# Analysis and Prediction of Chemical Treatment Cost of Potable Water in the Upper and Middle Vaal Water Management Areas

By

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Submitted in partial fulfilment of the requirements for the degree of

## Master of Science in Agriculture

In the

Discipline of Agricultural Economics

School of Agricultural Sciences and Agribusiness

Faculty of Science and Agriculture

University of KwaZulu-Natal

Pietermaritzburg Campus

2009

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# ABSTRACT

*This study is a component of a research project on the economic costs of eutrophication in the Vaal River system.  Its objective is to investigate the relationship between raw water quality and the chemical costs of producing potable water at two water treatment plants: Zuikerbosch Station #2 (owned by Rand Water) in the Upper Vaal Water Management Area (UVWMA), and Balkfontein (owned by Sedibeng Water) in the Middle Vaal Water Management Area (MVWMA).  Time series data on raw water quality and chemical dosages used to treat raw water were obtained for Zuikerbosch Station #2 (hereafter referred to as Zuikerbosch) for the period November 2004 – October 2006 and for Balkfontein for the period January 2004 to December 2006.  Descriptive statistics reveal that raw water in the Vaal River is of a poorer quality at Balkfontein compared to that at Zuikerbosch.  Furthermore, the actual real chemical water treatment costs (measured in 2006 ZAR) averaged R89.90 per megalitre at Zuikerbosch and R126.31 at Balkfontein, indicating that the chemical water treatment costs of producing potable water tend to increase as raw water quality declines.  Collinearity among water quality (WQ) variables at both water treatment plants was analysed using Principal Component Analysis (PCA).  The dimensions of water quality identified in the analysis are similar to those reported in Pieterse and van Vuuren's (1997) study of the Vaal River.*

*For both water treatment plants, Ordinary Least Squares (OLS) regression was used to identify the relationship between real chemical costs of water treatment and the dimensions of water quality identified through the respective Principal Components*

*Analyses. The estimated regression models account for over 50.2% and 34.7% of variation in real chemical water treatment costs at Zuikerbosch and Balkfontein, respectively. The coefficient estimated for $PC_1$ at Zuikerbosch is statistically significant at the 1% level of probability with high negative loadings of total alkalinity and turbidity. Increases in the levels of total alkalinity and turbidity in raw water treated at Zuikerbosch is negatively related to the chemical costs of water treatment. An increased total alkalinity level was found to reduce the chemical costs of treating potable water.*

*$PC_2$ is statistically the most important variable in the estimated explanatory model for Balkfontein. The estimated regression coefficient for $PC_2$ is statistically significant at the 5% level of probability. The estimated relationship between chemical water treatment costs and $PC_2$ shows that there is a positive relationship between the raw water temperature and chemical water treatment costs. However, increases in the levels of chlorophyll and pH in raw water treated at Balkfontein is negatively related to the chemical costs of water treatment. Total hardness, magnesium, calcium, sulphate, conductivity, and chloride, being the highest positive loadings in $PC_1$, relate negatively to the chemical cost of treating water.*

*For predictive rather than explanatory purposes, a partial adjustment regression model was estimated for each of the two water treatment plants. Using this model, real chemical water treatment costs were specified as a function of real chemical water treatment costs in the previous time period, and of raw water quality variables in the current period. The $R^2$ statistics for the two regression models were 61.4% using the data for Zuikerbosch*

*and 59.9% using the data for Balkfontein, suggesting that both models have reasonable levels of predictive power.*

*The chemical cost of water treatment for Zuikerbosch and Balkfontein are predicted at R 96.25 and R90.74 per megalitre per day respectively. If raw water nitrate in the UVWMA increases by 1% per megalitre a day while other factors remain constant, chemical water treatment costs at Zuikerbosch can be expected to increase by 0.297% per megalitre and the cost accompanied this change is(R0.285\*1998ML\*365days) R 207,841.95 provided that Zuikerbosch treats an average of 1998 megalitres per day. Likewise, if Zuikerbosch maintains its daily average operating capacity and is able to maintain an optimal level of total alkalinity in UVWMA, the estimated saving on chemical water treatment cost will be R 150.063.78 per annum. At Balkfontein, chemical water treatment cost is expected to increase on average by 0.346% per megalitre per day for a 1% per megalitre per day increase in the level of chlorophyll-a, and the cost accompanied this change is R 41,128.20 per annum. The prediction also shows a 2.077% per megalitre per day increase chemical water treatment cost for a 1% increase in turbidity and this accompanied with a chemical water treatment cost of R 249,003 per annum, provided that Balkfontein operates at its full capacity (i.e., 360 megalitres per day).*

# CONTENTS

## PAGE

## LIST OF TABLES                                                          PAGE

## LIST OF FIGURES                                                   PAGE

# INTRODUCTION

South Africa is, on the whole, considered to be a water stressed country. In view of expected growth in the demand for potable water in South Africa, researchers have projected that South Africa will be reclassified as being severely water stressed in the near future (Meyer, 2007; Lange and Hassan, 2006). Pollution of water bodies aggravates the scarcity of potable water in South Africa. Industrial effluents, domestic and commercial sewage, acid mine drainage and agricultural runoff are the main pollutants of South Africa's fresh water bodies, especially rivers (Rand Water, 2007). As the quality of raw water deteriorates, so more sophisticated and costly methods of water treatment are required to produce healthy and safe potable water (Lange and Hassan, 2006). Dearmont *et al.* (1998) and Netshidaulu (2007), amongst others, have pointed out that water treatment costs depend not only on the raw water quality, but also the standard to which the water is treated: as quality standards for potable water become increasingly stringent, so water treatment costs increase accordingly. South African potable water quality standards are high by world standards (Rand Water, 2007).

Eutrophication refers to a particular type of water quality problem. It is defined as the enrichment of water by nutrients (primarily phosphorous and nitrogen), causing an accelerated growth of algae and higher forms of plant life which adversely affects the balance of the biological system in the water, and the quality of the water concerned (Pretty *et al.*, 2002). According to UNEP (2005), eutrophication may occur naturally (natural eutrophication) or as a consequence of domestic, industrial and agricultural activities adding to naturally-occurring nutrient levels (cultural eutrophication).

1

Symptoms of eutrophication include an increase in water turbidity, a change in the composition of algal flora, an increased frequency of anoxic situations, and possibly more algal blooms (UNEP, 2005). Impacts of eutrophication include increased fish and invertebrate mortality; increased mortality and morbidity of livestock; increased occurrence of human health problems; reduced amenity and recreation value of waterside property (particularly if the water becomes turbid, and there is emission of unpleasant odours from algal blooms) and increased costs of treating raw water. Therefore, eutrophication has negative consequences for the conservation status of water resources, industry, agriculture, real estate values, recreation and tourism, the provision of potable water and public health costs (Walmsley, 2005; UNEP, 2005).

Because costly treatment is often required to overcome its negative effects, eutrophication creates problems for economic development and sustainable economic growth (Dennison and Lyne, 1997). Growth in the demand for clean water due to growth in real per capita incomes, population growth and urbanisation have exacerbated this problem over time (UNEP, 2005). Consequently, water eutrophication is regarded as a serious environmental problem that can pose a major challenge to sustainable economic development in South Africa and globally.

The Vaal River is a major river system in South Africa and has been described as the most important artery of the South African economy (VAALCO, 2006). It is the primary supplier of water to the economic heartland of South Africa. In particular, it supports the world's largest gold mining industry, as well as coal mining, agriculture, manufacturing and paper industries. In addition, it provides potable water to more

than eight (8) million South Africans, and water from the Vaal River is used for cooling electricity power stations. The Vaal River system is also used extensively for recreational and amenity purposes, such as swimming, fishing, sailing and picnicking along the riverbank (VAALCO, 2006; Rand Water, 2005; Bruwer *et al*., 1985). Bruwer *et al.* (1985) reported that in the early 1980s economic activity in the Vaal River Water Management Area accounted for almost one quarter of South Africa's GDP: the Upper Vaal Water Management Area (UVWMA) alone contributed approximately 20 % of South Africa's GDP and the Middle Vaal Water Management Area (MVWMA) contributed a further 4 % of South Africa's GDP. Historically the relative contribution of the Vaal River Water Management Areas to economic activity in South Africa has remained high (Rand Water, 2006), and it is expected to remain so in the future. Provision of adequate safe water to residents and industry in the Vaal River Water Management Area is therefore important for the South African economy.

The Vaal River has been described as a nutrient-enriched (eutrophic) river system, and in particular the mid- to lower reaches of the catchment (DWAF, 2004; Walmsley, 2005). The quality of raw water at a point in a river system is partly determined by the spatial distribution of human activities in the catchment, such as land use pattern, flow management, and effluent discharges from industrial, agricultural, and domestic sources (Dennison and Lyne, 1997). The water quality of the middle Vaal is affected not only by the economic activities in the region, but also by the water quality received from the upper Vaal region (and therefore the economic activities of the upper Vaal region) (DWAF, 2004). According to Basson and Schutte (2002), sources of eutrophication in the middle Vaal river system include large amounts of treated effluent from domestic and industrial sources in the Johannesburg

and Vaal Triangle industrial and mining areas. These effluents flow into the Vaal River downstream from the Zuikerbosch Water Treatment Plant, particularly via tributaries such as the Suikerbosrant, Klip, and Rietspruit which flow from industrial and heavily populated areas such as Johannesburg, Vereeniging and Sasolburg (Rand Water, 2008). Consequently, the water quality in the upper Vaal River is generally better than in the middle Vaal River. Venter *et al*. (2002) noted that poor water taste and odour and generally deteriorated water quality are typical characteristics of raw water abstracted from the middle Vaal River catchment.

This study investigates one of the costs of eutrophication, namely the increased costs of treating raw water to produce potable drinking water in the UVWMA (at Zuikerbosch Water Treatment Plant, Station #2) and the MVWMA (at Balkfontein Water Treatment Plant). Water treatment costs may be described as a compliance control cost (Pretty *et al.,* 2002). This means that treated potable water must comply with South African potable water standards and possibly other more stringent standards in accordance with the policy of the relevant water treatment companies. The primary objective of this study is to investigate the extent to which the chemical costs of treating water to comply with stringent potable water quality standards can be predicted for the MVWMA and UVWMA from raw water quality data. Although, similar studies have been conducted in South Africa for the Umgeni River in KwaZulu-Natal (e.g., Dennison and Lyne, 1997, and Graham *et al*., 1998), there are no peer-reviewed publications in the economics literature on the impacts of water quality on water treatment costs in the Vaal River.

A second objective of this study is to compare raw water quality and chemical water treatment costs in the UVWMA with results obtained for the MVWMA. The impact of pollution on water treatment costs depends upon the special pattern of human activities in the Vaal River catchment and the location and relative sizes of water treatment plants in the catchment.

This study is a component of a research project to investigate the economic costs associated with eutrophication in the Vaal River. The findings of this study will subsequently be used in a mathematical programming model to explore links between land use activities, water eutrophication, and the economic costs of water eutrophication in the Vaal River. Reliable information about the causes and consequences of water eutrophication are required to inform both policy and planning decisions.

The first chapter of the thesis presents a review of relevant literature. This review provides an overview of the problem of water eutrophication from an economic perspective. In particular, it identifies various categories of costs that arise from water eutrophication. It proceeds to discuss the costs of treating raw water to produce potable water and presents a review of past economic research on this topic. Chapter Two describes the study area and data collection and presents descriptive statistics of water quality and water treatment costs for the two water treatment stations studied in this research project. The third chapter presents the research methodology followed in this study. This section discusses the application of the Partial Adjustment Regression Model and Principal Component Analysis to estimate and predict the chemical costs of water treatment at each of the two water treatment stations. The

results of the econometric analysis are presented and discussed in Chapter Four. The final chapter presents the conclusions drawn from this study and provides recommendations for future research on this topic.

# CHAPTER 1:    A REVIEW OF RELEVANT LITERATURE

Eutrophication is often a result of water pollution from domestic, industrial and agricultural activities which augment the naturally occurring nutrient levels of a water body.  In a market economy, the decisions of households and industries are based only on the expected private economic costs and benefits of their options.  However, in the case of a market failure caused by externality, the activities of one industry or household may lead to additional benefits or costs for other industries or households, known as production externalities.

Externalities are known as external costs or benefits, external effects, external economies and diseconomies, spill over and neighbourhood effects.  Polluters often do not bear the full cost of the negative externality they generate. Hence, they continue to engage in an excessive amount of polluting from the perspective of society (UNEP, 2005; Field, 1997).  Considering that in most cases eutrophication is primarily attributable to human activity, the economic theory of pollution and pollution externalities provides a useful foundation for understanding the costs of eutrophication.

This section presents an overview of this theory, followed by a review of past economic studies on potable water treatment costs.  The chapter is concluded with a discussion of economic approaches for researching eutrophication problems, and in particular, the impact of eutrophication on treating raw water to produce potable water.

**1.1 The Economic Costs of Eutrophication**

Reduced water quality attributable to eutrophication can increase the cost per unit of production for water-users such as industries that use raw water for production processes (including farming), and agencies and municipalities that provide potable water for domestic use; hence, reduced water quality is a negative externality of pollution (Field, 1997; Anonymous, 2006; Pretty *et al.,* 2003). This section of the dissertation describes the possible cost classifications caused by eutrophication on an economy.

Following Pretty *et al.* (2002), the economic costs of eutrophication may be broadly categorised as damage costs and policy response costs. Damage costs refer to the reduced value of water, and may be further sub-divided into social damage cost and ecological damage cost. Policy response costs refer to the costs of addressing and responding to eutrophication and may also be divided into two types of costs, i.e., compliance control costs (arising from adverse effects of nutrient enrichment) and direct costs incurred by statutory agencies for monitoring, investigating and enforcing solutions to eutrophication.

**1.1.1 Damage Costs Arising From Eutrophication**

Pretty *et al.* (2002) explain the damage costs of eutrophication as a loss of existing value rather than an increase in cost. These damage costs are grouped into social damage costs (use value and option values) and ecological damage costs (non-use value). Use values are associated with private benefits gained from actual use of ecosystem services, such as agriculture and industry, recreation benefits, education

benefits and general amenity benefits (e.g., use of water bodies for water sports) (Pretty *et al.,* 2002). Option values are associated with unrealised benefits derived from potential use of these ecosystem services. Eutrophication can adversely affect the use and option values of water bodies.

Eutrophication may also cause damage to biota and ecosystem structures. These costs are known as ecological damage costs. According to Pretty *et al.* (2002), the value loss costs (related to the intrinsic value of species and ecosystem) caused by eutrophication are typically difficult to measure. Therefore, the cost of restoring the affected species and habitats may serve as to approximate the ecological damage costs of eutrophication.

## 1.1.2 Costs of Addressing Eutrophication

Costs of addressing eutrophication are direct costs that are incurred by firms, statutory agencies, sewage treatment companies, water treatment companies, and farmers (Pretty *et al.,* 2002). Sewage treatment companies, for example, incur costs in removing phosphorous and nitrogen before it enters the water resource after treatment. Policy response costs consist not only of the compliance costs arising from the adverse effects of nutrient enrichment, but also include the costs, using a variety of preventative and restorative measures, for the treatment of algal blooms in water sources (Ferguson *et al.,* 1996; Pretty *et al.,* 2002).

**1.1.2.1 Eutrophication Control Policy Costs**

Eutrophication involves costs to different stakeholders such as government, and legislative agencies to control, monitor, and implement solutions to the problem. Assessing water quality conditions and identifying impairments by nutrients and algae in water resources entails high resource (monetary) cost in order to identify changes and trends in water quality. This typically necessitates high costs by governmental and statutory monitoring and water management agencies (e.g., USEPA, 2000; Pretty *et al.,* 2002).

The development of eutrophication control policies and strategies are another cost incurred in addressing eutrophication problems. Appropriate strategies and policies comprise pollution reduction at source; environmental impact assessments; and enforceable standards for major point source discharges and high-risk non-point sources. To ensure the effectiveness of pollution prevention and control programs, they need to be supported by a proper institutional and legal framework and there must be adequate access to reliable information, trained human resources, and appropriate technologies. According to UNEP (2005) the promotion of public participation in the planning and decision making process, and sensitising the public to the need for rational water use and the protection of water quality may again involve costs.

**1.1.2.2 Water Treatment Costs**

Water treatment costs are incurred by water treatment plants in complying with compulsory national standards for the quality of potable water (Pretty *et al.,* 2002). In

South Africa, these standards are prescribed in the Regulations to the Water Services Act (Act No. 108 of 1997) (Republic of South Africa, 1997). Costs of water treatment are, therefore, an example of compliance costs.

According to Pretty *et al.* (2002), the cost of drinking water treatment depends primarily on the raw water quality abstracted from the river system. The most widely used method of water treatment is to control microbial and turbidity levels of surface water (Mohamed *et al.,* 2004). Drinking water treatments are aimed at removing microbial and chemical contaminants and may be costly. "The cost and quality of potable water are related to the nature of the catchment and the management thereof" (Msibi, 2002: 33).

The average cost of water treatment is influenced by factors such as: the applied water quality compliance standard; the number of customers (which influences the energy cost of water treatment plants); the age of the water treatment system and the size of the utility; the technology or process involved; and energy and labour costs (Sauer and Kimber, 2002). The microbial and chemical contaminants of the raw water abstracted are the main drivers of the cost. An increase in water turbidity can also increase chemical consumption of coagulants, hence increasing the real water treatment cost (Voortman and Reddy, 1997). Water treatment plants incur both capital and operating costs for water treatment (Pretty *et al.,* 2002). Finally, according to Netshidaulu (2007), water treatment cost depends on both the standard of treated final water and raw water quality.

*Capital Costs of Water Treatment Plants*

Water treatment plants incur capital costs, such as fixed facilities like buildings, water treatment machines and laboratory equipment that involve a once-off expenditure, as well as human capital (Pretty, *et al.,* 2002). These costs (e.g., annual depreciation and the opportunity cost of capital invested) are fixed regardless of the quantity of raw water treated at a water treatment plant, or the quality of the raw water that is treated.

*Chemical Cost as Operating Cost of Water Treatment Plants*

Operating costs of water treatment plants are recurring expenses that are related to the operation of water treatment. The cost of chemicals used to treat drinking water is a major component of the operating costs of water treatment plants. Some of these operating costs are variable costs (e.g., water treatment chemical costs and energy (electricity purchase) costs), and some are fixed costs (e.g., costs incurred in laboratory work to assess the water quality variables in the raw water and to monitor the final water standard (Rand Water, 1998; Pretty, *et al.,* 2002). Energy costs form a major part of the expenditure involved in the pumping and distribution of potable water to consumers (Rand Water, 1998).

**1.2 Previous Research on Water Treatment Costs**

Past research on the impact of eutrophication on water treatment costs may be divided into South African studies and those conducted in other countries. A comprehensive

review of published research on the impacts of eutrophication on water treatment costs in South Africa is presented in Section 1.2.1. Selected studies on water treatment costs in other countries are reviewed in Section 1.2.2. Section 1.2.3 presents a discussion on suitable research methodologies for future research on this topic.

## 1.2.1 South African Research

There are only a few published studies on the economic costs of water eutrophication for water treatment plants in South Africa, e.g., Graham *et al.* (1998), and Dennison and Lyne (1997). Dennison and Lyne (1997) conducted a study on water treatment chemical costs in the Umgeni River catchment in KwaZulu-Natal (KZN) at DV Harris Water Treatment Plant in KwaZulu-Natal using monthly data for 1990 – 1995. The objective of their study was to identify the main factors that contribute to high water treatment costs at the water treatment plant. They postulated that water treatment plants' primary objective is to produce potable water that satisfies minimum standards of water quality. Satisfying optimum (cost-minimising) standards of water quality is a secondary consideration. Therefore, following a change in raw water quality, water treatment will adjust over a period of time to the optimum standard of water quality.

Dennison and Lyne (1997) attempted to model this dynamic process using a partial adjustment regression model. However, although a partial adjustment process may correctly describe the response to an *improvement* in raw water quality (leading to a gradual reduction in water treatment costs), water treatment companies cannot gradually adjust water treatment in response to a *deterioration* in raw water quality if

they are to ensure that a minimum standard of water quality is always satisfied. For example, Dennison and Lyne's (1997) results suggest that in response to a decline in water quality, water treatment costs at the DV Harris Water Treatment Plant will have adjusted by only 80% of the required change after a period of one month. According to du Preez (2007), however, water treatment processes in South Africa fully adjust to a change in raw water quality "within a matter of hours". Consequently, the partial adjustment regression model is not suitable as an <u>explanatory</u> model of chemical water treatment costs, especially if weekly or monthly water cost and quality data is used in the analysis. The merits of using lagged cost as a <u>predictive</u> variable of water treatment cost are further discussed in the next chapter of this study.

Besides their use of a partial adjustment model, the methodology used by Dennison and Lyne (1997) to address the problem of collinearity amongst water quality variables is interesting. They used a Principal Components Analysis to extract seven orthogonal Principal Components from the 13 water quality variables (including the lagged cost of water treatment) specified in their partial adjustment model. Following a methodology provided in Nieuwoudt (1972), the loadings of the Principal Components were used to transform the regression coefficients estimated for the Principal Components into standardised coefficients for the original variables. These standardised coefficients, although useful for policy purposes because they are independent of the original units of measurement, were subsequently converted, using Kendall's (1957) methodology, to unstandardised coefficients that could be readily used for scenario analysis.

Graham *et al.* (1998) analysed the chemical costs of water treatment at four water treatment stations along the Umgeni River in KwaZulu-Natal, namely Hazelmere, Durban Heights, DV Harris, and Wiggins using monthly data for the period 1990 – 1996. A particular objective of this study was to explore the relationships between raw water quality (in particular the types and abundance of algal species) and water chemical treatment costs. Unlike Dennison and Lyne (1997), Graham *et al.* (1998) did not estimate partial adjustment models, but otherwise followed a similar methodology to that of Dennison and Lyne (1997), that is, a multiple regression analysis in conjunction with Principal Components Analysis and Nieuwoudt's (1972) and Kendall's (1957) methodologies. Graham *et al.* (1998) also made no attempt to interpret the Principal Components elicited in their analyses.

The average costs of water treatment at Hazelmere, Durban Heights, DV Harris, and Wiggins plants over the study period were, respectively, R40, R25, R28, and R20 per megalitre. The estimated regression equations had relatively high $R^2$ statistic coefficients of 0.79 for each of the estimated regression models for the Hazelmere and Wiggins plants, 0.67 for the DV Harris Water Treatment Plant and 0.64 for the Durban Heights Water Treatment Plant. Graham *et al.* (1998) concluded that physico-chemical water quality variables are typically more important predictors of water treatment costs than are algae data, with the exception of taste and odour-forming algae. Graham *et al.* (1998) recommended that future studies of the costs of treating potable water should, if possible, include the costs of electricity used in the water treatment process (e.g., costs of backwashing filters) because algae loadings in raw water are likely to impact significantly on the required frequency of backwashing filters.

To date there are no published peer-reviewed studies of the economic costs of eutrophication for water treatment plants on the Vaal River. Mirrilees *et al*. (2003) estimated the economic value of water resources in the Vaal River system. However, they did not address the costs of water quality deterioration or the costs of eutrophication. Likewise, Pieterse and van Vuuren (1997) investigated the relationship among physical, chemical, and biological water quality variables using Principal Component Analysis (PCA) in the Vaal River. However, they did not relate water quality to water treatment costs.

The study by Pieterse and van Vuuren (1997) is, however, relevant to the current study in so far as it identifies significant collinearity amongst water quality variables in the Vaal River. In particular, they demonstrate that nutrient availability and surface water temperature affect the growth and abundance of phytoplankton and various algae species. Their analysis contributes towards an improved understanding of the seasonal aspects of algal growth in the Vaal.

The implications of Pieterse and van Vuuren's (1997) study for this study are that collinearity is expected amongst water quality variables for the Vaal River. This must be suitably addressed in the econometric analysis used to relate raw water quality to the costs of producing potable water from water abstracted from the Vaal. Further, because there is a seasonal pattern to algal growth in the Vaal and considering that some algal species, such as *Cyanophyceae* (*Anabaena* and *Microcystis*) impact more on chemical water treatment costs than other species of algae (Dennison and Lyne, 1997; du Preez *et al.,* 2007), water quality data used in the current study should

ideally reflect the abundance of individual species of algae and phytoplankton rather than use aggregate measures, such as total chlorophyll loadings. This study suggests that interpretation of PCs elicited by Dennison and Lyne (1997) and Graham *et al.* (1998) in similar analyses may have benefited their studies.

### 1.2.2 Foreign Research

Globally, several studies have investigated the economics of water treatment costs. These studies may be divided into two categories: (a) those that have used mathematical programming models to investigate the most cost-effective technology for water treatment plants, e.g., Muiga and Reid (1979); and (b) econometric studies with the typical objective of estimating the impact of soil erosion on water treatment costs, e.g., Dearmont *et al.* (1998), Forster *et al.* (1987), and Moore and McCarl (1987).

Muiga and Reid (1979) used mathematical modelling to develop predictive equations of water treatment costs in developing countries for different water treatment technologies. The results were used to demonstrate that the most cost-effective design of a water treatment plant (slow sand filter, rapid sand filter, stabilisation lagoon, aerated lagoon, activated sludge, and trickling filter) is dependent on a range of factors, including a technological indicator (the percentage of imported materials), and the design capacity. Although Muiga and Reid (1979) did not empirically investigate the relationship between actual water quality and actual water treatment costs for particular water treatment stations, their study contributes to this literature

review in so far as it considers all costs of water treatment (construction, operation and maintenance costs).

An econometric analysis by Dearmont *et al.* (1998) estimated water chemical treatment cost using pooled time series data from 12 water treatment plants in Texas, USA, as a function of raw surface water pH, turbidity and annual rainfall. The authors note that turbidity is a measurement of water sediment, which is a source of chemical contaminants such as pesticides and fertilisers. This reflects that turbidity was used as a proxy of various related water quality attributes in order to solve the problem of multicollinearity amongst these water quality attributes. The specification of their regression model allowed for interaction among these raw water quality variables and non-linear relationships. For example, an interaction term between turbidity and pH was included in their regression model due to the chemical relationship between coagulants and pH adjusters. A dummy variable was included to reflect whether or not chemical contamination of groundwater was a problem at each water treatment plant. Despite inclusion of interaction terms and allowing for non-linear relationships between water quality variables and water treatment costs, the estimated regression model explained only 18% of observed variation in chemical water treatment costs. This study demonstrates that data on water pH, turbidity and annual runoff alone are not sufficient to explain or reasonably predict the chemical costs of water treatment in Texas. Because chemical contamination of raw water is a problem in the study areas, more information about the nature of the chemical contaminations may contribute towards a better understanding of variability in water treatment costs.

Using monthly data, Forster *et al.* (1987) estimated the relationship between water treatment costs and soil erosion in 12 water treatment plants in the Ohio Corn Belt of

the USA. The main objective of their study was to estimate the cost of erosion to downstream surface water users, especially the additional water treatment cost for communities. Their hypothesis was that as the annual rate of soil erosion in the upstream watershed increases, sediment loadings in raw water will increase, which will cause the variable costs of treating water to increase. Average variable chemical costs of water treatment were regressed on the daily volume of raw water treated, average raw water retention time (days), and the annual upstream watershed soil erosion estimate in a Cobb-Douglas function. The coefficient of $R^2$ statistic for their estimated regression equation was 0.84. The high explanatory power of this estimated regression equation compared to that of Dearmont *et al*. (1998) is attributed to soil erosion being the primary source of water pollution for the water treatment stations studied by Forster *et al*. (1987).

Another offsite effect of erosion on surface water treatment chemical cost was investigated by Moore and McCarl (1987) in a case study of the Colombia River in the USA. The objective of their study was to estimate a predictive model for daily alum (a flocculant) and lime usage in the treatment plant. They used the predictive equation estimated to develop a cost function that involves turbidity by multiplying daily chemical use equation by the chemical costs.

They estimated two regression models using two different functional forms, using daily water treatment records for a period of three years from H. D. Taylor water treatment plant in Oregon, USA. These records included the total alum and lime usage in pounds and the observed levels of volume of water treated; pH; raw water temperature; and turbidity. Using the double log model, total alum (in pounds) was

regressed on volume of raw water withdrawn from the river, turbidity level of the raw water, and raw water temperature. They obtain an $R^2$ statistic of 91.3% for this model. Total lime used was the dependent variable in the linear regression model estimated by Moore and McCarl (1987). Raw water pH and the alum used in treating raw water were the two explanatory variables used in the linear regression model and the coefficient estimated for the $R^2$ statistics value was 0.771. Their results show an average daily cost of $14.89 and $48.23 for lime and alum respectively. Therefore, the daily chemical water treatment cost was on average $63.11. Their findings indicated that a 1% decrease in the level of raw water turbidity would reduce chemical cost of water treatment by roughly 0.33%. They concluded that only 0.33% of the average cost is mitigated by a 1% marginal change in the sediment load.

### 1.2.3  Discussion of Research Methodologies Used in the Reviewed Studies

Studies of the costs of treating potable water reviewed in this section have tended to use multiple regression analysis to relate water costs to water quality attributes. The $R^2$ statistics of the models estimated by Dearmont *et al.* (1998) in the USA compared to the models estimated by Graham *et al.* (1998) in South Africa demonstrate that a wide range of water quality attributes are typically required to explain the chemical water treatment costs of potable water. In particular, data about the prevalence of various algae species can be important explanatory variables. Besides water quality data limitations, data about water treatment costs have typically focused on only the chemical costs of water treatment. Overcoming these data problems is difficult as researchers are reliant on information provided by water treatment plants in order to obtain the time series data required to carry out these analyses.

Another important aspect of the reviewed studies, and in particular the study of the Vaal River by Pieterse and van Vuuren (1997) and the studies of the Umgeni River by Dennison and Lyne (1997) and Graham *et al.* (1998), is that there is often significant collinearity amongst raw water quality attributes. Pollutants in raw water often have common sources (e.g., runoff from urban areas or agriculture), and growth of algal populations is not independent of other water quality attributes. Future studies of water treatment costs should anticipate such collinearity and address the problem of multicollinearity in multiple regression analysis.

# CHAPTER 2: RESEARCH METHODOLOGY

This chapter presents the research methodology applied in this study. Following Dennison and Lyne (1997), Graham *et al*. (1998), Forster *et al*. (1987) and Dearmont *et al*. (1998), this study uses multiple regression analysis to relate the costs of producing potable water from raw water to characteristics of the raw water. Because collinearity amongst water quality attributes in the Vaal River is expected (Pieterse and van Vuuren, 1997), the chapter begins with a discussion of the problem of multicollinearity in multiple regression, and considers various approaches to address this problem. The chapter proceeds to outline the methodologies of Nieuwoudt (1972) (to use Principal Component loadings to compute standardised regression coefficients for the original variables) and Kendall (1957) (to convert standardised regression coefficients to unstandardised regression coefficients). The final section of this chapter presents a discussion on the merits of using partial adjustment regression models as explanatory and predictive models of water treatment costs.

## 2.1 The Problem of Multicollinearity in Ordinary Least Squares Regression Analysis

Multicollinearity is the presence of a linear relationship among some or all explanatory variables included in the model (Gujarati, 2003: 342). Although OLS regression assumes no multicollinearity, its presence cannot be avoided totally. This section of the study discusses the nature of multicollinearity and the possible remedy through data transformation such as Principal Component analysis. The extent to which this problem can affect the estimated partial adjustment model, given its

objective (i.e., prediction of treatment cost), also is discussed. The OLS regression model emphasises some very important assumptions such as the assumption of non-stochastic Xs (explanatory variables) (Gujarati, 2003: 66). On the other hand, in OLS regression model $Y_t$ (the dependent variable) is stochastic. This study used a partial adjustment regression model as a predictive model. The partial adjustment regression model includes stochastic variable $Y_{t-1}$ in the model (Gujarati, 2003). Due to the inclusion of the stochastic explanatory variable $Y_{t-1}$ there is a possibility of correlation between $Y_{t-1}$ and the error term $v_t$ if the error term $u_t$ in the original model was serially correlated (Gujarati, 2003: 677). The classical linear regression model (OLS) also assumes that there is no multicollinearity among the explanatory variables included in the model (Gujarati, 2003: 75).

Gujarati (2003: 350) notes that OLS regression in the presence of multicollinearity has the following consequences:

- Precise estimation of the true regression coefficients is difficult because the OLS estimators have large variances; consequently, acceptance of the null hypothesis (i.e., that the true parameter value is zero) is more likely; and
- The OLS estimators and their standard errors can be sensitive to small changes in the data.

Remedial measures to the problem of multicollinearity include dropping explanatory variables from the model, and transformation of variables (e.g., use of the first difference regression model or Principal Components Analysis (PCA)) (Gujarati, 2003: 364-369). Dropping a variable is considered as the simplest solution to reduce

the multicollinearity problem. However, dropping a relevant variable from the model leads to a misspecification error (Gujarati, 2003: 365). This is problematic for regression models used for explanatory purposes, but not if the models are used for predictive purposes (Gujarati, 2003: 75).

Data transformations can also be employed to overcome problems of multicollinearity. Maddala (1992: 192) notes that using a first differences approach is often used in time-series analysis when a common trend is the source of multicollinearity; however, he warns that this transformation introduces autocorrelation. Therefore, this procedure cannot be justified just to "get rid of multicollinearity" (Maddala, 1992: 193).

Use of PCA is often a suggested solution to the multicollinearity problem, especially in the exploratory stages of an investigation. Drawbacks of this approach are that the PCs with the largest eigen values are not necessarily those that are most correlated with the dependent variable; and often the PCs (Equation 1) have no meaningful interpretation. Consequently, the method of PCA is limited and "is easily misused in econometric work" (Maddala, 1992: 193-4). Following Nieuwoudt (1972), the estimated regression coefficients for the PCs can be used to compute standardised regression coefficients for the original variables. This remedy to Maddala's (1992) concerns about the use of PCA as a solution to the multicollinearity problem is explored in the following sections of this chapter.

## 2.2 Principal Component Analysis

Principal Component Analysis (PCA) involves mathematical transformations that transform a large number of correlated variables into a smaller, uncorrelated number of variables. PCA constructs artificial orthogonal variables from linear combinations of the original variables called Principal Components (Koutsoyiannis, 1988). PCA is used in this study to address the problem of multicollinearity amongst water quality variables.

Although other approaches may be used to address the collinearity problem, PCA is a particularly useful technique as it may be used as an exploratory tool in identifying relationships amongst water quality attributes. For example, Pieterse and van Vuuren (1997) applied PCA to investigate the associations among physical, chemical, and biological characteristics of the raw water in the Vaal River. This study follows a similar method of PCA in investigating the relationships between raw water quality (WQ) variables at each of the two water treatment stations.

The mathematical expression of PCA is as follows:

$$PC_1 = a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + \ldots + a_{1j}X_j \qquad (2.1)$$

Variance of the $PC_1$ is as large as possible subject to the constraint that

$$a_{11}{}^2 + a_{12}{}^2 + a_{13}{}^2 + \ldots + a_{1j}{}^2 = 1,$$

$$PC_2 = a_{21}X_1 + a_{22}X_2 + a_{23}X_3 + \ldots + a_{2j}X_j,$$

Variance of the $PC_2$ is as large as possible subject to the constraint that

$a_{21}^2 + a_{22}^2 + a_{23}^2 + ... + a_{2j}^2 = 1$, *etc.* (Manly, 1994:78)

Where $PC_1$ = 1$^{st}$ Principal Component

$PC_2$ = 2$^{nd}$ Principal Component

$a_{ij}$ = component loadings

$X_j$ = original variables

The first Principal Component (PC) is the linear function of $Xs$ (original variables of water quality) that has the highest variance. $PC_2$ accounts for the second highest percentage of variance in the original variables. The subsequent PCs each account for the maximum remaining variation in the original variables (Maddala, 1992).

## 2.3 Computing Standardised Coefficient Estimates From PC Loadings

A regression model of chemical cost of water treatment ($Y$) can be estimated to deal with multicollinearity problems in the original water quality variables ($X_1, X_2, ...X_i$) using the Principal Component scores to obtain:

$$Y = \alpha_0 + \alpha_1 PC_1 + \alpha_2 PC_2 + ... + \alpha_p PC_p + e \qquad (2.2)$$

Where $Y$ = chemical cost of treating potable water

$PC_p$ = Principal Components

$\alpha_p$ = coefficients estimated for the PCs

$e$ = random error

$p$ = number of retained variables i.e.

The $\alpha_i$s for the above model computed as: $\alpha_i = \sum YPC_i / \lambda_i$. Where: $PC_i$ is retained Principal Components; $\lambda_i$ is Eigen value of the $PC_i$. However this study does not use the formula for computation of coefficients $\alpha_i$s since SPSS can compute it routinely.

According to Dennison and Lyne (1997), it is useful to estimate standardised regression coefficients for the original water quality variables for the purpose of comparing the relative importance of their effects on the chemical cost of water treatment. This can be achieved using the estimated regression coefficients from equation (2.2). The new coefficients of the standardised variables are obtained as:

$$\zeta_i = PC\,loading_1\alpha_1 + PC\,loading_2\alpha_2 + .... + PC\,loading_i\alpha_i$$

(2.3)

Where $\zeta_i$ = new coefficients in the standardised regression model.

The following conceptual equation of standardised original variables is as follows.

$$Y = \zeta_1 X_1 + \zeta_2 X_2 + \zeta_3 X_3 + ... + \zeta_i X_i \quad (1,\,2,\,...,i)$$

(2.4)

Following Dennison and Lyne (1997), the *t values* of the coefficients of a standardised regression model can be calculated as:

$$t = \frac{\zeta_i}{\sqrt{var(\zeta_i)}}$$

(2.5)

where, following Gujarati (1999):

$$var(\zeta_i) = \left((PC_1 loading)^2 \times var(\alpha_1)\right) + \left((PC_2\,loading)^2 \times var(\alpha_2)\right) + ... + \left((PC_p\,loading)^2 \times var(\alpha_i)\right)$$
(2.6)

Following Kendall (1957), the standardised regression coefficients estimated in equation (2.4) can be converted into unstandardised regression coefficients by multiplying the standardised regression coefficients by the ratio of the sample standard deviation of the dependent variable to the independent variable (Sy / Sx). The constant term for the unstandardised regression equation can be computed as the difference between the mean values of actual and predicted chemical cost of water treatment (Dennison and Lyne, 1997).

The approach explained in this section was demonstrated by both Dennison and Lyne (1997) and Graham *et al*. (1998), and is once again applied in this study. The final section of this chapter presents a discussion of the merits of using a partial adjustment model as an explanatory or predictive model of water treatment costs.

## 2.4     Partial Adjustment Regression Model

The partial adjustment model was first provided by Nerlove (1958, as cited by Gujarati, 2003) as a rationalisation of the Koyck transformation model. In the model using partial adjustment regression, water chemical treatment cost is regressed on the original water quality variables (and various transformations of these variables to allow for non-linear relationships) and variables are dropped from the model to solve the problem of multicollinearity. Because this procedure is likely to introduce specification bias, the model is used as a predictive model of water chemical treatment costs and not as an explanatory model.

The partial adjustment model includes a stochastic explanatory variable $Y_{t-1}$ which violates one of the assumptions of ordinary least squares (OLS) method, namely that

all explanatory variables in the model are assumed to be non-stochastic (Gujarati, 2003: 66).

$$Y_t^* = \beta_0 + \beta_1 X_t + u_t \quad \text{desired level cost.} \tag{2.7}$$

Where, $Y_t^*$ = The desired level of cost to satisfy minimum standards of water quality. $Y_t - Y_{t-1} = \delta (Y_t^* - Y_{t-1})$, where $\delta$ = coefficient of adjustment $(0 < \delta \leq 1)$; $Y_t - Y_{t-1}$ = the actual change in treatment cost; and $Y_t^* - Y_{t-1}$ = the desired change in treatment cost. $Y_t - Y_{t-1} = \delta (Y_t^* - Y_{t-1})$ alternatively can be written as:

$$Y_t = \delta Y_t^* + (1-\delta) Y_{t-1} \tag{2.8}$$

$$Y_t = \delta (\beta_0 + \beta_1 X_t + u_t) + (1-\delta) Y_{t-1}, \text{ substitute equation (2.7)}$$

$$Y_t = \delta\beta_0 + \delta\beta_1 X_t + (1-\delta) Y_{t-1} + \delta u_t \tag{2.9}$$

The actual change in Y in period t is the weighted average of the desired change in cost at that time t and the cost existing in the previous time period, $\delta$ and $1 - \delta$ being the weights (Dennison and Lyne, 1997).

As noted in the previous chapter, Dennison and Lyne (1997) specified a partial adjustment model to estimate the relationship between water treatment costs and raw water quality at the DV Harris water treatment station in the Umgeni River catchment. In other words, they assumed that adjustments to chemical doses used in water treatment may be only partially adjusted for changes in raw water quality in the space

of a single time period (a time period is a month in their study). According to du Preez (2007) and Netshidaulu (2007), Rand Water's and Sedibeng Water's water quality laboratories make full adjustments to chemical dosages almost immediately (certainly within the space of a day) following changes in raw water quality. Consequently, the partial adjustment model is inappropriate for explaining changes in water chemical treatment costs at both Zuikerbosch and Balkfontein water treatment plants.

However, partial adjustment models can capture the trends relevant in water quality characteristics that are not otherwise included in the model (e.g., the relative presence of certain types of algae and bacteria that are known to contribute to water taste and odour problems). Therefore, use of partial adjustment models improves the overall statistical fit of the model, and in particular the $R^2$ statistics. Consequently, following Dennison and Lyne (1997) and Graham *et al*. (1998), the partial adjustment model is used in this study to estimate a predictive model of water treatment costs. Because multicollinearity is not a problem for estimating predictive models of water treatment costs, unlike the explanatory models of water treatment costs estimated in this study, the predictive models of water treatment costs estimated in this study do not apply the method of PCA.

# CHAPTER 3: DATA SOURCE AND BACKGROUND OF STUDY AREA

The data used in this study were provided by Rand Water (for Zuikerbosch Water Treatment Plant, Station #2, hereafter referred to as Zuikerbosch) and Sedibeng Water (for Balkfontein Water Treatment Plant, hereafter referred to as Balkfontein). Zuikerbosch and Balkfontein water treatment plants were studied in this research project largely because they were identified as important, but geographically separated, water treatment stations along the Vaal River. Zuikerbosch is located in the Upper Vaal Water Management Area (UVWMA) and Balkfontein is located in the Middle Vaal Water Management Area (MVWMA). Consequently, their analysis will provide suitable information for the larger research project of the economic costs of eutrophication in the Vaal River (referred to in the Introduction).

This chapter is divided into two parts: the first part (Section 3.1) provides information about Zuikerbosch and presents descriptive statistics of the water treatment cost and water quality data obtained for Zuikerbosch. The second part (Section 3.2) provides similar information about Balkfontein.

## 3.1 Zuikerbosch Water Treatment Plant

The Upper Vaal Water Management Area (UVWMA) is bordered in the North by the Crocodile, Olifant, and Inkomati water management areas (WMAs), in the West by the Middle Vaal WMA, in the South by the Upper Orange WMA and Lesotho, and in the East and South East by Usutu and Thukela WMAs respectively (DWAF, 2007).

As shown in Figure 3.1, it is divided into three major sub-catchments: upstream Vaal Dam, downstream Vaal Dam, and Wilge.

Rand Water was established in 1903 and is Africa's leading Water Company. Currently it has the capacity to produce 3800 megalitres per day (Rand Water, 1998; Rand Water, 2006). It operates across four provinces of South Africa, namely Gauteng, part of Mpumalanga, Free State, and North West. The company buys raw water from the Department of Water Affairs and Forestry (DWAF), and draws it from the Vaal Dam. There are two water treatment plants in the UVWMA, namely Vereeniging and Zuikerbosch. With an average pumping capacity of 1998 megalitres per day, Zuikerbosch water treatment plant is one of the largest water purification plants in the southern hemisphere. It is situated on the banks of the Vaal River 30 kilometres downstream from the Vaal Dam and 20 kilometres east of Vereeniging city centre (Rand Water, 1998; VAALCO, 2006). Zuikerbosch water treatment plant has four water treatment stations. This study will investigate chemical water treatment costs at Zuikerbosch because the required data were relatively more available than for the other three stations.
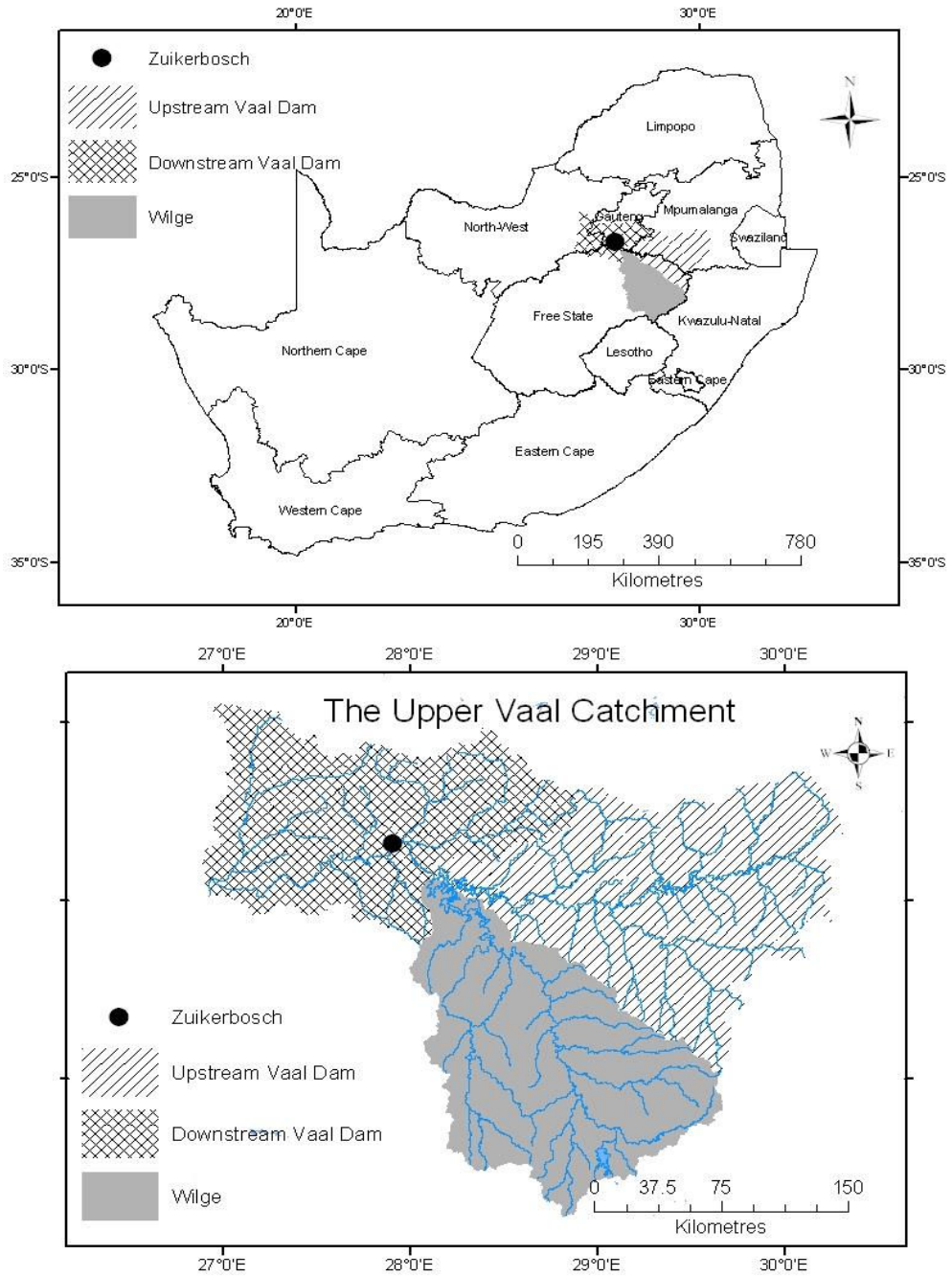
**Figure 3.1:** The location of Zuikerbosch Treatment Plant in the Upper Vaal WMA.

At Zuikerbosch the water treatment chemical dosages determine water treatment chemical costs. After abstracting the raw water, Zuikerbosch water treatment plant conducts laboratory analyses of water quality to determine the necessary chemical dosages to treat the water. At the same time, the quality of treated water is monitored to ensure that the required minimum standard is achieved, and chemical doses are adjusted if necessary. This process enables Zuikerbosch to adjust water treatment chemical doses in response to changes in raw water quality almost immediately (du Preez, 2007).

Rand Water provided daily time series data on raw water quality (including important biological and environmental variables) and water treatment dosages at Zuikerbosch for the period November 2004 – October 2006. (Suitable data prior to November 2004 were not available.) These data were aggregated to weekly data in order to smooth out unexpected and otherwise inexplicable fluctuations in the recorded daily chemical dosage data. Weekly real chemical costs of water treatment were computed from water treatment chemical dosages multiplied by the costs of each chemical, and adjusted to 2006 chemical prices using the consumer price index (CPI).

### 3.1.1 Raw Water Quality at Zuikerbosch

Table 3.1 presents descriptive statistics of mean raw water quality variables at Zuikerbosch for the study period, as well as Rand Water's recommended limits for each variable. According to Steynberg *et al.* (1996), attainment of these guidelines in the raw water sources will ensure that the present treatment technology used by Rand Water will be able to purify raw water sources to comply with strict international criteria. A comparison of the actual average water quality at Zuikerbosch with Rand

Water's recommended limits suggests that the quality of raw water processed at Zuikerbosch is, in general, relatively high. For example, the maximum level of chlorophyll recorded at Zuikerbosch during the study period (12.64 micrograms per litre (ug/l)) is well within the limit of 30 micro grams per litre (ug/l). There were noticeable peaks of chlorophyll over the study period but the relationship with chemical cost was not plainly noticeable at Zuikerbosch (Figure 3.2). The maximum pH (9.19 pH units) at Zuikerbosch during the study period, however, is higher than the recommended range, but the mean recorded pH is well with in the required range. The actual average total alkalinity (61.1 milligrams per litre (mg/l)) at Zuikerbosch over the study period is close to the recommended limit (65mg/l).
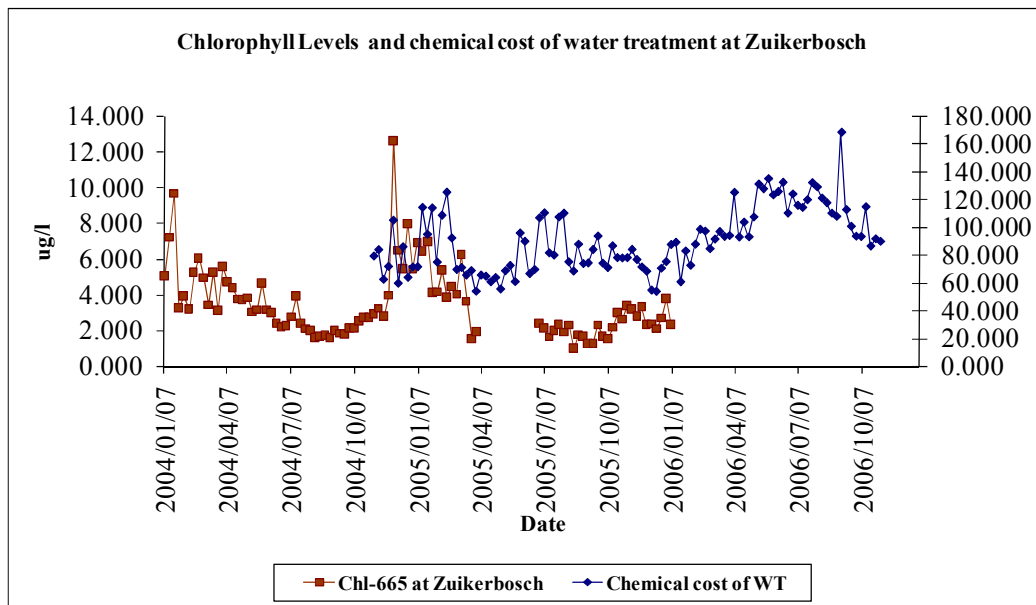


**Figure 3.2:** Chlorophyll level at Zuikerbosch for the period 2004 – 2006.

**Table 3.1:** Water Quality Descriptive Statistics of Zuikerbosch and Rand Water's recommended limits of raw water quality, November 2004 – October 2006.

| Variables | Recommended Limit | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|---|
| Ca (mg/l)(Calcium) | 150.00 | 93.00 | 10.50 | 20.20 | 13.50 | 1.28 |
| Al (mg/l) (Aluminium) | 1.50 | 93.00 | 0.34 | 4.40 | 1.96 | 1.01 |
| hardness (mg/l) (Hardness) | | 93.00 | 46.20 | 76.20 | 61.78 | 4.57 |
| Fe (mg/l) (Iron) | 1.00 | 93.00 | 0.19 | 2.50 | 1.11 | 0.47 |
| Mg (mg/l) (Magnesium) | 70.00 | 93.00 | 5.65 | 7.90 | 6.85 | 0.44 |
| NO3 (mg/l) (Nitrate) | 3.00 | 76.00 | 0.05 | 0.78 | 0.30 | 0.13 |
| P (mg/l) (Phosphoreous) | | 93.00 | 0.02 | 0.51 | 0.12 | 0.08 |
| NO2 (mg/l) (Nitrite) | 20.00 | 41.00 | 0.02 | 0.24 | 0.06 | 0.04 |
| Si (mg/l) (Silicon) | | 93.00 | 5.58 | 12.20 | 8.70 | 1.34 |
| Na (mg/l) (Sodium) | 20.00 | 93.00 | 5.84 | 8.66 | 7.43 | 0.55 |
| NH4 (mg/l) (Ammonia) | 1.00 | 41.00 | 0.03 | 0.42 | 0.06 | 0.07 |
| H_Chl_66 (ug/l) (Chlorophyll 665 | 30.00 | 93.00 | 0.97 | 12.64 | 3.44 | 1.94 |
| Geosmin (mg/l) (Geosmin) | | 93.00 | - | 29.20 | 5.41 | 5.28 |
| PO4 (mg/l) (Phosphate) | 0.30 | 76.00 | 0.03 | 0.20 | 0.05 | 0.03 |
| Mn (mg/l) (Manganese) | 0.20 | 93.00 | 0.00 | 0.03 | 0.01 | 0.00 |
| SO4 (mg/l) (Sulphate) | 200.00 | 77.00 | - | 21.40 | 13.93 | 3.64 |
| K (mg/l) (Potassium) | 20.00 | 93.00 | - | 3.22 | 2.25 | 0.50 |
| pH | >7 - <9 | 105.00 | 6.65 | 9.19 | 7.78 | 0.38 |
| Total_al (mg/l) (Total alkalinity) | >65 | 105.00 | 45.00 | 76.19 | 61.11 | 6.65 |
| EC (dS/m)(Electrical conductivity) | 70.00 | 105.00 | 14.06 | 22.57 | 17.08 | 1.01 |
| NTU (Turbidity) | | 105.00 | 56.50 | 141.29 | 85.88 | 26.80 |
| Lag_real_chmcost (Lag-cost) | | 104.00 | 53.28 | 167.87 | 90.00 | 22.87 |
| **Valid N (listwise)** | | **38.00** | | | | |

A notable characteristic of Table 3.1 is that the data set suffers from a considerable amount of missing data. The number of weekly observations for each raw water variable ranges from as low as 41 for ammonia and nitrite to 105 for total alkalinity and pH. Measurements of all variables were provided for only 38 out of 105 weeks of the study period. Moreover, data on the relative presence of certain algal species in the raw water which may affect the taste and odour of treated water, were not available.

## 3.1.2 Chemical Treatment Costs at Zuikerbosch

Total chemical costs of water treatment and the composition of these costs at Zuikerbosch are shown in Figures 3.3, 3.4 and 3.5. The average real water treatment cost at Zuikerbosch over the study period was R 89.99 per megalitre. The range of real chemical water treatment cost at Zuikerbosch was from as low as R53.3 per megalitre to as high as R167.87 per megalitre (2006 = 100). The distribution of cost over time at Zuikerbosch is indicated by the standard deviation (22.76), which suggests that the real chemical water treatment cost at Zuikerbosch varies significantly over the study period.
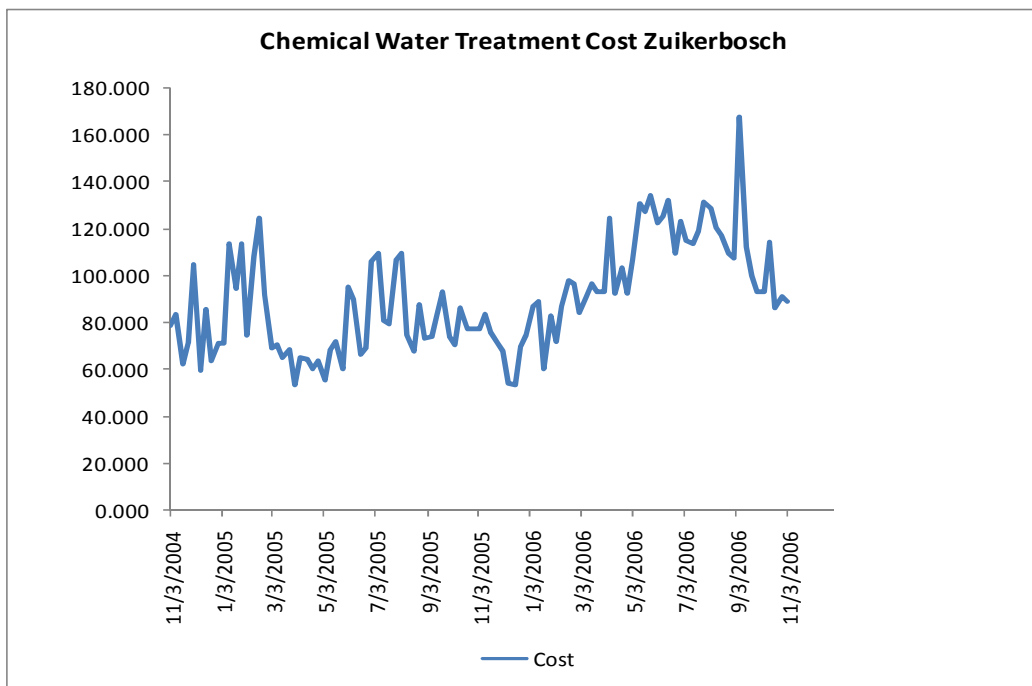


**Figure 3.3:** Real chemical cost of treating potable water at Zuikerbosch.

On average, polymer coagulants (poly) account for about 49% of chemical water treatment costs at Zuikerbosch. Lime, which is used as a pH adjuster, accounted for an average of 25% of chemical treatment costs. Chlorine gas, which is used to

disinfect treated water, accounts for, on average, 13% of total chemical costs at Zuikerbosch. Silica, which is a coagulant and, therefore, a partial substitute for poly, accounted for 10% of total chemical costs during the study period.
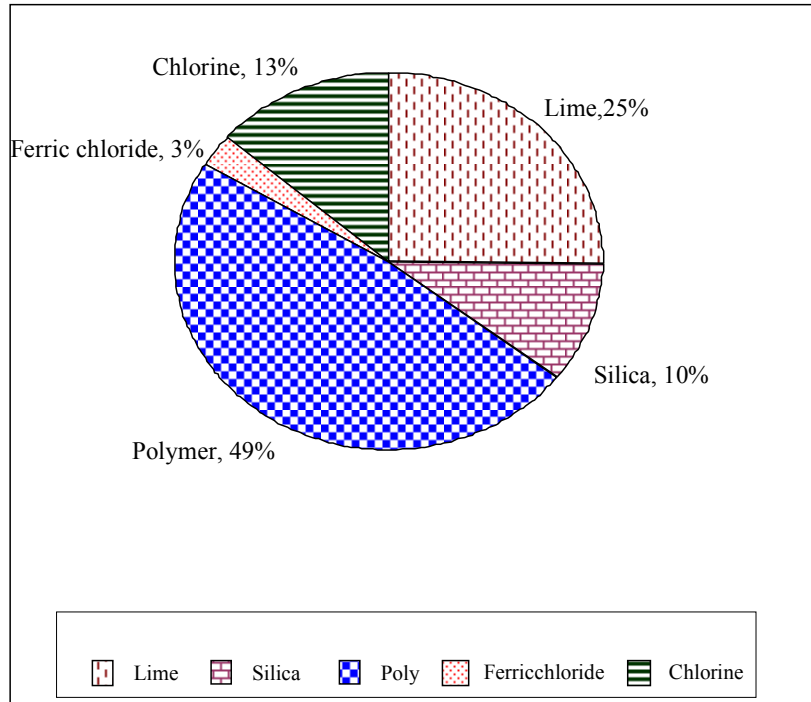


**Figure 3.4:** Chemical cost composition at Zuikerbosch, Nov 2004 – Oct 2006. (2006 =100)
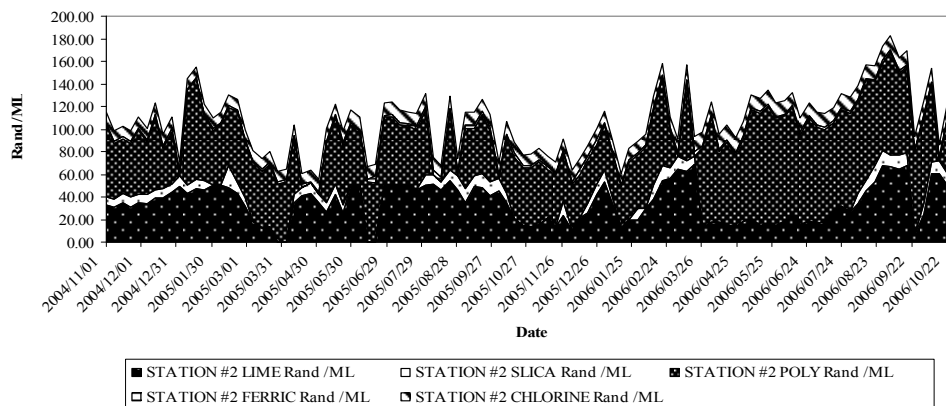


**Figure 3.5:** The composition of chemical water treatment costs at Zuikerbosch, Nov 2004 – Oct 2006 (2006 = 100).

**3.2 Balkfontein Water Treatment Plant**

Balkfontein was identified as being suitable for the purposes of this study due to its geographic location in the MVWMA, a region of the catchment known to experience water eutrophication problems. Balkfontein is owned and operated by Sedibeng Water, which was established in 1979. It is one of the largest water utilities in the middle Vaal. Its operational area covers 86000km$^2$, spanning three provinces, namely Free State, North West and Northern Cape (Sedibeng Water, 2007). Sedibeng Water's Balkfontein water treatment plant has a capacity of 360 megalitres (ML) per day and abstracts its raw water directly from the Vaal River close to Bothavile in the Free State province (Ceronio *et al.,* 2002).

The water treatment process at Balkfontein is based on both raw water quality and treated water standard. This means that decisions on water treatment chemical dosage are initially based on characteristics of the raw water quality, and then adjusted according to the results of continual testing of the quality of treated water – with the objective of minimising chemical water treatment costs while still producing water that is compliant with standards set by Sedibeng Water (Netshidaulu, 2007).

**3.2.1 Raw Water Quality at Balkfontein**

Sedibeng Water provided daily time series secondary data on important biological and environmental variables and real water treatment cost for the year 2004 – 2006. (Data prior to 2004 were not available). These data were then aggregated to weekly data. Weekly real water treatment costs were adjusted to 2006 chemical prices using the consumer price index (CPI) by aggregating from daily water treatment chemical

dosages. Figure 3.6 shows the trends of chlorophyll-a in the raw water abstracted at Balkfontein and the costs of treating the water. Chlorophyll-a is a direct measurement of the quantity of plant nutrients in the water and is, therefore, regarded as a measure of water eutrophication. The trends indicate that during the study period there were several periods of relatively high levels of chlorophyll-a (> 20 ug/l).
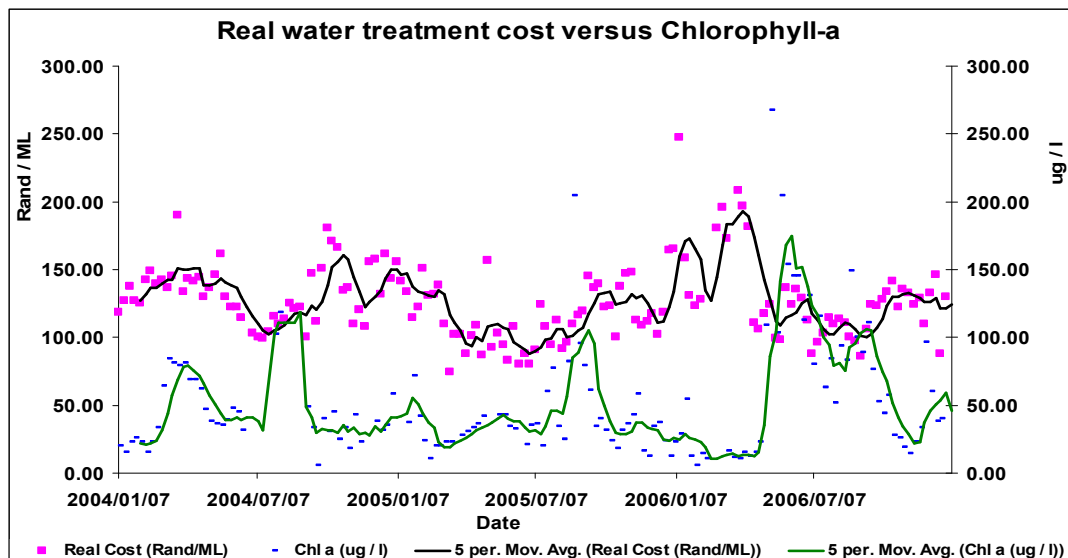


**Figure 3.6:** Trends of real chemical costs of water treatment and chlorophyll-a at Balkfontein, 2004 – 2006.

Figure 3.6 does not portray the expected positive relationship between the real water treatment cost and chlorophyll-a. There are two main reasons for this. Firstly, chlorophyll-a is a measure that indicates the total quantity of algae in the water, but does not indicate the algal species. Some algal species, such as *Cyanophyceae* (*Anabaena* and *Microcystis*) impact more on chemical water treatment costs than other species of algae (Dennison and Lyne, 1997; du Preez *et al.,* 2007). Secondly, chemical water treatment costs are also driven by other characteristics of raw water

40

quality such as turbidity, pH, Mn and temperature (Graham *et al.*, 1998; Dennison & Lyne, 1997). The average chlorophyll-a level of 51.53 ug/l for the study period (see Table 3.2) shows that eutrophication was a real water quality problem at the Balkfontein water treatment plant. Similar average levels of chlorophyll-a in raw water were also identified by Basson and Schutte (2002) as an indication of relatively poor water quality for Balkfontein water treatment plant. Chlorophyll-a in excess of 20 ug/l is considered to be a problem for drinking water quality (NEAP, 2007).

**Table 3.2:** Descriptive statistics showing characteristics of raw water treated at Balkfontein, 2004 – 2006.

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Al (mg/l) (aluminium) | 125 | 0.010 | 8.900 | 0.524 | 1.226 |
| Ca (mg/l) (calcium) | 144 | 20.100 | 86.780 | 60.580 | 15.524 |
| Chl a (ug/l) (chlorophyll) | 135 | 5.755 | 267.800 | 51.534 | 42.480 |
| Cl (mg/l) (chloride) | 127 | 8.800 | 234.560 | 68.540 | 28.762 |
| Colour | 152 | 83.400 | 2450.400 | 300.776 | 307.548 |
| DOC (mg/l) (dissolved organic carbon) | 72 | 5.310 | 12.700 | 8.773 | 1.665 |
| EC (dS/m) (electrical conductivity) | 146 | 21.380 | 166.860 | 78.857 | 24.578 |
| Fe (mg/l) (iron) | 118 | 0.020 | 5.900 | 0.515 | 0.884 |
| Mg (mg/l) (magnesium) | 139 | 6.300 | 55.595 | 27.376 | 8.657 |
| Mn (mg/l) (manganese) | 113 | 0.010 | 0.642 | 0.112 | 0.092 |
| pH | 151 | 7.274 | 9.498 | 8.492 | 0.552 |
| SO4 (mg/l) (sulphate) | 148 | 29.800 | 268.000 | 150.181 | 56.887 |
| T hard (mg/l) (total hardness) | 146 | 91.400 | 376.160 | 261.627 | 65.902 |
| TDS (mg/l) (total dissolved solids) | 64 | 104.000 | 722.000 | 477.344 | 151.180 |
| Temp (°C)(temperature) | 152 | 9.880 | 27.660 | 19.422 | 4.629 |
| Turb (NTU)(turbidity) | 147 | 6.268 | 200.400 | 24.218 | 31.631 |
| UVA (ultra violet absorbance) | 121 | 11.000 | 36.000 | 16.849 | 4.289 |
| Valid N (listwise) | 44 | | | | |

Another notable characteristic of Table 3.2 is that the number of weekly observations for each raw water variable varies from as low as 64 for TDS to 152 for water temperature. Measurements of all variables were provided for only 44 out of 152 weeks of the study period. Moreover, data on the relative presence of certain algal species in the raw water were not available. Despite these data limitations, the

available data were used to estimate a model to predict the chemical costs of water treatment at Balkfontein.

### 3.2.2 Chemical Treatment Cost at Balkfontein

Water chemical treatment costs at Balkfontein were computed in real terms by computing daily chemical dosages by real chemical prices, measured in Rands according to the 2006 CPI. The daily data were then aggregated into weekly data in order to smooth the fluctuations present in the daily cost data. The average chemical cost composition of Balkfontein water for the period 2004 – 2006 is shown in Figure 3.7. On average, chlorine accounts for about 48% of chemical costs. This high utilisation of chlorine may have been required to disinfect the highly eutrophic and microbially contaminated raw water abstracted from the Vaal River. Polymers, which are used to treat problems of water turbidity, account for the second highest component of chemical treatment costs (18%). Lime and Ferric chloride together make up 32% of the real chemical costs at Balkfontein.
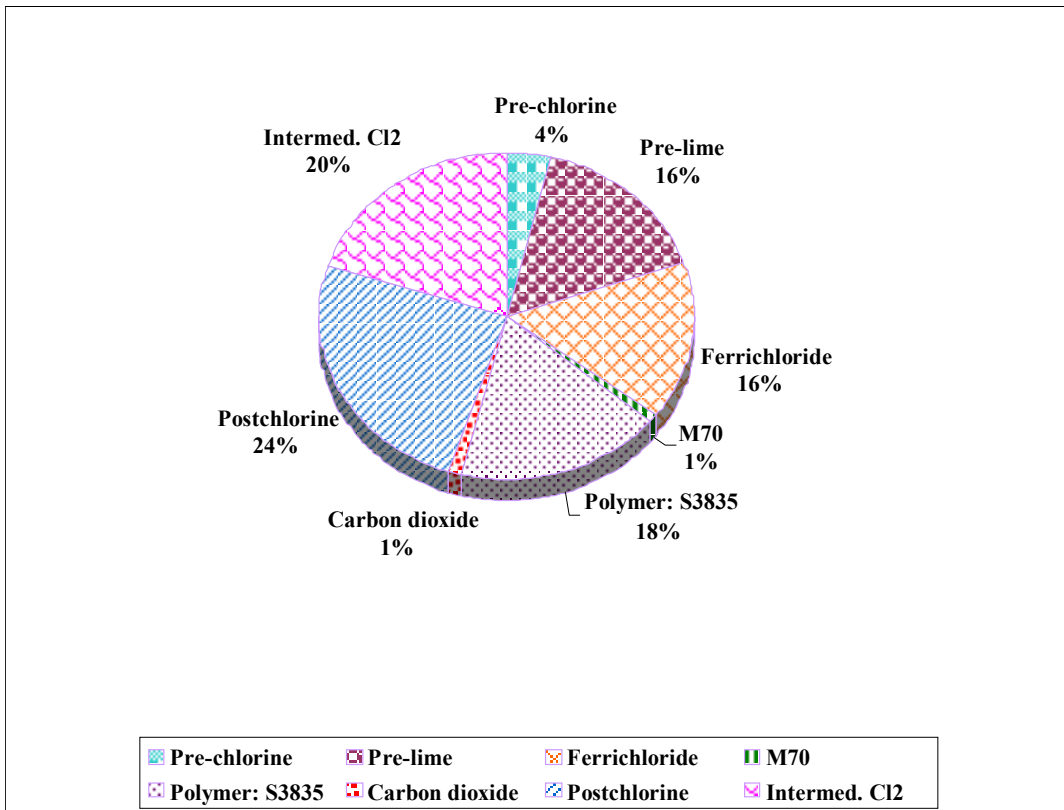
**Figure 3.7**: Balkfontein chemical cost composition for the year 2004 – 2006.

The average water treatment cost at Balkfontein over the study period was R 126.31 / ML / week. This cost ranges between R 74.37 / ML / week and R 247.25 / ML / week. Dennison and Lyne (1997) established that the average real water treatment cost (base year = 1995) for the Durban Heights station of Umgeni Water was R 28 / ML / week. Graham *et al.* (1998) established the average cost of treating water at Hazelmere water treatment plant to be R 40 / ML/week. These values by Dennison and Lyne (1997) and Graham *et al.* (1998) are equivalent to R 51.82 and R 74 in 2006 prices. Prices are adjusted to a 2006 base year using the consumer price index (CPI).

The difference between the average weekly cost of water treatment at Balkfontein and the one calculated by Dennison and Lyne (1997) for Durban Heights might be for two

reasons. First, the characteristics (geographic and climatic) of the two catchment areas differ. Hence, higher average water treatment costs can be expected at Balkfontein as a result of the high eutrophic nature of the middle Vaal River. Second, a possible difference in the technology of water treatment and type of management can also be the source of difference between the two treatment plants.

## 3.3 Comparison Between Balkfontein and Zuikerbosch Water Treatment Plants

The level of chlorophyll 665 for Zuikerbosch ranged from 0.97 ug/l to 12.64ug/l. On the other hand, Balkfontein water treatment station in the MVWMA experienced levels of chlorophyll-a ranging from 5.755 ug/l to 267.8 ug/l, indicating that water eutrophication is a relatively smaller problem in the UVWMA than in the MVWMA. Figure 3.8 shows the levels of chlorophyll at the two treatment plants from 2004 – 2006. No clear relationship is apparent between chlorophyll levels in the UVWMA and the MVWMA.
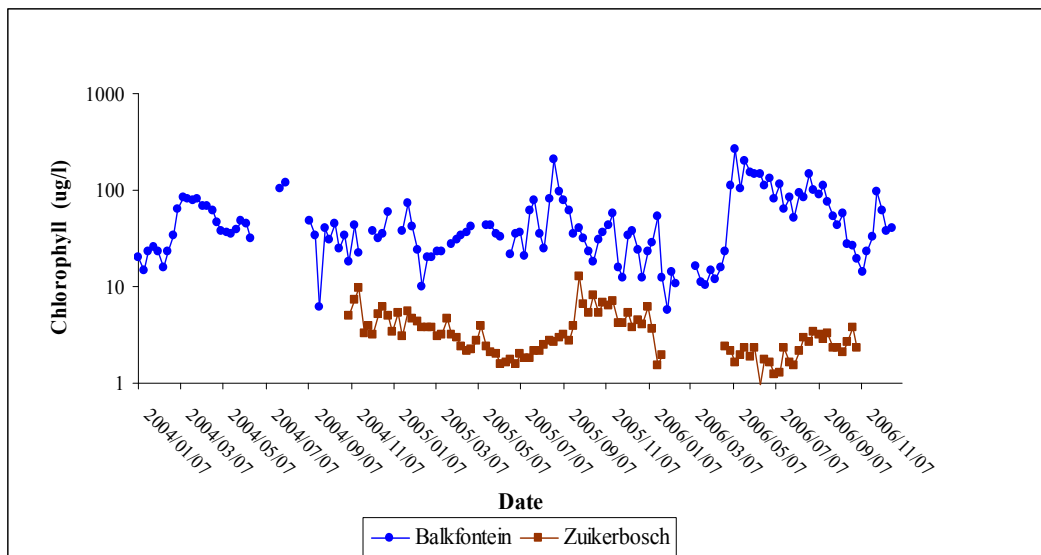


**Figure 3.8:**    Chlorophyll levels in raw water at Zuikerbosch and Balkfontein water treatment stations, 2004 – 2006.

44

Figure 3.9 compares the water chemical treatment costs at Zuikerbosch with those at Balkfontein. The average chemical water treatment cost for Balkfontein was R126.31 per megalitre and ranges from R74.37 per megalitre to R247.25 per megalitre (2006 = 100). Higher average chemical costs of water treatment at Balkfontein are consistent with generally poorer water quality in the MVWMA.
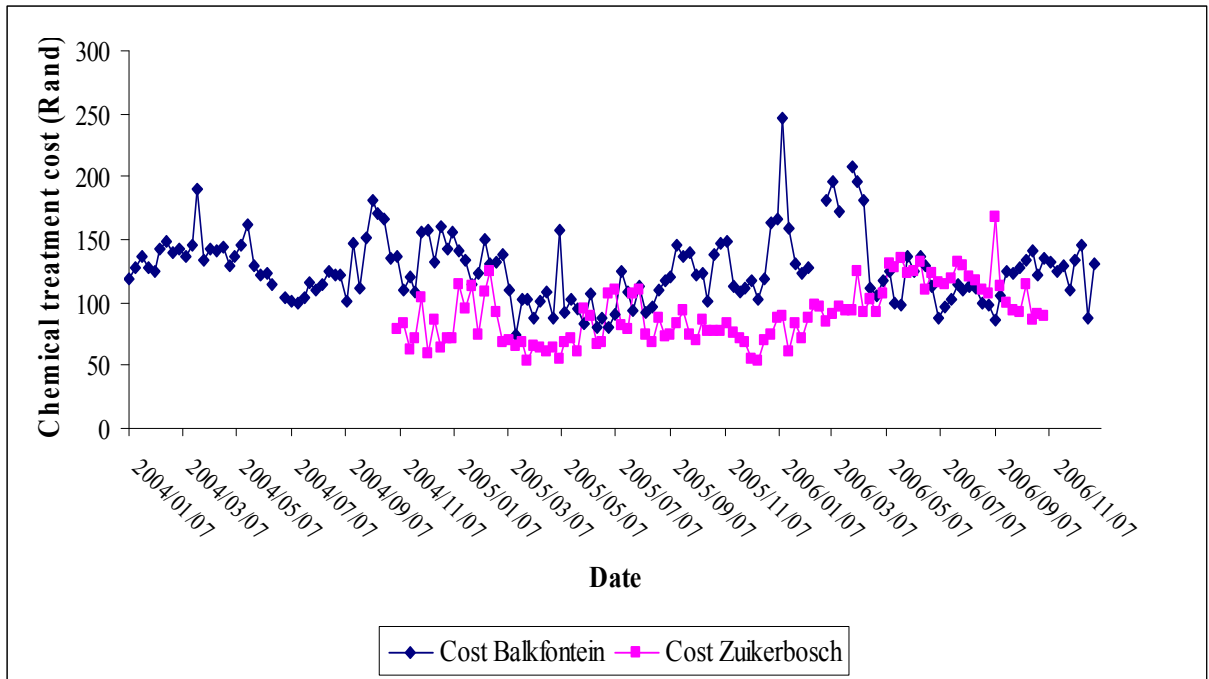


**Figure 3.9:** Chemical water treatment costs at Balkfontein and Zuikerbosch, 2004 – 2006 (2006 = 100).

The major chemical cost item at Zuikerbosch is polymer coagulants, and the major chemical cost item at Balkfontein is chlorine (48% of water chemical treatment costs). Relatively more chlorine is used at Balkfontein because the raw water quality in the MVWMA is considerably lower than the raw water quality in the UVWMA.

According to du Preez (2007) and Marais (2007), for various reasons, Zuikerbosch used a relatively expensive type of poly during parts of 2006, which accounts for the marked increase in expenditure on polymer from March to October 2006 (see Figure 3.9 and Figure 3.4 in Section 3.1.2). This explains why for parts of 2006 Zuikerbosch and Balkfontein incurred similar chemical water treatment costs despite the raw water quality being lower at Balkfontein.

The results for Zuikerbosch water treatment plant were compared to those of Balkfontein water treatment plant and it was found that the average cost in Balkfontein (R126.31), which is situated downstream of the Upper Vaal, was higher than the average water treatment cost at Zuikerbosch (R89.99). Clearly, this demonstrates that raw water quality was deteriorating between the Upper Vaal River and the Middle Vaal River.

**3.3.1 Limitations of the Comparison Between Zuikerbosch and Balkfontein Plants**

There are some limitations to the comparisons between Balkfontein and Zuikerbosch water treatment plants. The comparisons between the two water treatment plants were based exclusively on the eutrophication level (water quality) and the chemical cost of water treatment. Some of the reasons for this being cited as a limitation are that different categories of water treatment cost – such as other operating costs and capital costs – were not available. For example, the electricity cost was only available on a monthly basis as a total electricity cost for the whole water treatment plant. Therefore, it was difficult to establish a weekly electricity cost specifically for the backwashing

period at the water treatment plants. The technology used by these two water

treatment plants and the age of each facility might also differ.

# CHAPTER 4: RESULTS AND DISCUSSION FOR ZUIKERBOSCH

This chapter presents results of the statistical analysis of the costs of water treatment at Zuikerbosch. The first section presents a PCA of water quality attributes of the raw water at Zuikerbosch. These PCs are interpreted as dimensions of water quality. Section 4.2 presents the results of a regression analysis to explain the impact of different water quality variables on the chemical costs of water treatment. The next section presents the standardised and unstandardised coefficients of the original variables using Principal Components. This section compares with the model estimated using PCs. Finally, a predictive model using a partial adjustment regression model is presented.

## 4.1 Principal Component Analysis

A PCA based on the correlation matrix and using un-rotated factor solution was conducted on 19 of the 21 variables contained in Table 4.1. $NO_2$ and $NH_4$ were excluded from the analysis due to the relatively high number of missing values for these two variables. Nine factor loadings were elicited by dropping successive factors until sign of each estimated coefficients stabilised and accounting for over 86% of the variation contained in the original 19 variables; the PC loadings in (Table 4.1) were computed from the factor loadings (computed by the SPSS) dividing to the square root of their respective Eigen value. The first Principal Component accounts for 28.35% of the total variation in the water quality variables. Iron, silicon, total alkalinity, turbidity, and potassium (K) have moderately low to moderate component loadings (>0.295) in this component, which implies that loadings of these five

variables in raw water are highly correlated. In other words, when the raw water loading of iron is high (low), raw water loadings of potassium and silicon also tend to be high (low).

PC$_3$ accounts for 9.88% of the total variation in raw water quality and has high positive loadings for chlorophyll 665 and pH, and moderate to high negative loading for NO3. This component reflects that at times when chlorophyll 665 nitrate tended to be relatively low, and *vice versa*. This is because algal uptake of nitrate in the raw water can reduce the level of NO3.

**Table 4.1:** Component Matrix for the water quality variables at Zuikerbosch.

| | PC$_1$ | PC$_2$ | PC$_3$ | PC$_4$ | PC$_5$ | PC$_6$ | PC$_7$ | PC$_8$ | PC$_9$ |
|---|---|---|---|---|---|---|---|---|---|
| Ca | -0.127 | **0.456** | 0.050 | -0.056 | 0.217 | -0.200 | 0.153 | 0.091 | 0.078 |
| Al | 0.307 | 0.122 | 0.237 | -0.174 | 0.154 | **0.340** | -0.196 | -0.080 | 0.152 |
| Hardness | -0.029 | **0.501** | 0.031 | -0.129 | 0.144 | -0.210 | 0.089 | 0.017 | 0.060 |
| Fe | **0.337** | 0.078 | 0.256 | -0.191 | 0.138 | 0.247 | -0.203 | 0.094 | 0.093 |
| Mg | 0.169 | **0.429** | -0.089 | -0.201 | 0.016 | -0.046 | 0.020 | 0.013 | -0.122 |
| NO$_3$ | 0.195 | 0.088 | **-0.360** | 0.033 | -0.242 | 0.335 | 0.021 | **0.372** | -0.047 |
| P | 0.225 | -0.050 | -0.102 | 0.336 | 0.088 | -0.072 | 0.337 | -0.463 | **0.524** |
| Si | **0.358** | 0.028 | 0.235 | 0.074 | 0.087 | 0.155 | -0.109 | -0.001 | 0.213 |
| Na | 0.262 | **0.300** | -0.203 | 0.037 | -0.043 | -0.107 | 0.193 | -0.174 | -0.188 |
| H_Chl_665 | -0.207 | -0.039 | **0.461** | -0.079 | -0.075 | 0.211 | 0.334 | -0.030 | 0.158 |
| Geosmin | 0.050 | -0.173 | 0.227 | **-0.517** | -0.185 | -0.124 | **0.563** | 0.140 | 0.006 |
| PO$_4$ | -0.014 | -0.102 | -0.104 | 0.237 | **0.582** | 0.345 | 0.419 | 0.360 | -0.205 |
| Mn | 0.186 | -0.079 | 0.137 | 0.258 | 0.031 | **-0.505** | -0.085 | **0.621** | 0.353 |
| SO$_4$ | -0.154 | 0.118 | -0.338 | -0.212 | -0.317 | 0.269 | 0.047 | 0.213 | **0.507** |
| K | **0.340** | -0.050 | 0.014 | -0.098 | 0.034 | -0.119 | 0.107 | 0.017 | -0.213 |
| pH | -0.034 | 0.180 | **0.418** | 0.285 | -0.405 | 0.026 | -0.068 | 0.105 | -0.235 |
| Total_alkalinity | **-0.295** | 0.229 | 0.216 | 0.274 | 0.045 | 0.173 | 0.031 | 0.020 | 0.007 |
| EC | 0.187 | 0.198 | 0.024 | **0.382** | -0.379 | 0.151 | 0.281 | -0.001 | -0.061 |
| NTU | **-0.344** | 0.212 | 0.003 | -0.019 | 0.149 | 0.097 | -0.127 | 0.018 | 0.179 |
| S Square | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Eigen value | 5.386 | 3.351 | 1.877 | 1.302 | 1.258 | 1.014 | 0.876 | 0.761 | 0.690 |
| % Variance | 28.35 | 17.63 | 9.88 | 6.85 | 6.62 | 5.33 | 4.61 | 4.00 | 3.63 |
| Cuml % | 28.35 | 45.98 | 55.86 | 62.72 | 69.34 | 74.67 | 79.28 | 83.29 | 86.92 |

Low to moderate positive correlation between chlorophyll and pH suggests that algal blooms (indicated by an increase in chlorophyll) at Zuikerbosch were reducing the carbon dioxide concentration in the raw water, and this is associated with an increase in the pH of the raw water (Pieterse and van Vuuren, 1997). Pieterse and van Vuuren (1997) also identified this correlation using time series data for seven years for the Vaal River, taken from four different sampling points. The finding of this study on the correlation between chlorophyll and pH at Zuikerbosch is similar to this past study even with shorter time series data. A strong positive correlation between chlorophyll and pH in the Middle Vaal Water Management Area was also experienced for the study period.

PC$_2$ accounts for 17.63% of the variation in the original water quality variables. This component reflects that raw water loadings of calcium, magnesium, water hardness, and sodium (Na) are positively correlated. This finding is consistent with *a priori* expectations because the primary contributors to hardness are Ca and Mg (Charles *et al.,* 2002).

PC$_4$ accounts for 6.85% of the total variation in water quality and has high loadings for geosmin, EC, and pH. The pH of a sample of water is a measure of the concentration of hydrogen ions, and EC estimates the total amount of ions in the raw water. As pH decreases by 1 pH unit, 10 hydrogen ions are added into the raw water (WOW, 2004). Therefore, the expectation is that the relationship between pH and EC should be negative. However, contrary to the expectation, this component reveals a strong positive relationship between these two variables.

PC$_7$ accounts for 4.6% of the total variation in water quality. This component has a high positive loading for geosmin and a moderate positive loading for chlorophyll 665, phosphate (PO4), phosphorous (P). This shows that geosmin (a taste and odour factor of raw water) has a moderate correlation with chlorophyll 665, PO4, and P as expected. Geosmin is a production of certain algae species such as *Cyanobacterium* (Naes *et al.,* 1985).

PC$_9$ has a high positive component loading for phosphorous and accounts for 3.63% of the total variation in water quality. P is positively correlated with SO4 and manganese (Mn) in the Principal Component. PC$_5$ has a high positive loading for phosphate and moderate negative loadings for pH and EC. PC$_8$ has a high positive loading for manganese only. Finally, PC$_6$ has a moderate positive loading for aluminium.

**4.2 The Explanatory Model Using PC scores at Zuikerbosch**

The estimated OLS regression model in which water chemical treatment costs were regressed on the PCs elicited (Jolliffe, 2002), is presented in Table 4.2. The estimated regression coefficients for PC$_5$, PC$_8$ PC$_9$ were not statistically different from zero and were therefore omitted from the model. The model accounted for 50.2% of variation in water chemical treatment costs and is statistically significant, as indicated by the adjusted R$^2$ statistic of 43.2% and the F-statistic of approximately 7.168. The d statistic for the model (1.636) is inconclusive whether autocorrelation is present or not. The VIF values are all equal to 1 (i.e., there is no collinearity between the explanatory variables) because the elicited PCs are orthogonal.

**Table 4.2:** Estimated OLS regression model of water chemical costs at Zuikerbosch

Principal Components as explanatory variables, November 2004 – October

2006.

| Coefficients | Unstandardized Coefficients | | Standardized Coefficients | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| | B | Std. Error | Beta | t | Sig. | Tolerance | VIF |
| Constant | 93.451 | 2.117 | | 44.134 | 0.000 | | |
| $PC_1$ | 10.103 | 2.132 | 0.418 | 4.739 | 0.000 | 1 | 1 |
| $PC_2$ | -8.525 | 2.132 | -0.353 | -3.999 | 0.000 | 1 | 1 |
| $PC_3$ | -4.393 | 2.132 | -0.182 | -2.061 | 0.043 | 1 | 1 |
| $PC_4$ | -6.211 | 2.132 | -0.257 | -2.913 | 0.005 | 1 | 1 |
| $PC_5$ | -2.277 | 2.132 | -0.094 | -1.068 | 0.290 | 1 | 1 |
| $PC_6$ | -4.767 | 2.132 | -0.197 | -2.236 | 0.029 | 1 | 1 |
| $PC_7$ | -5.078 | 2.132 | -0.210 | -2.382 | 0.020 | 1 | 1 |
| $PC_8$ | 1.948 | 2.132 | 0.081 | 0.914 | 0.364 | 1 | 1 |
| $PC_9$ | -1.752 | 2.132 | -0.072 | -0.822 | 0.414 | 1 | 1 |
| Df | 64 | | | | | | |
| R Square | 50.20% | | | | | | |
| Adj R Square | 43.20% | | | | | | |
| F Value | 7.168 | | | | | | |
| D statistivc | 1.636 | | | | | | |

Dependent Variable: real_chm

Where: \*\*\*, \*\*, \* indicate significance at the 1%, 5%, and 10% levels of probability

respectively.

The relative magnitude of the standardised Beta coefficient for $PC_1$ indicates that from a statistical perspective it is the most important explanatory variable in the estimated model. The estimated regression coefficient for $PC_1$ is statistically different to zero at the 1% level of probability. The estimated relationship between chemical water treatment costs and $PC_1$ shows that there is a negative relationship between total hardness, calcium, magnesium, chloride, sulphate, and conductivity (EC) in raw water and water chemical treatment costs. Turbidity and chlorophyll are positively correlated in this component and are negatively related with chemical cost of water treatment.

Chlorophyll may also aid in the flocculation process by increasing the turbidity level as algae, detritus (dead organic materials), and silt are the three major particles of turbidity, thereby decreasing cost (WOW, 2004). When algae population (measured by the level of chlorophyll) in raw water increases, turbidity also increases. Higher levels of algae may, however, impact adversely on other categories of water treatment costs, e.g., water filtration costs. However, increases in the levels of iron (Fe), silicon (Si), and potassium (k) in raw water treated at Zuikerbosch are positively related to water chemical treatment costs.

The estimated coefficient for $PC_2$ (the second most important determinant of real water chemical treatment costs) is also statistically significant at the 1% level of probability. The responsible variables in this component with the highest loadings are calcium (Ca), water hardness, and magnesium (Mg). This result suggests that the combined increase in these three variables lowers chemical water treatment cost. It is expected that an increase in raw water hardness will reduce the dose of lime required to treat water. The estimated regression coefficient for $PC_4$ is the third important determinant of real water treatment cost and is statistically significant at 5% probability of significance. Chemical water treatment cost has a positive relationship with geosmin and negative relationship with EC.

Although the estimated regression coefficient for $PC_3$ is the sixth most important determinant of water chemical treatment costs, it is statistically different from zero at the 99% level of confidence. The estimated coefficient shows that increases in raw water pH and chlorophyll 665 are associated with lower water chemical treatment costs but increase in nitrate decreases cost. This result is consistent with expectations

because as pH rises, less lime is added to raw water during water treatment. This result is consistent with the findings of Graham *et al*. (1998) and Dennison and Lyne (1997). This negative relationship of chlorophyll and chemical water treatment cost is unexpected, but may suggest that low levels of chlorophyll, such as those experienced in the UVWMA, do not directly impact on water treatment costs. Instead, because nitrate is a source of food for algal biomass (Lai and Lam, 1997), algal nitrate uptake is associated with reduced nitrate loadings in raw water, and therefore leads to lower chemical costs of treatment water.

The next most important variable in the model (as identified using the standardised Beta coefficients) is $PC_6$. The estimated regression coefficients for these variables show that an increase in the level of manganese (Mn), in raw water is positively related to increased water chemical treatment costs. All of these results are consistent with *a priori* expectations.

## 4.3 Standardised and Unstandardised Regression models: Zuikerbosch Water Treatment Plant

The standardised regression coefficients computed from the PCs were useful in identifying their relative influence on chemical water treatment cost. Water quality variables that have a greater impact on chemical cost of treating water have greater coefficients (Table 4.3). The t-values were computed from $\beta_i$ divided by the standard deviation of $\beta_i$; i.e., t-value $= \dfrac{\beta_i}{\sqrt{\mathrm{var}(\beta_i)}}$ (Dennison and Lyne, 1997).

**Table 4.3:** Standardised regression coefficients estimated for water quality

variables from the elicited PC loadings at Zuikerbosch Plant.

| Water Quality Variables | Standardised($\beta i$) | Var ($\beta i$) | t-values |
|---|---|---|---|
| Ca | -5.317 | 1.615 | -4.185 *** |
| Al | 0.700 | 1.829 | 0.518 |
| Hardness | -3.750 | 1.576 | -2.987 *** |
| Fe | 2.352 | 1.639 | 1.837 * |
| Mg | 0.004 | 1.268 | 0.004 |
| NO3 | 2.249 | 2.215 | 1.511 |
| Na | -2.328 | 3.600 | -1.227 |
| H_Chl_66 | 1.131 | 1.267 | 1.005 |
| Geosmin | 0.368 | 1.444 | 0.307 |
| Mn | -6.169 | 2.051 | -4.308 *** |
| K | 2.609 | 3.348 | 1.426 |
| pH | -4.332 | 4.014 | -2.162 ** |
| Total_alkalinity | 3.704 | 4.091 | 1.831 * |
| EC | -1.035 | 3.068 | -0.591 |
| NTU | 4.758 | 0.910 | 4.987 *** |
| df | 64 | | |
| $R^2$ | 0.502 | | |
| d statistic | 1.636 | | |

Dependent variable: Chemical cost of water treatment.

Where: ***, **, * denote significance level at 1%, 5%, and 10% probabilities respectively.

The regression coefficients of the standardised variables in Table 4.3 were converted

to unstandardised coefficients by multiplying the standardised coefficients by $Sy / Sx_i$.

The unstandardised coefficients was then compared to the regression analysis

estimated using the PC scores at Zuikerbosch Water Treatment Plant. Table 4.4

illustrates the results computed to obtain unstandardised regression coefficients.

**Table 4.4:**  Unstandardised coefficients estimated for water quality variables after removing multicollinearity at Zuikerbosch

| Variables | Unstandardised ($\beta_i$) | t-values |
|---|---|---|
| Constant | -2.636 | |
| Ca | -94.166 | -4.185 *** |
| Al | 15.781 | 0.518 |
| Hardness | -18.666 | -2.987 *** |
| Fe | 113.827 | 1.837 * |
| Mg | 0.220 | 0.004 |
| NO3 | 385.931 | 1.511 |
| Na | -95.495 | -1.227 |
| H_Chl_66 | 13.272 | 1.005 |
| Geosmin | 1.586 | 0.307 |
| Mn | -34093.283 | -4.308 *** |
| K | 118.620 | 1.426 |
| pH | -262.536 | -2.162 ** |
| Total_alkalinity | 12.672 | 1.831 * |
| EC | -23.295 | -0.591 |
| NTU | 4.040 | 4.987 *** |
| df | 64 | |
| $R^2$ | 0.502 | |
| d statistic | 1.636 | |

Dependent variable: Chemical cost of water treatment.

Where: ***, **, * denote significance level at 1%, 5%, and 10% probabilities respectively.

However, results of Table 4.4 were not consistent with the results interpreted in Section 4.2 in Table 4.2.  The coefficient estimated for chlorophyll was not statistically significant but the sign was consistent with the coefficient estimated for chlorophyll in Table 4.2.  The coefficients obtained for hardness and calcium in Table 4.2, were also consistent with the coefficients computed in Table 4.4 for these variables found to increase the chemical cost of treating potable water. However, the

magnitudes of most of the coefficients estimated in the unstandardised model for Zuikerbosch were unexpectedly large. An increase in the level of turbidity in raw water at Zuikerbosch also tends to increase chemical cost of water treatment.

**4.4 The Predictive Model using PA Regression at Zuikerbosch**

The partial adjustment model specified in equation (4.1) was estimated to be a better predictive model of water treatment chemical costs at Zuikerbosch. In other words, the objective was to find a model with a higher $R^2$ statistic than the model presented in Table 4.2. All of the water quality variables reported in Table 3.1, and various transformations thereof, were considered in the partial adjustment model. Equation (4.1) includes only the variables retained in the model after the dropping of certain variables to remedy problems of multicollinearity whilst maximising the adjusted $R^2$ statistic. Variables measuring raw water turbidity and chlorophyll content were retained in the model as these variables are required in the predictive model that will be used in a study of the economic costs of eutrophication in the Vaal River.

*(Real chm cost)$_t$ = $\beta_0$ + $\beta_1$ (NO$_3$)$_t$ + $\beta_2$ (Total_alkalinity)$_t$ + $\beta_3$ EC$_t$ + $\beta_4$ (SO$_4$)$_t$ + $\beta_5$*

*(NO$_3$)$_t^2$ + $\beta_6$ (TA)$_t^2$ + $\beta7$ (SO$_4$)$_t^2$ + $\beta_8$ (H Chl 665)$_t$ + $\beta_9$ (NTU)$_t$ + $\beta_{10}$ (Real chm*

*cost)$_{t-1}$*

$$(4.1)$$

Where:

| | |
|---|---|
| *(Real chm cost)$_t$* | = Real water treatment cost per ML (Rand) in time period *t* |
| *(NO$_3$)$_t$* | = Nitrate loading (mg/l) in time period *t* |
| *(Total_alkalinity)$_t$* | = Total alkalinity loading (mg/l) in time period *t* |
| *(EC)$_t$* | = Electrical conductivity (dS/m) in time period *t* |

| | | | | | | |
|---|---|---|---|---|---|---|
| $(SO_4)_t$ | | = Sulphate loading (mg/l) in time period $t$ | | | | |
| $(H\ Chl\ 665)_t$ | | = Chlorophyll 665 (µg/l) in time period $t$ | | | | |
| $(NTU)_t$ | | = Turbidity (NTU) in time period $t$ | | | | |
| $\beta_i$ | | = estimated regression coefficients ($i$ = 1, 2, …, 8) | | | | |

The estimated partial adjustment model is presented in Table 4.5. The model explains 61.6% of the variation in real water chemical treatment costs during the study period, suggesting that it is a better model for predicting water chemical treatment costs at Zuikerbosch than the model presented in Table 4.2

**Table 4.5:** OLS Regression Model for Zuikerbosch before omitting chlorophyll 665 and turbidity for the period November 2004 – October 2006.

| Variables | Unstandardized Coefficients | | | | Collinearity Statistics | |
|---|---|---|---|---|---|---|
| | B | Std. Error | t | Sig. | Tolerance | VIF |
| Constant | 446.176 | 187.066 | 2.385 | 0.02** | | |
| NO3 | 139.152 | 64.537 | 2.156 | 0.035** | 0.061 | 16.291 |
| $(NO3)^2$ | -135.695 | 91.239 | -1.487 | 0.142 | 0.08 | 12.541 |
| Total alkalinity | -12.081 | 6.17 | -1.958 | 0.055** | 0.002 | 407.075 |
| $(Total\ alkalinity)^2$ | 0.1 | 0.054 | 1.862 | 0.067* | 0.002 | 420.175 |
| SO4 | 3.916 | 1.682 | 2.328 | 0.023** | 0.097 | 10.332 |
| $(SO4)^2$ | -0.214 | 0.082 | -2.611 | 0.011** | 0.078 | 12.744 |
| EC | -3.55 | 2.108 | -1.684 | 0.097* | 0.641 | 1.559 |
| H Chl 665 | -0.699 | 1.272 | -0.549 | 0.585 | 0.594 | 1.684 |
| NTU | -0.003 | 0.122 | -0.026 | 0.979 | 0.29 | 3.443 |
| Real-chm-cost $_{t-1}$ | 0.349 | 0.115 | 3.018 | 0.004*** | 0.456 | 2.191 |
| Df | 62 | | | | | |
| R2 | 0.616 | | | | | |
| Adj R2 | 0.554 | | | | | |
| F value | 9.934*** | | | | | |
| d statistic | 2.418 | | | | | |
| h statistic | -1.785 | | | | | |

Dependent Variable: Real_chm_cost $_t$

Where: ***, **, * denote significance level at 1%, 5%, and 10% probabilities respectively.

Because the estimated regression coefficients for H Chl665 and NTU were highly statistically insignificant, these two variables were dropped from the model. The final model is presented in Table 4.6. The $R^2$ statistic of this model was 0.614. Findings show that real water chemical treatment costs at Zuikerbosch can be predicted from four water quality variables, namely nitrate, total alkalinity, electrical conductivity, sulphate, and previous period (week) cost. Nonetheless, the model is not suitable as an explanatory model of water chemical treatment costs and the model should not be used to predict water treatment costs for raw water qualities significantly different from those experienced in the UVWMA during the period November 2004 – October 2006. In other words, the model is suitable for interpolation, but not extrapolation.

**Table 4.6:**  OLS Regression model for period November 2004 – October 2006, Zuikerbosch after omitting chlorophyll 665 and turbidity.

| | Unstandardised Coefficients | | Standardised Coefficients | | | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|
| Variables | B | Std. Error | Beta | t | Sig. | Tolerance | VIF |
| (Constant) | 458.987 | 176.496 | | 2.601 | 0.01*** | | |
| NO3 | 149.168 | 58.879 | 0.734 | 2.533 | 0.013** | 0.071 | 13.930 |
| $(NO3)^2$ | -145.327 | 85.953 | -0.444 | -1.691 | 0.095* | 0.087 | 11.433 |
| Total_alkalinity | -12.547 | 5.920 | -3.230 | -2.119 | 0.038** | 0.003 | 384.932 |
| $(Total\ alkalinity)^2$ | 0.104 | 0.051 | 3.106 | 2.021 | 0.048** | 0.003 | 391.672 |
| SO4 | 3.756 | 1.594 | 0.565 | 2.357 | 0.022** | 0.105 | 9.528 |
| $(SO4)^2$ | -0.207 | 0.074 | -0.708 | -2.781 | 0.007*** | 0.093 | 10.739 |
| EC | -3.626 | 1.889 | -0.169 | -1.919 | 0.059* | 0.777 | 1.287 |
| Real_chmcost$_{t-1}$ | 0.351 | 0.112 | 0.354 | 3.120 | 0.003*** | 0.469 | 2.134 |
| Df | 64 | | | | | | |
| R2 | 0.614 | | | | | | |
| Adj R2 | 0.566 | | | | | | |
| F value | 12.718*** | | | | | | |
| d statistic | 2.398 | | | | | | |
| h statistic | -1.700 | | | | | | |

Dependent Variable: Real_chm_cost$_t$

Where: ***, **, * indicate significance level at the 1%, 5%, and 10% probabilities respectively.

Predicted real water treatment costs estimated using the regression model presented in Table 4.6 are compared with actual real water treatment costs at Zuikerbosch for the study period.  The predicted costs are fairly similar to actual costs, suggesting that the model is useful as a predictor of water chemical treatment costs in the UVMWA for ranges of raw water quality similar to those experienced in the UVWMA during November 2004 – October 2006.  The model should not be used to predict real water chemical treatment costs elsewhere in the Vaal River system.
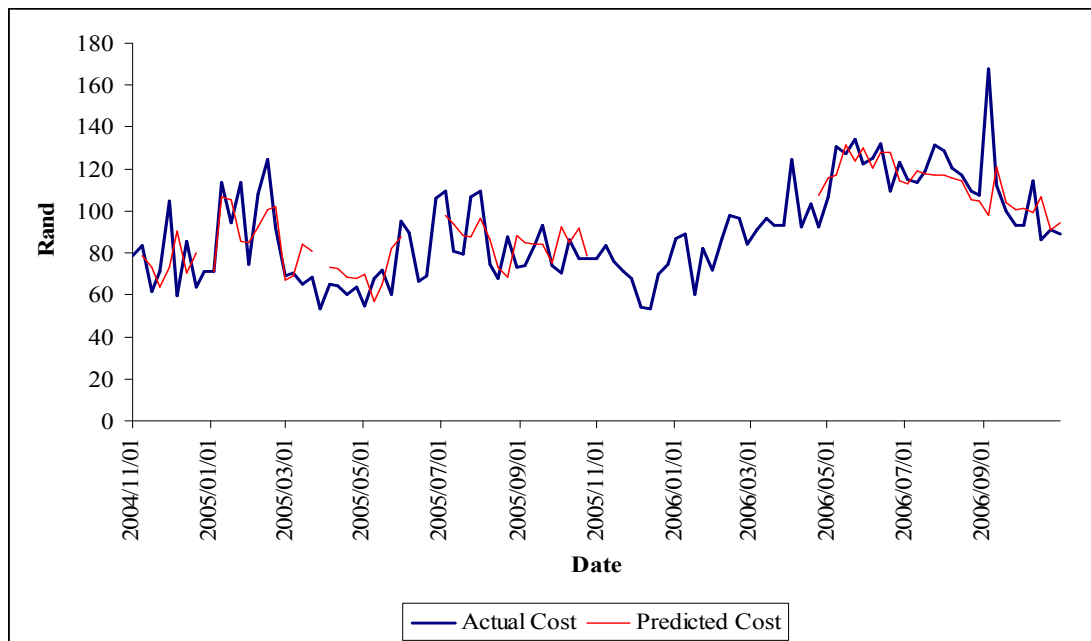


**Figure 4.1:**    The trend of Actual Cost versus Predicted Cost at Zuikerbosch, November 2004 – October 2006.

**4.5 Sensitivity Analysis Using Predictive Regression Model at Zuikerbosch**

A sensitivity analysis was conducted using the predictive regression model presented in Table 4.6. The average predicted chemical water treatment cost was computed from

the predictive regression equation and the actual mean loading of each water quality variables for the study period. The chemical water treatment cost was computed for 50 periods until the cost stabilized at R 96.25 per Mega litre. The sensitivity analysis was conducted in order to see the deviations from this cost if a 1% change in any of the water quality variables takes place by keeping the other water quality variables constant to their mean value. Using the predictive model, point elasticity and arc elasticity of chemical cost of water treatment have been computed. The point elasticity of treatment cost was computed using the following formula:

$$Ep = \frac{\delta Y}{\delta X} \times \frac{X}{Y} \quad \text{where, } Ep = \text{Point elasticity;}$$

$\delta Y$ = change in water treatment cost.

$\delta X$ = change in water quality variables

$X$ = value of water quality variables before increase;

$Y$ = predicted cost at period 50.

And the arc elasticity of chemical water treatment cost was computed as:

$$Ea = \frac{\Delta Y}{\Delta X} \times \left( \left( \frac{X_2 - X_1}{2} \right) / \left( \frac{Y_2 - Y_1}{2} \right) \right)$$

where, $Ea$ = Arc elasticity of cost

$\Delta Y$ = change in the predicted cost;

$\Delta X$ = change in the mean value of water quality variables;

$X_1$ = mean value of water quality variables before 1% increase.

$X_2$ = value of water quality variables after 1% increase

The results reported in Table 4.7 show the percentage change in predicted cost in response to a 1% increase in each of the original water quality variables of the predictive model, *ceteris paribus*. The change in predicted cost (d-c) for a 1% change in water quality variables were also presented in Table 4.7.

A 1% increase in $NO_3$ is predicted to increase chemical water treatment cost by less than 1% (0.297%) per mega litre, *ceteris paribus*. The partial adjustment regression model also predicted that an increase in TA (total alkalinity) by 1%, *ceteris paribus*, lowers chemical water treatment costs by about 0.223% per mega litre. The sensitivity analysis also shows that a 1% increase in EC (electrical conductivity) will lower chemical water treatment cost by 1.001% per mega litre, *ceteris paribus*.

**Table 4.7:** The change in the predicted chemical water treatment cost for a 1% change in WQ variables using Partial Adjustment regression model, Zuikerbosch.

| Variable | Before 1% increase (a) | After 1% increase (b) | Predicted cost at period 50 (c) | Resulting cost after increase (d) | Change in Predicted Cost (Rand/ML) (d-c) | Point Elasticity of Cost | Arc Elasticity of cost |
|---|---|---|---|---|---|---|---|
| NO3 (mg/l) | 0.299 | 0.302 | 96.25 | 96.53 | 0.285 | 0.296 | 0.297 |
| TA (mg/l) | 61.109 | 61.720 | 96.25 | 96.46 | 0.214 | 0.222 | 0.223 |
| EC (mg/l) | 17.078 | 17.249 | 96.25 | 95.29 | -0.954 | -0.991 | -1.001 |
| SO4 (mg/l) | 13.931 | 14.071 | 96.25 | 95.81 | -0.438 | -0.455 | -0.458 |

Similarly, a 1% increase in $SO_4$, *ceteris paribus*, is predicted to increase chemical water treatment cost by 0.458% per mega litre. The prediction suggests that total alkalinity is the main driver of chemical water treatment cost at Zuikerbosch and might be associated with the lime dosages required to treat water in the treatment plant.

# CHAPTER 5: RESULTS AND DISCUSSION FOR BALKFONTEIN

## 5.1 Principal Component Analysis: Balkfontein

A PCA based on the correlation matrix and using un-rotated factor solution was conducted on 15 of the 17 variables contained in Table 3.2. DOC and TDS were excluded from the analysis because of the relatively high number of missing values for these two variables. Principal Component Analysis (PCA) involves mathematical transformations that transform a large number of correlated variables into an uncorrelated smaller number of variables. PCA constructs artificial orthogonal variables from linear combinations of the original variables called Principal Components (Koutsoyiannis, 1988). It may be used as an exploratory tool of covariance between variables in a data set. Pieterse and van Vuuren (1997) applied PCA to investigate the associations among physical, chemical, and biological characteristics of the raw water in the Vaal River. This study follows similar method of PCA in investigating the relationships of raw WQ variables at Balkfontein.

Five factors were elicited by dropping successive Principal Components until sign of each estimated coefficients stabilised and accounting for over 85.75% of the variation contained in the original 15 variables; the PC loadings in (Table 5.1) were computed from the factor loadings (computed by the SPSS) dividing to the square root of their respective Eigen value. The first Principal Component accounts for 51.75% of the total variation in the water quality variables. Total hardness, calcium, chloride, magnesium, sulphate, and electrical conductivity (EC) have high component loadings in this component, colour and iron (Fe) have moderately high positive loading, which implies that loadings of these eight variables in raw water are highly correlated. In other words, when the raw water loading of total hardness is high (low), raw water

loadings of calcium and magnesium also tend to be high (low). Conversely, when the raw water loadings of calcium, chloride, magnesium, and sulphate are high (low), this tends to be reflected in EC. Pieterse and van Vuuren (1997) find a positive correlation among these ions and EC in the Vaal River at Balkfontein. The finding in this Principal Component also shows that colour and iron (Fe) have high positive correlation.

**Table 5.1:** Component Matrix for the water quality variables at Balkfontein.

|             | $PC_1$   | $PC_2$   | $PC_3$   | $PC_4$   | $PC_5$   |
|-------------|----------|----------|----------|----------|----------|
| T hard      | **0.331**| -0.081   | 0.222    | -0.016   | 0.069    |
| Ca          | **0.311**| -0.140   | 0.210    | -0.092   | 0.107    |
| Cl          | **0.270**| -0.128   | 0.236    | -0.196   | 0.226    |
| Mg          | **0.297**| 0.048    | 0.273    | -0.021   | 0.079    |
| SO4         | **0.284**| 0.209    | 0.239    | -0.225   | 0.120    |
| EC          | **0.278**| -0.159   | 0.129    | -0.078   | -0.137   |
| UVA         | -0.269   | 0.154    | 0.118    | -0.130   | **0.524**|
| Turb        | -0.310   | 0.092    | 0.173    | -0.151   | **0.326**|
| Colour      | **-0.309**| 0.160   | 0.178    | -0.147   | 0.278    |
| Chl a       | 0.077    | **0.531**| -0.150   | 0.356    | -0.065   |
| pH          | 0.204    | **0.476**| 0.043    | 0.120    | 0.176    |
| Temp        | -0.160   | **-0.470**| -0.147  | -0.127   | 0.159    |
| Al acid sol | -0.252   | -0.007   | **0.540**| 0.125    | -0.336   |
| Fe acid sol | -0.265   | 0.010    | **0.523**| 0.129    | -0.297   |
| Mn acid sol | 0.056    | -0.314   | 0.125    | **0.803**| 0.416    |
| **S Square**| **1.000**| **1.000**| **1.000**| **1.000**| **1.000**|
| **Eigen value**| **7.762**| **2.159**| **1.329**| **0.943**| **0.668**|
| **% Variance**| **51.75**| **14.40**| **8.86**| **6.29** | **4.45** |
| **Cumul %** | **51.75**| **66.14**| **75.00**| **81.29**| **85.75**|

$PC_2$ accounts for 14.4% of the variation in the original water quality variables. This component reflects that raw water levels of chlorophyll-a and pH are positively highly correlated, and negatively highly correlated with the level of water temperature. The positive correlation between chlorophyll-a and pH were as expected. According to

Pieterse and van Vuuren (1997), algal blooms reduce the carbon dioxide ($CO_2$) concentration in the raw water and this is associated with an increase in the pH level of the raw water. Low temperature is also associated with high oxygen concentration, and hence with maximum phytoplankton biomass – especially diatoms (Pieterse and van Vuuren, 1997). Therefore, temperature and chlorophyll-a are also expected to correlate negatively.

$PC_3$ accounts for 8.86% of the total variation in water quality and has high loadings for aluminium (Al) and iron (Fe). The strong positive correlation was as expected. $PC_4$ has a high positive loading for manganese only.

$PC_5$ accounts for 4.45% of the total variation in raw water quality and has high positive loadings for turbidity, colour, ultra-violet absorbance (UVA); a moderately high and low positive loadings for manganese (Mn) and colour respectively. This component reflects that at times when turbidity was high, colour and UVA were also high.

## 5.2 The Explanatory Model: Balkfontein Water Treatment Plant

The estimated OLS regression model in which water chemical treatment costs were regressed on the PCs elicited is presented in Table 5.2 (Jolliffe, 2002). The estimated regression coefficient for PC4 was not statistically different from zero and was therefore omitted from the model. The model accounted for 34.7% of variation in water chemical treatment costs and is statistically significant, as indicated by the adjusted $R^2$ statistic of 30.5% and the F-statistic of approximately 8.379. The d

statistic for the model (1.653) is inconclusive whether autocorrelation is present or not. The VIF values are all close to 1 (i.e., there is no collinearity between the explanatory variables) because the elicited PCs are orthogonal.

**Table 5.2:** Estimated OLS regression model of water chemical costs per ML at Balkfontein using Principal Components as explanatory variables, 2004 – 2006.

| Coefficients | Unstandardized Coefficients | | Standardized Coefficients | | | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | t | Sig. | Tolerance | VIF |
| Constant | 127.253 | 2.527 | | 50.358 | 0.000 | | |
| $PC_1$ | -12.006 | 2.740 | -0.400 | -4.382 | 0.000 | 0.990 | 1.010 |
| $PC_2$ | -7.416 | 2.510 | -0.269 | -2.955 | 0.004 | 0.999 | 1.001 |
| $PC_3$ | -6.009 | 2.599 | -0.211 | -2.312 | 0.023 | 0.993 | 1.007 |
| $PC_4$ | -3.184 | 2.545 | -0.114 | -1.251 | 0.214 | 0.997 | 1.003 |
| $PC_5$ | 6.305 | 2.535 | 0.226 | 2.487 | 0.015 | 0.999 | 1.001 |
| Df | 79 | | | | | | |
| R Square | 0.347 | | | | | | |
| Adj R Square | 0.305 | | | | | | |
| F Value | 8.379 | | | | | | |
| d Statistics | 1.653 | | | | | | |

Dependent Variable: Weekly cost/ML/week

Where: ***, **, * indicate significance at the 1%, 5%, and 10% levels of probability respectively.

The relative magnitude of the standardised Beta coefficient for $PC_1$ indicates that from a statistical perspective it is the most important explanatory variable in the estimated model. The estimated regression coefficient for $PC_1$ is statistically different to zero at the 1% level of probability. The estimated relationship between chemical water treatment costs and $PC_1$ shows that there is a negative relationship between the raw water total hardness, Ca, Mg, Cl, $SO_4$ and water chemical treatment costs. This result suggests that the combined increase in these variables lowers chemical water treatment cost. It is expected that an increase in raw water hardness will reduce the

dose of lime required to treat water. However, an increase in colour of the raw water treated at Balkfontein is positively related to the chemical costs of water treatment. The positive relationship between colour and chemical water treatment cost is expected.

The estimated coefficient for $PC_2$ (the second most important determinant of real water chemical treatment costs) is also statistically significant at the 1% level of probability. The responsible variables in this component with the highest loadings are chlorophyll a, pH, and raw water temperature. The estimated relationship between water chemical treatment cost and $PC_2$ shows that there is a positive relationship between the raw water temperature and water chemical treatment cost. However, increases in the level of chlorophyll and pH in raw water treated at Balkfontein are negatively related to the chemical costs of water treatment. This negative relationship is unexpected, but may be associated with the positive correlation between chlorophyll-a and pH. As the level of chlorophyll-a increases so does the raw water pH, and hence chemical water treatment cost at Balkfontein was decreasing. Increased levels of chlorophyll also facilitate the flocculation process in water treatment, consequently reducing the chemical cost of treating water. This result is consistent with expectations because as pH rises, less lime is added to raw water during water treatment. This result is consistent with the findings of Graham *et al*. (1998) and Dennison and Lyne (1997).

$PC_5$ is the third most important determinant of water chemical treatment cost. The estimated coefficient shows that increases in raw water turbidity, colour, and Ultra-Violet Absorbance (UVA) are associated with higher water chemical treatment costs.

**5.3 Standardised and Unstandardised Regression Models: Balkfontein Water Treatment Plant**

The standardised regression coefficients computed for Balkfontein plant from the PCs show that most of the chemical (hardness, Ca, Mg, SO4), physical (turbidity and conductivity), and biological (chlorophyll-a) characteristics of water quality do greatly impact on the chemical costs of water treatment. Water quality variables that have greater impact on the chemical cost of treating water have greater coefficients (Table 5.3).

**Table 5.3:** Standardised regression coefficients estimated for water quality variables from the PCs elicited for Balkfontein Water Treatment Plant.

| Water Quality Variables | Standardised($\beta_i$) | Var ($\beta i$) | t-values |
|---|---|---|---|
| T hard | -4.229 | 1.230 | -3.812 *** |
| Ca | -2.991 | 1.276 | -2.648 *** |
| Cl | -1.661 | 1.603 | -1.312 |
| Mg | -4.987 | 1.220 | -4.515 *** |
| SO4 | -4.924 | 1.688 | -3.790 *** |
| EC | -3.554 | 1.014 | -3.529 *** |
| UVA | 5.097 | 2.662 | 3.124 *** |
| Turb | 4.534 | 1.810 | 3.370 *** |
| Colour | 3.679 | 1.731 | 2.796 *** |
| Chl a | -5.511 | 2.820 | -3.282 *** |
| pH | -5.512 | 2.045 | -3.855 *** |
| Temp | 7.708 | 2.000 | 5.450 *** |
| Al acid sol | -2.687 | 3.277 | -1.485 |
| Fe acid sol | -2.324 | 3.051 | -1.330 |
| Mn acid sol | 0.975 | 6.038 | 0.397 |
| df | 80 | | |
| $R^2$ | 0.347 | | |
| d statistic | 1.653 | | |

**Table 5.4:**    Unstandardised coefficients estimated for water quality variables from the standardised coefficients: Balkfontein.

| Variable | Unstandardised($\beta i$) | t-values |
|---|---|---|
| Constant | -0.765 | |
| T hard | -1.742 | -3.812 *** |
| Ca | -5.230 | -2.648 *** |
| Cl | -1.568 | -1.312 |
| Mg | -15.639 | -4.515 *** |
| SO4 | -2.350 | -3.790 *** |
| EC | -3.925 | -3.529 *** |
| UVA | 32.257 | 3.124 *** |
| Turb | 3.891 | 3.370 *** |
| Colour | 0.325 | 2.796 *** |
| Chl a | -3.521 | -3.282 *** |
| pH | -271.033 | -3.855 *** |
| Temp | 45.202 | 5.450 *** |
| Al acid sol | -59.478 | -1.485 |
| Fe acid sol | -10.883 | -1.330 |
| Mn acid sol | 288.984 | 0.397 |
| df | 80 | |
| $R^2$ | 0.347 | |
| d statistic | 1.653 | |

Dependent variable: Chemical cost of water treatment.

The results of the standardised regression model for Balkfontein plant were consistent with the interpretation of the results in Table 5.2 except for the coefficient estimated for chloride (Cl) which turns to be not significant in Table 5.4. Chemical cost of water treatment is inversely related to total hardness, calcium, magnesium, sulphate, conductivity, pH and chlorophyll-a. On the other hand, cost is positively related to turbidity, UVA and temperature.

**5.4 Predictive Model using PA Regression: Balkfontein**

The partial adjustment model specified in equation (5.1) was estimated to find a better predictive model for water treatment chemical costs at Balkfontein. In other words, the objective was to find a model with a higher $R^2$ statistic than the model presented in Table 5.1. All of the water quality variables reported in Table 3.1, and various

transformations thereof, were considered in the partial adjustment model. Equation (5.1) includes only variables retained in the model after dropping variables to remedy problems of multicollinearity whilst maximising the adjusted $R^2$ statistic.

The algebraic model for Balkfontein water treatment plant is as follows:

$$(Real\ chm\ cost)_t = B_0 + B_1\ (Chl\text{-}a)_t + B_2\ (Turb)_t + B_3\ (Colour)_t + B_4\ (Temp)_t + B_5$$
$$(Cl)_t + B_6\ (Ca)_t + B_7\ (Fe)_t + B_8\ (Mn)_t + B_9\ (Thard)_t + B_{10}\ (Ca^2)_t$$
$$+ B_{11}\ (Mn^2)_t + B_{12}\ (Cl^2)_t + B_{13}\ (Real\ chm\ cost)_{t-1}$$
$$(5.1)$$

Where: $(Chl\text{-}a)_t$ = Chlorophyll-a (ug/l)

$(Turb)_t$ = Turbidity (NTU: Nephelometric Turbidity Units)

$(Colour)_t$ = Colour (Pt-co: Platinum Cobalt Standard)

$(Temp)_t$ = Temperature (degree Celsius)

$(Cl)_t$ = Chloride (mg/l)

$(Ca)_t$ = Calcium (mg/l)

$(Fe)_t$ = Iron (ug/l)

$(Mn)_t$ = Manganese (ug/l)

$(Thard)_t$ = Total hardness (mg/l)

$(Real\ chm\ cost)_{t-1}$ = Real water treatment cost lagged by one week(R)

The partial adjustment regression model is presented in Table 5.5. The $R^2$ statistic of this model was 0.599. Findings show that real water chemical treatment costs at Balkfontein can be predicted from nine water quality variables, namely calcium,

chlorophyll-a, chloride, colour, iron, manganese, total hardness, temperature, turbidity, and previous period (week) cost.  Nonetheless, the model is not suitable as an explanatory model of water chemical treatment costs and should not be used to predict water treatment costs for raw water qualities significantly different to those experienced in the MVWMA during the year 2004 – 2006.  In other words, the model is suitable for interpolation, but not extrapolation.

**Table 5.5:** Regression coefficients estimated for contaminants: Balkfontein water treatment plant for the years 2004 – 2006.

| Variables | Unstandardized Coefficients | | Standardized Coefficients | | | Collinearity Statistics | |
| | B | Std. Error | Beta | t | Sig. | Tolerance | VIF |
|---|---|---|---|---|---|---|---|
| Constant | 102.150 | 48.587 | | 2.102** | 0.039 | | |
| Ca | -4.075 | 1.667 | -2.314 | -2.444** | 0.017 | 0.006 | 165.438 |
| $(Ca)^2$ | 0.025 | 0.012 | 1.635 | 2.025** | 0.046 | 0.008 | 120.384 |
| Chl a | 0.143 | 0.069 | 0.209 | 2.079** | 0.041 | 0.534 | 1.872 |
| Cl | 0.554 | 0.374 | 0.617 | 1.478 | 0.144 | 0.031 | 32.165 |
| $(Cl)^2$ | -0.002 | 0.001 | -0.450 | -1.400 | 0.166 | 0.053 | 19.043 |
| Colour | -0.135 | 0.037 | -1.028 | -3.686*** | 0.000 | 0.070 | 14.373 |
| Fe acid sol | 5.581 | 3.824 | 0.186 | 1.459 | 0.149 | 0.334 | 2.995 |
| Mn acid sol | -161.664 | 61.247 | -0.577 | -2.640*** | 0.010 | 0.113 | 8.830 |
| $(Mn)^2$ | 234.586 | 104.214 | 0.440 | 2.251** | 0.027 | 0.142 | 7.048 |
| T hard | 0.141 | 0.104 | 0.343 | 1.356 | 0.179 | 0.085 | 11.789 |
| Temp | 1.922 | 0.568 | 0.350 | 3.382*** | 0.001 | 0.505 | 1.980 |
| Turb | 0.526 | 0.282 | 0.494 | 1.864* | 0.066 | 0.077 | 12.966 |
| (Real chm cost) $_{t-1}$ | 0.784 | 0.109 | 0.712 | 7.158*** | 0.000 | 0.548 | 1.825 |
| df | 74 | | | | | | |
| $R^2$ | 0.599 | | | | | | |
| Adj $R^2$ | 0.529 | | | | | | |
| F-value | 7.908*** | | | | | | |
| d statistic | 2.179 | | | | | | |
| h statistic | -7.660 | | | | | | |

Dependent Variable: Real chm cost $_t$ /ML

Where: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels of probability respectively.

Predicted real water treatment costs estimated using the regression model presented in Table 5.5 are compared with actual real water treatment costs at Balkfontein for the study period. The predicted costs are fairly similar to actual costs, suggesting that the model is useful as a predictor of water chemical treatment costs in the MVMWA for ranges of raw water quality similar to those experienced in the MVWMA during 2004 – 2006. The model should not be used to predict real water chemical treatment costs elsewhere in the Vaal River system.
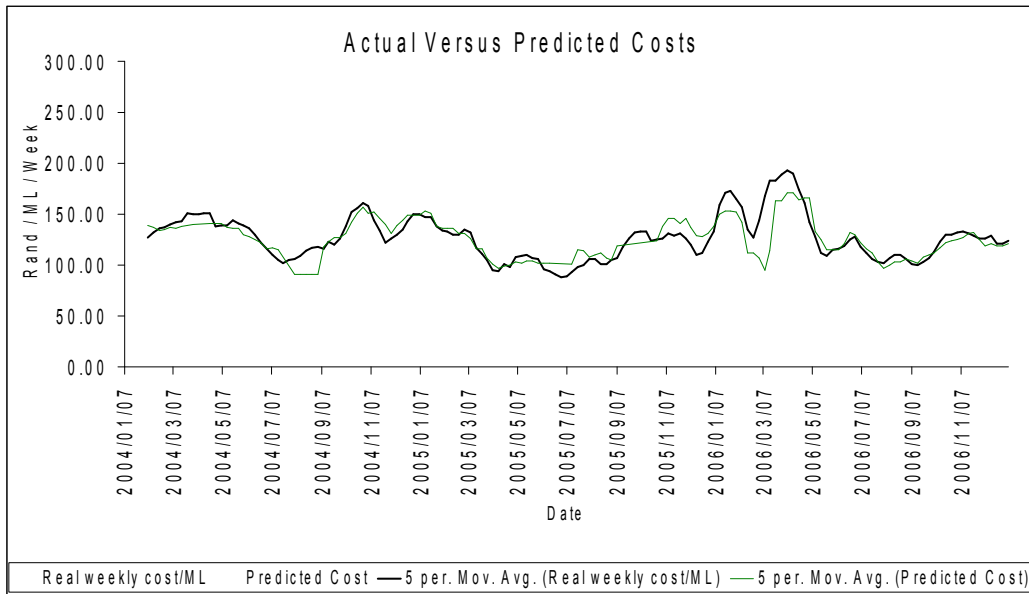
**Figure 5.1:** Actual real water treatment cost versus predicted chemical water treatment cost at Balkfontein for the period 2004 – 2006.

**5.5 Sensitivity Analysis Using the Estimated Predictive Regression Model**

A sensitivity analysis was conducted using the partial adjustment regression model presented in Table 5.5. The average predicted chemical water treatment cost was computed from the predictive regression equation and the actual mean loading of each water quality variables over the study period. The chemical water treatment cost was computed for 300 periods until the cost stabilized at R 90.74 per Mega litre. Similar method to Zuikerbosch were used to compute the elasticity of cost for Balkfontein. The results reported in Table 5.6 show how predicted cost changes in response to a 1% increase in each of the original water quality variables, *ceteris paribus*.

A 1% increase in temperature is predicted to increase cost by 1.886% per mega litre, *ceteris paribus*. The partial adjustment regression model also predicted that an

73

increase in total hardness in the raw water treated at Balkfontein by 1%, *ceteris paribus*, will increase chemical water treatment costs by 1.922% per mega litre. The sensitivity analysis also shows that a 1% increase in chlorophyll a will increase cost by only 0.346% per mega litre, *ceteris paribus*. Similarly, a 1% increase in Ca, *ceteris paribus*, is predicted to decrease chemical water treatment cost by 3.09% per mega litre. A 1% increase in turbidity is also predicted to increase chemical water treatment cost by 2.77% per mega litre. The prediction suggests that calcium is the main driver of chemical water treatment costs at Balkfontein. This could be due to the fact that the presence of more calcium in raw water treated in Balkfontein would reduce the amount of lime used by Balkfontein and the associated cost.

**Table 5.6:** The change in chemical water treatment cost for a 1% change in WQ variables using partial adjustment regression model, Balkfontein.

| Explanatory Variables | Before 1% increase (a) | After 1% increase (b) | Predicted cost at period 300 (c) | Resulting cost after increase (d) | Change in Predicted Cost (Rand/ML) (d-c) | Point Elasticity of Cost | Arc Elasticity of cost |
|---|---|---|---|---|---|---|---|
| Colour | 259.141 | 261.732 | 90.74767 | 89.12804 | -1.620 | -1.785 | -1.810 |
| Temp | 19.317 | 19.510 | 90.74767 | 92.46654 | 1.719 | 1.894 | 1.886 |
| Cl | 70.819 | 71.527 | 90.74767 | 91.63064 | 0.883 | 0.973 | 0.973 |
| Chl a | 47.237 | 47.710 | 90.74767 | 91.06040 | 0.313 | 0.345 | 0.346 |
| Turb | 20.006 | 20.206 | 90.74767 | 92.64276 | 1.895 | 2.088 | 2.077 |
| Ca | 62.063 | 62.683 | 90.74767 | 87.99980 | -2.748 | -3.028 | -3.090 |
| Fe | 0.439 | 0.443 | 90.74767 | 90.86104 | 0.113 | 0.125 | 0.125 |
| Thard | 268.445 | 271.129 | 90.74767 | 92.50002 | 1.752 | 1.931 | 1.922 |
| Mn | 0.109 | 0.110 | 90.74767 | 90.19054 | -0.557 | -0.614 | -0.619 |

# CHAPTER 6:     CONCLUSIONS

The study predicted chemical water treatment cost at Zuikerbosch and Balkfontein from the observed level of raw water quality variables. The predictive models estimated for Balkfontein and Zuikerbosch presented in Table 4.6 and 5.5 have $R^2$ statistics of 61.4 and 59.9% respectively. The chemical cost of water treatment for Zuikerbosch and Balkfontein are predicted at R 96.25 and R90.74 per megalitre per day respectively. The sensitivity of these predicted costs as a result of a 1% increase in the water quality variables has been also illustrated the magnitude by which these predicted costs deviate. At Zuikerbosch, an increase of1% per megalitre per day in nitrate, *ceteris paribus,* is predicted to increase real water chemical treatment costs by less than 0.3% per mega litre. An increase of 1% per megalitrre per day in total alkalinity loading in raw water is predicted to decrease real water chemical treatment cost by 0.223% per mega litre, *ceteris paribus*.

Chemical water treatment cost at Balkfontein is predicted to decrease by more than 3% per megalitre per day for a 1% per megalitre per day increase in the raw water loading of calcium, *ceteris paribus*. A 1% per megalitre per day rise in water temperature, *ceteris paribus*, is predicted to increase chemical water treatment cost by1.886%. At Balkfontein, chemical water treatment cost is expected to increase on average by 0.346% per megalitre per day for a 1% per megalitre increase in the level of chlorophyll-a, and 2.077% per megalitre per day for a 1% increase per megalitre per day in turbidity.

This study concluded that, if raw water nitrate in UVWMA increases by 1% per megalitre a day *ceteris paribus*, chemical water treatment cost at Zuikerbosch is predicted to increase by (R 0.285*1998ML*365 days) R207,841.95 per annum – provided that Zuikerbosch treats water at a daily average of 1998 mega litres per day. Likewise, if Zuikerbosch operates at its daily average capacity and is able to keep the optimum level of total alkalinity in UVWMA (thereby reducing the need for lime dosages to treat water), the estimated saving on chemical water treatment cost could be in the region of R156,063.78 per annum. The predictive partial adjustment regression model demonstrates that the relationship between chemical water treatment cost and total alkalinity as well as sulphate ($SO_4$) are more quadratic than linear.

Likewise, at Balkfontein total hardness, calcium, and turbidity are the main drivers of chemical cost of water treatment. An increase in 1% of raw water turbidity at Balkfontein could raise chemical water treatment cost by (R 1.895*360ML*365days) R 249,003 per annum. – Provided that Balkfontein treats water at its full capacity (i.e., 360 mega litres per day). In the same way, the increase in the level of calcium content in raw water by 1% could save Balkfontein R 361,087 per annum.

This study has investigated the collinearity between the water quality variables at Zuikerbosch and Balkfontein water treatment plants. Important relationships between the water quality variables and their implications for chemical water treatment cost were investigated for these two treatment plants using PCA. At both Balkfontein and Zuikerbosch, an increase in chlorophyll in raw water was accompanied by an increase in raw water pH level. The chemical and biological nature of water quality variables contributed to their interrelation to one another.

The explanatory model estimated for the Balkfontein station explains 34.7% of the chemical water treatment cost, while the model estimated for the Zuikerbosch treatment plant explains 50.2% of the variation in chemical water treatment cost. Although the models' explanatory power is limited, this study has attempted to explain the variation in chemical water treatment cost.

The explanatory model fitted for Balkfontein explained the combined effects of chlorophyll-a, pH, and temperature and the combined effects of total hardness, calcium, magnesium, chloride, sulphate, colour, and conductivity were the main drivers of chemical water treatment cost at Balkfontein. As pH increased, chemical water treatment cost fell. An increase in total hardness was also found to reduce chemical water treatment cost at Balkfontein. This result found from the explanatory model is inline with the results obtained from the predictive model. Moreover, less lime was used during the treatment process at Balkfontein. The combined increases in raw water turbidity, colour, and Ultra-Violet Absorbance (UVA) are also associated with higher water chemical treatment costs at Balkfontein.

At Zuikerbosch, the main drivers of chemical water treatment cost were both the combined effect of the levels of chlorophyll, pH, and nitrate loadings in raw water and the combined effect of water hardness, calcium, magnesium, and sodium (Na). The variability in chemical water treatment cost at Zuikerbosch was mainly due to the reduction in nitrate loadings as a source of food for insuring the growth of the relatively lower population of algae (indicated by low levels of chlorophyll 665) over the study period. Alternatively, the variability on water hardness could also be the

cause for the variation in chemical water treatment cost. An increase in total hardness was found to reduce the chemical water treatment cost, as a result of less lime being used during water treatment at Zuikerbosch. At times when the raw water pH level in the UVWMA increased, chemical water treatment cost decreased. Zuikerbosch plant was using less lime during the treatment process for the same reason.

Therefore, this study concludes that the variation in chemical water treatment cost at both Zuikerbosch and Balkfontein was largely associated with the cost of lime dosage over the study period. Lime comprises 25% of the total chemical cost composition at Zuikerbosch and 16% of the total chemical cost composition at Balkfontein.

Future research might focus on predicting the total cost of water treatment by including all the relevant observed costs of water treatment plants, such as energy costs, labour costs, and research and development costs, which were not available for this research. Treatment plants also need to improve their data recording practices on all the relevant variables of water quality and cost data in order to obtain workable, good quality raw data.

# SUMMARY

This study investigates the relationship between raw water quality and the chemical costs of treating water in both the UVWMA at the Zuikerbosch Water Treatment Plant and the MVWMA at the Balkfontein Water Treatment Plant. The primary objective of this study is to investigate the extent to which the chemical costs of treating water to comply with stringent potable water quality standards, can be predicted for the MVWMA and UVWMA from raw water quality data. A second objective of this study is to compare raw water quality and chemical water treatment costs in the UVWMA with results obtained for the MVWMA.

Eutrophication is often a result of water pollution from domestic, industrial and agricultural activities that augment the naturally occurring nutrient levels of a water body. In a market economy, the decisions of households and industries are based only on the expected private economic costs and benefits of their options. Reduced water quality due to eutrophication can increase the cost per unit of production for water-users such as industries that use raw water for production processes, and agencies and municipalities that provide potable water for domestic use; hence, reduced water quality is a negative externality of pollution.

Water treatment costs are incurred by water treatment plants in complying with compulsory national standards for the quality of potable water (Pretty *et al.,* 2002). In South Africa, these standards are prescribed in the Regulations to the Water Services Act. Water treatment plants incur both capital and operating costs for water treatment.

The cost of chemicals used to treat drinking water is a major component of the operating costs of water treatment plants.

This study used a partial adjustment regression model as a predictive model. A partial adjustment regression model includes stochastic variable $Y_{t-1}$. The partial adjustment model is inappropriate for explaining changes in water chemical treatment costs, but can capture the trends relevant in water quality characteristics that are not otherwise included in the model. The inclusion of a stochastic explanatory variable such as $Y_{t-1}$ is most likely to pose a collinearity problem. The approach used to address this problem of multicollinearity amongst water quality variables in this study is firstly to use PCA in an exploratory analysis as a tool of covariance between variables in a data set.

Explanatory models for both treatment plants were estimated using the component scores of the PCs elicited for each treatment plant. Standardised regression coefficients were computed from the PCs for both Zuikerbosch and Balkfontein to identify their relative influence on the chemical cost of water treatment. These standardised coefficients were then changed into unstandardised regression coefficients by multiplying by Sy / Sx (the ratio of the standard deviation of the dependent variable to the independent variable).

The data used in this study were provided by Rand Water and Sedibeng Water. The principal use of water from the Vaal River system is for domestic and industrial purposes. The average real water treatment cost at Zuikerbosch over the study period was R89.99 per mega litre but the average chemical water treatment cost for

Balkfontein was R126.31 per mega litre. The level of chlorophyll 665 for Zuikerbosch ranged from 0.97 ug/l to 12.64ug/l. On the other hand, Balkfontein water treatment station in the MVWMA experienced levels of chlorophyll-a from 5.755 ug/l to 267.8 ug/l, indicating that water eutrophication is a relatively smaller problem in the UVWMA compared to the MVWMA.

Findings show that real water chemical treatment costs at Balkfontein can be predicted from nine water quality variables, namely calcium, chlorophyll-a, chloride, colour, iron, manganese, total hardness, temperature, turbidity, and previous period (week) cost. At Zuikerbosch, chemical water treatment cost can be predicted from four water quality variables, namely nitrate, total alkalinity, electrical conductivity, sulphate, and previous period (week) cost.

The predictive models estimated for Balkfontein and Zuikerbosch presented in Table 4.6 and 5.5 have $R^2$ statistics of 61.4 and 59.9% respectively. The chemical cost of water treatment for Zuikerbosch and Balkfontein are predicted at R 96.25 and R90.74 per megalitre per day respectively. The sensitivity of these predicted costs as a result of a 1% increase in the water quality variables has been also illustrated the magnitude by which these predicted costs deviate. A sensitivity analysis was conducted using the predictive regression model presented in Table 4.2.

A 1% increase in $NO_3$ is predicted to increase chemical water treatment cost by less than 1% (0.297%) per mega litre, *ceteris paribus*. The partial adjustment regression model also predicted that an increase in TA (total alkalinity) by 1%, *ceteris paribus*, lowers chemical water treatment costs by about 0.223% per mega litre. The sensitivity

analysis also shows that a 1% increase in EC (electrical conductivity) will lower chemical water treatment cost by 1.001% per mega litre, *ceteris paribus*. In comparison, a 1% increase in temperature is predicted to increase cost by 1.886% per mega litre, *ceteris paribus*. The partial adjustment regression model also predicted that an increase in total hardness in the raw water treated at Balkfontein by 1%, *ceteris paribus*, will increase chemical water treatment costs by 1.922% per mega litre.

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# APPENDICES

## APPENDIX I : EUTROPHICATION IN THE VAAL RIVER SYSTEM

| | System | Level of problem | Type of problem | Principal cause | Action implemented |
|---|---|---|---|---|---|
| **Upper Vaal** | Vaal river at Parys | Persistently moderate | Algae and hyacinth | Sewage discharges and defuse pollution from agriculture | Special phosphate level of 1 mg/l |
| | Vaal river at Potchefstroom | Persistently moderate | Algae and hyacinth | Sewage discharges and defuse pollution from agriculture | Special phosphate level of 1 mg/l |
| | Klein Blesbokspruit | Low problem | Algae | Sewage discharge | Special phosphate level of 1 mg/l |
| | Blesbokspruit | Low problem | Weeds | Agricultural practice | Special phosphate level of 1 mg/l |
| | Vaal river at inflow from Bophelong | Persistently severe | Algae, hyacinth | Storm water from Bophelong | |
| | Upper Klip river | Persistently severe | Algae, weeds | Sewage discharge | Special phosphate level of 1 mg/l |
| | Rietspruit | Persistently severe | Algae, weeds | Sewage discharge | Special phosphate level of 1 mg/l |
| | Bocksburg lake | Persistently severe | Algae, water chemistry | Sewage discharge | Sample for phosphate |
| | Vaal river at Villiers | Infrequently severe | Algae, water chemistry | Sewage discharge | Special phosphate level of 1 mg/l |
| | Vaal Dam | Infrequently severe(low to moderate) | Blue green algae | Agriculture and sewage discharge | Report of spillage to DWAF, Assist with management of wastewater treatment works |
| **Middle Vaal** | Vaal river Barrage | Persistent severe (moderate to high) | All algae And macrophytes | Sewage discharge and informal settlements, high intensity farming | Physical removal of invader plants; Baley straw; reporting of spillage to DWAF; Assist with the management of wastewater treatment works |
| | Golf courses and urban impoundments | Persistent severe (moderately to high) | Algae and macrophytes | Sewage discharge and informal settlements, general run-off, contaminated ground water | |
| | Rivers including Klip River, Blesbokspruit | Persistent severe (moderately to high) | Macrophytes | Sewage discharges and informal settlements; high intensity farming | |
| **Lower Vaal** | Harts River | Seasonal moderate | Algae and water chemistry | Sewage discharges, surface run-off, irrigation backflows | |
| | Spitskop Dam | Moderate to extreme | Algae and water chemistry | Sewage discharges, surface run-off, irrigation backflows | Not yet in place as the Dam is not extensively used in the in the area |
| | Lower Vaal River | Low to moderately | Algae, water chemistry | Upstream pollution | |

Source: Walmsley (2005)

# APPENDIX II: BALKFONTEIN DATA FOR THE YEARS 2004 - 2006

| Date | Cost | Lag-cost | Al | Ca | Chla | Cl | Colour | DOC | EC | Fe | Mg | Mn | pH | SO4 | Thard | TDS | Temp | Turb | UVA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04/01/07 | 118.85 | -1.00 | 0.41 | 86.78 | 20.41 | 103.62 | 131.80 | 5.68 | 102.30 | 0.36 | 33.94 | 0.15 | 8.13 | 133.72 | 348.60 | 698.00 | 24.76 | 10.76 | 13.28 |
| 04/01/14 | 127.39 | 118.85 | 0.18 | 79.30 | 14.90 | 94.74 | 83.40 | 5.31 | 97.76 | 0.13 | 33.48 | 0.08 | 8.10 | 127.88 | 376.16 | 722.00 | 25.62 | 7.06 | 14.65 |
| 04/01/21 | 137.18 | 127.39 | 0.34 | 79.32 | 23.33 | 92.70 | 134.20 | 7.34 | 101.28 | 0.22 | 33.46 | 0.19 | 7.81 | 133.94 | 336.16 | -1.00 | 23.57 | 11.84 | 14.51 |
| 04/01/28 | 127.37 | 137.18 | 0.30 | 81.38 | 25.91 | 100.08 | 141.50 | 8.87 | 102.78 | 0.35 | 35.13 | 0.19 | 7.95 | 134.48 | 255.80 | -1.00 | 24.52 | 10.80 | 15.60 |
| 04/02/04 | 124.83 | 127.37 | 0.84 | 81.88 | 23.39 | 84.14 | 114.60 | 6.96 | 94.42 | 0.18 | 34.38 | 0.16 | 7.59 | 137.90 | 344.32 | -1.00 | 24.92 | 9.47 | 13.58 |
| 04/02/11 | 142.64 | 124.83 | 0.13 | 81.48 | 15.70 | 88.64 | 107.80 | 7.33 | 95.30 | 0.18 | 31.55 | 0.21 | 7.57 | 136.16 | 334.36 | -1.00 | 24.08 | 9.53 | 13.84 |
| 04/02/18 | 149.02 | 142.64 | 0.19 | 77.08 | 23.07 | 83.00 | 141.25 | -1.00 | 90.03 | 0.26 | 31.38 | 0.25 | 7.64 | 126.70 | 321.85 | 574.00 | 23.63 | 12.02 | 13.15 |
| 04/02/25 | 139.60 | 149.02 | 0.29 | 61.50 | 33.53 | 64.35 | 181.75 | -1.00 | 73.90 | 0.40 | 27.70 | 0.20 | 7.83 | 115.18 | 258.60 | 524.00 | 23.38 | 14.60 | 12.93 |
| 04/03/03 | 142.68 | 139.60 | 0.28 | 59.00 | 64.19 | 59.17 | 157.00 | -1.00 | 63.60 | 0.34 | 22.57 | 0.15 | 7.97 | 114.13 | 240.60 | -1.00 | 23.63 | 16.00 | 12.94 |
| 04/03/10 | 136.64 | 142.68 | 0.38 | 57.35 | 84.50 | 72.18 | 195.40 | -1.00 | 70.54 | -1.00 | 29.55 | -1.00 | 8.24 | 123.04 | 267.52 | -1.00 | 22.98 | 16.62 | 12.69 |
| 04/03/17 | 145.58 | 136.64 | 0.75 | -1.00 | 81.61 | 58.08 | 249.80 | -1.00 | 63.50 | 0.56 | -1.00 | 0.11 | 8.08 | 110.66 | 241.04 | -1.00 | 22.20 | 20.62 | 18.91 |
| 04/03/24 | 190.57 | 145.58 | 1.49 | -1.00 | 79.10 | 63.27 | 421.33 | -1.00 | 69.47 | 1.38 | -1.00 | 0.16 | 8.11 | 66.97 | 220.13 | -1.00 | 22.37 | 38.17 | 19.88 |
| 04/03/31 | 133.61 | 190.57 | 0.77 | -1.00 | 81.01 | 56.55 | 326.75 | -1.00 | 59.65 | 0.65 | -1.00 | 0.16 | 8.47 | 124.28 | 265.85 | -1.00 | 22.78 | 28.20 | 19.80 |
| 04/04/07 | 143.22 | 133.61 | 0.88 | -1.00 | 68.79 | 53.26 | 368.86 | 7.12 | 66.54 | 0.99 | -1.00 | 0.17 | 8.54 | 108.48 | 188.08 | -1.00 | 22.70 | 63.68 | 19.60 |
| 04/04/14 | 140.97 | 143.22 | 0.36 | -1.00 | 69.11 | 68.50 | 193.31 | 7.86 | 65.47 | 0.71 | -1.00 | 0.12 | 8.57 | 111.72 | 240.16 | -1.00 | 21.20 | 63.04 | 13.16 |
| 04/04/21 | 144.73 | 140.97 | 0.40 | 58.40 | 61.91 | 57.16 | 255.40 | 8.20 | 65.16 | 0.17 | 25.40 | 0.64 | 8.40 | 126.10 | 272.20 | -1.00 | 19.88 | 20.10 | 18.55 |
| 04/04/28 | 129.55 | 144.73 | -1.00 | -1.00 | 46.62 | 62.45 | 207.75 | -1.00 | 68.03 | -1.00 | -1.00 | 0.21 | 8.34 | 123.55 | 268.95 | -1.00 | 20.33 | 16.83 | 17.17 |
| 04/05/05 | 136.35 | 129.55 | -1.00 | -1.00 | 37.94 | 75.93 | 169.40 | 7.32 | 80.32 | 0.53 | 30.10 | 0.12 | 8.44 | 122.50 | 241.68 | -1.00 | 19.92 | 14.04 | 15.84 |
| 04/05/12 | 145.81 | 136.35 | -1.00 | 49.22 | 36.08 | 57.76 | 181.80 | 6.31 | 66.72 | 0.38 | 24.44 | 0.15 | 8.15 | 124.72 | 223.88 | -1.00 | 18.54 | 13.15 | 15.84 |
| 04/05/19 | 161.43 | 145.81 | 0.58 | 61.35 | 35.19 | 62.24 | 169.40 | 6.06 | 81.12 | 0.57 | 27.45 | 0.13 | 8.28 | 122.06 | 266.24 | -1.00 | 17.08 | 14.06 | 16.14 |
| 04/05/26 | 129.51 | 161.43 | 0.42 | 66.48 | 39.58 | 61.02 | 170.40 | 5.86 | 74.42 | 0.53 | 31.26 | 0.14 | 8.35 | 125.80 | 295.12 | -1.00 | 15.48 | 14.64 | 14.18 |
| 04/06/02 | 121.85 | 129.51 | -1.00 | 68.96 | 47.33 | 68.16 | 210.00 | 5.65 | 77.58 | 0.44 | 33.56 | 0.13 | 8.55 | 133.54 | 310.12 | -1.00 | 15.32 | 12.06 | 14.44 |
| 04/06/09 | 122.53 | 121.85 | 0.23 | 68.78 | 45.00 | 71.18 | 150.75 | 5.88 | 84.15 | 0.50 | 35.65 | 0.11 | 8.49 | 133.33 | 318.80 | -1.00 | 15.70 | 10.11 | 12.28 |
| 04/06/16 | 114.84 | 122.53 | 0.42 | 75.65 | 31.10 | 72.88 | 112.75 | -1.00 | 82.93 | 0.43 | 30.30 | 0.09 | 8.30 | 138.15 | 314.00 | -1.00 | 12.90 | 9.56 | 11.55 |
| 04/06/23 | -1.00 | 114.84 | 0.39 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 |
| 04/06/30 | 103.42 | -1.00 | 0.36 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 |
| 04/07/07 | 100.39 | 103.42 | 0.37 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 |
| 04/07/14 | 99.84 | 100.39 | 0.35 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 |
| 04/07/21 | 104.31 | 99.84 | 0.37 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 |
| 04/07/28 | 115.89 | 104.31 | 0.47 | -1.00 | 102.60 | 76.55 | 277.00 | -1.00 | 83.20 | 0.40 | -1.00 | 0.14 | 9.39 | 132.75 | 286.10 | -1.00 | 12.78 | 21.18 | 13.08 |
| 04/08/04 | 109.89 | 115.89 | 0.48 | 62.15 | 118.94 | 76.55 | 426.00 | -1.00 | 81.78 | 0.90 | 36.80 | 0.21 | 9.50 | 147.25 | 294.55 | -1.00 | 12.10 | 36.00 | 14.13 |
| 04/08/11 | 114.01 | 109.89 | 0.47 | 63.00 | -1.00 | 78.84 | 352.25 | -1.00 | 84.24 | 0.52 | 34.34 | 0.24 | 9.29 | 135.65 | 299.12 | -1.00 | 13.32 | 22.15 | 14.33 |
| 04/08/18 | 124.72 | 114.01 | 0.44 | 52.80 | -1.00 | 80.01 | 339.80 | -1.00 | 85.24 | 0.58 | 35.00 | 0.25 | 9.12 | 148.80 | 295.80 | -1.00 | 13.42 | 19.18 | 16.74 |
| 04/08/25 | 121.21 | 124.72 | 0.30 | 60.04 | -1.00 | 83.66 | 271.20 | -1.00 | 84.34 | 0.34 | 31.68 | 0.23 | 9.20 | 137.20 | 252.24 | -1.00 | 15.72 | 14.10 | 15.45 |
| 04/09/01 | 121.87 | 121.21 | 0.31 | 69.08 | -1.00 | 83.98 | 224.00 | -1.00 | 89.04 | 0.43 | 29.94 | 0.21 | 9.15 | 136.20 | 296.16 | -1.00 | 17.40 | 13.26 | 15.82 |
| 04/09/08 | 100.59 | 121.87 | 0.36 | 68.70 | 48.28 | 81.26 | 208.00 | -1.00 | 74.08 | 0.40 | 35.06 | 0.20 | 9.23 | 168.22 | 316.24 | -1.00 | 16.00 | 26.70 | 15.65 |
| 04/09/15 | 146.75 | 100.59 | -1.00 | 80.08 | 33.85 | 85.35 | 144.25 | -1.00 | 101.28 | 0.27 | 35.10 | 0.16 | 9.13 | 140.00 | 344.95 | -1.00 | 19.30 | 48.14 | 16.53 |
| 04/09/22 | 111.63 | 146.75 | 0.31 | 74.10 | 6.11 | 86.60 | 147.25 | -1.00 | 159.33 | 0.30 | 32.78 | 0.19 | 8.80 | 137.25 | 320.20 | -1.00 | 17.55 | 8.22 | 17.58 |
| 04/09/29 | 150.78 | 111.63 | 0.37 | 71.62 | 40.41 | 86.06 | 228.60 | -1.00 | 92.16 | 0.39 | 33.04 | 0.22 | -1.00 | 143.00 | 315.40 | -1.00 | 18.60 | 12.65 | 19.22 |
| 04/10/06 | 180.80 | 150.78 | 0.24 | 71.78 | 30.49 | 88.92 | 193.00 | 8.17 | 98.06 | 0.29 | 37.84 | 0.19 | 8.74 | 178.00 | 335.26 | -1.00 | 22.08 | 10.98 | 15.18 |
| 04/10/13 | 171.08 | 180.80 | -1.00 | 77.98 | 45.28 | 80.48 | 186.25 | 7.13 | 98.98 | 0.41 | 34.03 | 0.26 | 8.55 | 159.05 | 335.05 | -1.00 | 19.65 | 11.65 | 17.95 |
| 04/10/20 | 166.60 | 171.08 | 0.29 | 71.78 | 25.10 | 90.62 | 158.60 | -1.00 | 90.24 | 0.28 | 33.43 | 0.19 | 8.51 | 143.80 | 324.84 | -1.00 | 22.26 | 9.35 | 16.58 |
| 04/10/27 | 135.05 | 166.60 | 0.28 | 78.35 | 33.53 | 94.46 | 183.80 | -1.00 | 104.04 | 0.35 | 34.32 | 0.21 | 8.55 | 179.00 | 337.36 | -1.00 | 21.58 | 12.00 | 16.13 |
| 04/11/03 | 136.94 | 135.05 | 0.43 | 77.58 | 18.27 | 93.18 | 180.60 | -1.00 | 99.02 | 0.47 | 30.50 | 0.23 | 8.38 | 139.00 | 319.68 | -1.00 | 21.46 | 12.44 | 17.41 |
| 04/11/10 | 110.10 | 136.94 | 0.26 | 78.92 | 43.13 | 99.12 | 225.60 | -1.00 | 102.50 | -1.00 | 33.98 | -1.00 | 8.45 | 131.00 | 321.84 | -1.00 | 22.90 | 13.66 | 17.61 |
| 04/11/17 | 120.04 | 110.10 | 0.29 | 79.84 | 22.59 | 95.08 | 102.20 | -1.00 | 86.02 | 0.25 | 32.04 | 0.19 | 8.46 | 177.00 | 331.72 | -1.00 | 23.00 | 26.17 | 17.66 |
| 04/11/24 | 108.16 | 120.04 | 0.30 | 76.50 | -1.00 | -1.00 | 187.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.31 | 143.00 | -1.00 | -1.00 | 22.38 | -1.00 | -1.00 |
| 04/12/01 | 155.85 | 108.16 | 0.45 | 63.38 | -1.00 | -1.00 | 217.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.24 | 133.80 | -1.00 | -1.00 | 22.80 | -1.00 | -1.00 |
| 04/12/08 | 157.91 | 155.85 | 0.30 | 57.28 | 37.87 | 79.53 | 205.50 | -1.00 | 81.23 | 0.32 | 22.68 | 0.21 | 8.07 | 127.50 | 236.30 | -1.00 | 23.23 | 13.50 | 16.45 |
| 04/12/15 | 132.16 | 157.91 | -1.00 | 57.06 | 31.82 | 74.28 | 210.60 | -1.00 | 80.96 | 0.29 | 23.67 | 0.16 | 8.54 | 150.00 | 247.08 | -1.00 | 24.36 | 13.76 | 16.75 |
| 04/12/22 | 161.03 | 132.16 | 0.35 | 56.08 | 35.57 | 71.44 | 229.80 | -1.00 | 72.52 | -1.00 | 20.84 | -1.00 | 8.67 | 121.00 | 225.88 | -1.00 | 22.82 | 14.72 | 16.38 |
| 04/12/29 | 142.91 | 161.03 | -1.00 | 48.08 | 58.30 | 55.96 | 192.60 | -1.00 | 61.74 | -1.00 | 24.82 | -1.00 | 8.48 | 110.00 | 222.48 | -1.00 | 23.48 | 13.46 | 13.60 |

| Date | Cost | Lag-cost | Al | Ca | Chla | Cl | Colour | DOC | EC | Fe | Mg | Mn | pH | SO4 | Thard | TDS | Temp | Turb | UVA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05/01/05 | 155.38 | 142.91 | 0.33 | 40.62 | -1.00 | 46.48 | 205.40 | -1.00 | 117.38 | 0.28 | 15.02 | -1.00 | 8.24 | 94.00 | 188.04 | -1.00 | 22.36 | 17.64 | 13.20 |
| 05/01/12 | 141.34 | 155.38 | 0.44 | 41.22 | -1.00 | 46.62 | 214.20 | -1.00 | 57.08 | 0.36 | 21.14 | -1.00 | 7.86 | 85.00 | 197.72 | -1.00 | 23.12 | 16.68 | 18.43 |
| 05/01/19 | 133.57 | 141.34 | 0.30 | 48.84 | 37.52 | 50.88 | 156.40 | -1.00 | 62.96 | 0.29 | 21.42 | 0.13 | 8.19 | 104.00 | 217.20 | -1.00 | 23.22 | 15.30 | 17.48 |
| 05/01/26 | 114.73 | 133.57 | 0.79 | 46.28 | 71.84 | 56.70 | 359.20 | -1.00 | 69.80 | 0.27 | 18.56 | 0.11 | 7.84 | 160.00 | 233.24 | -1.00 | 22.06 | 12.53 | 15.68 |
| 05/02/02 | 122.56 | 114.73 | 0.33 | 44.40 | 41.61 | 53.54 | 190.30 | -1.00 | 66.68 | 0.27 | 20.24 | 0.12 | 8.37 | 120.00 | 221.88 | -1.00 | 22.56 | 11.56 | 16.24 |
| 05/02/09 | 150.74 | 122.56 | 0.27 | 49.69 | 23.74 | 59.60 | 215.80 | -1.00 | 70.04 | 0.43 | 21.96 | 0.11 | 8.44 | 136.00 | 262.54 | -1.00 | 23.66 | 14.95 | 14.87 |
| 05/02/16 | 130.47 | 150.74 | 0.36 | 59.76 | 10.09 | 67.80 | 209.00 | -1.00 | 74.44 | 0.33 | 21.46 | 0.18 | 8.22 | 144.00 | 252.40 | -1.00 | 22.10 | 11.87 | -1.00 |
| 05/02/23 | 132.02 | 130.47 | 0.19 | 58.46 | 20.21 | 69.86 | 172.80 | -1.00 | 71.28 | 0.29 | 22.32 | 0.09 | 8.10 | 136.00 | 241.76 | -1.00 | 21.42 | 9.34 | 13.28 |
| 05/03/02 | 138.13 | 132.02 | 0.17 | 55.50 | 20.29 | 65.66 | 196.20 | -1.00 | 83.96 | 0.25 | 21.54 | 0.15 | 8.16 | 147.00 | 264.44 | -1.00 | 21.10 | 9.72 | 12.98 |
| 05/03/09 | 109.68 | 138.13 | 0.20 | 66.16 | 23.41 | 64.32 | 211.75 | -1.00 | 75.02 | 0.16 | 26.74 | 0.15 | 7.97 | 143.00 | 280.04 | -1.00 | 17.82 | 9.60 | 13.20 |
| 05/03/16 | 74.37 | 109.68 | 0.29 | 63.10 | 22.82 | 67.66 | 235.00 | -1.00 | 79.90 | 0.49 | 27.74 | 0.17 | 7.88 | 180.00 | 291.20 | -1.00 | 21.02 | 10.00 | 12.86 |
| 05/03/23 | 102.03 | 74.37 | -1.00 | 56.66 | -1.00 | 67.12 | 201.60 | -1.00 | 82.02 | -1.00 | 28.52 | -1.00 | 7.77 | 157.00 | 292.00 | -1.00 | 15.18 | 10.07 | 11.87 |
| 05/03/30 | 102.70 | 102.03 | 0.22 | 64.92 | 27.37 | 71.30 | 179.40 | -1.00 | 162.32 | 0.30 | 31.22 | 0.10 | 8.13 | 160.00 | 306.88 | -1.00 | 12.62 | 9.64 | 11.84 |
| 05/04/06 | 88.02 | 102.70 | 0.13 | 59.04 | 30.38 | 73.96 | 153.20 | -1.00 | 122.84 | 0.28 | 30.66 | 0.09 | 7.95 | 224.00 | 294.76 | -1.00 | 14.24 | 9.29 | 12.16 |
| 05/04/13 | 101.02 | 88.02 | 0.15 | 61.00 | 33.36 | 77.94 | 160.80 | -1.00 | 89.82 | 0.21 | 30.28 | 0.06 | 8.19 | 194.00 | 317.76 | -1.00 | 12.76 | 9.15 | 12.95 |
| 05/04/20 | 108.92 | 101.02 | 0.14 | 62.60 | 35.88 | 79.43 | 160.93 | -1.00 | 96.72 | 0.16 | 51.78 | 0.07 | 8.26 | 210.80 | 327.19 | -1.00 | 12.67 | 8.63 | 13.24 |
| 05/04/27 | 87.10 | 108.92 | 0.16 | 75.27 | 41.76 | 84.39 | 148.98 | -1.00 | 91.47 | 0.16 | 55.60 | 0.07 | 8.38 | 219.16 | 329.08 | -1.00 | 12.57 | 8.24 | 12.85 |
| 05/05/04 | 156.92 | 87.10 | 0.04 | 69.60 | -1.00 | 79.26 | 178.00 | -1.00 | 92.76 | 0.06 | 31.64 | -1.00 | 8.57 | 218.60 | 319.96 | 598.00 | 13.34 | 7.37 | 20.43 |
| 05/05/11 | 92.37 | 156.92 | -1.00 | 55.05 | -1.00 | 81.86 | 154.25 | -1.00 | 89.66 | -1.00 | 28.92 | -1.00 | 8.39 | 196.00 | 299.00 | -1.00 | 13.98 | 7.59 | 13.08 |
| 05/05/18 | 102.94 | 92.37 | 0.14 | 58.76 | 43.33 | 234.56 | 152.60 | -1.00 | 88.34 | 0.09 | 31.84 | 0.03 | 8.67 | 218.00 | 288.96 | -1.00 | 15.90 | 9.62 | 13.99 |
| 05/05/25 | 94.75 | 102.94 | -1.00 | 71.20 | 43.43 | 83.62 | 201.40 | -1.00 | 72.90 | -1.00 | 30.18 | -1.00 | 8.53 | 209.00 | 294.04 | -1.00 | 17.58 | 24.16 | -1.00 |
| 05/06/01 | 82.81 | 94.75 | -1.00 | 70.52 | 34.75 | 85.14 | 161.40 | -1.00 | 91.08 | -1.00 | 27.00 | -1.00 | 8.57 | 204.00 | 318.36 | -1.00 | 19.22 | 7.39 | 14.63 |
| 05/06/08 | 107.53 | 82.81 | -1.00 | 68.30 | 32.21 | 92.10 | 167.00 | -1.00 | 93.58 | -1.00 | 32.88 | -1.00 | 8.62 | 219.00 | 305.24 | -1.00 | 21.86 | 8.19 | -1.00 |
| 05/06/15 | 80.66 | 107.53 | -1.00 | 67.63 | -1.00 | -1.00 | 158.00 | -1.00 | 83.07 | -1.00 | 30.77 | -1.00 | 8.86 | 150.00 | 294.80 | -1.00 | 14.80 | 10.14 | -1.00 |
| 05/06/22 | 88.08 | 80.66 | -1.00 | 56.62 | 21.50 | -1.00 | 163.20 | -1.00 | 83.20 | -1.00 | 28.00 | -1.00 | 8.86 | 162.00 | 295.15 | -1.00 | 14.08 | 9.58 | -1.00 |
| 05/06/29 | 80.66 | 88.08 | -1.00 | 71.18 | 34.97 | -1.00 | 146.60 | -1.00 | 166.86 | -1.00 | 32.04 | -1.00 | 9.05 | 215.00 | 311.50 | -1.00 | 12.60 | 9.85 | -1.00 |
| 05/07/06 | 90.30 | 80.66 | -1.00 | 65.08 | 36.64 | -1.00 | 150.60 | -1.00 | 122.04 | -1.00 | 28.00 | -1.00 | 9.01 | 240.00 | 288.40 | -1.00 | 14.10 | 9.50 | -1.00 |
| 05/07/13 | 124.56 | 90.30 | 0.13 | 85.60 | 20.52 | 114.00 | 144.80 | 6.82 | 90.38 | 0.07 | 25.66 | 0.02 | 8.73 | 237.80 | 317.60 | 676.00 | 13.44 | 8.81 | 13.00 |
| 05/07/20 | 108.04 | 124.56 | 0.05 | 72.96 | 60.30 | 83.00 | 156.40 | 6.59 | 73.61 | 0.09 | 40.50 | 0.05 | 9.14 | 194.60 | 325.52 | 444.00 | 11.47 | 25.02 | 13.00 |
| 05/07/27 | 94.29 | 108.04 | 0.02 | 83.46 | 77.81 | 85.00 | 169.60 | -1.00 | 96.66 | 0.09 | 31.08 | 0.06 | 9.08 | 221.20 | 333.28 | 576.00 | 12.32 | 9.08 | 14.00 |
| 05/08/03 | 112.66 | 94.29 | 0.10 | 80.84 | 34.83 | 75.00 | 143.80 | -1.00 | 91.68 | 0.10 | 29.54 | 0.06 | 8.76 | 227.00 | 325.76 | 402.00 | 12.32 | 6.91 | 11.00 |
| 05/08/10 | 91.56 | 112.66 | 0.01 | 74.86 | 24.54 | 90.00 | 123.80 | -1.00 | 92.50 | 0.06 | 32.36 | 0.02 | 8.65 | 209.60 | 319.40 | 598.00 | 14.02 | 7.48 | 12.00 |
| 05/08/17 | 96.23 | 91.56 | -1.00 | 71.05 | 82.26 | -1.00 | 149.50 | -1.00 | 89.18 | -1.00 | 27.78 | -1.00 | 9.20 | 206.00 | 296.33 | -1.00 | 12.11 | 7.36 | -1.00 |
| 05/08/24 | 109.78 | 96.23 | -1.00 | 65.58 | 204.69 | -1.00 | 220.00 | -1.00 | 87.98 | -1.00 | 32.62 | -1.00 | 9.18 | 223.00 | 298.50 | -1.00 | 16.48 | 10.33 | -1.00 |
| 05/08/31 | 116.77 | 109.78 | -1.00 | 62.50 | 95.72 | -1.00 | 160.80 | -1.00 | 87.80 | -1.00 | 31.06 | -1.00 | 8.94 | 198.00 | 285.00 | -1.00 | 15.94 | 8.13 | -1.00 |
| 05/09/07 | 119.77 | 116.77 | -1.00 | 67.68 | 79.10 | -1.00 | 159.40 | -1.00 | 89.16 | -1.00 | 31.36 | -1.00 | 9.15 | 211.00 | 293.10 | -1.00 | 17.82 | 8.06 | -1.00 |
| 05/09/14 | 145.27 | 119.77 | 0.09 | 68.52 | 61.62 | -1.00 | 152.20 | -1.00 | 90.28 | -1.00 | 35.76 | -1.00 | 9.05 | 200.00 | 308.30 | -1.00 | 19.28 | 7.82 | -1.00 |
| 05/09/21 | 136.50 | 145.27 | 0.15 | 61.93 | 34.76 | -1.00 | 179.00 | -1.00 | 92.80 | -1.00 | 29.98 | -1.00 | 8.81 | 198.00 | 296.07 | -1.00 | 20.40 | 8.75 | -1.00 |
| 05/09/28 | 139.67 | 136.50 | 0.16 | 66.43 | 40.41 | -1.00 | 162.25 | -1.00 | 94.05 | -1.00 | 33.68 | -1.00 | 8.76 | 223.75 | 303.13 | -1.00 | 21.83 | 7.95 | -1.00 |
| 05/10/05 | 122.05 | 139.67 | -1.00 | 75.18 | 31.67 | -1.00 | 139.00 | -1.00 | 95.26 | -1.00 | 31.92 | -1.00 | 8.54 | 205.00 | 318.85 | -1.00 | 20.80 | 7.45 | -1.00 |
| 05/10/12 | 123.44 | 122.05 | -1.00 | 71.44 | 23.50 | -1.00 | 150.40 | -1.00 | 94.66 | -1.00 | 38.68 | -1.00 | 8.52 | 211.25 | 330.90 | -1.00 | 21.34 | 7.34 | -1.00 |
| 05/10/19 | 100.55 | 123.44 | -1.00 | 82.83 | 18.35 | -1.00 | 127.75 | -1.00 | 95.70 | -1.00 | 46.75 | -1.00 | 8.31 | 203.33 | 337.53 | -1.00 | 23.28 | 6.27 | -1.00 |
| 05/10/26 | 137.70 | 100.55 | 0.09 | 80.56 | 31.07 | 127.00 | 142.40 | 10.10 | 97.22 | 0.12 | 31.56 | 0.10 | 7.95 | 254.80 | 333.80 | 634.00 | 23.52 | 7.95 | 18.00 |
| 05/11/02 | 147.18 | 137.70 | 0.05 | 70.78 | 36.68 | 100.00 | 181.60 | 8.96 | 89.22 | 0.05 | 29.26 | 0.01 | 8.03 | 207.60 | 285.04 | 622.00 | 24.04 | 9.32 | 17.40 |
| 05/11/09 | 148.03 | 147.18 | 0.01 | 74.24 | 42.85 | 86.00 | 143.40 | 9.42 | 134.32 | 0.13 | 23.54 | 0.02 | 8.23 | 188.80 | 282.44 | 618.00 | 24.88 | 6.69 | 17.40 |
| 05/11/16 | 112.61 | 148.03 | -1.00 | 60.60 | 58.09 | -1.00 | 191.50 | -1.00 | 73.65 | -1.00 | 21.48 | -1.00 | 8.37 | 128.33 | 246.13 | -1.00 | 22.25 | 9.69 | -1.00 |
| 05/11/23 | 108.65 | 112.61 | 0.13 | 50.08 | 15.85 | 90.00 | 162.75 | 8.83 | 66.84 | 0.23 | 21.54 | 0.46 | 8.27 | 97.50 | 218.55 | -1.00 | 23.40 | 11.62 | 17.10 |
| 05/11/30 | 111.52 | 108.65 | 0.10 | 49.14 | 12.32 | 45.00 | 144.80 | 8.60 | 59.16 | 0.10 | 22.20 | -1.00 | 8.23 | 79.00 | 196.04 | 372.00 | 24.80 | 7.15 | 15.40 |
| 05/12/07 | 117.38 | 111.52 | 0.09 | 48.39 | 34.39 | 38.00 | 187.80 | 8.32 | 53.70 | 0.10 | 18.36 | 0.04 | 8.06 | 93.60 | 202.96 | 406.00 | 24.74 | 9.61 | 15.00 |
| 05/12/14 | 102.05 | 117.38 | 0.10 | 42.12 | 37.44 | 32.00 | 206.80 | 7.90 | 47.74 | 0.10 | 17.80 | 0.02 | 7.96 | 50.20 | 176.00 | 278.00 | 25.80 | 12.05 | 13.40 |
| 05/12/21 | 118.37 | 102.05 | 0.28 | 39.34 | 23.69 | 30.00 | 153.20 | 9.00 | 121.78 | 0.28 | 13.76 | 0.06 | 7.96 | 58.00 | 153.60 | 296.00 | 25.24 | 10.68 | 14.00 |
| 05/12/28 | 163.90 | 118.37 | 0.22 | 36.62 | 12.18 | 27.00 | 240.00 | 7.90 | 45.42 | 0.26 | 15.60 | 0.06 | 7.59 | 56.40 | 154.92 | 428.00 | 24.42 | 17.64 | 16.10 |

| Date | Cost | Lag-cost | Al | Ca | Chla | Cl | Colour | DOC | EC | Fe | Mg | Mn | pH | SO4 | Thard | TDS | Temp | Turb | UVA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06/01/04 | 165.66 | 163.90 | 0.20 | 48.52 | 22.75 | 41.00 | 190.20 | 8.20 | 57.36 | 0.14 | 15.60 | 0.02 | 7.80 | 67.50 | 181.85 | 582.00 | 26.04 | 11.19 | 16.60 |
| 06/01/11 | 247.25 | 165.66 | 0.07 | 43.46 | 28.28 | 50.00 | 161.60 | 8.20 | 53.24 | 0.07 | 15.96 | 0.01 | 7.78 | 82.50 | 171.15 | 104.00 | 26.64 | 8.82 | 16.00 |
| 06/01/18 | 158.86 | 247.25 | 0.04 | 48.54 | 54.25 | -1.00 | 262.60 | 9.40 | 67.92 | 0.02 | 19.40 | 0.01 | 7.84 | 122.50 | 212.00 | 510.00 | 27.66 | 49.76 | 14.00 |
| 06/01/25 | 130.76 | 158.86 | 8.90 | 24.64 | 12.24 | 19.00 | 1364.00 | 10.00 | 28.04 | 5.90 | 11.44 | 0.11 | 7.27 | 51.60 | 106.88 | 694.00 | 26.96 | 148.80 | 24.80 |
| 06/02/01 | 122.77 | 130.76 | 1.20 | 27.00 | 5.76 | 18.00 | 810.60 | 9.70 | 29.93 | 1.00 | 8.85 | 0.02 | 7.33 | 42.25 | 108.05 | 240.00 | 25.65 | 97.95 | 23.00 |
| 06/02/08 | 127.82 | 122.77 | 8.90 | 33.78 | 14.30 | 19.00 | 657.50 | 10.00 | 35.43 | 5.90 | 8.93 | 0.11 | 7.50 | 49.50 | 120.20 | 694.00 | 24.68 | 57.52 | 23.15 |
| 06/02/15 | -1.00 | 127.82 | 0.74 | 38.64 | 10.90 | 21.00 | 1126.40 | 9.26 | 45.66 | 0.70 | 18.82 | 0.02 | 7.47 | 88.00 | 159.20 | 220.00 | 24.78 | 104.48 | 21.50 |
| 06/02/22 | -1.00 | -1.00 | 0.94 | 29.10 | -1.00 | 11.00 | 2450.40 | 9.24 | 26.22 | 1.90 | 11.76 | 0.05 | 7.56 | 62.20 | 114.16 | 158.00 | 26.52 | 200.40 | -1.00 |
| 06/03/01 | 181.02 | -1.00 | 1.00 | 22.33 | -1.00 | 120.00 | 1349.33 | 9.80 | 25.40 | 2.20 | 10.15 | 0.06 | 7.67 | 36.50 | 97.05 | 156.00 | 24.95 | 114.75 | -1.00 |
| 06/03/08 | 196.17 | 181.02 | -1.00 | 31.08 | -1.00 | -1.00 | 1465.00 | -1.00 | 65.00 | -1.00 | 10.68 | -1.00 | 7.61 | 48.33 | 108.73 | -1.00 | 23.95 | 117.52 | -1.00 |
| 06/03/15 | 172.48 | 196.17 | 1.40 | 27.08 | 16.43 | 8.80 | 1002.00 | 12.20 | 21.90 | 1.30 | 6.30 | 0.02 | 7.60 | 29.80 | 94.28 | 642.00 | 22.60 | 132.40 | 35.80 |
| 06/03/22 | -1.00 | 172.48 | 6.00 | 20.10 | 11.28 | 12.00 | 1058.40 | 10.90 | 23.92 | 4.30 | 11.08 | 0.04 | 7.60 | 47.80 | 97.08 | 492.00 | 22.48 | 91.54 | 35.00 |
| 06/03/29 | 208.04 | -1.00 | 0.74 | 24.58 | 10.51 | 21.00 | 1307.00 | 9.26 | 25.90 | 0.70 | 8.78 | 0.02 | 7.62 | 68.50 | 109.45 | 220.00 | 23.03 | 141.00 | 21.50 |
| 06/04/05 | 196.65 | 208.04 | 2.20 | 23.82 | 14.83 | 10.00 | 886.00 | 10.90 | 21.38 | 1.70 | 9.48 | 0.03 | 7.70 | 34.40 | 91.40 | 430.00 | 19.98 | 108.60 | 36.00 |
| 06/04/12 | 181.12 | 196.65 | -1.00 | 25.86 | 12.09 | 10.00 | 974.00 | 10.90 | 24.50 | 1.70 | 9.60 | 0.03 | 7.79 | 38.80 | 99.27 | 430.00 | 20.07 | 91.36 | -1.00 |
| 06/04/19 | 110.97 | 181.12 | 0.74 | 34.18 | 15.76 | 16.00 | 703.60 | 10.10 | 48.64 | 1.60 | 13.10 | 0.07 | 7.89 | 37.00 | 131.00 | 192.00 | 19.56 | 74.28 | 27.90 |
| 06/04/26 | 105.97 | 110.97 | -1.00 | 40.57 | 22.93 | -1.00 | 674.67 | -1.00 | 39.03 | -1.00 | 14.43 | -1.00 | 7.87 | 52.50 | 171.50 | -1.00 | 19.43 | 73.53 | -1.00 |
| 06/05/03 | 117.35 | 105.97 | 0.70 | 49.14 | 109.39 | 39.00 | 364.67 | 9.80 | 58.12 | 63.00 | 18.04 | -1.00 | 8.79 | 141.40 | 202.44 | 318.00 | 17.86 | 24.42 | 21.40 |
| 06/05/10 | 124.12 | 117.35 | 0.41 | 52.90 | 267.80 | 37.00 | 406.00 | 10.30 | 56.83 | 0.36 | 18.45 | 0.02 | 9.11 | 148.00 | 209.07 | 364.00 | 16.50 | 24.72 | 21.50 |
| 06/05/17 | 99.68 | 124.12 | 0.31 | 43.70 | 103.43 | 38.00 | 482.25 | 10.60 | 52.50 | 0.38 | 27.00 | 0.04 | 8.85 | 86.00 | 222.00 | 344.00 | 14.78 | 27.20 | 19.70 |
| 06/05/24 | 98.04 | 99.68 | -1.00 | 41.43 | 204.33 | -1.00 | 371.75 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 9.08 | -1.00 | -1.00 | -1.00 | 14.03 | -1.00 | -1.00 |
| 06/05/31 | 136.41 | 98.04 | 0.70 | 44.98 | 154.27 | 32.00 | 233.07 | 10.60 | 53.90 | 0.60 | 21.00 | -1.00 | 9.31 | 107.00 | 220.00 | 514.00 | 11.30 | 28.20 | 19.80 |
| 06/06/07 | 124.20 | 136.41 | 0.60 | 46.54 | 145.62 | 34.00 | 375.80 | 9.60 | 51.30 | 0.60 | 22.00 | -1.00 | 9.31 | 109.00 | 192.00 | 336.00 | 11.22 | 25.70 | 17.90 |
| 06/06/14 | 136.06 | 124.20 | 0.41 | 33.82 | 145.03 | 46.00 | 464.75 | 8.34 | 53.70 | 0.45 | 25.00 | 0.03 | 9.21 | 123.00 | 204.00 | 318.00 | 12.45 | 28.10 | 18.20 |
| 06/06/21 | 129.42 | 136.06 | 0.52 | 51.20 | 112.35 | 43.00 | 255.50 | 7.34 | 70.20 | 0.47 | 26.00 | 0.05 | 9.49 | 129.00 | 223.00 | 354.00 | 12.13 | 18.20 | 17.00 |
| 06/06/28 | 112.37 | 129.42 | 0.24 | 46.52 | 130.92 | 58.00 | 261.60 | 6.44 | 67.30 | 0.34 | 30.00 | 0.13 | 9.35 | 215.00 | 233.00 | 442.00 | 11.72 | 15.40 | 16.60 |
| 06/07/05 | 87.56 | 112.37 | 0.20 | 58.08 | 80.15 | 57.00 | 200.80 | 6.81 | 76.00 | 0.24 | 30.00 | 0.10 | 9.44 | 192.00 | 254.00 | 486.00 | 9.88 | 10.90 | 16.40 |
| 06/07/12 | 96.02 | 87.56 | 0.37 | 61.68 | 115.22 | 82.00 | 170.50 | 11.80 | 80.70 | 0.50 | 24.00 | 0.13 | 9.44 | 256.00 | 272.00 | 542.00 | 11.53 | 7.90 | 15.40 |
| 06/07/19 | 102.96 | 96.02 | 0.13 | 67.58 | 63.32 | 68.00 | 224.00 | 8.42 | 80.50 | 0.21 | 36.00 | 0.07 | 9.38 | 229.00 | 288.00 | 488.00 | 12.02 | 16.80 | -1.00 |
| 06/07/26 | 114.47 | 102.96 | 0.11 | 72.83 | 84.02 | 76.00 | 275.25 | 10.60 | 95.40 | 0.22 | 34.00 | 0.07 | 9.11 | 234.00 | 308.00 | 550.00 | 13.58 | 15.80 | 15.80 |
| 06/08/02 | 110.25 | 114.47 | 0.15 | 64.74 | 51.73 | 76.00 | 265.20 | 12.70 | 85.60 | 0.13 | 37.00 | 0.09 | 9.08 | 221.00 | 312.00 | 468.00 | 13.34 | 12.20 | 16.20 |
| 06/08/09 | 113.57 | 110.25 | 0.19 | 59.96 | 94.10 | 69.00 | 293.80 | 8.60 | 80.80 | 0.15 | 49.00 | 0.03 | 9.14 | 226.00 | 335.00 | 504.00 | 12.66 | 12.80 | 15.90 |
| 06/08/16 | 110.92 | 113.57 | 0.20 | 72.48 | 82.80 | 62.00 | 227.25 | 8.22 | 84.60 | 0.16 | 33.00 | 0.04 | 8.92 | 196.00 | 297.00 | 576.00 | 11.58 | 18.70 | 16.00 |
| 06/08/23 | 99.84 | 110.92 | 0.03 | 75.52 | 148.57 | -1.00 | 236.20 | 7.15 | 84.40 | 0.11 | 30.00 | 0.01 | 9.25 | 184.00 | 284.00 | 490.00 | 14.50 | 15.30 | 11.80 |
| 06/08/30 | 97.55 | 99.84 | 0.13 | 68.72 | 100.17 | 62.00 | 189.20 | 8.61 | 82.40 | 0.14 | 30.00 | 0.03 | 9.03 | 183.00 | 285.00 | 328.00 | 14.82 | 10.90 | 16.20 |
| 06/09/06 | 85.58 | 97.55 | 0.14 | 74.70 | 88.68 | 74.00 | 285.60 | 8.88 | 85.20 | 0.13 | 33.00 | 0.04 | 9.25 | 223.00 | 298.00 | 526.00 | 16.00 | 14.50 | 16.40 |
| 06/09/13 | 106.05 | 85.58 | 0.12 | 66.50 | 110.47 | 72.00 | 194.40 | 9.93 | 84.60 | 0.10 | 30.00 | 0.04 | 9.50 | 216.00 | 297.00 | 518.00 | 16.44 | 10.60 | 17.80 |
| 06/09/20 | 124.19 | 106.05 | 0.09 | 54.26 | 76.52 | 88.00 | 248.20 | -1.00 | 79.80 | 0.10 | 23.00 | 0.02 | 9.04 | 211.00 | 245.00 | 638.00 | 19.60 | 12.00 | 18.80 |
| 06/09/27 | 123.70 | 124.19 | 0.34 | 67.62 | 52.97 | 83.00 | 263.00 | -1.00 | 83.80 | 0.26 | 32.00 | 0.07 | 9.16 | 218.00 | 289.00 | 708.00 | 17.82 | 14.20 | 18.90 |
| 06/10/04 | 127.70 | 123.70 | 0.29 | 75.20 | 43.61 | 71.00 | 298.50 | -1.00 | 83.50 | 0.23 | 32.00 | 0.06 | 9.00 | 190.00 | 303.00 | 546.00 | 19.23 | 19.00 | 19.00 |
| 06/10/11 | 134.14 | 127.70 | 0.11 | 70.48 | 57.03 | 89.00 | 304.40 | 10.20 | 80.00 | 0.14 | 34.00 | 0.05 | 9.19 | 226.00 | 295.00 | 504.00 | 19.12 | 14.00 | 18.70 |
| 06/10/18 | 141.18 | 134.14 | 0.12 | 67.16 | 27.66 | 106.00 | 314.80 | 10.20 | 81.70 | 0.13 | 31.00 | 0.05 | 8.91 | 268.00 | 292.00 | 500.00 | 19.94 | 14.70 | 18.60 |
| 06/10/25 | 122.22 | 141.18 | 0.12 | 72.34 | 26.22 | 106.00 | 285.20 | 10.20 | 81.70 | 0.13 | 31.00 | 0.05 | 8.98 | 268.00 | 292.00 | 500.00 | 21.50 | 14.70 | 18.60 |
| 06/11/01 | 135.46 | 122.22 | 0.12 | 68.24 | 19.16 | 68.00 | 260.60 | 8.28 | 81.40 | 0.21 | 36.00 | 0.04 | 9.00 | 195.00 | 301.00 | 566.00 | 23.06 | 15.50 | 17.90 |
| 06/11/08 | 132.76 | 135.46 | -1.00 | 76.88 | 14.33 | -1.00 | 277.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.74 | -1.00 | -1.00 | -1.00 | 22.05 | -1.00 | -1.00 |
| 06/11/15 | 124.36 | 132.76 | 0.12 | 76.78 | 23.41 | 76.00 | 200.50 | 10.40 | 86.60 | 0.37 | 35.00 | 0.10 | 8.56 | 188.00 | 310.00 | -1.00 | 22.20 | 12.10 | 23.60 |
| 06/11/22 | 129.31 | 124.36 | -1.00 | 72.44 | 33.20 | -1.00 | 314.60 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.65 | -1.00 | -1.00 | -1.00 | 22.34 | -1.00 | -1.00 |
| 06/11/29 | 109.93 | 129.31 | 0.17 | 65.06 | 96.30 | 65.00 | 371.40 | 9.84 | 118.90 | 0.20 | 26.00 | 0.09 | 8.60 | 155.00 | 267.00 | 560.00 | 23.24 | 15.00 | 20.00 |
| 06/12/06 | 133.17 | 109.93 | 0.22 | 61.44 | 60.38 | 63.00 | 324.80 | 10.90 | 72.40 | 0.18 | 26.00 | 0.07 | 8.77 | 150.00 | 250.00 | 632.00 | 22.90 | 16.80 | 20.80 |
| 06/12/13 | 145.79 | 133.17 | 0.21 | 65.34 | 37.97 | 62.00 | 294.00 | 9.84 | 75.80 | 0.18 | 26.00 | 0.06 | 8.98 | 148.00 | 258.00 | 632.00 | 23.50 | 19.30 | 20.00 |
| 06/12/20 | 87.63 | 145.79 | 0.17 | 67.02 | 40.49 | 91.00 | 383.60 | 9.86 | 73.80 | 0.18 | 24.00 | 0.06 | 8.75 | 161.00 | 250.00 | 586.00 | 24.28 | 21.40 | 19.00 |
| 06/12/27 | 130.27 | 87.63 | 0.16 | 61.14 | -1.00 | 80.00 | 296.25 | 9.64 | 75.30 | 0.18 | 27.00 | 0.05 | 8.63 | 168.00 | 256.00 | 482.00 | 24.60 | 26.30 | 18.60 |
| 07/01/03 | -1.00 | 130.27 | -1.00 | 65.65 | -1.00 | -1.00 | 296.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.29 | -1.00 | -1.00 | -1.00 | 24.00 | 15.90 | -1.00 |

**APPENDIX III:** ZUIKERBOSCH DATA FOR THE PERIOD NOVEMBER 2004 – OCTOBER 2006

| Date | Cost | Lagcost | Ca | Al | hard | Fe | Mg | NO3 | P | NO2 | Si | Na | NH4 | Chl665 | Geosm | PO4 | Mn | SO4 | K | pH | TA | EC | NTU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 04/11/07 | 78.79 | -1.00 | 13.80 | 0.79 | 62.00 | 0.62 | 6.70 | 0.78 | 0.10 | 0.24 | 6.76 | 7.08 | 0.42 | 5.06 | 3.00 | 0.06 | 0.01 | 20.80 | 1.88 | 7.87 | 65.76 | 17.43 | 127.19 |
| 04/11/14 | 83.32 | 78.79 | 14.00 | 0.64 | 62.60 | 0.60 | 6.86 | 0.17 | 0.04 | 0.04 | 7.22 | 7.16 | 0.05 | 7.20 | 5.62 | 0.03 | 0.01 | 14.20 | 1.90 | 7.96 | 65.61 | 17.75 | 129.90 |
| 04/11/21 | 61.92 | 83.32 | 13.60 | 1.29 | 60.40 | 0.93 | 6.46 | 0.07 | 0.06 | 0.04 | 7.58 | 6.52 | 0.11 | 9.66 | 6.66 | 0.06 | 0.02 | 14.20 | 1.72 | 7.98 | 64.02 | 16.10 | 132.52 |
| 04/11/28 | 71.28 | 61.92 | 14.40 | 0.51 | 63.40 | 0.26 | 6.76 | 0.05 | 0.07 | 0.03 | 7.64 | 5.88 | 0.03 | 3.24 | 4.20 | 0.07 | 0.02 | 14.00 | 1.92 | 7.87 | 64.36 | 16.08 | 126.74 |
| 04/12/05 | 104.56 | 71.28 | 12.80 | 0.40 | 58.00 | 0.19 | 6.22 | 0.05 | 0.14 | 0.04 | 6.66 | 5.84 | 0.04 | 3.92 | 5.34 | 0.07 | 0.01 | 12.60 | 1.66 | 7.96 | 67.19 | 15.93 | 118.54 |
| 04/12/12 | 59.23 | 104.56 | 12.40 | 0.65 | 56.20 | 0.45 | 6.04 | 0.08 | 0.11 | 0.04 | 6.22 | 6.12 | 0.03 | 3.16 | 4.80 | 0.07 | 0.01 | 12.40 | 1.35 | 7.74 | 67.30 | 15.53 | 119.28 |
| 04/12/19 | 85.46 | 59.23 | 13.00 | 0.57 | 60.00 | 0.50 | 6.48 | 0.05 | 0.04 | 0.05 | 6.60 | 6.83 | 0.09 | 5.23 | 3.00 | 0.11 | 0.01 | 12.75 | 1.43 | 7.63 | 67.00 | 15.43 | 126.67 |
| 04/12/26 | 63.40 | 85.46 | 12.40 | 0.79 | 55.60 | 0.71 | 5.94 | 0.05 | 0.03 | 0.04 | 7.32 | 5.96 | 0.08 | 6.06 | 2.40 | 0.09 | 0.01 | 13.00 | 1.02 | 7.58 | 67.97 | 15.49 | 134.99 |
| 05/01/02 | 70.89 | 63.40 | 12.00 | 1.02 | 52.75 | 0.75 | 5.65 | 0.05 | 0.04 | 0.11 | 7.10 | 6.68 | 0.04 | 4.95 | 3.00 | 0.04 | 0.01 | -1.00 | 1.02 | 7.56 | 68.12 | 15.81 | 141.10 |
| 05/01/09 | 71.00 | 70.89 | 20.20 | 0.74 | 76.20 | 0.72 | 6.48 | 0.05 | 0.05 | 0.03 | 7.44 | 7.14 | 0.06 | 3.40 | 3.00 | 0.11 | 0.02 | 14.40 | 1.62 | 7.23 | 68.57 | 16.08 | 140.78 |
| 05/01/16 | 113.71 | 71.00 | 13.40 | 1.68 | 60.20 | 0.64 | 6.42 | 0.58 | 0.05 | 0.10 | 6.94 | 6.68 | 0.03 | 5.26 | 3.00 | 0.12 | 0.01 | 12.20 | 1.68 | 7.50 | 68.62 | 15.82 | 131.69 |
| 05/01/23 | 94.42 | 113.71 | 14.20 | 0.67 | 63.20 | 0.48 | 6.72 | 0.19 | 0.10 | 0.13 | 6.44 | 6.98 | 0.05 | 3.09 | 3.00 | 0.06 | 0.01 | 13.00 | 1.72 | 6.65 | 60.90 | 14.14 | 111.48 |
| 05/01/30 | 113.38 | 94.42 | 14.00 | 1.62 | 62.80 | 0.80 | 6.78 | 0.13 | 0.06 | 0.08 | 7.60 | 7.04 | 0.13 | 5.56 | 3.00 | 0.03 | 0.01 | 14.00 | 1.80 | 7.94 | 65.38 | 16.33 | 134.03 |
| 05/02/06 | 74.44 | 113.38 | 14.40 | 0.87 | 64.00 | 0.63 | 6.96 | 0.12 | 0.02 | 0.08 | 7.32 | 6.94 | 0.23 | 4.72 | 3.00 | 0.03 | 0.01 | 15.60 | 1.72 | 7.80 | 61.52 | 16.29 | 139.62 |
| 05/02/13 | 108.13 | 74.44 | 13.80 | 1.88 | 62.40 | 1.02 | 6.88 | 0.26 | 0.05 | 0.04 | 8.78 | 6.94 | 0.04 | 4.36 | 3.00 | 0.03 | 0.01 | 15.80 | 1.82 | 7.77 | 62.74 | 14.06 | 141.29 |
| 05/02/20 | 124.71 | 108.13 | 14.50 | 2.45 | 67.20 | 1.26 | 7.60 | 0.33 | 0.12 | 0.07 | 9.54 | 7.68 | 0.06 | 3.74 | 3.00 | 0.05 | 0.01 | 15.00 | 2.16 | 7.67 | 64.52 | 17.07 | 139.75 |
| 05/02/27 | 91.75 | 124.71 | 14.00 | 1.72 | 64.00 | 0.88 | 7.06 | 0.37 | 0.06 | 0.10 | 7.52 | 7.30 | 0.04 | 3.72 | 3.00 | 0.03 | 0.01 | 17.20 | 1.68 | 7.65 | 64.43 | 17.00 | 138.96 |
| 05/03/06 | 69.06 | 91.75 | 14.00 | 1.25 | 64.20 | 0.70 | 7.04 | 0.19 | 0.11 | 0.05 | 7.72 | 7.84 | 0.03 | 3.82 | 3.00 | 0.03 | 0.01 | 20.00 | 1.98 | 7.61 | 64.86 | 17.14 | 136.66 |
| 05/03/13 | 70.48 | 69.06 | 13.60 | 1.04 | 60.60 | 0.64 | 6.58 | 0.29 | 0.10 | 0.03 | 7.44 | 6.98 | 0.03 | 3.02 | 3.00 | 0.03 | 0.01 | 19.20 | 1.78 | 7.60 | 60.81 | 17.02 | 136.36 |
| 05/03/20 | 65.09 | 70.48 | 14.40 | 1.95 | 64.80 | 1.18 | 7.14 | 0.37 | 0.08 | 0.05 | 9.18 | 7.66 | 0.03 | 3.14 | 3.00 | 0.04 | 0.01 | 16.20 | 1.98 | 7.59 | 63.57 | 17.37 | 131.63 |
| 05/03/27 | 68.29 | 65.09 | 14.00 | 2.27 | 63.67 | 1.41 | 7.00 | 0.30 | 0.10 | 0.04 | 8.73 | 8.10 | 0.06 | 4.63 | 3.00 | 0.05 | 0.01 | 15.33 | 2.10 | 7.45 | 63.00 | 17.36 | 123.24 |
| 05/04/03 | 53.38 | 68.29 | 13.75 | 3.40 | 63.75 | 1.93 | 7.08 | 0.32 | 0.18 | 0.08 | 10.28 | 7.88 | 0.04 | 3.15 | 3.00 | 0.03 | 0.01 | -1.00 | 2.23 | 7.79 | 63.98 | 17.36 | 113.19 |
| 05/04/10 | 65.07 | 53.38 | 13.60 | 1.88 | 63.60 | 0.82 | 7.06 | 0.39 | 0.13 | 0.03 | 8.02 | 7.76 | 0.03 | 2.98 | 2.20 | 0.03 | 0.01 | 17.80 | 0.00 | 7.69 | 63.29 | 17.54 | 113.99 |
| 05/04/17 | 64.22 | 65.07 | 14.40 | 2.70 | 64.60 | 1.46 | 7.22 | 0.70 | 0.07 | 0.07 | 9.52 | 7.56 | 0.03 | 2.38 | 3.00 | 0.08 | 0.01 | 18.00 | 2.08 | 7.62 | 63.69 | 17.76 | 107.21 |
| 05/04/24 | 60.19 | 64.22 | 14.60 | 1.97 | 66.80 | 0.84 | 7.36 | 0.32 | 0.05 | 0.03 | 8.58 | 7.82 | 0.10 | 2.18 | 3.00 | 0.04 | 0.01 | 19.20 | 1.96 | 7.66 | 63.17 | 17.43 | 103.45 |
| 05/05/01 | 63.32 | 60.19 | 14.00 | 2.29 | 64.25 | 0.77 | 7.15 | 0.34 | 0.05 | 0.03 | 7.78 | 7.65 | 0.06 | 2.23 | 3.00 | 0.03 | 0.01 | 19.75 | 1.95 | 7.60 | 65.07 | 17.32 | 100.34 |
| 05/05/08 | 55.05 | 63.32 | 13.75 | 1.00 | 63.50 | 0.66 | 6.93 | 0.33 | 0.22 | 0.09 | 7.48 | 7.80 | 0.06 | 2.75 | 3.00 | 0.20 | 0.01 | 19.00 | 2.13 | 7.46 | 63.19 | 17.40 | 100.61 |
| 05/05/15 | 68.09 | 55.05 | 15.40 | 0.41 | 68.80 | 0.43 | 7.46 | 0.37 | 0.10 | 0.07 | 6.56 | 8.36 | 0.03 | 3.90 | 3.00 | 0.04 | 0.01 | 21.40 | 2.28 | 7.76 | 64.87 | 17.94 | 97.62 |
| 05/05/22 | 71.95 | 68.09 | 14.40 | 1.89 | 65.40 | 0.89 | 7.20 | 0.32 | 0.11 | 0.03 | 8.30 | 7.60 | 0.03 | 2.38 | 3.00 | 0.04 | 0.01 | 20.00 | 2.18 | 7.85 | 64.71 | 18.00 | 95.52 |
| 05/05/29 | 60.38 | 71.95 | 14.60 | 2.52 | 66.00 | 1.17 | 7.20 | 0.25 | 0.13 | 0.05 | 9.00 | 7.22 | 0.03 | 2.08 | 4.60 | 0.03 | 0.01 | 15.40 | 2.12 | 7.83 | 66.44 | 17.40 | 95.29 |
| 05/06/05 | 95.35 | 60.38 | 15.00 | 2.08 | 68.40 | 1.38 | 7.46 | 0.40 | 0.04 | 0.03 | 9.28 | 7.46 | 0.03 | 1.98 | 2.40 | 0.03 | 0.01 | 17.00 | 2.08 | 8.44 | 71.57 | 18.40 | 103.86 |
| 05/06/12 | 89.39 | 95.35 | 15.40 | 2.22 | 71.60 | 1.17 | 7.90 | -1.00 | 0.11 | -1.00 | 9.42 | 8.10 | -1.00 | 1.60 | 2.40 | -1.00 | 0.01 | -1.00 | 2.22 | 8.88 | 75.50 | 18.33 | 95.55 |
| 05/06/19 | 66.16 | 89.39 | 13.75 | 2.55 | 63.50 | 1.05 | 7.10 | -1.00 | 0.09 | -1.00 | 8.75 | 7.63 | -1.00 | 1.65 | 2.25 | -1.00 | 0.01 | -1.00 | 2.23 | 7.56 | 65.43 | 15.86 | 80.29 |
| 05/06/26 | 69.04 | 66.16 | 14.60 | 1.85 | 67.00 | 0.96 | 7.34 | -1.00 | 0.10 | -1.00 | 8.64 | 8.24 | -1.00 | 1.72 | 2.40 | -1.00 | 0.01 | -1.00 | 2.50 | 8.77 | 76.19 | 18.08 | 94.80 |
| 05/07/03 | 106.29 | 69.04 | 14.20 | 1.84 | 65.60 | 1.22 | 7.36 | -1.00 | 0.12 | -1.00 | 10.50 | 8.38 | -1.00 | 1.60 | 2.40 | -1.00 | 0.01 | -1.00 | 2.56 | 8.57 | 70.80 | 18.00 | 82.00 |
| 05/07/10 | 109.78 | 106.29 | 13.80 | 1.33 | 62.80 | 0.85 | 6.96 | 0.37 | 0.10 | 0.05 | 8.46 | 7.78 | 0.04 | 2.00 | 2.40 | 0.03 | 0.02 | 15.00 | 2.16 | 7.90 | 60.50 | 17.71 | 78.31 |
| 05/07/17 | 81.07 | 109.78 | 14.00 | 2.40 | 65.60 | 1.27 | 7.40 | 0.32 | 0.16 | 0.04 | 9.32 | 7.54 | 0.04 | 1.82 | 2.40 | 0.05 | 0.01 | 15.60 | 2.32 | 7.79 | 61.29 | 18.00 | 77.57 |
| 05/07/24 | 79.41 | 81.07 | 14.60 | 2.03 | 66.60 | 1.24 | 7.38 | 0.36 | 0.23 | 0.02 | 9.64 | 8.12 | 0.08 | 1.78 | 2.40 | 0.07 | 0.01 | 14.80 | 2.44 | 7.69 | 58.52 | 18.00 | 76.48 |
| 05/07/31 | 106.83 | 79.41 | 14.40 | 3.00 | 65.80 | 1.54 | 7.24 | 0.33 | 0.18 | 0.02 | 10.70 | 8.14 | 0.07 | 2.12 | 2.40 | 0.03 | 0.01 | 14.00 | 2.40 | 7.63 | 61.71 | 18.00 | 75.43 |
| 05/08/07 | 109.62 | 106.83 | 15.20 | 1.01 | 69.40 | 0.84 | 7.70 | 0.31 | 0.12 | 0.02 | 8.68 | 8.66 | 0.03 | 2.12 | 2.40 | 0.03 | 0.02 | 14.00 | 2.68 | 7.76 | 62.29 | 18.00 | 76.86 |
| 05/08/14 | 74.56 | 109.62 | 13.50 | 3.53 | 63.50 | 2.00 | 7.15 | 0.33 | 0.16 | 0.04 | 11.43 | 8.10 | 0.03 | 2.50 | 2.25 | 0.06 | 0.02 | 0.00 | 2.63 | 7.96 | 62.14 | 18.00 | 75.71 |
| 05/08/21 | 67.99 | 74.56 | 14.80 | 3.70 | 68.60 | 1.88 | 7.66 | 0.34 | 0.22 | 0.04 | 11.14 | 8.52 | 0.03 | 2.72 | 2.40 | 0.11 | 0.01 | 0.00 | 2.72 | 7.93 | 61.38 | 18.24 | 74.96 |

| Date | Cost | Lagcost | Ca | Al | hard | Fe | Mg | NO3 | P | NO2 | Si | Na | NH4 | Chl665 | Geosm | PO4 | Mn | SO4 | K | pH | TA | EC | NTU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05/08/28 | 87.31 | 67.99 | 13.80 | 2.38 | 63.80 | 1.33 | 7.04 | 0.26 | 0.18 | 0.03 | 9.52 | 8.10 | 0.03 | 2.70 | 3.40 | 0.05 | 0.02 | 0.00 | 2.54 | 7.93 | 63.00 | 17.98 | 75.14 |
| 05/09/04 | 73.36 | 87.31 | 13.40 | 1.81 | 62.40 | 1.17 | 6.94 | 0.26 | 0.21 | 0.06 | 9.46 | 8.06 | 0.03 | 2.90 | 3.66 | 0.03 | 0.01 | 13.20 | 2.52 | 7.92 | 57.06 | 18.07 | 73.19 |
| 05/09/11 | 73.81 | 73.36 | 13.40 | 2.90 | 62.60 | 1.70 | 6.96 | 0.29 | 0.12 | 0.04 | 11.14 | 8.00 | 0.03 | 3.20 | 7.40 | 0.12 | 0.01 | 13.00 | 2.56 | 7.92 | 61.88 | 18.02 | 70.71 |
| 05/09/18 | 83.44 | 73.81 | 13.40 | 3.20 | 62.20 | 2.12 | 6.98 | 0.26 | 0.15 | -1.00 | 10.96 | 7.90 | -1.00 | 2.78 | 3.00 | 0.05 | 0.01 | 13.00 | 2.58 | 7.83 | 64.33 | 18.00 | 68.33 |
| 05/09/25 | 93.13 | 83.44 | 13.00 | 2.49 | 60.00 | 1.54 | 6.64 | 0.21 | 0.13 | -1.00 | 10.40 | 6.84 | -1.00 | 3.94 | 4.34 | 0.04 | 0.01 | 13.00 | 2.32 | 7.70 | 64.39 | 18.07 | 67.00 |
| 05/10/02 | 73.58 | 93.13 | 13.20 | 3.94 | 61.00 | 2.18 | 6.84 | 0.09 | 0.07 | -1.00 | 12.20 | 6.34 | -1.00 | 12.64 | 23.60 | 0.04 | 0.01 | 13.80 | 2.44 | 7.74 | 65.15 | 17.60 | 67.21 |
| 05/10/09 | 70.40 | 73.58 | 13.40 | 1.68 | 60.20 | 0.75 | 6.56 | 0.33 | 0.16 | -1.00 | 7.68 | 7.56 | -1.00 | 6.47 | 8.66 | 0.04 | 0.01 | 12.40 | 2.30 | 7.67 | 66.86 | 18.00 | 68.43 |
| 05/10/16 | 86.06 | 70.40 | 14.00 | 3.00 | 62.40 | 1.02 | 6.60 | 0.29 | 0.31 | -1.00 | 9.06 | 7.84 | -1.00 | 5.42 | 9.70 | 0.05 | 0.01 | 12.80 | 2.52 | 7.97 | 62.14 | 17.98 | 69.17 |
| 05/10/23 | 77.61 | 86.06 | 13.80 | 1.47 | 61.00 | 0.67 | 6.48 | 0.26 | 0.12 | -1.00 | 7.50 | 7.22 | -1.00 | 7.98 | 8.74 | 0.03 | 0.01 | 13.00 | 2.38 | 8.07 | 58.99 | 16.92 | 68.50 |
| 05/10/30 | 77.41 | 77.61 | 13.60 | 2.74 | 61.60 | 1.66 | 6.52 | 0.15 | 0.04 | -1.00 | 8.74 | 7.08 | -1.00 | 5.40 | 9.60 | 0.03 | 0.01 | 13.20 | 2.24 | 7.95 | 59.48 | 16.83 | 72.30 |
| 05/11/06 | 77.63 | 77.41 | 13.60 | 2.52 | 61.00 | 1.17 | 6.44 | -1.00 | 0.06 | -1.00 | 8.78 | 7.14 | -1.00 | 6.92 | 19.40 | -1.00 | 0.01 | 13.29 | 2.16 | 8.04 | 61.05 | 17.00 | 66.29 |
| 05/11/13 | 83.52 | 77.63 | 13.60 | 2.26 | 60.00 | 1.06 | 6.50 | -1.00 | 0.16 | -1.00 | 8.56 | 7.20 | -1.00 | 6.42 | 22.98 | -1.00 | 0.01 | -1.00 | 2.32 | 7.98 | 61.33 | 16.83 | 66.49 |
| 05/11/20 | 76.26 | 83.52 | 14.60 | 3.90 | 64.40 | 1.62 | 6.92 | -1.00 | 0.13 | -1.00 | 9.64 | 7.54 | -1.00 | 6.98 | 8.40 | -1.00 | 0.01 | -1.00 | 2.38 | 7.86 | 63.71 | 16.93 | 67.43 |
| 05/11/27 | 70.87 | 76.26 | 14.40 | 2.59 | 63.80 | 1.00 | 6.82 | -1.00 | 0.12 | -1.00 | 7.52 | 7.42 | -1.00 | 4.12 | 3.76 | -1.00 | 0.01 | -1.00 | 2.46 | 7.69 | 62.12 | 16.60 | 68.67 |
| 05/12/04 | 67.84 | 70.87 | 14.20 | 1.60 | 62.80 | 0.85 | 6.76 | -1.00 | 0.08 | -1.00 | 6.96 | 7.30 | -1.00 | 4.14 | 5.82 | -1.00 | 0.01 | -1.00 | 2.26 | 7.90 | 63.43 | 16.29 | 74.43 |
| 05/12/11 | 54.25 | 67.84 | 14.60 | 2.22 | 65.20 | 1.09 | 7.00 | -1.00 | 0.03 | -1.00 | 7.66 | 7.50 | -1.00 | 5.36 | 3.00 | -1.00 | 0.02 | -1.00 | 2.40 | 7.89 | 63.24 | 16.71 | 81.71 |
| 05/12/18 | 53.28 | 54.25 | 14.50 | 2.88 | 65.50 | 1.05 | 7.03 | -1.00 | 0.03 | -1.00 | 7.80 | 7.53 | -1.00 | 3.83 | 4.25 | -1.00 | 0.01 | -1.00 | 2.38 | 7.82 | 64.90 | 17.00 | 83.36 |
| 05/12/25 | 69.98 | 53.28 | 14.80 | 2.58 | 67.00 | 1.29 | 7.22 | -1.00 | 0.05 | -1.00 | 8.64 | 7.84 | -1.00 | 4.46 | 19.60 | -1.00 | 0.01 | -1.00 | 2.42 | 7.88 | 70.32 | 17.09 | 84.45 |
| 06/01/01 | 74.75 | 69.98 | 15.00 | 1.85 | 66.25 | 1.01 | 7.10 | -1.00 | 0.07 | -1.00 | 7.75 | 7.80 | -1.00 | 4.00 | 4.15 | -1.00 | 0.01 | -1.00 | 2.30 | 7.93 | 74.29 | 17.00 | 87.29 |
| 06/01/08 | 87.10 | 74.75 | 13.00 | 1.88 | 60.00 | 0.95 | 6.55 | -1.00 | 0.04 | -1.00 | 8.18 | 7.48 | -1.00 | 6.23 | 4.30 | -1.00 | 0.00 | -1.00 | 2.00 | 7.69 | 74.57 | 17.00 | 86.43 |
| 06/01/15 | 88.66 | 87.10 | 13.80 | 3.12 | 62.40 | 1.47 | 6.80 | -1.00 | 0.09 | -1.00 | 8.37 | 7.88 | -1.00 | 3.60 | 6.64 | -1.00 | 0.01 | 12.70 | 2.30 | 7.36 | 70.29 | 17.00 | 96.00 |
| 06/01/22 | 60.25 | 88.66 | 14.40 | 1.30 | 60.00 | 0.80 | 5.84 | -1.00 | 0.05 | -1.00 | 7.68 | 7.34 | -1.00 | 1.52 | 4.00 | -1.00 | 0.02 | 13.67 | 2.26 | 7.43 | 57.38 | 17.00 | 117.19 |
| 06/01/29 | 82.46 | 60.25 | 14.00 | 0.53 | 61.00 | 0.34 | 6.35 | -1.00 | 0.09 | -1.00 | 5.58 | 7.43 | -1.00 | 1.93 | 3.00 | -1.00 | 0.01 | -1.00 | 2.53 | 7.74 | 56.29 | 17.43 | 96.86 |
| 06/02/05 | 72.02 | 82.46 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.20 | 59.29 | 17.57 | 80.86 |
| 06/02/12 | 87.23 | 72.02 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.57 | 58.43 | 17.79 | 78.29 |
| 06/02/19 | 97.96 | 87.23 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.06 | 59.21 | 17.43 | 68.45 |
| 06/02/26 | 96.70 | 97.96 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 7.67 | 60.43 | 17.29 | 60.43 |
| 06/03/05 | 84.00 | 96.70 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.11 | 66.57 | 17.86 | 59.71 |
| 06/03/12 | 90.92 | 84.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.26 | 68.79 | 17.43 | 64.14 |
| 06/03/19 | 96.39 | 90.92 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 9.19 | 65.67 | 17.43 | 68.36 |
| 06/03/26 | 92.87 | 96.39 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.95 | 73.90 | 17.31 | 61.24 |
| 06/04/02 | 93.42 | 92.87 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 7.89 | 54.14 | 15.43 | 65.14 |
| 06/04/09 | 124.52 | 93.42 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.40 | 57.00 | 16.49 | 63.57 |
| 06/04/16 | 92.43 | 124.52 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 8.80 | 61.09 | 17.03 | 62.71 |
| 06/04/23 | 103.16 | 92.43 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | -1.00 | 7.54 | 54.29 | 16.00 | 64.71 |
| 06/04/30 | 92.52 | 103.16 | 11.75 | 2.66 | 56.25 | 1.15 | 6.60 | 0.27 | 0.10 | -1.00 | 9.68 | 7.40 | -1.00 | 2.40 | 6.00 | 0.08 | 0.01 | 12.79 | 2.83 | 7.19 | 53.14 | 16.00 | 63.71 |
| 06/05/07 | 106.92 | 92.52 | 12.50 | 1.52 | 60.75 | 1.07 | 7.10 | 0.26 | 0.07 | -1.00 | 8.23 | 8.03 | -1.00 | 2.13 | 11.25 | 0.03 | 0.01 | 12.00 | 2.85 | 7.36 | 47.43 | 16.00 | 65.29 |
| 06/05/14 | 130.62 | 106.92 | 12.40 | 4.40 | 60.20 | 2.05 | 7.04 | 0.34 | 0.12 | -1.00 | 9.96 | 7.80 | -1.00 | 1.62 | 5.10 | 0.05 | 0.01 | 15.03 | 2.90 | 7.54 | 48.64 | 16.14 | 66.00 |
| 06/05/21 | 127.19 | 130.62 | 12.40 | 4.26 | 59.40 | 1.66 | 7.00 | 0.37 | 0.27 | -1.00 | 10.54 | 7.74 | -1.00 | 1.96 | 3.00 | 0.04 | 0.02 | 12.18 | 2.88 | 7.44 | 49.21 | 15.86 | 64.57 |
| 06/05/28 | 134.46 | 127.19 | 11.60 | 1.05 | 55.60 | 0.85 | 6.50 | 0.36 | 0.15 | -1.00 | 7.82 | 7.46 | -1.00 | 2.30 | 29.20 | 0.05 | 0.01 | 12.71 | 2.46 | 7.43 | 50.29 | 16.57 | 65.86 |
| 06/06/04 | 122.78 | 134.46 | 13.00 | 2.02 | 61.40 | 1.85 | 7.20 | 0.37 | 0.37 | -1.00 | 10.58 | 7.82 | -1.00 | 1.88 | 4.60 | 0.04 | 0.01 | 13.25 | 2.90 | 7.57 | 48.00 | 17.00 | 66.00 |
| 06/06/11 | 125.18 | 122.78 | 13.00 | 1.08 | 61.80 | 1.17 | 7.18 | 0.38 | 0.13 | -1.00 | 8.70 | 7.28 | -1.00 | 2.28 | 18.88 | 0.05 | 0.02 | 13.08 | 2.42 | 7.69 | 51.03 | 16.73 | 64.14 |
| 06/06/18 | 131.85 | 125.18 | 13.00 | 2.13 | 62.00 | 1.28 | 7.10 | 0.45 | 0.16 | -1.00 | 9.63 | 7.33 | -1.00 | 0.97 | 3.00 | 0.03 | 0.01 | 12.95 | 2.55 | 7.59 | 49.71 | 16.43 | 61.71 |
| 06/06/25 | 109.69 | 131.85 | 12.40 | 3.28 | 59.40 | 2.00 | 6.88 | 0.34 | 0.16 | -1.00 | 10.06 | 7.08 | -1.00 | 1.74 | 12.92 | 0.05 | 0.01 | 14.17 | 2.36 | 7.47 | 48.86 | 15.86 | 59.86 |

| Date | Cost | Lagcost | Ca | Al | hard | Fe | Mg | NO3 | P | NO2 | Si | Na | NH4 | Chl665 | Geosm | PO4 | Mn | SO4 | K | pH | TA | EC | NTU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06/07/02 | 123.46 | 109.69 | 12.60 | 2.68 | 61.00 | 1.65 | 7.10 | 0.43 | 0.26 | -1.00 | 10.12 | 7.32 | -1.00 | 1.64 | 2.40 | 0.09 | 0.01 | 14.80 | 2.80 | 7.49 | 51.57 | 16.43 | 60.86 |
| 06/07/09 | 115.26 | 123.46 | 13.20 | 3.34 | 63.20 | 1.59 | 7.28 | 0.42 | 0.26 | -1.00 | 9.89 | 8.08 | -1.00 | 1.24 | 2.40 | 0.05 | 0.02 | 14.77 | 2.66 | 7.39 | 45.00 | 22.57 | 60.86 |
| 06/07/16 | 113.72 | 115.26 | 13.20 | 1.79 | 62.60 | 1.30 | 7.24 | 0.39 | 0.11 | -1.00 | 8.56 | 7.92 | -1.00 | 1.26 | 14.20 | 0.07 | 0.02 | 14.20 | 2.82 | 7.61 | 50.14 | 16.43 | 60.57 |
| 06/07/23 | 119.34 | 113.72 | 12.40 | 2.21 | 60.20 | 1.27 | 6.98 | 0.38 | 0.10 | -1.00 | 8.44 | 7.48 | -1.00 | 2.28 | 16.00 | 0.08 | 0.01 | 14.88 | 2.74 | 7.50 | 49.71 | 16.43 | 60.71 |
| 06/07/30 | 131.60 | 119.34 | 12.60 | 2.38 | 60.20 | 1.51 | 6.98 | 0.44 | 0.10 | -1.00 | 9.76 | 7.56 | -1.00 | 1.64 | 2.40 | 0.07 | 0.02 | 13.68 | 2.64 | 7.41 | 52.29 | 17.00 | 61.86 |
| 06/08/06 | 128.48 | 131.60 | 13.00 | 4.12 | 62.80 | 2.50 | 7.38 | 0.30 | 0.06 | -1.00 | 9.64 | 7.76 | -1.00 | 1.52 | 2.40 | 0.05 | 0.01 | 13.54 | 2.92 | 7.59 | 51.94 | 16.64 | 65.14 |
| 06/08/13 | 120.42 | 128.48 | 12.50 | 3.25 | 59.75 | 0.96 | 6.88 | 0.29 | 0.11 | -1.00 | 8.28 | 7.28 | -1.00 | 2.15 | 2.25 | 0.03 | 0.02 | 11.19 | 3.15 | 7.63 | 54.29 | 16.71 | 64.71 |
| 06/08/20 | 117.13 | 120.42 | 13.20 | 1.44 | 61.40 | 1.20 | 6.84 | 0.39 | 0.06 | -1.00 | 10.58 | 7.60 | -1.00 | 2.96 | 3.18 | 0.03 | 0.01 | 12.80 | 3.22 | 7.74 | 55.71 | 16.57 | 64.86 |
| 06/08/27 | 109.55 | 117.13 | 11.60 | 0.70 | 54.60 | 0.79 | 6.26 | 0.26 | 0.10 | -1.00 | 7.88 | 6.92 | -1.00 | 2.62 | 4.66 | 0.04 | 0.01 | 12.20 | 2.20 | 7.57 | 56.57 | 16.71 | 65.86 |
| 06/09/03 | 107.26 | 109.55 | 11.40 | 1.21 | 54.40 | 0.91 | 6.32 | 0.31 | 0.20 | -1.00 | 8.84 | 7.04 | -1.00 | 3.38 | 5.00 | 0.03 | 0.01 | 12.60 | 2.60 | 7.50 | 57.86 | 16.86 | 65.71 |
| 06/09/10 | 167.87 | 107.26 | 11.40 | 0.83 | 54.20 | 0.88 | 6.26 | 0.32 | 0.07 | -1.00 | 8.96 | 7.04 | -1.00 | 3.16 | 6.04 | 0.03 | 0.01 | 14.20 | 2.20 | 7.57 | 58.40 | 17.79 | 64.57 |
| 06/09/17 | 112.17 | 167.87 | 11.80 | 0.46 | 56.40 | 0.68 | 6.48 | 0.30 | 0.03 | -1.00 | 7.84 | 7.34 | -1.00 | 2.80 | 3.00 | 0.03 | 0.01 | 12.40 | 2.74 | 7.44 | 58.14 | 17.71 | 64.57 |
| 06/09/24 | 100.10 | 112.17 | 12.20 | 0.81 | 57.00 | 0.82 | 6.42 | 0.30 | 0.06 | -1.00 | 9.26 | 7.10 | -1.00 | 3.32 | 3.00 | 0.07 | 0.01 | 12.20 | 2.66 | 7.66 | 55.14 | 17.79 | 64.26 |
| 06/10/01 | 93.03 | 100.10 | 12.25 | 0.34 | 56.25 | 0.46 | 6.30 | 0.30 | 0.02 | -1.00 | 7.30 | 7.18 | -1.00 | 2.30 | 6.25 | 0.03 | 0.01 | 13.00 | 0.89 | 7.77 | 55.71 | 17.21 | 63.29 |
| 06/10/08 | 92.76 | 93.03 | 11.20 | 2.01 | 53.40 | 1.52 | 6.08 | 0.38 | 0.10 | -1.00 | 10.68 | 6.90 | -1.00 | 2.34 | 4.38 | 0.06 | 0.03 | 12.40 | 2.34 | 7.76 | 55.14 | 17.71 | 61.86 |
| 06/10/15 | 114.23 | 92.76 | 11.00 | 2.12 | 53.00 | 1.55 | 6.04 | 0.36 | 0.02 | -1.00 | 8.74 | 6.76 | -1.00 | 2.08 | 3.00 | 0.09 | 0.01 | 14.20 | 2.34 | 7.71 | 55.64 | 17.14 | 60.14 |
| 06/10/22 | 85.97 | 114.23 | 11.60 | 3.64 | 54.60 | 1.43 | 6.32 | 0.38 | 0.26 | -1.00 | 10.52 | 7.36 | -1.00 | 2.68 | 6.06 | 0.08 | 0.01 | 12.40 | 2.56 | 7.63 | 55.29 | 18.14 | 59.43 |
| 06/10/29 | 91.13 | 85.97 | 11.60 | 1.14 | 46.20 | 0.89 | 7.00 | 0.33 | 0.08 | -1.00 | 9.36 | 7.46 | -1.00 | 3.76 | 0.60 | 0.15 | 0.01 | 15.20 | 2.76 | 7.47 | 57.10 | 17.41 | 58.86 |
| 06/11/05 | 89.27 | 91.13 | 10.50 | 0.50 | 51.50 | 0.43 | 5.90 | 0.30 | 0.51 | -1.00 | 10.35 | 7.40 | -1.00 | 2.30 | 0.00 | 0.07 | 0.02 | 14.00 | 2.30 | 7.40 | 57.50 | 17.00 | 56.50 |