# APPENDIX I9

GREENHOUSE GAS EMISSIONS STUDY

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

# Assessment of Greenhouse Gas Emissions

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# 1 INTRODUCTION

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 impoundment, 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 (DM).

The overall project location and layout is presented in Figure 1.

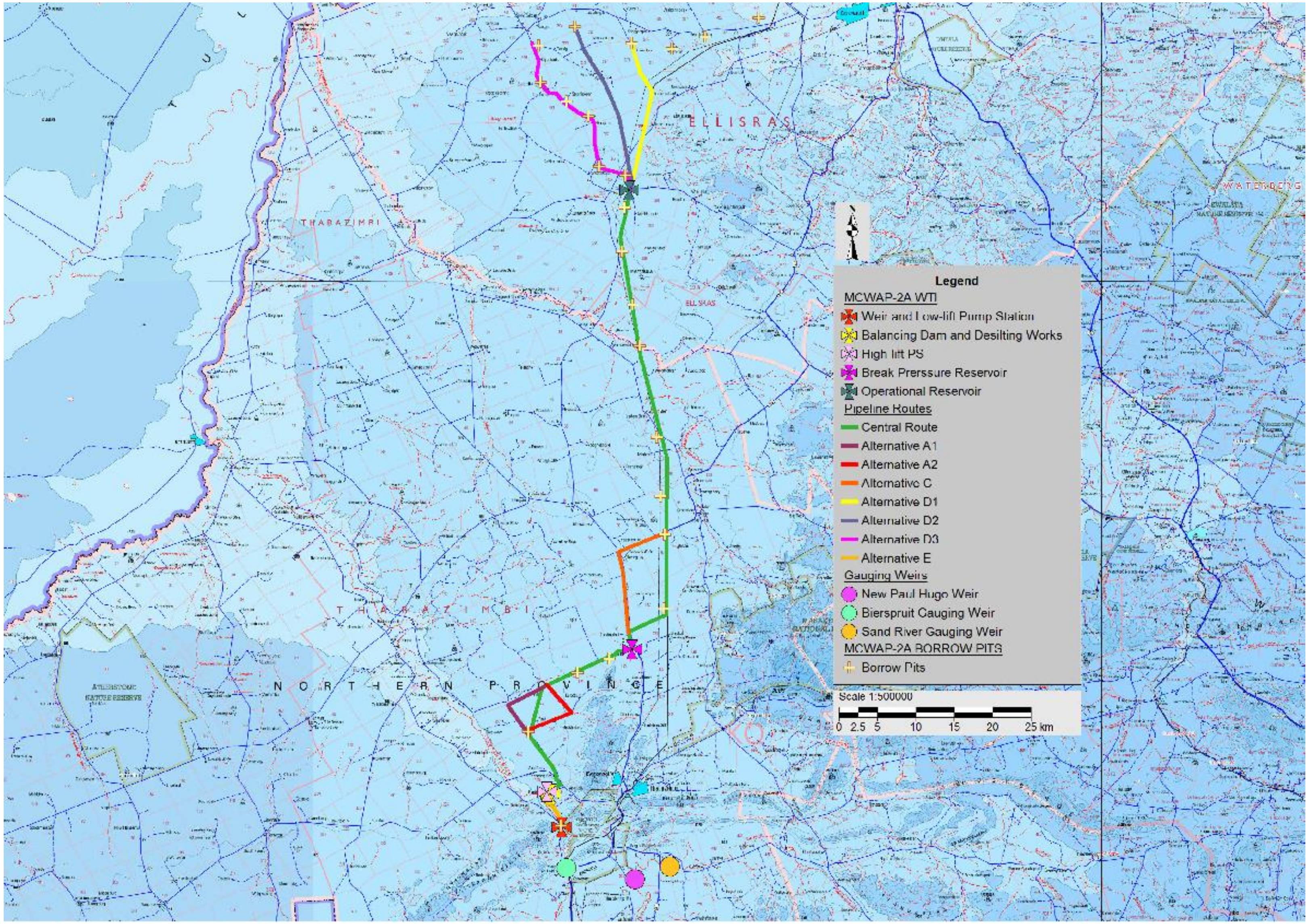


**Figure 1: Project location and layout**

The potential environmental impacts of the MCWAP-2A include the potential to generate greenhouse gas emissions (GHG) through the following 2 main processes:

- Construction of new weir at Vlieëpoort on the Crocodile River;
- Water level fluctuations in Hartbeespoort Dam;

This document assesses the potential GHG emissions from the proposed MCWAP-2A project.

# 2 BACKGROUND

Artificial reservoirs are distinct from natural systems in a number of key ways that may enhance GHG emissions from these systems:

- Reservoirs often experience greater fluctuations in water level than natural lakes. Drops in hydrostatic pressure during water level drawdowns can enhance $CH_4$ bubbling (e.g., ebullition) rates at least over the short term (Maeck et al. 2014). This enhanced ebullition may then decrease the fraction of $CH_4$ that is oxidized to $CO_2$, a less potent GHG;
- High catchment area–to–surface area ratios and close proximity to human activities characteristic of many reservoirs are likely to increase the delivery of organic matter and nutrients from land to water (relative to natural lakes), potentially fuelling additional decomposition; and
- Emission levels vary widely between different reservoirs depending upon the area and type of eco-systems flooded, reservoir depth and shape, the local climate, and the way in which the dam is operated.

The International Hydropower Association has developed the GHG Reservoir Tool (G-Res Tool) in association with UNESCO to calculate emissions from reservoirs. This tool was used in this assessment.

# 3 G-RES TOOL

The *G-res* tool's operating principles require the explicit consideration of:

- The GHG footprint of the landscape (upstream catchment, reservoir area, downstream river) prior to impoundment;
- The particular environmental setting of each reservoir (climatic, geographic, edaphic and hydrologic);
- The temporal evolution of the GHG emissions over the lifetime of the reservoir;
- Displaced GHG emissions, i.e. emissions that would have occurred somewhere else in the aquatic network regardless of the presence of a reservoir; and

- Emissions increasing the net GHG emission impact of the reservoir, but that are the result of release of nutrients and organic matter by human activity occurring upstream of or within the reservoir.

The G-Res Tool models GHG emissions using a series of modules which estimate emissions based on user inputs and calculated parameters based on those inputs. The modules address each part of the net GHG footprint calculation, namely pre-impoundment, post-impoundment, unrelated anthropogenic sources (UAS) and construction. Each of these modules can be summarised as:

- Pre-impoundment – the GHG balance associated with the area subsequently occupied by the reservoir, which is calculated based on the land cover and a set of emission factors which represent the flux of emissions for land cover at the location of the reservoir;
- Post-impoundment – the GHG balance associated with the reservoir after inundation, which is calculated using a semi-empirical model based on a comprehensive dataset collated from the published peer-reviewed literature on measured GHG fluxes for diffusive, bubbling and degassing emission pathways;
- Unrelated anthropogenic sources – the GHG emissions that can be attributed to activities within the catchment calculated based on the proportions of sources of nutrients and carbon flowing into the reservoir; and
- Construction – the GHG emission associated with materials, plant and transport required to construct the weir, pipeline and balancing dams, calculated based on the use of materials and emission factors.

# 4 DEFINITION OF UNITS

CO2e, or carbon dioxide equivalent, is a standard unit for measuring carbon footprints. The idea is to express the impact of each different greenhouse gas in terms of the amount of CO2 that would create the same amount of warming. For example, the global warming potential for methane is 21. This means that emissions of one metric tonne of methane are equivalent to the emissions of 21 metric tonnes of carbon dioxide. (The Guardian, 2011). Emissions are reported as tons CO2 equivalents per annum (tCO2e/yr) or grams CO2 equivalents per square metre per annum (gCO2e/m2/yr. Sometimes the units are refined further to grams of CO2 equivalents per square metre per day (gCO2e/m2/d).

# 5 MODEL INPUT DATA

## 5.1 Catchment Data

The G-Res Tool requires information to identify the nature and extent of various land covers, land uses and anthropogenic characteristics. **Table 4-*1*** presents the input data required.

**Table 4-1: G-Res Tool Catchment Input Data**

| Catchment data | Unit | Overview |
|---|---|---|
| Catchment area | $km^2$ | The area of the catchment of interest upstream of the dam, in square kilometres. |
| Catchment annual runoff | mm/a | Annual runoff is expressed as the amount of water in millimetres that flows from the catchment at the surface of the soil to a water body per annum. |
| Community wastewater treatment | n/a | Specify whether there is any wastewater treatment activity upstream of the dam, which may affect the water quality in the reservoir. Wastewater treatment is the level of purification that is applied to the water in the catchment. The options range from none to primary (mechanical removal), secondary (biological treatment) and tertiary (where additional treatment above primary and secondary is applied). |
| Population in the catchment | Number of person | Population within the catchment areas upstream of the dam, in number of persons, reference can be made to CIESIN (Center for International Earth Science Information Network), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT). (2005). Gridded Population of the World Version 3 (GPWv3): Population Density Grids. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available online at: http://sedac.ciesin.columbia.edu/gpw |
| Release of phosphorous form industrial sewage in the catchment Industrial wastewater treatment | kgP/a | The release of phosphorus in the catchment in kilograms of phosphorus per annum. |
| Industrial wastewater treatment | n/a | Specify whether there is any wastewater treatment activity of industrial sewage in the catchment upstream of the dam, which may affect the water quality in the reservoir. Wastewater treatment is the level of purification that is applied to the release of industrial sewage in the catchment. The options range from none to primary (mechanical removal), secondary (biological treatment) and tertiary (where additional treatment above primary and secondary is applied. |
| Catchment land cover | % | The land cover category of the catchment first needs to be identified. Then, each category needs to be represented as a percentage of the total catchment area. The nine catchment land cover categories are: |
| | | 1) Croplands |
| | | 2) Bare Areas |
| | | 3) Wetlands |
| | | 4) Forest |
| | | 5) Grassland / shrubland |
| | | 6) Permanent snow/ice |
| | | 7) Settlements |
| | | 8) Water bodies |
| | | 9) Drained peatland |

| Catchment data | Unit | Overview |
|---|---|---|
| | | Land cover is entered as a % of the study area and the km² is calculated. For some land cover categories, the Land Use Intensity should also be entered. This reflects whether the land is 'unmanaged' (low intensity, natural land cover) or 'managed' (high intensity land cover with human influence). |
| Pre-Impoundment land cover in the reservoir area (%) | % | Land cover is entered as a % of the study area and the km² is calculated. The percentage of mineral and organic soils should also be specified as well as the % of the organic soil that is drained. For some land cover categories, the Land Use Intensity should also be entered. This reflects whether the land is 'unmanaged' (low intensity) or 'managed' (high intensity). |
| Land Use Intensity | n/a | Used to describe the level of human influence on the land use. Broadly this means whether for Cropland, Grassland/Shrubland and Forest, it is heavily managed land, and for urban area whether the population density is high. |

## 5.2 Reservoir Data

The G-Res Tool requires information to identify the climatic and regional influences that may be exerted of the dam. **Table 4-*2*** presents the input data required.

**Table 4-2: G-Res Tool Reservoir Input Data**

| Reservoir data | Unit | Overview |
|---|---|---|
| Country | | Location of the reservoir (or for cross/border schemes, the country from which the reservoir is managed) |
| Longitude of Dam | DD | Longitude of point location of dam in decimal degrees (DD) |
| Latitude of Dam | DD | Latitude of point location of dam in decimal degrees (DD) |
| Climate zone (reservoir area) | choice | The appropriate climate category considering the following categories used in the model: Tropical, subtropical, temperate and boreal. Refer to the world maps of KöppenVGeiger climate classification for more details: http://koeppenVgeiger.vuVwien.ac.at/shifts.htm . The most representative choice should be used (where a reservoir is located across two zones, the zone with the largest proportion should be used). |
| Impoundment year | year | The year in which the flooding of land that formed the reservoir was completed. |
| Reservoir area | $km^2$ | The surface area occupied by the reservoir at normal (average) water level, in square kilometres. This should be defined based on the mean operating level over the course of a year. |
| Reservoir volume | $km^3$ | The total volume of water in the reservoir. This should be defined based on the mean operating level over the course of a year, in cubic kilometres. |

| Reservoir data | Unit | Overview |
|---|---|---|
| Mean/normal operating level | m a.s.l. | The mean operating level of the reservoir in meters above sea level. |
| Maximum depth | m | The maximum depth of the reservoir relative to the normal operating level of the reservoir, in metres. |
| Mean depth | m | The average depth of the reservoir relative to the normal operating level of the reservoir, in metres. This can be estimated by taking the mean operating reservoir volume and dividing by the mean operating reservoir area. |
| Littoral area | % | The littoral area represents the surface area of the reservoir between the shore and the distance to the shore at 3 m depth, where the water is shallower and the water temperature warmer than the rest of the reservoir. In the *G"res* tool, the percent littoral area is defined as the percentage of the reservoir area that has a depth less than 3 m. Where a GIS model is available, the littoral area can be calculated by calculating the area of the reservoir and the topographic profile of the reservoir area, or estimated by using the area of the maximum and minimum levels, comparing the reservoir area and the depth |
| Thermocline depth | m | The depth, from the surface of the reservoir, to the mean level of the thermocline during normal operation of the reservoir |
| Water intake depth | m | The depth, from the surface of the reservoir, to the level of the dam intake. |
| Water intake elevation | m a.s.l. | Elevation of the water intake of the reservoir in metres above sea level. |
| Soil carbon content under impounded area | kgC/m$^2$ | The typical carbon content of soils found beneath the flooded area of the reservoir, in kilograms of carbon per square metre. |
| Annual Wind Speed at 10m | m/s | The average wind speed at 10 m above the reservoir surface (U10), in metres per second. If the wind speed (Uz) is measured at a different height (z), please convert using the following equation (Crusius and Wanninkhof 2003): U10 = U_z*[1,087 9+*ln(10/z)].<br>Where measurements at the reservoir are not available, local weather station data could be used if available. In this case, if you cannot enter the wind speed at 10 m above the reservoir surface, please enter this information in the comments box, including the height above the reservoir surface at which the measurement was taken if known. |
| Water residence time | years | The water residence time represents the average amount of time that a molecule of water spends in the reservoir, in years. |
| Annual discharge from the reservoir | m$^3$/s | Annual average rate of discharge from the dam outlet in cubic meters per second. |
| Phosphorus concentration | µg/l | Mean phosphorus concentration within the reservoir. |

| Reservoir data | Unit | Overview |
|---|---|---|
| Trophic level | | The tropic state of the reservoir. There are four states to select from, and users should note the following thresholds: |
| | | • Oligotrophic = Less than 10 µg/l; |
| | | • Mesotrophic = Between 10 and 30 µg/l; |
| | | • Eutrophic = Between 30 and 100 µg/l; and |
| | | • Hypereutrotrophic = More than 100 µg/l. |
| Reservoir mean global horizontal radiance | kWh/m²/d | The annual or ice free average amount of the total solar radiation incident on a horizontal surface at the surface of the earth. See Annex III of the *G-res tool technical documentation* to convert to Cumulative global horizontal radiance (kWh/m²/period). |
| Mean air temperature per month at reservoir site | °C | The mean air temperature for each month at the reservoir site. Please provide data only if multi-Vyear monthly mean air temperature (°C) are available for all months from local data taken on the reservoir itself or from a nearby weather station. If no air temperature data are available, the *G"res* tool will use a monthly mean air temperature average of 50 years (1950V2000). |

## 5.3 Operating Rule Data

The G-Res Tool requires information to identify the primary, secondary and tertiary operating rules for the impoundment in order to allocate GHG emissions accurately between the various operations. The operating rule definitions used are:

- Primary: Operating rules are designed to maximise the benefits of this service for part or all of the year;
- Secondary: The service places operational constraints on the operating level of the reservoir for part or the whole of the year; and
- Tertiary: The service has little impact on the operation of the reservoir.

## 5.4 Construction Data

The G-Res Tool requires information on the nature and sourcing of material for the construction of the dam which is used to provide an estimate of GHG during the construction phase. **Table 4-*3*** presents the input data required.

**Table 4-3: G-Res Tool Construction Input Data**

| Construction | Unit | Description |
|---|---|---|
| Earth and rockfill | m³ and km | All rock, soil, sand, gravel brought to site and/or excavations for use in the construction of the required structures, expressed in m³. The average delivery/movement distance should be used. This should be balanced based on whether the materials are imported or site won. |
| Concrete | m³ and km | All concrete brought to site for the dam, tunnels, foundations and other structures, in m³. This is assumed to be a standard concrete mix. The transport distance can be specified and should be stated as an average of the constituent components (i.e., the weighted distance of concrete, aggregate and sand suppliers). |

| | | |
|---|---|---|
| Steel | Metric tonnes and km | All steel brought to site for reinforcement, pipelines, mechanical and electrical equipment, expressed in metric tonnes. Note there is likely to be some uncertainty in this due to the difference between steel sections, for example, and finished products that contain steel components. To be conservative, the total mass of steel should be included, but this may require some sensitivity testing |

# 6 RESULTS – PROPOSED WEIR ON CROCODILE RIVER (WEST)

The proposed Vlieëpoort weir on the Crocodile River (West) is a small structure with a small footprint and as such is below the scale applicable for all processes within the G-Res tool, except construction impacts. Table 5.1 presents the estimated construction data for the total MCWAP-2A.

**Table 5.1: Construction details for the proposed MCWAP-2A project**

| **Item** | **Earthworks ($m^3$)** | **Concrete ($m^3$)** | **Steel (expressed as 127 kg/m for steel pipe)** |
|---|---|---|---|
| Abstraction Weir | | 500 | |
| Low lift pumping station | | 1 750 | |
| Low lift rising main (2 pipes) | | | 1 102 360 |
| Sedimentation works | | | 12 000 |
| Balancing works | 272 800 | | |
| High lift pumping station | | 36 000 | |
| High lift rising main to Break Pressure Reservoir | | | 3 683 000 |
| Break Pressure Reservoir | | 9 000 | |
| Gravity Pipelines to Operating reservoir | | | 8 096 250 |
| Operating reservoir | | 9 000 | |
| Gravity pipeline from Operating reservoir to Medupi Tee-off (km) | | | 7 494 270 |
| Roads and borrow pits | 1 500 000 | | |
| | | | |
| **Total** | **1 772 800** | **56 250** | **20 387.88** |

Results from G-Res estimate that some 1 034 $tCO_2e$/yr will be emitted during construction of the MCWAP-2A project.

# 7 RESULTS – WATER LEVEL FLUCTUATIONS IN HARTBEESPOORT DAM

The G Res modelled results indicate that Hartbeespoort Dam is currently emitting 15 $tCO_2$ e/year or 1 $gCO_2e/m^2$/year. Published data for impoundments of the same age range from 0,2 $gCO_2e/m^2$/year to 1,4 $gCO_2e/m^2$/year (St. Louis, 2000). Projecting the increased release of water to the 2050 estimate of 120 million $m^3$ per annum did not affect this estimate.

As per Intergovernmental Panel on Climate Change (IPCC), Volume 4: Agriculture, Forestry and Other Land Use, it is expected that after the initial decay of vegetation in a dam, emissions will drop significantly. Evidence suggests that $CO_2$ emissions for approximately the first ten years after flooding are the results of decay of some of the organic matter on the land prior to storage. The easily degradable carbon and nutrients are made available to producer organisms upon storage and metabolized. Beyond this time period, $CO_2$ emissions are sustained by the input of organic material transferred into the flooded area from the catchment.

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 7.1):

**Table 7.1: 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 7.2 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 an eutrophic state. The 95$^{th}$ 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.

**Table 7.2: Summary statistics for Chlorophyll *a* in Hartbeespoort Dam from 1997 to 2018**

| **Statistics** | **ug/l** |
|---|---|
| Minimum | 0,35 |
| 5$^{th}$ percentile | 3,119 |
| Average | 118,616 7 |
| Median | 38,44 |
| 95th percentile | 273,075 4 |
| Maximum | 12 209 |

With respect to algal species dominance during the year, the winter dominant species are diatoms, specifically *Melosira sp*. 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.

The high 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 7.1. Figure 7.1 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 impoundment.

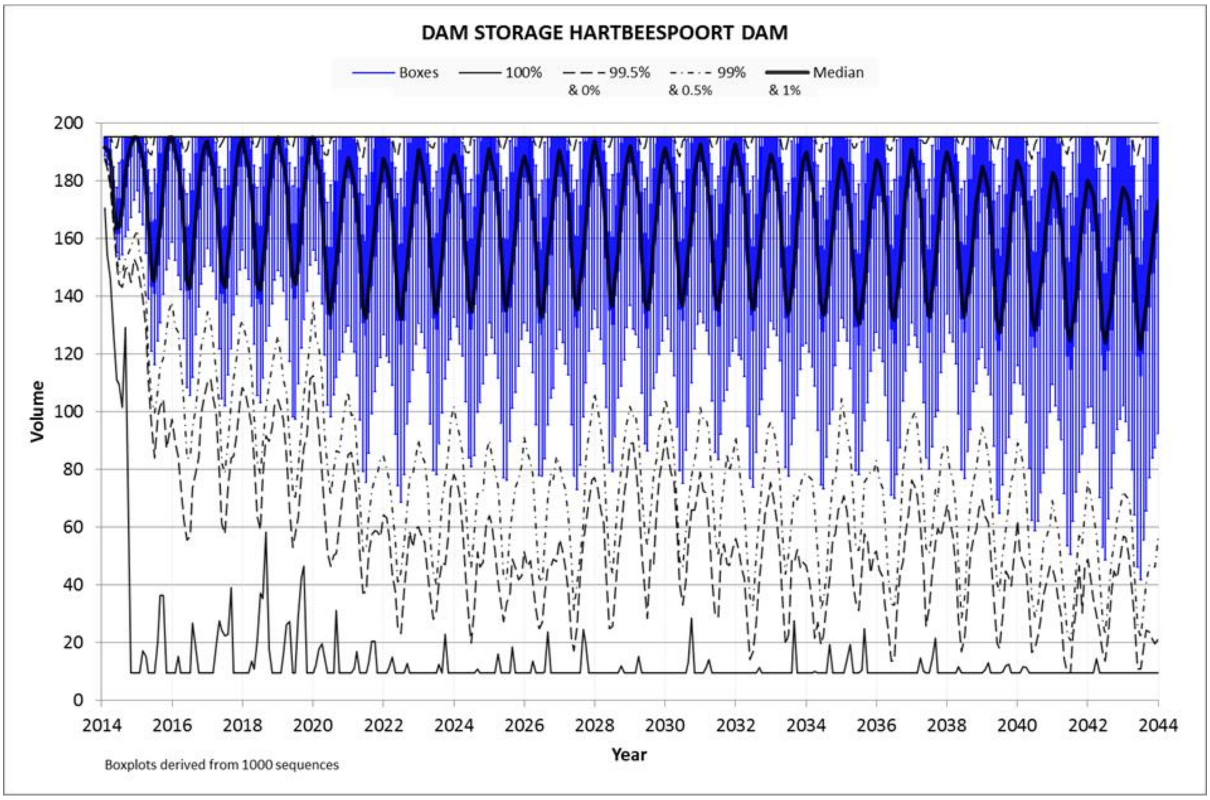


**Figure 7.1: Expected impoundment volumes with probability of risk.**

Converting this to a physical reduction in water level can be extrapolated from the area capacity curve for the impoundment (Table 7.3) When the impoundment is at 50% of its storage capacity, the area of the impoundment decreases by 40%.

**Table 7.3: 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 |

A comparison of $CO_2$and $CH_4$ fluxes from eutrophic reservoirs suggests that eutrophication does little to change the net carbon balance of reservoirs. (Deemer et al, 2016)). This suggests a potential positive feedback loop wherein a warming climate supports larger algal populations, larger algal populations provide more organic matter to support more methane production, and a portion of the methane produced escapes to the atmosphere. However, a recent laboratory study revealed that algal biomass quality, in terms of lipid content, enhanced rates of methane production (West et al. 2015). Because algae grown under nutrient rich conditions often tend to be relatively lipid poor, the authors suggest that feedback process may be limited. Thus in Hartbeespoort Dam, while the impoundment is hypereutrophic, it may not necessarily be actively contributing significantly to climate change. It is expected that the introduction of MCWAP-2A on Hartbeespoort dam is likely to have a limited effect on primary production in winter under the $50^{th}$ percentile scenario when the impoundment is dominated by diatoms. During summer, when the hypereutrophic conditions are at their worst, the potential changes to primary production as a result of MCWAP-2A are expected to be limited. This means that Hartbeespoort Dam will continue to be a GHG emitter.

# 8 CONCLUSION

The expected GHG emissions from the new MCWAP-2A and the fluctuating water levels in Hartbeespoort Dam are considered small. The construction emissions will cease once the project is complete and the Hartbeespoort Dam will remain a net GHG emitter.

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