Remediation and Prevention of Harmful Cyanobacteria Bloom in Setumo Dam, South Africa, using *BlueGreen* Water Technologies ("BlueGreen") *Lake Guard*® Oxy

Gabe Rozman, MSc

Senzo Yeni

Jurgens Van Loggerenberg

Oori Weisshaus, PhD

Prof. Aaron Kaplan

Gadi Weiss, PhD

Moshe Harel, PhD

Abstract

Studies performed in many water bodies around the world attributed the intensification of toxic cyanobacteria blooms to rising nutrient levels (i.e., Phosphorous (P) and Nitrogen (N)) and global warming (i.e., O'Neil et al. 2012, Chislock et al. 2013, Paerl et al. 2001). The blooms often release biological toxins that impact the liver, digestive and nervous systems of humans and animals as well as form a buildup of noxious mats on the water surface.

Setumo Dam is a 3.5km^2 dam in Northwest- Mahikeng, South Africa. There are severe cyanobacteria blooms, enhanced by a discharge of nutrients into the dam. This prompted locals to complain about noxious odor and taste in the water. The threat level of cyanotoxins in Setumo was raised above the accepted World Health Organization (WHO) *Guidelines for Drinking water Quality* (WHO, 1993, 1996, 1998) standards. A water treatment facility (that processes 17 megaliters a day (MLD)) operated by Sedibeng Water (South African Governmental body responsible for the treatment of wastewater and supply of potable water) resides on the Northwest section of the dam.

BlueGreen Water Technologies Ltd. (*BlueGreen*) took the initiative to treat Setumo Dam for its severe cyanobacteria infestation, in order to minimize the health risk of potential toxins to the water users. After an in-depth evaluation of the condition in the Dam (Fig. 1), *BlueGreen* implemented a unique and innovative method of treatment that induces the biological response of Programmed Cell Death (PCD) of the harmful cyanobacteria, while minimizing the concentration of product implemented to the water body.

The treatment was highly effective with results demonstrating: (1) a major visible improvement in water clarity, (2) an increase in the Resistance Index, (3) a significant

decrease in microcystin concentrations (a common toxin released by *Microcystis* sp.) and (4) a decrease in the relative frequency of chlorophyll concentrations.

Furthermore, the treatment proved to be highly cost-effective with reductions in coagulation, filtration, and disinfection costs, totaling ZAR >11,000,000/year.

These results have widespread implications on how harmful algal blooms can be combatted worldwide. They demonstrate *BlueGreen*'s ability to successfully treat HAB's in a cost-effective and environmentally friendly manner.

Further research is continuously being pursued including better understanding the optimal frequency and concentration of applications and how environmental factors impact the effectiveness of the treatment.

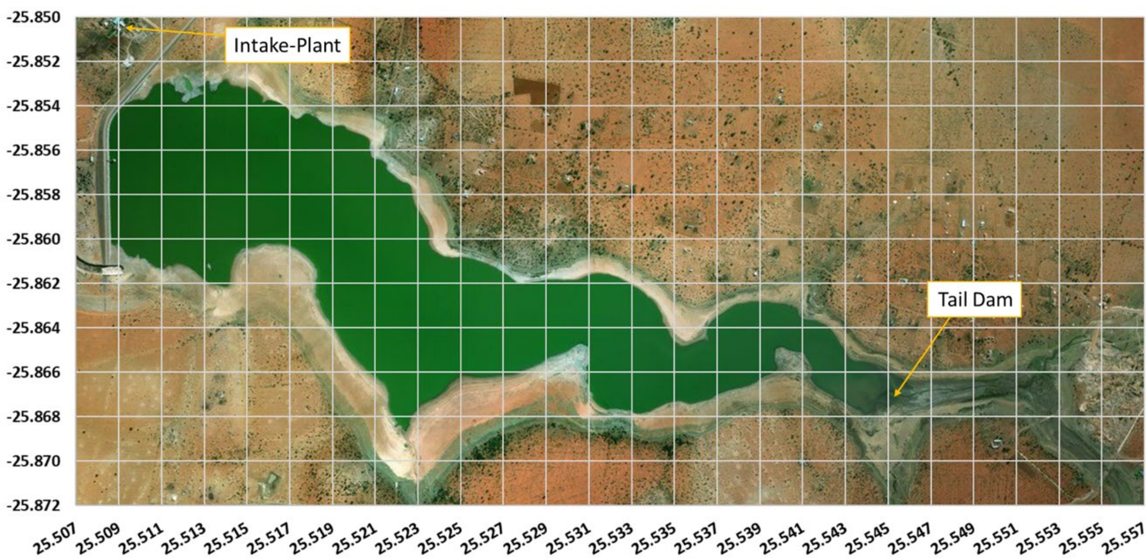

Figure 1: Setumo Dam satellite true-color image, sampling points marked by the red dots (sampling locations are indicated in the white text boxes).

Results and Discussion

Processed satellite images assessing the level of algae and cyanobacteria as described below (Fig. 2) and pictures taken from a drone (Fig. 3) before and after the treatment, as well as the data collected from the sampling points, provided clear evidence that the treatment was highly successful. Due to the fact that the treatment was conducted during the winter season, colder temperatures slowed the rate of cell activity. This affects both the reaction rate of the treatment as well as of the organisms that decompose the dead cells post-treatment contributes to the prolonged effect of the treatment of two months.

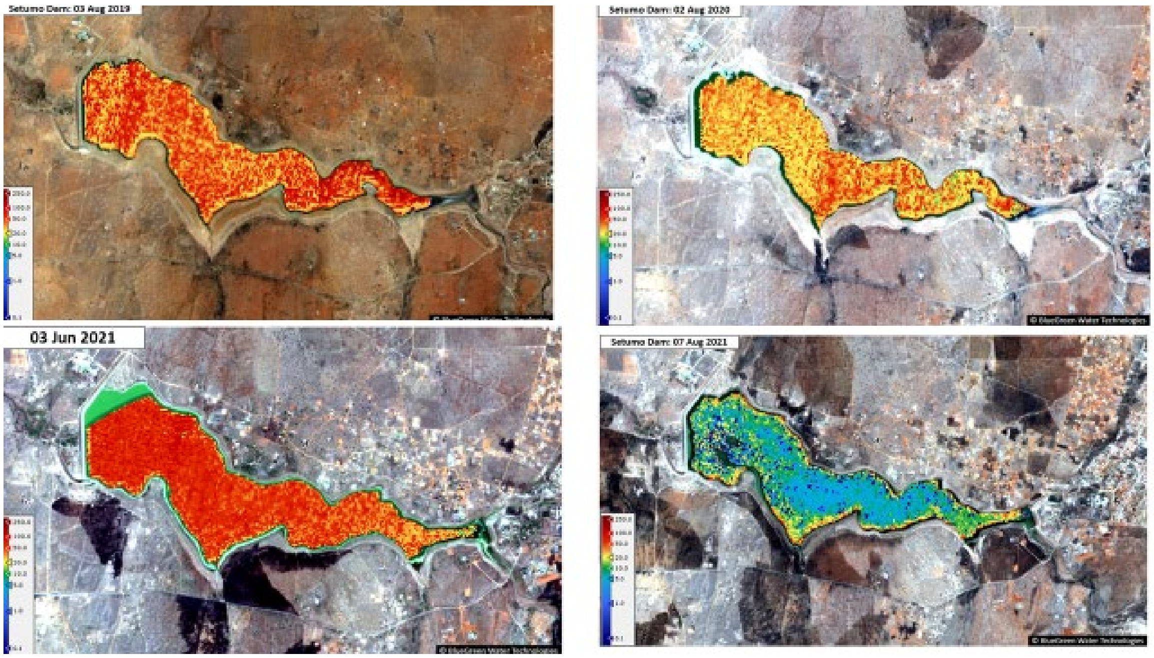

Figure 2: Satellite images from August 2019 (Upper left) August 2020 (upper right) June 2021 (lower left), a few days before the treatment, and August 2021 (lower right) two months after the treatment. The pictures were processed as described in "Satellite Method Summary", below. The darker the red color the higher the level of cyanobacterial pigments. The greenish part is shown in the June 2021 picture reflects the high density of water cabbage floating on the water.

Figure 3: Picture of Setumo Dam on Jun. 8th before treatment (left) and on Aug. 19th, 72 days after the treatment campaign with *Lake Guard*® Oxy (right).

A highly informative parameter is often termed the **Resistance Index.** It represents the chlorophyll/phycocyanin ratio measured in the water body. A rise in this ratio, as shown in Fig. 4, reflects a rising population of phycocyanin-lacking phytoplankton. It clearly indicates a recovery of the phytoplankton population no longer depressed by the toxic cyanobacteria. A continues rise in their abundance will likely depress the re-occurrence of toxic cyanobacteria but an additional treatment with *Lake Guard*® Oxy may be needed to achieve this goal.

Microcystin levels exhibited a decrease over time which indicates that cyanobacteria populations levels were negatively impacted by the treatment (Fig. 5).

Additionally, satellite images were processed and analyzed yearly from August 2018-2021 (see Satellite methods for more information). Relative frequency of chlorophyl concentrations divided into bins from pixelated remote sensing imagery revealed a significant shift in the distribution after treatment with *Lake Guard*® Oxy with a marked decrease in the frequency of higher levels of chlorophyll concentrations (Fig. 6).

It is important to note that not only was the treatment successful but also resulted in a significant reduction in costs for Sedibeng Water (South African Governmental body responsible for treatment of wastewater and supply of potable water). This included a monthly reduction in coagulation cost (saving = 187,506.60 ZAR, percentile saving = 78%), filtration cost (saving = 722,571.30, percentile saving = 75%), and disinfection cost (saving = 19,541.26, percentile saving = 43%). The total savings amounted to 929,619.16 ZAR per month and 11,155,429.91 ZAR per year (Fig. 7; see Cost Savings Summary for more information).

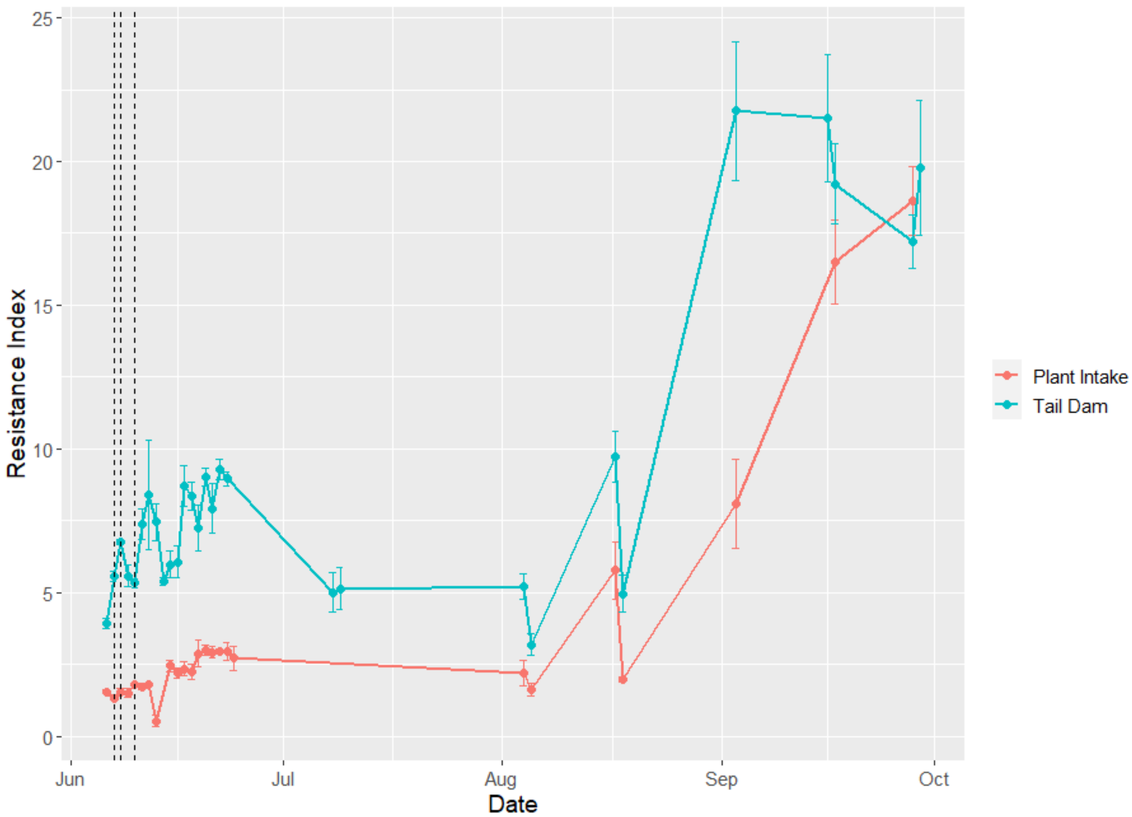

Figure 4: The Resistance Index over time reflecting the chlorophyll/phycocyanin ratio in the two most important sampling points (Tail Dam and Plant Intake). Dashed lines represent dates of *Lake Guard*® Oxy treatments.

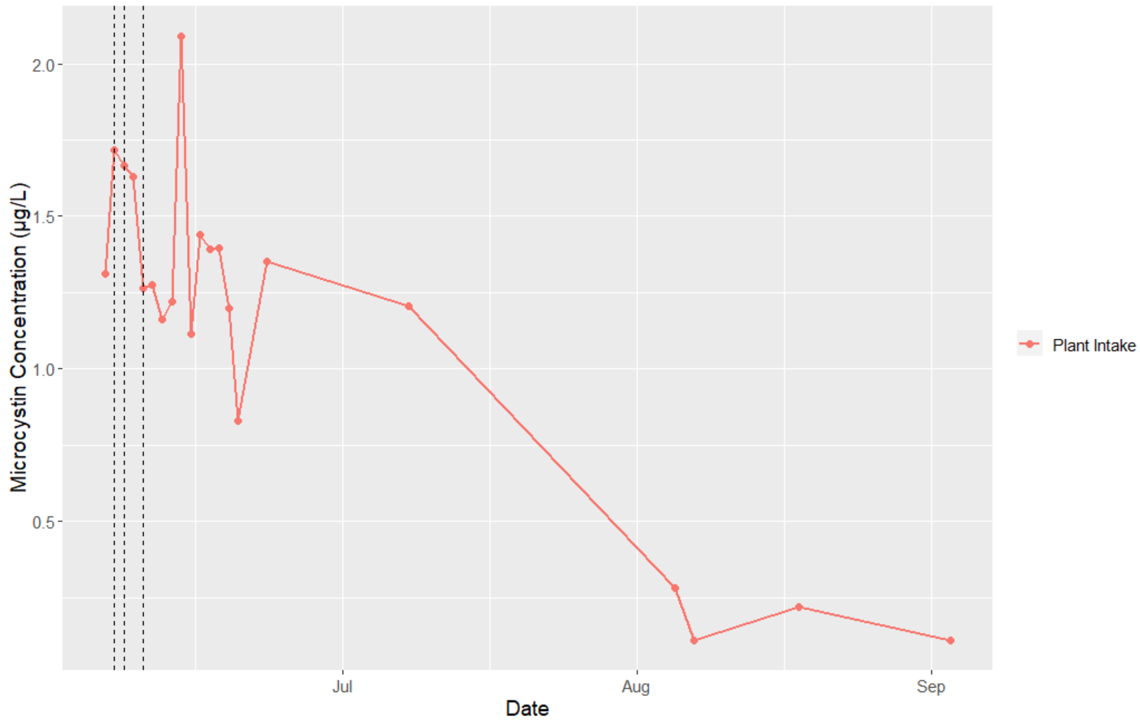

Figure 5: The concentrations (ug/L) of Microcystin over time at the Plant Intake sampling location. Dashed lines represent dates of *Lake Guard*® Oxy treatments. Analysis of the microcystin levels were performed by Rand Water in South Africa.

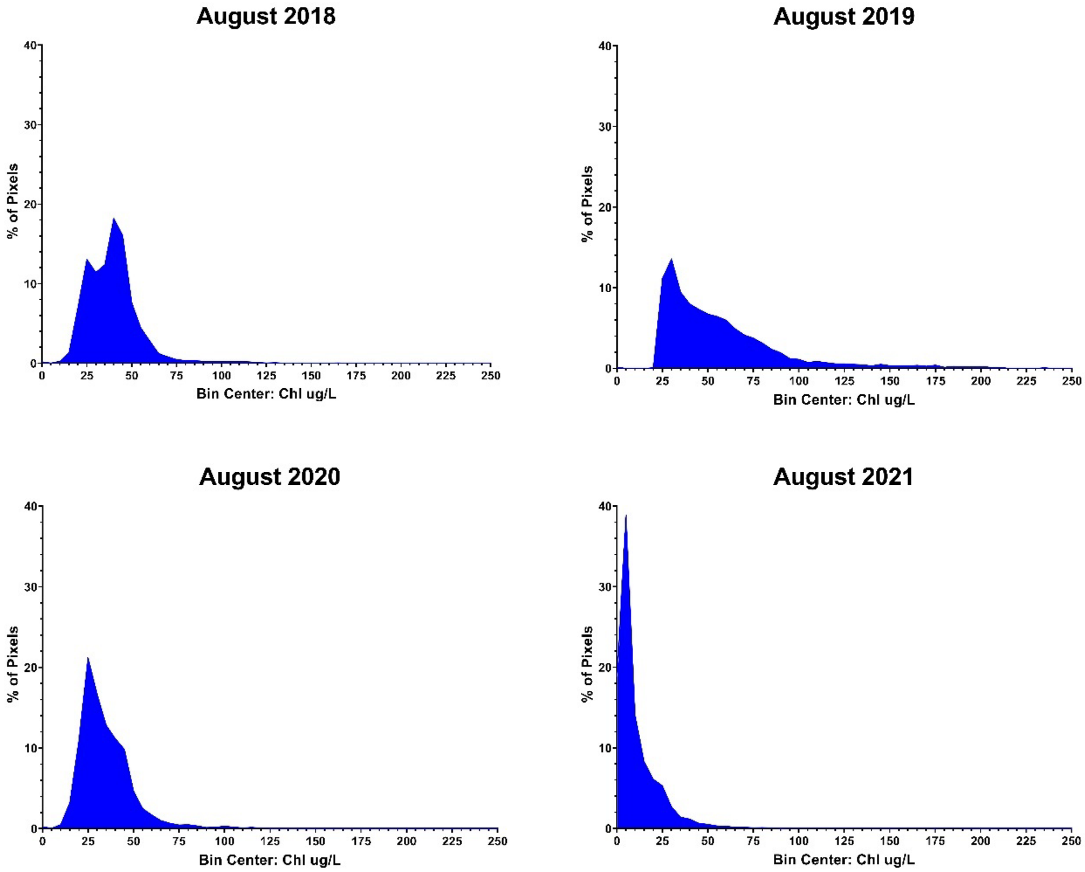

Figure 6: Yearly relative frequency of chlorophyl concentrations divided into bins from pixelated remote sensing imagery from August 2018-2021. Images were obtained from the Sentinel 2 satellite. *Lake Guard*® Oxy was applied prior to August 2021.

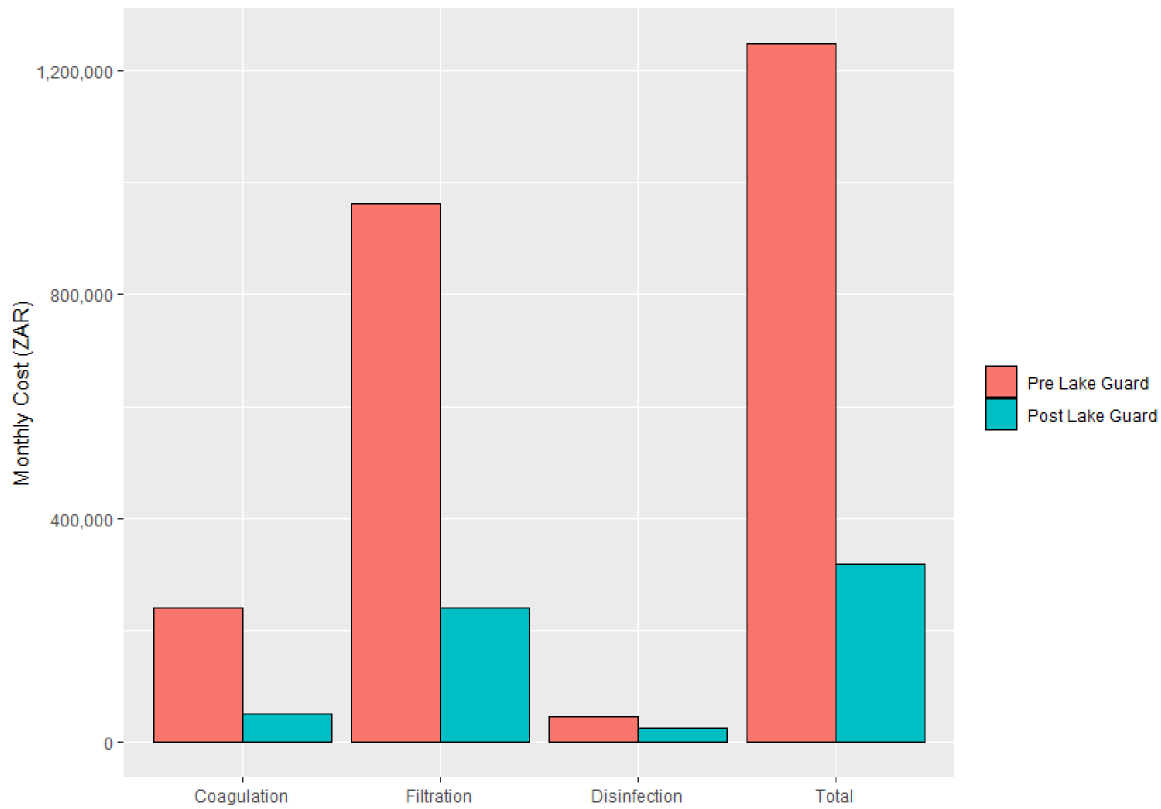

Figure 7: Monthly cost of water treatment before and after application of Lake Guard for Sedibeng Water (South African Governmental body responsible for treatment of wastewater and supply of potable water). Major costs include coagulation, filtration, and disinfection.

Concluding remarks

Treatment of the heavily contaminated Lake Setumo with *Lake Guard*® Oxy was highly successful as judged by the various parameters examined here. It resulted in the elimination of the toxic cyanobacteria population from most of the water body and thus enabling the recovery of non-toxic algae. Furthermore, anecdotal evidence provided by local workers in the facility suggest a strong positive impact on fish populations with an increase in biomass and abundance two months following the treatment. Further research to provide empirical evidence supporting this observation would be highly valuable.

Methodology

Lake Guard® Oxy technology was selected for the treatment of Setumo Dam due to its unique characteristics. It is a time-releasing active ingredient (H_2O_2) that is encapsulated by a hydrophobic shell and thus floats on the water surface migrating together with the toxic cyanobacteria along the same wind/current direction. The slow-release and hence long exposure to low H_2O_2 concentration triggers a biological process that specifically mitigate toxic cyanobacteria. Lake Guard® Oxy is approved by US EPA and certified by NSF/ANSI/CAN-60 for use in drinking water sources. It is currently being successfully used all over the world.

Lake Guard® Oxy treatments were applied on June 7th, 8th (twice, in the morning and afternoon), and 10th, 2021, using a total of 61.1 tons over the entire water surface, approximately 3.5 km^2. A helicopter carrying the *Lake Guard®* Oxy bags (650 kg each) was used to distribute the material all over the lake.

Satellite Method Summary

The method employed by BlueGreen Water Technologies (BlueGreen) to convert satellite imagery into cyanobacteria concentration on surface waters begins with quality-controlled .RGB files from Sentinel-2 (S2) and -3 (S3) missions downloaded from the European Union's Copernicus Program. The files, also known as products, are captured by two push-broom optical sensors: MultiSpectral Instrument (MSI), onboard S2, and Ocean Color and Land Imager (OCLI), onboard S3. Specifically, Copernicus processes the products for S2 MSI to Level-1C products, which provide "orthorectified Top-Of-Atmosphere (TOA) reflectance, with sub-pixel multispectral registration" (1). Furthermore, the product also includes cloud and land/water masks. The products for S3 OCLI are processed to Level 1B products, representing the instrument's output during Earth Observation processing mode under full resolution. The Level 1B product contains "calibrated, ortho-geolocated and spatially re-sampled Top Of Atmosphere (TOA) radiances [and] associated error estimates […] provided for each re-gridded pixel on the product image and for each removed pixel" (2). The products are further processed through SNAP (v6), a toolbox for processing data from the Sentinel missions. S2 MSI products used undergo geometric resampling and the S3 OCLI products are filtered with a mask to distinguish between land and surface water. The filtered and masked products are then processed by the color processor C2RCC, a validated algorithm that "uses a large database of radiative transfer simulations inverted by neural networks" (3,4). The C2RCC processes inherent optical properties in the water through inversion of the water-leaving reflectance and correction for atmospheric reflectance. The parameters chosen for the C2RCC processor include a neuronal network trained with reflectance data from turbid and optically complex inland water bodies, and a filter that provides remote sensing reflectance values containing the spectral color of the water below surface. Salinity and temperature are also inputted to improve the correction. Finally, arithmetic conversion factors convert the inherent optical properties into chlorophyll concentration (3).

Cost Savings Summary

The aim of this summary is to provide an explanation of the cost savings provided to Mmabatho Water Treatment Plant after the Setumo Dam cyanobacteria remediation done by BlueGreen Water Technologies Ltd.

The cost savings are realised in different stages of the water treatment process:

1. Coagulation / Flocculation - A chemical dosage step to reduce the suspended solids in the clarifier.
2. Filtration - entrapment of colloidal contaminants using rapid gravity filtration with silica sand as filter media. The design was predominantly used across Southern Africa as the cost of electricity was low and there was availability "cheap" water. The electricity consumption in this process is relatively high due to the air scouring and the high volume of water being pumped during the backwash process
3. Disinfection – Mainly in the chlorination process of the water in order to remove bacterial presence at the final stage to the drinking water process.

For each phase, a pre- vs. post Lake Guard™ treatment evaluation was performed as detailed below.

<u>Coagulation</u>

To determine the optimum dosage of flocculants that are required for the process, a bench top Jar Test was conducted. To achieve the prescribed settle turbidity of 3NTU the following product dosages were determined: Pre-Lake Guard™ treatment the dosage was determined to be a poly dose of 20mg/l and in addition, a ferric chloride dosage of 15 mg/l. Considering the current tender price of R8,56/kg Ferric Chloride and R17,09/kg Poly, as well as the operating capacity of Mmabatho WTW of 17MLD; the coagulant costs translate to R239K per month.

Post Lake Guard™ treatment of Setumo Dam, it was determined that due to the reduced organic matter mainly cyanobacterial cells in the dam, there was no need to dose Ferric chloride and the Poly dose reduced to 6mg/l. This translates to coagulant costs of R52k per month.

The coagulation savings translate to R187k per month. Percentile coagulation savings 78%.

Total Filtration Cost that Includes Electricity and Water Consumption

The costs associated with filtration include the power consumed by pumps and blowers during backwashing of the 6 rapid gravity filters at Mmabatho WTW. This is a process required to restore a filter by removing the impurities trapped on the filter sand surface by means of reverse flow of clean water and air. Not only does this process requires energy for running the pumps; also, clean water is used which reduces the total volume of clean water produced by the plant. The more organics inflow to the filter, the quicker the filter clogs and the more times backwashing is required, hence consuming more energy and clear water (and the inverse applies with less organics).

It was initially observed that pre–Lake Guard™ treatment, each of the 6 rapid gravity filters were backwashed twice a day translating to a power consumption of R 963k per month using an estimated electricity cost of R4.02 R/KWh. Post Lake Guard™ treatment, the filter backwashing frequency reduced to once a day at calculated costs of R240k per month. This translated to R722k saving on energy per month (75% percentile filtration saving).

With the reduced backwash frequency, a water savings was also incurred due to the longer times the filters would operate without the need to backwash. This means there was a 50% reduction of water losses from filter backwashing. The backwash cycle that was repeated in a shift to clean the filter and conducted twice per day. This was significantly reduced to a single backwash cycle per day providing an additional 1 920 m^3 of clean water to the community each day. At a water cost rate of R2.96 per m^3, this calculates to a significant R 722k saving per month. This has not only provided a financial benefit but also "increased the purification capacity" by 57 Mega litre per month that could be sold at a profit.

Disinfection Cost Savings

Mmabatho WTW uses chlorine gas for post chlorination in the disinfection of the final treated water.

It was observed that pre–Lake Guard™ treatment the required chlorine gas dosage was 7 mg/l for the disinfection process it is important to note that the plant still failed to provide a free chlorine residual in the final water. This translated to chlorine gas cost of R45,000 per month at R12,77/kg.

Post Lake Guard™ treatment, the chlorine demand was reduced to 4 mg/l: a monthly saving of R 19k and 43% percentile reduction in chlorine usage.

Total Treatment Monthly Cost Savings

Coagulation Cost	R 187,506
Rapid Gravity Sand Filtration Backwash Cost	R 722,571
Disinfection – Chlorination Cost	R 19,541
Total Monthly Treatment Cost Savings	R 929,618
Total Annual Treatment Cost Savings	R 11,155,416

Conclusion

It is important to note that these results apply directly to the Setumo Dam raw water characteristics and may differ from other raw water sources. The conclusion drawn from this case study is that Algal blooms have a major impact on a water purification plants operational cost. By reducing the natural organic matter / algal biomass one can reduce the operational cost significantly Increase the production throughput, reduce water losses and more importantly improve the water quality, reducing cyanobacteria toxins making water safe again.

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