modelling. The calibrated model is considered “work in progress” that needs to be continually updated and revised as additional data and information becomes available.

4.4.2.1 Head Calibration

The correlation between the measured and predicted heads for all the aquifer targets over the simulation period is shown in Figure 79 for the current model (Ver 3T1.MF2005_UZF).

Generally the simulated and observed head values for all the layers are within 2-3 m (see scatter graph in Figure 80). The correspondence between the predicted and observed heads for the two long-term DWS monitoring sites at Mbazwana and Sodwana is shown in Figure 80.

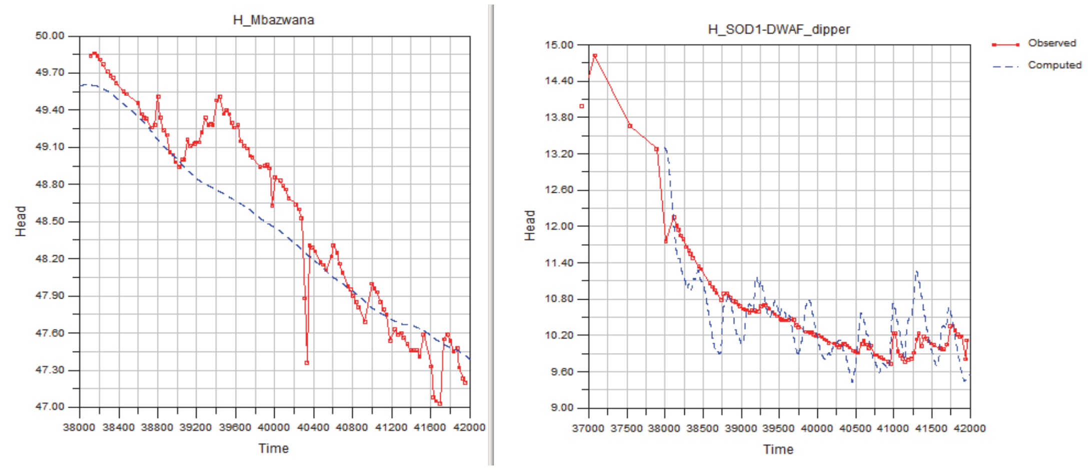


Figure 79. The correspondence between the measured and simulated piezometric head change at Mbazwana and Sodwana long term monitoring sites in the Uloa Formation.

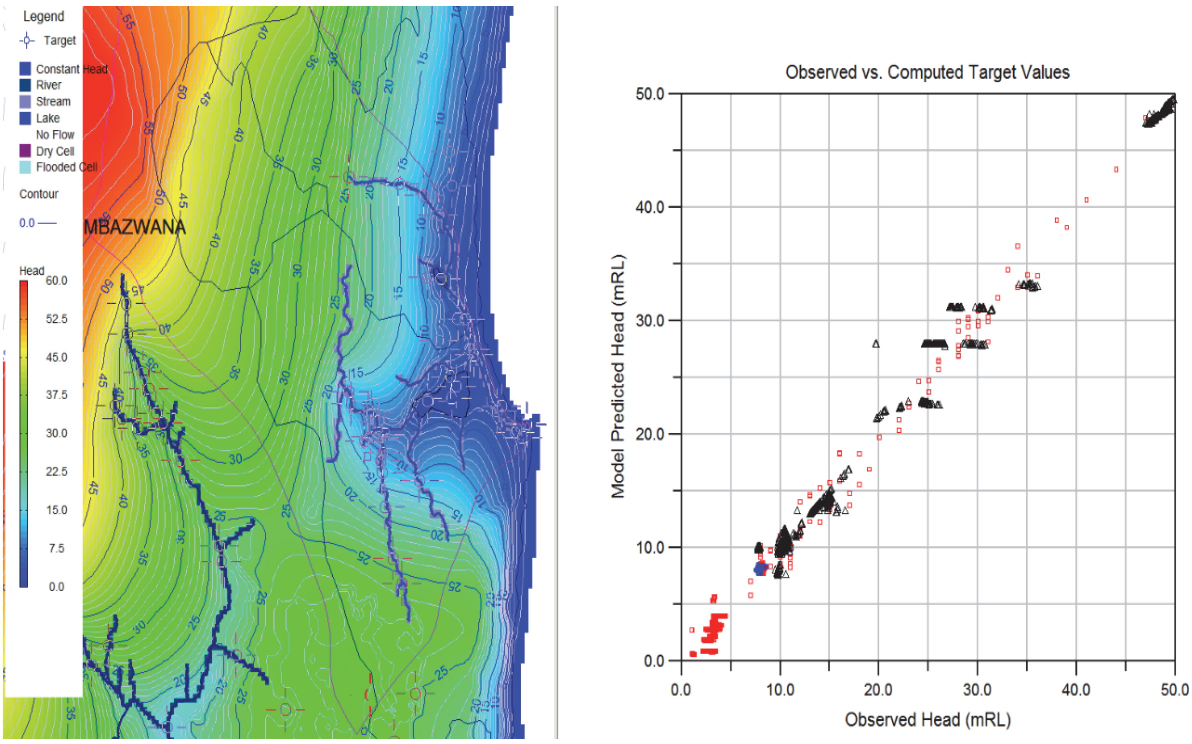


Figure 80. The scatter plot of the predicted and measured heads for ALL targets in all three layers at the locations shown on the map.

4.4.2.2 Flow calibration

The simulated and measured streamflow at several sites that were conducive for monitoring were compared to the model predictions during the calibration of the recharge rate. Figure 81 shows the level of agreement between the simulated and measured flow rates at the Tolla se Gat and Shazibe Culvert sites that monitor the flow into and out of Lake Shazibe. The current model (Version 3T3) correctly predicted the flow in the lake feeder stream but overestimated the flow out of Lake Shazibe by a factor of two on several occasions.

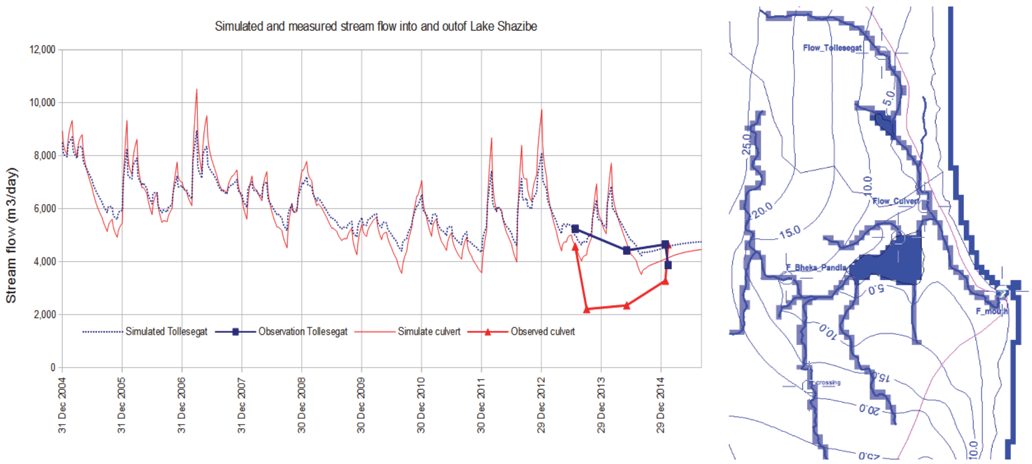


Figure 81. The measured and simulated flow for the stream feeding into and out of Lake Shazibe.

The flow in Tolla se Gat continued unabated up to February 2016 while the flow through the culvert stopped in the middle of October 2015 (Figure 23). The water level in the stream between the culvert and Lake Shazibe also appeared to have dried up during this period. It is considered likely that the water level in Lake Shazibe dropped to the level of some control features that restricted any outflow to the downstream swamp. If this is the situation then the water level in Lake Shazibe should remain relatively stationary. This would require a balance between the inflow from Tolla se Gat and the outflow that is likely to be through the groundwater toward the Indian Ocean. Consequently, it was difficult to establish the catchment boundary for Lake Shazibe.

The model simulation indicate a complex interaction with Lake Shazibe and feeder stream. There appears to be sections of the stream that have transmission losses, particularly below Tolla se Gat where the water table lies below the streambed and the groundwater flow directly toward the Ocean. This could be an explanation for the strong inflow to, but lack of outflow from Lake Shazibe at the end of 2015. The dune cordon to the east of Lake Shazibe may support a groundwater ridge during wet period that is eroded during dry period, hence allowing the groundwater flow to the Ocean.

The simulated flow rates for the channel downstream of the confluence into the estuary varied from 0.1 $m^3\ s^{-1}$ to over 0.3 $m^3\ s^{-1}$ with an average that is about half the measured flow rate through the beach berm prior to the mouth breaching.

4.4.2.3 Lake Water Balance

The water level elevation monitoring of Lake Mgobezeleni provided a surrogate indicator of the change in lake water storage as part of the water balance. The difference between the inflow from the streams, groundwater and UZF surface flows are expected to balance the change in storage resulting from the outflow to the estuary and the groundwater. The water balance components for Lake Mgobezeleni (Figure 82) indicate the change in the lake water level is within several centimetres of the measured lake level.

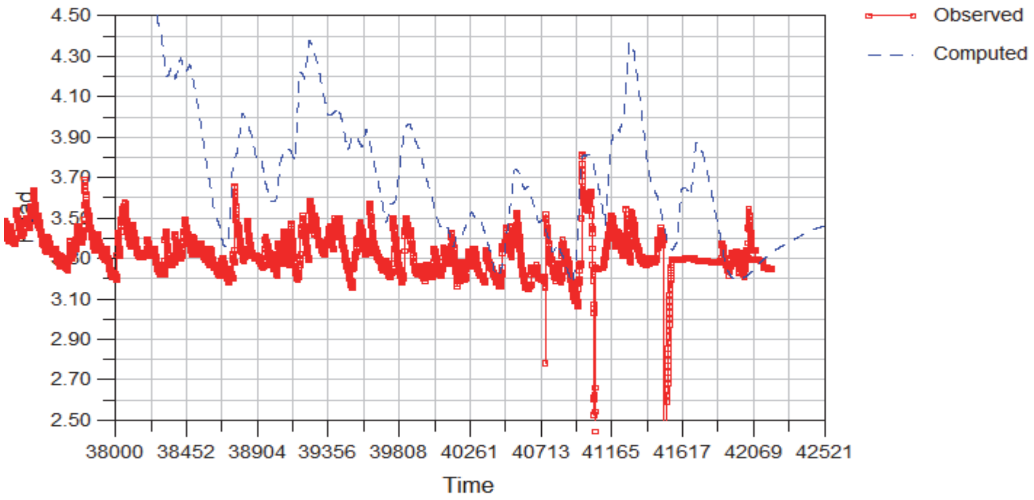


Figure 82. The simulated and measured water level for Lake Mgobezeleni.

The calculated water balance components for the Lakes is presented in Table 35. The simulated average water level for Lake Mgobezeleni is close to the measured levels but it is uncertain if the corresponding water level for Lake Shazibe are correct because they could not be surveyed. The model indicates that there was a steady decline in the water level for Lake Mgobezeleni of about 5 mm a year for the simulation period from 2004 to 2016. The lake water level measurements for Lake Mgobezeleni show a sudden drop in 2001 but the linear trend is not statistically significant (Figure 18).

The simulated average water volume for Lake Mgobezeleni is derived from the lake water level and the measured bathymetry that is assumed to be representative of the prevailing conditions. However, the bathymetry for Lake Shazibe has not been determined and the surface area was extracted from the exposed water surface in the model. The ecological studies described in Section 2.9 indicate that the lake is considerably greater in area but is covered by floating mass of vegetation with only a portion of the lake exposed. Consequently, the simulated volume of water in Lake Shazibe may be grossly underestimated.

The simulated surface water inflow and outflow for Lake Mgobezeleni is considerably higher than the other components. The simulated surface flow comprises the contribution from the four streams feeding into Lake Mgobezeleni (Figure 15), surface runoff into these streams (UZF component) and the surface runoff along the lake shoreline. UZ Honours students conducted measurements on three of these tributaries feeding into Lake Mgobezeleni on various occasions and the total inflow to the lake from these streams is estimated to be approximately 12,000 m^3 day^{-1} (Table 36). It was not possible to conduct measurements on the other feeder streams due to the nature of the channel. It is estimated that the total inflow from all four streams is of the order of 15,000 m^3 day^{-1}. This is less than half the simulated inflow (Table 35). The discrepancy may arise from the lake shoreline where the water table is very close to the surface and there is abundant peat formation that could induce significant surface flow. However, this discrepancy needs to be investigated. The simulated outflow is lower than the measured values at the mouth by UZ Honours students of approximately 70,000 m^3 day^{-1} but higher than other measurements (Table 36). Unfortunately, it is unknown if the UZ measured outflow included tidal contributions.

Table 35. The simulated water balance characteristics of the lakes under average (steady state) conditions.

Average (Steady State) conditions	Lake Mgobezeleni	Lake Shazibe*
Volume of water (m^3)	11,403,000	1,830,000
Water level (mRL)	3.41	4.29
Groundwater Inflow (m^3 day^{-1})	1,481	1,250
Groundwater Outflow (m^3 day^{-1})	8,116	349
Stream Inflow (m^3 day^{-1})	45,002	7,801
Stream Outflow (m^3 day^{-1})	36,906	8,441
Rainfall (m^3 day^{-1})	2,244	347
Evaporation (m^3 day^{-1})	3,884	647

**Note: The bathymetry of Lake Shazibe is unknown.*

Table 36. The average measured flow rates in selected tributaries to the lakes.

stream	Site	Average Flow (m^3 day^{-1})
1	Mouth (19377, 15604, 25478,	20,000
2	Tolla se Gat (feeding Shazibe) (Photograph 9)	4550
3	Culvert (draining Shazibe) (Photograph 11)	3411
4	Channel into Mgobezeleni (Photograph 8)	1077
5	Bheka Phandla (western tributary- Photograph 6)	6125
6	Southern tributary (Photograph 7)	4958
	TOTAL for three Streams feeding Mgobezeleni	12160

4.5 MODEL PREDICTIONS (MODEL VERSION – SODWANA_3T3_MF2005UZF.GWV)

The calibrated groundwater model was configured to simulate the groundwater dynamics, streamflow discharge and water level, the lake water balance and its offers the ability to extract mass balance estimates for user specified boundaries or regions (boxes around select areas) such as wetlands, boreholes and along the coastline. The model results for the calibration period from 01/01/2000 to 31/07/2015 are presented below. It is difficult to present the full 4D data set (spatial and temporal) generated by the model for the past few years so some selected conditions are presented in this section.

4.5.1 <u>Water Table Profile (Groundwater storage)</u>

The water table profile is a dynamic feature of the groundwater system that changes continuously with time. It defines the varying thickness of the unsaturated zone, the volume of groundwater storage and the hydraulic gradient that will influence the flow rate of groundwater in the aquifer.

4.5.1.1 Vertical Head Profile

The water table elevation in the upper layer (Kosi Bay Formation) may differ significantly from the head in the lower layer (Uloa Formation) if the intermediate layer (Kwambonambi Formation) creates a confining flow barrier.

Water level loggers were installed at three depth in the Kwambonambi, Kosi and Uloa formation at SOD6. Water level measurements were obtained for several month before the shallow boreholes became blocked by termite nests. Nevertheless, the short logger series (Figure 83) shows that all three aquifers responded similarly to major recharge events and had very similar recession rates in contrast to observations in Richards Bay where a head difference of 2 m is observed for these three Formations (Kelbe & Germishuyse, 2010). This implies that the hydraulic properties of the three layers is not substantially different.

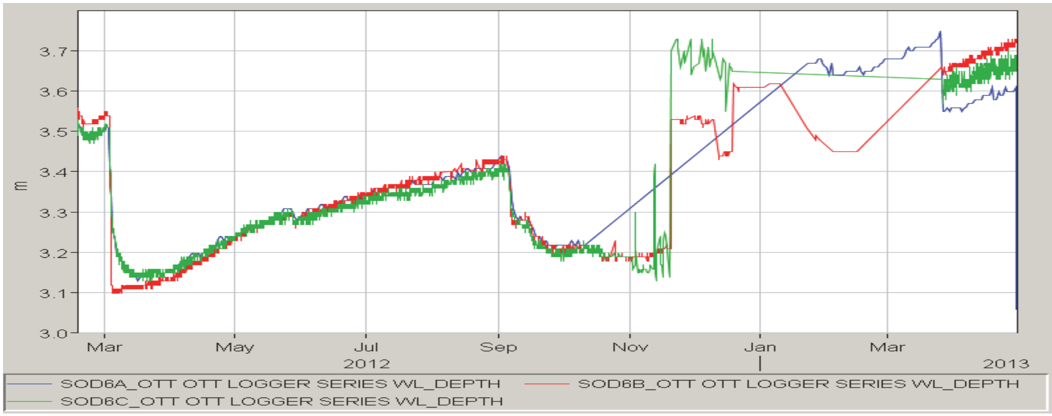


Figure 83. The measured water level changes in the three shallow boreholes at SOD6 monitoring the Kwambonambi, Kosi Bay and Uloa Formations.

The head profile along transects from west to east for 1 km intervals across the catchment are shown in Figure 84. In the northern catchment, there are no drainage boundaries (streams) that create depression in the water table profile. In these sections, the water table slopes from the ridge under Mbazwana to the coast. In the transects further to the south, the draining streams create depressions in the water table profile. Groundwater will flow from the ridge toward the drainage boundary.

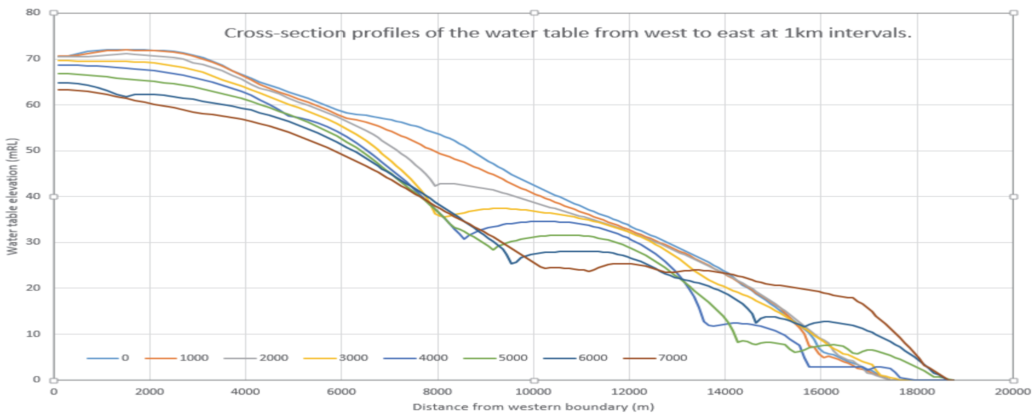


Figure 84. The simulated head profile along east-west transects at 1 km intervals across the model domain from north to south. The valley depressions in each profile represent the drainage lines that directly influence the groundwater ridge that form the catchment divide.

4.5.1.2 Average Water Level Profile and variability

The water table elevation contours under average hydrological condition covering the short calibration years are shown in Figure 85. The correspondence between the predicted and measured elevations at selected sites was described in the calibration section above. The average water table profile for the ten-year simulation period was used to derive the recharge zone (*i.e.* catchment) that is also shown in Figure 85.

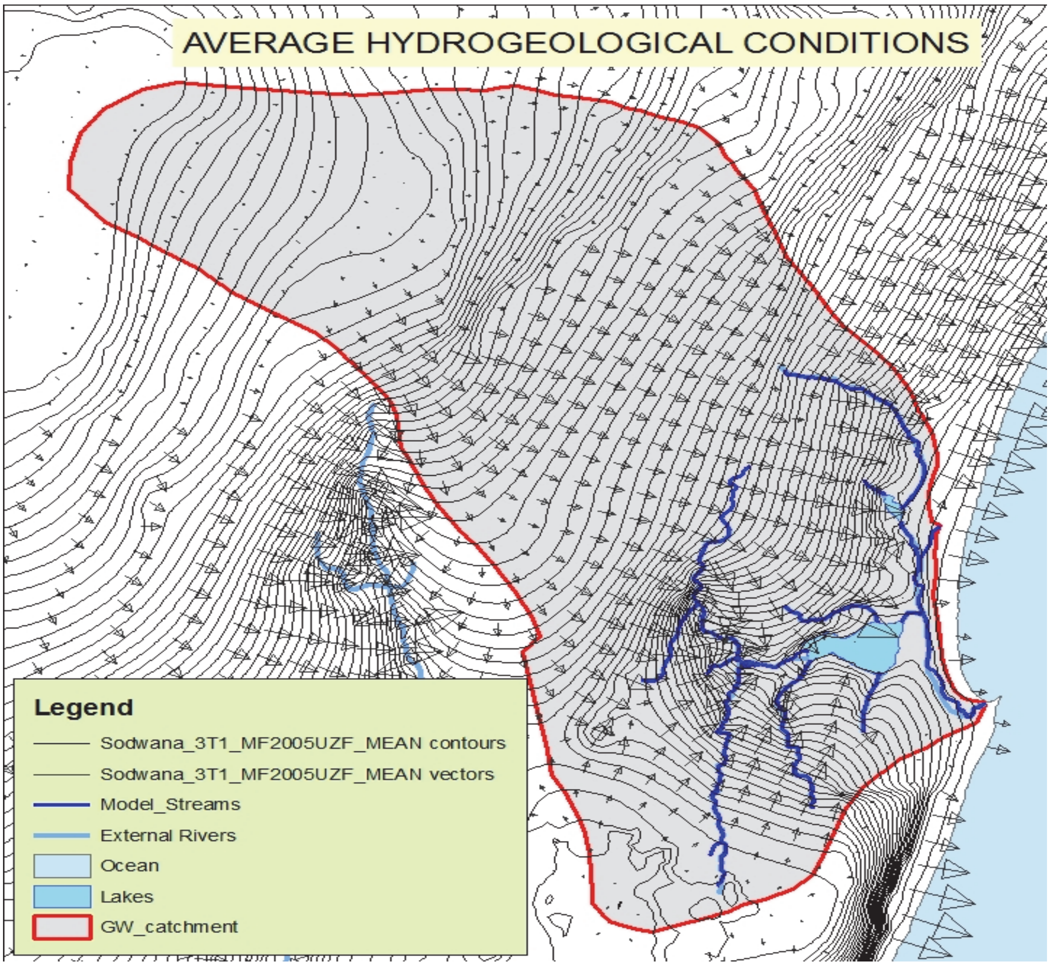


Figure 85. The mean water level elevation and velocity vectors in the surface layer for the simulation period from 2004 to 2015.

While the drainage boundaries are usually, static (*i.e.* streambed profile) the groundwater ridge is dynamic and will rise and fall in association with groundwater recharge and discharge that will influence the catchment recharge boundary, particularly in the zones with large standard deviation in water level shown in Figure 86. Consequently, the minimum and maximum water level profile has also been extracted from the transient series and used to estimate the relative change in the catchment zone in the next section. The minimum fluctuations (0 m contour) in the water table lie along sections of the drainage boundaries while the maximum Standard Deviation is >1 m near Mbazwana. The greatest variability in the water table elevation generally lies along the groundwater ridges.

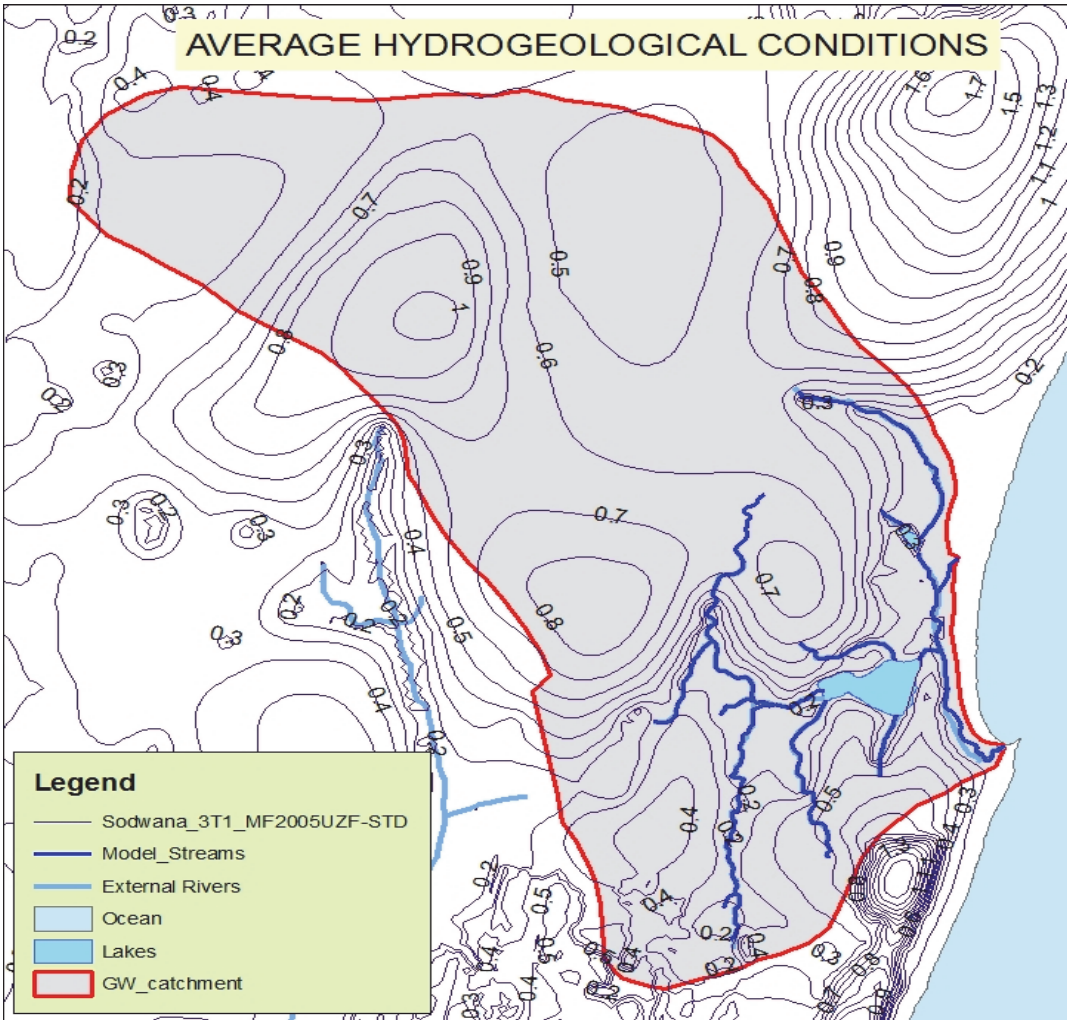


Figure 86. The standard deviation in water level elevation for the simulation period from 2004 to 2015.

4.5.1.3 Aquifer Storage and Transport

The demarcation of the groundwater catchment area from the model simulation of the groundwater divide provides a means of determining the groundwater storage in the aquifer and the expected resident time or flow through rate. The mass balance estimates for all three stratigraphic units representing the Kwambonambi, Kosi Bay and Uloa aquifers are summarised in Table 35. The simulated flow of groundwater from the Kwambonambi aquifer into the Kosi Bay aquifer is approximately 6000 m^3 day^{-1} with a return flow of about 8000 m^3 day^{-1} giving a net gain of 2000 m^3 day^{-1}. The main zone of exchange is in the vicinity of both lakes where the model assumes the lakebeds correspond with the top of the Kosi Bay Formation. The rate of mass transport between the three-aquifer units is listed in Table 37. Less than 20% of the recharge seeps into the deeper aquifer from the surface layer.

The simulated thickness of the water table above the basement of the primary aquifer within the average groundwater catchment is shown by the contours in Figure 87. The catchment area is about 10,000 ha; the median depth of saturation above the aquifer basement is about 70 m giving the total volume of water stored within the catchment recharge area of 7,000 Mm^3.

Table 37. Simulated vertical flow (m^3 day^{-1}) of groundwater between the layers (aquifers)

Vertical Upward flow	UPFLOW	DOWN FLOW	NET DOWNWARD FLOW
Layer 1-Layer 2	43,412	-29,920	13,492
Layer 2-Layer 3	17,639	-23,223	-5,584

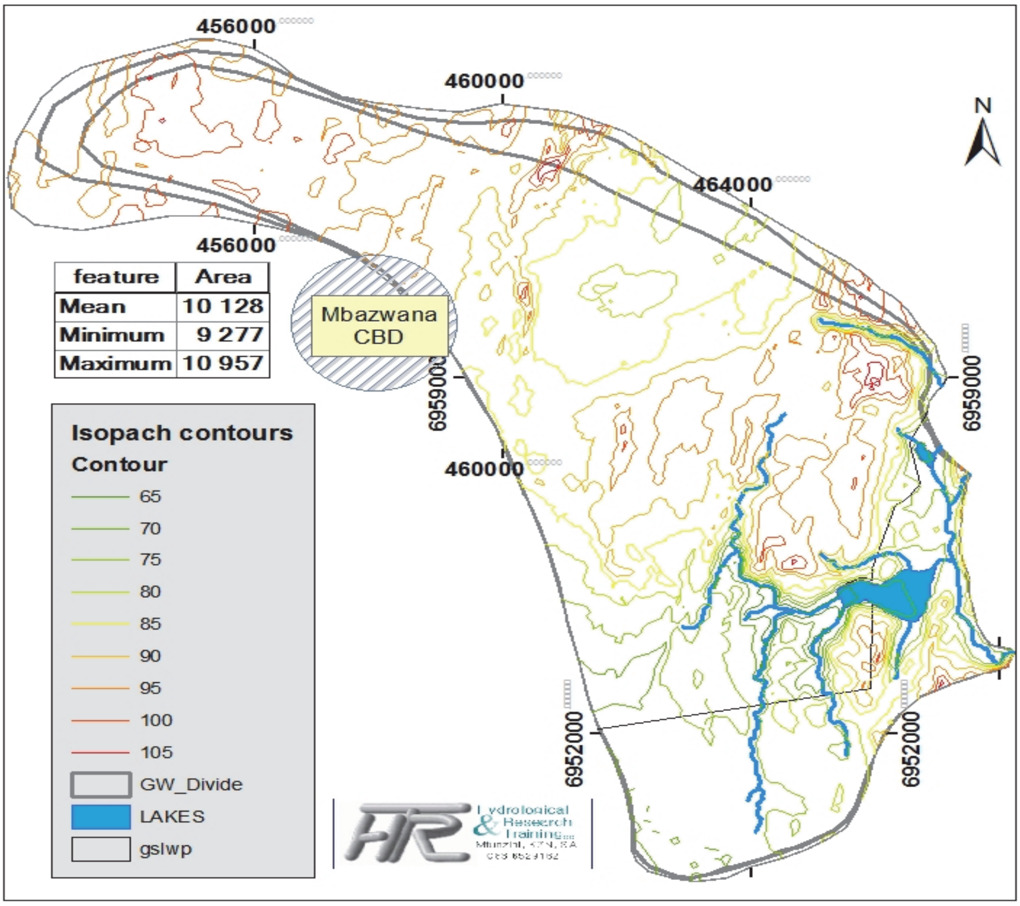


Figure 87. The simulated thickness of the saturated zone above the primary aquifer basement.

The flow rate, illustrated by the vector velocities in Figure 85 and the particle tracking study described in the next sections indicates that many particles released into the aquifer at the surface will not were captured by the drainage boundaries within the 10 year simulation period. Most of the recharge in the area is transported very slowly, particularly in the Mbazwana region and will only be captured in the drainage boundaries (stream and lakes) after several decades. This suggests that all recharge contaminates for the past 10-20 years are still resident in the aquifer.

The water quality study (Section 3.8) has indicated that the concentration of the major ions in the surface water are similar to the groundwater. This supports the conceptual model that the surface waters are derived mainly from the groundwater system. The nutrient loads in the groundwater indicate that the deep boreholes have higher than expected natural nitrogen levels (<1 mg l^{-1} = $1*10^{-6}$ tonne/m^3) although the phosphate levels do not appear to be elevated above expected values (see Chapter 3). The estimated volume of water in the Mgobezeleni catchment (see Table 38 in Section 4.5.2) is 1414 Mm^3. This implies a nitrogen load of about 1414 tonnes. The increase in population in the catchment area was proposed as a source of the higher than expected nitrogen loads. However, the total nitrogen load based on an average nitrate concentration of 1 mg l^{-1} is approximately 1,400 tonne. Studies by Corbett et al. (2002), quoted in Lindstrom (2000), indicate that the average pollutant loading (grams) per person per day is approximately 30g d^{-1} (for the combined grey+black water). Of this, the Total N and Total P loads were 13 and 5g d^{-1}. However, more recent studies by Mesddaghinia et al. (2015) show average values for Tehran that are indicate levels of 7g d^{-1} and 2 g d^{-1} for TKN and P respectively. Based on these values, it is estimated that the Total N discharge from human waste (sewage) in the study area is approximately 0.04tonne per year for the current population of 15,000 residents. Consequently, it would take approximately 30 thousand years to generate the quantity of nitrogen measured in the groundwater at an average rate of 0.04 tonne per year. An alternate hypothesis for the elevated nitrogen levels in the groundwater could be thunderstorms. Mean nitrate concentrations of 260 µg l^{-1} from 58 samples were measured in large KZN thunderstorms by Simpson (1991). These storms have prevailed over the catchment for centuries and could account for a significant proportion of the nitrogen levels observed in the deep groundwater.

4.5.2 Catchment Water Balance

The groundwater model provided estimates of the water balance for selected regions under transient hydrometeorological conditions and different landuse scenarios. The estimated groundwater volumes and fluxes under average conditions are summarised in Table 38 for the two scenarios that include the current landuse with extensive areas under plantations and woodlots and the assumed natural land cover with grasslands replacing the plantations.

The average annual recharge was in deficit for the past ten years during the drought conditions under both land use scenarios. The simulated evaporation rate was more than double the infiltration rate (Table 38) resulting in a net loss to the catchment of over 45 Mm^3 $year^{-1}$. The net loss has increased under the current land cover with plantation and woodlots by more than 3 Mm^3 $year^{-1}$.

Table 38. The simulated catchment characteristics under different land use conditions

Catchment	Plantation	Grassland	Units
Area	10,100	9,150	Ha
Ave depth	70	70	m
Aquifer saturated volume (Mm^3)	7,070	6,405	Mm^3
Water Volume (20% porosity)	1,414	1,280	Mm^3
Infiltration rate	31.73	37.09	Mm^3 $year^{-1}$
Evaporation rate	-80.634	-82.926	Mm^3 $year^{-1}$
Net recharge	-48.898	-45.833	Mm^3 $year^{-1}$

4.5.3 Groundwater Flow Paths (source to sinks)

The velocity vectors and the associated (advective) particle traces give a visual indication of the 3D flow pattern provided that the hydraulic parameters of the model were adequately calibrated. The flow velocity vectors, that run perpendicular to the water elevation contours, were used to manually demarcate the groundwater ridge (zero flow boundary) in the upper layer of the model that represents the catchment recharge zone (Figure 87) using the average head for the simulation period from 2004 to 2015. It is important to note that the piezometric heads in the deeper layers do not necessarily coincide with the water table ridge (upper layer). To establish the recharge catchment for the deeper aquifers it may be necessary to extend the external boundaries further than the current model domain.

4.5.4 Discharge Rates along the Coastline

The model configuration and calibration indicate that the regional groundwater flow direction is to the streams or the Indian Ocean. While there is some uncertainty about the interaction between the stream between Tolla se Gat and the road culvert through Lake Shazibe, the model does suggest that the predominant flow path in this specific region is toward the Indian Ocean. It is clear from the flow velocity vectors in Figure 85 that the highest groundwater fluxes are along the coastline and lowest along the groundwater ridges where the hydraulic gradient is close to zero. The average groundwater discharge to the Ocean along the entire coastline from Bhangazi north to Lake Sibaya is about 20,000 m^3 day^{-1} along a coastline of about 36 km giving an average discharge of about 500 m^3 day^{-1} per kilometre per 60 m profile depth (0.01 m^3 m^{-2}).

4.5.5 Abstraction from Boreholes

Municipal water infrastructure has several kilometres of pipelines to deliver potable water to the local community through standpipes spread throughout the study area. The water supply network is not available but the main pipeline was obtained from manhole covers in Google Earth. However, it transpires that the water has not been supplied by the pipeline for various technical reasons and that water was trucked in to supply the basic needs of the local community. The volume of water released into the environment by these communities is assumed to have negligible impact on the recharge to the groundwater and has not been included in the model.

The location of all the available production boreholes obtained by Prof Bate and incorporated into the groundwater model are shown in Figure 88. It was assumed that all the known boreholes located in the Sodwana area (Figure 88) are for household consumption or for commercial lodges. It is further assumed that the average household consumption is less than 60 m^3 $month^{-1}$ and that of lodges is 300 m^3 $month^{-1}$. It is also highly likely that the wastewater from these residential properties is discharged into the environment, so it was further assumed that the effective rainfall for each of these properties was increased by 50% of the abstraction rate. For pragmatic reasons, the combined impact (abstraction and recharge) were incorporated into the model as a reduced abstraction for each borehole.

The assumed abstraction from the groundwater for the Sodwana residential area is 8,000 m^3 $month^{-1}$ and is predicted to cause a negligible drop in the water table. Water level monitoring of the well field at Sodwana Bay Lodge very close to Lake Shazibe is shown in Figure 89 and illustrates a small drop from 2014 to 2015 that is highly correlate to the Lake level and hence may be attributed to the drought rather than abstraction.

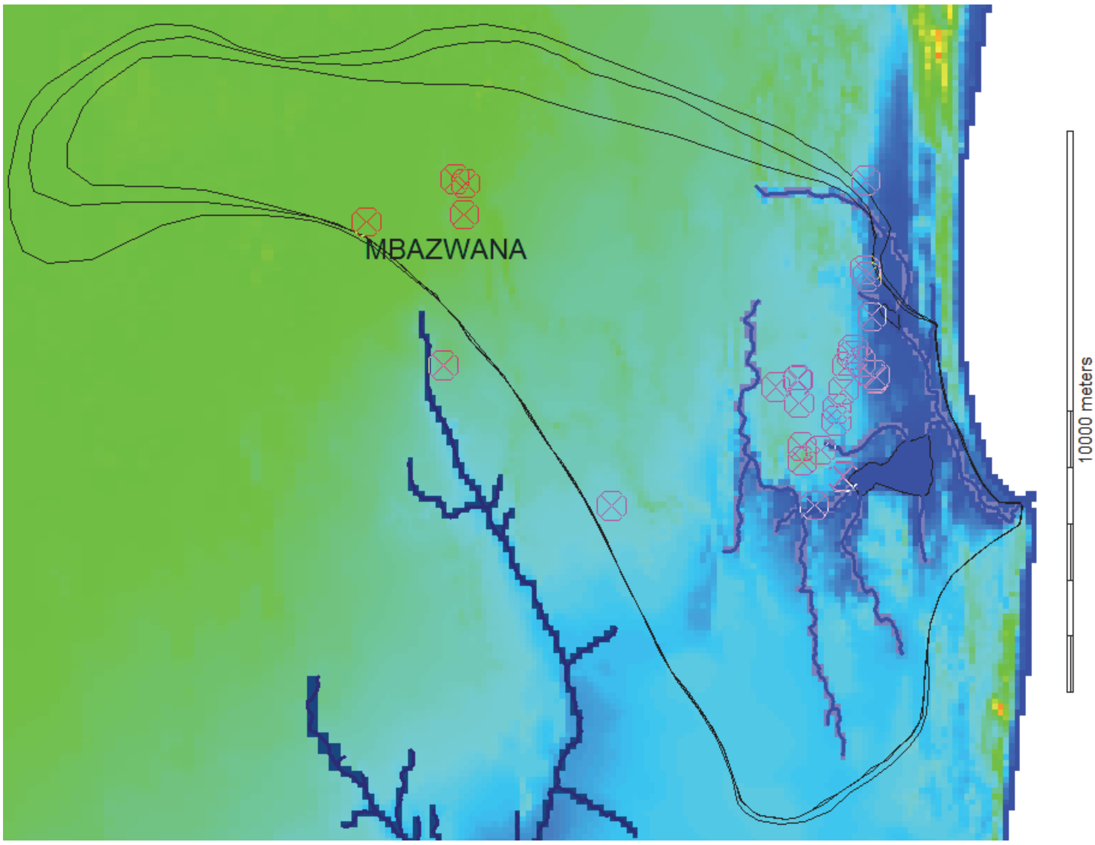


Figure 88. The location of all the known boreholes (crossed-circles) in the Sodwana region (from Prof Bate). The simulated thickness of the saturated zone above the primary aquifer basement.

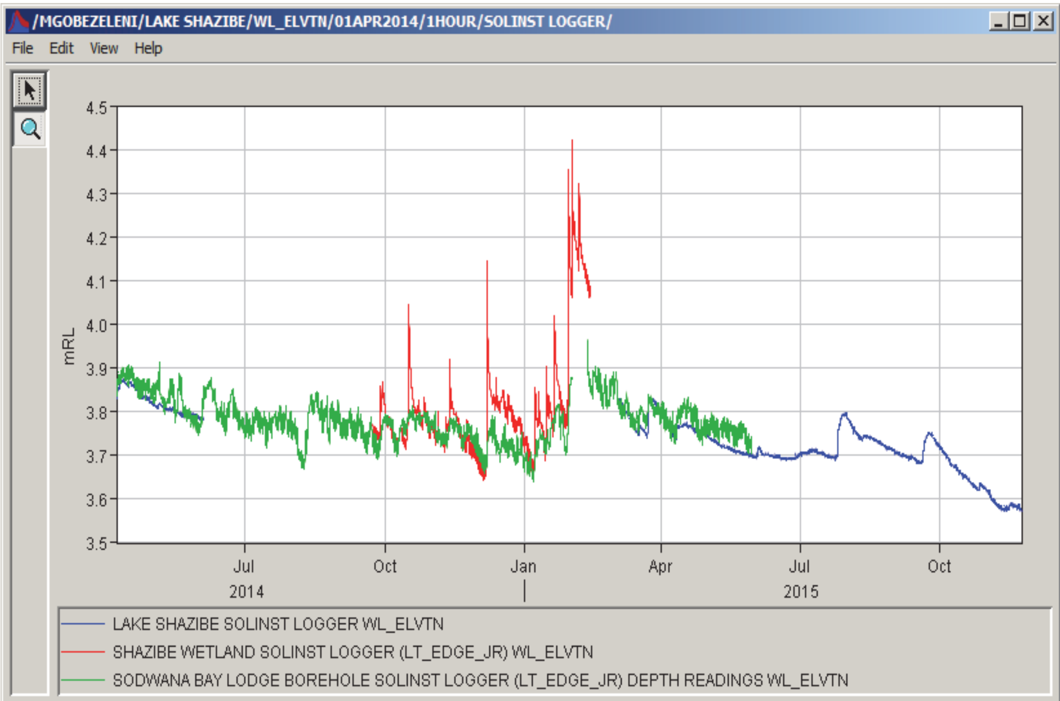


Figure 89. The measured fluctuation in the Sodwana Bay Lodge well field (green line) that may be attributed to groundwater abstraction on the water level for the period from April 2014 to Aug 2015. However, the water level in the well field is closely correlated to Lake Shazibe Water level indicating that the abstraction has had a negligible impact on the groundwater levels.

4.5.6 Impact of Plantations and Woodlots

The groundwater model parameters for recharge, evapotranspiration and the hydraulic properties were calibrated under the prevailing land use conditions that includes extensive areas of commercial and rural plantations as described in Section 4.5.6 The parameters for the commercial forestry and woodlot areas in the regional study area were changed to represent the same conditions as those used to describe the natural grasslands areas in an attempt to simulated groundwater fluxes for the assumed "natural" conditions without plantations.

4.5.6.1 Regional drawdown

The drawdown in the water table profile associated with the commercial and subsistence plantations showed a cone of depression in the central region of the commercial plantation with up to a 9 m reduced water table in 2015 (Figure 90).

The model indicates that there was an initial drawdown in the central region of the plantations of about 4 m that represented the long-term impact under average hydrological conditions that occurred before the simulation period from 2005 to 2015. This cone of depression around the core of the plantations increased by a further 5 m drawdown at the centre of the plantations for the ten-year simulation period. It is estimated from the model results that the commercial plantations and woodlots induce a systematic drawdown in the immediate vicinity of the plantations of up to 1 m year^{-1}. This corresponds to borehole measurements at Mbazwana (Figure 41) and other studies in Maputaland (Brites, 2010).

The cone of depression from the cumulative effects of the commercial plantations and woodlots extend well beyond the peripheral edges of the plantations and can cause an impact on the local communities and the drainage system. The contoured drawdown levels >=1 m relative to natural conditions (grasslands) are plotted in Figure 91 and show the affected communities in Mbazwana and Sodwana.

There was a likely drop in water level in several of the boreholes shown by the green circles. With the exception of the monitoring borehole at Mbazwana, not all the DWS monitoring boreholes would have shown the drawdown due to the plantations as they were effectively beyond the cone of depression. The measured and simulated drawdowns for the monitoring borehole at Mbazwana are shown in Figure 92. The simulated drawdown at Mbazwana under current land use conditions (plantations and woodlots) is approximately 0.0011 m day^{-1} (r^2=0.96). Under natural (grassland) conditions it is estimated that the drawdown would were 0.0003 m day^{-1} (r^2=0.66) due to the prevailing drought conditions.

4.5.6.2 Mgobezeleni Catchment

There could were a significant drawdown on the boreholes of all the local community dwelling in the region as well as the drainage system (streams). The simulated flow for the stream draining toward Tolla se Gat for the natural and plantation conditions are shown in Figure 93. The model indicates that the flow under natural conditions would be more than double the present flow into Lake Shazibe.

The drawdown due to the plantations was assessed using the groundwater model for the Mgobezeleni groundwater catchment. The drawdown at the end of 2015 was estimated at 30 Mm^3. This was approximately 10% of the total aquifer volume. In comparison, the loss due to borehole abstraction was only 100 m^3 day^{-1} (3650 m^3 year^{-1}) that is negligible.

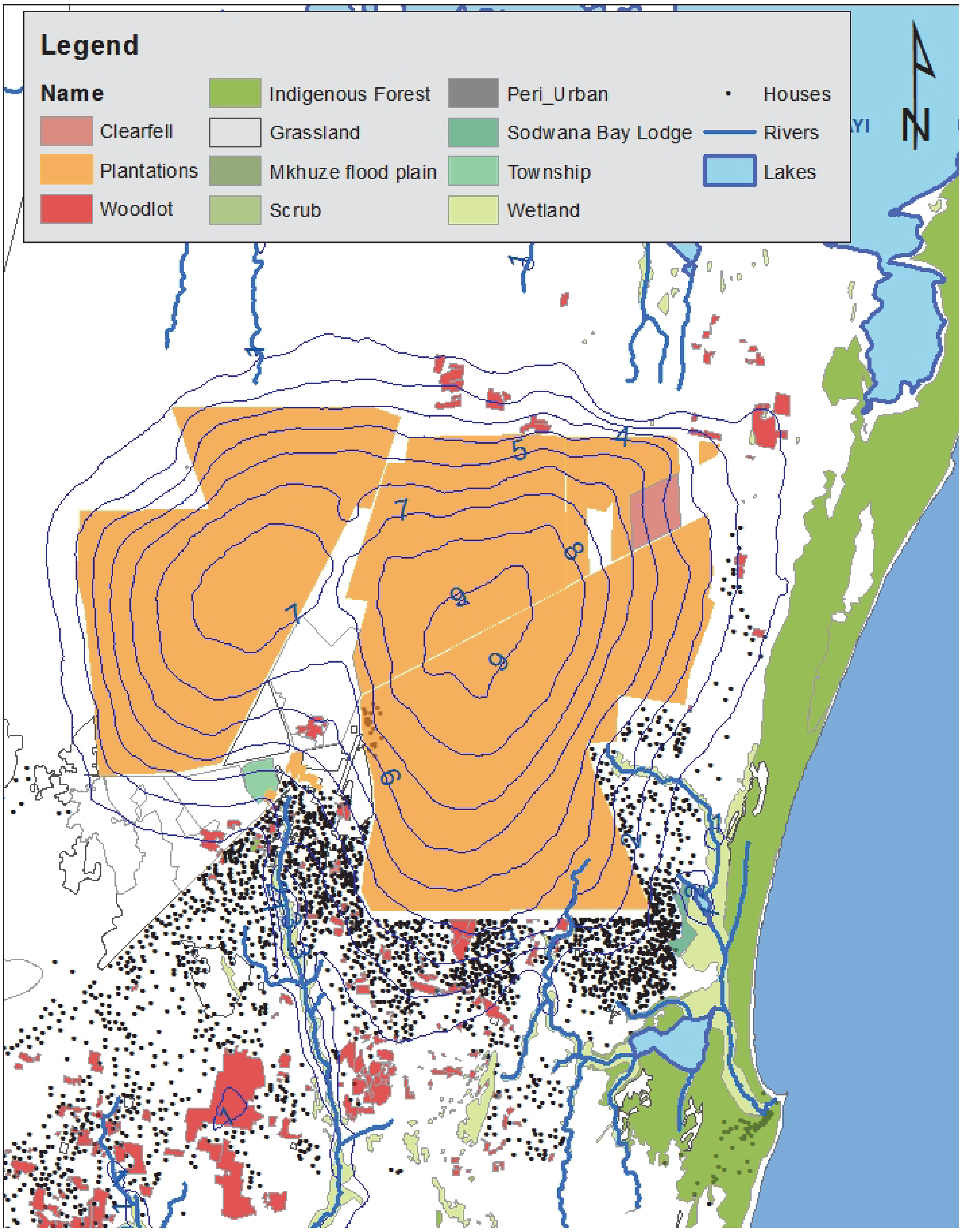


Figure 90. The simulated drawdown from the commercial plantations and woodlots over the simulation period. The initial drawdown of 4 m represents a long-term impact followed by a further 5 m for the ten-year simulation period.

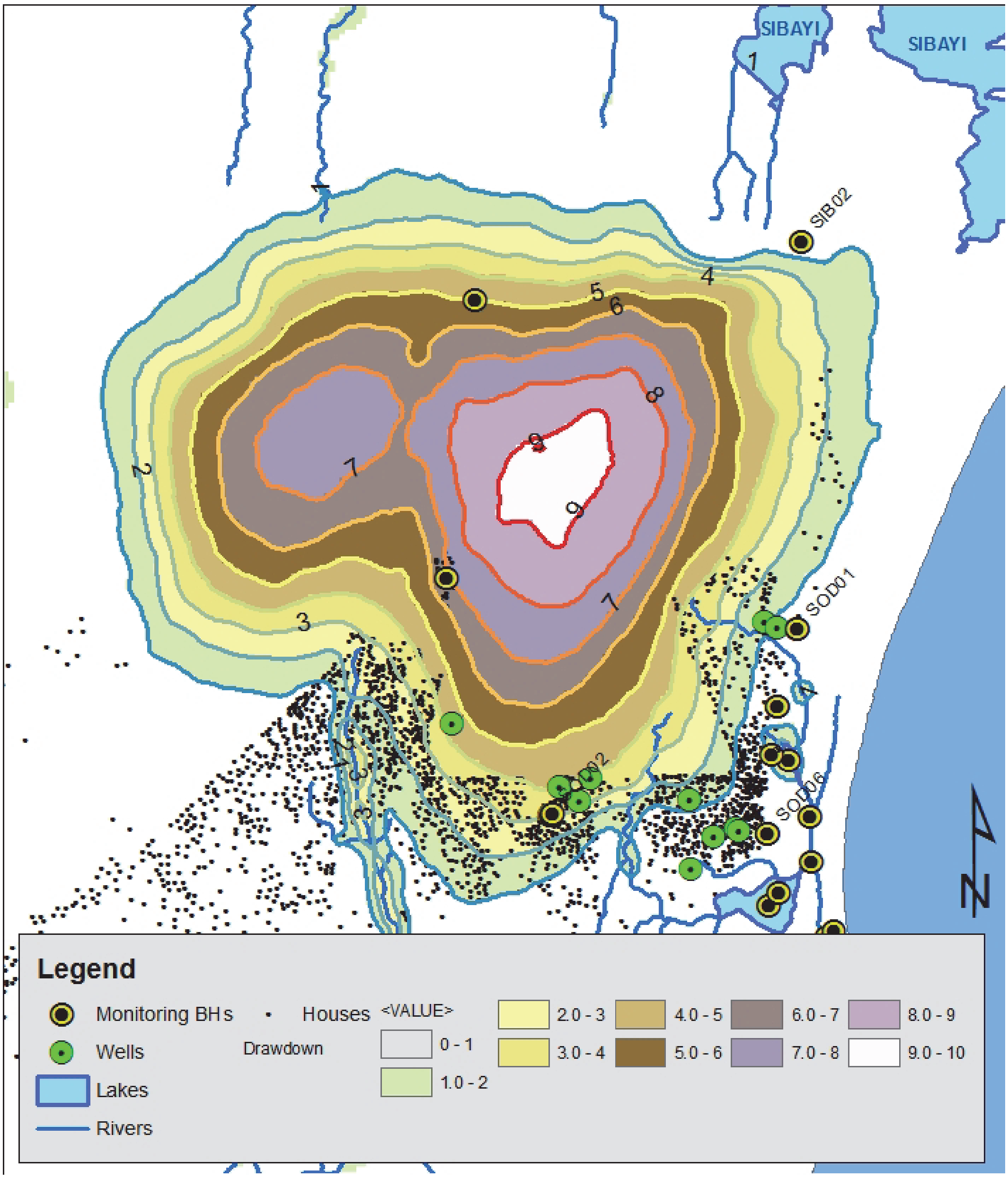


Figure 91. The cone of depression cause by the commercial plantations and woodlots in relation to the local communities.

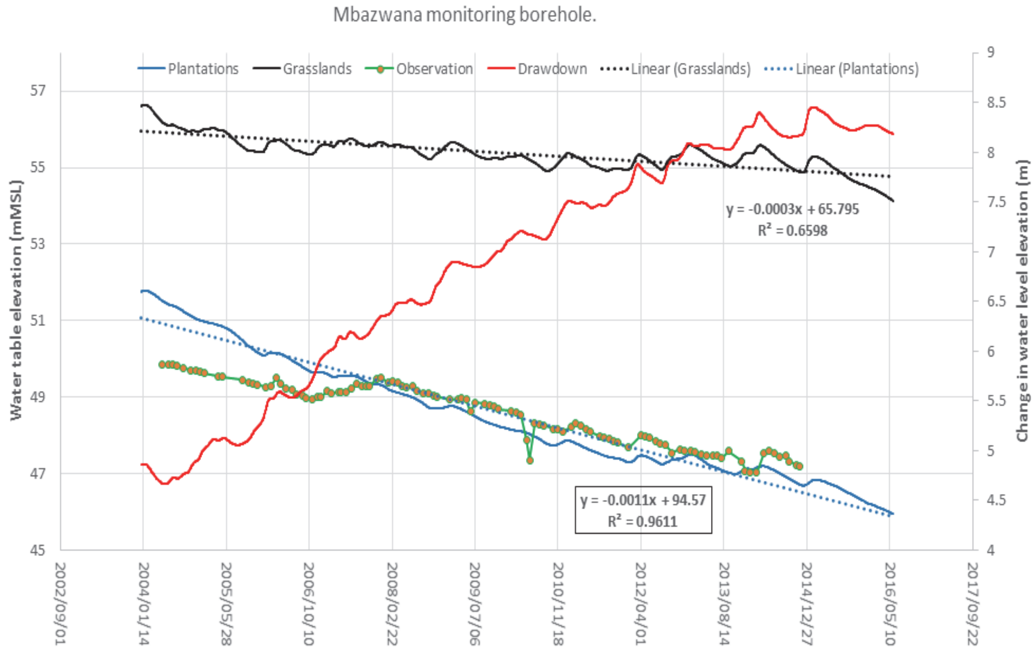


Figure 92. The measured water level decline at the Mbazwana monitoring borehole and simulated impact of plantations and woodlots on the water table elevation. The blue graph shows the drawdown associated with the plantations and woodlots from 2005 to 2015. The black graph shows the simulated natural water table decline for the same period. The initial difference in the simulated water table series of about 4 m represents the long-term drawdown under average hydrological conditions.

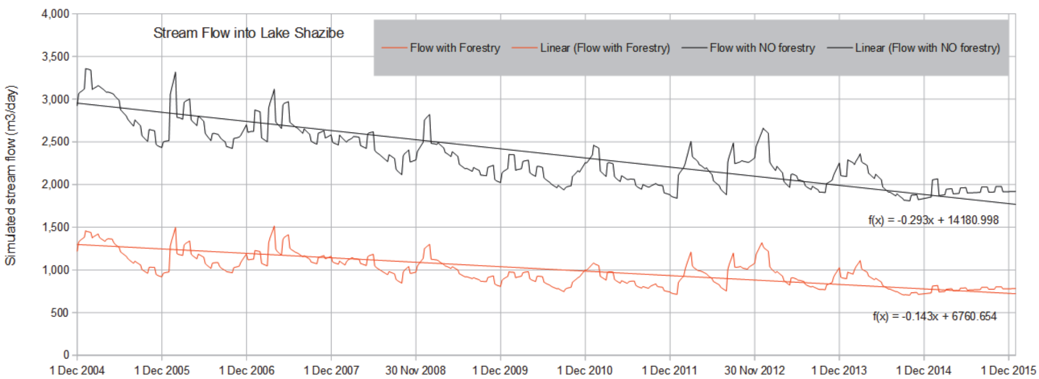


Figure 93. A comparison of the simulated flow in the feeder stream into Lake Shazibe under "Natural" and commercial forestry conditions.

The model calculated the daily infiltration and evapotranspiration rates for the simulation period. Figure 94 shows the daily infiltration and evapotranspiration rates for the Average Mgobezeleni catchment under current landuse conditions with plantations and woodlots. The average infiltration rate was 87,000 m^3 day^{-1} (0.8 mm day^{-1} or 318 mm $year^{-1}$). This was approximately 30% of the mean annual precipitation (MAP). However, the evapotranspiration rate was significantly higher at 220,000 m^3 day^{-1} (2 mm day^{-1} or 795 mm $year^{-1}$). The infiltration rate under natural grassland increased to 101,000 m^3 day^{-1} (405 mm $year^{-1}$) that is close to 40% of the MAP (Table 38).

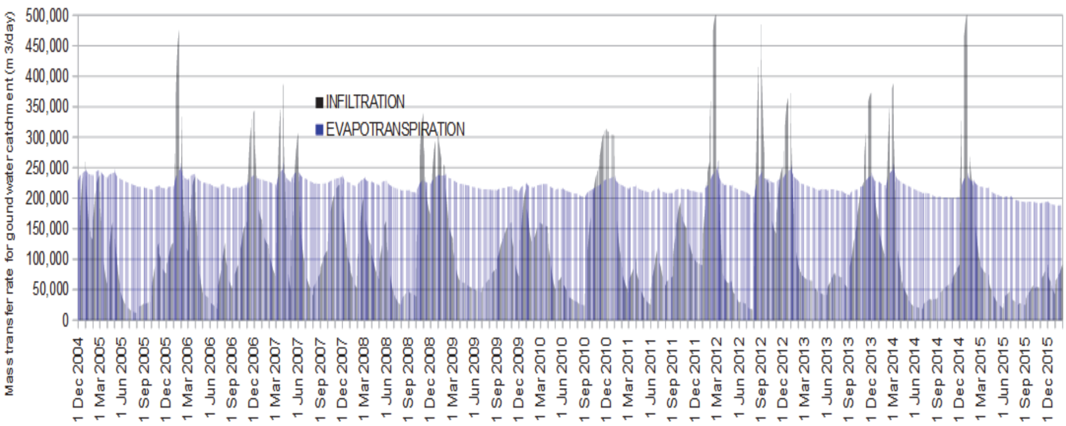


Figure 94. The simulated infiltration and evapotranspiration rate for the Mgobezeleni groundwater catchment under current conditions with plantations and woodlot.

The cumulative net recharge rates calculated from the infiltration rate minus the evapotranspiration rate for the simulation period from 2005 to 2016 for both the current landuse (plantations) and the assumed natural conditions (grasslands) are plotted in Figure 95. There is a consistent decline in the net recharge rate for both landuse types that can be attributed to the prevailing drought conditions that have resulted in a general drop in the groundwater level represented by the natural grassland conditions (see Figure 95). However, the current landuse with plantations and woodlot has lost nearly 30 Mm^3 over the past ten year relative to the natural grasslands (3 Mm^3 $year^{-1}$) (Table 38). This is significantly higher than the abstraction from boreholes for the same period.

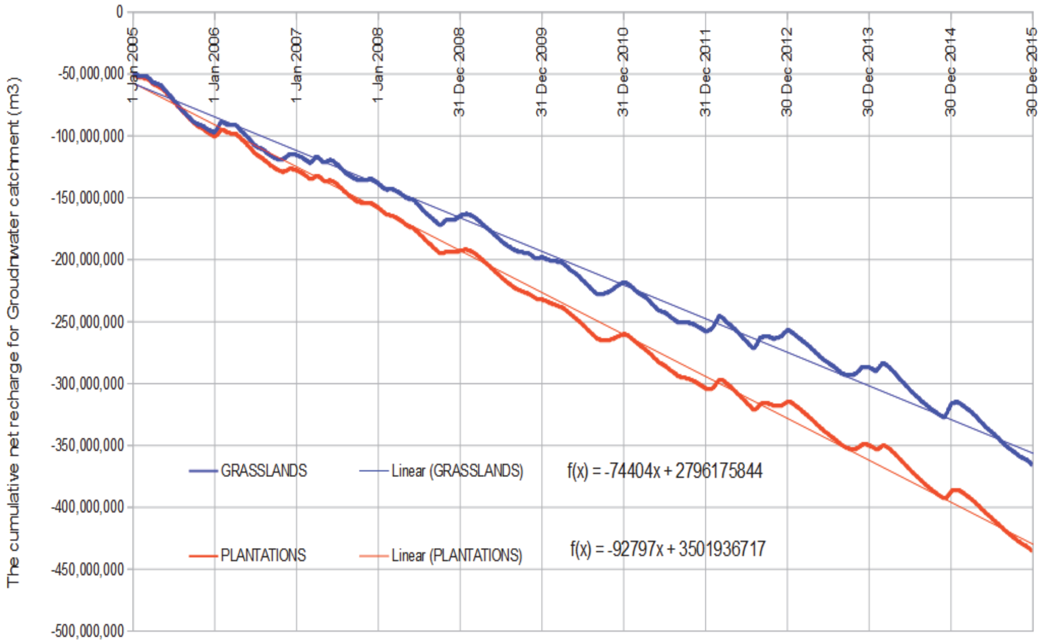


Figure 95. The cumulative NET recharge (infiltration-evapotranspiration) rate for the Mgobezeleni catchment under current (plantations) and natural (grassland) scenarios. The net loss to groundwater storage during the past 11 years was approximately 0.8 mm.

4.5.6.3 Water Table Depth and Area of Inundation

Kelbe et al. (2016) have used the water table depth below the soil surface to identify the possible occurrence of suitable geomorphic conditions for wetlands using a regional groundwater model in northern Maputaland. The assumption that the depth from the topographical surface to the water table surface is a limiting factor on the development of wetlands (Kelbe et al., 2016) was used in this study to identify the impact of plantations and woodlots on the possible degradation of the geomorphic conditions for palustrine wetlands. The simulated contour depth to the water table of up to 3 m is assumed to indicate suitable geomorphic conditions for the development of palustrine wetlands. The simulated contour depths of up to 3 m for the current landuse conditions with extensive plantations and woodlots was extracted and compared to the corresponding contours from the model simulations under grassland conditions (Figure 96). There was a significant loss of suitable wetlands conditions throughout the upper reaches of the Mgobezeleni catchment towards Mbazwana that could not be attributed to the drought conditions. This degradation of wetlands appears to have occurred in the headwater streams for Lake Mgobezeleni. There is no apparent impact of the plantations and woodlots on the Sangweni wetlands to the south of Mgobezeleni (Figure 96).

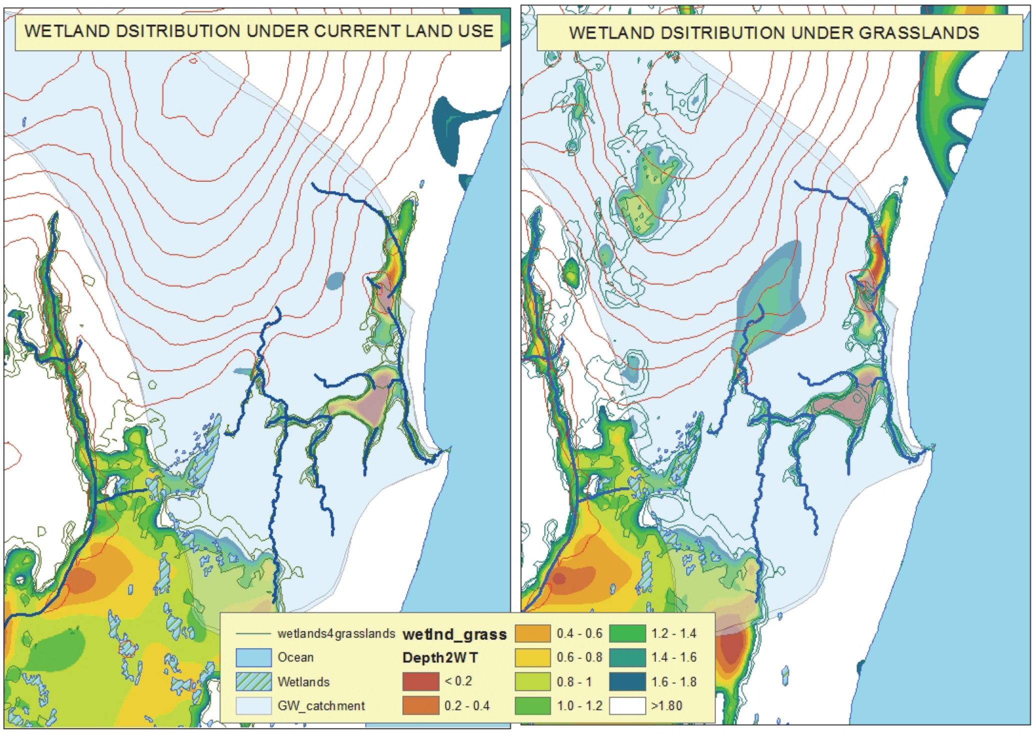


Figure 96. The simulated distribution of suitable geomorphic conditions for the development of palustrine wetlands under different landuse conditions.

4.6 PARTICLE TRACKING

The MODFLOW model simulates the flow regime from source of recharge to its discharge at various drainage boundaries (groundwater sinks) in three-dimensional space. This model enables the tracking of single or multiple hypothetical solute particles from a source to a sink using 'MODPATH or PATH3D packages (Pollock, 1994).

Hypothetical particles that are assumed to represent solute contaminants were located at the centre of all the grid cells that indicated residential dwellings in Google Earth (circles in Figure 97). The particles were all released at the water table surface at the start of the simulation period (January 2005) and would have moved through the groundwater at the same advection velocity as the simulated water movement. Since these dwelling were constructed over the past years, it is not known when they would were in a position to distribute contaminant sources so the particles were released in 2004 simulate the particle tracks rather than their current location.

The particles traces for the ten-year simulation period are shown in Figure 97. A vertical profile of ALL the particles tracks shown in Figure 98 indicates that the surface contamination pathways were restricted to the upper Kwambonambi Aquifer and do not appear to have flowed into the lower aquifer where most of the groundwater abstraction occurs. This further supports the minimal impact of the production boreholes for private residential properties. It is also not clear where the elevated nutrient loads in the Uloa Aquifer could have originated.

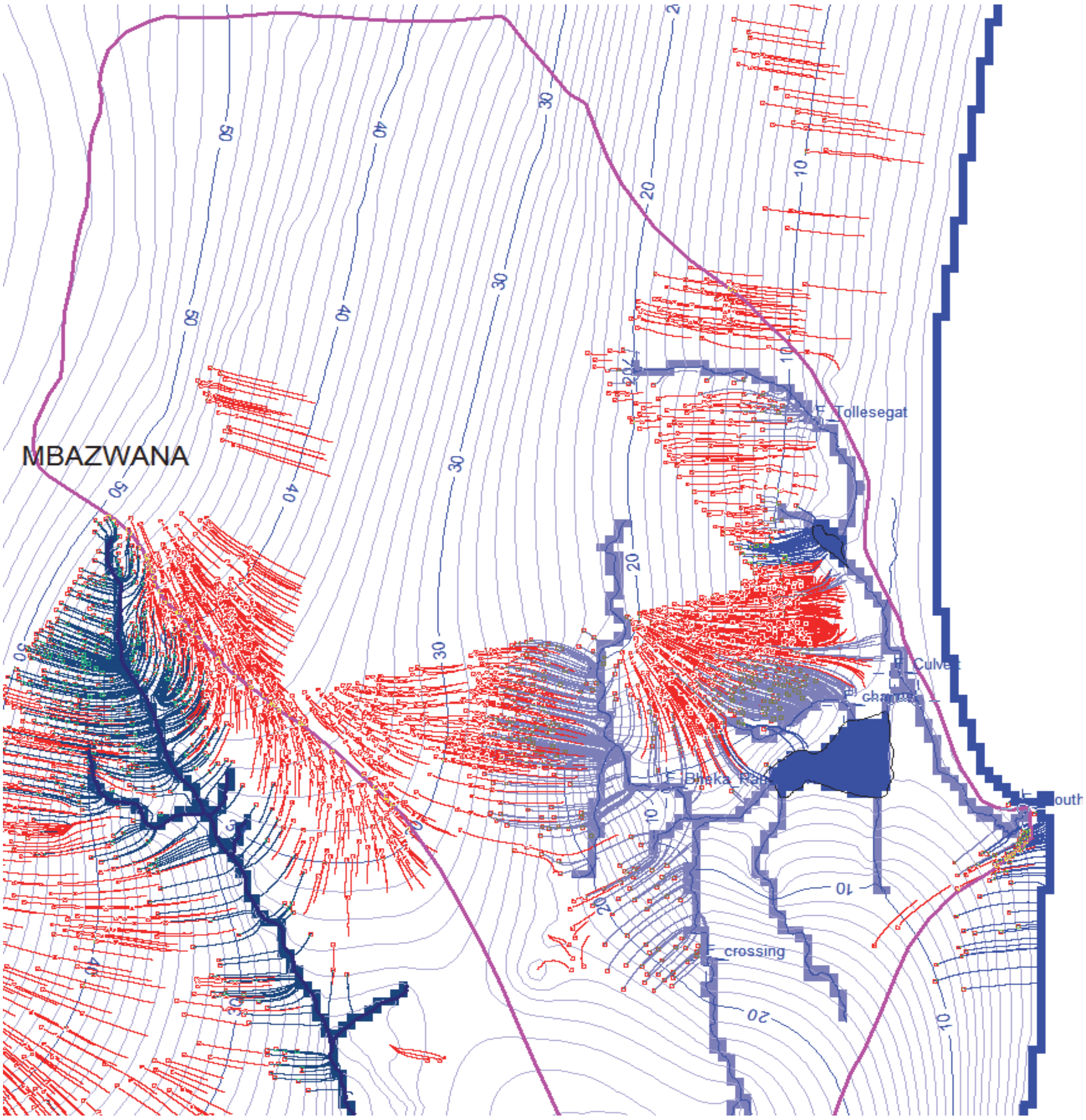


Figure 97. The simulate particle tracks for hypothetical contaminants released into the groundwater at all the dwelling sites in the Mgobezeleni and surrounding catchment.

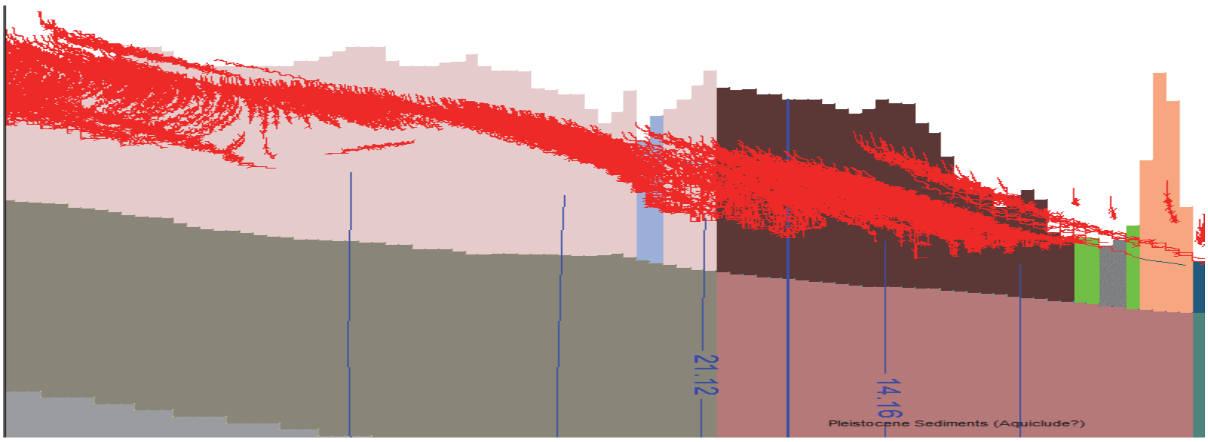


Figure 98. The vertical profile of the particle traces for all transects from contaminant sites on the top of the water table. Note, all particles are restricted to the upper layer.

CHAPTER 5. ECOLOGY

Our understanding of the hydrology of the wetlands is based on groundwater and surface-water elevations (measured by installed water level loggers), streamflows and hydrological modelling (described in Chapter 4). Complementing this is our understanding of the groundwater quality (Chapter 3). It is in the context of the physical and chemical components of the catchment that we interpret the observed ecological patterns.

The catchment is a sand aquifer. Etched into this are wetlands. The wetlands of the Mgobezeleni catchment are shown in Figure 99.

For this study, the wetlands were classified into six units. This classification is based on hydrology, topographic position and geomorphological setting. These are the main features controlling the expression of the vegetation associated with the wetlands. The wetland vegetation is also affected by substratum, fire, grazing, cultivation and salt-water penetration. These categories are the basic wetland units that we would expect to occur throughout the coastal areas of the Maputaland Coastal Plain.

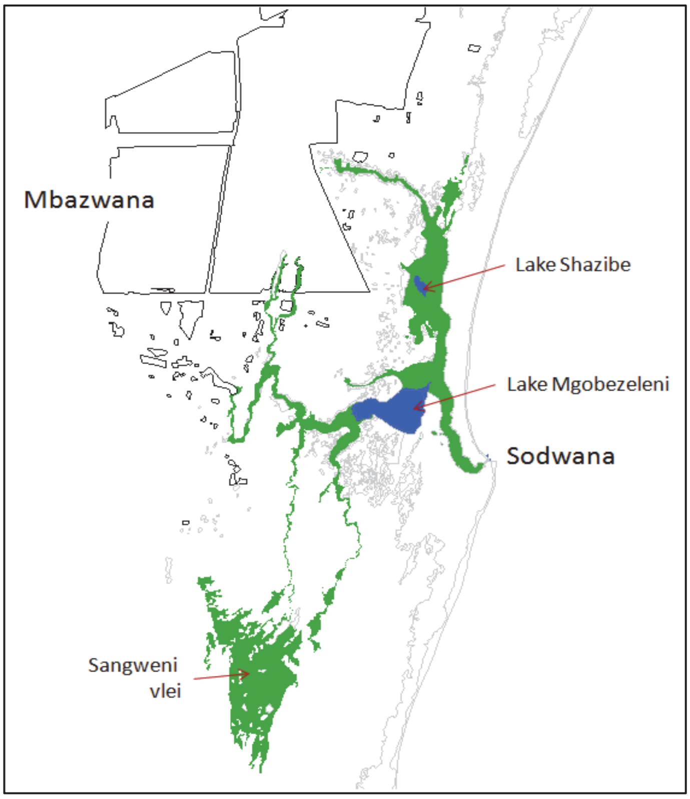


Figure 99. The wetlands of the Mgobezeleni catchment area (the green and blue coloured areas). The wetlands drain towards the two lakes and from there into the Mgobezeleni Estuary and then out to sea at Sodwana Bay. The outlines in the upper parts of the map are of the commercial and small-scale plantations.

The wetland units are:

5.1 UPPER-CATCHMENT VLEIS

This wetland type occurs in the upper reaches of the catchment (Figure 100). The Upper-catchment vleis are in the highest locations of the catchment in the places where the groundwater mound intersects the topographic surface. These wetlands may straddle the divide that separates adjacent catchments – with water from the wetland able to move in both directions. Being at the upper part of the groundwater mound it is that part of the catchment subject to the greatest water level fluctuations in response to wet/dry cycles. However, it is also the location where there is the slowest lateral movement of the upper stratum of the groundwater.

5.1.1 <u>Geomorphological setting</u>

At present, the only occurrence of this wetland type within the Mgobezeleni Catchment is the Sangweni Pan and its adjacent pans. We do not know if other similar pans used to exist in the area where there is currently commercial forestry. Some of this wetland type may have been lost there due to afforestation lowering the groundwater table.

The Sangweni Pan is a depression of about 4 km by 2 km, which spans the water divide along the southern margin of the Mgobezeleni Catchment. Most of the time the Sangweni Pan is endorheic – with no surface-water outlets and its water level is then that of the adjacent groundwater (Figure 101). From this pan, groundwater can move into the Mgobezeleni Catchment (to the north), into the Bhangazi-north catchment (to the south) and the Mbazwana Stream (to the west). Some water from the pan could possibly flow seawards under the coastal dunes. Surface water flows only occur during periods of extreme wetness when the pan fills up. This flow is all towards Lake Mgobezeleni (see Figure 100). In effect, the surface divide, in these wet conditions, is different from the groundwater divide.

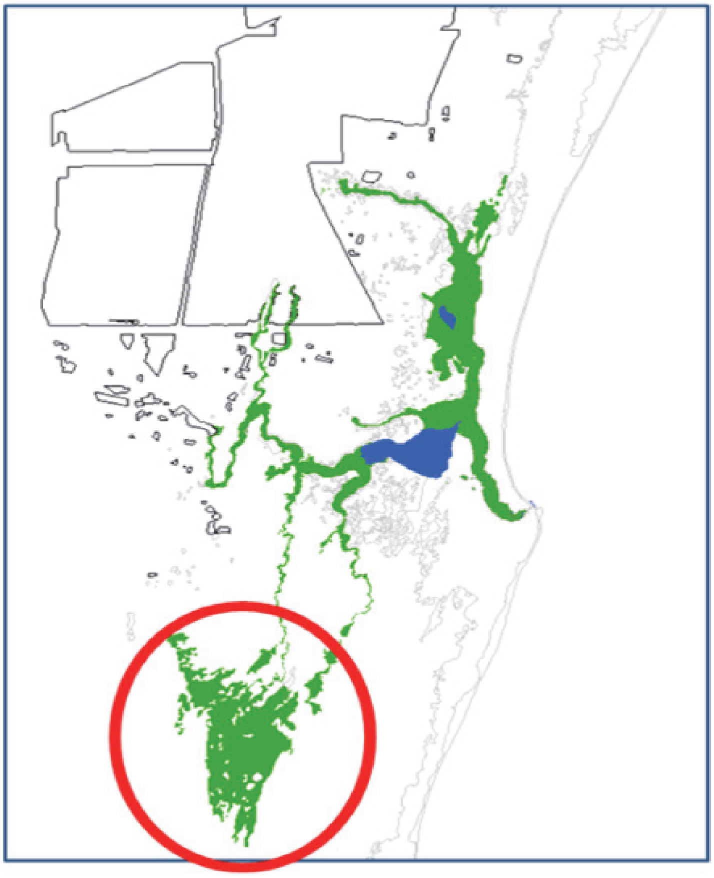


Figure 100. The upper-catchment wetlands.

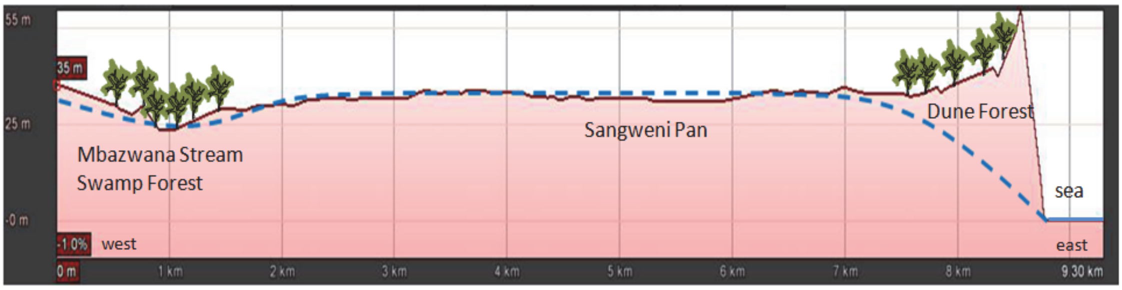


Figure 101. A Google Earth section through the Sangweni Pan. The section is in a west-east direction – with the Mbazwana Stream as the low point in the west and the coastal dunes and sea to the east. The dashed line schematically indicates the groundwater table – showing how it intersects the surface topography in the Sangweni Pan area.

The Lake Shazibe sub-catchment does not have an upper-catchment wetland as the water drains directly from a substantial sand aquifer directly into the Thuthukeni watercourse, which is a deeply incised watercourse.

The hydrology of this type of wetland is controlled to large extent by the wet/dry cycles of about a decade in duration that occur in Maputaland. During the passage of such a cycle, the water table rises and falls substantially. This type of wetland can be in one of three temporal states, which are described below. (We only observed state III during this study, but have extrapolated from our knowledge of the wetlands of the Eastern Shores of St Lucia to describe the other two states):

5.1.1.1 State I: The Endorheic standing-water state.

During 'normal' rainfall periods, there is standing water in the Sangweni Pan; but no surface-water outflows. The water level in the pan is a manifestation of the level of the groundwater.

Sangweni Pan is in this State I most of the time, and States II and III can be regarded as extreme conditions. When in this state the water level in the pan may rise and fall in response to cumulative rainfall that causes elevation changes in the groundwater table. The pan is shallow (generally with an average depth of less than 1 m), with only a few deeper portions. It has a large surface area: volume ratio – and hence is affected to a large degree by evaporation. It also is sensitive to temperature changes – heating up on a warm summer day and cooling in cold winter conditions.

There is little or no lateral movement of water within the pan. Wind-driven circulation within the pan is minimal as it is damped by the emergent vegetation.

5.1.1.2 State II: The surface outflow state:

In particularly wet periods, when the groundwater level has risen, water flows northwards over the natural spillway into the water courses that lead to Lake Mgobezeleni. Due to this spillway-effect, the water levels in the pan would stay constant during periods when there is outflow.

5.1.1.3 State III: The hygrophilous grassland state:

During prolonged dry conditions, the groundwater level subsides and the pan dries. At the start of our study, there were still remnants of water in the deeper portions of the pan, but for most of our study, the pan was dry. In this state, the groundwater table begins by being close to the surface – but gradually drops as the dry conditions progress. The hydrograph from the loggers in the pan (coordinates: -27.576 S; 32.622 E) indicate how the water table was dropping consistently (Figure 40). What is clear in this hydrograph are the spikes whenever there is a rainfall event.

When all the water is below the surface it is a very constant environment – as is typical of groundwater. Temperature is buffered – especially when deeper. Figure 40 is the thermograph that indicates this.

Water is lost from the pan by transpiration and capillarity coupled with evaporation – but only when the water table is close to the surface.

5.1.2 Physico-chemical environment.

The water chemistry is likely to differ when the pan is in its different states. We were only able to measure conditions when the pan was in the hygrophilous grassland state (State III), so for the other states it is conceptual.

5.1.2.1 State I: The Endorheic standing water state.

In this state, the pan is full but, as there are no outflows, it is endorheic. Under these conditions, salt, gained from sea spray, is likely to accumulate.

Although the water may be a dark colour, the shallowness enables light to penetrate to the bottom in all except the deepest places. Water temperatures can be very high in summer. There is little stirring of the water and a daily vertical temperature stratification is set up which breaks down at night (Vrdoljak, 2004).

As there is a large amount of decaying vegetation, there is likely to be a high Biological Oxygen Demand. This is evident in the accumulations of organic deposits (which may form peat) in the deeper parts of the pan where there is less oxygen.

The high evaporation rates mean that water lost is being replaced from surrounding groundwater.

5.1.2.2 State II: The surface outflow state:

During prolonged wet periods, or as a result of large rainfall events (such as the floods associated with Cyclone Domoina in 1984), flushing of the standing water occurs. It is only under these conditions that water can flow out of the system and, in doing so there is a loss of salts or other conservative materials.

5.1.2.3 State III: The hygrophilous grassland state:

During this state all the water is below the surface of the ground. Initially there is close contact between plants and the groundwater and the organic soils of the pan are wetted by capillarity. But, as the water table drops this contact is severed.

Organic accumulations that are exposed may dry out completely and oxidise. If ignited subterranean organic deposits may burn for many months at a time (as was the case in the southern parts of Sangweni Pan in 2003). Loss of organic materials and salt occurs when the peat and standing vegetation is burnt, or when plants are grazed by herbivores that move away from the pan after feeding.

5.1.3 Plants and animals

The Upper-catchment wetlands are vleis and sedge swamps. The plants in the wetlands are an expression of the level of the water and the rate of water level change that occur. These plants respond to the extreme changes that occur from the wet period to the dry conditions by becoming dormant or by eking out an existence when the pans are dry. During dry periods, there is a colonisation of the wetland by the pioneer dryland plant species described below for state I and III.

Fish and invertebrates were collected in similar pans of the Eastern Shores of St Lucia (Vrdoljak 2004; Vrdoljak and Hart, 2012). These include fish such as *Clarias theodori Clarias gariepinus* and small minnows such as *Aplocheilichthys katangae*. These are species that move a lot in very shallow water after rainfall events and we would expect to find them in the Sangweni Pan when it contains water – but only after the pan was in state II when colonisation is possible.

5.1.3.1 State I: The Endorheic standing water state.

The endorheic stage may last for several years at a time. The longer it lasts, the more the plants and animals are able to establish and there is a shift away from pioneer species – although these still colonise the shorelines, which are inundated or exposed, and whenever the water level rises or falls.

The shallow and fluctuating nature of the water promotes the growth of emergent wetland plants. Throughout the pan, the most abundant plants are sedges and grasses. These include the broad-leaved *Scleria poiformis* and reeds *Phragmites australis* in the deeper vegetated parts, *Eleocharis dulcis* and *Leersia hexandra* where it is shallower. There are a variety of sedges and grasses in the areas where there is wetting and drying due to water level fluctuations. These include the grasses *Hemarthria altissima*, *Acroceras macrum*, the sedges *Fuirena hirsuta*, *Cyperus prolifer* and forbs such as *Persicaria decipiens* and *Dissotis canescens*.

When the pan is full the deeper patches have open water which supports floating plants such as water lilies *Nymphaea nouchali var. caerulea* and *Nymphoides thunbergiana*.

As a drought progresses and the pan tends towards Stage III it undergoes a 'dry-down 'condition. There is a loss of water volume and a concentration of nutrients from this process and from those released by dying plants. Fish populations are concentrated in small pools of water and are extensively fed on by large numbers of water-birds.

Beyond the water, there is usually a heavily grazed zone where cattle and zebra, and formerly hippos, graze hygrophilous grasses. Typical plants of this zone are *Cyperus natalensis*, *Ischaemum fasciculatum*, *Acroceras macrum*, *Hemarthria altissima* (note that these grasses are all grazed to form a short lawn), *Sporobolus subtilis* and *Andropogon huillensis*. These are all plants that are found in the pan-bottom lawns of state III.

5.1.3.2 State II: The surface outflow state:

The change from the variable water level of State I to the more constant, spillway-controlled, level of this stage allows plants that do not cope well with water level fluctuations to thrive. These include *Syzygium cordatum* which will occur from this maximum height and above.

This is the state in which recolonisation by swimming animals from downstream in the wetland can occur. This is important after a particularly severe drought when fish may have died-out.

5.1.3.3 State III: The hygrophilous grassland state:

During severe droughts, all water will be lost from the pan and any plants or animals requiring water will die-out. When the drought is less severe, there may still be some standing water in the deeper localities. These may act as refugia for some species – from which rapid recolonisation takes place once water levels have risen and the pan shifts into Stage I (Figure 102).

Figure 102. University of Zululand Hydrology post-graduate students working in the dry Sangweni pan.

The damp soil and the sustained grazing pressure promote the formation of hygrophilous grazing lawns. This, with its dampness and organic-rich soils, becomes a very rich grazing habitat maintained as a lawn by heavy grazing. Typical plants include *Acroceras macruum, Ischaemum fasciculatus, Sporobolus subtilis, Hydrocotyle bonariensis* and *Centella asiatica.*

5.1.4 Ecosystem dynamics

During drought conditions, large herbivores concentrate on the dry pan-bottoms. These lawns of hygrophilous grasses 'drought-proof' the coastal grasslands by providing high quality grazing at times when the higher-lying grasslands are not productive.

Hippos are 'bio-engineers' in that they shape their environment. Through constant use of the same daytime wallows, they create pools of deeper water. They also create trench-like pathways, which facilitate connectivity between basins. The pools and channels linking different parts of the pan facilitate the survival of fish and other animals in refugia during times of low water levels. In recent decades, there was a loss of hippos from the Sangweni Pan, which may reduce the refugia available to aquatic species during dry periods

This type of upper-catchment wetland is a common feature throughout the Ozabeni area. It is also typical of many parts of the Eastern Shores of St Lucia. Vasi Pan, on the divide between the Kosi and Sibaya systems is also likely to be a wetland of this nature.

The Upper-catchment vleis in the Maputaland area 'flip' from one ecological state to another. The differences in the states are shown in Table 39.

Table 39. This indicates the differences in the states of the upper-catchment wetlands

Feature	State I: Pan holding water	State II : Pan full (Overtopping of surface water into watercourses)	State III : No standing water
Standing water	Yes	Yes	No
Water level	Fluctuates to a large degree – responding to the rise and fall of the groundwater table	Constant (controlled by 'spillway' level)	Below ground level
Water temperatures	Variable	Variable	Constant in groundwater
Biological Oxygen Demand (BOD)	High	High	Low (as above ground is dry)
Connectivity with other wetlands	None via water – only due to movements of birds and flying insects and terrestrial mammals	High (due to outflowing stream)	none
Loss of salts and organic material	No	Yes (Outflows)	Yes (burning and grazing)
Grazing	Yes – on the pan margins	No	Yes – very rich grazing on the hygrophilous lawns.

5.2 WATER COURSES

The watercourses are one of the noteworthy features of the Mgobezeleni Catchment. These are incised valleys (called *amahosha* by the Tonga people) (Figure 103). They often have a predominantly north-south orientation indicating that the position of the watercourses is fixed by the dune formations of the area. The watercourses would have eroded in the inter-dune valleys. This erosion is likely to have occurred during the past Glacial Period – when sea level was some 125 m below that of the present. Under these conditions, the groundwater boundary condition was very much lower than now and so the groundwater table would were deeper. The erosion of the watercourses would were due to rain events incising the valleys.

Now that the water table has risen in response to sea level rise, there are seepage lines along the toe of the sloping sides of the watercourses.

5.2.1.1 Geomorphological setting

This wetland type is in the bottom of the deeply incised interdune valleys (Figure 104). It is a linear feature where the wetland plant habitats are characterised by their positions in the profile of the valley. Within the valley, there is some habitat variability – often caused by water being dammed by slumping of the sides or the accumulation of plant growth where a tree has fallen. Where this occurs, small pockets of peat may form.

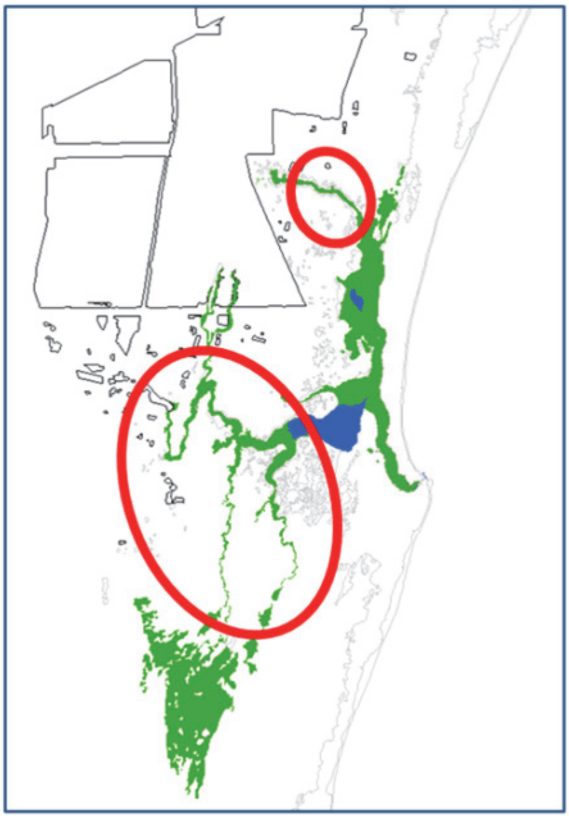


Figure 103. Wetlands in the incised watercourses of interdune valleys.

5.2.2 Hydrology

There are two sources of water that feed this wetland – groundwater seepage and water that flows from the upper-catchment wetlands (during very wet conditions only). In places in the upper parts of the watercourse, there may also be some loss of the surface water into the groundwater.

The main feature of this wetland is that the water is flowing. There may at times be flowing water in creeks downstream of this wetland, but here there is always some flow.

5.2.3 Physico-chemical environment

We have no records. The chemical make-up of the water from the two sources is likely to be different. That from the groundwater seepage is likely to be similar to the water measured in groundwater wells, and that from the pan is likely to be similar to water measured there.

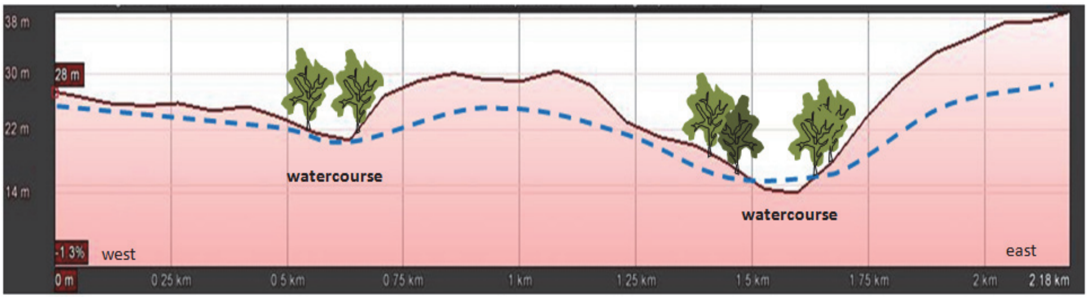


Figure 104. A west to east section of the landscape south of Lake Mgobezeleni showing two incised valleys (from Google Earth). The dashed line is a schematic depiction of the groundwater table.

5.2.4 Plants and animals

The sequence of the vegetation from the thalweg outward and up the sides of the valley would be: (Figures 105 and 106)

i. The stream in the lowest point, with fringing sedges and, where there are obstructions, pools with water lilies *Nymphaea nouchali var. caerulea*, *Nymphoides thunbergiana* and the sedge *Cyperus prolifer*.

ii. Sedge swamp or swamp forest (Containing plants such as *Syzygium cordatum* and *S. guineense, Morella serrata, Rauvolfia caffra, Voacanga thouarsii, Bridelia micrantha, Smilax anceps, Dissotis canescens* and *Cyperus dives*)

iii. Riparian forest. – which, although is drier than the swamp forest consists of much the same tree species

iv. Coastal forest or coastal grassland. Typical indicator trees would include *Albizia adianthifolia, Strychnos spinosa, Strelitzia nicolai* and *Dichrostachys cinerea.*

These habitats are in narrow linear bands that run the length of the watercourses. At the lower end, the watercourse widens as the slope flattens and peat starts accumulating. The swamp forest merges into that of the peat swamp wetland.

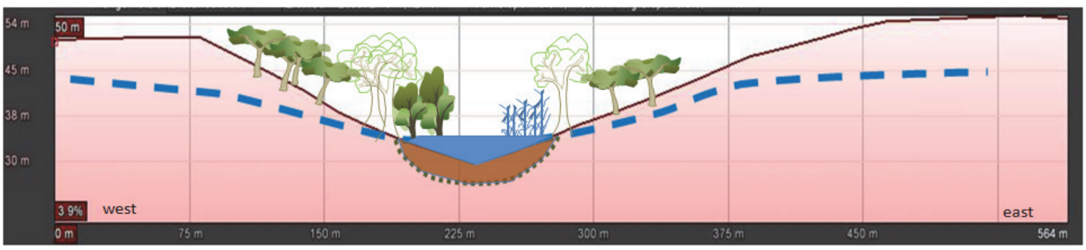


Figure 105. A Google Earth section of the watercourse entering the peat swamp upstream of Lake Mgobezeleni. The dashed line depicts the groundwater table and the dotted line the deposit of peat. NB all or none of these plant communities may be present. From the centre of the watercourse, moving up the slope the vegetation changes from that associated with permanent water (i.e. emergent reeds and sedges, and floating water lilies) to swamp forest, riparian forest and finally coastal forest or dry grassland.

The persistent groundwater seepage at the toe of the banks is the main determinant for habitats ii and iii.

The vegetation community at Thuthukeni (Tolla's Crossing) is typical of the widening watercourse vegetation. Here there are *Barringtonia racemosa* (which is a rare plant elsewhere in the Mgobezeleni Catchment), *Rauvolfia caffra, Macaranga capensis, Syzygium cordatum, Voacanga thouarsii* and *Ficus trichopoda* trees. The understory includes the indigenous bramble *Rubus rigidus*, the large swamp fern *Stenochlaena tenuifolia* and the climbing fern *Lygodium microphyllum.*

5.2.5 Ecosystem dynamics

There are two watercourses, which act as outlets to the Sangweni Pan. There are incised watercourses from the north that enter Lake Mgobezeleni and also the Thuthukeni Stream that flows towards Lake Shazibe via Tolla's Crossing.

The main impact affecting this stable community is the invasion of alien plants along the margins. Two of the main offenders are *Lantana camara* and *Chromolaena odorata*.

Examples of similar watercourse wetlands in Maputaland (outside of the Mgobezeleni Catchment) are few. Some occur in the inflowing streams into the Mkhuze Swamps and the watercourses flowing into Bhangazi-north.

Figure 106. An incised dune valley watercourse. Note the wetland in the bottom. There is groundwater seepage from the lateral sand slopes.

5.3 PEAT SWAMPS

Many wetlands in coastal Maputaland and especially those of the Mgobezeleni Catchment contain peat deposits (Ellery et al., 2012; Grundling et al., 2000). These wetlands are basins in a sandy landscape that have accumulated deep peat deposits over a long period.

For the purposes of this study, we use the term peat to indicate organic-rich deposits that were deposited under anoxic conditions. This organic matter is laid down in places where organic accumulation is greater than organic decay. Peat accumulation is a slow process. For deep deposits to have formed, the environment must were consistently wet for a very long time, possibly several thousand years. In Maputaland, this condition is achieved where groundwater provides the constant and sustained water supply needed to exclude oxygen.

In the Mgobezeleni Catchment the peat swamps occur where the gradient of the watercourses flattens out and widen (Figures 107 and 108).

5.3.1 Geomorphological setting

In the Mgobezeleni Catchment, the deep peat deposits occur in the palaeo-basins that are likely to have scoured during the last glacial period. These basins were flooded as sea levels rose since the last Glacial Maximum (18 000 years ago) (Ramsay & Cooper, 2002; Grundling, 2004) (Figure 109). Because the surface of the peat is often above that of current sea level, it is likely that this process occurred in these places during the past 3 000 to 6 000 years when the sea level was above that of present (Norström et al., 2012). This is consistent with the findings of Thamm et al. (1996) who have put ages to measured peat depths in numerous localities on the Maputaland Coastal Plain. Their only dated sample from the Mgobezeleni Catchment was taken from 1.43 m deep and the ^{14}C age obtained was 1100 ± 40 years BP. In the Mgobezeleni Catchment wetlands, this peat is in places over 5 m in depth.

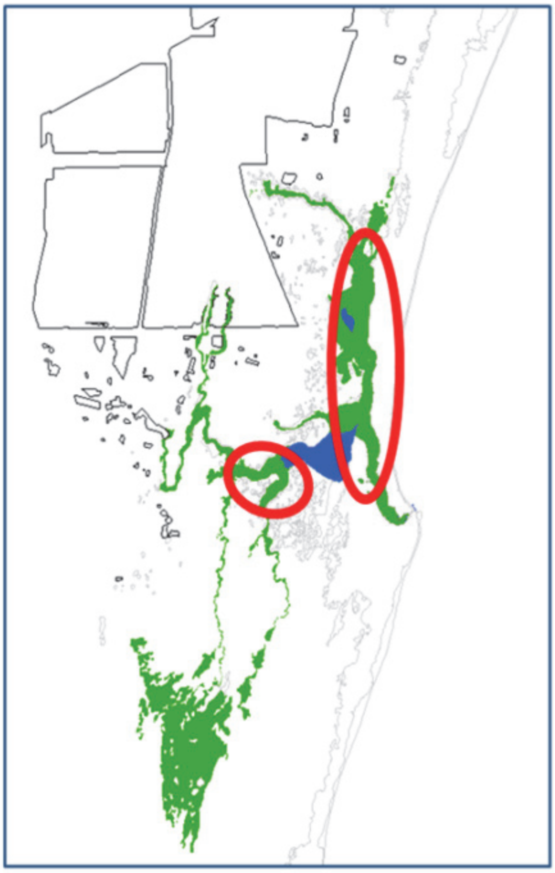


Figure 107. The peat swamp forests and sedge swamps that occur on deep peat deposits. The incised watercourses widen to merge into these peat wetlands. In the area that is the confluence of the two outlets from the lakes, this wetland type merges with the estuarine floodplain.

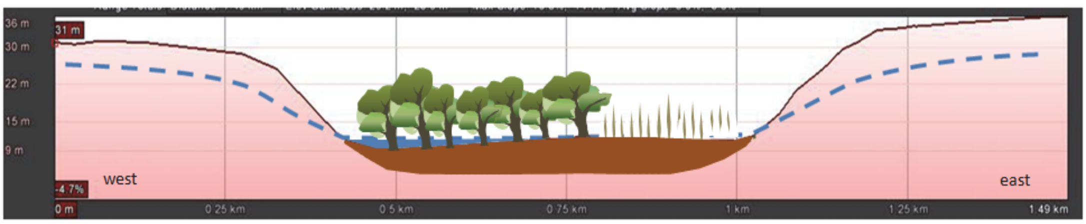


Figure 108. A north to south section through the wide valley east of Lake Mgobezeleni (Google Earth). The dashed line depicts the water table and the brown colour the deep peat deposit in the basin.

The peat-forming process is still ongoing and that the two lakes, Shazibe and Mgobezeleni, are still gaining organic material. Using pollen from introduced alien trees as markers Thamm et al. (1996) have estimated present day peat deposition rates to be just under 2 cm per year.

The peat deposits in the full Mgobezeleni Catchment cover an area of 441 ha (this study). As part of this study peat depths were measured at 198 points in the catchment. From these parameters, we estimate the volume of peat in the catchment to be 6.66 million m^3. This estimate was calculated using the depth averaged from each of the discrete peat regions within the catchment.

5.3.2 Hydrology

In many places, there is a stream that passes through the peat swamp. It is not always evident whether this is a natural channel or one cut by humans to drain fields. Most of the fields do have drainage channels – or are farmed using the ridge and furrow method.

A detailed study of the hydrological properties of peat was done in the Bheka Phandla site (cords -27.533S: 32.642 E) by Shabalala (2014). At this site (Figure 110), she measured peat depths (Figure 111) and conducted water permeability tests.

Throughout the area the consistency of the peat is variable – most of it is very compact and impermeable but in places it is very soft and almost fluid. When compact it has very low permeability to water (Shabalala, 2015). Our interpretation is that there is little lateral flow of water within the peat and it forms a plug that prevents water flow. What lateral flow there is would be through crab holes and channels where roots have decayed. In wet periods, there will be standing water on top of the peat; and there will be some surface flow. The peat deposit forms a partially confining layer for artisanal water – which rises from the sand aquifer below to the surface in the places where there is unconsolidated peat.

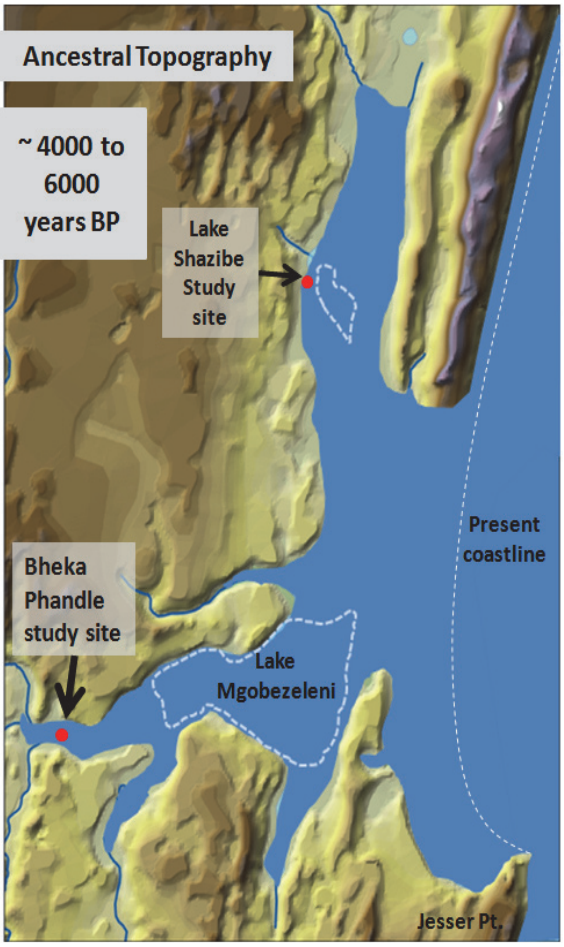


Figure 109. Area flooded at a sea level of +4 m (i.e. 4000 to 6000 years BP). We do not know if there was a barrier dune in place at that stage. Also shown are the localities of the Lake Shazibe and Bheka Phandle study sites.

The implication of this is that the peat deposits form plugs which impede water flow and hence are likely to raise the local groundwater level. This effect is lost when people farming the in the peat swamps dig drainage furrows. These furrows are likely to dry the peat in places – which would then oxidise and decay.

Figure 110. The Bheka Phandle study site indicating the points where peat depths have been measured, and the transect B to A for which the profile is shown in Figure 15. The other sample points mapped here were used to obtain a map of peat thicknesses throughout the study area for the project done by Shabalala (2015).

5.3.3 Physico-chemical environment

We have little information on the chemistry of this environment. We can assume that it is an anoxic environment, otherwise the peat would decay.)

5.3.4 Plants and animals

The natural vegetation is swamp forest, interspersed with patches of sedge swamp. However, there was a huge loss of swamp forest in the past few decades and now only remnants are left. This loss is due to clearing in order to plant crops.

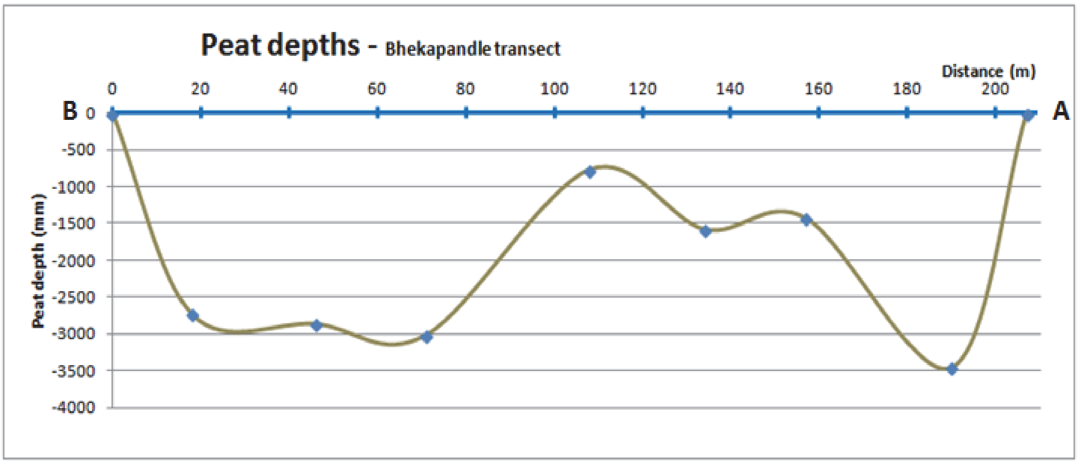


Figure 111. Peat section from point B to A (as shown in Figure 110). (The y-axis scale is exaggerated) This peat has very low lateral permeability to water (x-axis) and forms a semi-confined layer for water percolating up from below (through the depth – the y-axis). The profile shows two discrete deep areas, which is interpreted as being palaeo-channels from two water courses before they merged into one.

The swamp forest is dominated by tree species such as *Bridelia micrantha, Syzygium cordatum, Rauvolfia caffra, Voacanga thouarsii, Ficus trichopoda* and *Ficus sur*. The floristics of similar swamp forests, growing on peat, in the Kosi Bay area were described by Grobler, (2009) and Lubbe, (1997).

In the sedge swamps the main species include *Ficus verruculosa, Cladium mariscus, Cyperus dives, Tacazzea apiculata, Cyclosorus interruptus, Dissotis canescens, Cyperus prolifer, Ipomoea mauritianus,* and I*pomoea cairica.*

Luvano, (2013), in a study of a wetland in KwaMbonambi, has recorded the tendency for sedge swamps to change into swamp forests – a trajectory that is reversed by agriculture and fire. Historical aerial photos show that this is also the case in the Mgobezeleni peat swamps.

Large areas of the peat swamps in Maputaland are cultivated (Grobler et al. (2004); Sliva et al., 2004). Cultivation begins with the clearing of a small patch of swamp forest by felling and burning the trees, or the clearing of some sedge swamp. The peat is raised into hummocks and vegetables planted on the raised mounds. When the cultivation is at a subsistence level, there is intercropping using a number of different plants (including banana, sweet potato, lettuce, beetroot, cabbage, spinach, onions, sugar cane, pumpkins, cassava, and madumbies) (Figure 112). As the cultivated patch extends, some furrows may be excavated to lead off accumulated water (Figure 113). In more established sites, there is a shift from subsistence cultivation to commercial cultivation. The site expands and large-scale drainage is implemented. In both the small-scale and the commercial agriculture, insect pests are a problem and an abundance of insecticide is applied to the crops. This is a concern that requires more detailed investigation. Alien plants, that are often associated with previously cultivated areas include *Coix lacryma-jobi), Lantana camara*, *Mangifera indica*. Along the streams, there may be *Hedychium* sp. (Wild ginger)*,* and *Nasturtium officinale* (watercress).

Figure 112. Small-scale agriculture in an area that was formerly swamp forest. In the foreground are cabbages and in the background bananas.

5.3.5 Ecosystem dynamics

This wetland type is the most affected of the wetland types in the catchment. It was severely impacted by small-scale agriculture resulting in a loss of swamp forest and sedge swamp. The subsistence multi-cropping is rapidly changing to be commercial mono-crop farming. (e.g. banana plantations) Furrows were cut to drain the fields. This results in a decomposition of peat as it dries. This peat has a low water permeability and so loss of peat is likely to lower the groundwater table.

Figure 113. Large-scale commercial agriculture is replacing the small-scale subsistence gardening. Here a drainage furrow was excavated to take water off the banana crop. This sort of excavation is very damaging to the peat.

Management intervention is required to reduce drainage and prevent drying of peat. There is also a need to contain the agriculture to a sustainable level. Small-scale subsistence farming where there is intercropping can be tolerated but it is necessary to set a limit to the proportion of the peat swamps that can be under cultivation at any one time. Within the iSimangaliso Park, there should be no cultivation at all.

Similar peat swamps occur at Kosi and in the streams that flow into Sibaya from the north and the west. They also occur in the drainages flowing into Mkhuze Swamps and Lake Bhangazi-north. Most of these swamp forests are threatened by agriculture. The understanding of the impacts of loss of peat should be applied to all these systems. Possibly the only swamp forest unaffected by agriculture at this stage occurs along the western margin of the Mfabeni swamp on the Eastern Shores.

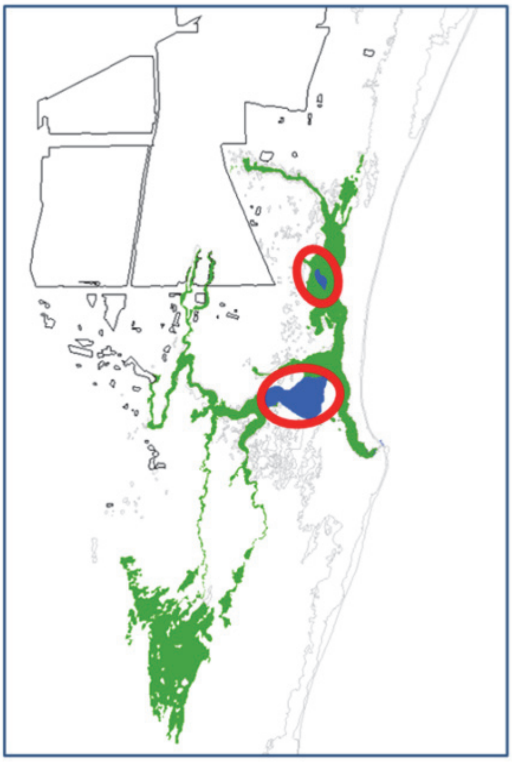


Figure 114. The coastal lakes. Lake Shazibe in the north and Lake Mgobezeleni in the south.

5.4 COASTAL LAKES

In the Mgobezeleni Catchment, there are two freshwater coastal lakes; Lake Shazibe and Lake Mgobezeleni (Figures 115 and 116). Both lakes are fed by water that has drained from the sand aquifer that is the Mgobezeleni Catchment. This water seeps into the interdunal watercourses and the peat swamps. Both lakes are linked to the sea – although in the case of Lake Shazibe this is quite a tenuous link. The link passes through a culvert under the road to Sodwana at esiKhovokeni. During extended low-rainfall, there is no flow here and the surface-flow link is severed. The estuary is a 'boundary condition' that controls the water levels in the lake and adjacent groundwater table. Because the lakes have very stable water levels, they both have an abundance of associated vegetation – on the shoreline, emergent, and, especially in the case of Lake Shazibe, as submerged plants. They both have clear, light brown stained water. Although they are both in sand basins, they have a considerable quantity of accumulated organic material on the bed of the lake. This is the case throughout Lake Shazibe, and only in the deeper parts and vegetated fringes of Lake Mgobezeleni.

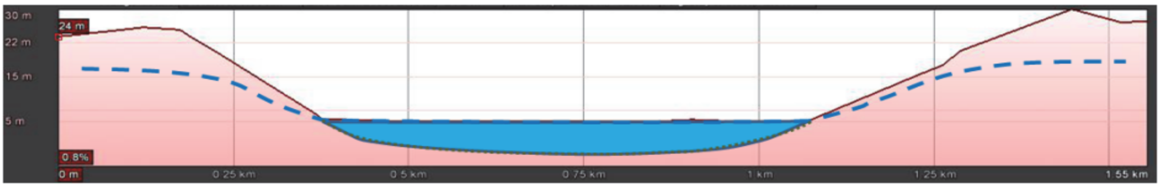


Figure 115. A north to south section through Lake Mgobezeleni. This Google Earth section depicts the water table (dashed line) and the water of the lake (blue).

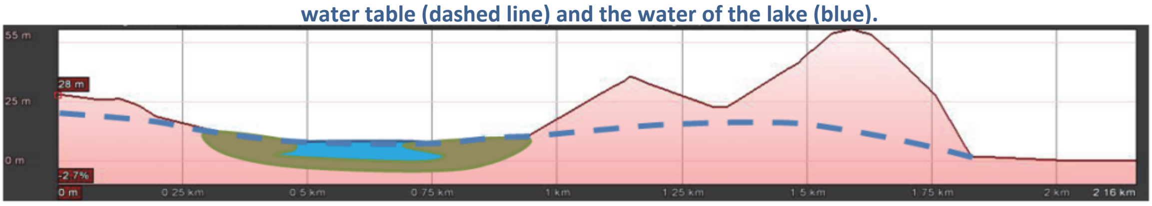


Figure 116. A west to east Google Earth section through Lake Shazibe schematically illustrates the lake (blue) embedded in peat (brown). The dashed line depicts the groundwater table.

5.4.1 Geomorphological setting

Lake Mgobezeleni has a surface area of 93 ha. Lake Shazibe is much smaller at 8 ha. Both lakes have maximum depths of a little more than 5 m.

The bathymetry was measured for Lake Mgobezeleni (Bruton, 1980, and this report – see Section 2.5.2). No bathymetry survey was done for Lake Shazibe due to the difficulty caused by a deep layer of soft organic matter on the bottom. Six probed depths in the northern part of the lake showed the depth to the sand base was more than 530 cm at its deepest. The bottom layer of organic matter was between 60 and 380 cm. This was liquefied near the top, gradually becoming more compact with depth. In all sites probed there were submerged macrophytes (*Ceratophyllum demersum*) (Figure 117).

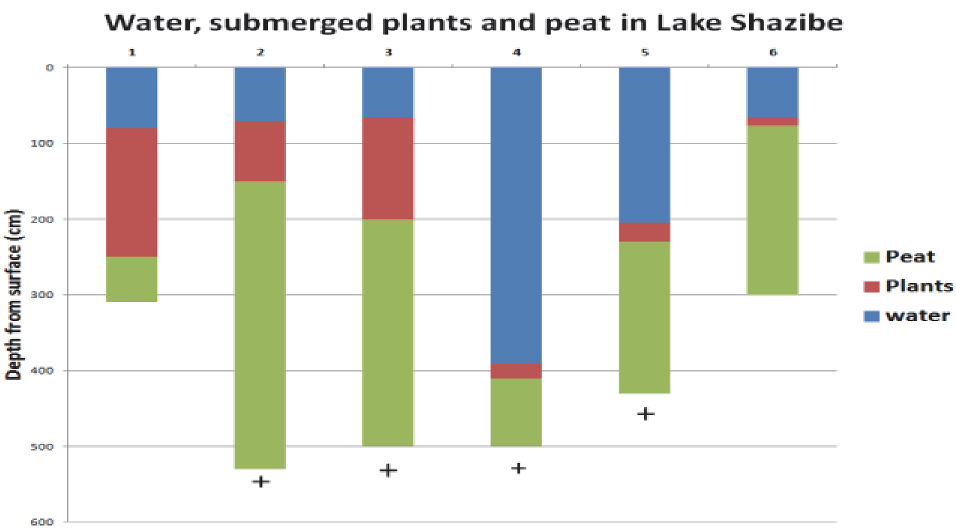


Figure 117. The strata in Lake Shazibe: water, living submerged macrophytes and organic deposits on the sandy bottom. In samples 2 to 5 the probe did not penetrate the peat layer to get to the sandy substratum.

The lakes are set in wide palaeo-basins with sandy substrata and both have the trajectory to become filled with peat. The process of infilling is very similar to that described as 'quaking peatland succession' by Mitsch and Gosselink (2000). In that case, there is a surface mat of floating vegetation (mainly *Pycreus nitidus*) and the deposition of peat from the outer margins of the lake towards the middle (Figure 118). Lake Shazibe is much further along this trajectory than Lake Mgobezeleni. Peat depths were measured along a transect on the western shoreline of the lake (Coordinates: -27.505 S; 32.662 E). The profile obtained is shown in Figure 119.

The trajectory of this process is to form a peat swamp – as in the Bheka Phandla site west of Lake Mgobezeleni where artesian water was detected (Shabalala, 2015).

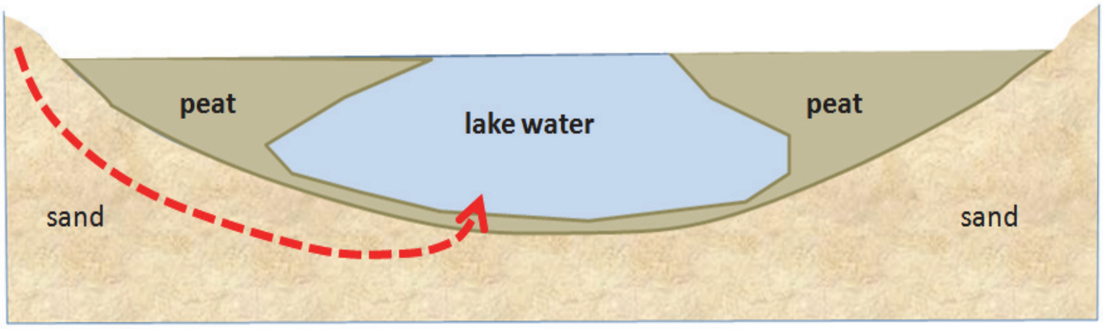


Figure 118. A schematic section through Lake Shazibe. As the compacted peat has low water permeability, it forms an confining layer diverting groundwater which rises to the surface through the lake bed. The red dashed line indicates water flow pathway. This is artesian water.

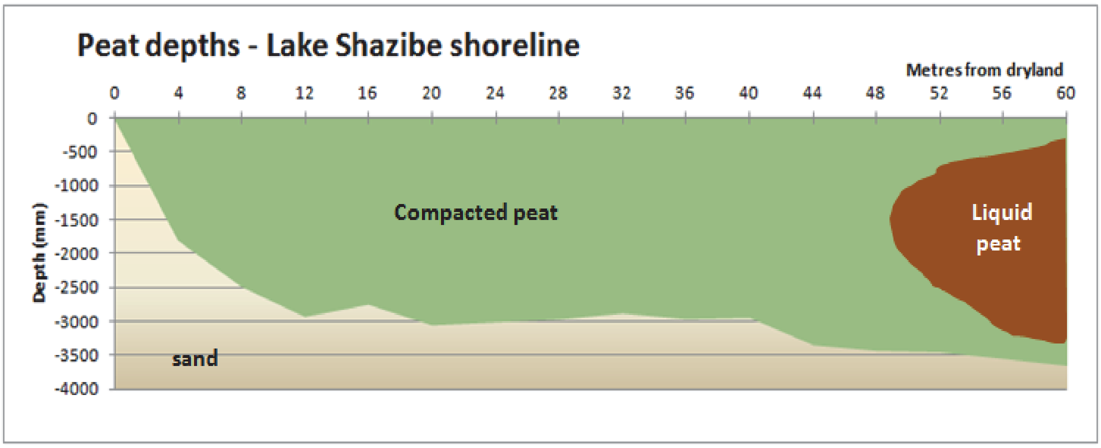


Figure 119. A profile of the peat deposit on the western shoreline of lake Shazibe (the site locality is shown in Figure 109). This profile is from the dry ground (left) to the lake margin (right). Peat is deposited from the outer edges and moves lakewards. Along the lake margin, the plants form a floating mat. Peat accumulates under the mat of plants -first as a liquid then consolidating into a compact peat.

5.4.2 Hydrology

The water level of both lakes is controlled by the level of the estuary and how far it backs up. Between the outlets of both lakes and the estuary there is sufficient constriction of the flow that the lakes do not respond to either the marine tides when the mouth is open, or the backing up of water when the mouth closes. However, this would act as a boundary that controls the overall water level. The result is that, from the ecological perspective, both lakes have remarkably stable water levels. (See Figure 18 for the Lake Mgobezeleni hydrograph).

The lakes are fed by the groundwater from the Mgobezeleni Catchment – and hence are likely to have most of the inflowing water as a constant base-flow. They are affected by rainfall events, which do cause a temporary rise in water levels. (See hydrographs). On average, the range in water levels over a year in Lake Mgobezeleni is about 50 cm. In a longer time scale, this may be almost 1 m.

The hydrograph record for Lake Shazibe is much shorter. It indicates that the average range in water levels is only about 15 to 20 cm – although a rain event would result in a short-duration peak more than that.

5.4.3 Physico-chemical environment

The water quality for the lakes is described in (Section 3). There are elevated nutrient levels in Lake Mgobezeleni. As human numbers in the catchment area rise, so further elevation of these nutrient levels can be expected. At this stage, we have little knowledge of flushing or retention times

Figure 120. Lake Mgobezeleni – with a shoreline that is rich in emergent plants.

Both lakes have clear, but lightly brown-stained water. Although in both lakes the water level is relatively constant, Lake Mgobezeleni (Figure 120) has extensive wind-generated wave action. Conversely, Lake Shazibe (Figure 121), because of its smaller size has significantly less wave action. This affects the growth of the emergent vegetation.

5.4.4 Plants and animals

The microalgae section of this report provides a detailed description of the phytoplankton of the lakes.

Figure 121. Lake Shazibe, surrounded by swamp forest and sedge swamp growing on deep peat. The encroaching vegetation is a floating mat of plants.

The stable water levels in both lakes is important for macrophytic plant growth. This enables a floating raft of plants to grow into the lake in Lake Shazibe, where there is little wave action, and a rich growth of emergent vegetation to form in Lake Mgobezeleni where wave action can be quite severe. In wave-protected sites along the far western edge of Lake Mgobezeleni, the floating vegetation is similar to that in Lake Shazibe – in species and in form.

The emergent plants in Lake Mgobezeleni grow on a sandy substratum (Figure 122). Their slender growth form enables them to cope with the wave action. The plants trap floating organic material, which is deposited in a line of wrack on the margin of the lake.

The depth ranges for the emergent plants along the Lake Mgobezeleni shoreline are given in Table 40).

Figure 122. A schematic depiction of the zones of emergent plants related to water depth. In the shallower water there is Phragmites australis, with Eleocharis dulcis where it is deeper. Beyond that is the submerged macrophyte, Potamogeton schweinfurthii.

Table 40. The measured range of depths for the dominant aquatic plants in Lake Mgobezeleni.

Species	Minimum (cm)	Maximum (cm)	n
Phragmites australis	26	168	16
Eleocharis dulcis	59	236	27
Nymphaea nouchali var *caerulea*	59	158	7
Nymphoides thunbergiana	91	138	2
Potamogeton schweinfurthii	230		1

When wave action is stilled enough, (e.g. in the quiet water embayment at the extreme western margin of the lake) a raft of floating plants will form. Like the floating vegetation in Lake Shazibe, this is composed mainly of the sedge *Pycreus nitidus*, but also includes other species such as also other spp – such as *Leersia hexandra, Cyperus prolifera* – and in places even *Cyperus papyrus*.

Along the margin of Lake Shazibe there is a succession of plants ranging from dryland through bands of *Typha capensis, Phragmites australis* and the fern *Cyclosorus interruptus* interspersed with *Syzygium cordatum* and *Bridelia micrantha* trees. In the deeper peat, there is more *Typha capensis* and also *Phragmites australis* and a rich growth of the sedge *Cyperus nitidus*, which grows out into a floating mat in the deeper water. Submerged water plants are dominated by *Ceratophyllum demersum.* In protected places along the margin is the blue water lily, *Nymphaea nouchali var. caerulea* on the surface, while the tropical *Nymphaea lotus* grows in slightly deeper water and where it is more exposed to wave action. Pygmy geese live in association with these water lilies and feed extensively on their ripening seed capsules.

Lake Shazibe also has some rare plant species. These include the seldom seen tiny flowering plants *Wolffiella denticulata* and *W. welwitschii* (Lemnaceae) (Obermeyer-Mauve, 1966).

Fish were collected in both the lakes. Lake Mgobezeleni is the only locality in South Africa where *Oreochromis placidus* (syn = *Sarotherodon placidus*) was recorded (Bruton, 1980). Noteworthy amongst the fish in Lake Shazibe are the threatened Broadhead sleeper *Eleotris melanosoma* and the rare Golden sleeper, *Hypseleotris cyprinoides* (Karssing, 2012).

5.4.5 Ecosystem dynamics

The two coastal lakes receive a relatively constant inflow of groundwater-fed freshwater, which is virtually free of mineral sediments.

Should the nutrient levels in the lakes rise they could become more prone to the infestations of alien plants. The floating Water Lettuce (Pistia stratiotes) already occurs in Lake Shazibe, and both systems could be more susceptible to infestations by *Eichhornia crassipes,* and *Hydrilla verticillata* should nutrient levels rise.

In Maputaland, there are several other coastal lakes. These include Lake Pithi in Mozambique, Kosi Lakes, Lake Zilonde, Lake Sibaya, Bhangazi-north and Bhangazi-south. The ones that are above sea level – such as Lake Sibaya and both Lake Bhangazi-North and Lake Bhangazi-South – exhibit a greater degree of water level fluctuations and hence have different shoreline vegetation. The limnology of the coastal lakes of South Africa was described by Hart (1995).

5.5 ESTUARINE FLOODPLAIN

The wetland linking the lakes and the estuary is a basin filled with peat of more than 3.5 m in depth. Incised into this peat is a channel, which carries flowing water. This links the lakes with the estuary. (Figure 123). Loggers installed in the floodplain channel and about 60 m away on the margin of the floodplain respond in unison as water level rises and falls. This indicates that the peat in this estuarine floodplain is unusually porous and is highly permeable to water. Whenever the estuary mouth closes and water backs up, this water fills the voids in the peat, moving laterally from the channel into the peat. At the point when the water is at the level of the surface of the peat, it rises from below to inundate the swamp. This behaviour is not typical of floodplains where the water flows as surface water over the floodplain.

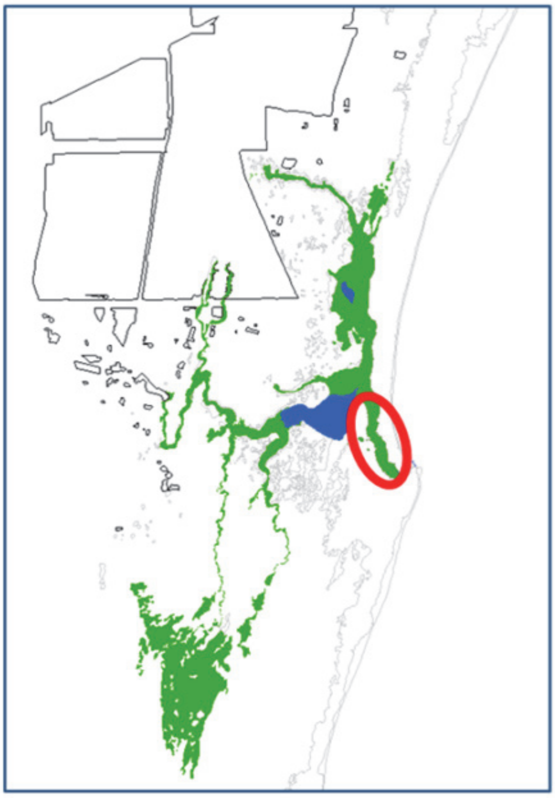


Figure 123. The estuarine floodplain. This is the area between the estuary and the confluence of the streams that exit the two lakes. It is a peat-filled palaeo-valley that is back-flooded whenever the estuary mouth closes.

5.5.1 Geomorphological setting

This floodplain is in a basin bounded by the vegetated coastal dunes and the estuary mouth to the east and elevated ground to the west. This basin is filled with peat to a depth of at least 3.5 m.

The floodplain is effectively the area downstream of the confluence of the streams that flow from the two lakes. This confluence is about 2.7 km from the mouth (at coordinates -27.526 S; 32.669 E). The width of the floodplain varies from about 200 to 300 m. The channel is mainly along the eastern part of the floodplain and is 3 to 10 m wide and 0.5 to 1.5 m deep. The lower part of this channel – where it is no longer affected by sea tides and beyond where the saltwater intrusion stops – is the river-estuary interface.

Saline water from the estuary penetrates at least 700 m upstream from the mouth and tidal attenuation occurs about 1 km upstream of the mouth

5.5.2 Hydrology

Whenever the estuary mouth closes raising the water level in the estuary, the floodplain fills up like a sponge. If the water rises further, then it becomes standing water on the surface of the floodplain. When the estuary breaches, the floodplain drains rapidly.

In effect, the floodplain acts as a large and very porous sponge that fills and drains in response to the state of the estuary mouth.

5.5.3 Physico-chemical environment

Little saline water enters the Mgobezeleni estuary, and what does enter remains at the bottom of the creek, as it is denser than freshwater. As a result, the water that affects the floodplain plants is all fresh – even adjacent to the creek where, in the lower parts, there may be saline water in the bottom. – especially when it is closed, the water in the floodplain is fresh.

As much of the water in the floodplain is shaded – by vegetation, or held in the porous peat, the water temperature is lower than the water temperature in the estuary. This is detected in the estuary as a drop in water temperature when there is an outflow of water when the mouth breaches.

In 2007, a large quantity of seawater entered the lower part of this floodplain. This was due to very high tides and sea conditions. Usually, due to the strong stratification, the saline water does not come into contact with the roots of the freshwater wetland vegetation. However, in this instance the volume of seawater entering was so large that it flooded and killed a large area of the swamp vegetation (Taylor, in press).

5.5.4 Plants and animals

The vegetation of the floodplain was described by Taylor (in press). It is either a *Ficus trichopoda*-dominated swamp forest, or a sedge-swamp. It is an area unaffected in recent years by agriculture, but old aerial photos do show a small degree of agriculture in the 1950s.

Older aerial photos show that this floodplain was dominated by a sedge swamp (*Typha capensis, Cyperus dives, Tacazzea apiculata*, *Smilax anceps* and *Cyclosorus interruptus* being the dominant plants, with the tropical *Ficus verruculosa* shrub being present). However, in the past 60 years there was an expansion of *Ficus trichopoda* forest, which was displacing this sedge swamp (Taylor in press). The rate of this expansion was measured by tracking the change in the margin of a single very distinctive *Ficus trichopoda* tree from 1942 to 2007. The results were back extrapolated to show that the start of the swamp forest expansion was likely prior to 1900 (Figure 124). The primary cause for this expansion is unlikely to be due to human interventions as so few people lived in the area at that early stage.

A lot of the peat cores collected from sedge swamps throughout the area contain pieces of wood. It seems that the peat swamps can support either a sedge swamp or a swamp forest. The one formation can flip to the other; however, it does take a long time for swamp forest trees to grow. From Figure 124 it seems likely that it reflects the actual rate of *Ficus* swamp forest expansion. In this case, the larger trees in the swamp forest started growing before the middle of the 1800s. This knowledge helps us to understand that the felling of swamp forests for agriculture is a reversible process albeit a very slow process.

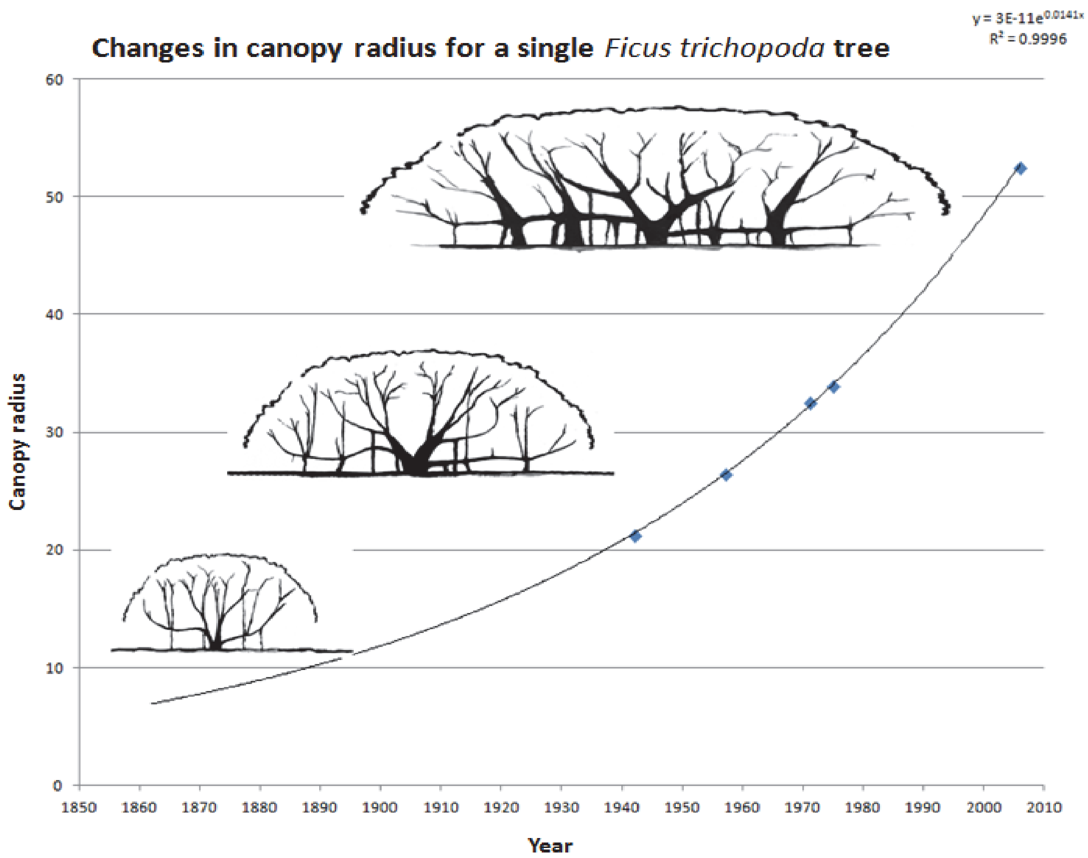


Figure 124. Graph showing the expansion of the canopy of a Ficus trichopoda tree – with back extrapolated to show when it started growing (Taylor, *in press*).

Figure 125. The sedge swamp vegetation of the estuarine floodplain.

The Mgobezeleni Floodplain immediately above the estuary is unique in Maputaland since there are no comparable floodplain features to those shown in Figures 125 and 126. Possibly a similar feature would be the drainage line that links Lake Zalondi to the Kosi Lakes.

Figure 126. The *Ficus trichopoda* dominated swamp forest in the estuarine floodplain.

5.5.5 Ecosystem dynamics

This system is very sensitive to agricultural clearing and the drainage of the peat (Sliva et al., 2004). Should this happen it would lower the water table during periods when the mouth is open and this lowering would be propagated upstream to lower the water level in the lakes. It thus also responds to estuary mouth management. The whole wetland is sensitive to sea-level rise.

5.6 ESTUARY

The Mgobezeleni Estuary (Figure 127) is very important, as it is the only estuary in the 175 km stretch of coastline between the St Lucia and Kosi estuaries even though it is very small. Downstream of the bridge is the lagoon that has a variable area of open water. Depending on whether the estuary mouth is open or closed, this area ranges from 0.2 to 1.3 ha. (Figure 128 a & b). The portion of the estuary upstream of the mouth is about 1 km long, with a width that tapers from 10 m to <1.5 m. It has an area of less than 0.5 ha. Thus, the total estuary has a variable area, ranging from 0.7 to 1.8 ha. In most places, it is steep-sided and its depth, ranging from about 0.5 to 2.0 m is dependent on the state of the mouth. The upstream basin is filled with *Acrostichum aureum* ferns, *Phragmites australis* reed beds and the remnants of a stand of large *Bruguiera gymnorrhiza* mangroves.

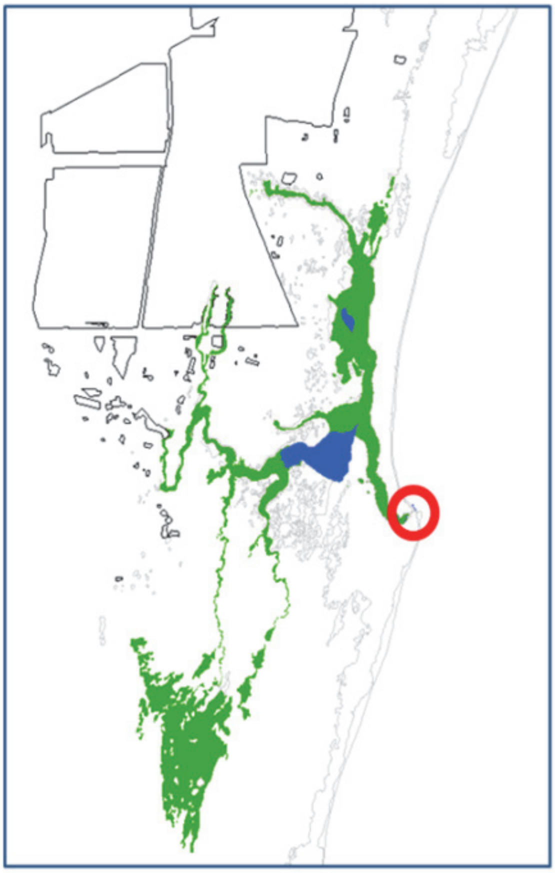


Figure 127. The Mgobezeleni Estuary enters the sea at Jesser Point.

5.6.1 Geomorphological setting

The Mgobezeleni Estuary enters the sea in the Sodwana bay where it is protected by the Jesser Point Rocks. It is a small estuary set in an infilled floodplain. Because of the narrow configuration of the estuary and the closeness of trees, there is little mixing of water by wind.

Figure 128. a & b: Aerial photos of the estuary (a) in its open phase and (b) when closed. The changes in water surface area of the beach basin are clearly visible. (Photos T Ferguson, EKZNW).

The location of the estuary mouth is variable – it has on occasions flowed to the south of the Jesser Point reef, but normally flows out to sea north of Jesser Point. The outlet can be at sea level – after a breach – or as a small outflow over a perched beach berm. If the latter is the case, the outflow channel is often sinuous and hence has a shallow gradient. Under these conditions, the water flow is slow and non-erosive.

The mouth dynamics are controlled to a large degree by the beach sediments. The dynamics of these sediments may were altered by the planting of casuarina trees and the building of a 'loffelstein' retaining wall at Jesser Point. These stabilise the drift-sand and possibly affect the beach dynamics.

5.6.2 Hydrology

For the purposes of this study, we regard the Mgobezeleni Estuary to be a Temporarily Open/Closed Estuary (TOCE) rather than an estuarine lake system. The functioning of the estuary is dependent on a pattern of regular closures and breechings. When there are large rainfall events, there is storm flow in streams and this gives a spike in the hydrograph – which may affect a breach if the mouth is closed. Because of the sustained base-flow and the small volume of the estuary, estuary water backs up to overtopping levels very rapidly after closure. Then, because there is only a very small tidal prism (and only during spring-tide periods), the mouth, once open, closes soon after breaching. These two features, combined with an abundant supply of available marine sediments, promote a cycle of frequent closures and breechings. For instance, in the period 26 July 2013 to 11 December 2014 there were 23 breaching events. A typical cycle is shown in Figure 129. For the purposes of this study, a breaching event is regarded as a sudden outflowing of the water after a period when water levels in the estuary were raised – but not necessarily closed.

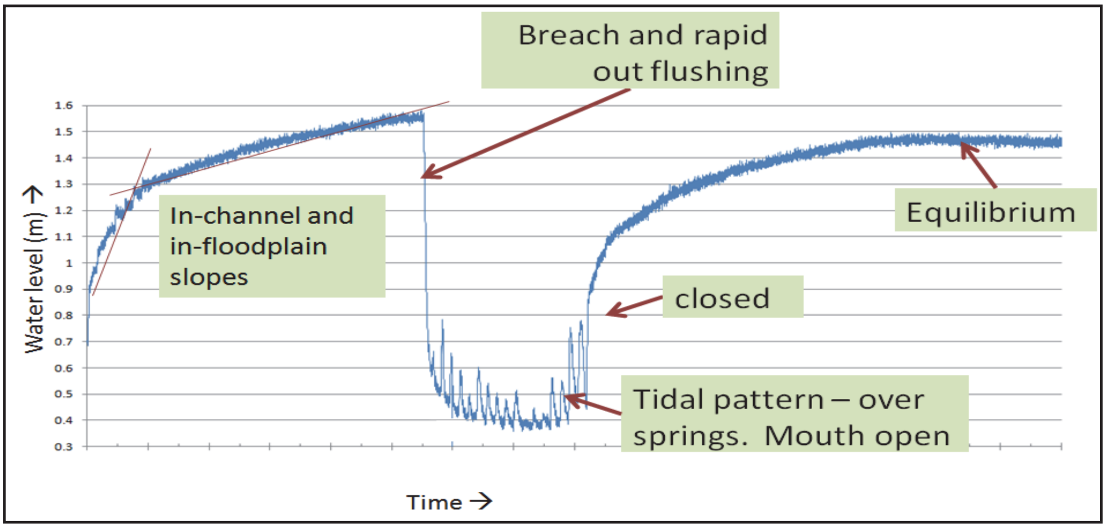


Figure 129. Hydrograph of the estuary showing open and breached conditions. Water level measurements at the Bridge crossing the Mgobezeleni Estuary showing the rise in level as the water backs up after estuary mouth closure. Then there is a catastrophic breach – and the water level drops by over 1 metre within a few hours. With the estuary mouth open, and as it was spring tides, the estuary is tidal for 10 days before the mouth closed naturally. This is the period when salt enters the system. Then, the water level rises again as the estuary backs up. This water level rise is steep at first as the channel fills up, and then slows as it fills the estuary floodplain.

At times, the closed estuary can attain an equilibrium state. This occurs when inflows which are fairly constant base flows) equal outflows. Under this condition, the main outflow is likely to be that of seepage seaward through the beach berm. Nevertheless, portion of it can be in the form of a slow-flowing stream overtopping the beach berm. Such an equilibrium can last for several months over winter when there is little rain. It is disrupted either by a sudden rainfall event that introduces a pulse of water which flows over the beach berm with enough velocity to be erosive, or due to rough sea conditions over a high tide which can erode the frontal slope of the beach berm and cause the overwashing of the sea into the estuary.

After a breach, the wind- and wave-driven beach processes rapidly build up the beach berm. As the berm level rises, the water backs up in the estuary. An increasing proportion of the water that flows seaward escapes to the sea as groundwater flow through this rising beach berm until overtopping ceases and inflow equals throughflow. Then, often triggered by a rain event, the estuary overtops and breaches in a catastrophic manner (Figure 130). The outflowing water erodes a deep wide channel – removing a large quantity of berm sediment. The breach empties virtually all the water from the estuary, before the berm starts building again (Figure 131). In the early stages after breaching there may be a significant amount of tidal exchange and overwash entering the estuary from the sea.

Figure 130. When the estuary breaches – on those occasions when the water level is raised to about 2 m above mean sea level – the breach is catastrophic. It starts slowly and gains momentum as the water enlarges the outlet. This causes faster flows and more scouring. At its peak outflow the water is a raging torrent as is shown in this photo. Within a few hours most of the water will have drained. Photo Mary Pieters.

Figure 131. After breaching the estuary is a narrow channel in the largely empty basin.

The estuary is also affected by large sea storms that occur only once every several years. These breach the estuary and surges of seawater penetrate into the estuary. The seawater inundates the lateral wetlands and the salt kills the wetland vegetation – as occurred in March 2007 (Taylor, in press).

The estuary water level is controlled to a large degree by the deposition and erosion of sediments in the beach-berm. To gain an understanding of the beach berm processes the berm morphology changes and sediments were analysed. This was part of an honours project done by M Kgatle (2014**).** The behaviour of the beach berm, and how it affects the estuary, is the subject of an MSc project currently being conducted by G Mkwela at the University of Zululand.

5.6.3 Physico-chemical environment

Seawater enters the estuary either when it is affected by marine tides –mainly during spring tides during the open mouth period – or when there is overwashing of the beach berm by waves. This latter condition is very much influenced by the height and width of the beach berm, the height of the spring high tides, the sea state which affects wave height and the angle of attack of the waves.

The salt water that enters the system sinks to the bottom and as there is little stirring, the stratification is persistent. The saline bottom water was measured to penetrate to at least 700 m upstream from the mouth. During this condition, the upper surface of the water is fresh.

5.6.4 Plants and animals

Although the estuary is small, it has, until recently, supported a dense and old stand of *Bruguiera gymnorrhiza* mangroves. Many of these were killed as a result of the construction of a bridge in the early 1970s that prevented salt water penetration and which dammed up the water level within the estuary upstream of the bridge (Bruton and Appleton, 1975; Bruton, 1980). Most of the remaining mangroves were then killed by conditions that were precipitated by the influx of seawater caused by extremely high tides that coincided with a storm event in 2007 (Taylor in press).

At present, the patch where the *Bruguiera gymnorrhiza* grew was colonised by the mangrove fern *Acrostichum aureum* – growing in amongst the dead trunks of the 15 m tall mangrove trees. Within the estuary area there is a fringe of *Hibiscus tiliaceus* and a little *Juncus kraussii*. There are beds of *Phragmites australis* in which *Typha capensis* becomes progressively more abundant with distance away from the estuary mouth.

5.6.5 Ecosystem dynamics

Although the estuary has a degree of stability imposed on it by the constant nature of the base flow, we can, in the longer term, expect changes to occur in response to changing rainfall patterns and a southwards shift in cyclone activity. A rise in sea level may be severe as it could alter the beach sediment dynamics, and hence the nature and frequency of estuary breaching.

It is important to care for the remaining mangroves. These are the source of propagules for recolonisation. Should these remaining trees die-out there is a very low probability for recolonisation from the adjacent St Lucia or Kosi Estuaries. The threats to these trees are bark stripping for muthi and the insidious expansion of the car park into the margin of the estuary.

5.7 SYNTHESIS

The wetlands of the Mgobezeleni catchment should be regarded as one system – all being fed by seepage from a single sand aquifer. Although there are different land-uses within the catchment, the whole catchment and all the wetlands should be managed as a single inter-connected system. It is useful to recognise the different wetland types – as shown schematically in Figure 132. Each of these wetland types has distinctive features that together support a variety of habitats.

We need to better understand the formation of the system in order to understand present day processes. The origins of the coastal plain and its coastal lakes were described *inter alia* by Hill (1975), Hobday, (1979), Maud (1980) and Wright (2000). These describe the changes in sea level and how critical they were in the formation of the lakes system since the last glacial maximum some 18 000 BP. There is a need to do more ageing of peat samples as this will allow us to understand the rates of the geomorphological active processes, and which are accelerated by human impacts.

The 2011 National Biodiversity Assessment (Van Niekerk and Turpie, 2012) classified the estuary, floodplain and coastal lakes as a 'coastal estuarine lake'. This classification was prior to this study when water elevation and salinity data were not available. For the purposes of this study, we regard the portion that exhibits marine tides or where there is penetration of marine salts to be the estuary.

Hydrologically there is little to justify Lake Mgobezeleni to be classification as an estuarine lake. Lake Mgobezeleni shows only a very small response to the closure of the estuary mouth. Lake Shazibe shows no response. Neither have any raised salinity levels

If we consider the biota, no plants and only a few species of animals in Lake Mgobezeleni can be considered estuarine. In Mgobezeleni the diatoms are all freshwater species. We do not have information on the zooplankton or zoobenthos to know if they have any distinct estuarine affinities. The only crustacean recorded in Lake Mgobezeleni that has marine links is *Varuna litterata*.

Bruton (1980) recorded 19 fish species in the lakes. Of these, "nine are primary freshwater species, one, *Oreochromis mossambicus* is a euryhaline cichlid and nine are euryhaline marine species". These include the Oxeye tarpon (*Megalops cyprinoides*), three species of Anguillid eels, two mullets (*Liza macrolepis, Myxus capensis*), and the goby *Glossogobius giuris*, the freshwater goby *Platygobius aeneofuscus* and the sleeper *Eleotris fusca*. In Lake Shazibe the fish survey conducted by Karssing (2012) indicated that the Broadheaded sleeper *Eleotris melanosoma* was the only fish which may be regarded as having estuarine links. None of the plants can be regarded as estuarine.

We do not believe that there is sufficient evidence to justify the classification of the full system as a Coastal Estuarine Lake. We, for this study, prefer to classify the wetlands as we have done; with the estuary as a TOCE. We still regard all the area below the 5 m contour to be within the Estuarine Functional Zone.

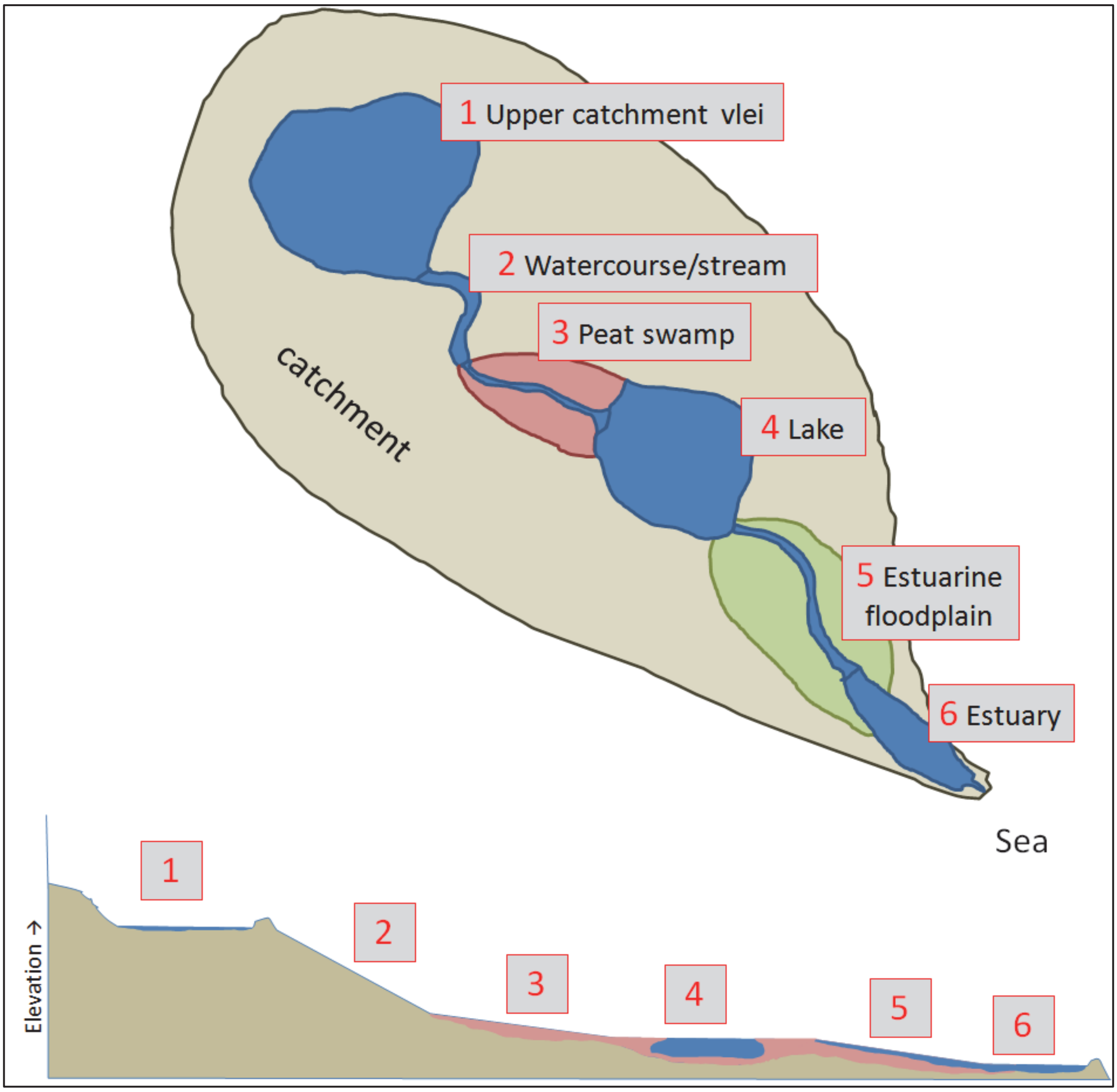


Figure 132. Schematic depiction of the different wetland components of the catchment (above) – with a longitudinal section showing their positions in the landscape – note the relative elevations and slopes of each of the components.

CHAPTER 6. SOCIAL ISSUES RELATED TO THE IMPLEMENTATION OF THE PROJECT

6.1 CONTACT WITH AND APPROVAL FROM LOCAL AUTHORITIES

Before the project formally got underway, Prof J. Simonis (University of Zululand) followed local protocol by contacting the indunas (JP Mboyazi (082 759 0361) from Mbazwana and Jethro Zikhali (082 583 6746) from Sodwana. The initial discussions were followed up by attending a meeting of the Mbazwana Tribal Authority. The late chief and all the indunas in the area were present at that meeting; hence, the proposal received good coverage. At this meeting, Prof Simonis highlighted the project and discussed the future of the project. Since that time he has had regular phone calls and meetings with Mr. Mboyazi on issues such as; the Nkosi that had passed away in car accident and the reporting of a theft of loggers etc. Mr. Mboyazi, who works as an Aids Councillor at the Mbazwana Hospital, is well versed in English and has always been a great help to us. Currently the best way to reach the Tribal Authorities is either through Mr. Mboyazi or through the Secretary whose name is Princess at the number 076 625 5909.

Dr Simonis followed up his tribal contacts with numerous formal and informal meetings with the Local Municipal Manager, uMhlabuyalingana Local Municipality and Mr Sbu Bukhosini. A formal meeting with the Municipality was helpful and Prof Simonis and Mr Mark Schapers reported the drilling and monitoring project to the Council. Mr Sbu Bukhosini's contact details are 084 602 8657.

At the inception of project K5/2259, a requirement of the contract was that there should be a component related to socio-economic issues. Professor Stephen Hosking from the Department of Economics at Nelson Mandela Metropolitan University, Port Elizabeth, initially undertook this component. However, Professor Hosking subsequently left the service of that University after one year and his leadership of that section became vacant.

In 2014, an attempt was made to replace Professor Hosking with another researcher, preferably by a specialist from the University of Zululand. The reason for this choice was that by this time we appreciated some of the problems being experienced by the population of the area and felt that a researcher from UNIZULU would be especially appropriate, i.e. someone who might be more likely to be acceptable to the rural community in the study area.

When nobody accepted the study, the decision was taken to investigate the social and economic issues on our own using BSc Hydrology Honours students from UNIZULU. The process adopted was one where householders in the different sub-areas (suburbs) were interviewed and, because during daylight hours the majority of males would likely be away at work, female students were selected for the interview process because they would be dealing mostly with female residents. We believe that this was an important decision that was only fully implemented in 2015. In 2014, both male and female students conducted the interviews together, but using females only proved beneficial because they connected better with residents although each interview took longer. In 2014, males had been included in the survey teams in order to provide a measure of security, however this proved to be unnecessary and only females conducted the interviews in 2015.

6.2 INTRODUCTION TO THE SOCIO-ECONOMIC STUDY

The Maputaland Coastal Plain (MCP) is internationally known for its distinct geological history, unique social system, rich biodiversity, diverse ecosystems, and internationally recognized wetlands. The KwaZulu-Natal Province, within which the MCP is located, has the highest percentage of wetland areas per province area, as well as the second highest wetland surface area (hectares) in South Africa.

Grundling et al. (2013) stated that "The aeolian sands of the Maputaland Coastal Plain are leached and low in nutrients, resulting in low agricultural potential (Watkeys et al., 1993), so local communities heavily rely on wetlands for their daily livelihood, especially on peat-dominated wetlands such as swamp forests (Grundling, 2000; Sliva J (2004). However, significant land-use pressures occur from both cultivation and forest plantations (Grundling et al., 1998) that affect both permanent wetlands (including swamp forests) and the temporary sedge/moist grassland wetlands on the MCP, while urbanisation impacts wetlands, for example, through infrastructure development (Cuperus et al., 1999)".

6.3 UMKHANYAKUDE DISTRICT MUNICIPALITY

The uMkhanyakude District Municipality borders the Zululand District Municipality and Swaziland to the west, Mozambique to the north, uThungulu District Municipality to the south and the Indian Ocean to the east. It is made up of five Local Municipalities and a District Management area (KZD27), constituting the jurisdiction of the District Municipality. The local municipalities within uMkhanyakude District Municipality are Jozini and uMhlabuyalingana in the north; Big 5 False Bay in the centre; and Hlabisa and Mtubatuba in the south. KZD27 has a number of nature reserves such as Hluhluwe-Umfolozi, and Ndumo. The main towns in the Umhlabuyalingana Local Municipality are Manguzi, Mboza, Mseleni, Sikhemelele and Mbazwana, which is in the catchment area of this study.

The District Municipality is largely rural although it does have a number of these small towns. It is characterized by commercial agriculture in the form of sugarcane, timber, cotton, sisal, and pineapples to the west but commercial agriculture constitutes only 2% of the total agricultural area of 275 km^2. The District Municipality is also a Water Service Provider (WSP) for the bulk and retail supply in others areas. External bulk WSPs include Mhlathuze Water and the Water Service Authority (WSA).

Tourism very largely drives the economy of the District because of the presence of several nature reserves. The total human population in the district was estimated at 503,874 people in 2011 with a total area of 12,819 km^2, indicating a low population density. However, this low population density arranged in small rural settlement clusters causes problems with regard to the provision of services. The reason for this is that these services are expensive in terms of the provision of capital infrastructure as well as high operational and maintenance costs due to the large distances that have to be covered and the relatively poor road infrastructure that results in the necessity to use 4X4 vehicles in many areas.

The uMhlabuyalingana Local Municipality is located in northern KwaZulu-Natal near the border of Mozambique to the north, Indian Ocean to the east, Jozini Municipality to the west and the Big Five False Bay Municipality to the south. It is 99% rural with its population spread among 17 municipal wards and 4 traditional councils such as Mashabane, Tembe, Zikhali and Mabaso. It has a total area of 3,621 km^2 and a population of 156,735 people, with an average household density of five people per household (STATSSA 2011). The population increased by 11.2% between 2001 and 2011. The current population growth is estimated by STATSSA at 0.3% per annum. The area has numerous informal settlements and approximately 60% of the area falls under the Traditional Authority Ownership and 40% commercial farms and conservation areas. About 50% of the dwellings are traditional.

The government has found it necessary to prioritise short-term developments but this is unfortunately to the detriment of long term and more sustainable developments. This in turn has resulted in less protection of sensitive environments (Porter and Clark, 2012). The relationship between the local resident communities and the conservation agencies is insufficient for the protection by local communities of the region's highly sensitive environment. The region is threatened by developmental as well as other forms of human pressures. Degradation of wetlands and terrestrial ecosystems are likely to impact on the estuary and the coastal environment.

The use of inappropriate wastewater disposal options, such as soak-aways, in areas surrounding the estuary and coastal lakes can result in contamination and eutrophication of these water resources. Commercial forestry in the catchments are reducing freshwater flow to the estuarine system as well (Rawlins and Kelbe, 1998) and the laws protecting these environments are not sufficiently strictly enforced for socio-political and socio-economic reasons.

Because South Africa is party to the World Heritage Convention, the government has an obligation to ensure that the identification, protection, conservation and transmission of the Cultural and Natural Heritage resources of the iSimangaliso Wetland Park to future generations is achieved. Since the ecological function of the aquatic systems is water quality dependent, there is a need to determine the status of the water quality in the Mgobezeleni Catchment and to determine the threshold levels of adverse anthropogenic impacts.

6.4 HISTORICAL BACKGROUND

During the socio-economic survey work undertaken in 2014/15 with students from the Hydrology Department of the University of Zululand, the rapid growth of the population was especially obvious because of one sees new house construction as a very common sight. This throws some doubt into the STATSSA (2011) population growth estimate of 0.3%

During the field surveys with students, one of the questions put to the respondents during the survey was "Where do you come from?". In every case, the response was "Local". In order to attempt an explanation for this response, an examination of historical social issues was undertaken.

Maputaland was occupied by humans from the early Stone Age. Three occupational sites of the Acheulean dating between 500 000 and one million years B.P, were identified in St. Lucia Wetland Park (Avery 1980). People of the Middle and Late Stone Age cultures have inhabited the Maputaland area since the last Interglacial, for 1.1 million years (Beaumont et al., 1978). The area was inhabited by precolonial agriculturists in the early (250-100 AD) and late (1000-1 840 AD) Iron Age periods and they occupied sites along the coastline as early as 1600 years ago, where they cut their fields while living in the coastal forests (Bruton et al., 1980). In the early nineteenth century, the area was occupied by Zulu-speaking Nguni tribes on the south with the Tembe-Thonga people in the north (Ross 1999). But, the prevalence of malaria and the cattle disease trypanosomiasis caused by the tsetse fly *Glossina*, resulted in extensive areas of Maputaland to be uninhabited (Bruton et al., 1980).

During the colonial period, the area was visited by hunters, traders and later missionaries (Bruton et al., 1980). In the recent past, many refugees from Mozambique crossed the international border and settled in the area (Kloppers 2004). Their sites are protected by National Heritage Legislation.

The present African inhabitants of the Mgobezeleni area are mainly Tembe-Thonga people. Their oral history and culture dates back many centuries. They are believed to have migrated from Karanga in Zimbabwe in the middle of the seventeenth century (Junod, 1962). They migrated as African societies of southeast Africa and emerged locally from long established communities of diverse origins and diverse cultures and languages (Maggs, 1989). Chief Tembe was in control in the Delagoa Bay (Maputo Bay) hinterland in the mid-16th century (Wright & Hamilton 1989, Kuper 1997). The Chief and his followers gradually established their authority over the people who lived in the area. In the early 1800s, the area of the Tembe-Thonga people stretched from the Maputo River in the west to the Indian Ocean in the east, and from Delagoa Bay in the north to as far south as Lake St. Lucia (Felgate 1982). However, during 1875 an international border was imposed between South Africa and Mozambique resulting in bisecting the areas where the Tembe-Thonga people were originally settled. Kloppers (2005) described how the southern Mozambique/South Africa borderland is a landscape epitomised by fluctuation, contradiction and constant transformation. “It is a world betwixt-and-between Mozambique and South Africa. The international border, imposed on the landscape more than a century ago, gives life to a new world that stretches across and away from it. The inhabitants of this transitional zone constantly shape and reshape their own identities vis-à-vis people on the opposite as well as on the same side of the border”.

By the end of the Mozambican War in 1992, the northern side of the borderland was populated by displaced refugees, demobilised soldiers and bandits, as well as returnees from neighbouring countries. Many of these people did not have any ancestral ties to the land nor kinship ties to its earlier inhabitants. Whereas a common Thonga identity had previously united people on both sides of the 1875 border, South African policies of apartheid increasingly promoted the Zulu language and culture on the southern side of the border. This situation is the likely reason that most of the persons questioned during the field surveys in 2014 and 2015 to state that they were “locals”.

6.5 RECENT BACKGROUND

In the mid-1960s Sodwana was totally undeveloped. Taylor (2013) wrote, "Pooley (1980) described it as a small game-guard outpost seldom visited by holidaymakers. The Mbazwana plantation was being developed in the mid-1960s – which attracted workers into the area around Mbazwana. Aerial photos from 1965 show partly planted plantations. In the early 1970s, the civil war developed in Mozambique causing the South African holidaymakers to stop going there. They wanted to be able to go to a tropical beach in South Africa. To cater for this need the then Natal Parks Board developed the campsites at Sodwana. The bridge across the Mgobezeleni estuary was first built in 1971 – this blocked the estuary and was rebuilt in 1977 (Bruton 1980). Prior to the bridge being there, access to Sodwana was along a track that went south of Mgobezeleni. Water for the camp was taken from Lake Mgobezeleni. This camp catered for the growing offshore ski-boat recreational fishery (Initially there was no scuba diving).

At this stage, there was no development away from Sodwana and few rural people were living in the Mgobezeleni catchment area. The development of a missile-testing site at Hells Gate in St Lucia had an influence. The test-range was extended to north of Bhangazi-North and residents within the range were moved out. It is not known how many of these moved into the Mgobezeleni catchment. The missile testing started in 1968, but people were only moved from the Ozabeni area some years later (about 1974-76) when the range was expanded. Gaisford (*Pers com.* 2013) remembers that when he was based at Sodwana in 1974 “there were hardly any muzis (settlements) between Mbazwana and Sodwana, "if I remember correctly there were quite a few between Shazibe lake and Sibaya – but they were widely spread out”. Bruton (1980) quotes an undated Natal Parks Board report from about that time which said that 416 people lived in the Mgobezeleni Catchment. Taylor (unpublished NPB document) reported that, based on the analysis of the 1999 aerial photography, there were a total of 470 homesteads, consisting of 1192 huts, in the catchment area (Note – this was a smaller catchment area than is currently used). Of these 16 homesteads were within the present park boundary. The number of people in the catchment area was not known – but by assuming a figure of five per hut (possibly an underestimate), then there were approximately 6000 people living in the Mgobezeleni catchment area. This number has increased very rapidly in the past 20 years". Other people who were involved in projects in the area before and after 1980 confirm that there were very few residents in the area (Mr. J. Hughes – Forester during the development of the plantations (Pers. Com.); Prof R. Hart, Pers. Com. – Officer-in-charge Research Station at Lake Sibaya).

The foregoing data supplied by Taylor (2013) are the best that are available to assess the population at the time the socio-economic component of this present project started in 2013, and to calculate the possible population 20 years later (2035). Using these data the population expansion was estimated by extrapolation. These results are shown in Figure 133. While these data are no more than a calculation of possible numbers into the future, they provide what may be a "worst case" scenario. Worst case because the early growth rate was in response to a potential caused by a number of factors coming together, which provided opportunities that are probably unlikely to continue into the future. In order to check this number, population data from Statistics South Africa (STATSSA) 2011 census were accessed (Frith 2014). This showed the number to be 13850 and an increase in that population number of 10% pa from the STATSSA 2011 data projects to 15,389 in 2015. The STATSSA data included information for all the suburban areas of Mbazwana as shown in Figure 134.

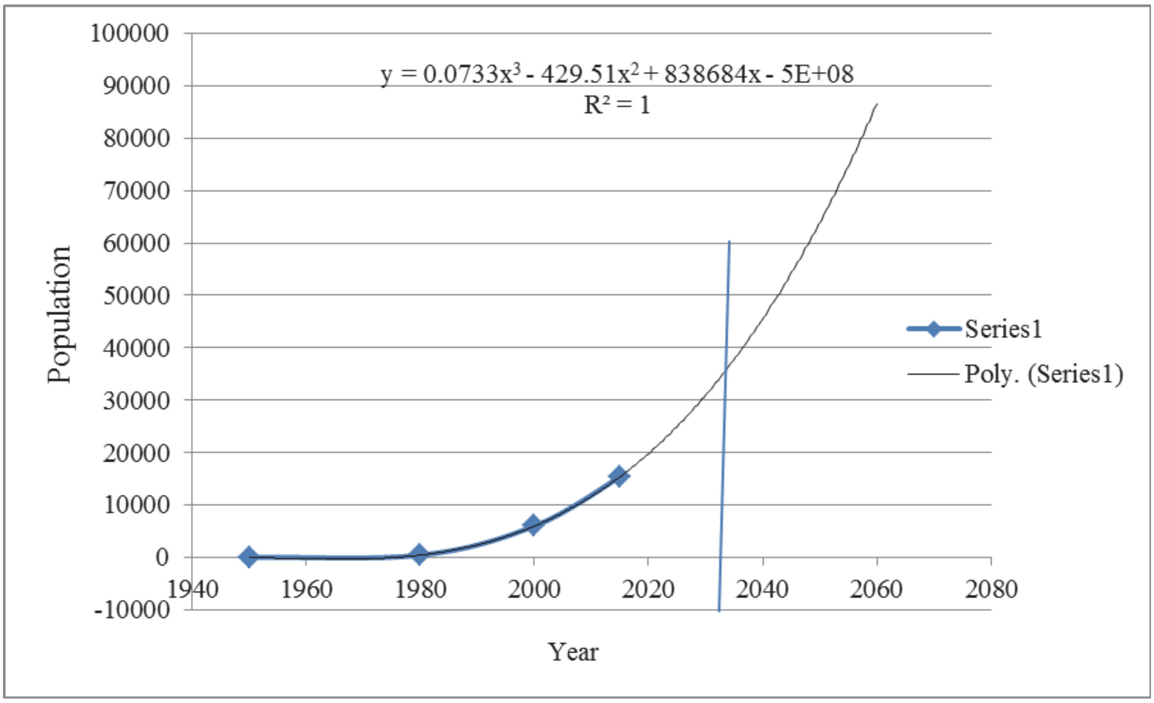


Figure 133. Illustration of the potential population growth by 2030-35 using the early (before 2015) population number increase.

Figure 134 shows that not the whole area considered by STATSSA falls within the catchment boundary. Hence, the effective population having an influence on the groundwater quality in the catchment is slightly less than that estimated by using either of the data sets.

Figure 134. The areas (suburbs) of Mbazwana used as places in which to allocate the population in the STATSSA 2011 data set. The outlined in black is the Mgobezeleni catchment area used in this project. North of Mbazwana is Hagaza (not shown) and between and Qondwane is the small area of Esiphaleni.

6.6 HOUSEHOLD SURVEYS

In 2014 and 2015, students from the Hydrology Department of the University of Zululand participated in a household survey in which the respondents were questioned about the number of residents in each household, the water supply available to them and the sewage facilities.

The teams of students were required to visit each house on an allocated track (Figure 135) and interview the householders (if they were available at the time) and collect data from a predetermined set of questions. At the same time, they had to collect water samples (borehole, tap water, etc.) and take the GPS coordinates of each household.

6.7 POPULATION SURVEYS IN THE MGOBEZELENI AREA

In the 2014 individual housing survey, the questions included the following:

- Number of persons in each dwelling
- Number of children

- Waste management
- Water supply (Tap, borehole, roof, stream, tank)
- Borehole water availability
- Latrine system used (Septic tank, VIP, Pit, bush)
- Livestock numbers (Cattle, chickens, dogs)
- House building (Estimate of expansion, how many new buildings were under construction).

Figure 135. Example of a track (yellow line with red points) allocated to students in the catchment area of the catchment.

The results of the 2014 survey are shown in Table 42a to 42d.

The geographic coordinates were to be noted but in 2014 students forgot to collect all and some numbers were transposed, which resulted in the loss of some geo-referenced data.

The data from these surveys are shown in Table 41.

An aspect of interest with respect to the tap-water users was that in many cases the water flowed out of the taps so slowly that it was stored in drums open to the air. Chickens, birds and dust then contaminated the water. Unfortunately, because we had not anticipated this, no water samples were collected from the drums or taps during the initial survey. This was corrected in during the 2015 survey.

The primary objectives of the subsequent questionnaires used in the 2015 study was that it aimed to acquire information related the information in the Box.

- Quantity of water available compared to:
- Water requirements
- Use to which water was being put
- Water supply means (river, tap, borehole, roof, etc.)
- Number of persons in the household
- Breakdown of adults and children
- Whether residents were working or on pension
- Gardening activities (and where)
- Animals being supported.

These data show that 382 persons in 62 households were included in the survey of whom 76% were adults. There were about 1.5 children aged less than 5 years in each household. Tap water was available to 45% of the homes and 34% had access to their own borehole but 20% of households had to buy their water.

The percentage of households using borehole water was similar between the 2014 and 2015 sampling surveys (15-21%). The use of tap water was substantially different, however, which supports the suggestion that there was a recent rapid rise in the local population, the growth of which has out-stripped the tap water supply facilities built earlier.

Table 41. Results of the Mgobezeleni project household survey undertaken in 2014.

Area	Total	Adults	Children < 5 yr.	House holds	BH water	Tap water	Buy water	Septic Tank users	VIP/Long drops	Bush
Mbazwana	201	149	52	26	2	21	3	12	18	-
Qondwana	93	71	22	18	12	4	2	11	5	14
Thungwini	88	72	16	18	7	3	8	7	10	Nil
TOTAL	382	292	90	62	21	28	13	30	33	14

An example of a hand-operated borehole that is referenced in Table 42 is shown in Figure 136.

Figure 136. Private hand-operated borehole water pump.

Table 42. Results of the Mgobezeleni project household survey undertaken in 2015.

(a) Water data

Answers from 54 houses	Number	(%)
Use Tap Water from Mbazwana	35	65
Use Borehole Water	8	15
Use some rain water	7	13
Have enough water	2	4
Daily water use	112	litres
Daily water needs (l)	167	litres
% Daily water needed		65
Have to buy water	11	17
Have electricity	20	37

(b) Toilet data

Answers from 54 houses	Number	%
Own their home	51	94
Rented house	0	0
Built their own home	50	93
No of families in the house	1	-
No adults > 5 yrs	224	71
No children < 5 yrs	90	29
No children per household	-	1.7
Have a septic tank	3	6
Have a VIP	26	48
Have a Long Drop	11	20
Use the bush	13	24
Neighbour's toilet	2	4

(Sample size 224 adults and 312 total population surveyed).

(c) Family data

Father is Head of family (%)	54
Mother is head of family (%)	29
Grandparent is head of family (%)	13
Son is head of family (%)	6
Daughter is head of family (%)	2
Nobody is head of family (%)	2
Head of family works (%)	27
Number receiving a pension (%)	23
Other workers in the household (%)	13
Local people (Adults) (%)	100
Have a car (%)	26
Have a bakkie (%)	4
Use the bus (%)	0
Use a taxi (%)	74

(d) Crop data

Grow vegetables (%)	48
Where (Yard)(%)	98
Where (River)	1
Fertilizer NPK (%)	12
Fertilizer Cow (%)	58
Other (%)	10
Pesticides	0
Irrigate (%)	44
River (%)	1
Cows	34
Chickens	293
Goats	1
Cats	14
Dogs	34
Telephone (%)	76

In a study undertaken in an informal settlement in the greater Durban Metropolitan area by Smith et al. (2004), there were 300 respondents (50% male) and the results indicated that 37% of the households had access to tap water, but 20% had to buy water. These percentages are relatively similar to the data collected in the Mgobezeleni study, but the conditions under which the informal settlement people were living are completely different. In the Mgobezeleni survey, the people were not living in the extremely cramped conditions of an urban settlement and their housing facilities were unquestionably much superior. All houses in Mgobezeleni are freestanding with plenty of surrounding space for children to play. Although some of the houses were built with stone and poles with galvanized iron roofs, in many instances it was possible to feel that this was temporary because cement bricks were being manufactured nearby, presumably for the purpose of constructing new housing. This conclusion is supported by the data in Table 42(b) where respondents maintained that 93% of homes were self-built. At the same time, many houses appeared to be architecturally designed and built with concrete brick and mortar with plastered walls. So while the living conditions at Mgobezeleni appear at times to be distinctly rural, the way of life must be infinitely better than for those who have migrated to the cities.

Smith et al. (2004) from the USA undertook research in a Durban KZN, informal settlement community to identify sanitation needs and available water. Team members from nursing and health facilities focused on those conditions that resulted from lack of access to safe water, disease transmission from poor sanitation habits. The research posed questions to the heads of households, both male (58%) and female (42%). Most of those participating only had access to pit latrines and community standpipes, but 20% had no access to a latrine. In Mgobezeleni, the number of households without a latrine was 24% (used the bush). This is a surprisingly similar percentage and suggests that there might be a number of questions that might be asked about attitude.

The results of the project (Smith, 2004 in Table 43) indicated that there was a link between sanitation and community health. In this link, water was identified as a critical element of sanitation, hygiene and health. While a link between water supplies and health was not studied specifically in this project, there can be no reason to think that the same situation does not apply to residents in Mgobezeleni.

Table 43. Information collected from an informal settlement in Durban in 2004 (Smith et al., 2004)

Sanitary facilities		
Variable	n	%
Pit latrine	120	40
No toilets	52	17
Community toilet	42	14
Bush/trees	25	8
Private outside flush toilet	17	6
Private in-house flush toilet	5	2
Other	32	11
Not answered	6	2

Source of drinking water		
Variable	n	%
Communal standpipe	112	37
Buy water	60	2
Yard tank	51	17
In-house connection	3	1
Other (river, stream, etc.)	48	16
Private yard tap	21	7
Roof tank	3	1
Missing	2	0.7

In 2015, the socio-economic study was expanded to examine;

- Tourism in the Mgobezeleni area
- A project examining the water treatment works in Mbazwana.
- A project examining the water treatment works at the Ezemvelo Camp
- The main Mbazwana water supply situation to the various communities

6.8 TOURISM IN THE MGOBEZELENI AREA

While surveying the households in which local inhabitants were living, it became apparent that while their numbers in 2015 might be about 15 000 the number of people visiting the area annually for vacation purposes might well raise the total number of toilet visits substantially and thus the amount of N and P entering the groundwater in the catchment. There are two main areas where visitors stay during visits to the area. The Sodwana Camp area run by EKZN Wildlife has both camping sites and cottages. In addition to those, Bed and Breakfast facilities, hotel accommodation and private camping and caravanning facilities were established widely throughout the area south of the Mbazwana plantations.

Because it would be impossible to obtain an accurate estimate of the numbers of people who visit the area annually due to variability, seasonality and reluctance of owners to provide data, the approach taken was to examine the facilities available on the internet and to estimate the number based on the number of beds available and then apply a factor relating to the annual rate of occupation. In this way, the data shown in Table 44 were accumulated.

On the site http://www.kznwildlife.com/sodwana-camping-and-caravaning.html, the following information is provided:

- Sodwana Bay with its many exciting coral reefs and outstanding climate, has distinguished itself as one of the premier sport diving destinations in the world.
- Many popular dive sites with a great diversity of underwater seascapes and marine flora and fauna, corals, beautiful overhangs, drop-offs and mushroom rocks, as well as spectacular night dives have made this place a not-to-be-missed destination for the scuba diving enthusiast.
- Scuba diving equipment is available for hire.
- Sodwana Bay camp grounds feature 413 open space campsites that accommodate both caravans and tents, set into shady surroundings in the coastal forest.
- Campsites have shared cold-water taps and barbecue facilities.
- A number of campsites feature electrical plug points.
- The ablution facilities provide hot and cold running water, flush toilets, showers, and baths, dishwashing, and laundry facilities.

Table 44. Name of accommodation facility, the number of advertised beds, the number of available annually, the location of the facility and the web source of information for holiday resorts in the Mgobezeleni, Sodwana Bay Area.

Accommodation name	Advertised beds	Coordinates	Coordinates	Info Source
A Day in Africa	24	-27.51666	32.65779	sodwanabay.com
Bheka Phandle	15	-27.52527	32.64178	Personal visit
Blue Eye Inn	6	-27.51363	32.65550	www.sodwanabay.com/advertisers/blue-eye-inn.html
Camp Jonathan	96	-27.51439	32.65543	www.booking.com
Crafters Lodge	12	-27.51475	32.65538	www.crafterslodge.co.za
Dinango Lodge	14	-27.49707	32.58290	http://www.dinangolodge.co.za/dinango-lodge.html
Flat Cat	62	-27.51294	32.64475	flatcat.co.za
Inkwazi Beach Camp	35	-27.51443	32.65727	https://www.accommodirect.com/
Librodi lodge	8	-27.51455	32.65883	http://www.sodwanabay.com/advertisers/librodi-lodge.html
Mafuta's Khaya	26	-27.51456	32.59521	Sodwanabay.com
Natural Moments Bush Camp	66	-27.51465	32.65807	www.divesodwana.com/
Nemo Diving Charters	72	-27.51719	32.60687	wwwq.nemodiving.com
Nwabu Lodge	40	-27.51317	32.62106	www.sodwanabay.com/advertisers/nwabu-lodge.htm
Reefteach Lodge	28	-27.50708	32.65450	www.reefteach.co.za/
Seavarkie Guest House	18	-27.51916	32.62885	Sodwanabay.com
Shayamoya Lodge	8	-27.52396	32.64362	Personal visit
Sodwana Bay Lodge	600	-27.51275	32.66039	Main office
Sodwana Road Lodge	30	-27.50244	32.59112	Sodwanabay.com
Sunsets	4	-27.51442	32.65728	Sodwanabay.com
The Ditch Bush Camp	17	-27.47825	32.56590	Sodwanabay.com
Triton Dive Lodge	52	-27.49525	32.59718	Sodwanabay.com
Villa Villion	6	-27.51528	32.65452	Sodwanabay.com
Vis-Agies	28	-27.51343	32.65551	www.sodwana-accommodation.co.za
Viskoors	4	-27.51842	32.65781	www.viskoors.
Total beds	1271			
Bed Days per annum	463915			@20% occupancy this = 92783
Outside the Mgobezeleni Catchment				
Sodwana Bay Resort Chalets	132			KZNParks.com
Gwalagwala Camping & Caravaning	2100			http://www.kznwildlife.com/about-sodwana-campsite.html
" Electrified sites	66			
Coral Divers	?			www.coraldivers.co.za/
Sea Escapes	62			
Total beds	2360	861400		
Total Bed Days per annum	861400	861400		@ 20% Occupancy this = 265,063

A smaller, more modern camping area is available with 33 electrified campsites that can take caravans or tents, each with their own barbecue, electric lights, running water and modem communal ablution blocks.

Freezer and refrigeration facilities are also available.

The conclusion reached from the data provided in Table 44 is that there are a great number of potential spaces for tourists in the Sodwana area and that much of the trading activity that is associated with those spaces will be positioned within the area where people will access toilets, i.e. shops and restaurants. This implies that the total of N and P entering the groundwater is likely one to two orders of magnitude greater than would be entering from the estimated 15,000 permanent residents of the area.

The Water Treatment Works for the Ezemvelo KZN Camp

Water for the large camp within Ezemvelo KZN facility at Sodwana comes from Lake Mgobezeleni. The water is drawn from the lake by a pump located at the Jetty (-27.53507, 032.660224) on the south of the lake. At one stage, the inlet pipe used to be held off the bottom by means of a floatation device but this has recently been removed and the pump draws in material from the sediment surface that has settled out of the water column. From the intake, the water is pumped to a reservoir located near the main office area of the facility (-27.548351, 032.666021). From the storage reservoir, water is pumped into a tank with a conical bottom (see Fig FFF) where chemicals are added to cause the flocculation of particles. This is a batch process. Once the process of flocculation is complete, the flocculated material is discharged to waste (into the trees). The water is then chlorinated and pumped to a large high-level reservoir (-27.550761, 032.674370) from where it is distributed by gravity to users.

In the section on microalgae, reference was made to the potential toxicity of the cyanophyte microalgae in Lake Mgobezeleni. This aspect needs to be taken seriously to ensure the safety of the visitors to the facility and tests should be made on a regular basis to check for species, microalgal cell densities and microalgal biomass. These parameters are all useful indicators of the direction the microalgal population is heading.

A project examining the water treatment works and supply to Mbazwana.

Buthelezi Musawenkosi Zomokwakhe Student number: 201123463.

A hydrological assessment of the Mbazwana water treatment plant. Sources, Quantity and Quality.

(The contents of this student project are summarized here rather than produced in full in the interests of saving space).

In South Africa, in terms of the National Water Act, there is a minimum amount of water that has to be made available for domestic use and these standards determine the amounts that each municipal water works use for their supply criteria.

The local source for the town of Mbazwana is Lake Sibaya where there is a pump station. The pipeline from the lake to the water treatment works is 12.5 km.

The operation of pumping the water was sub-contracted to WSSA (Water Services South Africa). Who have their extraction point at the coordinates -27.419671 032.696755.

The water is extracted and pumped to the Mbazwana Water Treatment Works using electric pumps along a 250 mm Ø PVC pipeline. There is a second older (auxiliary) diesel pump and 150 mm Ø pipeline but this line no longer has the capability to deliver water to the town due to “operational challenges”.

In last 5 years (2010 to 2015), the area supplied by the WTW has increased significantly. The increase is attributed to the growing number of informal settlements as well as an increase in business enterprises, all of whom require an additional water supply. With the declining volume of lake water in the last five years, there are inevitable challenges in terms of adequate water for registered users. Between 1997 and 2002 the water level in the lake varied between 18.2 m and 20.4 m amsl (Meyer and Godfrey 1995). From that time, the level has steadily declined to 16.6 m amsl (Weitz and Demile 2013).

The local inhabitants complain about inadequate supplies of water and accuse the Water Treatment Works for the situation. However, at least part of the problem is the serious drought being experienced in the whole of South Africa. Northern KZN is also in the grip of a serious drought that has caused the level of the water in Lake Sibaya to drop. This drop was so severe that by August 2015 it was necessary to relocate the intake position at Lake Sibaya. Figure 137 shows the “before and after” intake positions at Lake Sibaya.

In the last 5 years to 2015, the area supplied with water has increased. The increase is attributed to the growing number of informal settlements as well as business enterprises that all require additional water. With the declining volume of water in the last five years, there are inevitable challenges in terms of adequate water for registered users.

In October 2015, the Mbazwana water treatment plant supplied consumers in the following areas; Mbazwana Township; Hagaza, Esiphahleni, Uqongwana, Othugweni, Mntanenkosi, Oqondwani, Mphakathini, and Mbube villages and, while there is no known water services backlog in the area, it is estimated that a large portion of the population in this rural area do not have adequate access to free basic water (UMkhanyakude DM, WSDP, 2007).

There are no major water quality problems at the Mbazwana water treatment works. This is because the water quality in Lake Sibaya is naturally good and there are no reported water quality problems associated with the it (Table 45).

The recorded data for raw water that the works receive from the source was used to determine how much of water the plant had receive per day for the previous seven months and data for the final water supplied for the same 7 months was also taken to be able to estimate how much water they supply to the community. All the data was recoded with the use of flow meter readings in the plant.

The concentrations of phosphate, nitrates and nitrite were obtained using water samples that were collected from Lake Sibaya followed chemical laboratory analysis.

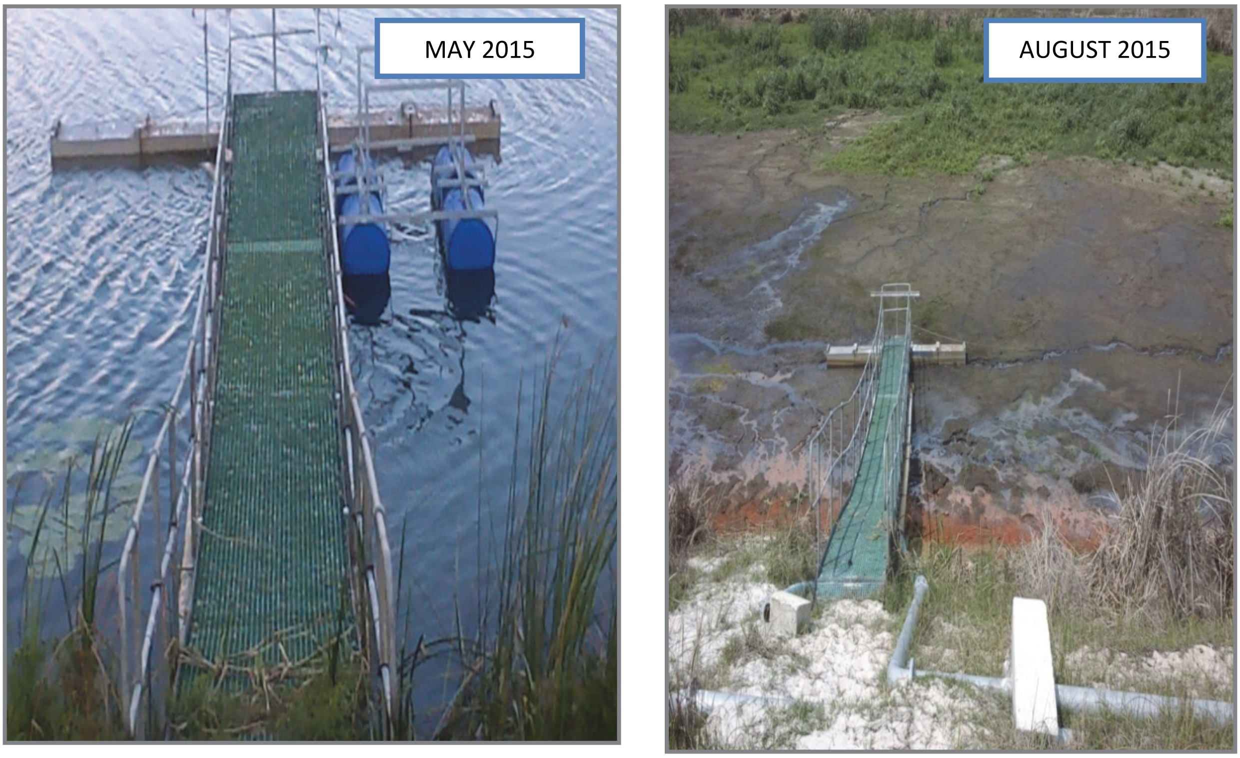


Figure 137. (a) Water extraction from Lake Sibaya showing water level in May 2015 and (b) three months later when there was very little water to extract. It was necessary to reposition the intake.

Table 45. Levels of nitrogen and phosphate (mg l^{-1}) in samples from the pump station at Lake Sibaya and at the water treatment works.

Site	Nitrate	Nitrite	Phosphate
Pump station	<0.35	0.10	<0.03
Raw water received	<0.35	<0.01	<0.03
Final water	<0.35	<0.01	<0.03
Reservoir	<0.400	<0.01	<0.03

The water treatment plant performs numerous physio-chemical treatment processes that can be examined into several phases. The first involves measuring the amount arriving from Lake Sibaya. This is achieved using flow meters reading before the raw water is delivered to the three sedimentation tanks. In the second phase, water is sucked from the sedimentation tanks by vacuum using a pipe connected to all five sand filters that back wash automatically every four hours. The three large sand filtration tanks backwash for ninety minutes each while the two smaller ones take one hour to backwash (Figure 138).

Figure 138. View of the three water sedimentation tanks at the Mbazwana WTW and the five sand filters used in the early treatment process.

Water that is used to backwash the sand/dirt from the filters is not measured. The plant operators mentioned that the sand filters use a lot of water when backwashing. An example of the effectiveness of the WTW is shown in Figure 139. The effective recovery of water from this process is shown in Figure 140 and demonstrates that there is a big wastage of water at this stage in the whole process.

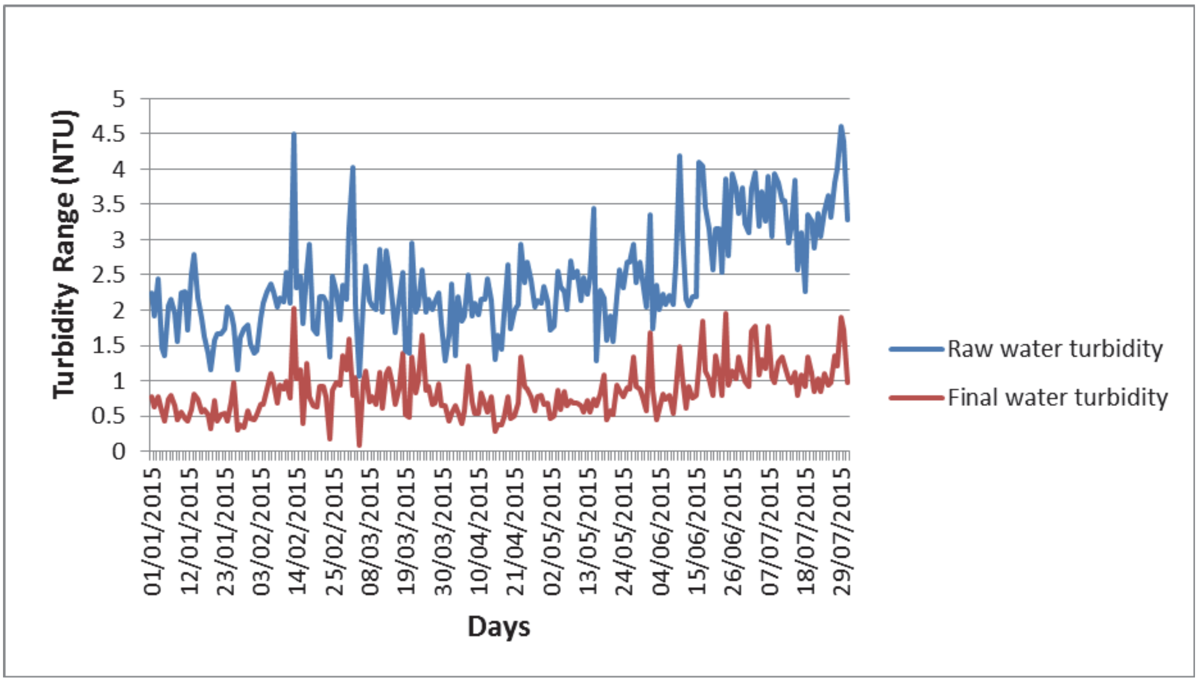


Figure 139. Turbidity of the water before and after settlement and sand filtration in the Mbazwana WTW.

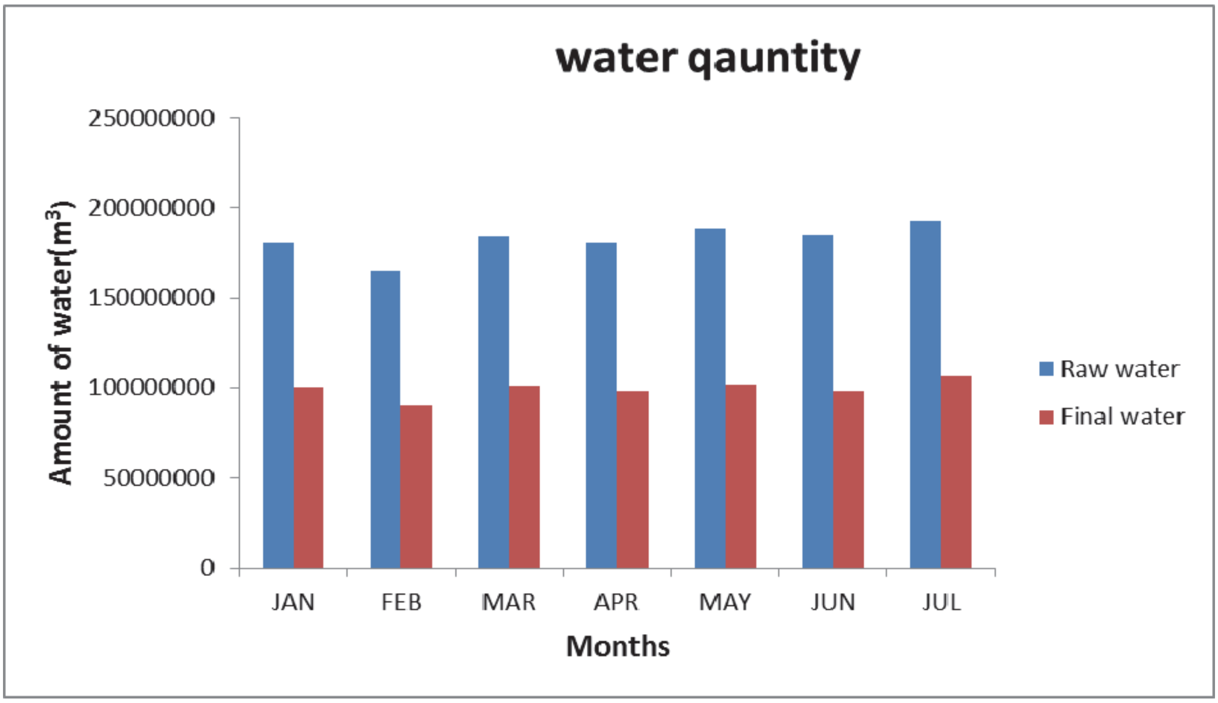


Figure 140. Amount of water that the WTW plant receives and the amount that is supplied to Mbazwana users. (Daily data for 7 months in 2015 was used to assess the raw water (natural water from the lake) and final water (treated water) leaving the Mbazwana Water Treatment Works.

Lake Sibaya does not have enough water to cater for all water users currently in Mbazwana. The water level in the lake is now below sea level and so seawater might move into the Lake. If this were to happen, it will no longer be suitable as a source.

The water for domestic use that is treated by the Mbazwana WTW at its existing capacity is not adequate to meet the water requirements of both the township and the sounding rural areas. The evidence for this is that there are areas of supply, which are no longer getting water from their taps. This is possibly because there are a number of illegal connections to the main pipes supplying water to those areas.

The current population in the town of Mbazwana is estimated to be 4321 (stats SA, census 2001/2007 community survey) and the Mbazwana WTW cannot produce the amount to supply all of this area with the increasing number of people. From this, it is clear that the water service need to be increased in order to meet the demand.

Economic characteristics of the Mbazwana area

Mbazwana is a rural town with informal settlements and has the following main economic characteristics. Agriculture is the most common economic activity. Commercial farming and livestock production are equally common among the rural community. The agriculture is subsistence agriculture that is mostly for household use and thus has limited contribution to the economy of the area. There are obstacles currently facing the agricultural sector, such as limited access to water despite an apparent abundance of natural resources; poorly developed access roads to agricultural production areas, as well as to internal and external markets. Despite these problems, agro-industry has the potential to increasing the economic growth of the area (UMkhanyakude DM, WSDP, 2007).

There are hotel accommodation facilities in the town, as well as a number of shops and restaurants to serve the many tourists that visit the area.

There are many tourist attractions and especially wildlife ones such as the hippos, crocodiles and birds in Lake Sibaya. There are also natural forests and heritage sites in the neighbourhood of Mbazwana and surrounding areas, which provide an important economic facility around the town that was growing over the last number of years.

The vegetation of Maputaland was in a very good condition in the early 1950s and the residents lived in harmony with their surroundings (Moll, 1980). However, after 1950 there were a number of development projects that threatened the survival of the vegetation. The Governor of the Cape colony who brought the tree seeds from Mauritius introduced the first Eucalyptus trees into South Africa in 1828 (Coppen 2002). In 1953 the use of eucalyptus was recognised in Maputaland and today the these trees are mainly grown for pulp production for paper manufacturing (Meadows, 1999). In 1958, the Department of Forestry started an extensive Pine afforestation programme and by 1980, over 17,395 ha of plantation were established (Bruton, Smith & Taylor 1980).

There is a need to develop the water service infrastructure in the area and there is a need for additional water sources such as Pongolapoort Dam to supplement the existing water supply. There is potential for increasing the exploration and drilling of more communal boreholes and there is a need to improve the water supply infrastructures to areas currently not mapped. There is also a need to improve housing infrastructures to harvest rainwater.

6.9 GENERAL DISCUSSION

Bearing in mind that information found on the internet is not always 100% accurate, the following aspects are considered relevant to the present socio-economic situation in the Mgobezeleni catchment.

6.9.1 Extract (1) from the internet (dated 2001) is relevant.

https://en.wikipedia.org/wiki/Water_supply_and_sanitation_in_South_Africa#Water)

Free basic water policy (2001)

Durban was the first South African city to introduce a policy of free basic water in 1998. After Thabo Mbeki became President of South Africa in 1999 and a cholera outbreak occurred in 2000, the African National Congress promised free basic water during a municipal election campaign in December 2000. In July 2001 free basic water became a national policy through a revised tariff structure that included at least 6 "kilolitres" (cubic metres) of free water per month (40 litre capita^{-1} day for a family of five or 25 litre capita^{-1} day for a family of eight). The policy was implemented gradually within the means of each municipality.

It would seem that this policy was not implemented in Mbazwana.

6.9.2 Extract 2 from the internet

http://12.000.scripts.mit.edu/mission2017/case-studies/water-access-in-south-africa/

South Africa has a population of 51 million people with 60 percent of the population living in urban environments and 40 percent living in rural settlements. Currently, South Africa has access to surface water (77 percent of total use), groundwater (9 percent of total use), and recycled water (14 percent of total use). However, the population's dependence on water is not evenly distributed. Due to a lack of water infrastructure in rural settlements, 74 percent of all rural people are entirely dependent upon groundwater (i.e. local wells and pumps). On the other hand, cities with universal water distribution systems get most of their water from surface sources like the Limpopo and Komati rivers. Due to immigration and population growth, growth in rural settlements is putting stress on South Africa's water supply. Currently, 19 percent of the rural population lacks access to a reliable water supply and 33 percent do not have basic sanitation services. While rural citizens suffer the most, over 26 percent of all schools (urban or rural), and 45 percent of clinics, have no water access either. (UN Water. Water a Shared Responsibility (2006).

6.9.3 Extract 3.

Retrieved from:

http://unesdoc.unesco.org/images/0014/001454/145405e.pdf#page=519

Currently, South Africa has a policy called Free Basic Water Access. According to the South African Constitution every citizen is entitled to a certain amount of water regardless of his ability to pay for it; this policy defines the amount of entitlement be 6000 litres per household per month. However, the organization in charge of water allocation, the South African Department of Water Affairs and Forestry (SADWAF), is ineffective at determining what amount of water people use per month in rural areas where there is a lack monitoring devices. By not monitoring water usage, SADWAF is unable to determine when a waterline has broken or how much to charge water-users when they go beyond 6000 litres a month. Because broken water lines can be traced to well over 20 percent of all "stolen" or lost water, South Africa loses much of its available water supply due to communication errors.

6.9.4 Extract 4. ACCESS TO WATER

Retrieved from:

https://www.dwa.gov.za/io/Docs/CMA/CMA%20GB%20Training%20Manuals/gbtrainingmanualchapter1.pdf

Access to water was one of the key needs identified by poor communities in 1994. Only 44,7% of South Africans households have a tap inside their dwellings. 16,7% have a tap in the yard, 19,8% fetch water from a public tap, and over 14% access water from dams, river, boreholes, rainwater or water carriers or tankers.

CHAPTER 7. RISKS, IMPACTS AND RESPONSES

The main aim of this study was to link the ecology with the hydrological state and its changes. In addition, the project has included a social assessment relating to water use – the provisioning of water to people and the impacts of human waste on nutrient levels in the water resource.

Human numbers have increased exponentially within the catchment since the 1960s. The impacts on the hydrology and ecology are largely related, either directly or indirectly, to the impacts of commercial forestry and to the increasing numbers of people living in and using the catchment. There are also impacts from beyond the catchment – due to regional and global changes. These we do not consider.

7.1 Hydrological Changes and Risks

The Mgobezeleni system is fed and sustained by groundwater that is discharged into the wetlands in a slow and persistent manner. This has provided a very reliable source of water that would not have changed substantially over decades or longer. However, there has been a significant drawdown of the groundwater below and around the commercial plantations. These plantations are expanding with the establishment of the small-scale plantations to cover a substantial proportion of the Mgobezeleni catchment. This drawdown has reduced the flow of freshwater into the system that will increase with the increasing plantations.

A confounding issue is that of inter-annual variability in rainfall. There is a high degree of natural variability in the environment – and it becomes difficult to separate what is natural and what is human-induced. However, there is evidence that anthropogenic impacts have exceeded the natural variability in the catchment.

The health of the Mgobezeleni streams, lakes and estuary is vitally important for the rural community and for the eco-tourism in the Sodwana Bay region. These water resources are fed and sustained by the persistent discharge from the groundwater catchment that extends well to the west of Sodwana and includes the urban development of Mbazwana and large commercial plantations. These developments have a significant impact on the groundwater that will ultimately propagate downstream to the rivers, lakes and estuary.

The urban sprawl around Mbazwana has many light industries that could potentially increase the level of pollution. Unfortunately, the groundwater flow rates around Mbazwana are extremely slow so the pollution could accumulate and threaten the environment many years later when it would be too difficult to rehabilitate. There is a need to establish groundwater monitoring of the water table drawdown and water quality in the Mbazwana area, particularly for LPG (Liquefied Petroleum Gas) products and heavy metals.

The average net infiltration was exceeded by the average evapotranspiration creating a slow drawdown of the aquifer storage over the past ten years. This was exacerbated by the commercial and subsistence plantations, which have had a major impact on the groundwater, particularly near Mbazwana. This drawdown would have seriously affected the wetlands, streams and rural water supply that lie within at least 2 km of the plantations. The drawdown of the groundwater storage from the plantations and woodlots has greatly exceeded the other anthropogenic actions that ultimately affect the wetlands, the stream runoff and the lake water balance.

7.2 Threats

The concept of 'Carrying Capacity' is one that is used to gain an understanding on how the impacts of the increasing pressures that humans have on the water resources and on the ecosystem. Carrying Capacity is defined as the level of impact above which there is 'overloading' causing an unacceptably high deterioration of the resources. The overload point is usually difficult to measure – but it is often very evident when it has been exceeded.

The impact of exceeding the carrying capacity can be on the natural resources – the water, soils or ecology. Alternatively, it can be on the infrastructural environment – where the infrastructure (such as water reticulation) can no longer cope with the demand. Or, it can be on the social environment – where the quality of life for the people living or using the area deteriorates. There are different sensitivities within the natural, infrastructure and social environments – and these may occur in different parts of the catchment.

To understand carrying capacity, it is first necessary to understand the threats.

The main threats to the system are:

i. The existing plantations and the possibility of an increase in plantations in the area – especially when it involves a change from pine trees to eucalyptus trees – is a concern, as it will lower the groundwater table and reduce water flow to the wetlands.

ii. There is a large demand for wetland agriculture. The number of small-scale gardens with intercropping of a number of species is increasing. However, the biggest concern is the proliferation of commercial agriculture in the wetlands. This is mainly for bananas. To farm effectively it is necessary to install large drains, which lower the water table and dries the peat. This reduces the plug effect of the peat and is likely to influence the groundwater away from the peat swamps. This will reduce wetland area as well as alter the dynamics of the estuary. It is a mandate of the conservation agencies to manage this within the iSimangaliso Wetland Park and the Municipality and the mandate of the Department of Agriculture to manage those areas outside the park.

iii. Increased agriculture in the wetlands is leading to a loss of swamp forests and sedge swamps.

iv. A lower water table will mean a reduced baseflow entering the estuary. This will cause a change in the estuary mouth-breaching regime. It is likely to breach less frequently as the baseflow decreases. An altered breaching regime will alter the nature of the estuarine ecosystem – it would be less saline and less exposed to tidal fluctuations. (At this stage not taking sea-level rise into account).

v. The increasing number of people using the catchment is likely to lead to an increase in nutrients in the groundwater. This is exacerbated by the drive to provide sanitation for all in South Africa. In the Mgobezeleni area, this is mainly in the form of pit latrines. This is an effective way to control disease; however, it effectively puts sewage nutrients into the groundwater.

vi. The demands for ecotourism are growing and the 'hotspot' for the tourism is the bay protected by Jesser point. This is also a vital area for the estuary. Conflicts between tourism and the wellbeing of the estuary will need to be managed carefully to maintain natural sediment movement processes and the functioning of the estuary mouth.

vii. Invasive alien plants and animals are a threat to the wetlands. Some are already in the system – however if there are raised nutrient levels, the susceptibility of the area to alien wetland plants will increase. Invasive water plants such as *Pistia, Eichhornia* and *Azolla* are encouraged by rising nutrient levels.

viii. Increased nutrients will increase algal populations – and potentially cyanotoxins. Increased algal densities result in difficulties in filtering water for consumption.

ix. In the dry lands the lowering of the groundwater table (such as occurs adjacent to plantations) promotes an increase in woody plants – causing the loss of grasslands and reducing grazing capacity. Many of these woody plants are invasive aliens. A lower water table also reduces agricultural capacity by drying soils.

x. There is a severe malfunctioning of the water reticulation systems in the Mgobezeleni Catchment. Partly this is due to over-use and partly due the decay of the infrastructure. Groundwater is abundant in the catchment and it is a good option to install wells with hand pumps. However, if there is commercial-level extraction of the groundwater, this could result in overuse of the resource.

The costs to society of the plantations and loss of water quality need to be properly analysed. There are costs associated with wells drying up and the deepening of wells. The increased costs of water filtration as algal populations increase may be severe. As cyanobacteria increase – so there is a risk of cyanotoxicity and bad taste to the water reducing the value of water resources. As nutrient levels rise, so the risks of waterborne diseases increase as the water become eutrophic. In addition, there are large costs associated with the management of invasive plants that are a response to increased nutrient levels.

7.3 Management

How much water exploitation and quality deterioration is possible before there is irreversible damage to the 'ecological infrastructure' that reduces the benefits of the water resources to society? Visible changes can be insidious and difficult to detect. It is important to recognise this and monitoring needs to be implemented to detect the changes. Similarly, management actions need to be implemented before overloading problems manifest themselves. Often it is difficult to reverse changes, and with groundwater, there may be a lag time of decades before impacts are evident.

The main management tools are:

i. Zoning for different landuse which will establish different types and levels of human impacts in different parts of the catchment. Thus the more sensitive sites can be protected and human impacts focussed on those areas most able to cope with the impacts.

ii. Cooperative management and governance, which are needed to have an integrated approach to catchment management. Through cooperative action the landuses that have greatest impact on the catchment can be reduced or removed.

7.4 Recommendations

Water level monitoring at strategic locations in and around the Mgobezeleni system has provided nearly three years of high-resolution data. Unfortunately, the absolute datum for these sites has not been established within the necessary level of accuracy. This is particularly of concern to the monitoring datum relative to the sea level fluctuations. It is recommended that a temporary piezometer be installed just off Jesser Point to measure the sea level elevation and sea state (Figure 141). It is also recommended that a permanent long-term monitoring gauge be installed in the estuary close to the mouth to measure water level elevation and the vertical salinity fluctuations.

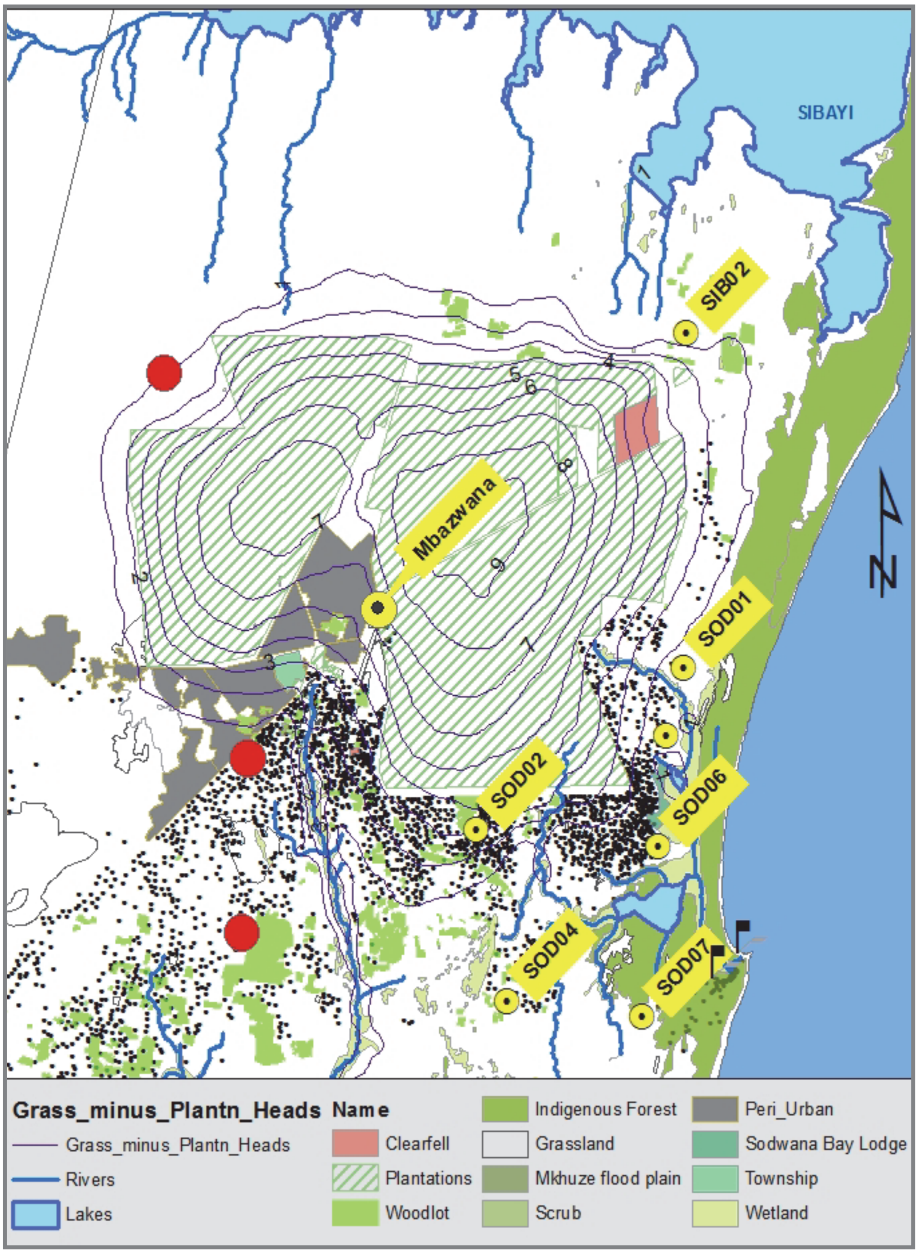


Figure 141. The current deep DWS groundwater boreholes and the proposed additional sites (red dots and black fags) for head and water quality monitoring. The black flags show the approximate location of the water level monitoring at the mouth and the red dots show the position of the proposed groundwater monitoring boreholes. These boreholes should be screened for the full depth of the aquifer.

The groundwater model was unable to simulate the estuary mouth dynamics because of the strong marine influence. However, the project has acquired and analysed data that could contribute to the development of a suitable physically based model of the estuary that needs to be investigated.

The hydrological model has indicated that the commercial plantations, when consolidated in one large area have a major impact on the groundwater abstraction and water levels. The estimated cone of depression from the large commercial plantation at Mbazwana extend to beyond 1-2 km of the plantations. In times of drought, such as that currently being experienced in the Mbazwana area, when the local community has severe water restrictions, these plantations do not show severe signs of water stress and appear to continue abstracting groundwater at depths that probably exceed 10 m of the natural water table. It is strongly recommended that the optimum distribution, density and area of plantation and woodlots be determined to protect the local community from their impact. Similarly, the streamflow reduction emanating from the drawdown of these large consolidated plantations is likely to have an impact on the water resources of the Mgobezeleni Estuary. The magnitude and severity of this impact needs to be determined to protect the resources for conservation, recreation, ecotourism and local water supply. It is recommended that several fully screened groundwater-monitoring boreholes be established in addition to the existing ones to monitor the drawdown and water quality (Figure 141).

The impact of plantations on wetlands varies in relation to the level of drawdown in the vicinity of the wetland. A drawdown along a stream channel will reduce the seepage face causing a streamflow reduction. A drawdown in the vicinity of a wetland will desiccate the wetland. A sustainable drawdown for each wetland needs to be established. This vertical drawdown needs to be converted to a horizontal distance if the concept of a buffer zone is considered in implementing plantation management options. The groundwater gradient in relation to the topographic gradient determines the horizontal buffer. This is NOT uniform in the catchment but site specific. Based on the implied drawdown of 1 m at distances of up to 2 km around the Mbazwana plantations, it is recommend that this horizontal buffer should be considered as an INTERIM BUFFER around all sensitive wetlands until the level of drawdown at each wetland is determined.

There is uncertainty concerning the level of anthropogenic impact on the water quality of the Mgobezeleni system that needs to be resolved. It is well established that sewage reticulation systems have a poor record of protecting the environment due to several factors. However, the accumulation of effluent requires a reliable purification system that minimises the release of nutrients into the environment. Many of the KZN estuaries were severely impacted by sewage works over the past few years. It is recommended that the level of pollution from the current forms of sewage disposal through wet and dry septic tanks should be investigated to reduce groundwater pollution and the need for expensive reticulation systems. The groundwater model with particle tracking and solute transport routine can greatly assist in the identification of pollutant pathways that could support a more detailed study of the pollution sources and sinks.

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APPENDIX I: ATKINSON AND BARICHIEVY – MGOBEZELENI SOILS POSTER

SOILS OF THE MGOBEZELENI ESTUARY CATCHMENT WITH A PARTICULAR EMPHASIS ON THEIR DISTRIBUTION AND AGRICULTURAL SIGNIFICANCE

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[1] KZN Department of Agriculture and Rural Development

INTRODUCTION AND STUDY OBJECTIVES

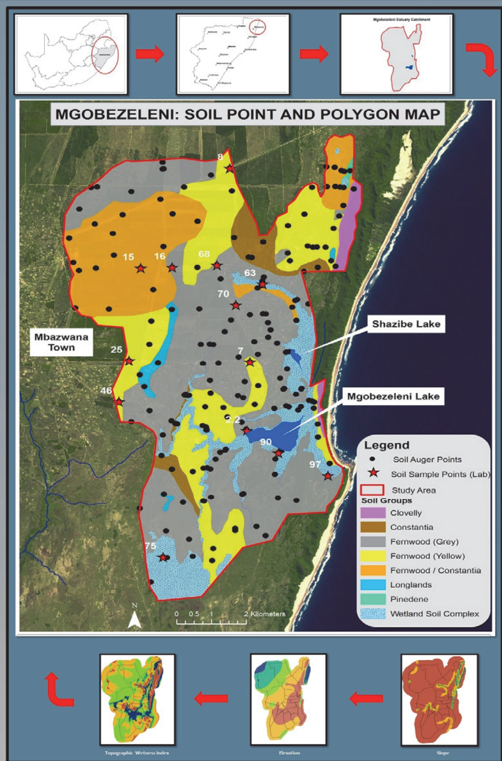
National Government has identified the Jozini and Umhlabuylingana Local Municipalities in Northern KwaZulu-Natal (KZN) as a priority agricultural production area. Historically, these areas have been underperforming with regards to agricultural production, due to unheeded soil physical and chemical related limitations, poor land management and crop selection. Preliminary soil fertility results from a community garden in the region are encouraging and indicate that with the proper guidance and management even lower potential soils can be sustainably productive. The objective of this study is to improve our understanding of the spatial soil dynamics, identify soil limitations and ultimately provide workable land management solutions for the coastal plain section of this priority area.

MATERIALS AND METHODS

The Mgobezeleni Estuary Catchment covers approximately 8 325 ha and contains a number of important hydrological features including Mgobezeleni and Shazibe lakes and large areas of wetlands and swamp forest.

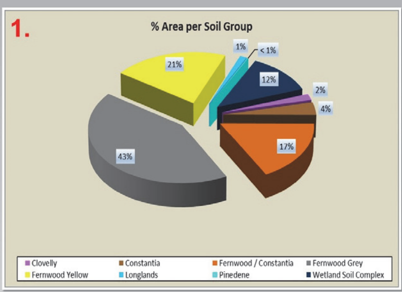
A soil sampling strategy was developed based on a thematic map of variation and was ultimately created through the systematic combination of terrain covariate datasets.

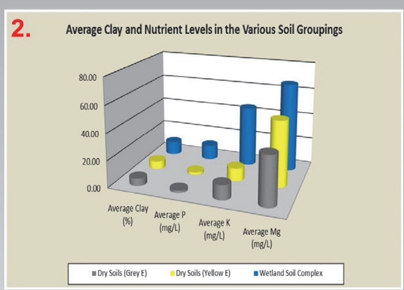
A total of 192 soil points were assessed up to a depth of 2.5 metres and 46 soil samples were extracted for detailed laboratory analysis. Samples were spread over a number of soil forms, soil horizons and land uses *inter alia* forestry, community gardens, natural veld and wetlands.

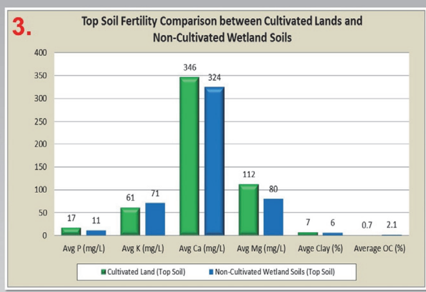


RESULTS AND DISCUSSION

- The results from the soil mapping and fertility exercise indicate that:
  - 64% of the study area is dominated by deep, sandy and dystrophic soils being either of the grey or yellow Fernwood Soil Form (**Fig. 1**).
  - Wetland soils cover approximately 12% of the surveyed area and were mapped as a soil complex which encompasses the Champagne, Katspruit, Kroonstad and Longlands Forms.
  - As expected, samples from the wetland soil complex contain more clay and nutrients than the "drier" soil forms and are thus more attractive to subsistence farmers (**Fig. 2**).
  - Spatially, this trend is evident in that most subsistence activities are concentrated in these higher productive soils which are either in permanent or seasonal wetlands.
- Results obtained from a community garden project, engaged in permaculture, have shown that through improved water management and soil nutrient conservation practices it is possible to improve the fertility status and production output of inherently dystrophic soils to a level comparable to that of an uncultivated wetland soil (**Fig. 3**).







CONCLUSIONS

The challenge facing both the agricultural and environmental sectors is identifying potential soil management approaches that could be applied to the non-wetland soils in the area but still provide the same nutrient benefits obtainable from the highly productive organic soils in the catchment. Unfortunately poor agricultural practices and rapid population growth has resulted in the unsustainable exploitation of highly nutrient-enriched areas such as wetlands in the Mgobezeleni catchment. However, initiatives such as permaculture, soil nutrient conservation and keyhole gardens may ease the agricultural development pressures on the ecologically sensitive wetland systems of the Mgobezalени Catchment. The preliminary results from the community garden show that through sustainable site management, even the most marginalised areas have adequate agricultural potential.

APPENDIX II: REPORT ON THE VEGETATION RESOURCE ASSESSMENT OF THE MGOBEZELENI CATCHMENT, NORTHERN KWAZULU-NATAL

agriculture
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Department: agriculture
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PROVINCE OF KWAZULU-NATAL

Section: Natural Resources
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Report on the Vegetation Resource Assessment of the Mgobezeleni Catchment, Northern KwaZulu-Natal

A.II.1. Introduction

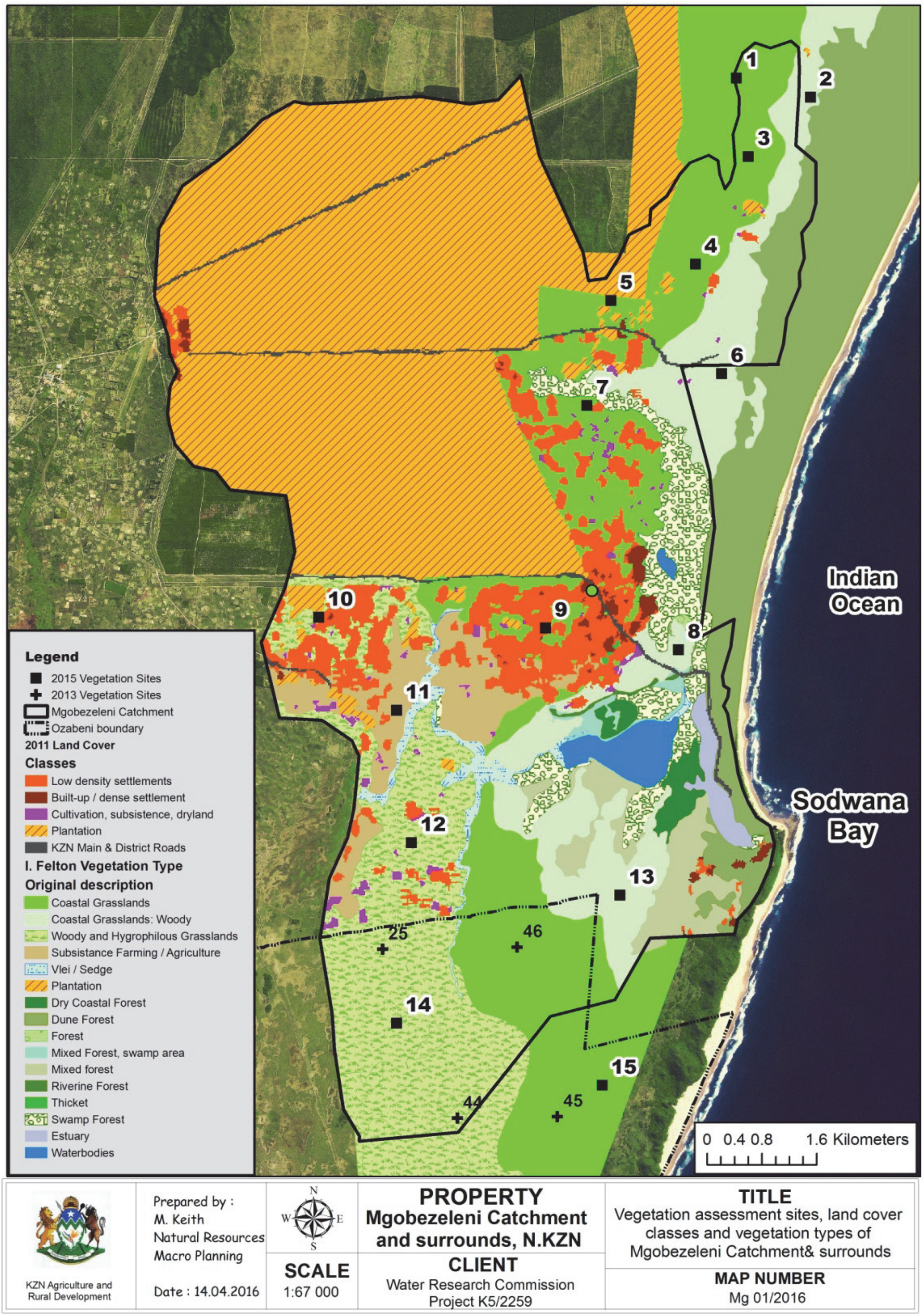
As per Water Research Commission project K5/2259 request an assessment of the sub-tropical Maputaland coastal grasslands of the Mgobezeleni Catchment (8 325ha) was undertaken to determine the current veld condition (Map Mg 01/2016) and woody species composition in order to quantify the measurable risk, impact and response of the natural vegetation resource.

A.II.2. Sampling Procedure

- Felton (200) vegetation map was used as the vegetation type spatial layer. Vegetation types surveyed were Subsistence Agriculture (920ha) and the untransformed grasslands (2993ha), namely Woody Coastal Grasslands, Woody and Hygrophilous Grasslands and Coastal Grasslands (Map Mg 01/2016). Plantations, wetlands and forested vegetation types excluded. Low density settlements, as identified by Ezemvelo KZN Wildlife 2011 KZN Land Cover (SPOT 5) dataset, were added to the Subsistence Agriculture map unit.
- Sampling sites were stratified within each vegetation type based on landscape position, woody vegetation density, nearest water source, anthropogenic factors and access to sites in order to capture the majority of the heterogeneity of the area.
- Fifteen sites were surveyed during March 2015. Data from an additional four sites, within the Ozabeni Reserve section of the catchment collected during April 2013 were also utilised.

A.II.2.1. Collection and analysis of data

- Two different sampling techniques were used to assess the herbaceous layer. The herbaceous species composition and standing herbaceous biomass on a 50 x 25 m plot in grassland areas and a 25 x 25 m plot in the savanna areas.
- Where woody species were present on a site, woody species composition (excluding geoxylic suffrutices or geoxyles), above ground biomass and density was assessed using two 2.4 m belt transects conducted on 2 parallel sides of the plot.



Map A.II.1: *Vegetation assessment sites, land cover classes and vegetation types of Mgobezeleni and surrounds*

- **Herbaceous species composition** was assessed using a descending point method, by making a minimum of 200 nearest plant observations at 1 m intervals within the plot. Geoxyles were recorded separately from other forbs, sedges and grasses due to the unique nature of this grassland. The occurrences of each species were tallied in order to provide a species frequency. Each grass species was assigned a grazing value based on its palatability and fodder production potential. The species together with its grazing value resulted in a rangeland condition score per species, which in turn, were tallied to obtain a rangeland condition score for the site. The site score was measured against that of the benchmark for the coastal vegetation biome, Bioresource

Group 1. This benchmark represents the species composition of rangeland considered to be in highly productive state for animal production purposes. The resultant score is an index of the site score against the benchmark value and is called the rangeland condition which is expressed as a percentage. Herbaceous species were placed into ecological classes based on how they react to different utilisation or grazing regimes. From these figures grazing capacity and stocking rate were calculated and current management impacts assessed, details provided in full report.

- **Standing herbaceous biomass** data was collected using a falling disc pasture meter. One hundred disc meter readings were recorded within the plot. Analysis was done using the Lubbe, 2003 regression formula, details provided in full report.
- **Woody species** composition and density was assessed within the belt transects Woody plants were identified and their growth form was characterized using seven measurements. The data were analyzed using the BECVOL model developed by Smit, 1996. Tree density and leaf mass together with phenology and animal utilisation factors were used to calculate browse capacity for each vegetation type. Full details of field procedures and analysis will be illustrated in full report.

Scores for all sites within each of the four vegetation types were averaged in order to calculate the grazing capacity, browse capacity and stocking rate for each vegetation type.

A.II.3. Results and discussion

Results for each vegetation type are summarised in Table A.II.1.

***Table A.II.1**: The areas, number of sites and average rangeland condition, herbaceous biomass and tree density for four vegetation types surveyed within the Mgobezeleni Catchment*

Vegetation Type	Area (ha)	No. of sites	Average Veld Condition Score (%)	Average Tree density* (plants/ha)	Herbaceous Biomass (kg/ha)
Coastal Grassland	1 200	7	51	4 488	3 786
Coastal Woody Grassland	775	4	45	2 354	3 113
Woody & Hygrophilous Grasslands	1 018	4	64	656	2 725
Subsistance farming	920	4	55	3 157	3 536
Forests, Plantation, Lakes & Estuary	4 412	0	N/A	N/A	N/A
TOTAL	**8 325**				
* tree density excludes all geoxylic suffritices					

- Rangeland condition for the sites surveyed varied from a poor 39% to a good 75% of benchmark for all four vegetation types. The overall average was 51% for the Coastal, 45% for the Woody Coastal, 64% for the Woody & Hygrophilous Grasslands and 55% for the Subsistence Agriculture area.
- Tree density for each site varied dramatically between and within the four vegetation types with the average site density ranging from 0 to 10 166 plants/ha with an average of 3 290 plants/ha for all vegetation types. The high average tree density within these grassland vegetation types is of grave concern when taking into account Edwards, 1983 grassland description. Further increases in density must be prevented to maintain these vegetation types as sub-tropical coastal grasslands
- 79% of all woody plants recorded, for all 7 sites; in the Coastal Grasslands were *Dichrostachys cinerea*. 31% of all woody plants, for 50% of sites in the Woody Coastal Grasslands were *D. cinerea* and 75% of all woody plants, for 50% of sites in the Subsistence Agriculture area were *D.*

cinerea. One site with woody plants in the Woody & Hygrophilous Grasslands had a very high 87% *D. cinerea* recorded.

- From Figure A.II.2 below it is important to note that the number of woody plants within the <0.5 m and 0.5 m to 1.5 m height classes are dramatically higher than all the classes >1.5 m. This is especially noticeable in the Coastal Grassland vegetation type but all vegetation types are affected to a degree. The dominance of woody plant height <1.5 m reflects that these woody plants have either been affected by fire and thus remain within this zone or that there is new recruitment of seedlings within this zone. Either way in order to maintain these grassland vegetation types as grasslands regular effective fires must be used.

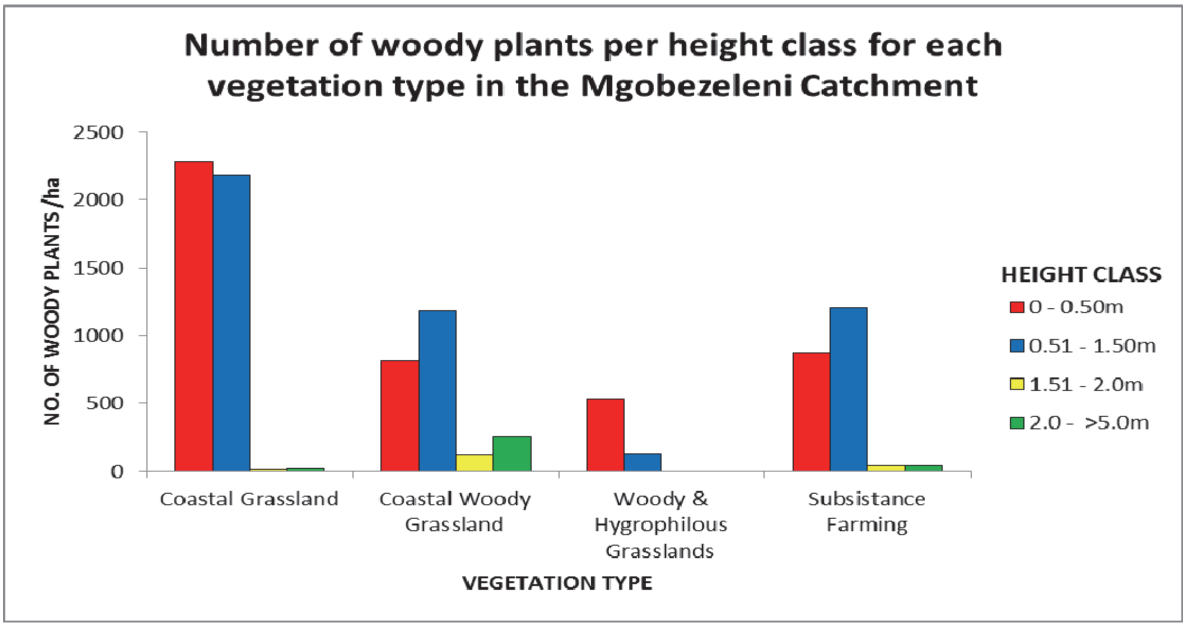


***Figure A.II.2**: Number of woody plants (240 m²) per height class for sites within each vegetation type of the Mgobezeleni Catchment*

- High tree densities reduced the grazing capacity on average, by 65% and 42% within the Coastal and Woody Coastal Grasslands respectively and by a limited 78% on the Subsistence Agriculture area with no impact on grazing capacity in the Woody & Hygrophilous Grasslands.
- Standing herbaceous biomass ranged from 1 070 to 4 583 kg dry matter (DM) per hectare with an average of 3 368 kg DM/ha for the surveyed areas. Generally the lower biomass (< 2 800 kg/ha) was as a result of either recent burning, higher utilisation by livestock or due to historical cultivation. Biomass of >4 000 kg DM/ha has been found to be sufficient to effectively control woody plant encroachment in some vegetation types. 37% of the sites within the Mgobezeleni Catchment achieved this target.
- There was a noticeable increase in pioneer grass species with the Subsistence Agriculture area when compared to the other vegetation types. This could well be attributed to increased grazing pressure and indiscriminate burning. Anthropogenic factors like old cultivated lands, footpaths and vehicle tracks will continue to escalate this trend. There was a less noticeable presence in the pioneer grass species within the other 3 vegetation types when compared to benchmark.
- Alien invasive species, *Lantana camara* and *Psidium guava,* were recorded at 39% of the vegetation sites outside of Ozabeni Reserve. All affected sites were within close proximity to

housing or woodlots. There was no evidence of alien invasive woody plants on sites within Ozabeni Reserve.

A.II.4. Conclusions

- There is a substantial anthropogenic threat to the remaining natural sub-tropical Maputaland grasslands through further transformation factors like plantation, woodlot and cultivated land establishment, additional roads and paths, increased human and livestock pressure, illegal and uncoordinated building of houses and commercial enterprises must be limited to a minimum or highly controlled in future.
- Further fragmentation of the area only makes essential rangeland management practices like fire, resting and correct stocking rates more difficult to implement for all stakeholders.
- Many biological factors threaten these grasslands like bush encroachment of *D. cinerea* and possible other indigenous woody plant thickening (e.g. *Strychnos* and *Ochna* spp). The spread of existing alien invasive species and the introduction of new alien species as well as increasing livestock stocking rates are all important factors requiring a single strategic fire and stocking rate stakeholder driven management plan. Without single vegetation management plan mitigation of the risks identified above will lead to further deterioration of this threatened grassland.

A.II.5. References

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