APPENDIX I8

HARTBEESPOORT DAM SPECIALIST OPINION

Proposed Mokolo and Crocodile River (West) Water Augmentation Project (Phase 2A) (MCWAP-2A)

Specialist Opinion: Impact of MCWAP-2A on Hartbeespoort Dam

July 2018

Submitted to:
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1 INTRODUCTION

1.1 Background to the project

Water requirements will increase in the Lephalale area due to various planned and anticipated developments associated with the Waterberg coalfields. The Department of Water and Sanitation (DWS) commissioned the Proposed Mokolo and Crocodile River (West) Water Augmentation Project (Phase 2A) (MCWAP-2A) Feasibility Study to investigate the options for meeting the aforementioned water requirements.

The proposed **MCWAP-2A Water Transfer Infrastructure** (WTI) consists of the following:

- Weir and abstraction infrastructure, including a balancing dam, desilting woks, and a high-lift pumping station at Vlieëpoort (near Thabazimbi);
- Transfer system (approximately 100 km);
- Break Pressure Reservoir;
- Operational Reservoir; and
- Delivery system, consisting of a gravity pipeline (approximately 30 km) running from the Operational Reservoir to the terminal point near Steenbokpan.

The project is located within the western part of the Limpopo Province. The footprint of MCWAP-2A WTI traverses the Thabazimbi Local Municipality (LM) and Lephalale LM, which fall within the Waterberg District Municipality (See Figure 1.1).

A key part of the MCWAP is the role that Hartbeespoort Dam will play. The impoundment will be used as a water supply to MCWAP-2A, releasing water when required. This is a different role to the historical supply of water for irrigation, industrial and domestic use as the impoundment will release water when there is a deficit in the system as opposed to the current situation when irrigation tends to be reduced in the winter months. Currently the impoundment remains almost full for most of the year. In future, there will be times in the year when the impoundment will be half full, and in times of extreme drought conditions, it will be almost empty (WRP, 2018). The water level in the dam would thus fluctuate, refer to Figure 3.4.

The focus of this report is the impact of the implementation of the MCWAP-2A on the limnology of Hartbeespoort Dam and specifically potential consequences of the impoundment having variable water levels during certain parts of the year.

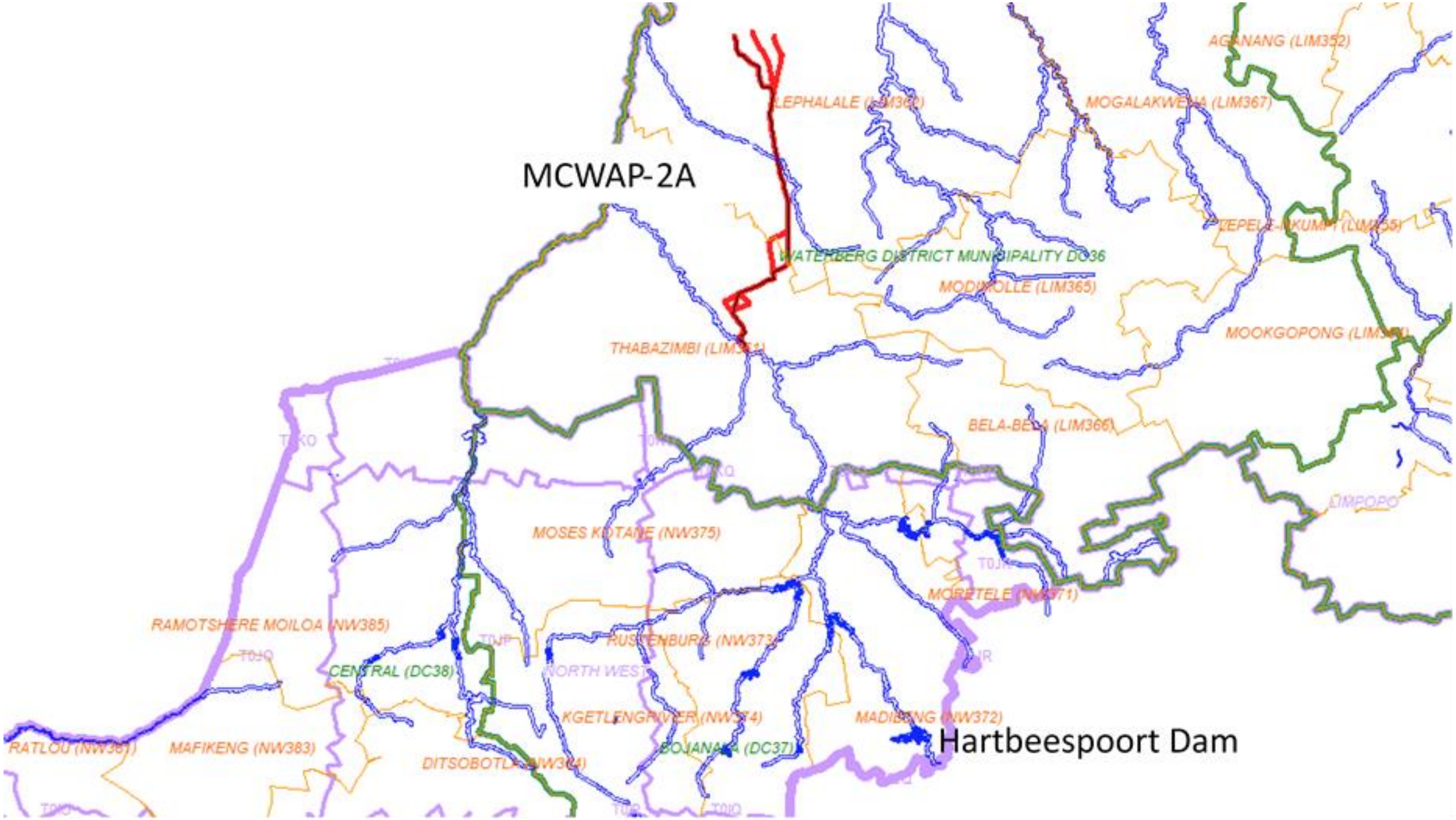

Figure 1.1: Layout of MCWAP-2A

1.2 Study Area

Hartbeespoort Dam is situated in the North West Province of South Africa. It lies in a valley to the south of the Magaliesberg mountain range and north of the Witwatersberg mountain range, about 35 kilometres west of Pretoria. The dam was originally (early 20th century) implemented for irrigation, which is currently its primary use, as well as for domestic and industrial use.

The impoundment lies at the confluence of the Crocodile and Magalies Rivers. The full supply capacity is 195 million m^3, and covers an area of 20 km^2. The maximum depth of the impoundment is 32,6 m and the average depth is 9,6m (Ashton et al, undated).

The catchment area of the dam is 4 100 km^2 and drains the predominantly urban areas of Johannesburg, Pretoria and Krugersdorp (see Figure 1.2).

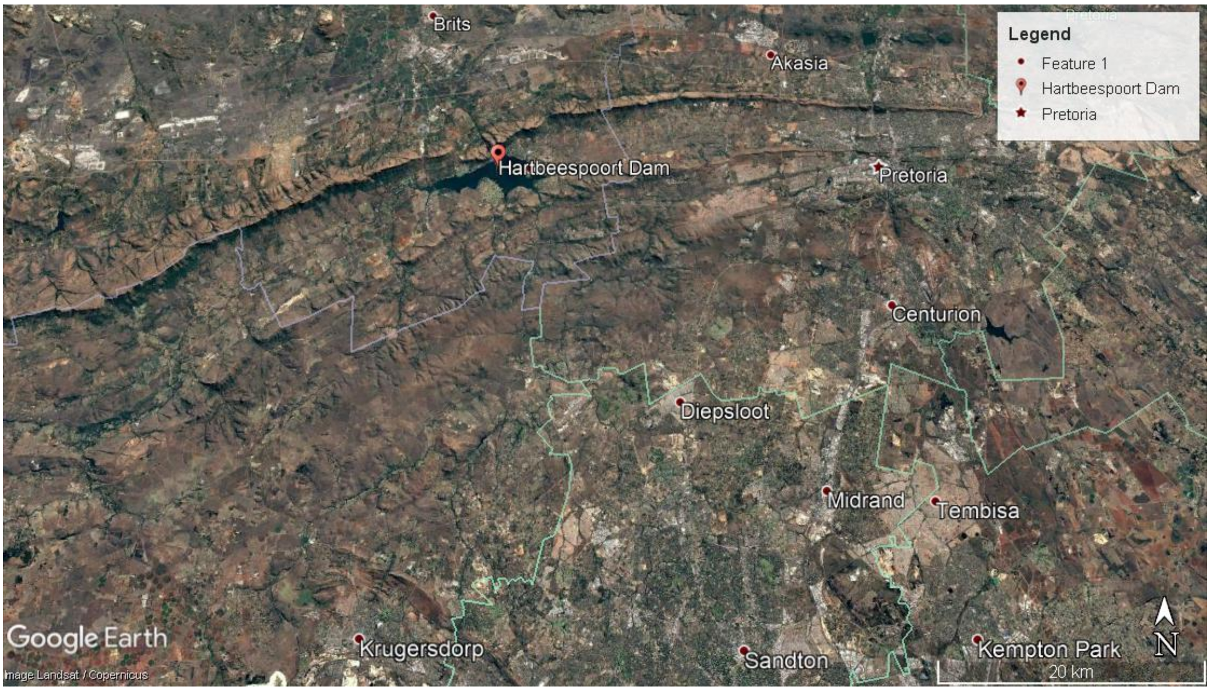

Figure 1.2: Site location of Hartbeespoort Dam

2 APPROACH TO SPECIALIST OPINION

The approach used in this opinion is based on an assessment of the current status of the impoundment, identification of the type of impacts that can occur and thereafter an evaluation of the possible impacts of the MCWAP-2A on the impoundment.

Data for this assessment was sourced from the Department of Water and Sanitation as follows:

- 1997 to 2018 Water Quality Data;
- 1997 to 2018 National Eutrophication Monitoring Programme;
- 1997 to 2018 Hydrological Monitoring Data;
- “Stelselontleding en gebruiksreëls” – Presentation to Hartebeespoort Dam stakeholders 13 March 2018; and
- Presentations during the Hartbeespoort Public Meeting 13 March 2018.

The Opinion provides a potential for impact occurrence and does not include any quantitative predictive modelling.

3 PROPOSED MCWAP-2A IMPACTS ON HARTBEESPOORT DAM

3.1 Overview

Hartbeespoort Dam is a warm hypertrophic, monomictic impoundment. It is prone to periodic massive blooms of cyanobacteria which forms dense scums on the surface of the impoundment. At times the impoundment is covered by dense stands of Water Hyacinth (*Eichornia crassipes*). The primary reason for the hypertrophic conditions in the impoundment are the influx of nutrients from waste water treatment works (WWTW) in its catchment, raw sewage and agricultural runoff.

With the implementation of MCWAP-2A and the predicted fluctuating water levels, it is necessary to identify the effect this will have on the following aspects:

- Overall water balance and morphometry;
- Water Quality;
- Primary Production; and
- Macrophytes.

3.2 Water balance and morphometry

3.2.1 Current State

For the past 20 years Hartbeespoort Dam has remained close to or at its Full Supply Capacity. Figure 3.1 shows that while there are many changes in the net storage in the impoundment, the volume remained relatively constant. Releases are made from the impoundment to supply irrigation, industrial and domestic to Magalies Water, and a small component of local domestic use. The overall impoundment balance for Hartbeespoort Dam is shown in Figure 3.2.

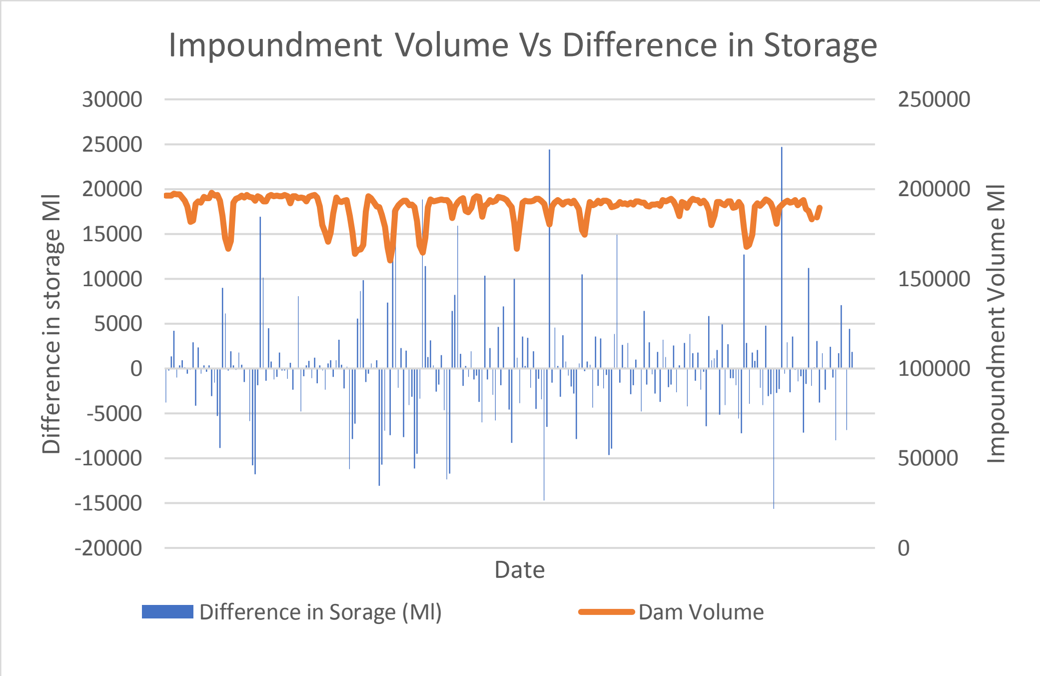

Figure 3.1: Hartbeespoort Dam volume and in storage 1997 to 2018 (DWS, 2018)

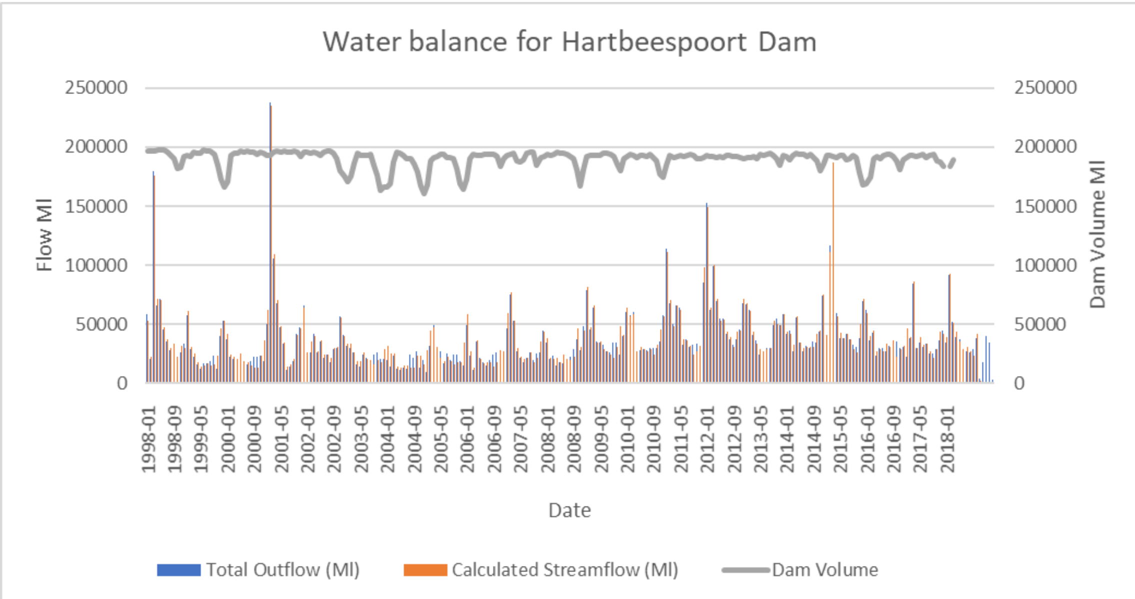

Figure 3.2: Bulk water balance for Hartbeespoort Dam 1997 to 2018 (DWS, 2018)

The water balance for Hartbeespoort Dam indicates that for the period 1997 to 2018 inflows and releases from the impoundment were closely tied. The outflows presented here exclude the spillway releases during high flow conditions. This 'extra' or spill water is a consequence of the impoundment being kept at nearly full supply capacity and can at times be significant.

The contribution of inflow from the Crocodile River to total inflow is presented in Figure 3.3. The graph demonstrates that the Crocodile River contributes the bulk of the flow into Hartbeespoort Dam.

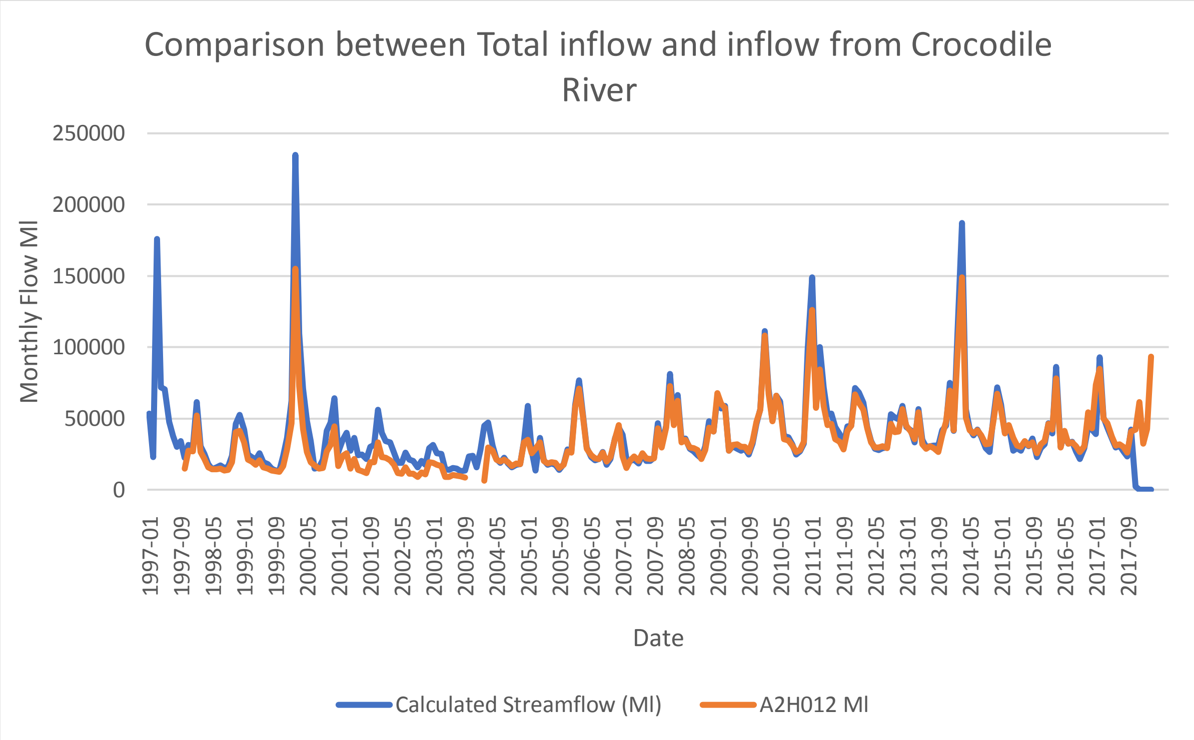

Figure 3.3: Total inflow to Hartbeespoort Demand contribution from Crocodile River (Monitoring Station A2H012), from 1997 to 2018 (DWS, 2018)

3.2.2 Consequences of MCWAP-2A

The assurance of supply of water for the MCWAP-2A will mean that there will be more variability in the stored volume of water in the impoundment. This is shown in Figure 3.4. Figure 3.4 presents the probability of impoundment storage volumes for a number of scenarios primarily of which is the inflow regime for the impoundment. In times of drought where the inflow to the impoundment is primarily from the point source discharges in the catchment, the demand for water to MCWAP-2A could result in the impoundment being operated at lower levels. The very worst case (1 of 1 000 sequences), when 100% of the inflow water is needed for downstream use, the impoundment will be approaching its minimum storage level. At a more realistic volume, where 50% of the inflow to the impoundment is required downstream, the impoundment will drop from a full supply capacity (FSC) of approximately 195 million m^3 to approximately 130 million m^3 each winter, i.e. approximately 6 m below the full supply level (FSL) of the dam.

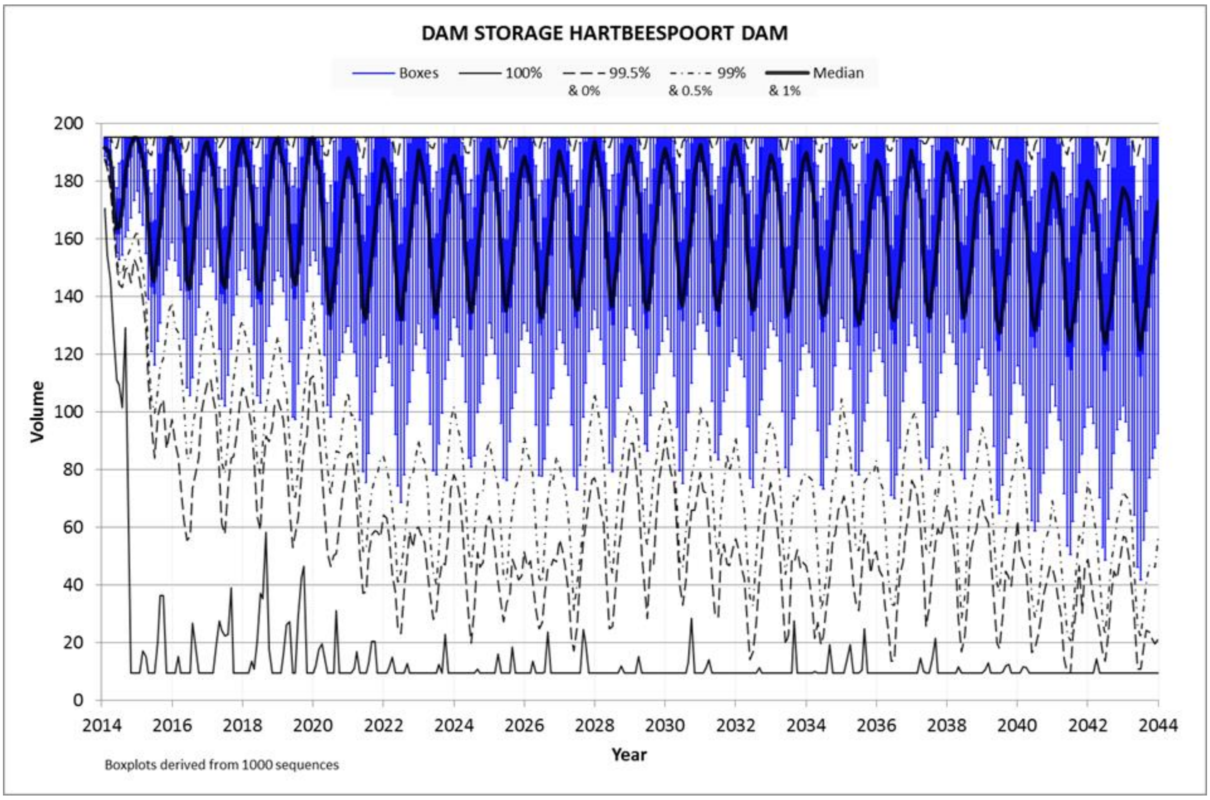

Figure 3.4: Expected impoundment volumes with probability of risk.

Converting this to a physical reduction in water level can be extrapolated from the area capacity curve for the impoundment (Figure 3.5) and Table 3.1. When the dam is at 50% of its full supply capacity (FSC), the depth of the impoundment decreases by approximately 6 m. At the FSC the water depth is 29,950 m, at the dam wall. At 50% of the FSC the depth will be 24,260 m (14,430 + 9,830) which is still above the lowest outflow pipe which is at 20,120 m below the FSL. Table 3.1 summarises the different volumes/area.

Table 3.1: Volume / area detail for Hartbeespoort Dam.

Reduced Level (RL) (m.a.s.l.)	Area (ha)	Gross Volume (million m^3)	Nett Volume (million m^3)	Gross FSC (%)	Nett FSC (%)	Gauge Plate (m)
1 132,390	4,32	0,009	0,000	**0,01**	0,00	-9,830
1 142,220 (lowest outlet pipe)	208,18	8,609 (dead storage capacity)	0	4,41	**0**	**0,00**
1 156,650	1 253,86	101,925	93,316	52,26	**50,05**	14,430
1 162,340 (FSL)	2 065,20	195,050	186,441 (FSC)	**100,0**	**100,0**	20,120

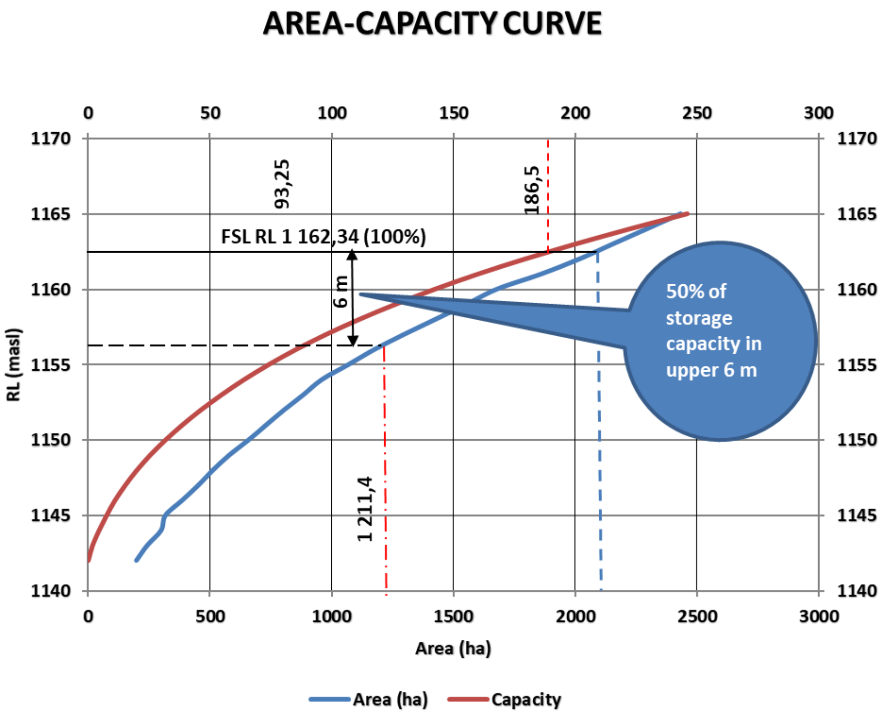

Figure 3.5: Area capacity curve for Hartbeespoort Dam

The change in surface area of the impoundment as is shown in Figure 3.6, where the dark blue area is at the FSC and the red area is at 50% capacity of the FSC, the average condition in winter after discharges for MCWAP-2A.

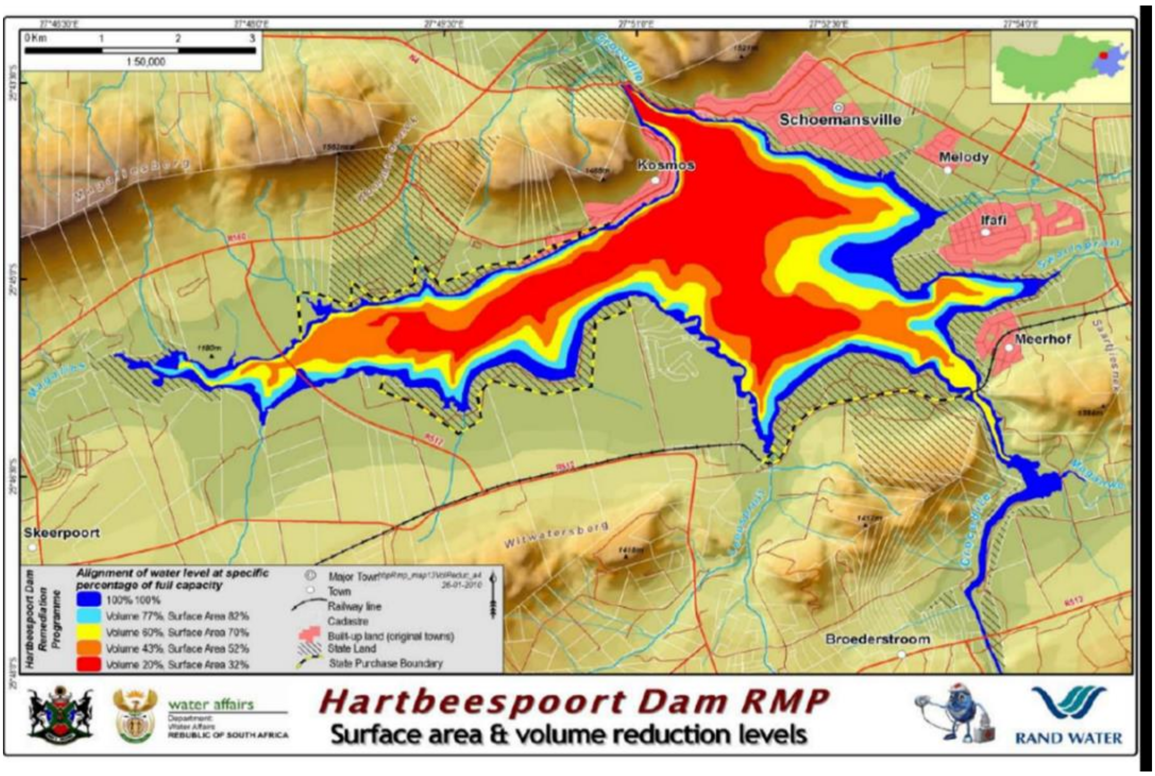

Figure 3.6: Surface area and volume reduction levels in Hartbeespoort Dam with MCWAP-2A

Of importance from this graph is that the surface area at 50% FSC will decrease from 2 065,20 ha at FSL to 1 253 ha (a 40 per cent reduction in area) and the distance from shore to water ranges between little change (at Cosmos) to approximately 500 m on the eastern shore. The approximate average distance around the impoundment is equal to 100 m.

3.2.3 Impacts on Hartbeespoort Dam

The impacts of MCWAP-2A on the water balance and morphometry of Hartbeespoort Dam, resulting from the probability of a 50% annual decrease in volume, depth and area, are:

- Smaller volume in the impoundment will increase the impact of the nutrient load to the impoundment as there is a smaller buffering capacity;
- The lowered depth will impact on shoreline areas as more land would be exposed, external influences from wind and sun will increase and the stratification patterns within the impoundment may change; and
- The reduction in surface area will provide less area for macrophyte infestation and thus the nature of compaction and removal may also change.

These impacts will be explored in more detail under the individual water quality, primary production and macrophyte impact sections.

3.2.4 Mitigation measures

There are no mitigation measures for the expected volume changes, changes to depth and surface area. It is the nature of MCWAP-2A that such impacts will occur.

3.3 Water Quality

Hartbeespoort Dam is classified as a hypereutrophic impoundment. The source of the eutrophication is nutrients rich waters entering the impoundment from WWTWs, urban runoff and agricultural return flow. The consequence of this are high concentrations of algae in the impoundment resulting in odour, taste and use problems and the proliferation of macrophyte infestations (Water Hyacinth).

The water quality of the impoundment is therefore of importance to the current and future use of the water. In the following sections, various water quality parameters are assessed:

- Oxygen and temperature regimes;
- Nitrogen compounds;
- Phosphorous compounds;
- Suspended sediments; and
- Salinity.

3.3.1 Oxygen and Temperature Regime

3.3.1.1 Current State

From late spring through early autumn, Hartbeespoort Dam experiences thermal stratification**,** a phenomenon where lakes separate into three distinct thermal layers. The warming of the surface of the water by the sun causes water density variations and initiates thermal stratification. Cooler, denser water settles to the bottom of the lake forming the hypolimnion. A layer of warmer water, called the epilimnion, floats on top. A thin middle layer called the metalimnion (or thermocline) separates the top and bottom layers and is characterized by a rapid change in water temperature. This separation often is strong enough to resist mixing of the layers by the wind. The most extreme thermal stratification occurs within lakes during the warm summer months. During autumn turnover, the epilimnion cools, sinks and falls below the thermocline, resulting in mixing.

Oxygen can enter a lake via three different routes. The main mechanism is atmospheric diffusion where oxygen in the air is absorbed by surface water due to a difference in oxygen concentrations. Second, aquatic plants photosynthesize and release oxygen into the water. Finally, rivers and streams bring oxygenated water into the lake. In stratified lakes, the hypolimnion receives little oxygen from atmospheric diffusion and is too dark to support oxygen-producing plant life. Riverine input has only minimal impacts on the oxygen content of large water bodies Thus, the deep hypolimnion receives very little dissolved oxygen during summer thermal stratification.

Once dissolved oxygen levels drop below 2 mg/l, the water is described as hypoxic. As it approaches 0 mg/l, it becomes anoxic. (Great Lakes Science, 2018). A general guide is that warm water fish require 5 mg/l oxygen (MDEQ, 1994).

The impoundment shows a strong thermocline at 15 m below surface at the dam wall (see Figure 3.7). There is an average of 5 degrees C difference in summer and 0,5 degrees C in winter (Figure 3.8).

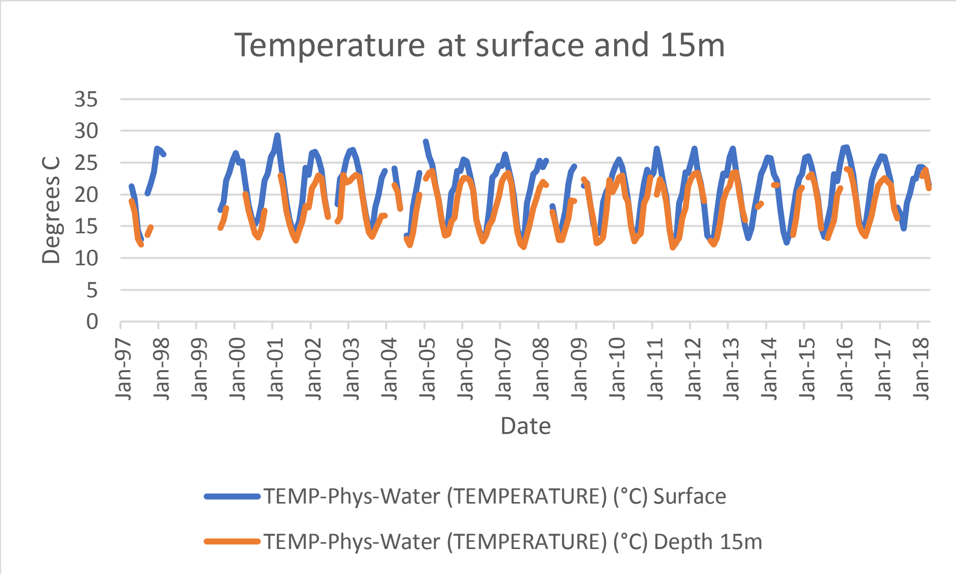

Figure 3.7: Temperature in impoundment at surface and 15m below surface

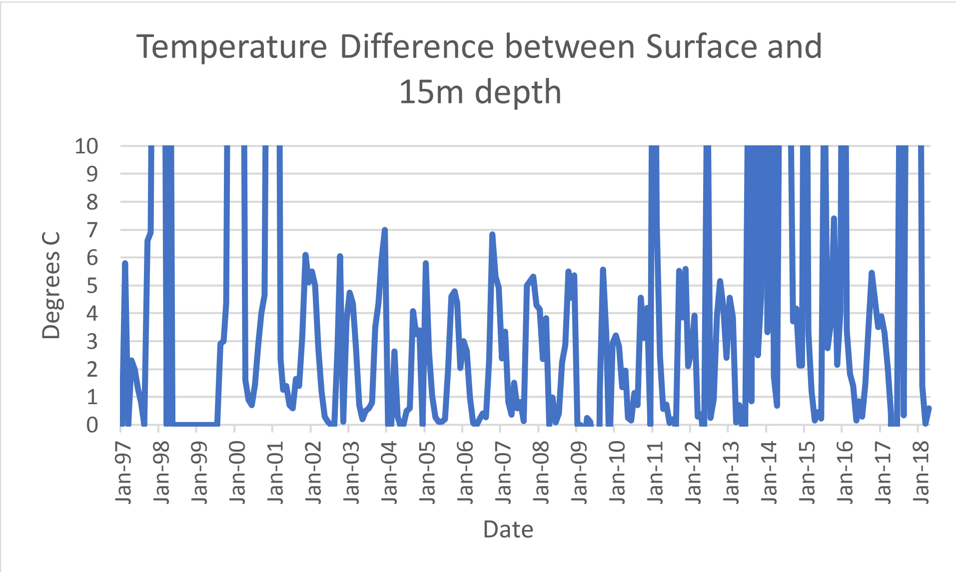

Figure 3.8: Difference in temperature in the impoundment between surface and 15m below surface (1997 to 2018)

The thermocline forms the barrier for oxygen replenishment and Figure 3.9 shows the existence of anoxic conditions during summer (<1 mg/l) but oxygenated in winter (>4 mg/l) at 15 m depth.

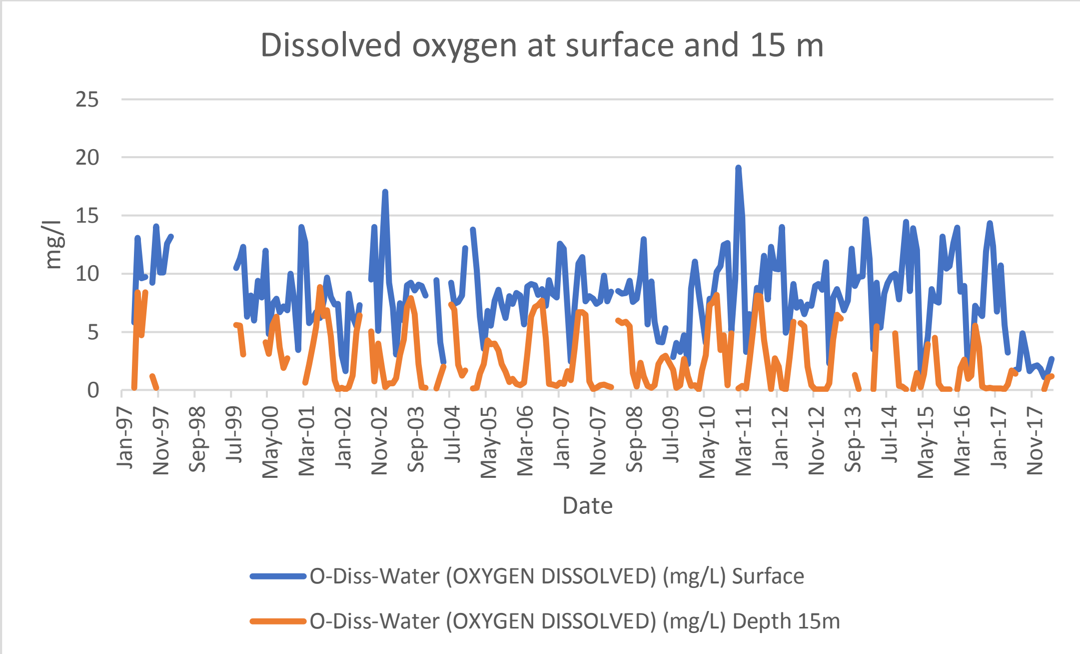

Figure 3.9: Oxygen concentrations in Hartbeespoort Dam

3.3.1.2 Consequences of MCWAP-2A

The primary consequence of the implementation of MCWAP is if there is a change in either temperature or oxygen profiles in Hartbeespoort Dam. It has become increasingly recognized that thermocline depth is an important and integrative factor for plankton community structure and function in stratified lakes, especially for the phytoplankton, which have more limited motility than other groups (e.g., Berger et al. 2006). Thus, should the fluctuation in depth last over more than the winter period into the time when stratification occurs, and the impoundment changes its stratification pattern, then this could provide more water habitat for phytoplankton and thus increase the biomass. For a hypereutrophic impoundment, this could exacerbate cyanobacteria blooms.

3.3.1.3 Impacts on Hartbeespoort Dam

In the period between 1997 and 2018, the impoundment was operated at or near the FSL. There were however some variable water volumes during the period 2004 to 2009 (see Figure 3.10). The capacity of the impoundment decreased by some 30 million m^3 during spring and early summer due to a decrease in natural inflow to the impoundment. Comparing these volumes to the area capacity curve for Hartbeespoort Dam (Figure 3.5) the net decrease in depth during the low volume levels was approximately 2 m. From Figure 3.10 it can clearly be seen that during these low volume periods and a drop in water level by 2 m, there was still a strong hypolimnion with anoxic conditions. The predicted water volumes and thus depth for spring and early summer during the implementation of MCWAP-2A (Figure 3.4) indicate that the depth of the impoundment will be 2 m below FSL at this time. It is thus anticipated that there will be limited impact on the thermocline and hypolimnion during average demand from Hartbeespoort Dam. Since the impoundment is not stratified during winter, there will be no change to current status of the stratification of the impoundment as a result of the MCWAP-2A.

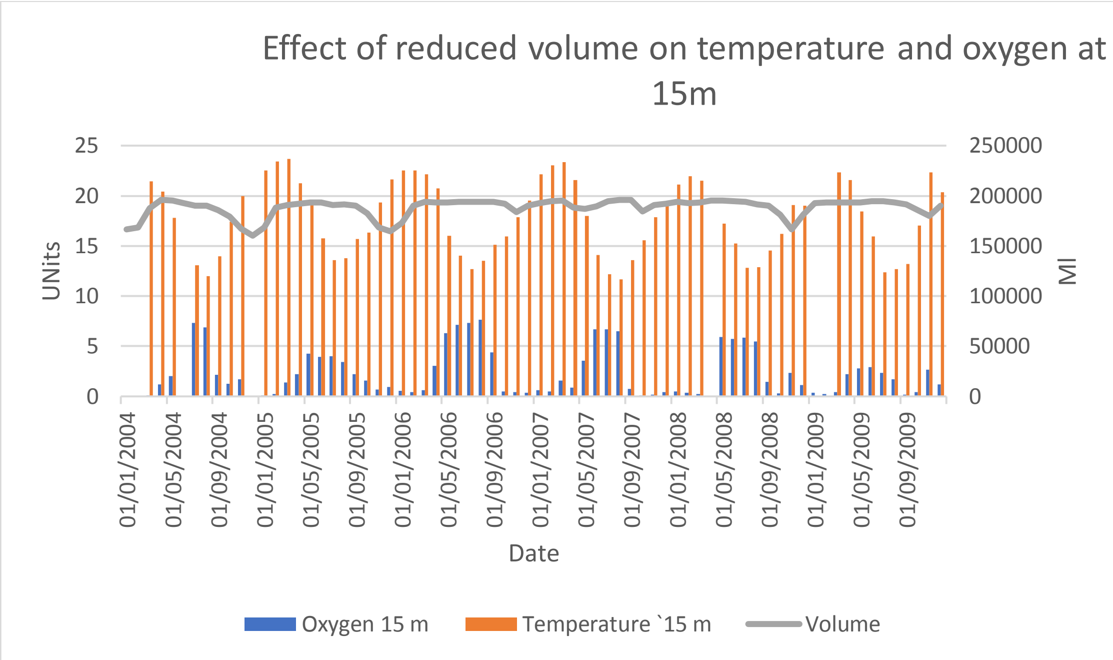

Figure 3.10: Effect of reduced volume on temperature and oxygen at 15 m below surface

3.3.1.4 Mitigation measures

It is not anticipated that there will be a significant change to the stratification and hypolimnion in Hartbeespoort Dam and thus no mitigation measures are proposed.

3.3.2 Primary Production

3.3.2.1 Current State

The trophic status of a water body can roughly be assessed by using information about the concentration of the limiting nutrient (phosphorus), chlorophyll (an indicator of phytoplankton biomass), and transparency (dependent on both algal biomass and sediment resuspension, expressed as Secchi depth) (Istvánovics, 2009). The most widely accepted limits are those suggested by the Organization for Economic Cooperation and Development (OECD) (Table 3.2):

Table 3.2: OECD limits for trophic state of impoundments

Trophic category	*Mean total, P (µg l^{-1})*	*Mean (µg chl-a l^{-1})*	*Max. (µg chl-a l^{-1})*	*Mean Secchi depth (m)*
Oligotrophic	<10	<2,5	<8	>6
Mesotrophic	10–35	2,5–8	8–25	6–3
Eutrophic	>35	>8	>25	<3

Table 3.3 summarises the chlorophyll *a* concentrations in Hartbeespoort Dam from 1997 to 2018. The median value (more representative than average) is 38,4 ug/l. This indicates

eutrophic state. The 95th percentile value of 273,07 ug/l is far in excess of the maximum limit and confirms the eutrophic state. The median Total Phosphate concentration is 200 ug/l, confirming the eutrophic state of Hartbeespoort Dam (see Section 3.3.5)

Table 3.3: Summary statistics for Chlorophyll *a* in Hartbeespoort Dam from 1997 to 2018

Statistics	ug/l
Minimum	0,35
5th percentile	3,119
Average	118,616 7
Median	38,44
95th percentile	273,075 4
Maximum	12 209

The time series of Chlorophyll a in the impoundment is shown in Figure 3.11. The seasonal variation in concentration demonstrates the role that external factors such as light, temperature and nutrients may play in the productivity of the impoundment.

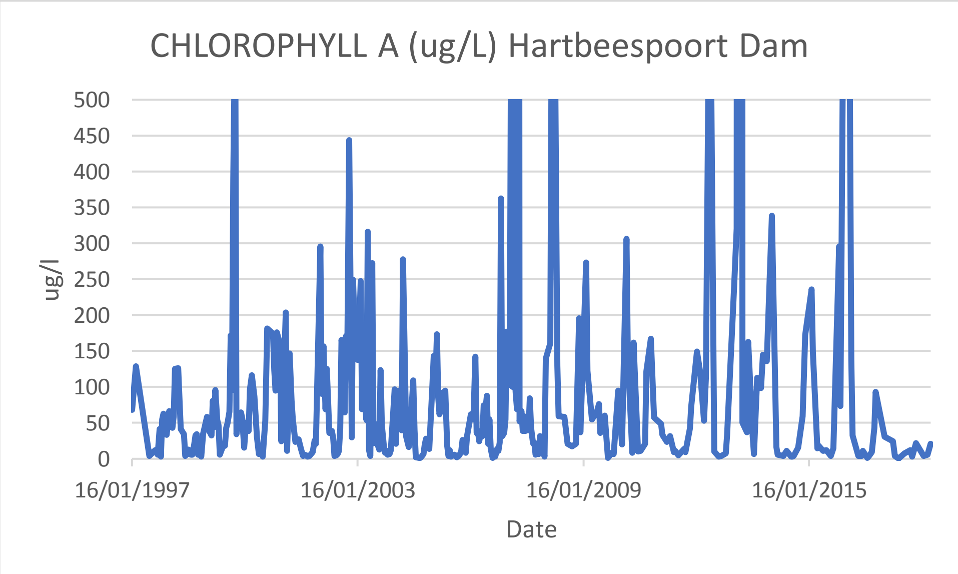

Figure 3.11: Chlorophyll a concentration in Hartbeespoort Dam from 1997 to 2018

With respect to algal species dominance during the year, the winter dominant species are diatoms, specifically *Melosira sp* (Figure 3.12). In summer, the dominant species is *Microcystis sp*. A Cyanobacteria which forms dense algal scums and produces odour and taste problems when the scums decay.

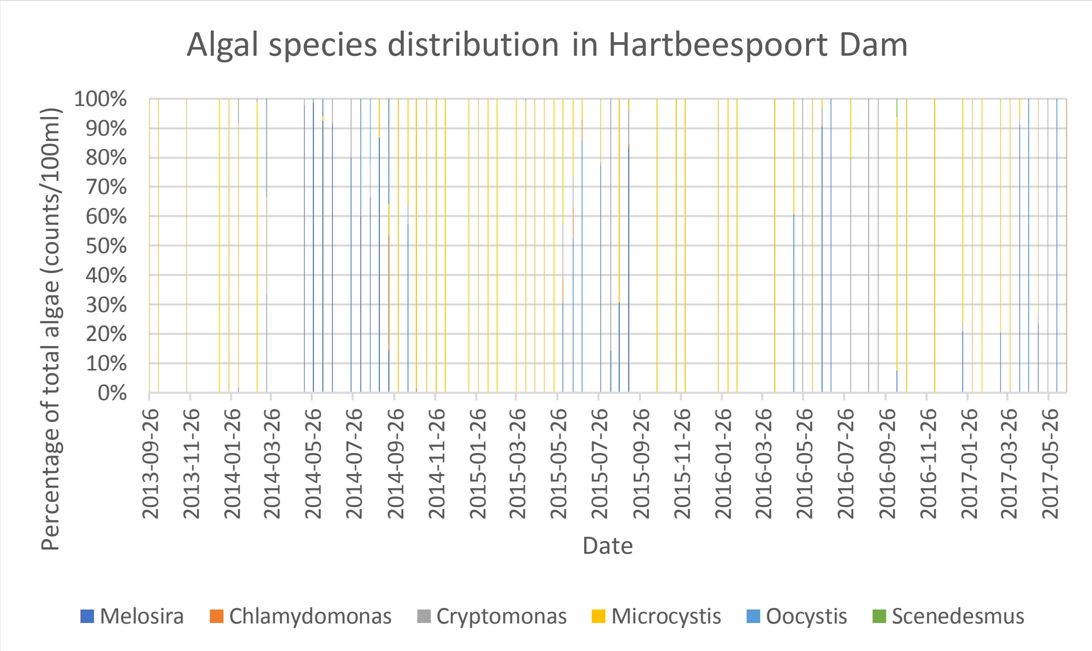

Figure 3.12: Algal dominance in Hartbeespoort Dam

Table 3.4: Legend for algal genus and type

Genus	Type
Melosira	Diatom
Chlamydomonas	Green
Cryptomonas	Green
Microcystis	Cyanobacteria
Oocystis	Green
Scenedesmus	Green

3.3.2.2 Consequences of MCWAP-2A

The implementation of MCWAP-2A could have important implications for the algal concentrations and type in Hartbeespoort Dam and these could either reduce the impact of problematic algal species in the impoundment or exacerbate it.

3.3.2.3 Impacts on Hartbeespoort Dam

Algae require a number of optimal conditions to grow. In general these can be grouped together as:

- Physical conditions such as temperature and light availability; and
- Chemical conditions such as nutrients.

Physical conditions - Temperature

As discussed in Section 3.2, the net decrease in surface area during the winter period at the 50th percentile is 40 %. This decrease is unlikely to influence the temperature to change the algal production in the impoundment during winter when production is already low.

During summer periods (at 50th percentile), it is estimated that there will be no major change to the thermocline (Section 3.3.1). The impoundment is classified as hypereutrophic and thus summer algal blooms will continue to occur as a result of temperature.

Chemical conditions – Nutrients

Eutrophication of lakes or reservoirs is usually marked as the increase of phytoplankton. Phytoplankton abundance [measured as chlorophyll-a (chl-a)] is associated with a number of (among which, phosphorus (P) is usually regarded as the primary limiting nutrients. However, sometimes unexplained variations occur in the total phosphorus (TP)-chl-a relations. Accordingly, total nitrogen: total phosphorus ratio (TN:TP ratio) is often proposed as an index to divide lakes or reservoirs into N- and P-limited categories. Usually, lakes or reservoirs have been regarded as limited by total phosphorus (TP) if TN:TP ratio was relatively large (>10), limited by total nitrogen (TN) if TN:TP ratio was relatively small (<10) (Cui, 2011).

The TN:TP in Hartbeespoort Dam is greater than 10 in summer, and at times less than 10 in winter (Figure 3.13). However, in Hartbeespoort Dam, the relationship between TN:TP and chlorophyll *a* is not well defined. This would indicate that the nutrient limitation to primary production fluctuates between nitrogen and phosphorous depending on other factors. Summer dominance of algae by *Microsystis sp* is probably a function of its intracellular structures, the gas vesicles, which provide cells with buoyancy. These hollow, gas-filled structures can keep Microcystis cells close to the surface of the water body, where there is optimal light and oxygen for growth. There is some evidence that Microcystis can co-exist with nitrogen fixing species such as Anabaena sp. and utilise the additional dissolved inorganic nitrogen in the water (Parrish, 2014).

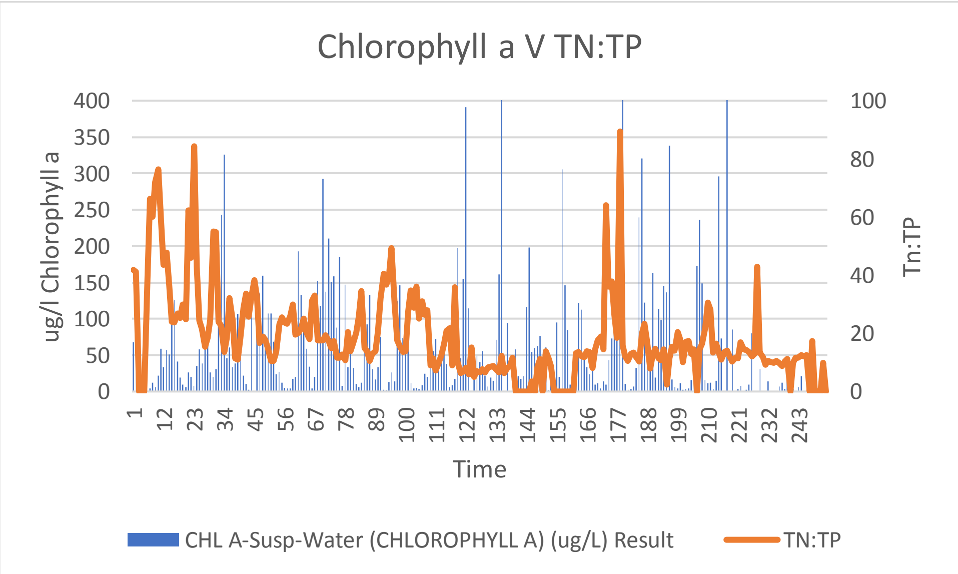

Figure 3.13: Chlorophyll *a* versus TN:TP in Hartbeespoort Dam (data shown in months)

The potential impact of MCWAP on primary production in Hartbeespoort Dam is unlikely to influence primary production in Hartbeespoort Dam. The physical parameters controlling problem aquatic algae won't change during the winter, as colder conditions currently limit production.

As far as nutrients are concerned, problem algal production will still occur as the dominant species is Microcyctis which is able to thrive in low nitrogen conditions and which outcompetes other algae due to its physical attributes.

3.3.2.4 Mitigation measures

Mitigation measures to reduce in lake primary production need to address inflow water quality and any residual nutrients accumulated in the lake.

3.3.3 Nitrogen Compounds

3.3.3.1 Current State

Algae, cyanobacteria, and other photosynthetic organisms require over 20 elements for growth and survival. Nitrogen (N), and phosphorus (P), are often in shortest supply in relation to demand in lakes; thus their concentrations often limit phytoplankton growth (Schaedel, 2011). Hartbeespoort Dam is hypereutrophic and thus has an abundance of Nitrogen and Phosphorous which results in large algal blooms, often times by cyanobacteria. The chemical forms of N and P also play a role in the competition between phytoplankton species in lakes. For example, most algae require N as ammonium (NH_4 +) or nitrate (NO_3 -) while some cyanobacteria species can utilize dissolved N gas (N_2). This gives cyanobacteria a competitive advantage when NH_4 + and NO_3 - concentrations are depleted and P is not limiting (Schaedel, 2011).

The inflowing rivers to Hartbeespoort Dam drain Johannesburg, Krugersdorp and parts of Pretoria. The rivers are receivers for point source discharges from WWTWs, diffuse runoff from urban areas (including sewer breaks) and agricultural return flow. Figure 3.14 shows the concentration of nitrates in the 3 inflowing rivers to the impoundment, the Swartspruit, Magalies and Crocodile Rivers from 1997 until 2017. It is evident from the graph that the concentrations of nitrates in the Crocodile River are consistently significantly greater than the other 2 rivers.

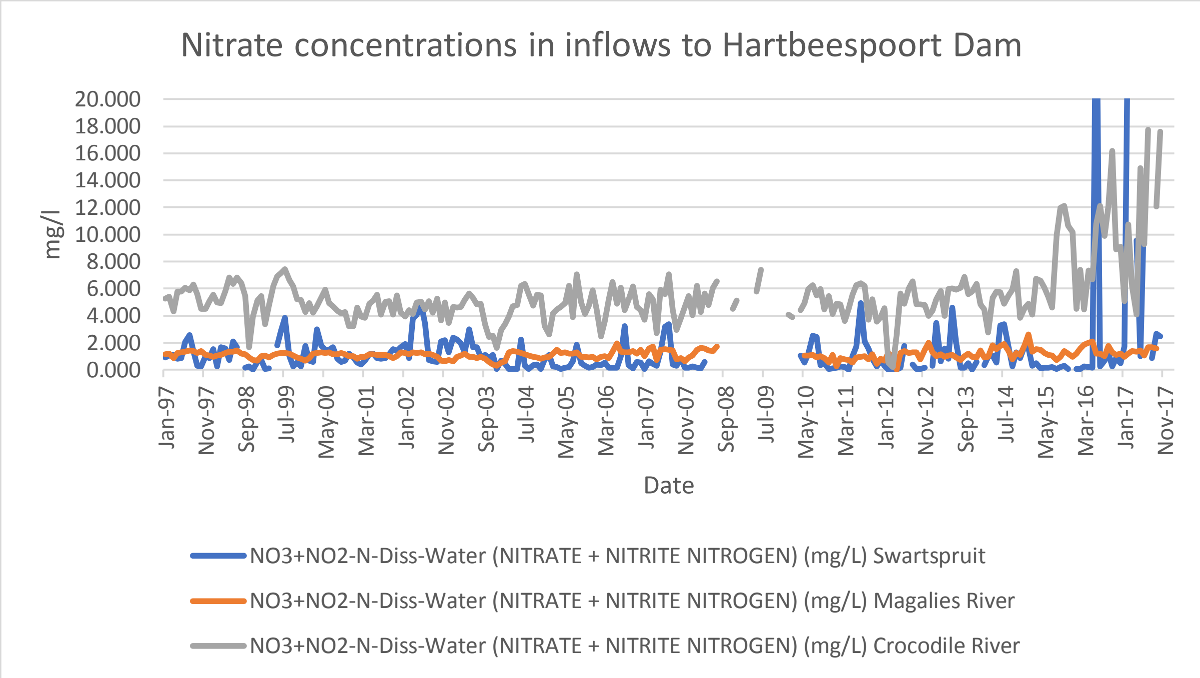

Figure 3.14: Nitrate concentrations in the Swartspruit, Magalies and Crocodile Rivers

As identified in Figure 3.3, the Crocodile River is also the main volume contributor to the inflow to Hartbeespoort Dam.

It has been identified that the significantly high concentrations of nitrates in late 2016 are related to WWTW breakdowns, but the graph would indicate that either this is an ongoing issue or that there are other significant contributors.

In-lake concentration of nitrates follow a similar pattern to the inflows from the Crocodile River (Figure 3.15). However, a regression analysis yields an R^2 of 0,251 3 between the inflow concentration and the in-lake concentration, which suggests that nitrates in the inflow to the nitrates in the impoundment are not well correlated.

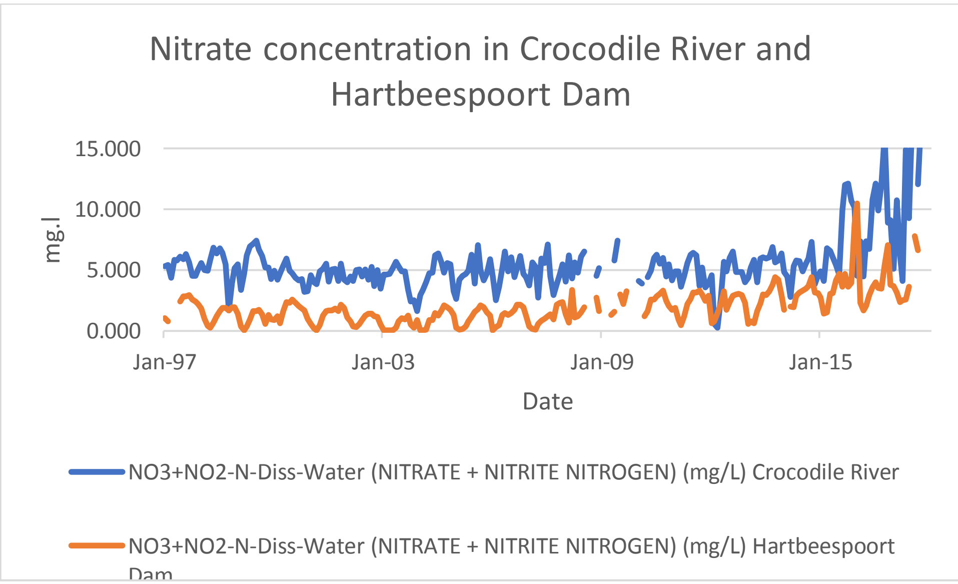

Figure 3.15 Nitrate concentration in Hartbeespoort Dam

3.3.3.2 Consequences of MCWAP-2A

The consequences of the implementation of MCWAP on the concentration of nitrates in Hartbeespoort Dam could result in a change to the composition of algae within the impoundment as well as the abundance of the algae in the impoundment.

3.3.3.3 Impacts on Hartbeespoort Dam

The potential impacts on Hartbeespoort Dam can be divided into winter and summer impacts.

During winter at the 50th percentile, with the implementation of MCWAP, impoundment levels are expected to drop by up to 6 m. However, as the area capacity curve and area volume map shows (Figure 3.5 and 3.6) the impoundment surface area will only reduce by 800 ha. This reduction in area by 40% is unlikely to have a significant effect in winter, as primary production is limited by temperature and light during this period.

During summer periods under the 50th percentile scenario, high concentrations of nitrates are suitable for blooms of algae. With the advent of MCWAP-2A, these high concentrations are expected to continue and thus blooms of algae will continue to occur.

3.3.3.4 Mitigation measures

No specific mitigation measures for MCWAP-2A can be identified because of the significance of loading from upstream sources rather than operational factors of the Impoundment. However, the MCWAP-2A will be impacted by the quality of the water that is released from Hartbeespoort Dam. It would be in the Department's best interests to consider external mitigation measures such as:

- Reduction at source – reduce nutrient loading by maintaining upgrading point source water treatment works and diffuse source breakdown of water reticulation systems;
- Pre-impoundment treatment – installation of a pre-lake or wetland to assist with the removal of nutrients before they enter the impoundment; and
- In-lake treatment – building from the now defunct Hartbeespoort Dam's Resource Management Plan for a longer period of time and a on a continuous basis.

3.3.4 Phosphorous Compounds

3.3.4.1 Current State

The consequences of phosphorus enrichment in reservoirs are primarily connected with the emerging abundance of cyanobacteria. However, the N:P ratio turns out to be the factor which regulates the dominance of planktonic communities by blue-green or green microorganisms.

Decrease of the N:P ratio, through the addition of phosphorus compounds, leads to cyanobacterial blooming (Jin Lv et al,2011).

Figure 3.16 shows the concentration of phosphates in the 3 inflowing rivers to the impoundment, i.e. the Swartspruit, Magalies and Crocodile Rivers. The highest concentration of phosphates are recorded in the Swartspruit, but since it's volume contribution is small, the total load from the Swartspruit is also relatively small. Figure 3.17 graphs the load contributions for the Swartspruit and the Crocodile River.

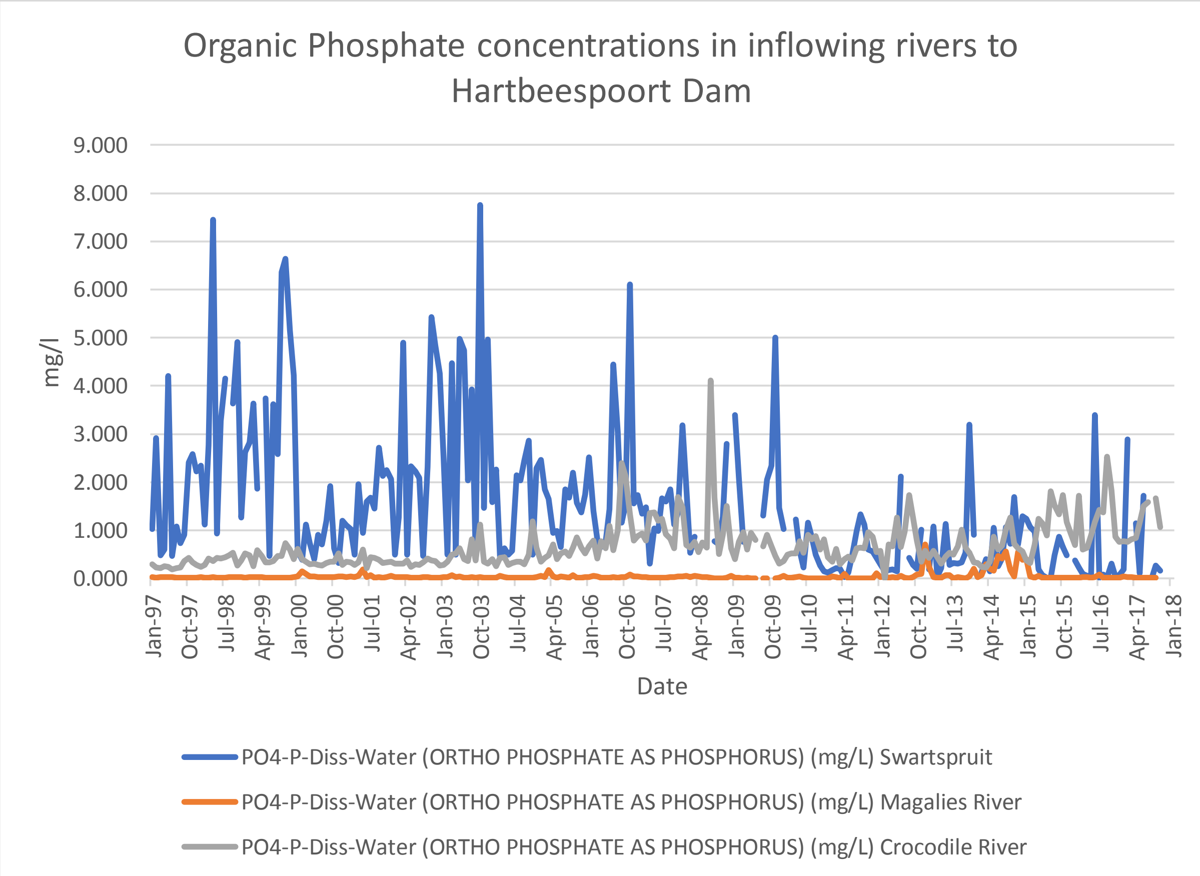

Figure 3.16: Phosphate concentrations in the Swartspruit, Magalies and Crocodile Rivers

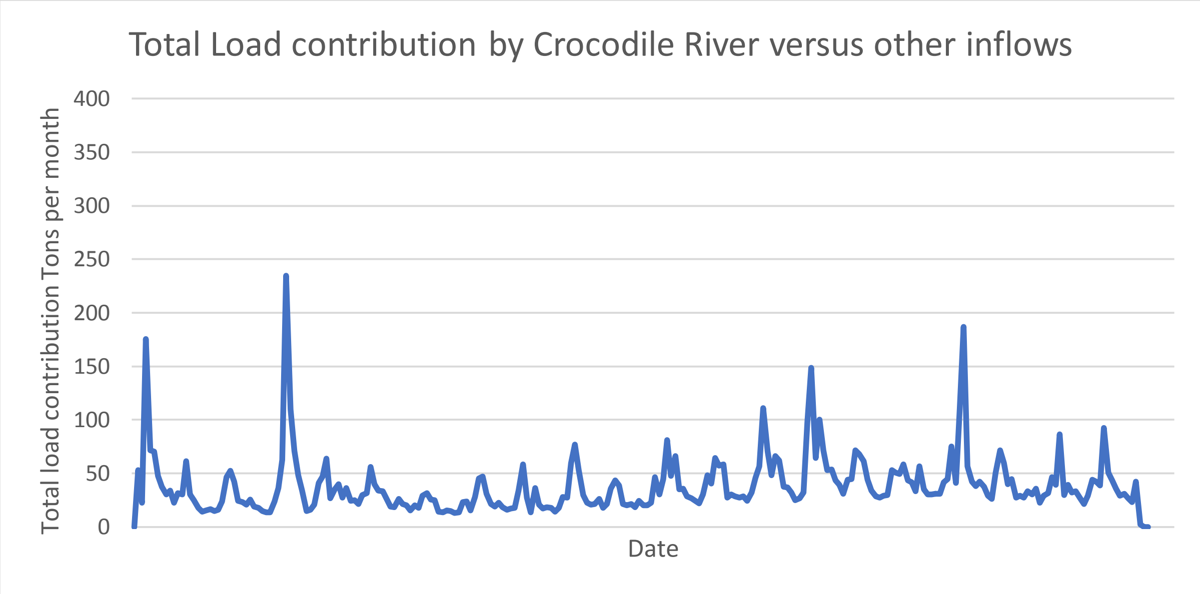

Figure 3.17: Net load contributions for the Crocodile River compared to other inflows

Figure 3.17 shows that the dominant phosphate load entering Hartbeespoort Dam is the Crocodile River. The contribution from the Crocodile River is some 6 200 tons from 1997 to 2018. The other inflows account for a total load of 975 tons from 1997 to 1018.

Figure 3.18 presents the concentration of Phosphates in the Crocodile River and in the impoundment.

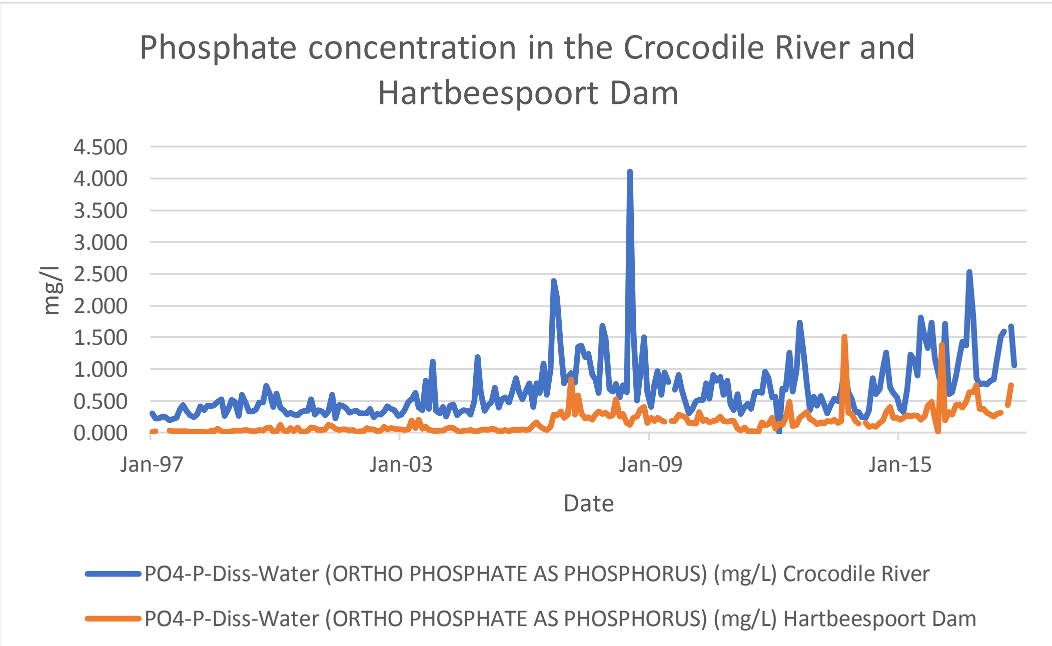

Figure 3.18: Phosphate concentration in the Crocodile River and Hartbeespoort Dam

The cause of the dramatic peak in phosphate concentration in December 2008 is unknown.

An additional source of phosphates in Hartbeespoort Dam are the sediments in the impoundment. In a study by Kukic and Venter (circa 2008), the conclusion was drawn that the sediments are a large source of nutrients to the impoundment, primarily phosphorous, and a significant contributor to eutrophication. Estimates at that time indicated that the major part of sediments (more than 80%) was distributed over approximately 25% of the Impoundment's area. The accumulation of sediments was predominantly in the once natural river beds and valleys. In this study it was also estimated that there was some 1 000 tons of phosphate bound within the sediments.

3.3.4.2 Consequences of MCWAP-2A

The consequences of the implementation of MCWAP-2A on the concentration of phosphates in Hartbeespoort Dam could result in a change to the composition of algae within the impoundment as well as the abundance of the algae in the impoundment.

An additional consequence is the exposure of parts of the impoundment during winter which on subsequent filling in summer, could release phosphate back into the impoundment and exacerbate the total phosphate load within the impoundment.

3.3.4.3 Impacts on Hartbeespoort Dam

In a similar fashion to nitrate in the impoundment, the relative change of the eutrophication status of the impoundment is unlikely to change for the better with the implementation of MCWAP-2A. There are 2 main sources of phosphates, inflow from the Crocodile River and the sediments in the impoundment, and this in fact may make the impoundment more eutrophic.

During winter under the 50^{th} percentile scenario, the load to the impoundment remains constant as the dominant flow is the Crocodile River. However, the lowered water level in the impoundment will expose a certain portion of the sediments and through desiccation and physical action by wind, phosphates can be released when the impoundment starts to refill. The scale of this release is difficult to assess because the bulk of the sediment lies within the deeper basin which will not be influenced by the lower winter levels. There is however, a portion of the sediments deposited in the Crocodile River basin in the impoundment and a portion of these could be exposed during low water levels. It is for this reason that there is a possibility that the primary production in the impoundment will increase during the early spring and summer period when temperature and solar radiation becomes favourable for algal growth.

3.3.4.4 Mitigation measures

No specific mitigation measures for MCWAP-2A can be identified because of the significance of loading from upstream sources rather than operational factors of the Impoundment. However, the MCWAP-2A will be impacted by the quality of the water that is released from Hartbeespoort Dam and accordingly the water users will have to design for this situation. It would be in the Department's best interests to consider external mitigation measures such as:

- Reduction at source – reduce nutrient loading by maintaining upgrading point source water treatment works and diffuse source breakdown of water reticulation systems;
- Pre-impoundment treatment – installation of a pre-lake or wetland to assist with the removal of nutrients before they enter the impoundment; and
- In-lake treatment – Dredging of sediments during winter when the lower impoundment water levels provides greater surface area for mechanical removal.

3.3.5 Salinity

3.3.5.1 Current State

In the period 1997 to 2008, Hartbeespoort Dam salinity levels remained fairly constant at around 350 mg/l Dissolved Mineral Salts (DMS) (Figure 3.19). During the period 2008 to 2014 there was a marginal increase in DMS to 375 mg/l. From 2015 to date the DMS has increased slightly and remains fairly constant throughout the year. Peak concentrations occur during summer months.

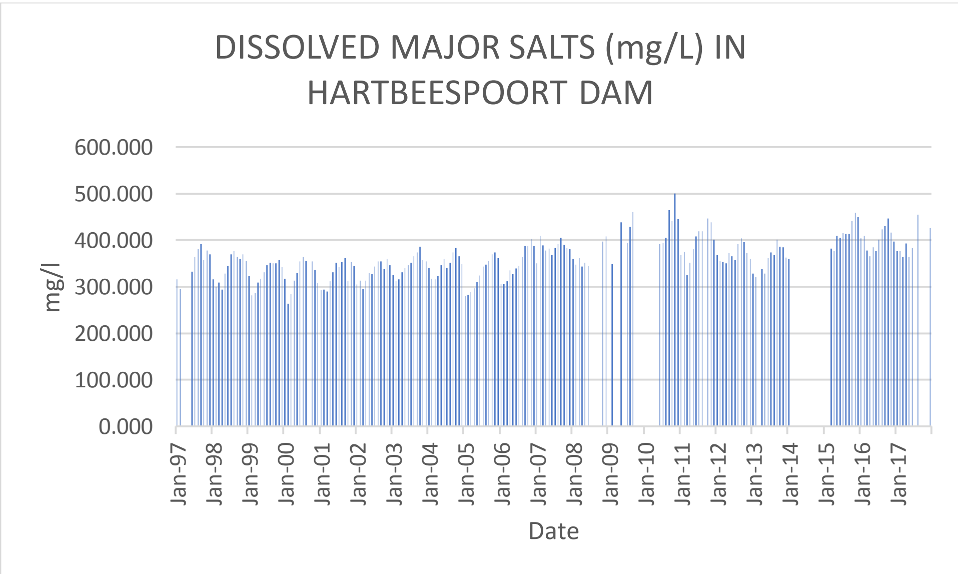

Figure 3.19: Dissolved Major Salts concentration on Hartbeespoort Dam

The DMS concentration in Hartbeespoort Dam is influenced by the DMS in the Crocodile River (Figure 3.20). There is a slight dilution effect within the impoundment. This means that any change in the inflow DMS from the Crocodile River will be reflected in the DMS concentration in the impoundment itself.

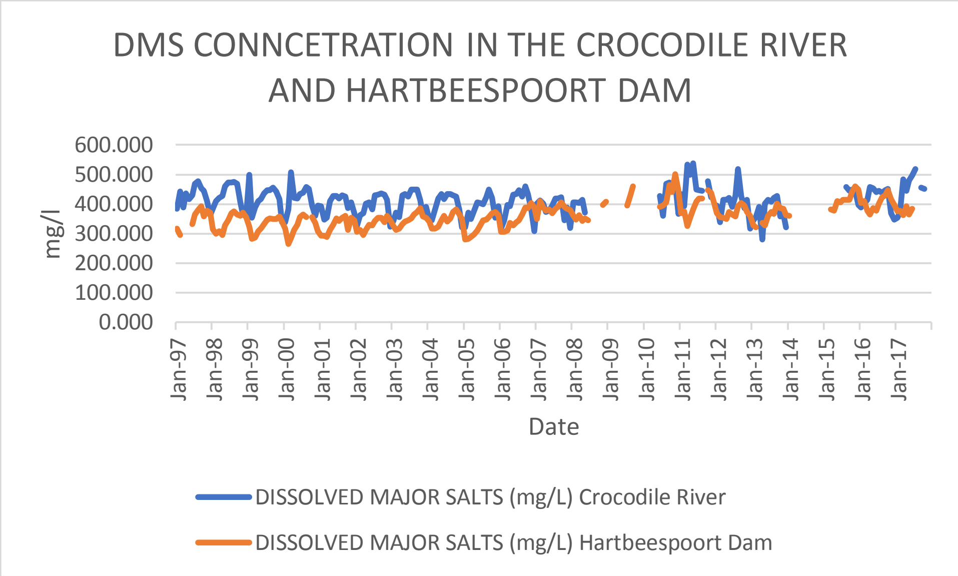

Figure 3.20: Dissolved Mineral Salt concentrations in the Crocodile River and Hartbeespoort Dam

3.3.5.2 Consequences of MCWAP-2A

The consequence of implementing the MCWAP-2A on salinity in Hartbeespoort Dam could mean that catchment related activities will increase the salinity of the impoundment. This could have implications for both in-lake processes and downstream users of the MCWAP-2A water.

3.3.5.3 Impacts on Hartbeespoort Dam

The nature of changing water quality in a large number of South African rivers is increasing salinity. An increase in salinity can impact on a number of reservoir processes:

- Biodiversity; and
- Reservoir chemical processes;

The current concentrations of DMS in the impoundment are not a cause for concern, but incremental changes over time may impact of the ecological nature of the impoundment.

3.3.5.3.1 <u>Biodiversity</u>

Research has identified that in general, freshwater ecosystems undergo little ecological stress when subjected to salinities up to 1 000 mg/l. However, this view could lead to the misinterpretation that freshwater ecosystems below 1 000 mg/l are ‘healthy’, and there will be no adverse effects on biota or ecosystems. For many taxa, sub-lethal effects may not be apparent at the community level for many generations (Nielsen, 2003). Thus increasing salinity in Hartbeespoort Dam may not be seen for a number of seasons after the salinity has already increased.

3.3.5.3.2 In-lake chemical processes;

Salinization can alter the relative proportions of cations and anions in water that can change chemical equilibria and solubility of some minerals. The major cationic (Na+, K+, Mg2+, and Ca2+) and anionic species (Cl– , SO_4 2–, HCO_3 – /CO_3 –) vary between locations in both abundance and concentration. Freshwater biota are influenced as much by the ionic composition and pH of water as by the total concentration of dissolved substances (Frey 1993). The relative proportions of the main cations and anions modify the way biota respond to high salinities, (Nielsen, 2003). The chemical constituent of the increasing salinity, such as an increase in sulphate as a result of mining related activities in the Hartbeespoort Dam catchment, may have a greater impact at lower increases than a larger increase of the DMS in total.

3.3.5.4 Mitigation measures

Mitigation measures for increasing salinity in Hartbeespoort Dam are currently not required but in future it may be necessary to investigate pre-impoundment systems such as wetlands and ion specific options such as sulphate precipitation.

3.4 Macrophytes

3.4.1.1 Current State

"Water hyacinth is frequently branded as the world's worst aquatic weed due to its invasive potential, negative impact on aquatic ecosystems, and the cost it necessitates to control it." (ARC, 2014)

E. crassipes has been declared a category 1b weed in terms of the National Environmental Management: Biodiversity Act (No. 10 of 2004): Alien and Invasive Species Regulations, 2014, which necessitates its control or eradication where possible (ARC, 2014).

Water Hyacinth (*Eichornia crassipes*) has been a dominant feature of Hartbeespoort Dam since the 1970's. The following Google images show the coverage at specific dates from 2004 to 2017.

Figure 3.21: Google image for May 2004 showing large areas of the Hartbeespoort Dam covered by Water Hyacinth.

Figure 3.22: Google image for March 2016 showing large areas of the Hartbeespoort Dam covered by Water Hyacinth.

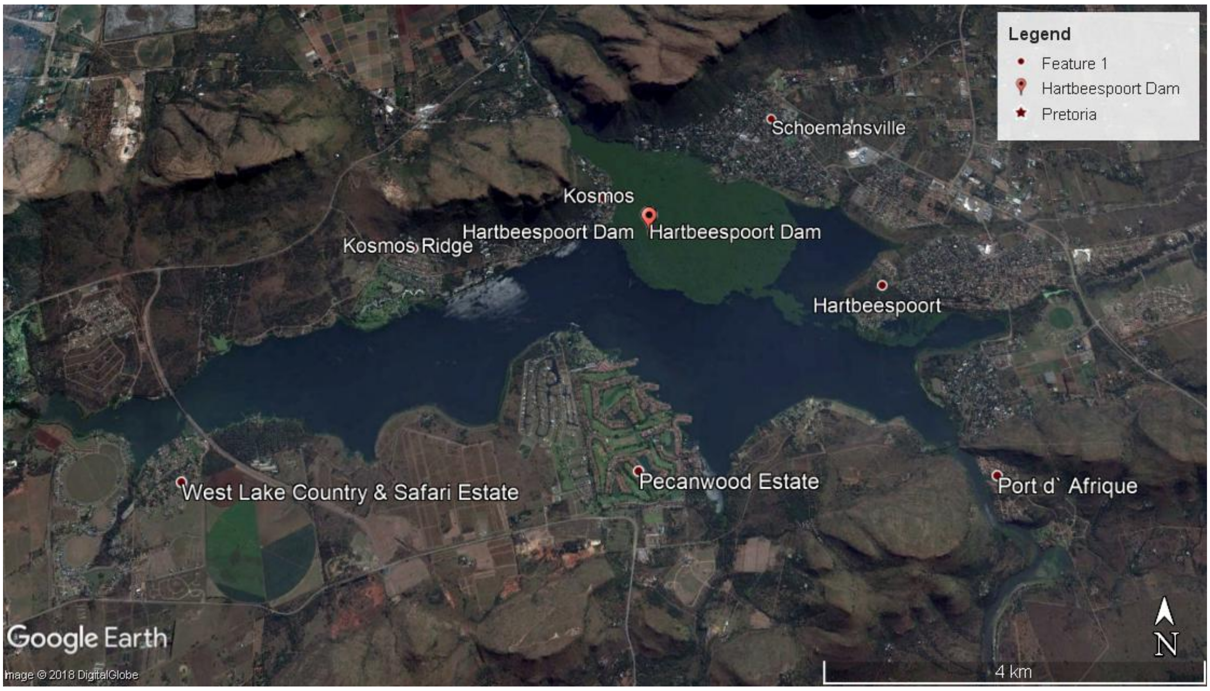

Figure 3.23: Google image for May 2017 showing main basin area of the Hartbeespoort Dam covered by Water Hyacinth.

Figure 3.24: Google image for March 2018 showing Magalies River arm and main basin of the Hartbeespoort Dam covered by Water Hyacinth.

3.4.1.2 Consequences of MCWAP-2A

Water Hyacinth is a floating plant which can over large areas of the impoundment in a relatively short period of time. Dense stands of hyacinth accumulate down wind and against barriers. During high wind episodes these stands can move about the impoundment, causing use related problems at different times. With the implementation of the MCWAP-2A, these stands will be contained in the main basin areas which may allow for the increased coverage of the impoundment because of the smaller surface area.

3.4.1.3 Impacts on Hartbeespoort Dam

Water hyacinth die back in the winter periods. It's minimum temperature tolerance is 12 degrees C. The leaves are prone to frost. The impact of the MCWAP-2A in winter (when the lowest water levels will be experienced) is unlikely to affect the current status of hyacinth in the impoundment.

As the temperature rises in spring, the hyacinth begin to recover and once temperatures reach the mid 20's, hyacinth is at its most productive. Hyacinth are prolific growers and can double in mat size within 2 weeks. Hyacinth reproduces with runners but seed production can be many thousand per plant and can survive for over 20 years. During this period it is expected that the impoundment water level will be 2 m shallower than the recent past. As per the area capacity curve in Figure 3.3, the reduction in area is relatively small and thus there is unlikely to be any significant change to the prolific growth of hyacinth on Hartbeespoort Dam.

3.4.1.4 Mitigation measures

The *Harties, Metsi a me (My water)* programme was developed by the former Department of Water Affairs to address the water quality problems and symptoms at Hartbeespoort Dam. This programme covered a range of interventions grouped into Phase 1 (reservoir strategies) and Phase 2 (upstream strategies). As part of Phase 1, the harvesting of Water Hyacinth was implemented.

The *Metsi a me* programme operated for 7 years from 2006 until it was stopped in 2013. During that period significant inroads were made to the water hyacinth problem. After the termination of the programme, water hyacinth proliferated and became a big problem on the impoundment. Subsequently a permit was issued to private entrepreneurs to harvest the hyacinth. This made the problem a land based one as there were mountains of decaying hyacinth on the shoreline. Recently programmes to make fertiliser out of the hyacinth have been proposed.

The containment and harvesting of hyacinth in specific areas and conversion to fertiliser, could remove significant amounts of nutrients from the impoundment and provide sustainable opportunities and is supported.

4 CONCLUSIONS

4.1 Summaries

Aspect Considered	Summary
Stratification	It is not anticipated that there will be a significant change to the stratification and hypolimnion in Hartbeespoort Dam.
Primary Production	The potential impact of MCWAP-2A on primary production in Hartbeespoort Dam is unlikely to influence primary production in Hartbeespoort Dam. The physical parameters controlling problem aquatic algae won't change during the winter, as colder conditions currently limit production.
NItrates	The potential impacts on Hartbeespoort Dam can be divided into winter and summer impacts. During winter, with the implementation of MCWAP-2A, impoundment levels are expected to drop by up to 6 m. However, as the area capacity curve and area volume map shows (Figures 3.5 and 3.6) the impoundment surface area will only reduce by 800 ha. This reduction in area by 40% is unlikely to have a significant effect in winter, as primary production is limited by temperature and light during this period. During summer, high concentrations of nitrates are suitable for blooms of algae. With the advent of MCWAP-2A, these high concentrations are expected to continue and thus blooms of algae will continue to occur.
Phosphates	During winter the load to the impoundment remains constant as the dominant flow is remains the Crocodile River. However, the lowered water level will expose a certain portion of the sediments and through desiccation and physical action by wind, phosphates can be released when the impoundments starts to fill. The scale of this release is difficult to assess because the bulk of the sediment lies within the deeper basin

	which will not be influenced by the lower winter levels. There is however, a portion of the sediments deposited in the Crocodile River basin in the impoundment and a portion of these could be exposed during low water levels. It is for this reason that there is a possibility that the primary production in the impoundment will increase during the early spring and summer period when temperature and solar radiation becomes favourable for algal growth.
Salinity	The nature of changing water quality in a large number of South African rivers is increasing salinity. An increase in salinity can impact on a number of in-lake processes: • Biodiversity; and • In-lake chemical processes. The current concentrations of DMS in the impoundment are not a cause for concern, but incremental changes over time may impact of the ecological nature of the impoundment.
Water Hyacinth	Water hyacinth die back in the winter periods. It's minimum temperature tolerance is 12 degrees C. The leaves are prone to frost. The impact of the MCWAP-2A in winter (when the lowest water levels are expected) is unlikely to affect the current status of hyacinth in the impoundment. As the temperature rises in spring, the hyacinth begin to recover and once temperatures reach the mid 20's, hyacinth is at its most productive. Hyacinth are prolific growers and can double in mat size within 2 weeks. Hyacinth reproduces with runners but seed production can be many thousand per plant and can survive for over 20 years. During this period it is expected that the impoundment will be 2 m shallower than the recent past. As per the area capacity curve in Figure 3.3, the reduction in area is relatively small and thus there is unlikely to be any significant change to the prolific growth of hyacinth on Hartbeespoort Dam.

4.2 Mitigation Measures

Aspect Considered for Mitigation	Mitigation
Primary Production	Mitigation measures to address in lake primary production need to address inflow water quality and any residual nutrients accumulated in the lake.
Nitrates	While there are no specific measures identified as a result of MCWAP-2A implementation, general catchment mitigation measures could include measures such as: • Reduction at source – reduce nutrient loading by maintaining upgrading point source water treatment works and diffuse source breakdown of water reticulation systems; • Pre-impoundment treatment – installation of a pre-lake or wetland to assist with the removal of nutrients before they enter the impoundment; and • In-lake treatment – building from the now defunct Hartbeespoort Dam Management Plan for a longer period of time and a on a continuous basis.
Phosphates	While there are no specific measures idenified as a result of MCWAP-2A implementation, general catchment mitigation: • Reduction at source – reduce nutrient loading by maintaining upgrading point source water treatment works and diffuse source breakdown of water reticulation systems; • Pre-impoundment treatment – installation of a pre-lake or wetland to assist with the removal of nutrients before they enter the impoundment; and • In-lake treatment – Dredging of sediments during winter when the lower impoundment water levels provides greater surface area for mechanical removal.
Water Hyacinth	The containment and harvesting of hyacinth in specific areas and conversion to fertiliser, could remove significant amounts of nutrients from

	the impoundment and provide sustainable opportunities.

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