DIVISION OF WATER ENVIRONMENT AND FORESTRY TECHNOLOGY, CSIR

REPORT ON THE GEOHYDROLOGY AROUND LAKE SIBAYA, NORTHERN ZULULAND COASTAL PLAIN, KWAZULU-NATAL

by

R Meyer and L Godfrey

Submitted to: RDM Office
Department of Water Affairs and Forestry
Private Bag x313
Pretoria
0001

Prepared by: Environmentek, CSIR
P O Box 395
Pretoria

Pretoria
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1. INTRODUCTION

This groundwater investigation is undertaken in response to a licence application to abstract 1.825 Mm^3/a of water, in effect groundwater, from Lake Sibaya, to provide water for basic human needs to the town of Mbazwana. The report supports a preliminary determination of the Reserve for the Lake Sibaya subcatchment, situated in quaternary catchment W70A.

2. PHYSIOGRAPHIC FEATURES

Lake Sibaya, the largest freshwater inland lake in South Africa, is situated on an extensive sand covered coastal plain along the northern KwaZulu-Natal coast. The Lake occupies a position between 27°15'S to 27°25'S and 32°33'E to 32°43'E and covers a surface area of approximately 65 km^2 (Miller, 2001). The coastal plain extends from Mtunzini in the south to the KwaZulu-Natal/Mozambique border (a distance of approximately 250km and a maximum width of some 70km). It continues for a further approximately 1000km into Mozambique where it attains a width of up to 250km in places. A number of large and ecologically important freshwater lakes occur on the South African part this plain, i.e. Sibaya, Mzingazi, Nhlabane and Cubhu. Apart from these freshwater lakes, there are also two lake systems with direct connection to the sea, viz. Lake Kosi and Lake St Lucia.

In the area around Lake Sibaya the coastal plain extends for about 60km inland terminating against the foothills of the north-south striking Lebombo Mountains. The topography of the coastal plain in the vicinity of Lake Sibaya is characterised by a series of palaeo-dune ridges roughly parallel to the coastline. For the purpose of this report the two most important palaeo-dunes are the one between the eastern shore of Lake Sibaya and the sea, with an elevation of up to 170m opposite the lake, and one forming the surface watershed between the Lake Sibaya and the Pongola River quaternary catchments (W70A and W45B respectively, Midgley *et al*, 1994). Apart from the palaeo-dune topography, the area is characterised by low undulating and irregularly spaced grass covered dunes with small and often isolated patches of indigenous trees spread throughout the area. To the south and north of the Lake, intensive commercial pine and eucalyptus forests have been established. The topography does not support drainage features of any significance. Midgley *et al* (1994) refers to the area as a local endoreic area (surface water drainage not leaving the catchment). This statement by Midgley *et al* (1994), together with the nature of the soils and the flat topography, is extremely important, as it rules out surface water as the primary source of water for Lake Sibaya and other lakes.

The water level of the lake fluctuates by just over one metre around an average of about +20mamsl (DWAF, 2002). The most recent bathymetry of the lake, indicates that it has a maximum depth of 41m (Miller, 2001).

3. CLIMATIC CONDITIONS

Average annual rainfall across the coastal plain varies from 1120 mm/a (Pitman and Hutchison, 1975) close to the coast, to about 600mm/a at the Lebombo Mountains (Midgley *et al*, 1994). Forty three percent of the annual rainfall occurs during the months of January to March (Wright and Mason, 1990). The average annual Symonds Pan evaporation at a research station on the eastern shore of the lake and measured over a period of 8 years, is 1423mm (Pitman and Hutchison, 1975).

4. GEOLOGY AND GEOHYDROLOGY

Crucial to understanding the geohydrology of the coastal plain, is a knowledge of the underlying geology. The stratigraphic column for the area is shown in Table 1. Geohydrologically the rocks of Cretaceous and Palaeocene age can be regarded as the geological basement. These were deposited unconformably on rhyolites of the Jozini formation which form the Lebombo mountains along the western edge of the coastal plain. The Cretaceous succession of mainly fine siltstones, conglomerates and sandstones is collectively known as the Zululand Group and comprises three formations; the St Lucia (younger), Mzinene and Makatini (older) Formations. Apart from having a very low permeability, the quality and quantity of ground water encountered in these formations is extremely poor (TDS >8 000 mg/l), and therefore are regarded as the "basement" rocks for this study. The Zululand group is overlain by a thin veneer of Cenozoic sediments, similar in composition to the St Lucia Formation. The sedimentary succession of the Miocene to the Holocene has provisionally been allocated the name Maputoland Group by Botha (1997).

The Cretaceous and Palaeocene age sediments are overlain by a sequence of mainly calcarenites in turn overlying basal boulder beds, referred to as the Uloa Formation. These Miocene age sediments are geohydrologically very important as they can be regarded as one of the main aquifers in the succession (Worthington, 1978; Meyer *et al*, 2001). Drilling results to the north and northwest of the lake indicate thicknesses of the Uloa formation of up to 35m (Kruger and Meyer, 1988). The upper surface of the coquina has been subject to karst solution weathering prior to the deposition of the overlying calcarenite. Seismic profiling on Lake Sibaya revealed that the Uloa formation only occurs under the western part of the lake, roughly up to the middle of the main basin (Miller, 2001).

The Miocene sediments are overlain by a thick succession of loosely consolidated sands, silts, clays and lignite of lower Pleistocene age and known as the Port Durnford Formation (Hobday and Orme, 1974; Miller, 2001). The Port Durnford Formation has been described in the Richards Bay area as comprising of a lower, more argillaceous layer, separated from an upper arenaceous layer by a persistent but discontinuous lignite band. This lignite band was formed over larger areas and was observed in and described from borehole samples near Kosi Bay by Kruger and Meyer (1988). In the area just to the north west of the lake, a thickness of 60m for the Port Durnford formation has been confirmed through drilling (Meyer, 1994). Close to the eastern edge of the main basin, the base of the Port Durnford Formation is at an elevation of approximately –20m with respect to present sea level (Miller, 2001).

Table 1: Simplified geological sequence for the Zululand Coastal Plain

Age (ma)	System / Period	Series/Epoch	Etage	Group	Formation	Lithology
0.1	Quaternary	Holocene (Recent)				Alluvium, dune, aeolian and beach sands
<1.6		Pleistocene	Upper Pleistocene		Berea	Sand, red clay rich sand
			Middle Upper Pleistocene		Bluff	Calcareous sandstone
			Lower Pleistocene		Upper Port Durnford	Sand and sandstone
						Lignite
					Lower Port Durnford	Clay rich sandstone
1.6 - 65	Tertiary	Late Miocene to Pleistocene			Uloa	Calcareous sandstone and coquina
		Palaeocene	Thanetian - Danian	Zululand	St Lucia	Siltstone and sandstone
65 - 146	Cretaceous	Late Cretaceous	Albian - Cenomanian		Mzinene	Glauconitic siltstone
		Early Cretaceous	Upper Barremian - Upper Aptian		Makatini	Conclomerate, sandstone and siltstone
146 - 208	Jurassic			Lebombo	Mpilo/Movene	Amygdaloidal trachybasalt
					Jozini	Rhyodacite and rhyolite
					Letaba	Basalt and rhyolitic lava

Near Mbazwane, southeast of the lake, the upper surface is at an elevation of approximately 50 mamsl (Fockema, 1986; Kruger and Meyer, 1988; Davies *et al*, 1992), whereas to the northwest of the lake it is at about 60 mamsl (Meyer, 1994).

The Port Durnford Formation is overlain by fluvial and aeolian sands of Middle to Upper Pleistocene and Holocene age. These sands are predominantly fine grained, contain an average of about 5% silt and clay (Davies *et al*, 1992; Meyer *et al*, 1993) and are largely unconsolidated. Extensive exposures of clayey red sand occur especially more inland and have been termed Berea-type clayey red sand by McCarthy (1992). These red sands are the result of intense weathering of dune rock and from late Tertiary aeolianites. The coversands of Holocene age exceed 70m in places.

5. DESCRIPTION OF THE AQUIFER(S)

5.1 General description

The Zululand coastal plain hosts the most extensive and largest unconsolidated primary aquifer in South Africa. The majority of the sedimentary succession above the Cretaceous floor rocks can all be treated as potential aquifer units. Borehole data, as well as hand dug wells and shallow augering have indicated that the arenaceous succession is generally fully saturated from the interface with the Cretaceous formations up to a generally shallow groundwater level. Studies by Australian Groundwater Consultants (1975), Worthington (1978), Meyer and Kruger (1988), Meyer and Godfrey (1995) and Meyer *et* al, (2001) identified the Miocene Uloa Formation to be the most promising aquifer unit in the region. The calcarenite has been observed in borehole core samples to contain some dissolution channels which increases its porosity and permeability significantly. This layer is not present everywhere but thicknesses of up to 25 m have been reported. Worthington (1978) is of the opinion that the mode of distribution of this Miocene succession is determined to a large extent by the undulations in the erosion surface of the underlying Palaeocene siltstones.

The Uloa aquifer is overlain by the Port Durnford Formation aquifer. This aquifer has not been exploited to any great extent, although north of Richards Bay new well fields have been developed recently in this formation with good success (RBM, personal communication). Northwest of Lake Sibaya, large scale irrigation of pecan nut plantations from both the Port Durnford and Uloa Fomations has been successfully operated for many years.

Water stored in the Holocene deposits support the shallow, mostly hand-dug wells, shallow pans, commercial forestry and natural vegetation in the area. These are currently not exploited extensively, but due to the high porosity, vast quantities of water are stored in these and can be exploited.

5.2 Surface water/groundwater interaction

The northern part of the plain, due to its endoreic nature and thick succession of unconsolidated and semi-consolidated sediments, is annually replenished by rainfall and stores vast quantities of fresh water. A close relationship between water levels and surface topography has been established (Meyer, *et al*, 2001). This suggests that the near surface deposits possess a relatively low hydraulic permeability. The regional groundwater level gradient reported in Meyer *et al*, (2001) is approximately 1:300 with the general groundwater flow direction being perpendicular to the coastline. Around Lake Sibaya this regional pattern is somewhat distorted with flowlines indicating some flow towards the lake.

The shallow water level over most of the area results in the formation of numerous shallow lakes or pans of different size throughout the area. Lake Sibaya is the largest of these. These lakes or pans are often mistaken to be the result of surface water inflow, whereas they are in fact almost exclusively fed by groundwater. The surface elevation of these lakes is merely a reflection of the local groundwater level, and the presence of the lake is again evidence that the surface topography is below that of the local groundwater level. Where these pans are shallow (say less than 2m), groundwater level fluctuations with time can result in these pans temporarily drying up. Following good rainfall events geohydrologically upstream (but not necessarily in the immediate vicinity of the "pan") recharging the aquifer, these are restored to "pan or small lake" status once the groundwater levels have again equilibrated. Depending on the hydraulic permeability of the aquifer, the hydraulic head and the distance between recharge areas and the pan, time delays between rainfall and pan recharge occur.

Lake Sibaya is the largest of these depressions and is almost entirely replenished from groundwater sources. The annual inflow of surface water to the lake is regarded as negligible compared to that supplied from groundwater sources, as the flow in these streams is also almost entirely groundwater derived. Based on the most recent bathymetry of the lake (Miller, 2001), and at a lake water level elevation of 19.82 mamsl, the Council for Geoscience have calculated the volume of the lake to be 818.5 x $10^6 m^3$ (Perrit *et al*, 2002). This capacity is approximately a third of the FSC of the nearby Jozini dam (2500 x10^6m) (DWAF, 1986).

5.3 Hydraulic parameters

Reports by Davies, Lynn and Partners (1992) indicated that the grain size distribution, as well as the porosity of the Holocene age cover sands, the underlying more cemented aeolian sands and the Port Durnford Formation are virtually the same. The permeabilities obtained from pumping tests are within the range of 0.5 - 23.6 m/d with an average of 4.5 m/d. Hydraulic permeability of the Port Durnford Formation has been determined for the Eastern Shores of Lake St Lucia and found to be around 4 - 5 m/d. Values for the storage coefficient range from 1.9 x 10^{-5} to 4.7 x 10^{-3} with an average at 1.9 x 10^{-3}. The tests revealed delayed yield and leaky confined aquifer conditions. Pumping test results from this aquifer reported by Australian Groundwater Consultants (1975), Worthington (1978), Simmonds (1990) and Meyer (1994), indicated yields of up to 25 l/s in areas where this layer is more than 20m thick. Transmissivities obtained from pumping tests in production boreholes at Coastal Cashews tapping the Port Durnford and the Uloa formations, gave values ranging from about 500 m^2/day to almost 5000m^2/day, with specific capacities around 150m^3/d/m (Meyer, 1994).

For the unconsolidated Holocene sands forming an unconfined aquifer, Kelbe and Rawlins (1992) used a specific yield of 35% and for the Port Durnford Formation a specific yield of 20% in their aquifer simulation studies.

5.4 Groundwater levels and flow directions

Water level (mamsl) contour lines are in general parallel to the coast. Near the watershed in the west, the groundwater elevation is around 70-80mamsl from where it drops towards the coast reaching about 20mamsl against the coastal dune cordon (Meyer *et al*, 2001). This is also the average level reflected in Lake Sibaya. Over the section between the watershed and the lake, the ground water gradient is approximately 1:250 with a flow direction perpendicular to the coastline. Along the 2-3 km wide coastal dune cordon the gradient steepens to about 1:100. This is manifested in the freshwater occurrences along the coastline (Meyer *et al*, 2001)

Groundwater levels and flow patterns are affected by the presence of Lake Sibaya. Closer to the lake, water level contours broadly follow the edge of the lake, whereas flow is also directed towards the lake shoreline.

6. GROUNDWATER RECHARGE

Ground water recharge estimates for the different areas of the Zululand Coastal Plain have been reported by Worthington (1978) and Meyer and Kruger (1987), Bredenkamp (1993), Bredenkamp *et al* (1995) and Meyer *et al* (2001). Worthington used a water balance approach and calculated that the net recharge in the vicinity of Richards Bay is approximately 24% of the mean annual precipitation (MAP). Using a rainfall recharge relationship proposed by Bredenkamp (1985) which is based only on the MAP, Meyer and Kruger (1987) reported a recharge figure of approximately 21% of MAP for an area just north of Sibaya. For the St Lucia area Bredenkamp *et al* (1995) obtained recharge values ranging between 7% and 37% of MAP using the chloride method.

For the area around Sibaya, the values cited by Meyer *et* al (2001) are believed to be the most representative as these are based on observations over a three-year period. The authors used the chloride method and averages were determined over a three-year period along a profile stretching from the coast to the Lebombo mountain range. The resulting recharge data indicated that the recharge varies from 18% (of MAP) near the coast to about 5% (of MAP) at a distance of 50 km inland.

Using the recharge values determined by Meyer *et* al (2001), the integrated net annual recharge over the north eastern section of the Zululand coastal plain (north of Lake St Lucia to the Mozambique border and east of the watershed) is approximately 267 x 10^6 m^3. Using the same values, the net annual recharge onto the Sibaya catchment is approximately 53 x 10^6 m^3 assuming a sub-catchment area of 530 km^2. In calculating these values, an average of 11% of MAP (900 mm) was used in each case.

7. WATER RESOURCES

7.1 Groundwater resources

In terms of the volume of water in storage, the northern part of the Zululand Coastal plain probably represents the largest primary unconsolidated aquifer system in South Africa. Apart from the limited groundwater use in the area (agriculture, forestry, town and rural water supply) this vast water resource is unused.

The amount of groundwater in storage for the northern part of the coastal plain (Mozambique border to the Mkuze catchment and westward from the watershed to the coast) is estimated to be between 27 x $10^9 m^3$ and 54 x $10^9 m^3$ using an effective aquifer porosity of 10% and 20% respectively. This figure is based on water level measurements, aquifer thicknesses and porosity values reported by Meyer *et* al (2001).

Using the same sources of information and based on the catchment boundary reported by Pitman and Hutchison (1975), the volume of groundwater stored within the boundaries of the Sibaya catchment, is estimated to be between 5.2 x $10^9 m^3$ and 10.4 x $10^9 m^3$ (excluding the estimated 830 x $10^6 m^3$ (Perrit *et al,* 2002) volume of water in Lake Sibaya at a water level of 19.82 mamsl. Therefore the water stored in the Sibaya catchment is about 19% of that of the larger northern Zululand groundwater catchment draining towards the coast.

7.2 Lake Sibaya water resources

Data on lake levels (as metres) was obtained from DWAF gauging stations W7R001 A02 (1967-1975) and W7R001 A03 (1980-present). When plotted as metres above mean sea level, discrepancies in the two sets of data were evident, due to difference in the recorded height of the reference plates. The reference plate for A03 has been surveyed and therefore the water levels as mamsl are assumed to be correct. The reference plate for A02 was not surveyed, and as such, the associated water levels as mamsl are questionable. Based on similarities in water levels and degree of exposed shoreline, the A02 levels were adjusted down, to match A03 level data, as depicted in Figure 1.

8. WATER QUALITY

8.1 Groundwater quality

Groundwater quality analyses from samples collected from boreholes at Coastal Cashews just north of Lake Sibaya during pumping tests in 1994 are listed in Table 2. These samples represent an integrated view of the water quality within the various aquifers, as screens were installed at different aquifer horizons. It is clear from the table that the water conforms in almost all instances to the "ideal water quality" category of DWAF.

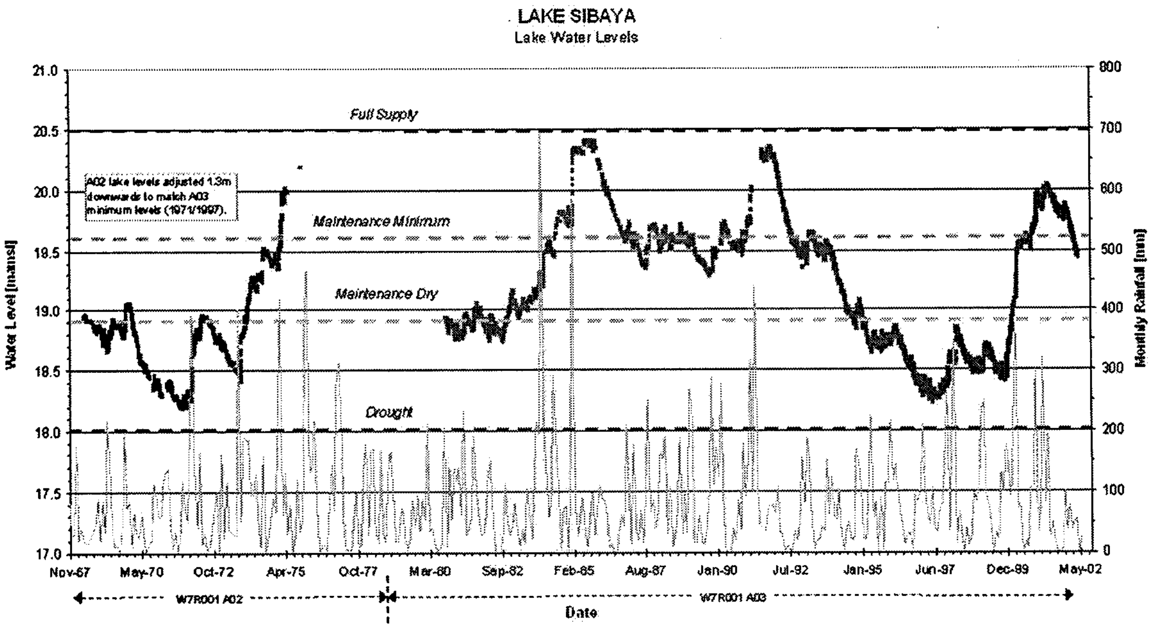

Figure 1: Lake Sibaya water level fluctuations and monthly rainfall since 1967.

Lake water levels are seen to fluctuate between 18.2 mamsl and 20.4 mamsl with an average level of 19.3 mamsl. A strong relationship between lake levels and rainfall is evident (Figure 2).

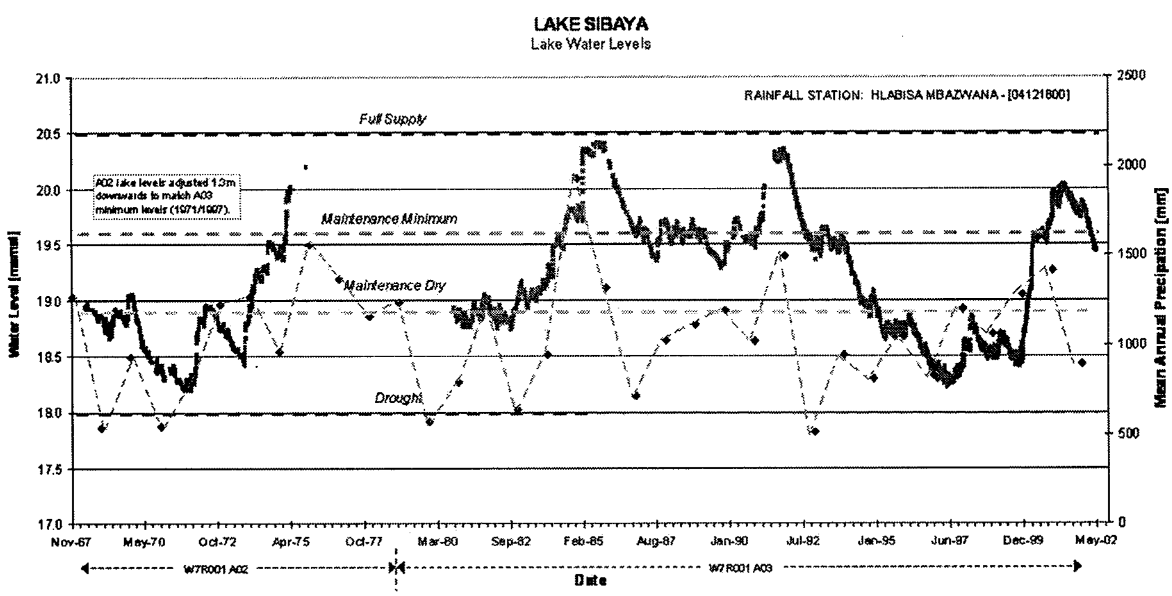

Figure 2: Lake Sibaya water level fluctuations and mean annual rainfall since 1967.

8.2 Lake Sibaya water quality

During a geohydrological study of the Zululand coastal plain the CSIR analysed the water quality of Lake Sibaya monthly for a period of three years. The small variations recorded during this time are insignificant and are within analytical accuracy (Tables 2 and 3). Except for the chloride concentration (Class I), the water conforms to DWAF, Class 0 water quality standards.

Table 2: Groundwater quality from deep boreholes northwest of Lake Sibaya

Determinant	Unit	Borehole number				DWAF Water Quality Class				
		N8	N14	N15	N33	0 Ideal	I Good	II Marginal	III Poor	IV Unacceptable
Potassium as K	mg/l	7.8	11	5.4	5.7	<25	25-50	50-100	100-500	>500
Sodium as Na	mg/l	84.4	63	34.1	42.9	<100	100-200	200-400	400-1000	>1000
Calcium as Ca	mg/l	59.4	36	40.8	60.1	0-80	80-150	150-300	>300	ns
Magnesium as Mg	mg/l	8.1	6	5	8.3	0-70	70-100	100-200	200-400	>400
Sulphate as SO_4	mg/l	9	10	8.4	8	<200	200-400	400-600	600-1000	>1000
Chloride as Cl	mg/l	254	74	37.5	55	<100	100-200	200-600	600-1200	>1200
Alkalinity as $CaCO_3$	mg/l	9	143	142	194					
Nitrate as N	mg/l		0.2	<0.1	<0.1	<6	6-10	10-20	20-40	>40
Phosphate as P	mg/l			0.3						
Fluoride as F	mg/l		<0.2		<0.1	<0.7	0.7-1.0	1.0-1.5	1.5-3.5	>3.5
Silica as Si	mg/l				12.6					
Iron as Fe	mg/l		0.11	3.9	0.06	<0.5	0.5-1.0	1.0-5.0	5-10	>10
Manganese as Mn	mg/l			0.11		<0.1	0.1-0.4	0.4-1.0	1.0-5	>5
Boron as B	mg/l		0.12	0.1	0.08					
Conductivity (EC)	mS/m	75.8	56	41	56	0-70	70-150	150-370	370-520	>520
PH		8.0	6.8	7.5	8.1	6.0-9.0	5.0-9.0	4.0-10.0	3.5-10.5	<3.5 or >10.5
Hardness as $CaCO_3$	mg/l	182		122		0-200	200-300	300-600	>600	ns
Balance	%	0.15	2.74	0.81	1.71					

Table 3: Lake Sibaya water quality

Determinant	Unit	Date sampled					
		01/07/1988	02/02/1989	01/06/1989	03/08/1989	21/12/1989	15/02/1990
Potassium as K	mg/l	7	7	9	7	7	7
Sodium as Na	mg/l	81	81	83	81	81	78
Calcium as Ca	mg/l	23	23	23	23	24	23
Magnesium as Mg	mg/l	9	9	9	9	9	9
Sulphate as SO_4	mg/l	10	9	9	9	8	9
Chloride as Cl	mg/l	110	111	113	112	113	111
Alkalinity as $CaCO_3$	mg/l	124	124	124	124	124	124
Nitrate as N	mg/l	0	0	0	0	0	0
Conductivity (EC)	mS/m	60	60	60	60	61	60

9. GROUNDWATER USE AND DISCHARGE

9.1 Groundwater use

Apart from the natural evapotranspiration, there is only very limited use made of the groundwater resources in the Lake Sibaya catchment. These user sectors are currently, in order of annual consumption, forestry, agriculture, town and rural water supply. Annual use figures cited in Lindsay and Scott (1987), Kienzle and Schulze (1991), Meyer and Godfrey (1995) and Meyer *et al*, (2001) for the different users are (Table 4):

Table 3: Groundwater use in the Sibaya area.

Water Use Sector	Volume (10^6 m^3)
Forestry (based on 45 000ha)	2.9 (maximum)
Irrigation	1.5
Domestic (Manzengwenya and rural)	0.05 (estimated)

Meyer *et al* (2001) simulated the impact of afforestation on the groundwater conditions in the coastal zone around Lake Sibaya. Due to uncertainties in the water consumption by plantations under the prevailing climatic and groundwater conditions, different scenarios were simulated. Varying evapotranspiration rates (0, 200, 1000, 1500 and 2000mm/a per unit area) with an annual groundwater recharge of 150mm were used in the simulations. The lake level was kept constant at 20 mamsl. Along a section line through Lake Sibaya and perpendicular to the coast, the groundwater gradient remained towards Lake Sibaya even under the worst evapotranspiration condition of 2000 mm/a. However, the impact on ground water levels extends for about 4 km north and south of the Lake. At these distances groundwater levels can be up to 15 m lower at maximum evapotranspiration rates. The groundwater level contour and flow direction map, with and without afforestation is reported in Meyer *et al.* (2001).

9.2 Groundwater discharge

Sources of groundwater discharge include abstraction for domestic and agricultural use, natural evapotranspiration, forestry, direct evaporation from the lake, and natural outflow to the ocean. Ignoring natural fluctuations in lake and groundwater levels, it is argued that the system is in balance. As a result the annual net recharge to the catchment is also leaving the system through natural outflow. Groundwater flow directions and gradients indicate that the natural flow is towards the coast, although a small proportion is directed towards the lake. However, the results of isotope studies reported by Meyer *et al.* (2001) proved that the lake is discharging large volumes of water to the sea. If we accept the calculated recharge figures for the coastal plain and the Lake Sibaya catchment as representative (267 x 10^6 and 53 x 10^6 m^3 respectively, and accept that this volume is required to keep the system in balance (Section 5), approximately 3 x 10^6 m^3/a flows into the ocean per kilometre of coastline (assuming a 100km coastline). It is important to note that the current permit application for water abstraction from Lake Sibaya represents only about 3.5% of annual recharge to the

Sibaya catchment. Expressed in terms of the seepage towards the coast opposite Lake Sibaya (assuming an approximately 10km seepage front), the proposed abstraction for Mbazwana is approximately 6.1%.of the seepage to the coast.

Pitman and Hutchison (1975) have calculated the outflow opposite Lake Sibaya to be between 1 x 10^6 and 4 x $10^6 m^3/a$ or 1 x10^5 to 4 x $10^5 m^3/a$ per kilometre of coastline. For this calculation they assumed a 10km long by 25m deep seepage front. Geophysical investigations reported by Meyer *et al* (2001) indicate that the average depth of unconsolidated sediments along the eastern shore of Lake Sibaya is closer to 100m and that the erosion channel extends for a distance of approximately 20km. Using these dimensions and allowing an annual flow rate of 53 x $10^6 m^3$ (the net recharge calculated for the Sibaya catchment) towards the sea, results in a hydraulic conductivity of approximately 11m/d, almost three times higher than that used by Pitman and Hutchison (1975).

10. LAKE SIBAYA WATER LEVEL MANAGEMENT

The natural maximum water level fluctuations recorded for Lake Sibaya (Figure 1, minimum ~18.2 and maximum 20.4 mamsl) represent a volume change of roughly 165 x $10^6 m^3$ (Perrit et al., 2002). The volume applied for in the permit application represents approximately 1.1% of this natural fluctuation.

Based on the recorded long-term, lake levels from gauging stations W7R001 A03, and the ecological requirements, the following lake reserve levels were set.

Table 5: Lake Sibaya Reserve water levels.

	Lake Water Level [mamsl*]	Equivalent Lake Volume [Mm^3]
Current full supply level	20.5	-
Maintenance minimum water level	19.6	802.2
Maintenance minimum dry season water level	18.9	752.7
Drought minimum water level	18.0	693.2

Results of the bathymetry survey conducted by the Council for Geoscience (Miller, 2001) were used to calculate the corresponding lake volume for the various set Reserve levels (Table 5).

11. CONCLUSIONS AND RECOMMENDATIONS

Lake Sibaya is the end result of a sequence of geological processes which culminated with the formation of a coastal dune barrier and thereby causing water to accumulate in the deep erosional features on the inland side of the coastal dune barrier. Contrary to the general belief, Lake Sibaya is not an accumulation of surface water runoff, but is the expression of the local natural ground water level in the area. The fluctuations of the lake water level and water quality of the lake, is directly linked to those of groundwater. As such the system should be managed together with the groundwater resources in the area, and should not be regarded as an isolated system with its own management plan.

The Northern KwaZulu-Natal coastal plain has vast unused groundwater resources. Most of these are naturally discharged to the ocean and can be utilised without any negative effect on the land based ecological systems. The development of the groundwater resources of the coastal plain is hampered by incorrect borehole drilling and construction techniques which have been used. This has led to a distrust in the sustainable supply of water from boreholes and groundwater sources in general. By applying appropriate drilling and borehole construction techniques, a water supply scheme from a properly designed well field can be established without any negative impact on the sensitive ecological conditions in the area. It is further believed that this can, at least for the volume of water for which a licence application has been lodged, be done at a much lower capital outlay and with less impact on the environment compared to that of a pipeline to and associated abstraction infrastructure at lake Sibaya. It is therefore strongly recommended that a groundwater development scheme using well designed boreholes be considered as an alternative to the Lake Sibaya abstraction scheme.

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