The water quality of Bospoort Dam

DE Mogakabe and CE van Ginkel

water & forestry

Department:
Water Affairs and Forestry
REPUBLIC OF SOUTH AFRICA

TITLE:	The Water Quality of the Bospoort Dam
REPORT NUMBER:	N/0000/00/DEQ/0108
PROJECT:	National Eutrophication Monitoring Programme (NEMP)
STATUS OF REPORT:	Final Draft
DATE:	January 2008

ACKNOWLEDGEMENTS

- The Hydrobiological and Chemical Laboratories of Resource Quality Services are essential to this programme and are acknowledged for their contribution to this internal report.
- The Technical Division of Resource Quality Monitoring and all other monitors of the National Eutrophication Monitoring Programme, whose dedication to do the monitoring at selected sites, are acknowledged.
- The personnel of RQS Sample Reception for their support receiving samples.
- The DWAF Management Support is acknowledged for providing the time and resources to complete this report.

RECOMMENDED FOR THE DEPARTMENT OF WATER AFFAIRS AND FORESTRY

Mr B. Madikizela 21/7/2008
Deputy Director: Resource Quality Monitoring

APPROVED FOR THE DEPARTMENT OF WATER AFFAIRS AND FORESTRY

Mr A. Diefenbach
Acting Director: Resource Quality Services

This report to be cited as:

Mogakabe, D.E. and Van Ginkel, C.E. (2008). The water quality of the Bospoort Dam. Internal Report No. N/0000/00/DEQ/0108 for the Department of Water Affairs and Forestry, South Africa.

EXECUTIVE SUMMARY

This *ad hoc* investigation was initiated as a project for Mrs P. Mphumbude at Resource Quality Services. Mr D.E. Mogakabe, with the assistance from the National NEMP Coordinator, Dr C.E. van Ginkel, compiled this report following the resignation of Mrs P. Mphumbude. In previous NEMP annual reports, Bospoort Dam were reported in the hypertrophic state, possible causes for the increasing deterioration in the water quality are discussed and highlighted. Eutrophication related parameters and possible heavy metals contamination in the dam are furthermore highlighted in the annual reports.

The Bospoort Dam is a small state-owned impoundment situated on the Hex River upstream of the Vaalkop Dam, northeast of Rustenburg in the Crocodile West/Marico WMA in the North West Province. The land-uses in the catchment include urban developments (e.g. Rustenburg), intensive mining areas, as well as agricultural activities.

The Bospoort dam is used for irrigation and domestic water supply. Bospoort Water Treatment Works (WTW) was constructed at the dam to treat the water for potable supply to town. Due to increase in deterioration of water quality, the Bospoort WTW ceased to operate as a result of nuisance problems (taste and odour) caused by excessive proliferation of algal bloom. Proliferation of algal blooms made the dam to appear almost completely green. Severe taste and odour problems were also experienced at Vaalkop dam that receive water from the Bospoort dam. Vaalkop dam was also used to supply potable water to the Rustenburg region (van der Walt *et al*., 2006)

Nutrient loading in the Bospoort dam seem to be a cause of concern as the system does not show any sign of recovery from the previous trophic state classifications. The continuous hypertrophic nature of the impoundment suggests possible contamination arising from the sewage treatment works upstream, agricultural run-offs, urban run-offs and re-circulation of nutrients from bottom sediments. Control needs to be exercised in the management of the sewage treatment upstream of the dam and the use of fertilizers in agricultural fields to reduce the cumulative impact in the dam. Impacts caused by informal settlements along the Hex River leading to the dam should be determined, monitored and controlled to avoid further health risk.

Even though cyanobacterial blooms were not prominent throughout the investigation, it occurred in high concentrations during the early part of the investigation. Cyanobacteria or Blue-green algae are organisms with some characteristics of bacteria and some of algae and they can produce toxic substances (i.e. Microcystins). These blue-green algae are commonly found in freshwater systems that have high nutrient load. Their presence is of concern because of previous blooms and their potential toxicity in the system. Their presence in other sites of the dam is not ruled out since only the site near the dam wall, as with all other NEMP sites, was sampled in this investigation. Cyanobacterial toxins in a water resource may pose a health hazard to aquatic invertebrates, recreational users and livestock animals.

The presence of heavy metals such as Cadmium (Cd), Arsenic (As) and Lead (Pb) in the water albeit in minimal concentration is also of concern considering that these metals might have elevated concentration in the sediment part of the impoundment. Their concentration might pose a greater risk to aquatic life in the system. Because the dam is subject to fishing effort, bioaccumulation of these toxic metals in the impoundment may cause the fish to be unfit for human consumption. Possible sources of these heavy metals include mining activities and also possible runoff from agricultural fields i.e. pesticides used along the Hex River Catchments leading to the dam.

The system also shows a high salt content, commonly indicated by conductivity values. Urban surface runoff and mining activities are possible sources of ions that contributed to the high salinity levels in the Bospoort dam.

Previous studies indicated that the source of nutrient loading was contributed significantly by the two sewerage plant systems, Rustenburg Wastewater Treatment Work (WWTW) and the Boitekong WWTW, discharging upstream the Bospoort dam. Due to subsequent upgrading of the system to handle increased sewerage and treatment of phosphates control measures should be put in place to ensure compliance. All potential polluters must be compelled to comply with the requirements of their respective water licenses use upstream of the dam.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Report Aim

The aim of this report is to assess the water quality of the Bospoort Dam with reference to the Trophic Status and associated problems, salinity composition and heavy metal pollution of the reservoir.

1.2 Background and Study Site

The study was initiated as a project for Mrs P. Mphumbude at Resource Quality Services. She was responsible for compiling the Terms of Reference (ToR) and designing the monitoring programme under supervision of the National Eutrophication Monitoring Programme (NEMP) Coordinator. Following the resignation of Mrs P. Mphumbude at the end of October 2006, the new employee Mr D.E. Mogakabe, with the assistance from the NEMP Coordinator compiled the report.

The Bospoort Dam is a small state-owned impoundment situated on the Hex River, in the North West Province of South Africa. The reservoir is downstream of Rustenburg (Figure 1.1) in the Crocodile West/Marico WMA. Rustenburg is a large town that is expanding due to mining activities in the catchment. At the time of the investigation, the Rustenburg wastewater treatment works (WWTW) did not keep up with the expanding and increasing sewerage loads received from the city, effluent from the WWTW polluted the Hex River which flows into the Bospoort Dam (van der Walt *et al.*, 2006)

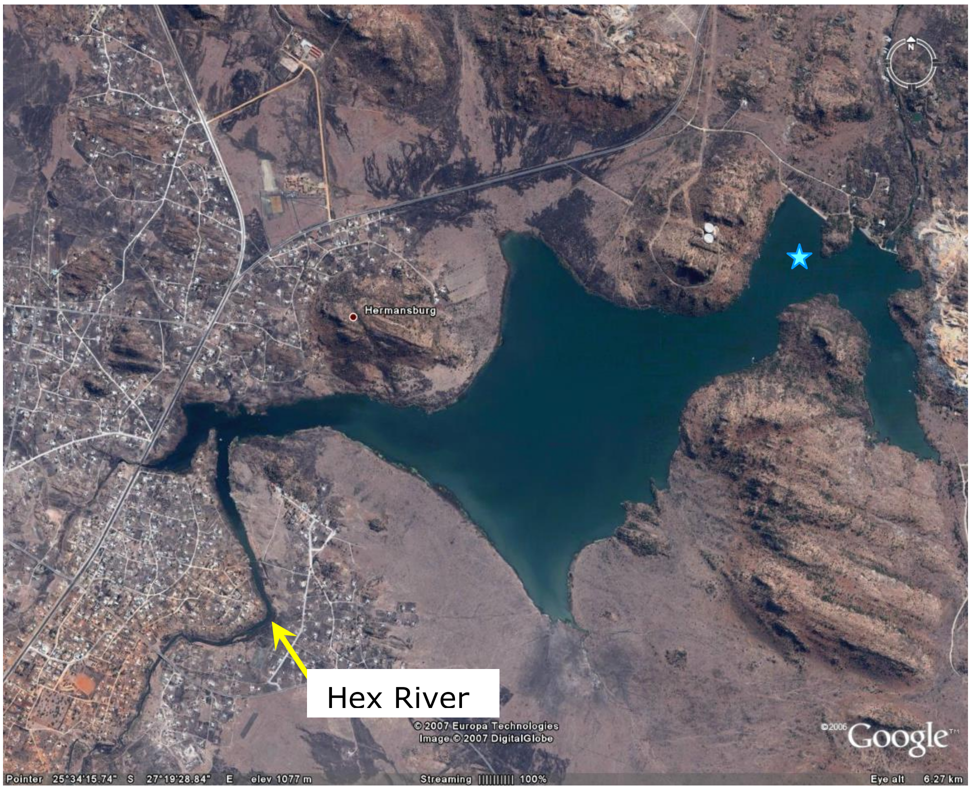


Figure 1.1. The Bospoort Dam with sampling site (star) close to the dam wall and the main inflowing River, the Hex River

The Rustenburg WWTW management has been taken over by Magalies Water. It is foreseen that the functionality of the WWTW will improve in future. Magalies Water has also completed the upgrade of the Drinking Water Treatment Works that extract water from the Bospoort Dam. This upgrade was in progress during the study period. Magalies Water will in future take control of the improved Water Treatment Works just downstream of the Bospoort Dam and supply in addition to supplies from Vaalkop Dam to Rustenburg. The Hex River is the main contributor of inflow into the Bospoort Dam. All the other little streams that enter the Bospoort Dam is small and do not extend far beyond the borders of the Bospoort Dam.

In addition to the Rustenburg WWTW, there is also gold and platinum mine effluent that discharges into the Hex River upstream of the Bospoort Dam. Large rural developments of high density housing are furthermore evident in the catchment and can be seen in Figure 1.1 at the inflow of the Hex River into the Bospoort Dam.

Water of the Bospoort Dam is used for drinking water and recreational purposes. The drinking water treatment facility situated at the Bospoort Dam was the first works in South Africa that had to be closed down because the works could not guarantee safe drinking water due to varying and poor quality source water.

The Bospoort Dam has been classified as hypertrophic (Van Ginkel 1999; 2004; 2005 and 2006). The Dam is known to experience severe cyanobacterial blooms. The first such an event led to the establishment of the Elands River Forum. The local stakeholders were severely impacted by the *Microcystis* bloom that was present in the Bospoort Dam in 1999. Resource Quality Services investigated the event and reported to the DWAF Regional Office of the potential hazard to the locals.

The study will indicate if the system recovered from previous water quality problems. This assessment will include some limnological characteristics of the reservoir including trophic status, physical characteristics, an assessment of the phytoplankton community, salinity and the heavy metal pollution that may be present in of the Bospoort Dam.

CHAPTER 2

SAMPLING METHODS

All water samples were collected from the Bospoort dam near the main dam wall from March 2006 until January 2007. The sampling frequency was bi-weekly. An integrated sample (0-5m depth) was taken during sampling using a hosepipe and dispensed into three separate containers. The 350ml white bottle container with blue cap was used for the water sampling of macro chemical analyses, field filtration for Hydro- biological analyses and the 250ml glass bottle for Algal identification. To preserve the integrity of the macro and algal identification samples, 2 ml mercury chloride, 0.5 ml lugol solution were respectively added. All the bottles were stored in coolers containing ice-sheets immediately after collection and taken to Resource Quality Service (RQS) accredited laboratory for analyses.

For physical parameters, depth profiles for pH, temperature and dissolved Oxygen (DO) were measured in the field using digital automatic temperature, oxygen and pH meter (YSI). The instrument was pre-calibrated appropriately prior to use. The Secchi disk was used to measure light penetration into the water column. The disk consists of a round plate divided into alternate black and white sections. The disk is attached to a graduated rope divided into measuring units of 0.1 m apart, lowered into the water and the measurement recorded when it becomes immediately invisible.

All the water samples were analysed by appropriate and acceptable international standards in the accredited RQS laboratory of the Department of Water Affairs and Forestry (IWQS test methods, 1998). The reagents used were of analytical grade and instruments pre-calibrated appropriately prior to use. To ascertain quality assurance, replicate analyses were conducted for each determination. Analyses were performed for major inorganic chemical variables, total nutrients (total nitrogen and total phosphorus) and the response variables (chlorophyll *a,* algal group and species identification).

Figure 2.1. Field preparation of samples

CHAPTER 3

ASSESSMENT OF BOSPOORT DAM WATER QUALITY

3.1 Nutrients

The nutrient content of the Bospoort dam is a cause of concern. The impoundment was previously classified as hypertrophic (Van Ginkel et al., 2005). The reservoir is, therefore, highly enriched with plant nutrients with special reference to phosphorous and nitrogen. Figure 3.1 indicates the nitrogen concentrations in the Bospoort Dam.

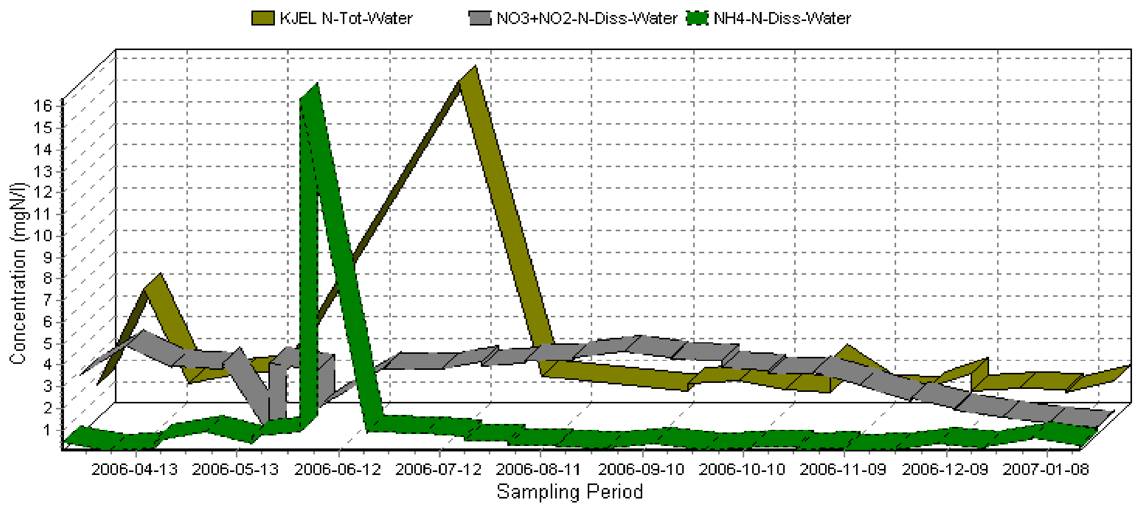


Figure 3.1. Nitrogen content in Bospoort Dam 2006-2007

Nitrogen must be available in dissolved inorganic forms (i.e., NH_4^+, NO_3^- and NO_2^-) in order to be used by phytoplankton. The particulate organic form of N was measured as Kjeldahl nitrogen (KN). According to Figure 3.1, the concentration of the NO_3^-+NO_2^- and NH_4-N species ranged from 0.04 mgN/l to 3.86 mgN/l and 0.02 mgN/l to 16.37 mgN/l, respectively. The minimum and maximum KN values recorded were 1.22 mgN/l and 15.68 mgN/l, respectively. There is a common noticeable seasonal trend in concentrations amongst the nitrogen species. An increase in concentrations from the beginning of the study to July 2006 was observed followed by a decrease in concentrations with a sharp decrease observed for $NO3^-$+NO_2^- (Appendix A).

There were major peaks during April to May which corresponds with autumn turnover of the system (Figure 3.1 and 3.6). This may potentially indicate to re-cycling of the nutrients from the sediments. Internal loading may play an important role.

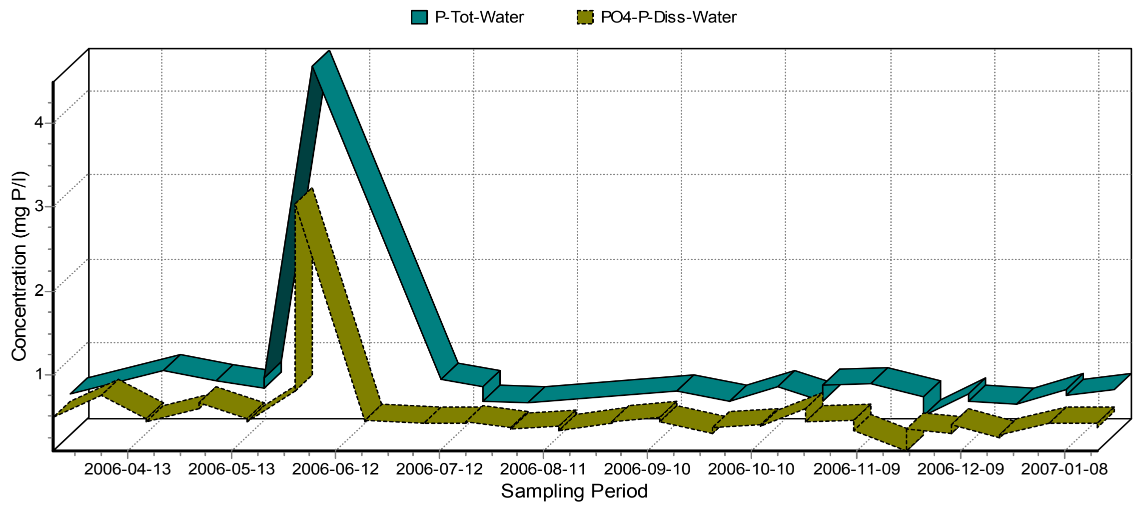


Figure 3.2. Phosphorus concentrations in Bospoort Dam 2006-2007

The inorganic form of phosphorus (orthophosphate, PO_4-P) that is readily available for phytoplankton usage must also be in dissolved state. To include also particulate organic phosphorus that can be cycled to inorganic orthophosphate and vice versa, the total phosphorus (TP) of the system was measured. Figure 3.2 indicates fluctuations in concentrations of total phosphorus (TP) and ortho-phosphorus (PO_4-P). The trend in PO_4-P concentrations shows a slight increase in the earlier period (March to April 2006). Major peaks in both TP and PO_4-P during May to June were found, followed by a decline in concentration until November 2006. A slight increase was observed from December 2006 to January 2007 (Appendix A). The minimum, maximum and annual mean TP were 0.47 mgP/l, 4.48 mgP/l and 0.85 mgP/l, respectively. According to the trophic status table for classification of impoundment (van Ginkel, 2002) the recorded TP mean indicates that Bospoort dam is a seriously hypertrophic system. The source of this high level phosphorus may be brought up by the waste water treatment plant discharge into the Hex River that is impounded by the Bospoort dam downstream the treatment plant or surface run-offs discharge from agricultural activities in the Hex river catchments. The peaks in the phosphorous concentrations again corresponds with the autumn turnover and points to internal loading from the sediments.

Table 3.1 depicts the ratio of total nitrogen to total phosphorus in Bospoort dam. The ratio of nitrogen to phosphorus indicates the limiting nutrient within the system (van Ginkel, 2002). A TN: TP ratio greater than 10:1 is thought to signify phosphorus limitation, implying that the available supply of phosphorus will be used up long before the supply of nitrogen is used up. According to Table 3.1, for the greater part of the study the ratio of TN: TP was less than 10:1 indicating that nitrogen was the limiting nutrient. This is undesirable from a management perspective, as nitrogen cannot be easily controlled and nitrogen limitation is associated with high cyanobacterial growth.

Table 3.1 The ratio of TN: TP in Bospoort Dam 2006-2007

Sampling Period	TP	TN*	TN: TP
2006/03/22	0.589	4.3	7.3
2006/04/18	0.862	4.8	5.6
2006/05/03	0.75	5.2	6.9
2006/05/17	0.658	2.3	3.5
2006/05/31	4.483	1.3	0.3
2006/07/07	0.757	18.8	24.8
2006/07/19	0.497	3.2	6.4
2006/08/01	0.483	5.5	11.4
2006/09/13	0.623	5.2	8.3
2006/09/28	0.498	5.2	10.4
2006/10/12	0.673	4.4	6.5
2006/10/25	0.697	5.6	8.0
2006/11/08	0.707	3.7	5.2
2006/11/23	0.552	3	5.4
2006/12/06	0.579	3.3	5.7
2006/12/20	0.471	2.3	4.9
2007/01/07	0.561	1.8	3.2

* TN = KN + NO_2 +NO_3

3.2 Response and physical variables

Chlorophyll *a* is an indicator of primary productivity in the system, and is the response to high nutrient availability in association with sufficient light. The concentrations of Chlorophyll *a* are indicated in Figure 3.3.

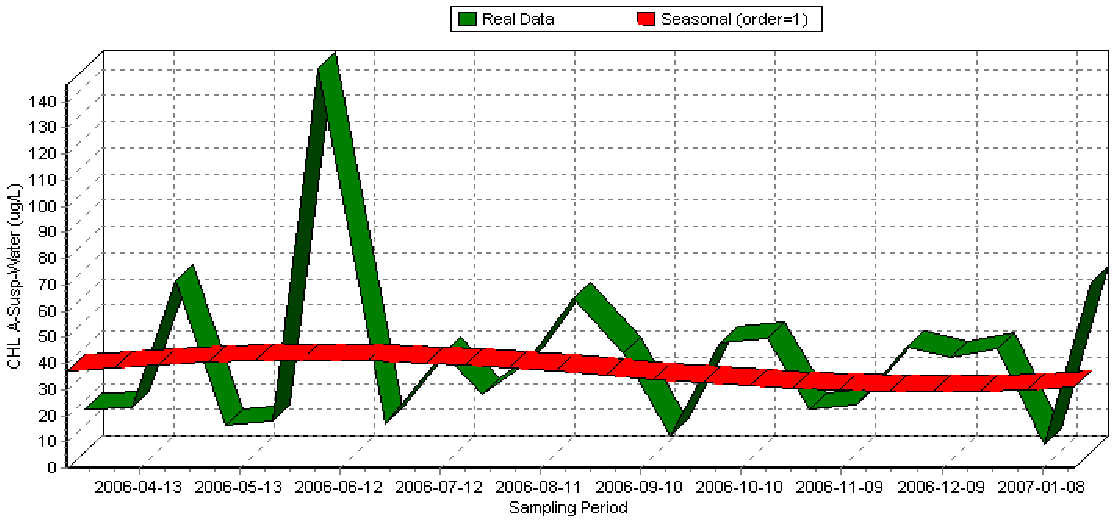


Figure 3.3. Chlorophyll *a* concentrations in Bospoort Dam 2006-2007

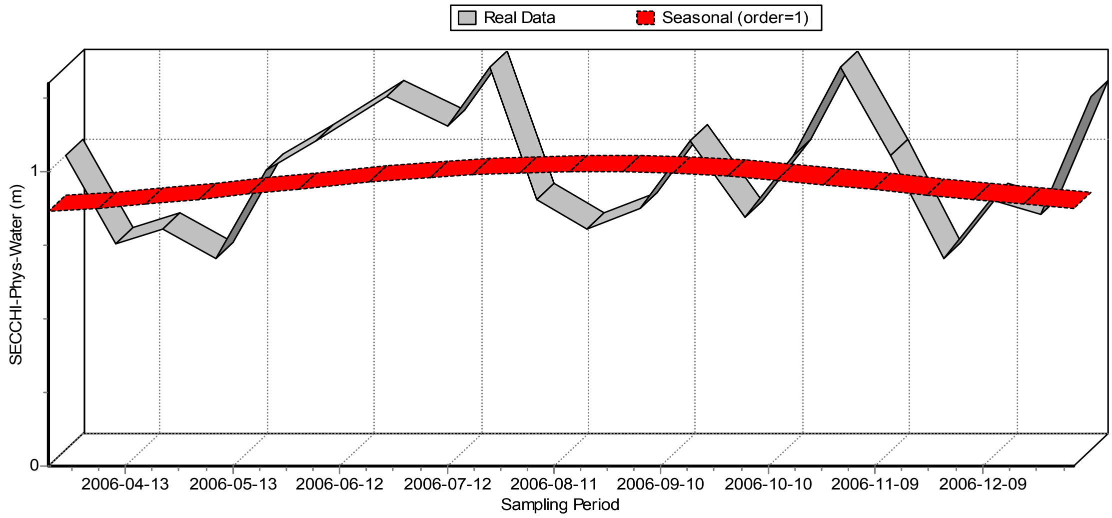


Figure 3.4. Secchi disc readings in Bospoort Dam 2006-2007

The minimum, maximum and mean Chlorophyll *a* concentrations were 2.5 µg/l, 146.49 µg/l and 33.89 µg/l, respectively for the whole sampling period. A peak of 146.29 µg/l Chlorophyll *a* was observed in one sample (31 May 2006) indicating high algal biomass and also corresponding with the autumn turnover of the dam. It was during this peak whereby TP concentration was extremely high (4.483 mg/l) and cyanobacterial colonies were present. There was a positive correlation between the TP obtained during the highest peak of chlorophyll a concentration (Figure 3.2 and Figure 3.3), indicating that TP had a significant positive effect on accrual rates of algal biomass. The increase in Chlorophyll *a* concentration (highest peak) did not correspond to the Secchi-depth recorded (1.05 m) (Figure 3.4), as it indicated higher light penetration than before, rather than a reduction in light in the water column of the impoundment. This suggests that the dense blooms of *Mycrocystis* sp. were still well exposed to sufficient amount of light penetration in the (epilimnion) water column for growth. In one study by van Ginkel *et al* (2001), it was also shown that *Mycrocystis* are frequently available when there is high algal biomass/bloom in the freshwater, especially during the early period of the year (January to May).

The trend shown by chlorophyll *a* concentration suggests that proper interventions are required for the impoundment to recover. The mean annual Chlorophyll *a* concentration (33.89 µg/l) of the dam showed that the impoundment is a hypertrophic system (van Ginkel, 2002).

The composition of the phytoplankton community in the Bospoort Dam is shown in Figure 3.5.

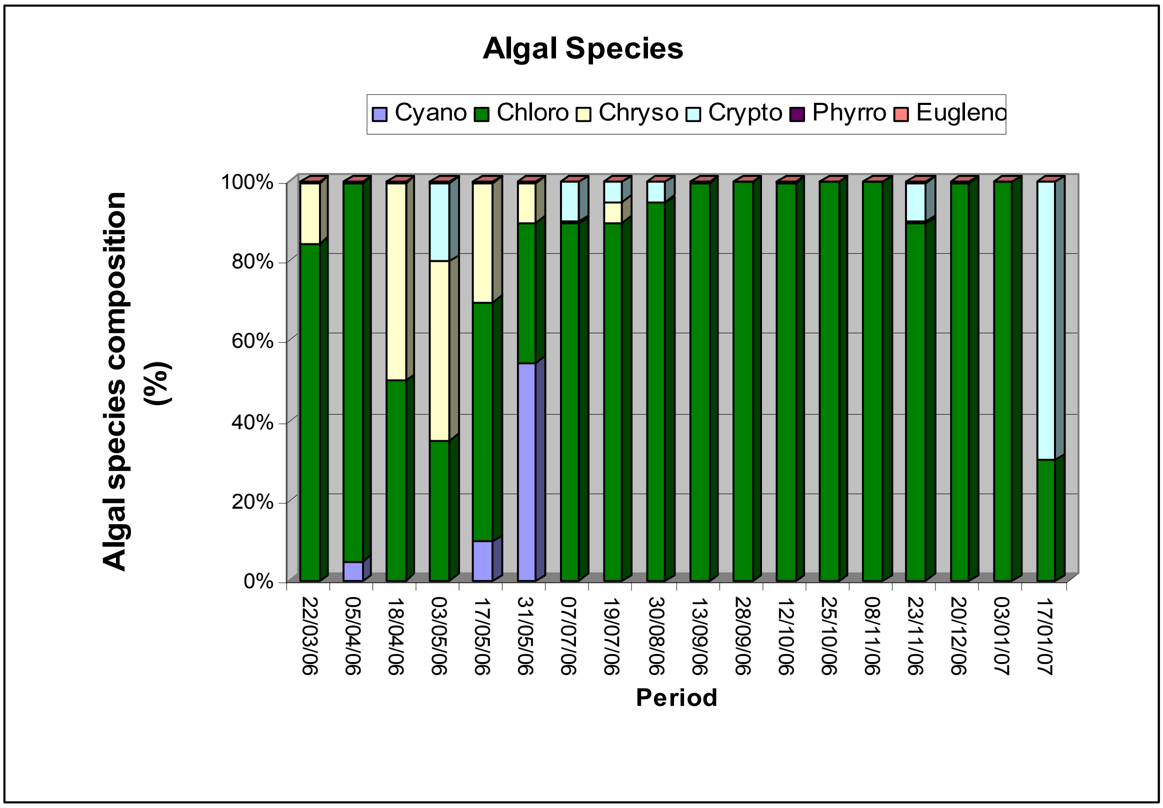


Figure 3.5. Percentage composition of algal community in Bospoort dam 2006-2007

The algal groups indicated are Cyanobacteria, Chlorophyta, Chrysophyta and Cryptophyta. The dominant algal group was Chlorophyta, followed by the Chrysophyta (*Diadesmus* /*Navicula* and *Melosira*) and Cryptophyta throughout the study period. In terms of algal species diversity, the Chlorophyta (*Scendesmus, Coelestrum, Pediastrum* and *Oocystis*) was also dominant over the others. The Cyanobacteria (*Mycrocystis* sp) and Chrysophyta (*Cryptomonas*) were only present during the earlier period (March to May 2006). Cryptophyta appeared in May, July and early August periods and resurfaced in November and January. Succession of algal species is clearly demonstrated thus indicating the nutrient enriched state of the impoundment. Of the Chlorophyta species identified, *Coelestrum* dominated the autumn period and *Oocystis* was most dominant during winter to summer periods (31 May 2006 to 17 Jan 2007).

The temperature and dissolved oxygen profiles of the water column of the Bospoort dam are given below in Figure 3.6 and Figure 3.7, respectively.

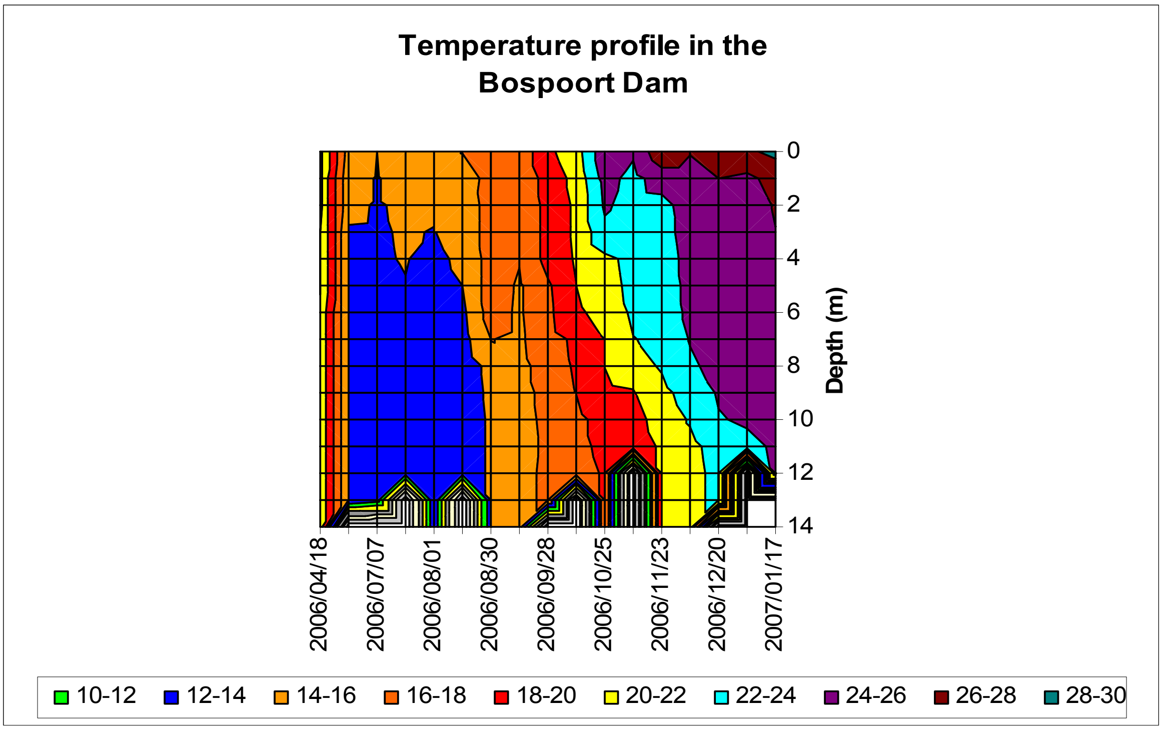


Figure 3.6. Temperature profile in Bospoort Dam 2006-2007

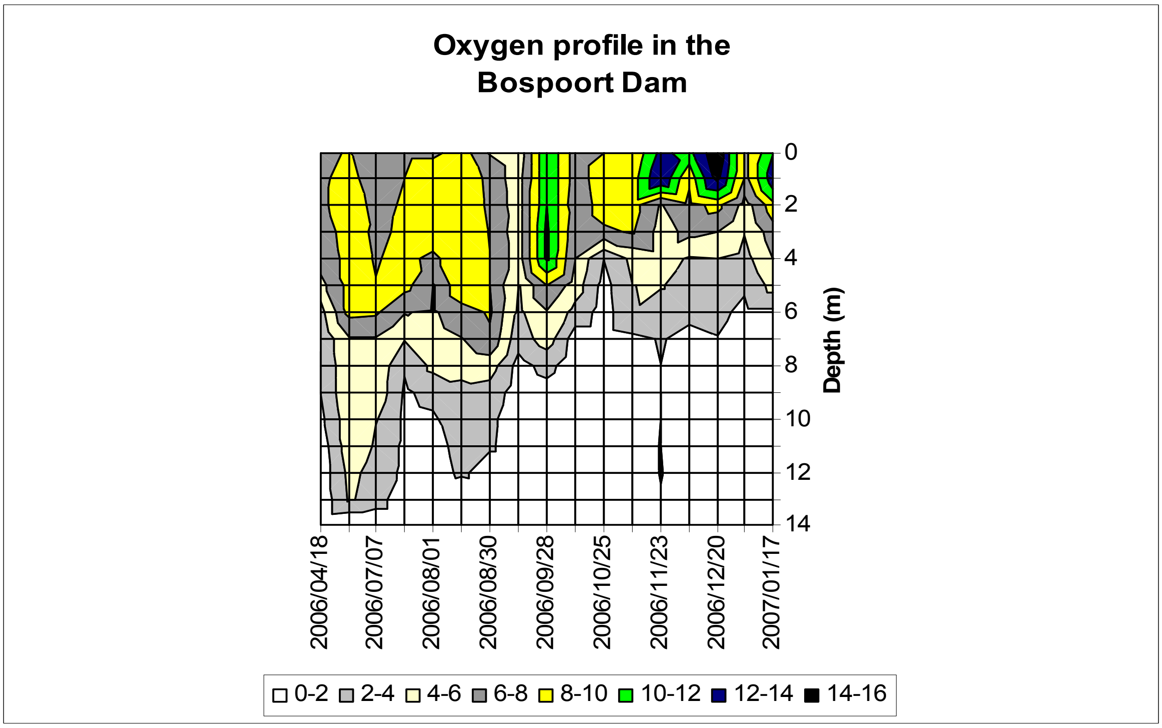


Figure 3.7. Dissolved Oxygen (DO) profile in Bospoort Dam 2006-2007

There was clear temperature stratification in the dam from August 2006 to January 2007, when temperatures started to increase above 16°C pushing the warmer water to deeper depths and reaching highs of up to 28°C during the summer months. Complete mixing of the water column is apparent from April to the start of August with temperatures between 10 and 14°C. During summer period, biological activities increase when photosynthetic activity is driven by high solar radiation. As a result of photosynthesis during the summer periods, the epilimnetic dissolved oxygen concentration increased, ranging from 8 mg/L to 16 mg/L as shown in Figure 3.7. There was a positive correlation between the increased temperature and dissolved oxygen concentrations during summer periods (08

Nov 2006 to 17 Jan 2007). The dissolved oxygen profile in the system showed with a strong hypolimnion, where DO declined compared to the epilimnetic DO. There was an observable depletion of dissolved oxygen in the lower deeper part of the impoundment, which was possibly brought up by decomposition of settling organic matter which may include algal bloom biomass.

Secchi depth during the same summer periods (08 Nov 2006 to 17 Jan 2007) ranged from 0.65m to 1.2m (average of 0.9m) of the water column, while in the winter months, transparency increased slightly to an average of 1.05 m (03 May 2006 to 19 July 2006). In Figure 3.8, the pH increased slightly during summer (pH= 8-10) compared to winter period (pH= 6-8). The increase in pH correlated with the increase in temperature, dissolved oxygen concentration and algal biomass during the summer period. According to the South African water quality guidelines (1996), the target water quality range (TWQR) for pH with respect to aquatic systems is between 6.5 and 9.0 (DWAF, 1996). For the greater part of the sampling period, it is evident (Figure 3.8) that most values in Bospoort dam were still within the required TWQR for aquatic systems and domestic (pH 6-9) use (DWAF, 1996a)

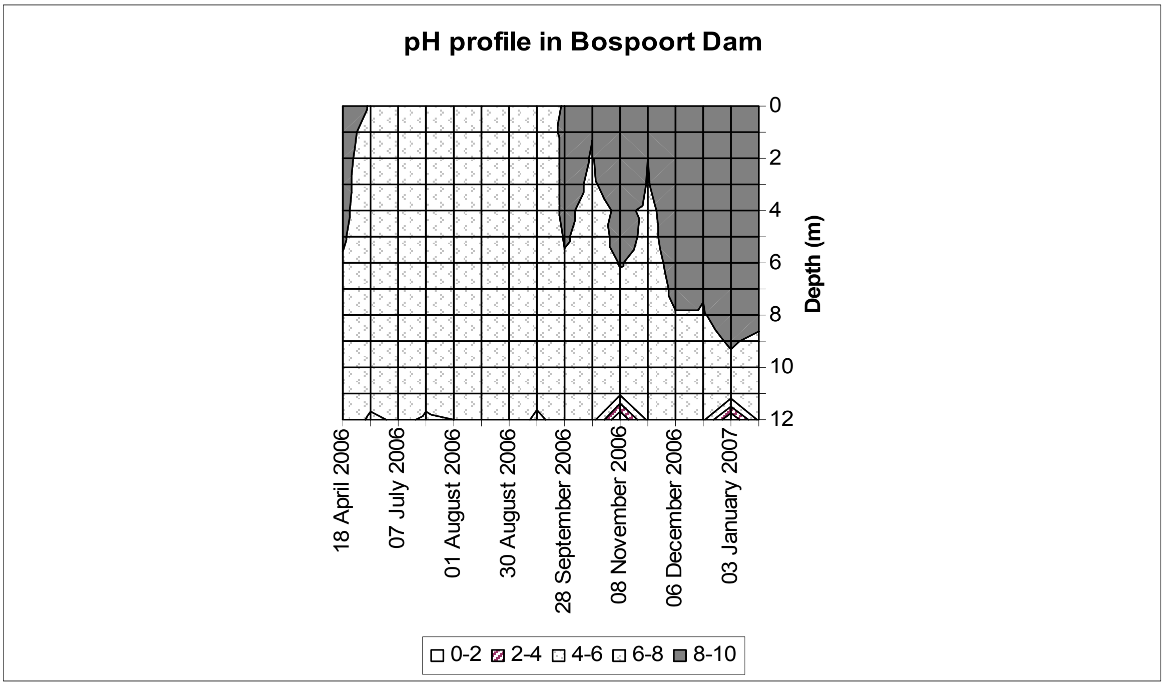


Figure 3.8. pH profile in Bospoort Dam 2006-2007

3.3 Salinity and conductivity

Total concentration of all dissolved ions in the water indicates salinity. The common cations and anions associated with salinity are Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2-}, and HCO^{3-}. Figure 3.9 indicates the concentrations of the ions over the whole sampling period.

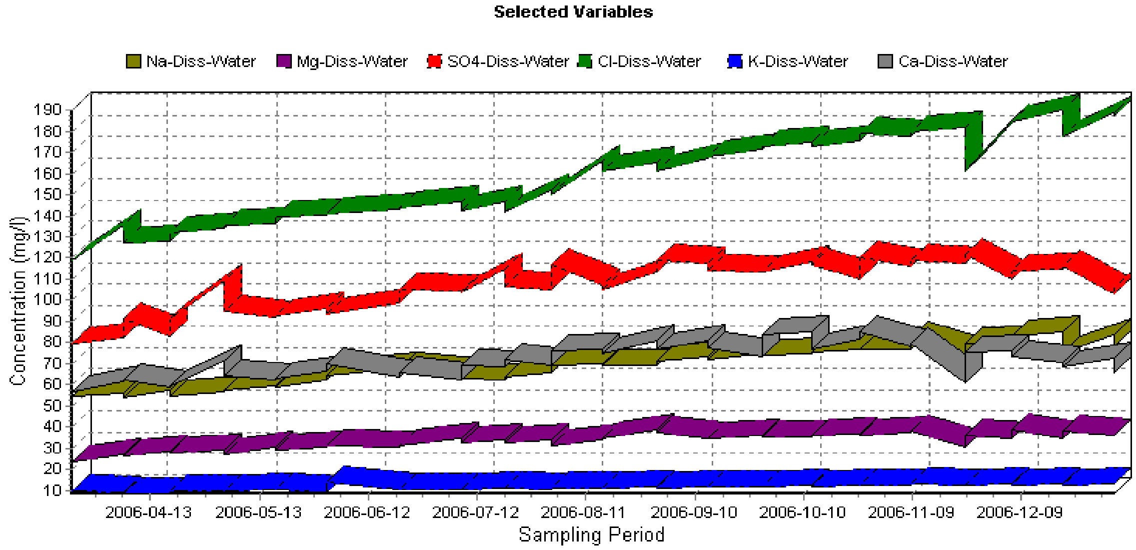


Figure 3.9. Salinity in Bospoort Dam 2006-2007

Throughout the sampling period, the concentration of Cl^- increased steadily with time. High salinity can cause physiological effects on aquatic organisms resulting in a loss or gain of species (Nielsen *et al*., 2003). Most of the ions (i.e. SO_4^{2-} ions, TWQR 0-400 mg/l) were within the required limit according to the South African water quality guidelines for aquatic systems (DWAF, 1996). For domestic use all the ions exceeded the maximum required limit with the exception of the K^+ and SO_4^{2-} ions concentrations (DWAF, 1996 a; DWAF, 1996 b). The Electrical conductivity (EC) of the dam water is shown in Figure 3.10. Electrical conductivity (EC) estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions in the water. EC is also a measure of salinity. The graph indicates an increase in conductivity with time. The EC readings varied between 70 mS/m and 115mS/m. The conductivity values predominantly exceed the TWQR for aquatic ecosystems (EC of ±70 mS/m) domestic (0-40 mS/m) and irrigation water (0-19 mS/m) uses according to the South African Water Quality Guidelines for each water use (DWAF, 1996; DWAF, 1996a and DWAF 1996b).

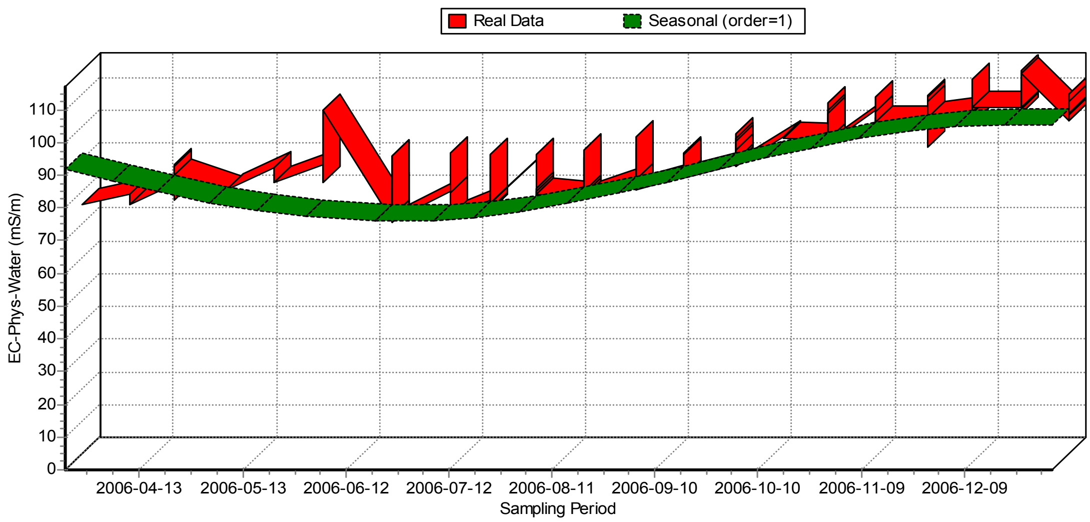


Figure 3.10. Electrical Conductivity trends in Bospoort Dam 2006 -2007

3.4 Heavy Metals

Heavy metal pollution in the freshwater is a cause for concern as these metals are capable of bioaccumulation in tissues of aquatic biota and can also affect the composition, distribution and diversity benthic organisms (Geydu-Ababio et al., 1999). The concentration of selected heavy metal concentrations in the dam are indicated in Figure 3.11 (a) and (b).

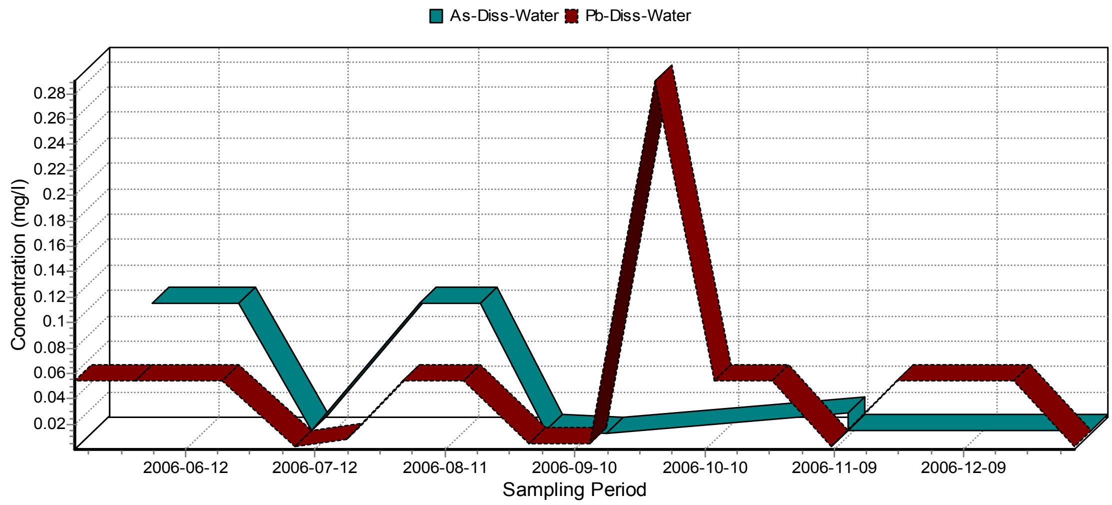
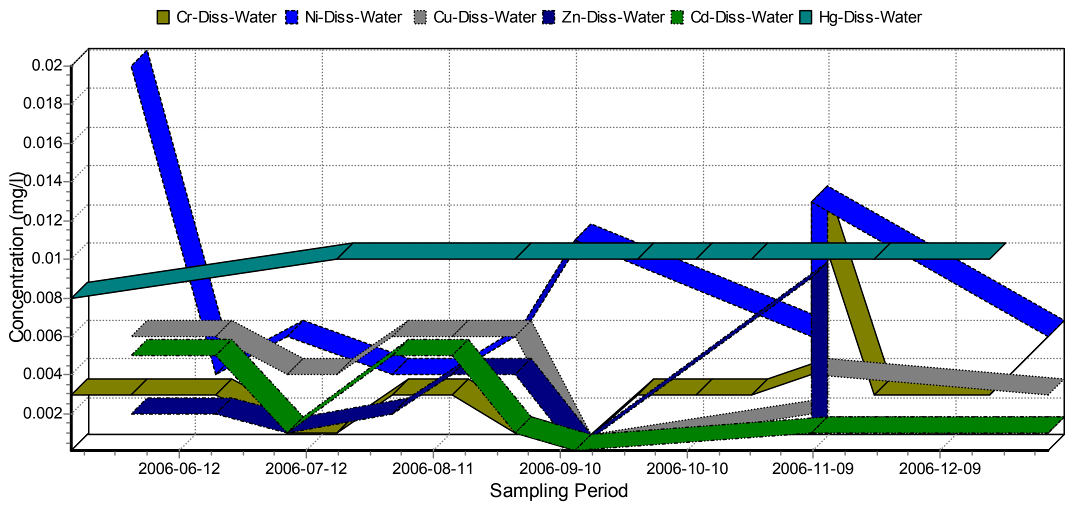
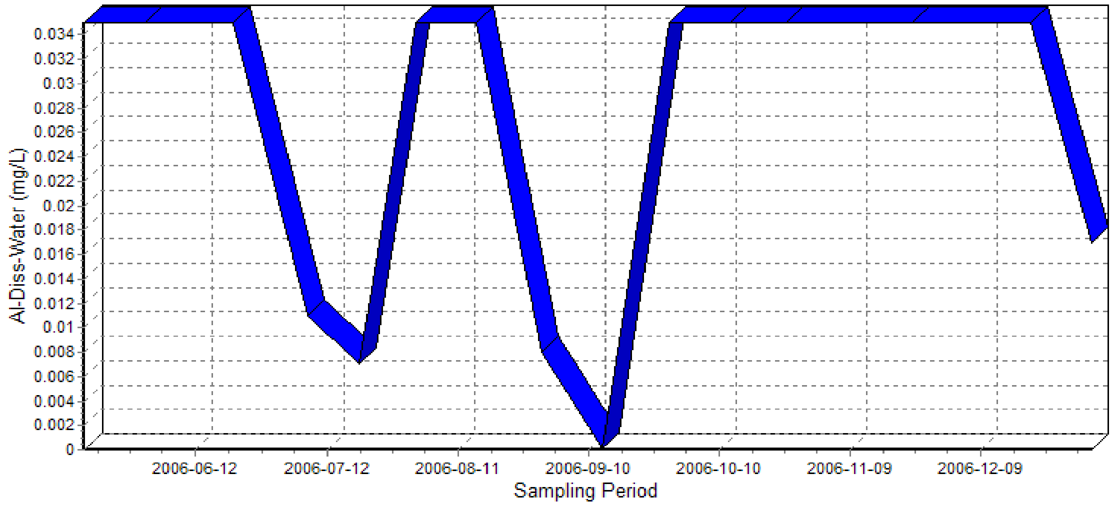


Figure 3.11. Heavy metals concentrations in Bospoort Dam 2006-2007
(a) Arsenic (As) and Lead (Pb) concentrations (mg/l)



(b) Nickel (Ni), Chromium (Cr), Zinc (Zn), Cadmium (Cd) and Mercury (Hg) (mg/l)



(c) Aluminium (Al) concentration

There is relatively low concentration of heavy metals throughout the sampling period in the water column. Of concern, is the Arsenic (As) and Lead (Pb) concentrations (Fig. 3.11 a) that are relatively high compared to heavy metals shown in Figure 3.11b. This relatively low concentration in the water column is not a clear indication of the heavy metal pollution in the dam because metals tend to sediment to the bottom of the water where they concentrate (Hanson *et al*., 1993; Davies *et al*., 1991).

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

The high nutrient load is of great concern especially as this has been an ongoing problem as indicated by the previous trophic status of the Bospoort dam. Since the nutrient concentrations were determined only near the dam wall, the possibility exist that concentrations of both phosphorus and nitrogen species might be higher elsewhere in the Bospoort Dam, especially at the inflowing site in the Hex River. The most likely sources of nutrient loading might be from a) the sewage treatment works upstream, b) agricultural activities, c) urban runoff and d) autumn turnover re-circulating nutrients released under anaerobic hypolimnetic summer conditions from bottom sediments.

Control needs to be exercised in the catchment of the Bospoort Dam by the management of the sewage treatment upstream and the use of fertilizers in agricultural fields to reduce the cumulative impact of nutrient loading in the dam. All potential polluters must be compelled to comply with the requirements of their respective water license use upstream the dam.

The history of cyanobacteria blooms (*Mycrocystis*) in Bospoort Dam is a cause for concern considering their potential toxicity in the system. Their presence in other sites of the dam is not ruled off since only the site near the dam wall was sampled in this investigation. Cyanobacterial toxins may pose a health hazard to aquatic invertebrates, recreational users and livestock farmers. During fieldwork noxious odours could be smelt, produced from algal scums when they breakdown by bacteria.

Even though there was minimal heavy metal pollution in the water column of the impoundment, it should be noted that these metals tend to accumulate in the sediment. Care and control should be taken to ensure that mining managers comply with their water quality licences discharge requirements or indicate the quality of their effluent before discharging in the Hex River upstream the dam. Heavy metal pollution poses a greater risk to aquatic life in the dam. Since the dam is subject to fishing effort, bioaccumulation of these toxic metals in fish bodies may cause the fish to be unfit for human consumption.

Conductivity was on the increase in the dam. Though, high rates of evaporation and minimal rainfall might have contributed to high concentration of salinity and/or conductivity, ion contamination from mining areas and urban or agricultural runoff are not ruled out.

Proper structures (i.e. increasing the capacity of the sewage treatment works) must be put in place to cope with the increasing rate of developments in Rustenburg urban area to avoid or minimise the water quality impact on water resources.

CHAPTER 5

REFERENCES

Davies C.A., Tomlinson K. and Stephenson T. (1991). Heavy metal in River Tees estuary sediments. *Environ. Technol.* **12**: 961 - 972.

Department of Water Affairs and Forestry (DWAF). (1996). South African Water Quality Guidelines. Volume 7: Aquatic Ecosystems. First Edition. Pretoria.

DWAF. (1996a). South African Water Quality Guidelines. Volume 1: Domestic Water Use. Second Edition. Pretoria.

DWAF. (1996b). South African Water Quality Guidelines. Volume 4: Agricultural Water Use: Irrigation. First Edition. Pretoria.

Gyedu-Ababio T.K., Furstenberg J.P., Baird D. and Vanreusel A. (1999) Nematodes as indicators of pollution: A case study from the Swartkops River system, South Africa. *Hydrobiologia* **397** 155-169.

Hanson P.J., Evans D.W., Colby D.R. and Zdanowicz V.S. (1983). Assessment of elemental contamination in estuarine and coastal environments based on geochemical and statistical modeling of sediments. *Marine Environ. Res.* **36** 237-266.

Nielsen D.L., Brock M.A., Rees G.N. and Baldwin D.S. (2003). Effects of increasing salinity on freshwater ecosystem in Australia. *Australian Journal of Botany* **51** 655-665.

Van der Walt M., Marx C., Fouché L., Pretorius N., St Arnaud J. (2006). Turning the sewage tide around. A good news case study about the Hex River Catchment. WISA 2006 Biennial Conference & Exhibition , Durban. URL: http://www.ewisa.co.za/literature/files/274%20van%20der%20Walt.pdf

Van Ginkel C.E. (1999) Toxic Algae in Erfenis and Allemanskraal Dams – 1999. IWQS Report No. N/C400/03/DEQ/1999.

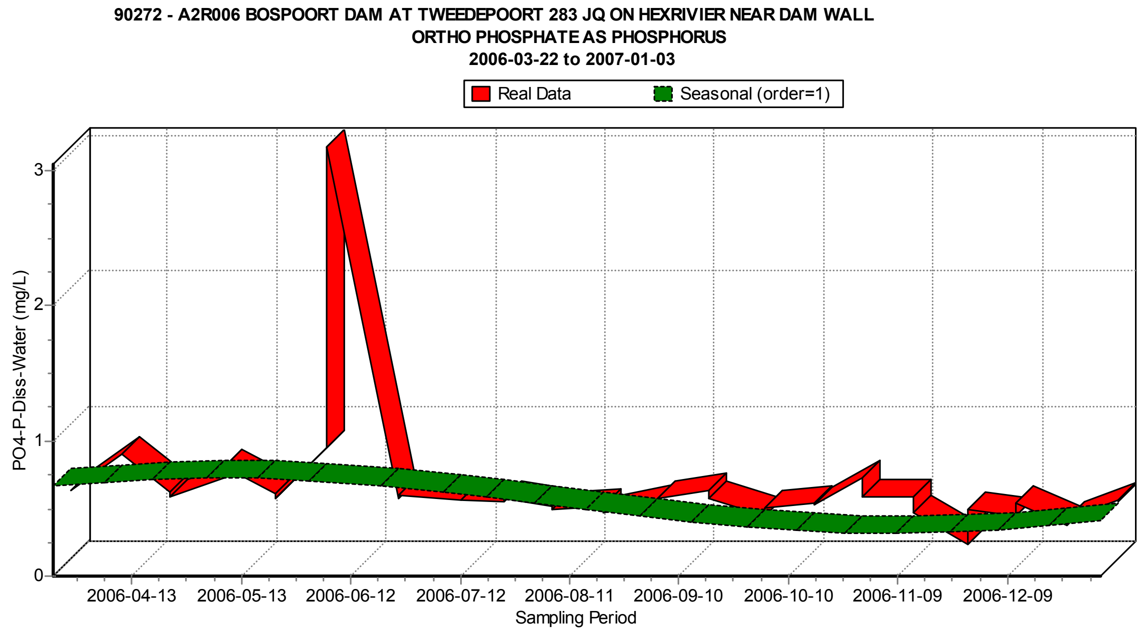
Van Ginkel C.E. (2002). Trophic Status Assessment. Executive Summary. DWAF IWQS.

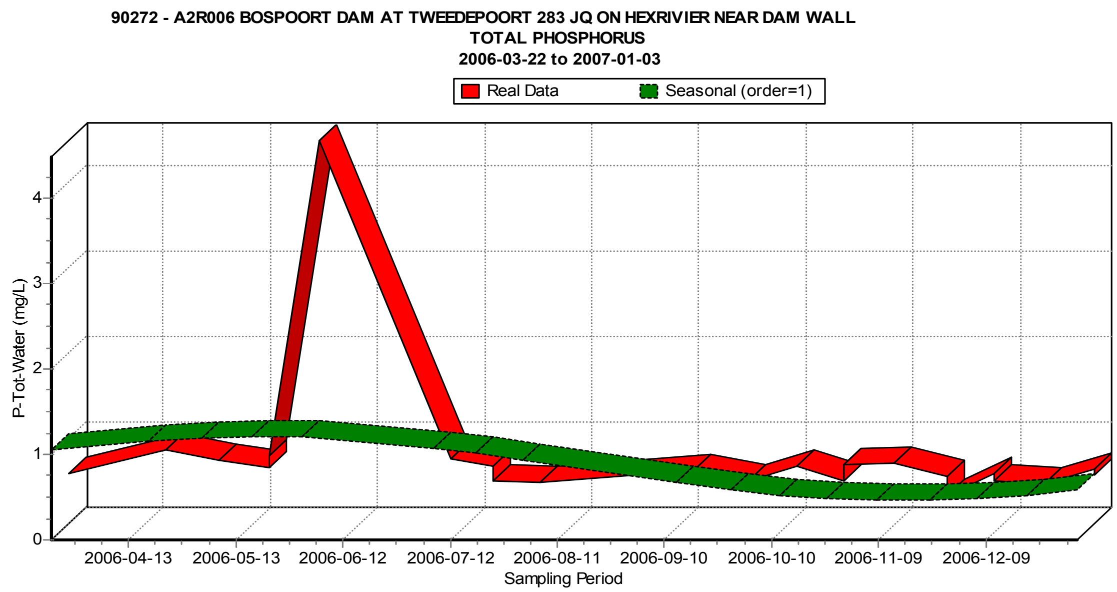
Van Ginkel C.E., Hohls B.C., and Vermaak E. (2001). A *Ceratium hirundinella* (O.F Műller) bloom in Hartbeespoort Dam, South Africa. *Water SA* **27** (2) 269-275.

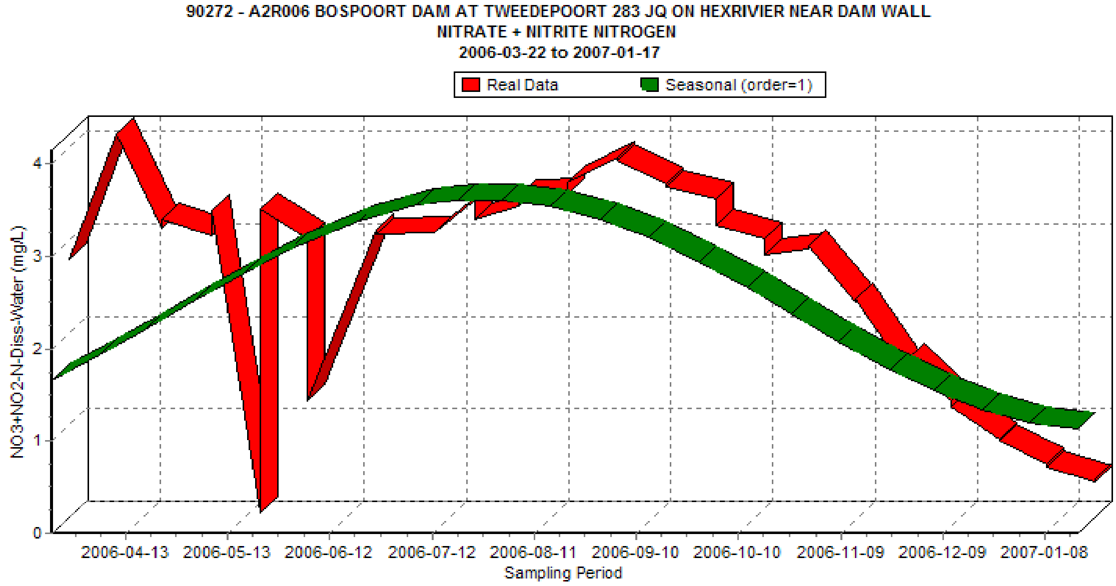
CHAPTER 6

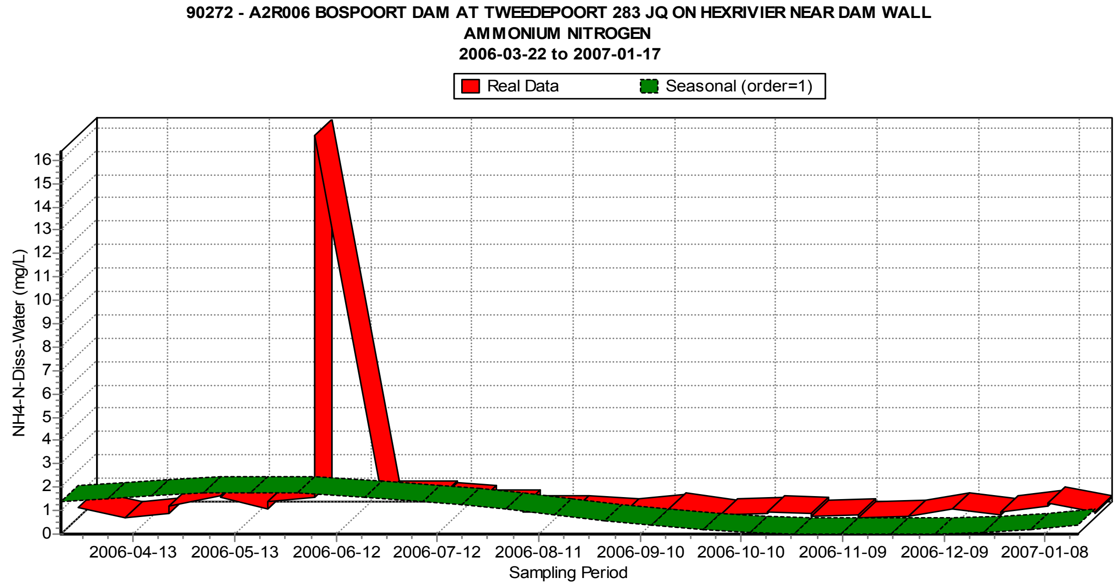
APPENDIX A

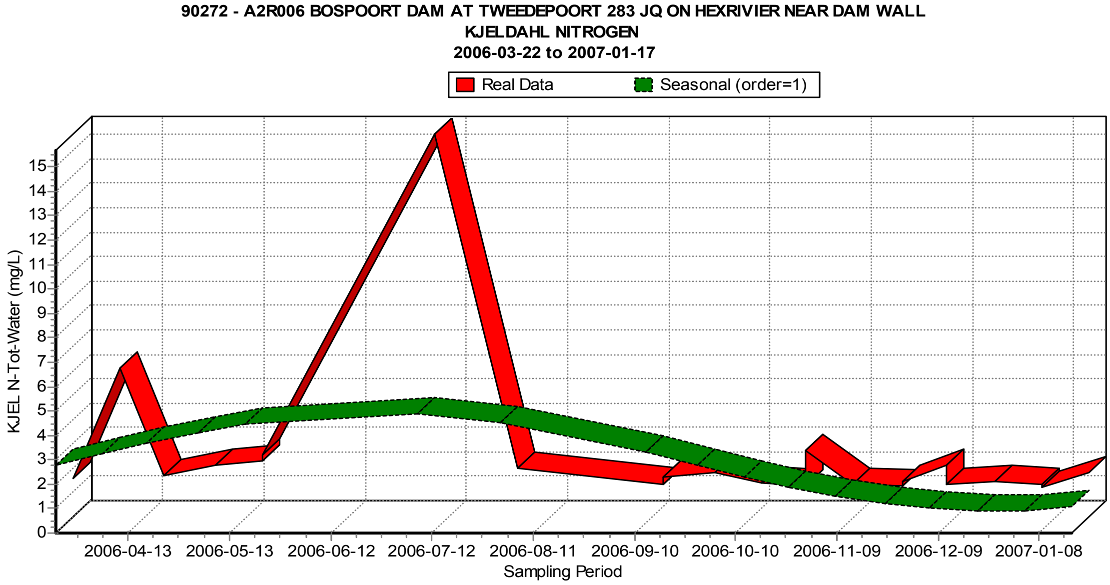
Seasonal Trends in Nutrients Concentrations



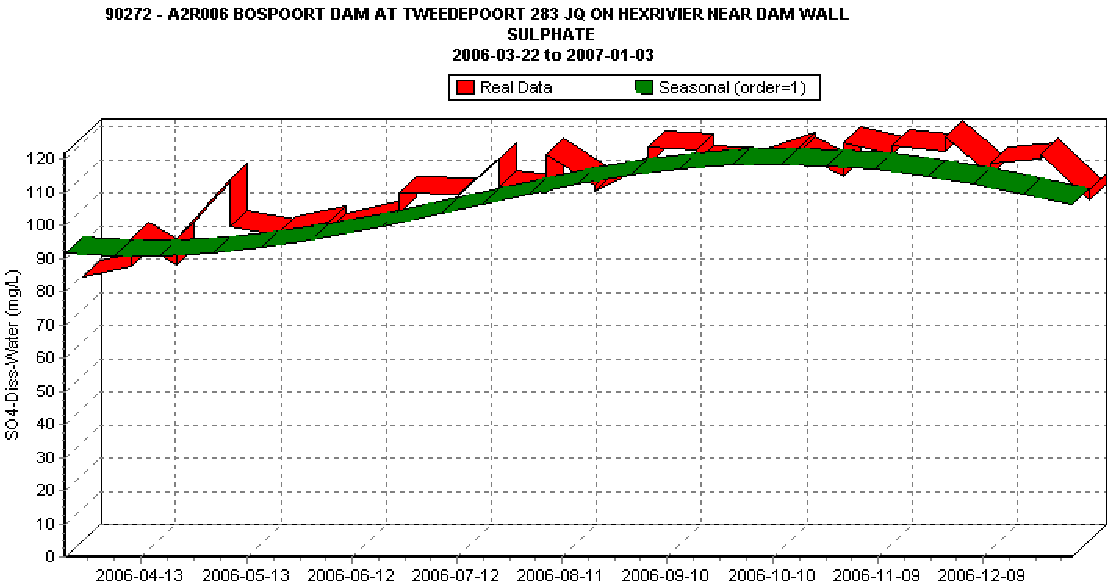


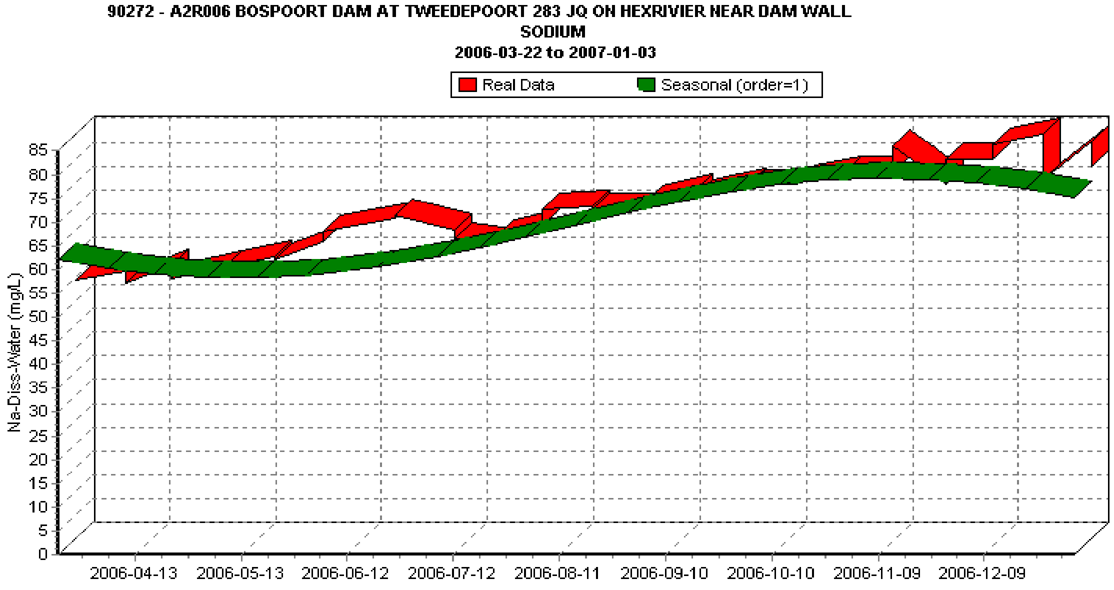

90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
NITRATE + NITRITE NITROGEN
2006-03-22 to 2007-01-17
Real Data
Seasonal (order=1)
NO3+NO2-N-Diss-Water (mg/L)
0
1
2
3
4
2006-04-13
2006-05-13
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09
2007-01-08
Sampling Period

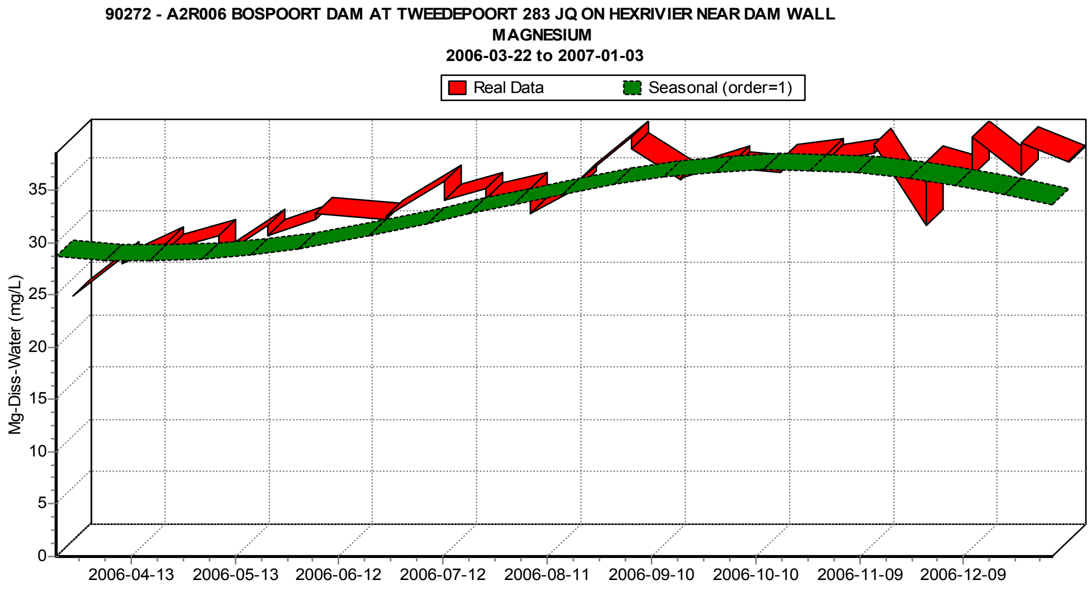

90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
AMMONIUM NITROGEN
2006-03-22 to 2007-01-17
Real Data
Seasonal (order=1)
NH4-N-Diss-Water (mg/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
2006-04-13
2006-05-13
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09
2007-01-08
Sampling Period

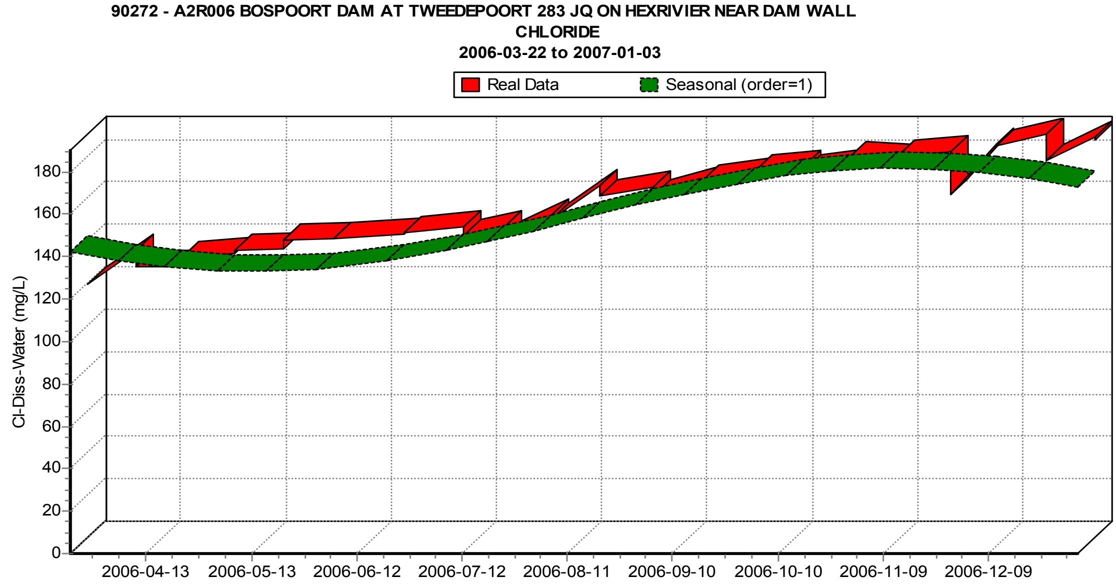


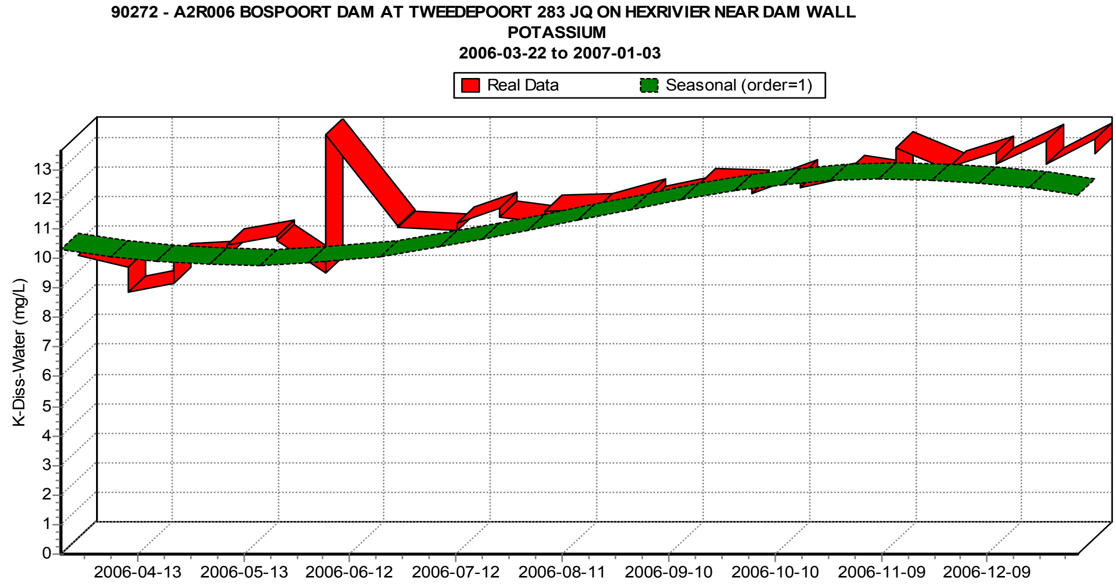
Seasonal Trends in salinity ions

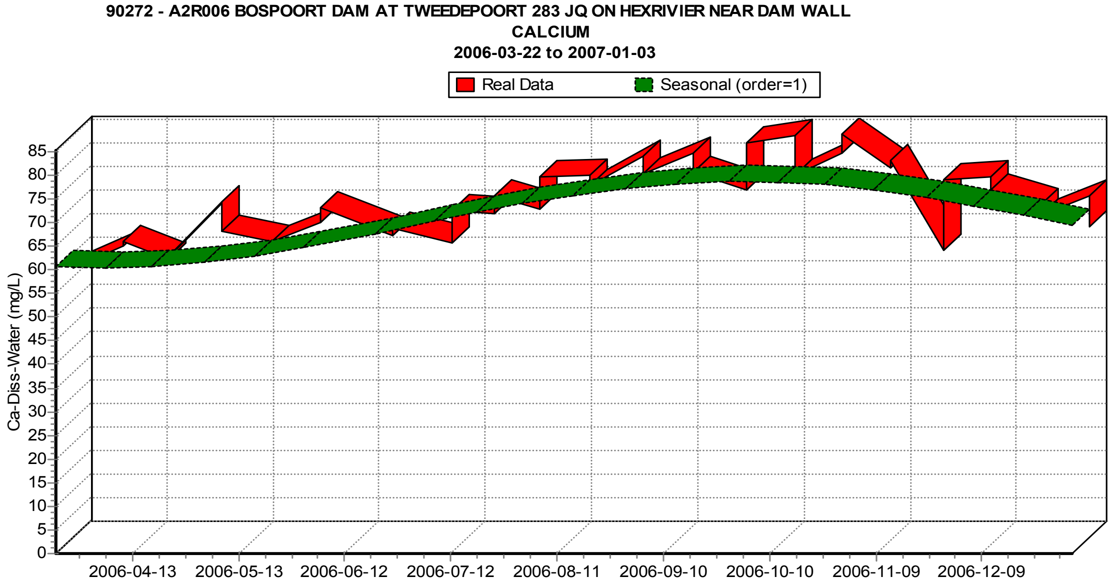


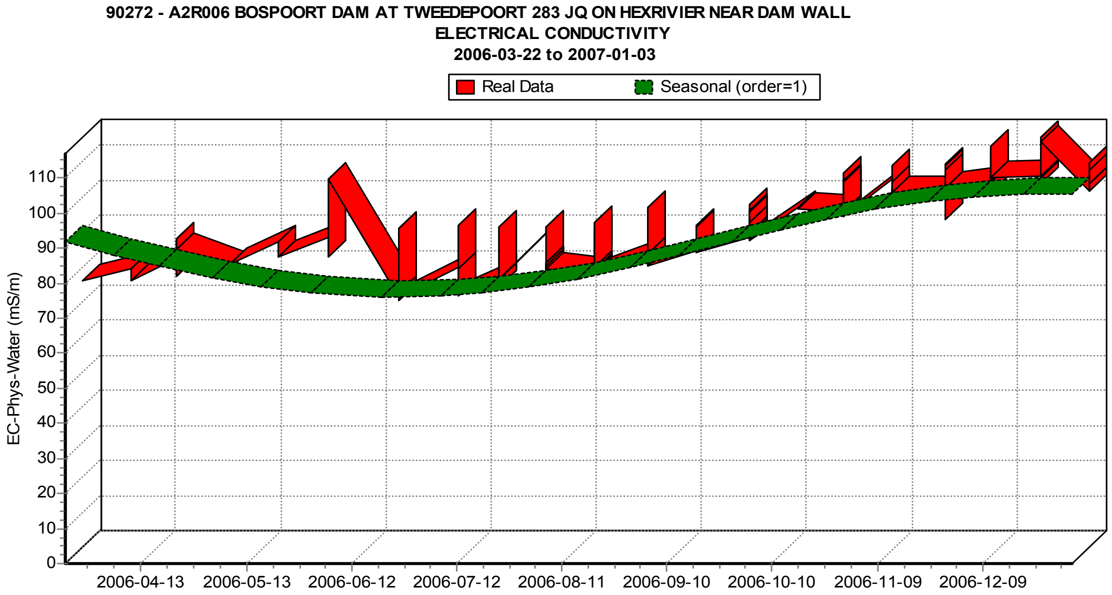

90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
SODIUM
2006-03-22 to 2007-01-03
Real Data
Seasonal (order=1)
Na-Diss-Water (mg/L)
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
2006-04-13
2006-05-13
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09


90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
MAGNESIUM
2006-03-22 to 2007-01-03
Real Data
Seasonal (order=1)
Mg-Diss-Water (mg/L)
35
30
25
20
15
10
5
0
2006-04-13
2006-05-13
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09

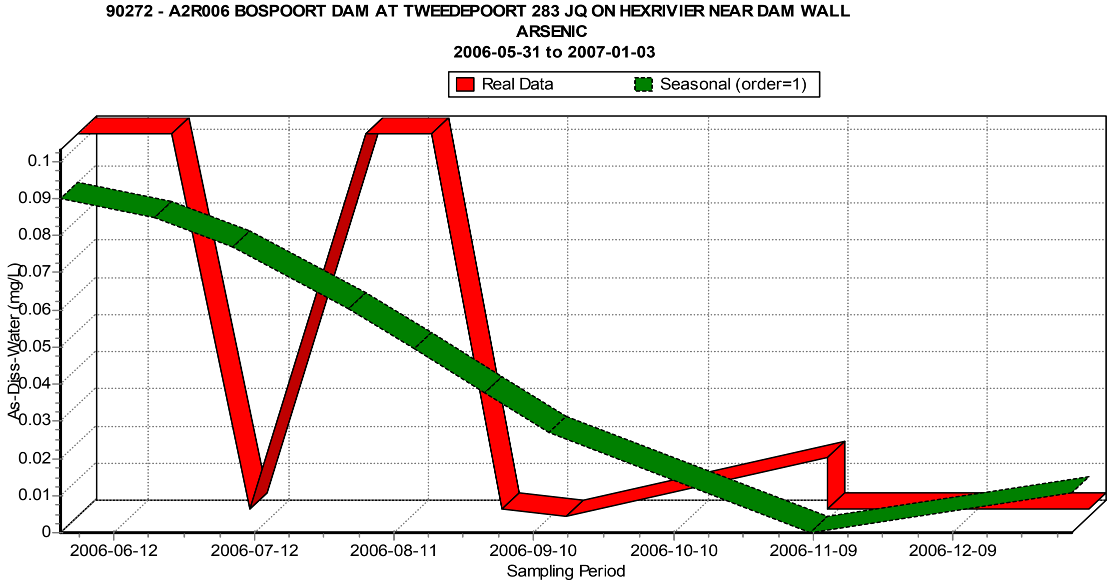

90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
CHLORIDE
2006-03-22 to 2007-01-03
Real Data
Seasonal (order=1)
Cl-Diss-Water (mg/L)
0
20
40
60
80
100
120
140
160
180
2006-04-13
2006-05-13
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09

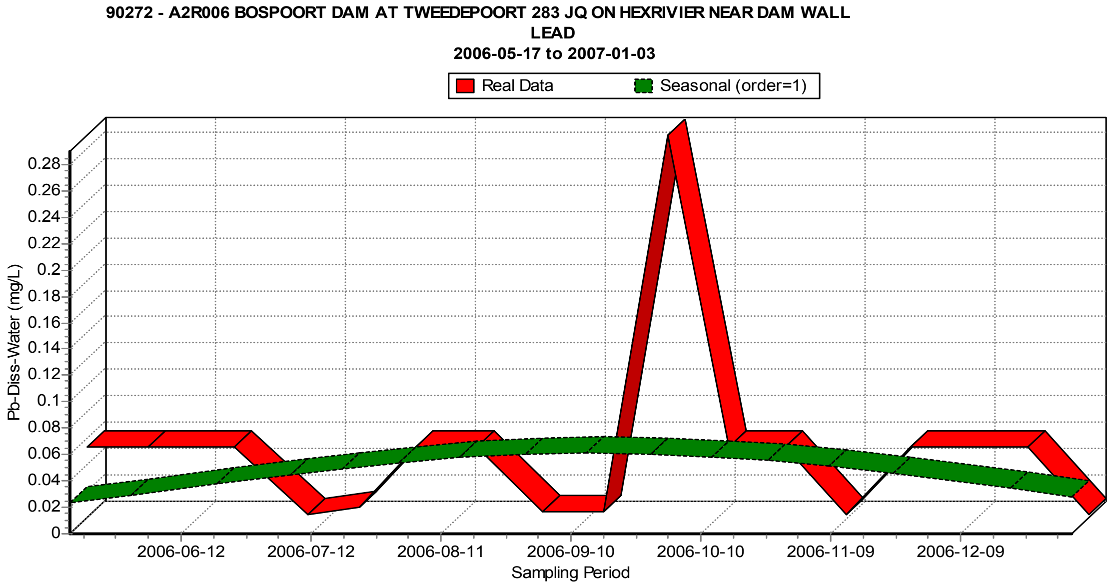

90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
POTASSIUM
2006-03-22 to 2007-01-03
Real Data
Seasonal (order=1)
K-Diss-Water (mg/L)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
2006-04-13
2006-05-13
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09


90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
CALCIUM
2006-03-22 to 2007-01-03
Real Data
Seasonal (order=1)
Ca-Diss-Water (mg/L)
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
2006-04-13
2006-05-13
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09


90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
ELECTRICAL CONDUCTIVITY
2006-03-22 to 2007-01-03
Real Data
Seasonal (order=1)
EC-Phys-Water (mS/m)
110
100
90
80
70
60
50
40
30
20
10
0
2006-04-13
2006-05-13
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09

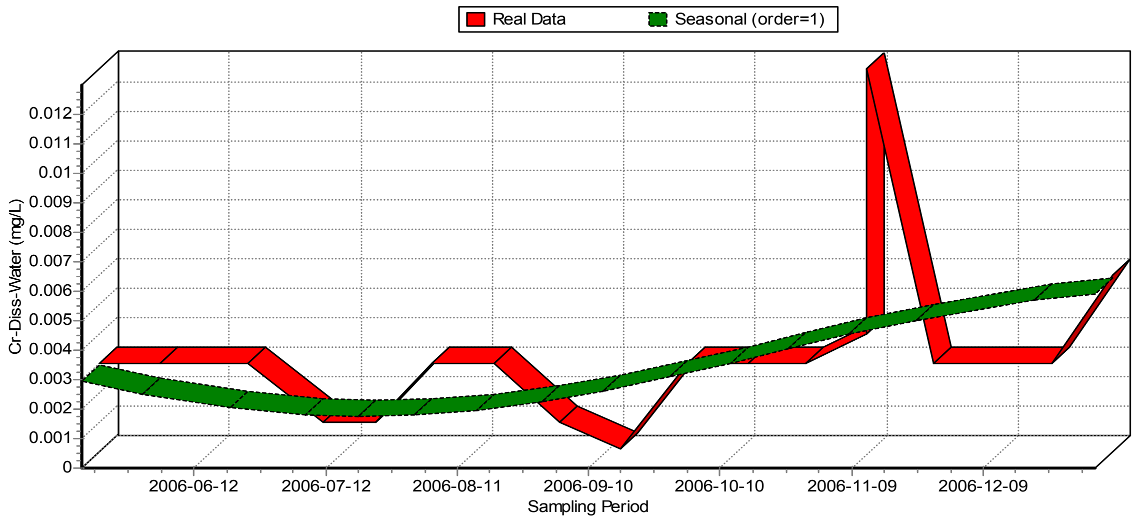
Seasonal Trends in Heavy Metals Concentrations

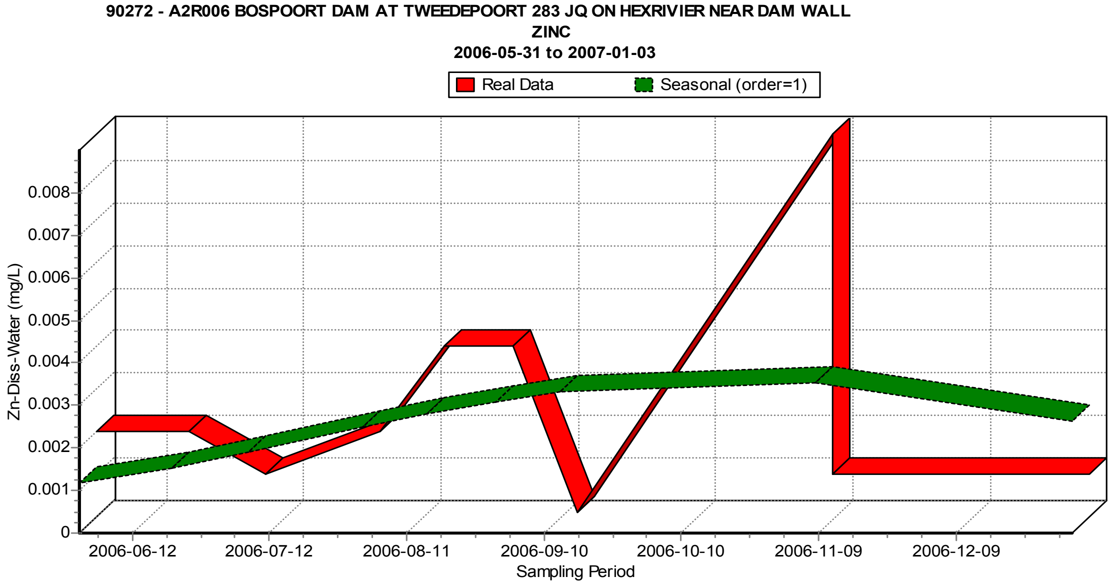


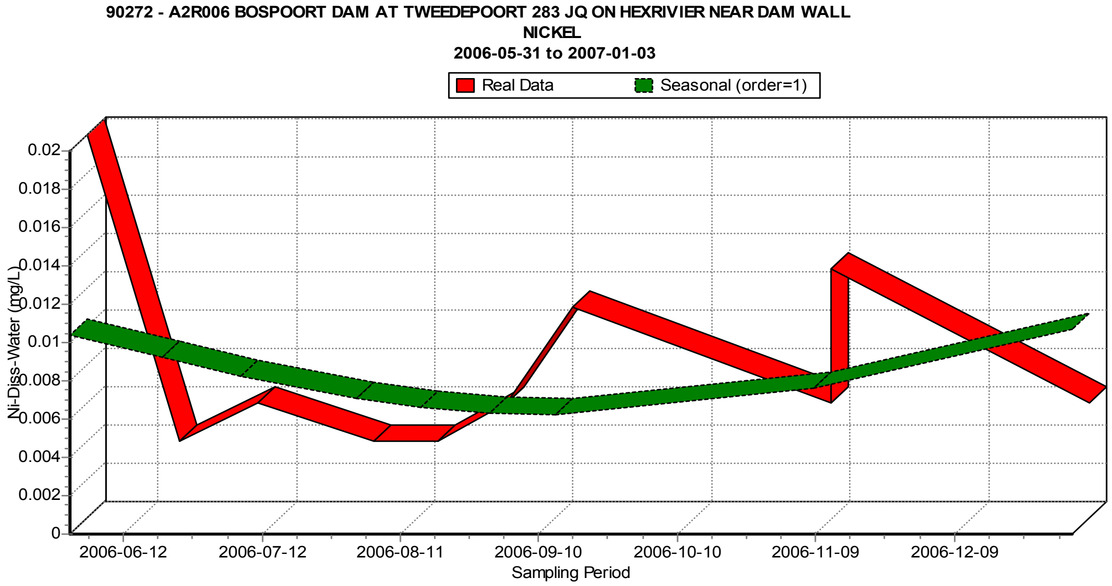


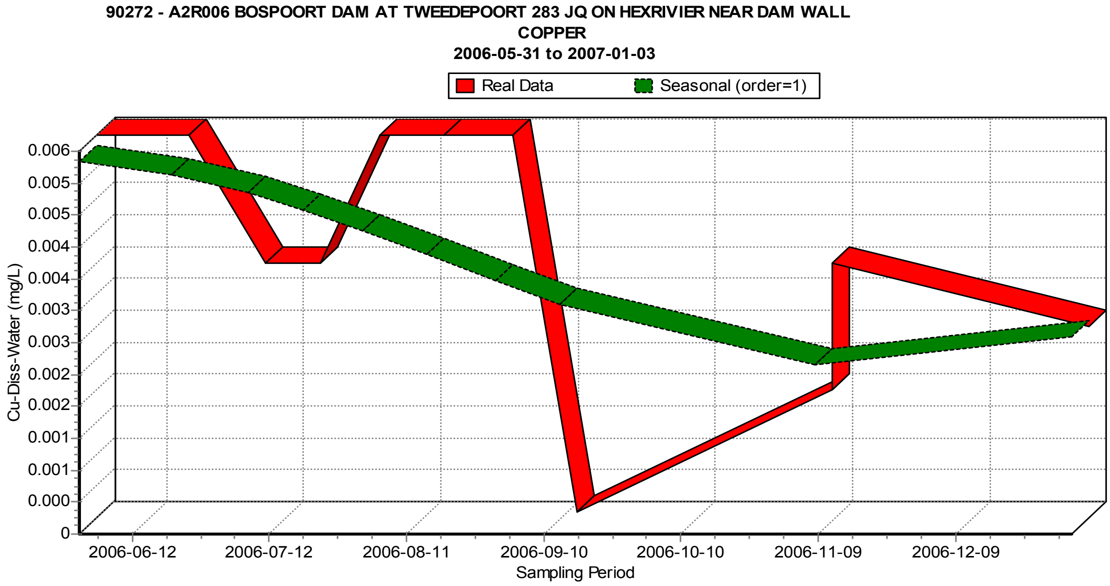
90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
CADMIUM
2006-05-31 to 2007-01-03

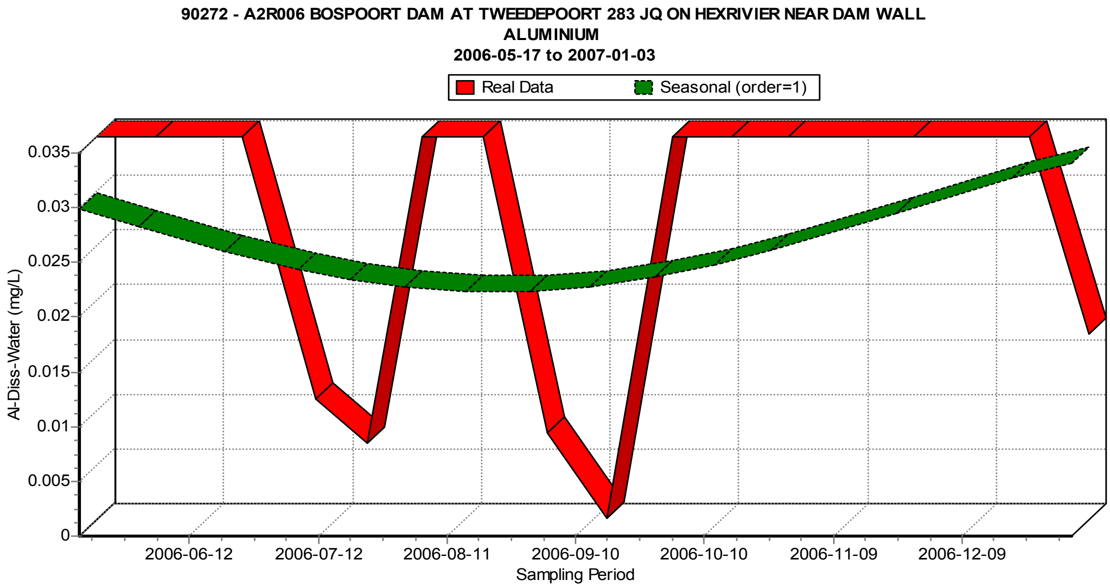
90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
CHROMIUM
2006-05-17 to 2007-01-03




90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
ZINC
2006-05-31 to 2007-01-03
Real Data
Seasonal (order=1)
Zn-Diss-Water (mg/L)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09
Sampling Period


90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
NICKEL
2006-05-31 to 2007-01-03
Real Data
Seasonal (order=1)
Ni-Diss-Water (mg/L)
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09
Sampling Period


90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
COPPER
2006-05-31 to 2007-01-03
Real Data
Seasonal (order=1)
Cu-Diss-Water (mg/L)
0.006
0.005
0.005
0.004
0.004
0.003
0.003
0.002
0.002
0.001
0.001
0.000
0
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09
Sampling Period


90272 - A2R006 BOSPOORT DAM AT TWEEDEPOORT 283 JQ ON HEXRIVIER NEAR DAM WALL
ALUMINIUM
2006-05-17 to 2007-01-03
Real Data
Seasonal (order=1)
Al-Diss-Water (mg/L)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
2006-06-12
2006-07-12
2006-08-11
2006-09-10
2006-10-10
2006-11-09
2006-12-09
Sampling Period