

**An Economic Evaluation of Water Treatment Costs
in the Umgeni Catchment Area**

BY

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I hereby certify that, unless specifically indicated to the contrary in the text, this thesis is the result of my own work.

D. B. Dennison

ABSTRACT

This study has two objectives: first, to identify the main contaminants responsible for high water treatment costs in the Umgeni catchment area, and second, to predict water treatment costs from observed levels of contaminants. Reliable information about the origin of high water treatment costs is required to inform both policy and planning decisions. Partial adjustment models of water treatment costs are estimated using ordinary least squares regression and principal component analysis.

First a model is estimated for the DV Harris treatment plant, which draws water from Midmar Dam. This model highlights important policy issues and explains 61 per cent of the variation in chemical treatment costs. Environmental contaminants have a marked impact on real water treatment costs at the DV Harris plant. Water treatment costs increase when levels of alkalinity, sodium and turbidity fall. Conversely, real costs rise with higher levels of dissolved oxygen and water stability. Paradoxically, clean water - typical of Midmar Dam - is expensive to treat. Water treatment costs also rise when concentrations of the algae, *Chlorella*, decline.

Second, a model is estimated for the Durban Heights treatment plant, which draws water from Nagle and Inanda Dams. This model explains 68 per cent of the variation in chemical treatment costs. Biological contaminants have a marked impact on real water treatment costs at the Durban Heights plant. Again,

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water treatment costs increase when levels of, *Chlorella* fall. Apparently the level of *Chlorella* varies inversely with the level of other, more expensive, contaminants at both treatment plants. Conversely, real costs rise with higher levels of total kjeldahl nitrogen, temperature, *Anabaena* and *Microcystis*. Water treatment costs also rise when turbidity and concentrations of silica, suspended solids and iron increase.

The model predicts actual water treatment costs well (except during occasional peak cost periods) and provides a useful tool for scenario testing. For example, a simulation exercise in which turbidity levels were held constant at 6 NTU (nephelometric turbidity units) indicated an annual saving of R54 531 in water treatment costs.

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INTRODUCTION

The enrichment of scarce water resources with plant nutrients such as phosphorus and nitrogen, generally known as eutrophication, creates many problems for development in South Africa (O'Keeffe *et al.*, 1992; Haynes and Viljoen, 1985). The main consequence of eutrophication is abundant algal growth, which can lead to increased water treatment costs. The real average costs of water treatment have been increasing at Umgeni Water, a parastatal that manages water supply in the Umgeni catchment area of KwaZulu-Natal. This study has two objectives: first, to identify the main contaminants responsible for high water treatment costs in the Umgeni catchment area, and second, to predict water treatment costs from observed levels of contaminants. Water treatment costs refer to financial costs incurred in ensuring that the water is potable. In 1995, Umgeni Water spent R 8 046 252 on chemicals for the purification of drinking water (Umgeni Water, 1994 -1995).

A partial adjustment model is used to analyse the cost of chemicals applied at the treatment plants: DV Harris, which draws water from Midmar Dam, and the Durban Heights plant, which draws water from Nagle and Inanda Dams. Raw water stored in the latter, coastal, impoundments can become highly eutrophic relative to the 'clean' water entering Midmar Dam. As a result, treatment problems and costs differ markedly between the DV Harris and Durban Heights plants. Costs were therefore analysed separately at each plant.

Umgeni Water is currently developing a model that relates algae concentrations to various environmental factors. The results of the economic and algae/environment models will be combined in a later study to explore links between land use activities, water quality and water treatment costs. Reliable information about the origin of high water treatment costs is required to inform both policy and planning decisions.

The first chapter of this thesis describes the problems facing water managers. Increasing levels of pollution in the catchment area, and the resulting deterioration in quality of water stored in impoundments, lead to rising water treatment costs to meet the customers' requirements for drinking water. The second chapters rationalises the use of a partial adjustment model to analyse water treatment costs. Chapters 3 and 4 present the results estimated for DV Harris and Durban Heights respectively. Principal component analysis was used to overcome the problem of multicollinearity using the method described by Chatterjee and Price (1977) and Nieuwoudt (1972) and the resulting coefficients were converted back to original units following the method suggested by Kendall (1957).

CHAPTER 1

THE PROBLEM IN CONTEXT

Policy-makers can attempt to influence the demand for, or supply, of scarce water resources (Mirrilees *et al.*, 1994). Demand management involves mechanisms such as quotas, property rights, water markets and other allocative institutions. However, these are beyond the scope of this study. In managing supply, “water authorities and engineers have traditionally tried to alleviate shortages by making more and better resources available” (Mirrilees *et al.*, 1994: appendix A.1-2). In other words, water managers are concerned with both the *quantity* and the *quality* of water as determinants of the available water supply. This study focuses on the quality aspect. If water is of poor quality it may not be readily or realistically available for use, and treatment may be very time consuming or prohibitively expensive.

1.1 Causes of water quality deterioration

Whereas the quantity of water is largely determined stochastically by natural phenomena, the quality of water is greatly influenced by human activities.

These are known as *anthropogenic effects* (Breen *et al.*, 1985) and include:

- *Land use patterns*: Changes in farming practices, formal and informal settlements, and industrial growth have an impact on water quality.

- **Flow management:** Water quality in a river is governed by the interaction between nutrient load and river processes. Interruptions to the free flow of a river, either by impoundment or abstraction, affect the quality of its water. Impoundments can affect water quality both positively, by acting as nutrient and sediment traps, and negatively, as the retention of water can allow problem algae to proliferate. Abstractions too, can increase the nutrient load by reducing the rate of flow (Mirrilees *et al.*, 1994).
- **Effluent discharge:** Increases in effluent discharged from sewage treatment plants and industry can have a detrimental effect on water quality by increasing the load of nutrients and pollutants.

The three main sources of local water pollution as described by Umgeni Water (1994 - 1995) are:

- **Industrial waste:** Oils, solvents, acids, alkalis and metals.
- **Agricultural waste:** Nutrients from fertiliser run-off, pesticides and suspended solids from soil run-off.
- **Domestic effluent:** Disease-bearing faecal bacteria, nutrients and organic material.

For policy purposes, these sources are usually categorised into two classes:

- **Point source pollution** enters the water-way at a particular traceable point, *e.g.* industrial effluent and domestic effluent being released from a sewage treatment plant.

- **Nonpoint source pollution** originates from diffuse sources that are not easily identifiable or distinguishable, *e.g.* nutrients from fertiliser run-off and sewage run-off from informal settlements.

According to Dickens (1996) both point and nonpoint sources are equally important in the Umgeni catchment area (Figure 1.1). The main contributors to point source pollution are sewage works and industrial waste. Much of this pollution can be traced to the Darvill sewage works and factories in Pietermaritzburg. Effluent is discharged into the Msunduzi River which feeds into Inanda Dam.

Large areas of farmland and informal settlements contribute to nonpoint source pollution in the catchment area. Most of the arable land is planted to timber, sugarcane and pasture for dairy production. Large informal settlements stretch along the banks of the Msunduzi and Mgeni Rivers, from Pietermaritzburg to the coast.

1.2 Consequences of water quality deterioration

There are several consequences of water pollution. The first of these is aesthetic, with unsightly litter, oil scums and foam patches resulting from pollution. Second, water becomes stagnant and aquatic life cannot survive in these conditions. The third consequence of poor water quality is the health risk. Water-borne microbes detected in the Umgeni catchment include those that

UMGENI WATER - MAIN OPERATIONAL AREA MAY 1994

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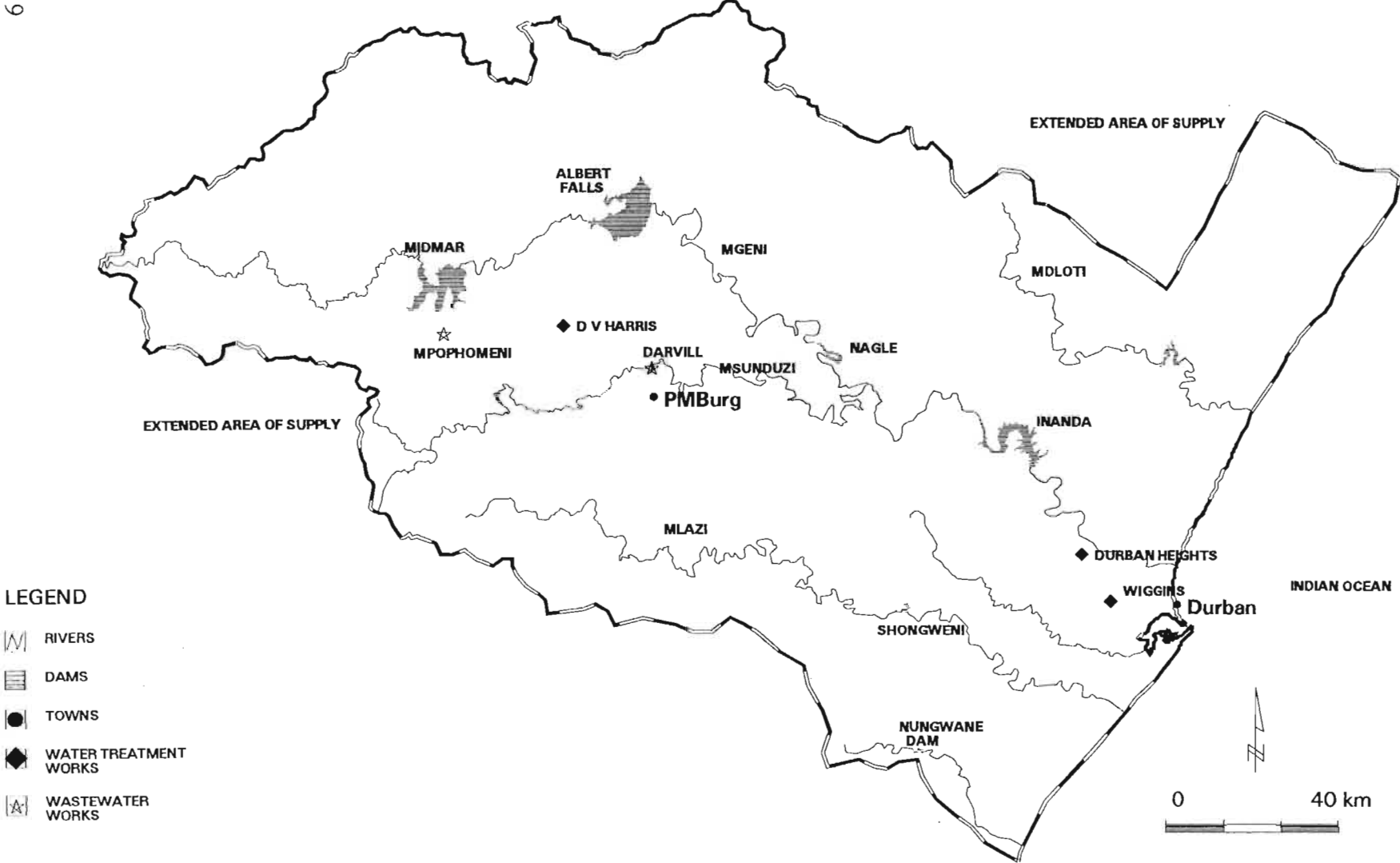


Figure 1.1 Umgeni Water Main Operational Area - 1994

cause cholera, typhoid, dysentery and infectious hepatitis (Umgeni Water, 1994 - 1995).

Eutrophication is another well-documented result of the human impact upon aquatic ecosystems (Wetzel, 1983). It refers to the process of nutrient enrichment, originating mainly from treated and untreated sewage and agricultural run-off (Umgeni Water, 1994 -1995), and an associated increase in primary nutrient production (O'Keeffe *et al.*, 1992). A symptom of eutrophication is the over-abundant increase in algae, aquatic plants or both (Bruwer, 1979).

The following problems have been experienced as a result of eutrophication (Bruwer, 1979; Palmer 1980; Haynes and Viljoen, 1985):

- ***Increased cost of water treatment*** to potable standards. Costs increase due to increased demand for treatment chemicals and decreased length of filter runs. All the usual treatment chemicals (section 1.3) are used in greater quantities and activated carbon may also be necessary to eliminate taste and odour problems caused by blue-green algae. Filters get clogged with algae and treated water is wasted on frequent backwashing.
- ***The production of anaerobic hypolimnia*** in lakes. This occurs when large numbers of algae die at the same time and consume oxygen in the water as they decompose. This has adverse effects on lake biota - especially oxygen dependent organisms - and lake chemistry.

- *Aesthetic problems* such as large unsightly algal blooms.
- *Interference with the recreational use of water bodies.* Algal blooms interfere with the recreational use of water bodies and degrade the beauty of the area. Blue-green algae may cause skin irritations and gastro-enteritis in swimmers.
- *Loss of livestock* as a result of algal toxins produced by certain algae.
- *Fish deaths* due to toxin-producing algal blooms.
- *Adverse effects on adjacent real estate development.* Property developments next to water bodies may suffer rapid depreciation if the water quality deteriorates causing aesthetic problems; for example the Marina da Gama in Muizenburg, where unsightly blooms and bad odours became problematic (Bruwer, 1979).

Of concern in this analysis is the fact that water pollution exacerbates eutrophication which leads to increased algal growth and high water treatment costs to ensure the provision of potable water. A brief description of the treatment process is relevant at this point as it lends perspective to the models presented in chapters 3 and 4.

1.3 The treatment process

Water extracted from dams and rivers via pipelines and tunnels is passed through wire screens to remove any solid objects. As the water enters the treatment plant

a sample of it flows through a series of recording instruments. These measurements determine the appropriate dosage of treatment chemicals. The amount of sediment suspended in the water is a key determinant of its treatment cost because it defines the level of polymer needed to coagulate suspended particles and dirt into floc (Umgeni Water, 1994-1995). Lime may also be required to adjust the pH to a level at which the polymer works optimally. Bentonite - a type of clay - must be added if the water is 'too clean', *i.e.* if there are too few sediment particles for the floc to form effectively (Graham, 1995). Powdered activated carbon is added when necessary to remove bad tastes and odours caused by algae and other contaminants. Clear water is skimmed off and passed through graded sand filters which remove all remaining suspended matter. Finally, chlorine, is added to kill any remaining microbes (Umgeni Water, 1994 -1995). Chlorine is usually applied in gaseous form and may be mixed with ammonia when the water has a long way to travel. Ammonia helps to extend the effectiveness of the chlorine gas at the inland plants (Graham, 1995).

Bentonite improves the efficiency of polymer when the water is 'too clean'. In effect, bentonite is a substitute for polymer. Figure 1.2 shows that changes in water treatment costs at the DV Harris plant follow changes in the combined cost of bentonite (B) and polymer (P). This result was predictable because Midmar Dam is characterised by relatively clean water.

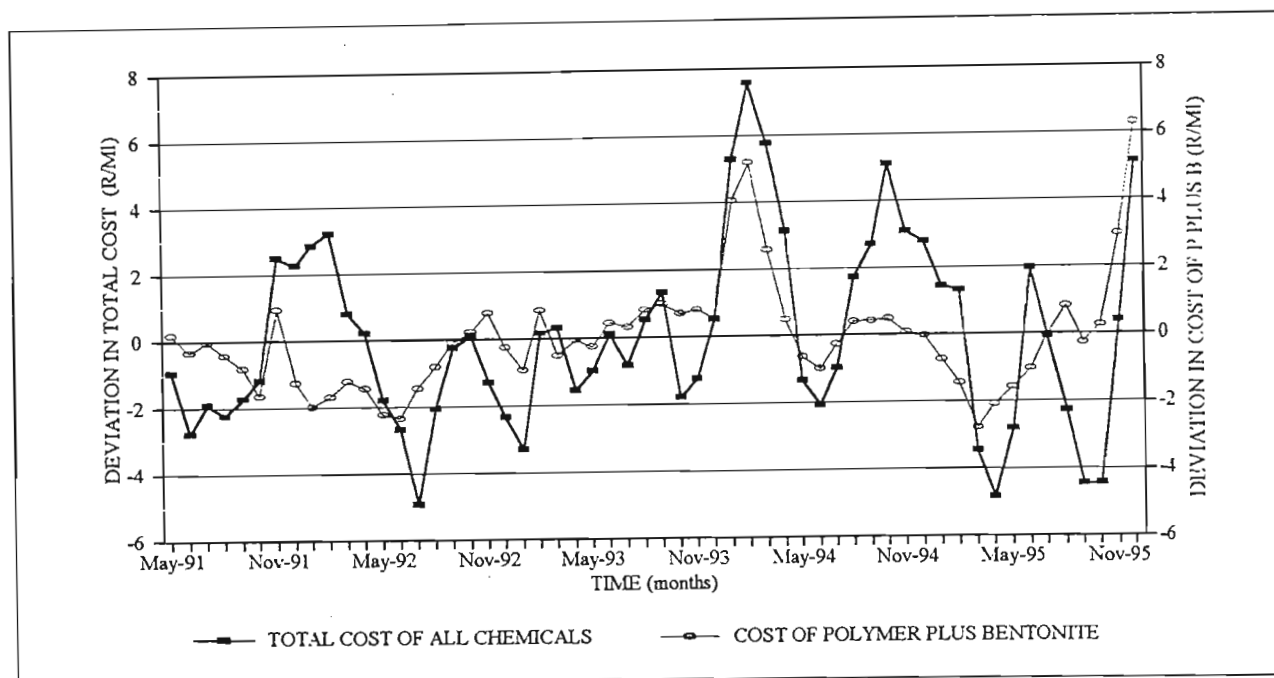


Figure 1.2 Deviations in the total cost of all chemicals and in the cost of polymer plus bentonite at the DV Harris plant

Total water treatment costs refer only to expenditure on chemicals. The cost of backwashing was excluded because Umgeni Water does not make short-term adjustments to the time spent backwashing.

CHAPTER 2

METHODOLOGY: PARTIAL ADJUSTMENT REGRESSION MODEL

A distributed lag model has intuitive appeal for analysing water treatment costs because cost incurred in one period is a function of nutrient loads in previous periods. In this case, the distributed lag model can be rationalised as an autoregressive partial adjustment model (Gujarati, 1988: 515; Kelejian and Oates, 1989) and estimated using ordinary least squares regression (Gujarati, 1988: 519).

For convenience assume that there is only one explanatory variable, nutrient load, denoted as X in equation 1.

$$Y_t = \alpha + \beta_0 X_t + \beta_1 X_{t-1} + \beta_2 X_{t-2} + \dots + u_t \quad (1)$$

A distributed lag model can be “converted” to an autoregressive model using the *Koyck transformation* (Gujarati, 1988: 515). Although current cost depends on the nutrient loads in earlier periods, the impact of the load in the more distant past is less than that of the load in more recent periods. More specifically, current cost is a weighted sum of present and past loads (plus a disturbance term), where the weights diminish successively for more distant periods (Kelejian and Oates, 1989). Koyck assumes that the lag effects decline geometrically as follows:

$$\beta_k = \beta_0 \lambda^k \quad k = 0, 1, \dots, n \text{ distant time periods} \quad (2)$$

where λ , such that $0 < \lambda < 1$, is known as the *rate of decline, or decay*, of the distributed lag and where $1 - \lambda$ is known as the *speed of adjustment*. Substituting equation 2 into equation 1 yields :

$$Y_t = \alpha + \beta_0 X_t + \beta_0 \lambda X_{t-1} + \beta_0 \lambda^2 X_{t-2} + \dots + u_t. \quad (3)$$

Equation 3 postulates that current cost levels depend on both present and past nutrient loads, but since λ raised to higher powers becomes continually smaller, coefficients (β_k) become progressively smaller for periods reaching back in time (Kelejian and Oates, 1989). Expressed this way, the model is not amenable to easy estimation as there are a large number of parameters to be estimated and the parameter λ enters in a highly non-linear form.

Koyck suggested an ingenious simplification by lagging equation 3 to obtain:

$$Y_{t-1} = \alpha + \beta_0 X_{t-1} + \beta_0 \lambda X_{t-2} + \beta_0 \lambda^2 X_{t-3} + \dots + u_{t-1}. \quad (4)$$

Multiplying equation 4 by λ and subtracting the product from equation 3 yields:

$$Y_t - \lambda Y_{t-1} = \alpha(1-\lambda) + \beta_0 X_t + (u_t - \lambda u_{t-1}). \quad (5)$$

Rearranging terms, equation 1 can be expressed in its autoregressive form:

$$Y_t = \alpha(1-\lambda) + \beta_0 X_t + \lambda Y_{t-1} + v_t \quad (6)$$

where $v_t = (u_t - \lambda u_{t-1})$, a moving average of u_t and u_{t-1} .

This autoregressive version of equation 1 is particularly useful when estimating partial adjustment models using ordinary least squares regression. In this case, the partial adjustment model postulates that actual treatments are intended to satisfy minimum rather than optimum standards of water quality. Consequently, the desired or optimum level of treatment and its associated cost Y^* is unobservable:

$$Y^* = \beta_0 + \beta_1 X_t + u_t \quad (7)$$

Nerlove (1958 as cited by Gujurati, 1988) expresses the partial adjustment model as follows:

$$Y_t - Y_{t-1} = \delta(Y_t^* - Y_{t-1}) \quad (8)$$

where δ , such that $0 < \delta \leq 1$, is known as the *coefficient of adjustment* and where $Y_t - Y_{t-1}$ = actual change and $(Y_t^* - Y_{t-1})$ = desired change. Equation 8 shows that the actual change in costs in period t is some fraction δ of the optimum change in cost. If $\delta = 1$, it means that the actual cost is equal to the optimum cost, *i.e.* actual cost adjusts to the optimum level in the same time period. If $\delta = 0$, it means that nothing changes since the actual cost at time t is the same as that observed in the

previous time period. Typically, δ is expected to lie between these extremes because treatments are aimed at meeting minimum rather than optimum standards of water quality. The partial adjustment model can also be written as:

$$Y_t = \delta Y_t^* + (1 - \delta)Y_{t-1} \quad (9)$$

showing that the observed cost at time t is a weighted average of the 'optimum' cost at that time and the cost observed in the previous time period, δ and $(1 - \delta)$ being the weights. Substitution of equation 7 into equation 9 yields the partial adjustment model in its estimable form:

$$\begin{aligned} Y_t &= \delta(\beta_0 + \beta_1 X_t + u_t) + (1 - \delta)Y_{t-1} \\ &= \delta\beta_0 + \delta\beta_1 X_t + (1 - \delta)Y_{t-1} + \delta u_t. \end{aligned} \quad (10)$$

Equation 6, when compared to equation 1, allows for better maintenance of the degrees of freedom but there are also some problems which need to be addressed; Y_{t-1} , like Y_t is stochastic, which means that the model includes a stochastic explanatory variable and the error term v_t could be serially correlated if the error term u_t in the original model was serially correlated (Gujurati, 1988: 523-524).

CHAPTER 3

THE DV HARRIS TREATMENT PLANT

The DV Harris plant draws water from Midmar dam, an inland impoundment characterised by clean water. Midmar dam's catchment area comprises mostly extensive grazing and afforested land; and a single township at Mpophomeni which has a sewerage treatment plant. However, the water in Midmar dam becomes more expensive to treat when it is supplemented with water pumped from the Mooi River.

3.1 Data source

All data used in this study were sourced from Umgeni Water. Observations were recorded at regular intervals over a period of six years, 1990 to 1995. Water quality data and dosage rates were supplied by Umgeni's Water Quality Department. Water chemistry and algae data are accredited by the South African Bureau of Standards and ISO 9000. Cost data, measured at 1995 prices, were supplied by their Purchasing Department (Appendix I). Prices relate to the brand of chemicals used most frequently as substitutes involve similar costs per unit of water treated (Graham, 1995). Costs were expressed per megalitre (ML) of water treated, and refer only to expenditure on chemicals (section 1.3).

All observations recorded at the Midmar site, at the dam wall, were expressed in monthly terms to coincide with monthly measures of chemical usage

(Appendix II). Unfortunately, chemical dosage data were recorded only from May 1991 to December 1995 at the DV Harris plant, reducing the number of valid observations from 71 to 52.

3.2 Variables selected for DV Harris treatment plant

Descriptive statistics were calculated and checked by Umgeni staff to ensure that the data had been correctly captured. The observations spanned 79 different algae and 51 environmental variables. In order to isolate the contaminants most closely associated with cost, zero-order correlation coefficients were computed and those with significant coefficients were selected for further analysis. The literature was also checked to ensure that algae and other contaminants recognised as being problematic were not omitted (Collingwood, 1980; Palmer, 1980 and Walker, 1983).

The variables selected for analysis at the DV Harris plant are presented in Table 3.1. Although cost was significantly correlated with biological oxygen demand and sunlight hours, these variables were omitted owing to a large number of missing values. Nitrite, a potential contaminant, was also excluded because there was no variation in the level of nitrite observed at Midmar Dam.

Table 3.1 Correlation coefficients for important algae and environmental variables at the DV Harris plant

VARIABLE		UNITS	Correlation with COST
Chlorella	(CHLEL)	cells per ml	-0.4590**
Crucigenia	(CRUCI)	cells per ml	-0.3049*
Gonium	(GONIU)	cells per ml	0.2870*
Alkalinity	(ALKAL)	mg/l CaCO ₃	-0.5232**
Sodium	(NA)	mg/l	-0.3114**
Percentage Dissolved	(PDO)	%	0.4193**
Oxygen			
Secchi	(SECC)	m	0.3252**
Stability	(STAB)	10 ⁻⁴ S ⁻²	0.4482**
Temperature	(TEMP)	°C	0.3864**
Turbidity	(TURB)	NTU	-0.3692**
Pumping	(PUMP)	MI	0.3537**
Trend Variable	(NUM)	Month	0.1211

Notes: * implies significance at the 5% level of probability

** implies significance at the 1% level of probability

Biological systems are inherently interrelated, as similar species react in similar ways under the same conditions and all species compete for available nutrients. The dynamic nature of this system means that the relationship between individual species and water treatment costs cannot easily be predicted.

Alkalinity is expected to have a negative impact on the cost of treating Midmar water. As alkalinity increases so the quantity of lime needed decreases, decreasing the costs of water treatment.

When the level of sodium is low, the level of dissolved charged particles is also low and renders the polymer inefficient. This necessitates the addition of bentonite (Graham, 1996) and explains the inverse relationship between sodium and water treatment costs at the DV Harris plant.

Stability is a measure of the stability of the water column. In summer, when the top layer of water is warmer than water at the bottom of the dam, the water stratifies reducing currents and increasing stability. In winter, when the top layer of water cools, all the water is of the same temperature and the wind is able to cause convection currents. These currents stir up sediment from the bottom of the dam. This suggests a negative relationship between stability and water treatment costs. However, the effect is reversed when the water is particularly clean because bentonite has to be added for effective treatment. This situation is typical of Midmar Dam and explains the positive correlation between stability and water treatment costs.

Turbidity measures the amount of light either absorbed or scattered by particles suspended in the water sample. Consequently, turbidity rises with the level of sediment found in an impoundment. While this would appear to suggest a positive relationship between turbidity and water treatment costs, the effect is reversed at DV Harris because water from Midmar Dam is 'too clean' and bentonite has to be added to make the flocculent effective. Secchi reports the depth at which a metal disc lowered into the dam is last visible. It is therefore an

inverse measure of suspended solids and is expected to impact positively on the cost of treating water that is 'too clean'.

As anticipated, temperature is positively correlated with water treatment costs because it captures seasonal effects. Water treatment costs increase in summer when higher levels of runoff add to nutrient loads and pollutants found in the storage dams.

The variable PUMP, which is positively correlated with water treatment costs, measures the quantity of water pumped from the Mooi River to Midmar Dam. Past experience has shown that water treatment costs rise when pumping occurs, but the exact reasons for this have yet to be established (Freese, 1995). Similarly the causal relationship between percentage dissolved oxygen and water treatment costs is not well understood. The trend variable (NUM) measures long-term changes in water treatment costs and was retained for analysis in order to isolate the variables responsible for short-term variations in water treatment costs.

3.3 Results estimated for the DV Harris plant

Results of the model estimated for the DV Harris plant are presented in Table 3.2. Explanatory power is reasonably good ($R^2=64\%$) but the t -values are extremely low. This is a classic symptom of the multicollinearity anticipated in the model (Gujurati, 1988: 299). The variable LCOST represents water treatment costs lagged by one period. In terms of the partial adjustment model, the coefficients

estimated for this variable represents the share of the optimum level of treatment which is not achieved during the current period.

Principal component analysis was employed to overcome the problem of multicollinearity (Chatterjee and Price, 1977). This technique converts the original variables into uncorrelated variables called principal components, PC's.

Table 3.2 Regression coefficients estimated for contaminants before removing multicollinearity: DV Harris plant

Explanatory Variables	Coefficients (β_i)	<i>t</i> -values
Constant	23.0538	2.29**
CHLEL	-0.0033	-1.39
CRUCI	-0.0013	-0.67
GONIU	-0.0075	-0.25
ALKAL	-0.3813	-1.51
NA	-0.4561	-0.42
PDO	0.0298	0.53
SECC	0.4708	0.52
STAB	0.1463	0.55
TEMP	0.0335	0.23
TURB	0.0699	0.59
PUMP	0.0019	0.24
NUM	-0.0043	-0.18
LCOST	0.4288	2.57**
R ² (%)	64.06	
F	5.07**	

Notes: * implies significance at the 5% level of probability

** implies significance at the 1% level of probability

PC's are linear combinations of the original variables:

$$PC_i = a_{i1}X_1 + a_{i2}X_2 + \dots + a_{ik}X_k$$

where $PC_i = i$ th principal component

$a_{ij} =$ component loadings¹

$X_j =$ original variables

The principal components must satisfy two conditions; they must be orthogonal and the first component (PC_1) should account for the maximum proportion of variation in the original variables. Each subsequent PC should account for the maximum remaining variation in the original variables. A correlation matrix was used to derive the principal components because the units of measure differed between variables. Successive principal components were dropped until sign and magnitude of each estimated coefficient stabilised. Following this approach, a total of seven principal components were retained, accounting for almost 90 percent of the variation in the original variables. The loadings estimated for the retained PC's are presented in Table 3.3.

¹ SPSS (Norusis, 1994) normalises factor loadings such that the squared loadings sum to the eigen value. The factor loadings were manually adjusted so that the squared loadings summed to unity.

Table 3.3 Component loadings estimated for the seven principal components retained: DV Harris plant

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7
CHLEL	-0.4264	0.7406	-0.0508	-0.0480	0.1449	0.0668	0.0431
CRUCI	-0.3965	-0.1303	0.2054	0.5318	0.3582	-0.4842	0.3380
GONIU	0.3774	-0.1996	-0.0437	-0.4481	0.6554	0.2424	0.3221
ALKAL	-0.5246	0.4761	0.0854	0.2554	0.1894	0.3938	0.0087
NA	-0.3705	0.4502	0.6355	-0.0707	0.0379	0.2087	-0.0761
PDO	0.5177	0.0979	0.5959	-0.3598	-0.2249	-0.1214	0.1549
SECC	0.6549	0.4863	-0.3651	0.2071	0.0981	0.0259	-0.0088
STAB	0.6577	0.1487	0.6342	0.0001	0.0988	-0.1583	-0.1194
TEMP	0.7418	0.3337	0.2307	0.3611	-0.0583	0.0609	0.1463
TURB	-0.7333	-0.4290	0.2757	-0.2379	-0.0542	0.1149	0.1271
PUMP	0.5134	-0.3859	0.0236	0.3520	-0.3139	0.4441	0.3312
NUM	0.1053	-0.6071	0.3265	0.3774	0.3281	0.2026	-0.4029
LCOST	0.8046	-0.0136	-0.1806	-0.1803	0.2326	-0.0389	-0.1637
Eigen Value	4.0334	2.1158	1.6175	1.2143	0.9527	0.7935	0.6004
% Variance	31.0	16.3	12.4	9.3	7.3	6.1	4.6
Cum. %	31.0	47.3	59.7	69.1	76.4	82.5	87.1

The regression models were then re-estimated using the principal components as explanatory variables and standardised COST (ZCOST) as the dependent variable. Results are presented in Table 3.4.

Table 3.4 Regression coefficients estimated for principal components: DV
Harris plant

Explanatory Variables	Coefficients (α_i)	<i>t</i> - values
Constant	0.000025	0.00
PC1	0.3665	7.73**
PC2	-0.1662	-2.45**
PC3	0.0032	0.04
	-0.1621	-1.87
PC5	-0.0173	-0.18
PC6	-0.0895	-0.84
PC7	-0.0654	-0.53
R ²	61.16%	

Notes: * implies significance at the 5% level of probability

** implies significance at the 1% level of probability

No attempt was made to interpret the principal components because they were employed only to combat multicollinearity and not for predictive or policy purposes. To accomplish these goals, the models presented in Table 3.4 were expressed in terms of the original variables following the procedure described by Chatterjee and Price (1977) and Nieuwoudt (1972). This procedure uses the component loadings to transform the regression coefficients estimated for the

principal components into standardised estimates for the original variables. For example, the standardised coefficients of CHLEL and ALKAL were computed as follows:

$$b_1 = 0.4264a_1 + 0.7406a_2 - 0.0508a_3 - 0.0480a_4 + 0.1449a_5 + 0.0668a_6 \\ + 0.0431 a_7$$

$$b_2 = -0.5246a_1 + 0.4761a_2 + 0.0854a_3 + 0.2553a_4 + 0.1894a_5 + 0.3938a_6 \\ + 0.0087a_7$$

where $a_1=0.3665$, $a_2=-0.1662$, $a_3= 0.0032$, $a_4=-0.1621$, $a_5=-0.0173$,
 $a_6=-0.0895$, $a_7=-0.0654$.

Table 3.5 presents the standardised regression coefficients for the original explanatory variables. The t -values were computed as

$$\frac{b_i}{\sqrt{\text{Var}(b_i)}}$$

where
$$\text{Var}(b_i) = \sum_{i=1}^k ((\text{PC loading}_i)^2 * \text{Var}(\alpha_i))$$

k = the number of principal components retained.

Table 3.5 Standardised regression coefficients estimated for contaminants after removing multicollinearity: DV Harris plant

Explanatory Variables	Coefficients (b_i)	t -values
CHLEL	-0.1685	-4.16**
CRUCI	-0.1215	-1.25
GONIU		0.98
ALKAL	-0.2312	-3.82**
NA	-0.1224	-2.34*
PDO	0.1409	2.37*
SECC	0.0291	0.73
STAB	0.1289	2.58*
TEMP	0.0274	0.59
TURB	-0.0707	-1.60
PUMP	0.0191	0.22
NUM	0.0415	0.47
LCOST	0.1882	4.29**
R^2	61.16%	

Notes: * implies significance at the 5% level of probability

** implies significance at the 1% level of probability

These standardised coefficients (b_i) are useful for policy purposes because they are independent of the original units of measurement and therefore show the relative importance of each explanatory variable to changes in cost (Nieuwoudt, 1972). The contaminants that have the greatest impact on water treatment costs, in descending order, are alkalinity, *Chlorella*, percentage dissolved oxygen, stability, and sodium.

However, for predictive purposes the standardised variables were converted to original scale using the method proposed by Kendall (1957). The b_i 's were multiplied by S_y/S_{x_i} (the standard deviation of the dependent variable divided by the standard deviation of the independent variable) and the constant term was calculated as the difference between the mean values of the observed and predicted costs. Table 3.6 presents the regression coefficients computed for the original variables measured in their original units.

The Durbin h statistic computed for the final model exceeds 1.96. Consequently, the null hypothesis that there is no autocorrelation cannot be rejected at the five per cent level of probability. However, the Geary Runs statistic fell within its 95 per cent confidence limits so autocorrelation was not considered to be a significant problem (Gujurati, 1995: 420).

Table 3.6 Unstandardised regression coefficients estimated for contaminants before and after removing multicollinearity: DV Harris plant

Explanatory Variables	Original Model	<i>t</i> -values	Final Model	<i>t</i> -values
Constant	23.0538	2.29**	32.1503	
CHLEL	-0.0033	-1.39	-0.0026	-4.16**
CRUCI	-0.0013	-0.67	-0.0021	-1.25
GONIU	-0.0075	-0.25	0.0241	0.98
ALKAL	-0.3813	-1.51	-0.4408	-3.82**
NA	-0.4561	-0.42	-0.9485	-2.34*
PDO	0.0298	0.53	0.0471	2.37*
SECC	0.4708	0.52	0.1216	0.73
STAB	0.1463	0.55	0.1439	2.58*
TEMP	0.0335	0.23	0.0192	0.59
TURB	0.0699	0.59	-0.0355	-1.60
PUMP	0.0019	0.24	0.0011	0.22
NUM	-0.0043	-0.18	0.0075	0.47
LCOST	0.4288	2.57**	0.1977	4.29**
R ² (%)	64.06		61.16	
Durbin <i>h</i>			2.16	

Notes: * implies significance at the 5% level of probability

** implies significance at the 1% level of probability

Although the final model presented in Table 3.6 exhibits some loss in explanatory power when compared to the original model, it is clear that the original model was severely affected by multicollinearity. In particular, the t -values created the false impression that none of the contaminants had any significant effect on water treatment costs. Despite the loss in predictive power, the final model was considered to be a more robust predictor of water treatment costs owing to the absence of multicollinearity. Figure 3.1 shows a reasonable match between actual and predicted costs.

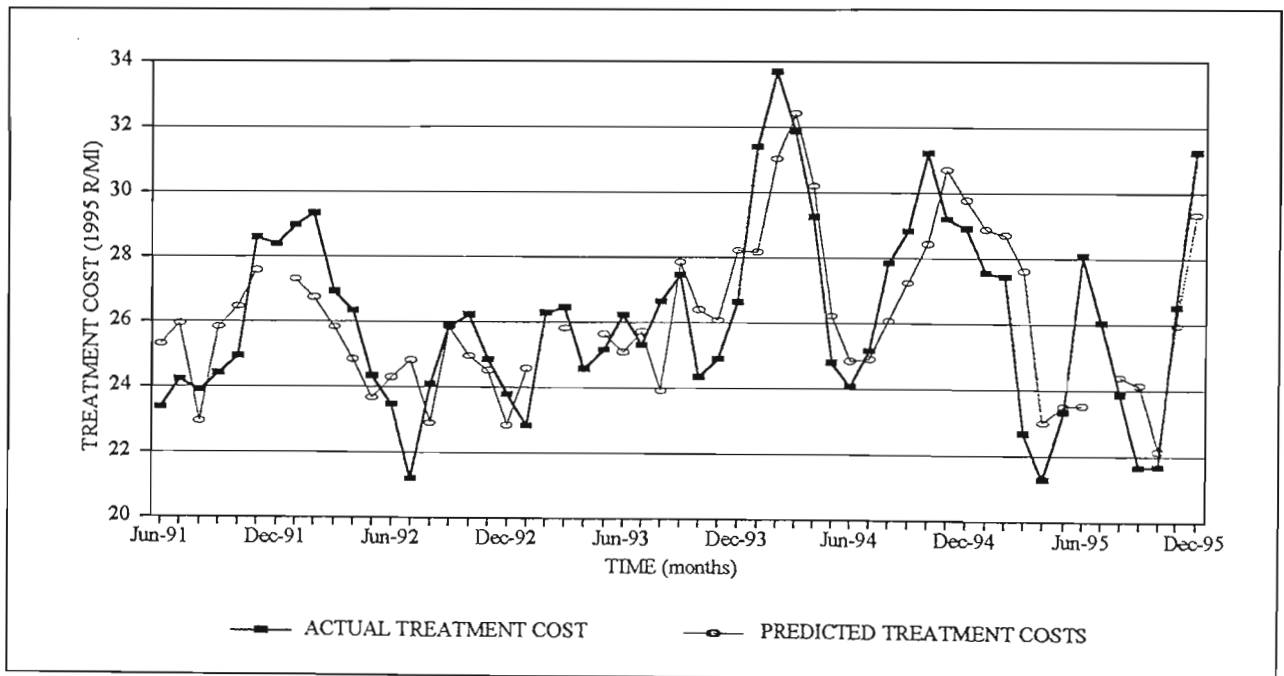


Figure 3.1 Predicted versus actual water treatment costs for the DV Harris plant (constant 1995 Rands)

3.4 Discussion

The results suggest that real water treatment costs at the DV Harris plant diminish with an increase in the quantity of *Chlorella* in Midmar Dam (Figure 3.2). It would seem that the quantity of *Chlorella* varies inversely with the quantity of one or more substitutes, and that the (unobserved) substitutes may pose a serious management problem. For example, *Chlorella* may be consuming nutrients that would otherwise contribute to an increase in water treatment costs. More research is needed to unmask the harmful substitutes that vary inversely with *Chlorella*.

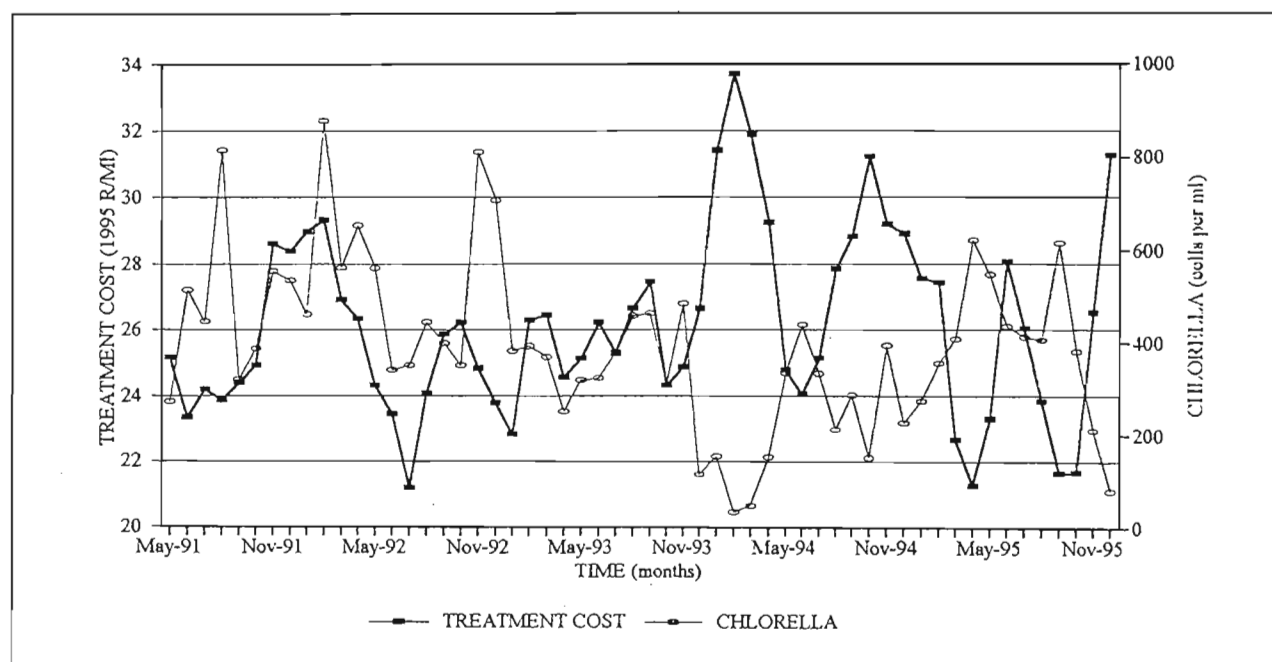


Figure 3.2 Water treatment costs versus *Chlorella* concentration: DV Harris plant

Figure 3.3 illustrates the negative relationship between alkalinity and water treatment costs at DV Harris. Surprisingly, alkalinity is not significantly correlated with the cost of lime but is correlated with the cost of polymer and bentonite. The cause of this relationship is not obvious and requires further investigation.

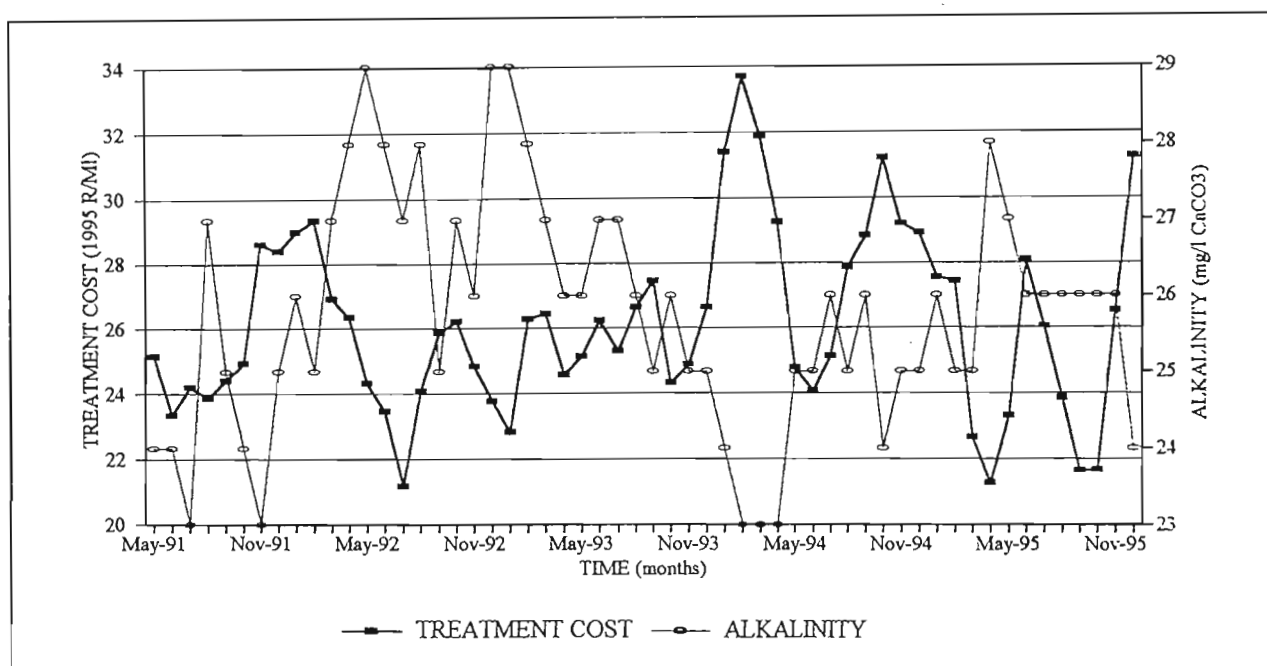


Figure 3.3 Water treatment costs versus alkalinity: DV Harris plant

Water treatment costs rise with increasing stability (Figure 3.4) and decreasing turbidity. These relationships and the negative effect of increased sodium levels on water treatment costs highlight the paradox of treating water that is 'too clean'.

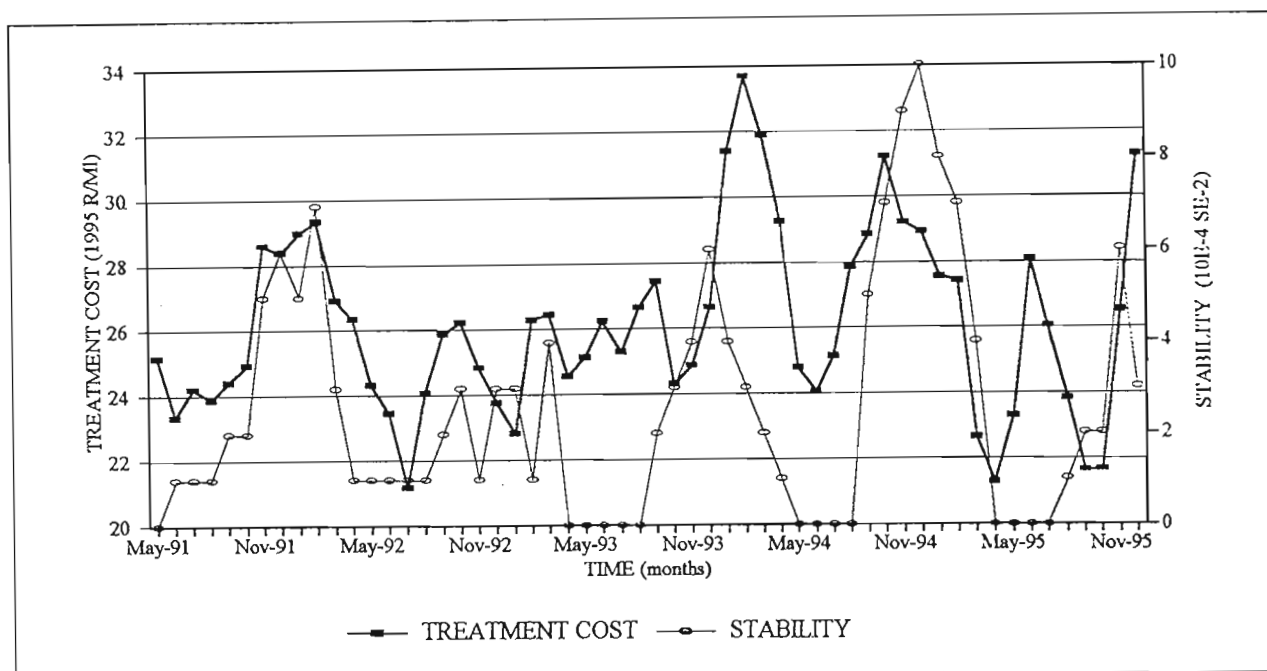


Figure 3.4 Water treatment costs versus stability: DV Harris plant

Percentage dissolved oxygen bears positively on water treatment costs at DV Harris plant. The reasons for this positive relationship (illustrated in Figure 3.5) are unclear and require further investigation by water treatment experts. Lagged cost has no policy implications. Its coefficient suggests that 80 per cent (*i.e.* 1-0.1997) of the “full” treatment cost required to achieve optimal (rather than minimal) water quality is incurred in the space of one month.

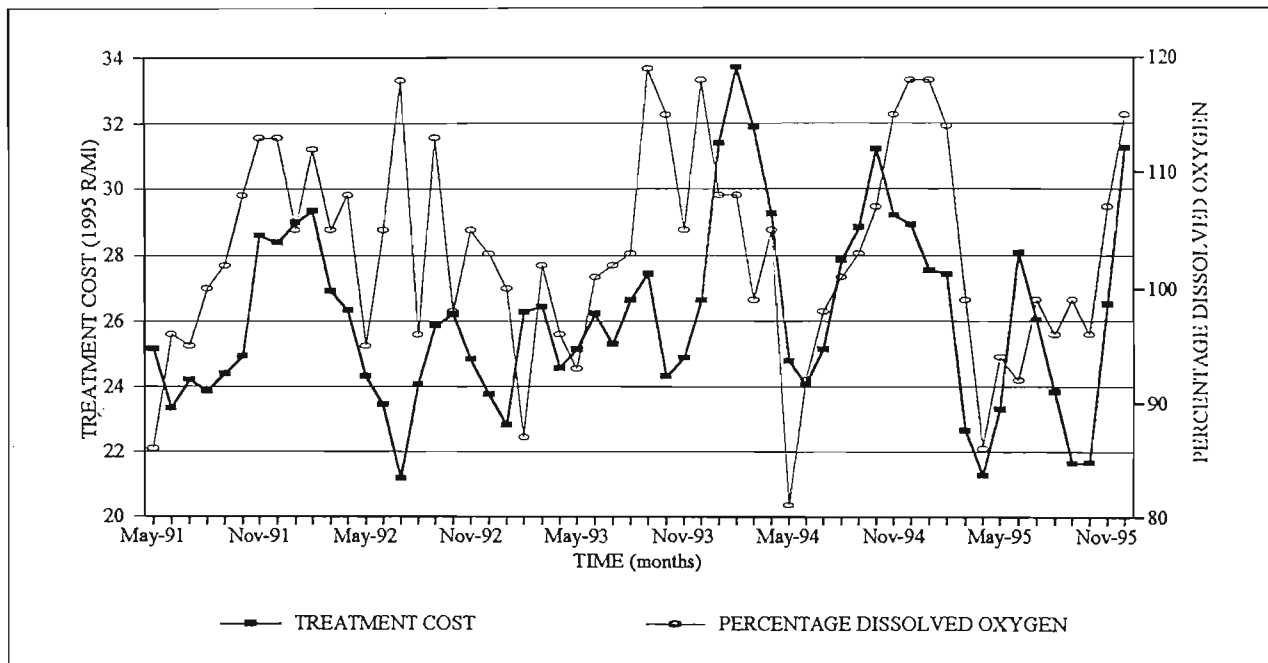


Figure 3.5 Water treatment costs versus percentage dissolved oxygen: DV Harris

CHAPTER 4

THE DURBAN HEIGHTS TREATMENT PLANT

The Durban Heights plant draws water from Nagle and Inanda Dams. Inanda dam is served by a large catchment - including the area surrounding Pietermaritzburg. Pietermaritzburg has dense informal settlement, industrial areas and a substantial wastewater works. Raw water entering these dams is rich in nutrients.

4.1 Data source

Unlike the data used to analyse water treatment costs at DV Harris, all observations made at Durban Heights were recorded on a weekly basis (Appendix III). The water quality data were recorded at the raw water inflow to the waterworks. Chemical dosage data were recorded at the Durban Heights plant from 15 February 1990 to 28 December 1995, yielding a total of 313 observations.

4.2 Variables selected for the Durban Heights plant

The variables selected for analysis at the Durban Heights plant (using the same method as described for the DV Harris plant in section 3.2) are presented in Table 4.1. Although cost was significantly correlated with calcium, chloride, chromium, hardness, magnesium, nitrate and sulfate, these variables were excluded from the analysis because they had large numbers of missing values. Including them would have reduced the number of valid observations from 313 to 64.

Based on past experience, *Anabaena* and *Microcystis* were expected to have a positive effect on water treatment costs (Dickens, Graham and Thompson, 1996). *Anabaena* and *Microcystis* are recognised as causing taste and odour problems. Palmer (1980:53) attributes the pigpen odour to products of decomposition when the algae die off in large numbers.

There is a positive relationship between turbidity and the cost of treating water at the Durban Heights plant. This relationship was anticipated because water stored in coastal impoundments is unlikely to be 'too clean' as was the case for water from Midmar Dam. Secchi, being an inverse measure of turbidity, is expected to impact negatively on the cost of treating raw water at Durban Heights.

Table 4.1 Correlation coefficients for important algae and environmental variables at the Durban Heights plant

VARIABLE		UNITS	Correlation with COST
Anabaena	(ANABA)	cells per ml	0.1317*
Chlorella	(CHLEL)	cells per ml	-0.2084**
Diatoma	(DIATO)	cells per ml	0.2077**
Microcystis	(MICRO)	cells per ml	0.0671
Turbidity	(TURB)	NTU	0.5199**
Suspended Solids	(SS)	mg/l	0.4459**
Secchi	(SECC)	m	-0.2342**
Silica	(SI)	mg/l	0.2765**
Total Aluminium	(TAL)	µg/l	0.3754**
Iron	(FE)	mg/l	0.3765**
Manganese	(MN)	mg/l	0.3352**
Temperature	(TEMP)	°C	0.4114**
Total Kjeldahl Nitrogen	(TKN)	mgN/l	0.2810**
Dissolved Oxygen	(DO)	mg/l	-0.2499**
Trend Variable	(NUM)	Month	0.1270*

Notes: * implies significance at the 5% level of probability

** implies significance at the 1% level of probability

Water treatment costs, especially those associated with polymer, rise with an increase in the level of suspended solids, silica or total aluminium (Graham, 1996). High concentrations of iron and manganese also raise water treatment costs (Freese, 1996).

Again, temperature is positively correlated with water treatment costs because it captures seasonal effects. Water treatment costs increase in summer when higher levels of runoff add to nutrient loads and pollutants found in the storage dams.

Total kjeldahl nitrogen (TKN) is a measure of biologically-bound nitrogen in the water. High levels of TKN indicate the presence of organic pollution (Freese, 1996). This suggests a positive relationship between total kjeldahl nitrogen and water treatment costs. A decrease in dissolved oxygen levels indicates a deterioration in water quality (Graham, 1996) and should therefore have a negative impact on water treatment costs. The trend variable (NUM), again measures long-term changes in water treatment costs and was retained for analysis in order to isolate the variables responsible for short-term cost variations.

4.3 Results estimated for the Durban Heights plant

Results of the model estimated for the Durban Heights plant are presented in Table 4.2. Explanatory power is reasonably good ($R^2=77\%$) but, as in the model estimated for the DV Harris plant, the t -values are extremely low.

Table 4.2 Regression coefficients estimated for contaminants before removing multicollinearity: Durban Heights plant

Explanatory Variables	Coefficients (β_i)	<i>t</i> -values
Constant	-3.7122	-0.85
ANABA	-0.0004	-1.67
CHLEL	-0.0028	-1.95*
DIATO	0.2577	1.11
MICRO	0.0057	3.05**
TURB	0.0467	1.08
SS	0.0062	0.14
SECC	-0.3848	-0.51
SI	0.7533	1.83
TAL	0.0018	0.68
FE	-0.8142	-0.52
MN	-16.6311	-1.51
TEMP	0.2359	2.43**
TKN	0.7950	2.33*
DO	0.2021	0.87
NUM	0.0135	2.37*
LCOST	0.7249	16.27**
R ²	77.52%	
F	48.2898**	

Notes: * implies significance at the 5% level of probability

** implies significance at the 1% level of probability

Principal component analysis was employed, as described in section 3.3, to overcome the problem of multicollinearity. In this case, ten principal components were retained, accounting for 88 percent of the variation in the original variables. The component loadings are presented in Table 4.3.

The regression models were then re-estimated using the principal components as explanatory variables and standardised COST (ZCOST) as the dependent variable. The results are presented in Table 4.4.

Again, no attempt was made to interpret the principal components because they were employed only to combat multicollinearity and not for predictive or policy purposes. The models presented in Table 4.4 were expressed in terms of the original variables following the same procedure described in section 3.3.

According to the standardised coefficients, *Chlorella*, total kjeldahl nitrogen, temperature, *Anabaena*, *Microcystis* and turbidity are the contaminants that have the largest impact on water treatment costs. Taken as a group, algae have a major impact on water treatment costs at the Durban Heights plant. Table 4.6 presents the regression coefficients for the original variables measured in their original units. This final model was used for predictive purposes.

Table 4.3 Component loadings estimated for the ten principal components retained: Durban Heights plant

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
ANABA	0.0583	0.0432	0.6119	-0.0475	0.2227	0.4294	-0.1646	0.1337	-0.1889	-0.1455
CHLEL	-0.2395	0.1905	0.3031	0.2346	0.2303	-0.0936	-0.2917	0.2207	-0.1567	0.5674
DIATO	0.1771	0.0304	0.1629	0.3454	-0.5456	-0.0596	0.2744	0.0873	-0.6392	-0.0416
MICRO	-0.0132	0.0326	0.3709	0.5658	-0.0256	-0.1118	0.4006	-0.1893	0.5624	0.0307
TURB	0.4141	-0.0258	-0.0598	0.1237	-0.0312	0.0328	-0.0835	-0.0903	-0.0008	0.1725
SS	0.3726	-0.1809	0.0564	0.0201	0.1015	0.0964	-0.0699	0.1818	0.1538	0.0831
SECC	-0.1933	0.0165	0.0392	-0.3687	-0.4977	0.3711	0.2850	0.3327	0.2696	0.3279
SI	0.1921	0.5319	-0.1491	0.1518	-0.0612	0.2219	-0.1336	0.0624	0.1071	-0.2392
TAL	0.3669	-0.0908	-0.1391	0.1222	-0.1303	0.1631	-0.1637	0.0935	0.0939	0.3968
FE	0.3469	0.0208	-0.2608	0.1297	0.0132	0.0618	-0.1354	-0.0279	0.0393	0.0931
MN	0.2959	-0.0831	0.1457	-0.0959	0.1636	-0.1880	0.1394	0.5967	0.1425	-0.1691
TEMP	0.1839	0.2568	0.3243	-0.3379	-0.2354	-0.0883	-0.2111	-0.4968	0.0963	0.2171
TKN	0.0635	0.3959	-0.2152	-0.1001	0.4252	-0.0036	0.5561	-0.0229	-0.2102	0.3684
DO	-0.2071	-0.1622	-0.1797	0.3055	0.1084	0.6769	0.012	-0.1458	-0.0273	0.0003
NUM	0.1127	-0.6068	0.0928	-0.1024	0.1368	-0.0085	0.1699	-0.2329	-0.1394	0.2022
LCOST	0.2952	0.1028	0.1952	-0.2440	0.1601	0.2481	0.3061	-0.2141	-0.0539	-0.1855
EigenValue	4.7343	1.8640	1.4998	1.1865	0.9914	0.9189	0.8813	0.7580	0.7075	0.5480
%Variation	29.6	11.7	9.4	7.4	6.2	5.7	5.5	4.7	4.4	3.4
Cum. %	29.6	41.2	50.6	58.0	64.2	70.0	75.5	80.2	84.6	88.1

Table 4.4 Regression coefficients estimated for principal components:

Durban Heights plant

Explanatory Variables	Coefficients (α_i)	t- values
Constant	-0.0101	-0.27
PC1	0.3085	17.55**
PC2	0.0937	2.89**
PC3	0.1173	3.82**
PC4	-0.1275	-3.70**
PC5	0.0756	1.98*
PC6	0.	4.73**
PC7	0.3171	7.97**
PC8	-0.3074	-7.00**
PC9	-0.0107	-0.24
PC10	-0.0730	-1.41
R ²	68.35%	

Notes: * implies significance at the 5% level of probability

** implies significance at the 1% level of probability

The final model fails the Durbin h and Geary Runs tests for zero autocorrelation. Analysis of the residuals suggested that a relevant variable (with a seasonal effect on water treatment costs) had been omitted from the model resulting in “false” autocorrelation (Maddala, 1977:274).

Table 4.5 Standardised regression coefficients estimated for contaminants after removing multicollinearity: Durban Heights plant

Explanatory Variables	Coefficients (b_i)	t -values
ANABA	0.1773	3.85**
CHLEL	-0.2508	-6.61**
DIATO	0.0501	1.27
	0.1242	3.23**
TURB	0.0951	6.99**
SS	0.0422	2.69**
SECC	-0.0126	-0.32
SI	0.0644	2.52*
TAL	-0.0168	-0.66
FE	0.0329	2.43*
MN	-0.0388	-1.23
TEMP	0.1963	5.92**
TKN	0.2344	6.21**
DO	0.0461	1.47
NUM	0.1227	4.53**
LCOST	0.3908	15.76**
R ²	68.35%	

Notes: * implies significance at the 5% level of probability

** implies significance at the 1% level of probability

Table 4.6 Unstandardised regression coefficients estimated for contaminants before and after removing multicollinearity: Durban Heights plant

Explanatory Variables	Original Model	<i>t</i> -values	Final Model	<i>t</i> -values
Constant	-3.7122	-0.85	-1.2692	
ANABA	-0.0004	-1.67	0.0007	3.85**
CHLEL	-0.0028	-1.95*	-0.0093	-6.61**
DIATO	0.2577	1.11	0.3314	1.27
MICRO	0.0057	3.05**	0.0069	3.23**
TURB	0.0467	1.08	0.0605	6.99**
SS	0.0062	0.14	0.0344	2.69**
SECC	-0.3848	-0.51	-0.2637	-0.32
SI	0.7533	1.83	0.5326	2.52*
TAL	0.0018	0.68	-0.0008	-0.66
FE	-0.8142	-0.52	1.0800	2.43*
MN	-16.6311	-1.51	-9.9066	-1.23
TEMP	0.2359	2.43**	0.4798	5.92**
TKN	0.7950	2.33*	2.2631	6.21**
DO	0.2021	0.87	0.2841	1.47
NUM	0.0135	2.37*	0.0141	4.53**
LCOST	0.7249	16.27**	0.3948	15.76**
R ²	77.52%		68.35%	
Durbin <i>h</i>			4.76	

Notes: * implies significance at the 5% level of probability

** implies significance at the 1% level of probability

The consequences of autocorrelation are that the OLS estimators remain linear-unbiased and consistent, but are not efficient (Gujarati, 1988:365). Hence the *t*-values are likely to be over-estimated and the significance of the contaminants overstated. It is possible that relevant variables were not observed, or were omitted due to missing values (section 4.1).

Although the final model presented in Table 4.5 exhibits some loss in explanatory power, it was considered to be a more robust predictor of water treatment costs owing to the absence of multicollinearity. Figure 4.1 shows a good match between actual costs and those predicted by the final model.

4.4 Discussion

4.4.1 Policy implications

The results suggest that water treatment costs at the Durban Heights plant diminish with an increase in the quantity of *Chlorella* in the raw water. The quantities of polymer, chlorine and lime required all decrease with an increase in *Chlorella*. Again, it seems that the quantity of *Chlorella* varies inversely with the quantity of one or more substitutes, and that the (unobserved) substitutes may pose a serious management problem.

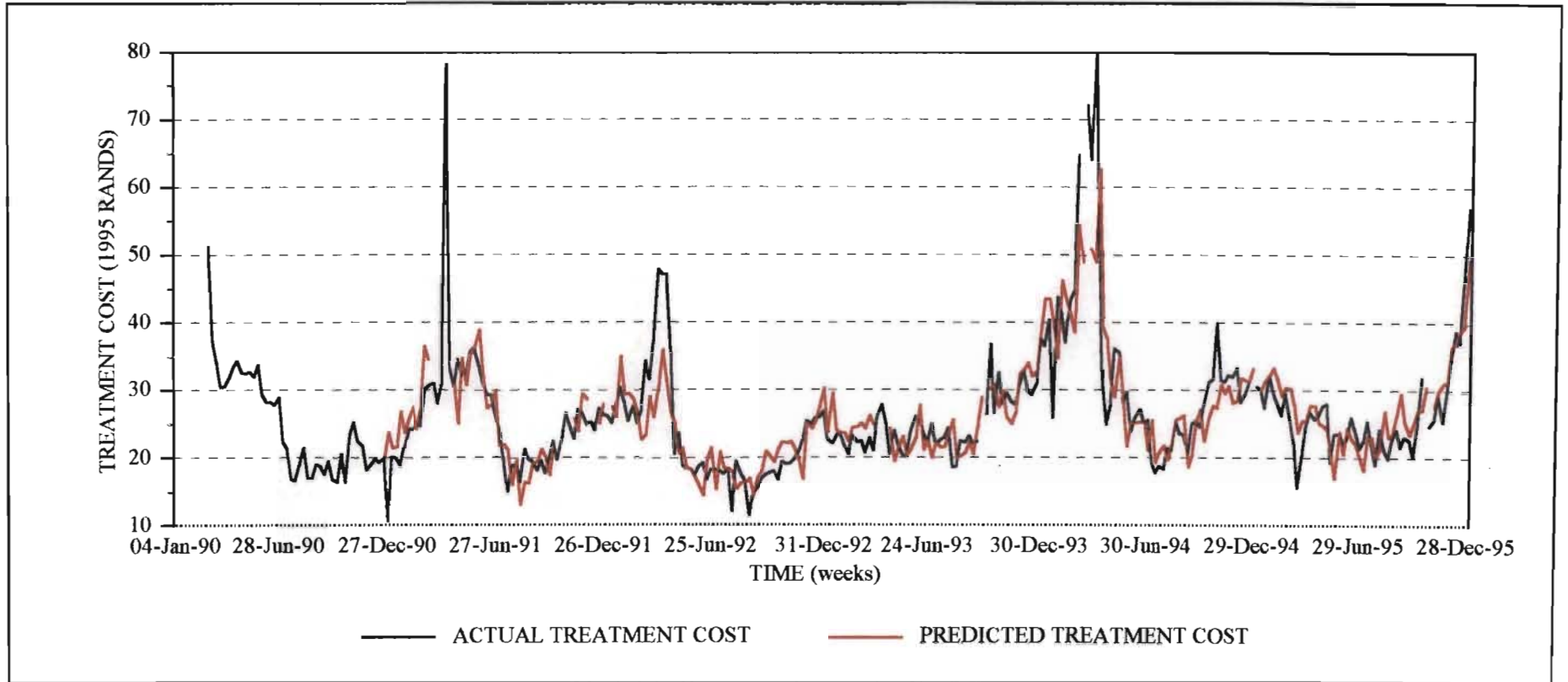


Figure 4.1 Predicted versus actual treatment costs for the Durban Heights plant

Total kjeldahl nitrogen has a positive effect on treatment cost, as anticipated. Surprisingly, an increase in the level of total kjeldahl nitrogen is associated with an increase in the use of bentonite in the treatment of the water. The reasons for this are not clear and require further investigation by water treatment experts.

The positive coefficient estimated for temperature confirms that water treatment costs rise during summer owing to increased rainfall runoff and the attendant deterioration in water quality. *Anabaena* and *Microcystis*, algae recognised as causing taste and odour problems, both carry positive and significant regression coefficients, but *Anabaena* has a larger standardised coefficient and therefore poses a greater threat.

The trend variable (NUM) also has a positive regression coefficient indicating that raw water has become more expensive to treat over time. Real water treatment costs have increased from an average of about R24 per Ml at the beginning of the period of study to an average of about R28 per Ml at the end.

This represents a compound annual growth of 2.6² per cent when all of the other variables included in the model are held constant. The implication is that factors other than these variables are responsible for a steady increase in real water treatment costs. The variables omitted due to missing cases could account for this unexplained variation.

Water treatment costs rise with increasing turbidity, silica, suspended solids and iron, but the impact of these contaminants is relatively small. The coefficient

² $24(1+i)^6 = 28$ implies that $i=0.026$

estimated for LCOST suggests that only 60 per cent (1-0.3948) of the “full” treatment cost required to achieve optimal (rather than minimal) water quality is incurred in the space of one week. The weekly share is smaller, and therefore consistent with the monthly share estimated for DV Harris.

The results show that *Diatoma*, dissolved oxygen, manganese, total aluminium and secchi depth do not add significantly to water treatment costs, other factors held constant. The policy implication is that resources should not be wasted on these apparent problems.

4.4.2 Simulation exercise

The predictive model is a useful management tool. Regression coefficients estimated using ordinary least squares and principal components quantify the independent effects of each explanatory variable. It follows that the (final) model can be used to predict the outcome of a management-induced change in one or more of the explanatory variables. Plausible scenarios can be simulated rapidly using a standard spreadsheet package.

To illustrate, the model estimated for Durban Heights was used to predict water treatment costs for 1994 and 1995 with turbidity held constant at 6 NTU. The observed level of turbidity is closer to 23 NTU but this could be reduced and controlled by raising the height of the dam wall, or by altering the depth at which raw water is abstracted. Weekly observations recorded for each explanatory variable, apart from turbidity and lagged cost (LCOST), were substituted into the predictive model. Turbidity was held constant at 6 NTU and

LCOST was taken as the cost predicted for the previous week. The predicted values were computed using Quattro Pro (Table 4.7).

Table 4.7 Minitableau illustrating a cost simulation spreadsheet

	Chlorella	...	Turbidity	...	LCOST	Simulated Cost
Regression coefficient	A1	...	D1	...	F1	
Week 1	A2		6.2		F2	G2
Week 2	A3		6.2		G2	G3
:	:		:		G3	:
:	:		:		:	:
Week n	An	...	6.2	...	Gn-1	Gn

Note: $G2 = (A1 * A2) + \dots + (D1 * 6.2) + \dots + (F1 * F2)$

The difference between this simulation and the original predictions, where all inputs varied, measures the impact of reduced turbidity on treatment costs, (Figure 4.2). In this example the difference in the average real treatment cost is R1.79 per megalitre - a saving of R54532 per annum when expressed in current (1996) prices.

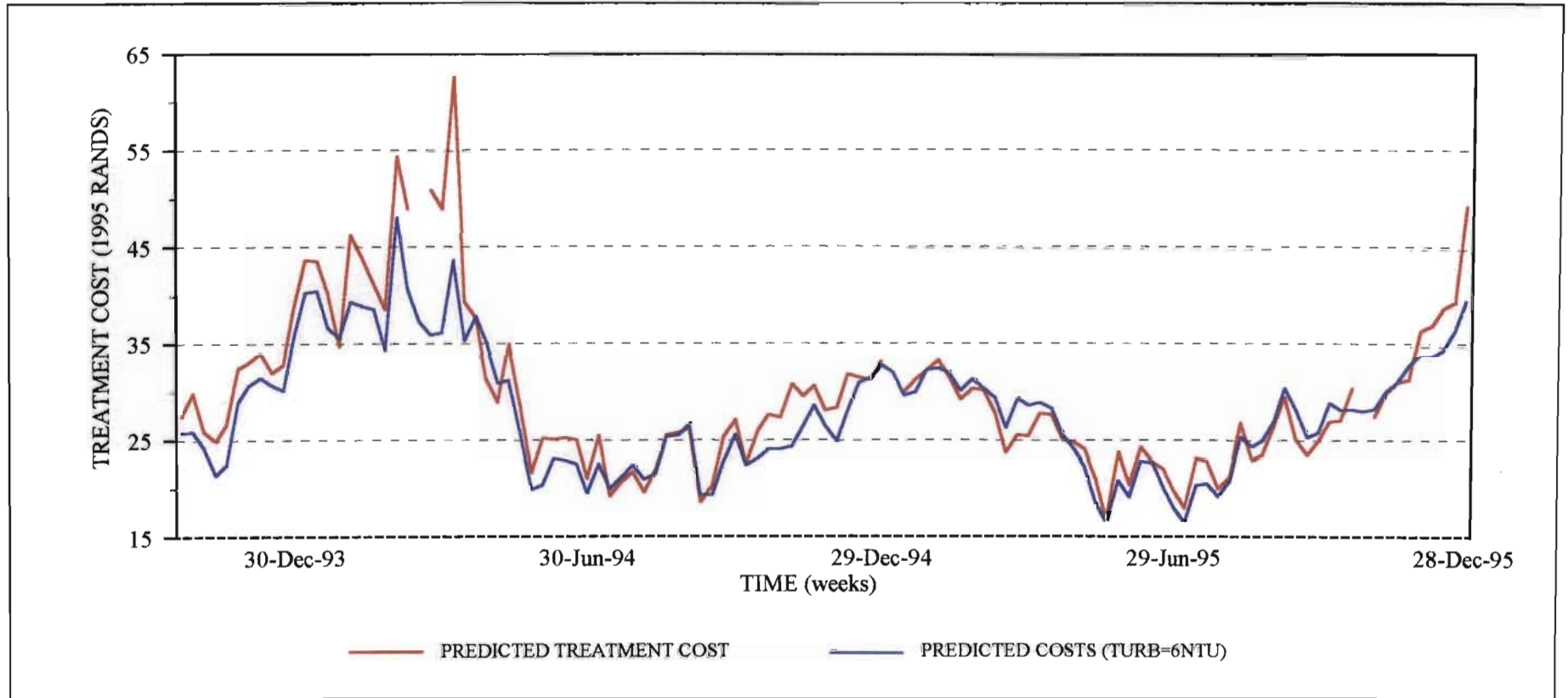


Figure 4.2 Treatment costs predicted holding turbidity constant versus predicted treatment costs for the Durban Heights plant

CONCLUSIONS

The study identifies some important factors contributing to high and rising real water treatment costs at the DV Harris and Durban Heights plants. Environmental contaminants have a marked impact on water treatment costs at the DV Harris plant. Water treatment costs increase when levels of alkalinity, sodium and turbidity fall. Conversely, costs rise with higher levels of dissolved oxygen and water stability. Paradoxically, clean water - typical of Midmar Dam - is expensive to treat. Water treatment costs also rise when concentrations of the algae, *Chlorella*, decline.

Algae have a major impact on water treatment costs at the Durban Heights plant. Water treatment costs increase when concentrations of *Chlorella* fall and when those of *Anabaena* and *Microcystis* rise. Costs are also responsive to an increase in total kjeldahl nitrogen and temperature. Turbidity, silica, suspended solids and iron have significant but relatively small positive effects on water treatment costs at the Durban Heights plant.

The model estimated for the DV Harris plant explains 61 per cent of the variation in chemical treatment costs, and that estimated for the Durban Heights plant 68 per cent of the variation in chemical treatment costs. The models predict actual costs well (except during occasional peak cost periods) and are easily applied to simulation exercises. Of course, regular updating with current data will be necessary to ensure that the results remain relevant.

Apparently the level of *Chlorella* varies inversely with the level of other, more harmful, contaminants. Similarly, the trend variable NUM indicates that factors other than those included in the model have a significant effect on water treatment costs at the Durban Heights plant. These results and other relationships identified by the models, highlight several policy issues which require further investigation. Interaction effects were not considered in this study and may also warrant further research.

SUMMARY

The enrichment of scarce water resources with plant nutrients such as phosphorus and nitrogen, generally known as eutrophication, creates many problems for development in South Africa. The main consequence of eutrophication is abundant algal growth, which can lead to increased water treatment costs. Real average costs of water treatment have been increasing at Umgeni Water, a parastatal that manages water supply in the Umgeni catchment area of KwaZulu-Natal. This study has two objectives: first, to identify the main contaminants responsible for high water treatment costs in the Umgeni Valley, and second, to predict water treatment costs from observed levels of contaminants. Treatment costs refer to the cost of chemicals used to ensure that water is potable.

Autoregressive partial adjustment models of water treatment costs were estimated using ordinary least squares regression and principal component analysis. Principal component analysis was used only to overcome the problem of multicollinearity. The regression models were expressed in terms of original variables and units once the effects of multicollinearity had been removed.

Water treatment costs were analysed at two treatment plants: DV Harris, which draws water from Midmar Dam, and the Durban Heights plant, which draws water from Nagle and Inanda Dams. Raw water stored in the latter, coastal, impoundments can become highly eutrophic relative to the 'clean' water entering Midmar Dam. As a result, treatment problems and costs differ markedly

between the DV Harris and Durban Heights plants. Costs were therefore analysed separately at each plant.

The regression model estimated for DV Harris highlights important policy issues and explains 61 per cent of the variation in chemical treatment costs. Environmental contaminants are important at the DV Harris plant. Treatment costs increase when levels of alkalinity, sodium and turbidity fall. Conversely, real costs rise with higher levels of dissolved oxygen and water stability. Paradoxically, clean water - typical of Midmar Dam - is expensive to treat. Water treatment costs also rise when concentrations of the algae, *Chlorella*, decline.

The regression model estimated for Durban Heights explains 68 per cent of the variation in chemical treatment costs. Biological contaminants are important at the Durban Heights plant. Again, treatment costs increase when levels of *Chlorella* fall. Apparently the level of *Chlorella* varies inversely with the level of other contaminants at both treatment plants. Conversely, real costs rise with higher levels of total kjeldahl nitrogen, temperature, *Anabaena* and *Microcystis*. Water treatment costs also rise when turbidity and concentrations of silica, suspended solids and iron increase.

Both models predict actual water treatment costs well (except during occasional peak cost periods) and serve as useful tools for scenario testing. For example, a simulation exercise in which turbidity levels were held constant at 6 NTU indicated an annual saving of R54 531 in water treatment costs at the Durban Heights plant.

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APPENDIX I

Treatment chemical prices (constant 1995 Rands)

Treatment Chemical	Price in Rands per Kg
Chlorine	2.614
Ammonia	5.65
HTH	7.15
Polymer (CatFlocs)	4.16
Lime (white)	0.655
Bentonite	0.583
Powdered Activated Carbon	3.249

APPENDIX II

DV HARRIS DATA

NUM	STAB	TEMP	SECC	TURB	ALKAL	NA	PDO	CHLEL	CRUCI	GONIU	PUMP	COST	LCOST
1	-1	-1	-1	-1	-1	-1	-1	36	27	0			
2	3	22	1	6	22	-1	96	57	31	0			
3	2	19	2	8	21	4	98	485	86	0			
4	2	19	2	12	22	4	91	686	171	0			
5	1	18	1	14	22	4	90	569	129	0			
6	0	14	1	13	23	4	94	463	101	0			
7	1	13	1	12	23	4	102	917	443	0			
8	1	15	1	10	24	5	108	678	199	105			
9	1	15	1	8	25	5	100	908	188	0			
10	4	19	1	6	24	5	94	572	196	0			
11	6	22	2	5	25	5	104	677	0	0			
12	4	21	2	3	23	4	91	734	89	0			
13	6	23	2	3	26	4	100	489	169	0			
14	6	23	1	12	22	4	92	913	62	0			
15	4	22	1	6	22	4	95	1013	221	0			
16	1	18	2	4	22	4	83	392	86	0			
17	0	17		11	24	4	86	273	34	0	0	25.17	

NUM	STAB	TEMP	SECC	TURB	ALKAL	NA	PDO	CHLEL	CRUCI	GONIU	PUMP	COST	LCOST
18	1	15	1	13	24	4	96	515	299	0	0	23.35	25.17
19	1	15	1	12	23	4	95	447	84	0	0	24.21	23.35
20	1	14	1	10	27	5	100	815	168	0	0	23.88	24.21
21	2	16	1	8	25	5	102	322	219	0	0	24.40	23.88
22	2	19	1	7	24	4	108	388	172	0	0	24.94	24.40
23	5	22	2	6	23	5	113	556	39	0	0	28.60	24.94
24	6	24	2	4	25		113	536	49	0	0	28.38	28.60
25	5	24	2	4	26	4	105	462	90	0	0	28.97	28.38
26	7	26	3	3	25	5	112	878	226	0	0	29.33	28.97
27	3	23	2	4	27	5	105	563	147	0	0	26.92	29.33
28	1	21	4	3	28	5	108	654	118	0	0	26.34	26.92
29	1	18	1	9	29	4	95	562	246	0	0	24.32	26.34
30	1	16	1	12	28	5	105	342	143	0	0	23.46	24.32
31	1	13	1	14	27	5	118	352	203	0	0	21.19	23.46
32	1	13	1	17	28	5	96	446	99	0	0	24.08	21.19
33	2	16	1	16	25	4	113	400	266		0	25.87	24.08
34	3	19	1	13	27	5	98	352	118	0	0	26.23	25.87
35	1	20	1	19	26	5	105	811	74	0	0	24.84	26.23
36	3	23	1	11	29	5	103	707	258	0	0	23.78	24.84
37	3	24	1	9	29	5	100	383	176	17	0	22.82	23.78
38	1			19	28	5	87	393	99	0	0	26.29	22.82

NUM	STAB	TEMP	SECC	TURB	ALKAL	NA	PDO	CHLEL	CRUCI	GONIU	PUMP	COST	LCOST
39	4	24	1	10	27	4	102	370	335	0	0	26.45	26.29
40	0	21		18	26	4	96	252	59	0	0	24.57	26.45
41	0	17	1	14	26	4	93	321	92	0	0	25.15	24.57
42	0	14	1	14	27	4	101	325	118	0	0	26.24	25.15
43	0	12	1	20	27	4	102	380	39	10	0	25.30	26.24
44	0	13	0	22	26	5	103	459	88	0	0	26.65	25.30
45	2	17	1	20	25	4	119	464	74	39	0	27.46	26.65
46	3	20	1	22	26	5	115	310	82	0	72	24.32	27.46
47	4	21	1	15	25	5	105	485	0	0	72	24.88	24.32
48	6	24	1	12	25	4	118	114	270	0	183	26.64	24.88
49	4	24	1	9	24	4	108	154	186	0	198	31.40	26.64
50	3	24	2	5	23	4	108	33	0	0	161	33.69	31.40
51	2	22	3	2	23	4	99	47	67	51	155	31.88	33.69
52	1	21	3	2	23	4	105	152	169	0	40	29.25	31.88
53	0	17	1	7	25	4	81	336	157	0	0	24.79	29.25
54	0	14	1	14	25	4		439	236	0	0	24.06	24.79
55	0	11	1	17	26	4	98	334	236	0	0	25.15	24.06
56	0	12	1	18	25	4	101	212	76		0	27.85	25.15
57	5	15	1	12	26	4	103	287	347	20	0	28.83	27.85
58	7	18	1	8	24	5	107	151	229	0	0	31.22	28.83
59	9	21	1	6	25	5	115	395	0	47	0	29.20	31.22
60	10	22	1	5	25	5	118	227	71	0	0	28.92	29.20

NUM	STAB	TEMP	SECC	TURB	ALKAL	NA	PDO	CHLEL	CRUCI	GONIU	PUMP	COST	LCOST
61	8	24	2	4	26	5	118	274	118	0	21	27.56	28.92
62	7	24	2	4	25	4	114	356	77	0	57	27.44	27.56
63	4	22	3	3	25	4	99	409	0	0	52	22.67	27.44
64	0	19	1	9	28		86	622	105	0	141	21.28	22.67
65	0	17	1	9	27	5	94	548	217	0	0	23.32	21.28
66	0	13	1	16	26	5	92	436	315	0	0	28.09	23.32
67	0	11	0	21	26		99	413	79	0	0	26.05	28.09
68	1	13	0	18	26	5	96	407	341	0	0	23.85	26.05
69	2	16	0	18	26	5	99	616	285	0	0	21.66	23.85
70	2	18	1	19	26	5	96	382	1139	0	5	21.68	21.66
71	6	22	1	16	26	5	107	210	276	0	58	26.53	21.68
72	3	22	1	14	24	4	115	79	0	0	64	31.25	26.53

APPENDIX III

DURBAN HEIGHTS DATA

NUM	TEMP	SECC	TURB	TAL	FE	MN	SI	SS	DO	TKN	MICRO	ANABA	CHLEL	DIATO	COST	LCOST
1											0	0	57	3		
2											0	0	170	0		
3											0	0	113	0		
4											0	0	50	0		
5											0	136	72	0		
6											0	25	38	0		
7	26.00		27.00	174.00	0.47	0.03		11.20	7		0	0	27	2		
8	25.50		28.10	130.00	0.85	0.04		14.80	7		0	72	17	0		
9	25.60		28.10	65.00	1.14	0.03	5.00	13.60	7		0	116	22	0	51.26	
10	25.70		26.70	167.00	1.10	0.03	4.80	13.60	6		0	13	70	0	37.24	51.26
11	24.50		25.40	169.00	0.84	0.02	4.90	13.20	6		0	78	22	0	33.94	37.24
12	23.90		23.80	149.00	1.22	0.04	4.70	14.80	6		0	63	85	0	30.36	33.94
13	23.30		21.50	102.00	0.83	0.02	2.70	46.30	7		0	235	117	0	30.51	30.36
14	23.50		18.20	124.00	0.51	0.01	5.00	10.40	6		0	58	37	0	31.80	30.51
15	23.50		20.50	91.00	0.74	0.01	4.80	16.80	6		0	0	23	0	33.30	31.80
16	23.10		15.70	31.00	0.76	0.02	6.50	12.00	7		0	0	539	0	34.32	33.30
17	22.80		15.80	57.00	0.54	0.01	5.10	12.70	6		0	0	136	0	32.51	34.32
18	22.30		15.40	49.00	0.76	0.02	4.90	7.80	6		0	13	146	0	32.34	32.51
19	21.50	0.64	12.80	85.00	0.60	0.02	4.30	13.20	6		0	0	90	0	32.70	32.34
20	21.40	0.60	14.60	79.00	0.88	0.03	5.00	9.60			0	0	52	0	31.89	32.70
21	20.10	0.72	16.10	124.00	0.49	0.01	4.90	14.00	7		0	0	382	0	33.75	31.89
22	19.40	0.80	16.90	164.00	0.77	0.01	5.10	15.20	8		0	0	146	0	29.27	33.75
23	18.60	0.82	11.70	115.00	0.52	0.03	5.00	9.60	8		0	0	230	0	28.14	29.27
24	17.80	0.80	11.90	108.00	0.65	0.02	4.40	10.60	9		0	0	190	0	28.20	28.14
25	16.50	0.80	10.00	72.00	0.60	0.03	4.10	6.40	9		0	0	87	0	27.75	28.20
26	15.50	1.00	10.30	90.00	0.61	0.02	5.00	4.80	9		0	0	193	0	28.85	27.75
27	15.40	1.00	12.00	63.00	0.54	0.03	4.60	2.00	9		0	0	200	0	22.21	28.85
28	15.20	0.90	10.70	40.00	0.67	0.03	4.40	2.00	8		0	0	126	0	21.35	22.21
29	15.10	1.10	10.31	51.00	0.47	0.02	4.60	14.00	9		0	0	786	0	16.81	21.35
30	15.20	1.30	10.40	96.00	0.48	0.05	4.50	2.00	9		0	0	312	0	16.51	16.81
31	15.80	1.70	7.50	41.00	0.46	0.02	4.60	10.80	8		0	0	228	0	19.02	16.51
32	16.20	1.86	9.00	146.00	0.58	0.01	4.60	8.80	8		0	0	272	0	21.44	19.02
33	16.00	0.60	6.83	33.00		0.02	4.80	6.80	9		0	248	65	0	17.00	21.44
34	16.20	2.36	7.99	66.00	0.53	0.01	5.40	5.20	8		0	118	224	0	16.92	17.00
35	14.90	1.69	6.51	63.00	0.45	0.02	4.30	4.80	8		0	0	165	0	18.93	16.92
36	16.50	1.92	7.64	70.00	0.44	0.01	4.90	2.00	8		12	0	100	0	18.71	18.93
37	18.60	1.88	8.50	57.00	0.47	0.02	4.70	4.80	9		0	0	47	0	17.54	18.71
38	15.80	2.05	8.02	26.00	0.44	0.01	4.20	4.80	9		0	0	148	0	19.45	17.54
39	20.80	1.66	8.81	55.00	0.43	0.02	4.80	5.60	8		0	0	7961	0	16.70	19.45
40	18.40	1.87	7.67	55.00	0.48	0.01	4.60	4.40	9		0	0	850	0	16.35	16.70
41	20.50	2.00	8.98	50.00	0.39	0.04	4.60	4.40	7		0	0	241	0	20.46	16.35
42	22.20	1.90	7.65	14.00	0.36	0.04		2.00	9		0	0	1750	0	16.34	20.46
43	20.60		18.20	71.00	0.46	0.01	4.60	4.40	5		0	0	885	0	23.25	16.34

NUM	TEMP	SECC	TURB	TAL	FE	MN	SI	SS	DO	TKN	MICRO	ANABA	CHLEL	DIATO	COST	LCOST
44	20.40		11.72	65.00	0.49	0.01	4.60	2.00	8		0	0	731	0	25.19	23.25
45	20.90		8.23	30.00	0.44	0.02	4.50	2.00	7		0	0	657	0	22.34	25.19
46	20.10		7.10	25.00	0.40	0.01	4.40	21.20	7		12	0	83	0	21.72	22.34
47	22.50	1.86	6.87	36.00	0.46	0.01	4.30	6.40	8	0.35	0	0	467	0	18.17	21.72
48	23.60		8.54	78.00	0.41	0.02	4.40	12.40	7	1.15	0	0	317	0	18.95	18.17
49	22.80		9.00	42.00	0.52	0.01	4.60	4.80	8	0.35	0	0	376	0	19.74	18.95
50	23.80		11.40	60.00	0.45	0.02	4.50	6.20	7	1.44	0	0	383	0	19.24	19.74
51	22.50	1.33	10.40	81.00	0.54	0.01	4.60	5.60	6	0.35	0	0	383	0	19.85	19.24
52	23.10	1.28	22.40	183.00	1.02	0.04	4.90	9.60	8	0.35	0	0	242	0	10.58	19.85
53	23.40	1.28	17.10	145.00	0.65	0.01	4.60	6.00	7	0.35	0	0	0	0	20.21	10.58
54	23.30	1.20	13.40	135.00	0.52	0.02	4.70	2.00	7	0.35	0	0	332	0	19.82	20.21
55	23.50	1.30	13.10	134.00	0.62	0.02	5.50	2.00	7	2.75	0	0	418	0	18.84	19.82
56	23.90	1.30	13.10	98.00	0.59	0.06	4.50	2.00	7	0.35	0	0	37	0	21.50	18.84
57	25.10	1.40	22.90	176.00	0.73	0.04	4.80	4.40	9	0.35	0	0	125	0	24.36	21.50
58	26.50	1.35	21.10	167.00	0.65	0.03	4.80	12.80	7	0.35	0	0	140	0	24.20	24.36
59	26.60	1.40	17.40	125.00	0.56	0.05	4.70	6.00	8	0.35	0	0	434	0	25.06	24.20
60	24.80	1.33	22.00	129.00	0.83	0.03	4.90	10.40	6	0.84	0	0	236	0	24.75	25.06
61	24.60	1.15	20.80	72.00	0.70	0.03	4.70	11.30	8	5.37	0	0	363	0	30.10	24.75
62	25.20	1.40	18.70	73.00	0.72	0.07	4.60	7.20	8	3.97	0	197	423	0	30.65	30.10
63	24.60		20.50	65.00	1.00	0.05	5.20	2.00	7	1.32	0	0	354	0	30.96	30.65
64	25.40		13.60	110.00	0.47	0.08	5.50	13.00	8	2.64	462	0	442	0	27.99	30.96
65	24.90		12.90	112.00	0.62	0.06	5.70	18.20	8	0.35	0	118	885	0	30.72	27.99
66	24.10		16.10	185.00	0.64	0.05	5.60	29.60	8	3.41	0	0	442	0	78.09	30.72
67	23.20		17.70	114.00	0.75	0.05	5.50	20.40	7	5.35	0	0	619	0	33.74	78.09
68	24.20	1.05	10.60	68.00	0.50	0.01	5.50	5.20	7	4.33	0	0	1017	0	30.56	33.74
69	23.00	1.44	11.20	52.00	0.48	0.03	5.40	8.40	8	0.89	0	0	614	0	34.58	30.56
70	22.60	0.86	12.00	43.00	0.41	0.03	4.90	9.00	7	3.94	0	0	430	0	32.48	34.58
71	22.60	1.18	7.90	36.00	0.46	0.05	4.50	2.00	8	3.27	0	0	531	0	31.88	32.48
72	21.10	1.33	16.50	110.00	0.57	0.06	3.10	10.00	8	4.32	0	0	199	0	35.62	31.88
73	20.30	1.29	11.32	91.00	0.54	0.05	5.20	5.20	8	3.92	0	0	199	0	36.33	35.62
74	19.00	1.23	11.60	81.00	0.48	0.03	4.90	7.20		5.74	0	0	324	0	33.48	36.33
75	18.30	1.07	9.57	91.00	0.62	0.05	5.20	9.60	8	3.59	0	0	398	0	31.08	33.48
76	19.10	1.52	10.30	65.00	0.71	0.04	5.00	7.20	8	2.82	0	0	651	0	29.40	31.08
77	16.60	1.50	10.20	74.00	0.65	0.06	5.10	12.40	9	2.55	0	0	344	0	29.30	29.40
78	15.90	1.37	17.80	151.00	0.89	0.05	4.90	12.00	8	3.44	0	0	347	0	26.45	29.30
79	16.10	2.00	10.70	76.00	0.61	0.05	5.10	4.40	8	0.54	0	0	295	0	24.30	26.45
80	17.50	1.50	7.63	36.00	0.41	0.02	4.90	14.00	8	0.52	0	0	295	0	19.79	24.30
81	17.30	1.35	8.32	94.00	0.56	0.03	5.10	9.20	9	0.60	0	0	236	0	14.96	19.79
82	15.80	1.50	8.64	89.00	0.43	0.01	4.80	4.80	9	0.57	15	0	472	0	18.71	14.96
83	16.30	1.25	9.72	67.00	0.56	0.02	5.30	6.80	9	0.74	0	0	369	0	19.24	18.71
84	15.40	1.25	7.98	95.00	0.53	0.03	4.30	6.00	9	0.40	0	0	872	0	16.58	19.24
85	16.00	2.00	7.96	59.00	0.48	0.01	4.50	2.00	9	0.71	0	0	511	0	21.16	16.58
86	15.90	1.75	7.50	42.00	0.54	0.01	4.10	2.00	9	0.71	10	0	708	0	19.93	21.16
87	16.80	2.00	7.01	29.00	0.47	0.01	4.20	4.40	9	1.04	0	0	472	0	19.56	19.93
88	17.30	1.75	9.60	69.00	0.45	0.03	4.70	4.80	10	0.86	0	0	456	0	18.26	19.56
89	18.60	2.00	6.50	79.00	0.45	0.01	4.20	4.80	9	1.29	0	0	310	0	19.67	18.26
90	18.50	1.61	6.29	84.00	0.39	0.01	5.30	2.00	9	1.09	0	0	492	0	17.86	19.67
91	19.40	1.50	6.88	90.00	0.55	0.03	5.00	2.00	9	0.94	0	0	702	0	20.17	17.86

NUM	TEMP	SECC	TURB	TAL	FE	MN	SI	SS	DO	TKN	MICRO	ANABA	CHLEL	DIATO	COST	LCOST
92	20.20	1.20	8.80	114.00	0.54	0.02	4.50	6.00	9	0.91	0	0	376	0	22.52	20.17
93	19.20		8.12	119.00	0.31	0.02	4.90	4.40	9	1.37	0	0	398	0	19.80	22.52
94	20.90		9.70	149.00	0.53	0.03	4.80	6.00	10	0.81	0	0	229	0	22.95	19.80
95	19.80		10.10	140.00	0.58	0.02	4.80	6.00	9	0.91	0	0	467	0	26.58	22.95
96	21.60		12.20	96.00	0.65	0.01	5.00	2.00	8	1.06	0	0	280	0	24.84	26.58
97	22.00	1.20	13.60	114.00	0.68	0.04	4.80	5.20	10	0.40	66	147	265	0	22.85	24.84
98	22.80	1.50	15.10	151.00	0.51	0.01	5.00	9.60	8	0.40	0	0	332	0	27.15	22.85
99	23.10	2.00	13.70	82.00	0.50	0.01	4.50	7.60	8	1.01	0	0	44	0	26.69	27.15
100	23.60	0.70	23.20	196.00	1.05	0.01	4.80	11.20	8	0.40	7	0	177		24.98	26.69
101	21.60		17.20	142.00	0.81	0.05	4.70	7.60	8	1.14	0	295	347	0	25.40	24.98
102	24.00		16.10	190.00	0.92	0.01	4.50	8.40	8	0.40	0	295	265	0	24.01	25.40
103	24.60	0.80	13.20	103.00	0.79	0.03	4.00	10.00	6	0.40	0	147	280	0	27.39	24.01
104	24.60	1.04	21.60	76.00	0.95	0.02	4.60	18.80	5	0.69	0	516	339	0	26.46	27.39
105	24.50	1.00	18.90	174.00	0.89	0.04	4.00	10.00		1.04	0	0	391	0	26.13	26.46
106	25.50	1.20	20.30	194.00	1.04	0.03	3.70	20.00	6	0.90	0	0	347	0	25.17	26.13
107	24.50	1.17	17.50	210.00	0.84	0.02	4.50	4.80	7	0.92	0	0	405	0	27.82	25.17
108	24.90	1.17	14.00	129.00	0.64	0.01	4.10	7.60	8	0.93	1032	0	356	0	30.33	27.82
109	25.70	1.30	13.80	125.00	0.65	0.05	4.10	4.40	7	0.68	0	0	184	0	28.25	30.33
110	26.10	1.80	11.90	124.00	0.62	0.06	4.00	11.60	8	0.96	0	0	177	0	25.50	28.25
111	24.80	2.10	10.30	77.00	0.47	0.02	3.60	12.40	7	0.74	0	0	0	0	27.69	25.50
112	25.50	2.10	17.00	230.00	0.61	0.06	4.10	10.80	7	0.40	0	0	280	0	25.19	27.69
113	25.40	1.70	10.70	80.00	0.44	0.03	3.50	6.40	8	0.40	0	0	575	0	27.01	25.19
114	24.40	1.90	12.50	101.00	0.02	0.01	3.95	8.00		0.40	0	0	528	0	34.20	27.01
115	24.30	1.70	13.80	144.00	0.62	0.03	3.90	4.80	10	0.40	0	0	340	0	31.53	34.20
116	24.40	2.10	12.90	103.00	0.36	0.03	4.30	10.40	8	0.10	0	0	423	0	37.09	31.53
117	24.50	1.90	7.54	75.00	0.30	0.03	4.10	6.00	9	0.40	0	0	197	0	47.77	37.09
118	24.30	2.10	9.41	98.00	0.46	0.04	3.60	8.00	7	0.91	0	0	140	0	47.12	47.77
119	24.30	3.50	5.96	74.00	0.59	0.05	3.30	4.40	8	0.10	39	0	383	0	47.07	47.12
120	23.20	1.20	9.88	93.00	0.25	0.03	4.20	5.60	6	0.22	0	0	909	0	35.55	47.07
121	23.40	3.00	9.52	60.00	0.27	0.01	4.20	5.20	8	0.50	0	0	693	0	20.64	35.55
122	23.00	2.00	9.60	92.00	0.32	0.02	3.60	8.40	8	0.10	0	0	412	0	23.69	20.64
123	21.60	1.20	12.70	111.00	0.32	0.07	4.60	9.20	7	0.10	0	0	405	0	19.01	23.69
124	20.80	1.30	15.60	161.00	0.71	0.04	3.60	12.40	7	0.40	0	0	590	0	18.48	19.01
125	19.70	1.30	10.70	45.00	0.42	0.03	3.90	8.80	7	0.40	0	0	511	0	18.24	18.48
126	19.10	1.00	8.82	73.00	0.22	0.02	2.40	10.00	7	0.70	0	0	560	0	17.42	18.24
127	18.20	1.40	7.89	77.00	0.33	0.06	2.50	6.00	9	0.64	0	0	608	0	18.67	17.42
128	16.90	1.32	7.78	113.00	0.32	0.01	4.00	18.00	10	0.20	0	0	848	0	19.31	18.67
129	18.40	1.24	9.86	100.00	0.37	0.01	3.10	6.00	11	0.46	0	0	405	0	16.89	19.31
130	16.80	1.00	8.11	23.00	0.27	0.02	2.60	5.20	9	0.10	1659	0	1087	0	18.35	16.89
131	17.10	1.20	8.45	64.00	0.27	0.01	3.00	6.53	10		15	0	649	0	18.29	18.35
132	15.50	1.15	11.80	84.00	0.12	0.06	3.60	9.40	10	0.30	0	0	0	0	18.02	18.29
133	16.40	1.40	10.40	30.00	0.15	0.01	3.40	4.67	12	0.32	295	0	605	0	17.64	18.02
134	16.70	1.45	8.13	55.00	0.19	0.01	3.30	2.00	12	0.76	0	0	479	0	18.37	17.64
135	16.50	1.43	9.05	78.00	0.34	0.01	3.70	12.80	9	0.10	0	0	373	0	12.08	18.37
136	16.60	1.59	5.68	40.00	0.18	0.01	2.40	6.80	9	0.83	0	0	418	0	19.55	12.08
137	14.50	1.70	7.59	110.00	0.27	0.09	4.20	7.73	10	0.10	0	393	452	0	17.61	19.55
138	15.40	1.80	9.69	89.00	0.43	0.02	3.80	12.00	10	0.10	0	589	531	0	16.64	17.61
139	15.20	2.00	12.60	92.00	0.32	0.01	3.40	9.46	9	0.23	0	15	347	0	11.41	16.64

NUM	TEMP	SECC	TURB	TAL	FE	MN	SI	SS	DO	TKN	MICRO	ANABA	CHLEL	DIATO	COST	LCOST
140	17.20	1.80	8.46	69.00	0.44	0.02	3.10	4.66	9	0.21	0	0	442	0	14.95	11.41
141	18.70	1.60	9.10	65.00	0.47	0.01	3.60	8.13	10	0.10	0	0	467	0	15.49	14.95
142	17.90	1.60	8.81	66.00	0.53	0.01	3.30	4.67	9	0.45	0	0	369	0	16.92	15.49
143	17.90	1.40	9.60	55.00	0.40	0.01	3.20	2.00	10	0.23	354	413	383	0	17.43	16.92
144	21.00	1.80	10.80	125.00	0.52	0.01	3.10	2.00	11	0.10	0	117	354	0	17.75	17.43
145	20.10	2.00	11.30	86.20	0.46	0.01	2.90	10.40	9	0.27	0	0	405	0	17.98	17.75
146	20.60	1.80	11.60	46.00	0.50	0.01	3.70	11.80	9	0.23	0	59	295	0	16.71	17.98
147	20.90	1.50	12.80		0.43	0.01	2.90	15.40	12	0.10	147	334	305	0	19.35	16.71
148	22.00	1.35	12.30	69.00	0.47	0.01	2.60	8.60	9	0.10	0	1229	319	0	19.06	
149	21.80	1.40	19.60	70.00	0.55	0.02	2.50	16.40	11	0.10	0	1086	393	0	19.22	19.06
150	22.50	1.20	16.50	29.00	0.54	0.02	5.40	12.40	10	0.10	0	3649	848	0	19.76	19.22
151	21.60	1.18	15.30	77.00	0.32	0.01	3.40	12.40	9	0.20	0	2267	774	0	20.85	19.76
152	20.50	1.10	14.80	117.00	0.60	0.01	3.30	8.40	8	0.10	0	2912	1051	0	22.61	20.85
153	23.00	1.00	17.50	111.00	0.19	0.02	3.40	10.40	10	0.28	74	4700	627	0	25.44	22.61
154	24.20	1.19	15.20	101.00	0.47	0.02	3.30	9.20	10	0.10	0	4460	793	0	25.01	25.44
155	25.30	1.45	14.90	108.00	0.37	0.02	3.00	12.80	8	0.46	0	8073	977	0	25.88	25.01
156	24.00	1.20	18.00	119.00	0.40	0.02	3.20	6.40	9	0.41	0	4774	516	0	25.90	25.88
157	23.20	1.20	14.20	141.00	0.38	0.02	3.40	2.00	9	0.10	0	3778	0	0	26.87	25.90
158	24.10	1.41	11.90	153.00	0.41	0.02	2.90	11.60	9	0.39	0	590	608	0	22.66	26.87
159	25.30	1.50	18.70	99.00	0.49	0.03	3.20	14.40	9	2.05	0	3893	590	0	22.08	22.66
160	25.90	1.80	12.30	93.00	0.38	0.02	3.00	8.80	10	0.20	0	2094	560	0	23.15	22.08
161	24.60	1.60	14.30	49.00	0.38	0.02	2.90	12.80	8	0.27	0	111	424	0	23.65	23.15
162	25.10	1.60	12.90	81.00	0.28	0.01	4.30	8.00	9	0.20	0	10	531	0	21.76	23.65
163	26.40	1.40	15.50	125.00	0.28	0.04	3.70	8.00	8	0.10	10	0	560	0	20.48	21.76
164	24.90	1.38	20.70	145.00	0.39	0.02	2.90	21.80	8	0.15	0	0	275	0	23.18	20.48
165	24.50	1.14	25.30	120.00	0.73	0.02	2.90	13.60	7	0.27	0	0	413	0	22.20	23.18
166	24.80	0.90	25.60	100.00	0.75	0.01	3.10	15.40	8	0.31	0	0	413	0	22.53	22.20
167	25.20	0.90	26.80	103.00	0.29	0.03	2.90	11.40	9	0.10	0	0	413	0	20.73	22.53
168	25.20	1.00	18.70	81.00	0.64	0.02	3.00	11.80	8	0.10	0	0	108	0	22.84	20.73
169	24.00	0.95	17.80	184.00	0.78	0.02	3.60	14.00	7	0.10	0	0	305	0	20.99	22.84
170	24.00		25.40	125.00	0.64	0.03	3.40	25.80	7	0.36	0	0	0	0	26.18	20.99
171	23.50		18.10	159.00	0.68	0.10	3.60	24.80	7	0.47	0	0	295	0	27.77	26.18
172	24.00		16.70	234.00	0.46	0.12	2.60	22.40	8	0.20	0	0	275	0	25.01	27.77
173	23.90	1.22	14.00	79.00	0.49	0.14	2.50	16.60	5	0.54	39	0	285	0	20.48	25.01
174	22.50	1.24	14.10	188.00	0.40	0.09	2.80	12.80	1	0.33	0	0	383	0	24.04	20.48
175	23.10	1.17	12.80	242.00	0.19	0.11	3.30	10.80	7	0.10	0	0	442	0	21.80	24.04
176	22.10	1.40	27.90	154.00	0.65	0.13	3.60	24.10	7	0.32	0	69	383	0	20.33	21.80
177	21.30	1.13	15.00	184.00	0.35	0.05	2.10	16.40	3	0.49	0	0	344	0	20.25	20.33
178	20.80	1.89	16.80	206.00	0.50	0.07	3.00	10.20	6	0.58	0	560	383	0	23.94	20.25
179	20.00	1.27	13.40	190.00	0.55	0.10	2.60	23.00	8	0.10	0	0	212	0	26.09	23.94
180	18.90	1.25	16.70	157.00	0.56	0.07	3.20	12.00	8	0.34	590	0	295	0	25.59	26.09
181	17.30	1.10	14.10	97.00	0.58	0.04	2.20	14.00	8	0.22	0	0	403	0	23.64	25.59
182	16.80	0.98	17.10	164.00	0.58	0.05	3.20	12.00	8	0.17	0	0	187	0	22.27	23.64
183	16.20	1.05	21.50	101.00	0.51	0.09	2.50	10.80	8	0.10	0	0	295	0	24.99	22.27
184	16.50	0.89	20.00	79.00	0.92	0.07	2.70	13.80	8	0.25	0	0	305	0	21.98	24.99
185	16.00	1.08	16.80	72.00	0.65	0.06	3.00	11.00	9	0.47	0	0	285	0	22.63	21.98
186	16.70	1.23	17.10	114.00		0.08	2.80	15.80	9	0.63	0	0	324	0	22.91	22.63
187	17.20	1.40	18.50	91.00	0.83	0.06	2.10	18.40	10	0.90	0	0	315	0	24.40	22.91

NUM	TEMP	SECC	TURB	TAL	FE	MN	SI	SS	DO	TKN	MICRO	ANABA	CHLEL	DIATO	COST	LCOST
188	17.50	1.55	19.50	104.00	0.44	0.03	3.60	14.80	9	1.28	0	0	285	0	18.59	24.40
189	17.10	1.28	12.50	205.00	0.38	0.07	3.60	14.00	10	0.23	0	0	295	0	18.67	18.59
190	18.00	1.60	13.72	207.00	0.44	0.05	3.80	13.00	9	0.38	0	0	364	0	22.46	18.67
191	16.90	1.33	16.40	154.00	0.67	0.05	3.10	11.20	9	0.37	0	0	413	0	22.24	22.46
192	18.90	1.63	15.60	305.00	0.56	0.05	2.70	15.00	8	0.53	0	0	305	0	23.17	22.24
193	8.90	1.80	17.00	53.00	0.48	0.06	2.30	16.20	9	1.05	0	0	172	0	22.17	23.17
194	18.90	1.79	15.20	264.50	0.59	0.05	3.20	12.60	9	1.52	0	0	332	0	22.43	22.17
195	20.80	1.54	24.60	374.00	0.60	0.04	3.70	16.00	9	1.59	0	0	130	0		22.43
196	18.20	1.32	23.00	326.00	1.48	0.02	3.60	12.00	8	0.10	0	0	157	0	26.49	
197	18.00	0.83	30.00	234.00	1.93	0.02	3.60	18.40	8	1.08	0	0	105	0	36.73	26.49
198	19.30	1.55	31.60	485.00	1.02	0.08	3.20	32.80	4	0.75	0	0	167	0	26.61	36.73
199	21.50	1.10	30.00	525.00	0.66	0.07	3.50	21.20	9	0.45	0	0	236	0	32.52	26.61
200	22.50	1.34	27.40	413.00	0.73	0.09	2.70	20.80	8	0.85	0	0	275	0	27.96	32.52
201	21.20	1.10	20.30	513.00	1.18	0.08	5.40	16.60	8	0.10	0	0	413	0	29.58	27.96
202	22.20	0.93	29.20	253.00	0.61	0.08	2.50	16.00	8	0.34	0	0	550	0	28.19	29.58
203	24.80	1.06	29.20	194.00	0.87	0.09	2.40	22.00	8	0.10	39	0	452	0	27.85	28.19
204	23.50	1.10	27.90	197.00	0.92	0.07	3.50	23.20	8	0.96	0	0	17	0	30.77	27.85
205	26.90	1.00	33.20	251.00	0.56	0.10	3.30	22.80	8	0.24	0	0	17	0	32.75	30.77
206	22.80	0.88	35.10	214.00	0.93	0.09	3.50	35.80	8	0.60	0	0	8	0	29.76	32.75
207	20.80	1.01	37.80	226.00	0.71	0.11	3.10	40.00	8	0.77	0	0	0	0	29.25	29.76
208	21.80	1.54	58.90	1370.0	1.72	0.19	4.59	58.00	8	0.25	0	0	17	0	30.95	29.25
209	23.70	0.60	53.10	321.00	0.99	0.04	4.50	43.20	8	2.00	0	0	59	0	37.57	30.95
210	23.00	0.71	49.80	626.00	0.96	0.06	4.70	30.80	9	3.26	0	0	17	0	36.51	37.57
211	24.00	0.64	82.10	893.00	0.97	0.08	4.70	42.20	8	1.38	0	0	42	8	40.53	36.51
212	24.60	0.95	64.20		0.92	0.13	4.10	46.00	6	0.96	0	0	8	0	25.95	40.53
213	25.00	0.97	61.40	791.00	0.99	0.13	5.70	58.00	5	0.73	0	25	0	0	43.85	25.95
214	26.60	1.02	67.10	738.00	1.46	0.11	5.10	28.60	4	0.13	0	0	0	17	41.42	43.85
215	23.70	0.87	72.70	323.00	0.69	0.04	7.00	23.20	2	1.64	202	51	25	0	37.15	41.42
216	24.60	1.16	60.00	227.00	0.63	0.11	6.40	21.20	8	1.69	0	0	8	0	43.63	37.15
217	23.40	0.88	43.30	310.00	0.53	0.10	5.80	21.00	8	0.13	0	1222	67	0	44.84	43.63
218	24.00	1.14	40.70	198.00	0.57	0.11	5.70	41.20	8	0.48	1087	6412	67	8	64.67	44.84
219	24.20	0.80	37.20	206.00	1.15	0.03	4.50	20.60	10	0.84	42	320	118	0		64.67
220	24.60	0.76	38.30	185.00	0.66	0.10	3.40	28.00	9	0.98	0	716		0	72.06	
221	24.00	1.55	29.50	261.00	0.85	0.13	3.30	30.00	10	1.23	0	76	8	0	64.00	72.06
222	23.80	0.83	36.40	240.00	0.53	0.04	5.00	15.20	7	1.59	0	0	25	0	79.86	64.00
223	24.20	1.38	34.30	380.00	0.90	0.15	4.90	58.60	6	0.55	0	13236	0	0	50.32	79.86
224	24.30	1.21	29.00	298.00	0.79	0.12	4.90	18.60	7	0.29	14	5421	506	0	31.54	50.32
225	24.20	1.49	26.60	234.00	0.79	0.14	3.70	32.25	6	1.48	0	4318	0	0	24.98	31.54
226	22.60	1.09	27.60	199.00	0.78	0.11	4.40	26.00	7	1.09	0	0	0	0	27.61	24.98
227	22.10	1.08	22.30	187.00	0.77	0.06	4.60	25.80	6	1.07	0	256	354	0	36.17	27.61
228	20.60	0.60	32.60	233.00	0.79	0.15	4.80	22.20	7	1.52	0	0	101	0	35.48	36.17
229	20.40	1.53	23.90	222.00	0.71	0.11	4.00	25.20	7	0.83	0	0	492	0	28.12	35.48
230	20.20	0.50	20.00	167.00	0.51	0.07	3.60	6.60	8	0.10	0	166	719	0	29.74	28.12
231	20.00	0.64	22.90	78.00	0.91	0.07	3.80	33.00	6	0.15	0	0	511	0	23.91	29.74
232	16.80	0.50	15.70	150.00	0.78	0.05	3.90	21.20	9	0.46	0	0	197	0	25.95	23.91
233	16.00	0.65	27.30	210.00	0.97	0.07	4.50	27.20	9	0.64	0	0	393	0	27.15	25.95
234	15.80	0.90	20.00	141.00	0.89		4.30	14.00	9	0.45	20	0	354	0	25.15	27.15
235	15.30	0.72	13.90	167.00	0.67	0.02	3.70	5.40	10	0.66	17	0	642	0	25.59	25.15

NUM	TEMP	SECC	TURB	TAL	FE	MN	SI	SS	DO	TKN	MICRO	ANABA	CHLEL	DIATO	COST	LCOST
236	15.00	0.74	15.50	154.25	0.66	0.02	3.40	12.00	9	0.10	0	0	0	0	19.12	25.59
237	14.60	1.00	16.60	128.00	0.65	0.02	3.60	12.00		0.30	0	0	472	0	17.76	19.12
238	14.30	1.25	12.70	181.00	0.66	0.02	3.40	11.80	9	0.26	0	0	157	0	18.69	17.76
239	14.70	1.02	10.65		0.63	0.03	2.70	12.40	9	1.41	0	0	334	0	18.34	18.69
240	15.10	1.00	11.40	184.00	0.66	0.02	3.50	20.00	9	0.31	24	0	401	0	21.43	18.34
241	14.30	1.50	9.66	100.00	0.53	0.01	3.10	6.00	9	0.37	0	0	143	0	21.12	21.43
242	17.00	1.20	12.40	86.00	0.51	0.02	2.60	2.00	9	1.04	0	0	15	0	25.36	21.12
243	16.00	1.20	10.65	77.00	0.50	0.01	3.50	2.00	9	0.34	0	0	0	0	23.58	25.36
244	17.40	1.20	11.20	94.00	0.57	0.01	3.10	9.32	9	1.35	0	0	216	0	23.45	23.58
245	17.20	1.20	14.40	118.00	0.55	0.01	2.50	5.72	9	0.27	0	0	727	0	20.66	23.45
246		1.80	13.90	44.00	0.52	0.01	2.50	6.00	9	1.03	0	0	590	0	25.05	20.66
247	17.68	1.20	11.35	71.00	0.41	0.02	3.30	9.20	9	0.71	0	0	216	0	25.42	25.05
248	19.60	1.20	14.50	65.00	0.37	0.01	3.20	5.60	9	0.34	0	0	59	0	24.54	25.42
249	16.80	1.10	14.45	109.00	0.59	0.01	3.03	12.40	10	0.59	0	0	511	0	28.09	24.54
250	18.00	0.90	16.50	148.00	0.70	0.02	3.20	12.00	8	0.10	0	0	192	0	31.21	28.09
251	19.50	1.40	12.40	152.00	0.62	0.02	2.40	6.40	9	1.07	0	0	377	0	31.66	31.21
252	20.30	1.50	10.90	119.00	0.55	0.02	2.90	8.40	8	0.20	0	0	244	0		31.66
253	21.30	1.40	8.56	73.00	0.51	0.02	2.70	7.08	9	0.10	0	0	256	0	31.52	39.85
254	22.00	1.10	11.10	82.00	0.60	0.02	2.80	9.32	8	0.10	0	0	90	0	31.24	31.52
255	21.80	1.10	8.20	87.00	0.41	0.01	3.00	10.60	8	0.56	0	0	51	0	32.28	31.24
256	20.90	1.10	9.33	63.00	0.55	0.01	2.60	8.80	8	0.68	0	0	350	0	31.96	32.28
257	21.00	1.00	27.90	176.00	0.70	0.02	3.00	22.40	9	0.10	0	0	397	0	33.28	31.96
	23.60	0.90	12.40	191.00	0.42	0.03	3.40	10.40	11	0.10	0	0	118	0	28.24	33.28
259	23.00	1.20	13.40	188.00	0.54	0.02	3.40	68.40	8	0.10	0	0	51	0	29.43	28.24
260	24.10	1.10	13.60	179.00	0.67	0.02	3.30	2.00	8	0.30	0	0	0	0	30.94	29.43
261	23.90	1.02	15.88	166.00	0.40	0.02	2.70	27.20	9	1.18	0	0	138	0		30.94
262	24.80	1.27	22.90	224.00	0.63	0.02	2.90	35.60	8	0.60	0	0	219	0	30.56	
263	24.80	1.05	21.30	154.00	0.61	0.03	2.80	10.40	8	0.58	0	0	334	0	30.10	30.56
264	25.00	1.53	24.00	138.00	0.51	0.03	2.80	10.30	8	0.44	0	0	147	0	27.42	30.10
265	25.30	1.26	21.10	118.00	0.48	0.03	2.80	7.50	7	2.39	0	0	374	0	32.16	27.42
266	25.70	1.21	20.40	288.00	0.43	0.03	2.60	13.60	8	1.23	0	0	216	0	29.63	32.16
267	26.50	0.93	17.20	174.00	0.43	0.03	2.80	10.00	8	0.56	0	0	164	0	28.04	29.63
268	26.00	1.12	16.40	113.00		0.03	2.50	7.72	8	0.59	0	0	295	0	26.30	28.04
269	24.80	1.18	14.90	104.00	0.49	0.05	2.20	16.80	9	0.95	200	958	379	0	29.57	26.30
270	25.35	1.38	14.40	87.00	0.57	0.04	2.30	9.10	8	0.44	0	236	197	0	25.44	29.57
271	26.00	1.57	12.30	124.00	0.44	0.02	2.80	6.80	8	0.61	0	413	374	0	22.11	25.44
272	24.60	1.61	11.30	63.00	0.44	0.03	2.80	8.00	9	0.60	20	1160	688	0	15.65	22.11
273	24.70	1.96	13.70	74.00	0.54	0.05	3.00	7.60	8	1.62	118	1533	550	0	20.36	15.65
274	24.30	1.51	11.60	59.00	0.31	0.03	2.50	16.00	7	0.17	20	6704	668	0	24.88	20.36
275	23.70	1.22	11.50	120.00	0.29	0.04	2.80	19.60	7	0.29	66	3735	442	0	26.74	24.88
276	22.60	1.32	10.00	53.00	0.27	0.04	3.00	8.00	7	0.54	216	6645	826	0	25.78	26.74
277	22.60	1.34	15.00	76.00	0.26	0.05	1.79	7.60	7	0.79	177	492	590	0	26.33	25.78
278	22.90	1.41	11.60	82.00	0.25	0.07	3.04	22.10	7	0.20	20	0	433	0	27.70	26.33
279	21.20	1.34	10.40	53.00	0.32	0.06	2.69	11.20	7	0.24	0	0	433	0	27.99	27.70
280	22.00	1.66	8.00	44.00	0.25	0.04	1.93	12.00	8	0.18	0	0	786	0	19.35	27.99
281	22.10	1.46	6.10	46.00	0.23	0.05	1.99	6.00	8	0.14	0	0	814		23.53	19.35
282	20.70	1.34	8.64	49.00	0.29	0.07	1.93	9.60	8	0.96	374	0	681	0	23.60	23.53
283	18.40	1.14	8.79	44.00	0.32	0.08	1.64	2.00	8	0.15	0	0	393	0	22.14	23.60

NUM	TEMP	SECC	TURB	TAL	FE	MN	SI	SS	DO	TKN	MICRO	ANABA	CHLEL	DIATO	COST	LCOST
284	18.40	1.20	10.50	53.00	0.40	0.07	1.70	13.60	7	0.43	0	0	37	0	22.95	22.14
285	19.30	1.24	7.61	59.00	0.35	0.10	1.75	9.48	8	0.95	0	0	369	0	26.05	22.95
286	16.80	1.40	14.50	63.00	0.43	0.10	1.62	20.00	9	0.66	0	0	492	0	23.97	26.05
287	15.70	1.12	9.80	51.00	0.36	0.07	1.87	4.40	8	0.17	37	0	424	0	21.40	23.97
288	12.00	1.08	10.00	63.00	0.51	0.03	1.81	12.80	8	1.08	20	0	609	0	22.51	21.40
289	15.60	1.10	12.30	136.00	0.61	0.04	1.98	12.80	8	0.64	0	0	197	0	25.43	22.51
290	15.10	1.40	10.70	138.00	0.46	0.05	2.20	12.80	8	0.77	0	138	334	0	21.84	25.43
291	16.80	0.95	12.00	174.00	0.37	0.04	2.53	9.20	9	0.52	0	0	550	0	19.03	21.84
292	16.00	1.56	14.00	165.00	0.32	0.03	2.28	19.00	9	0.47	0	0	275	0	24.25	19.03
293	18.30	1.51	9.38	229.00	0.44	0.02	1.98	4.00	9	0.92	0	0	52	0	21.03	24.25
294	17.20	1.27	11.30	66.00	0.41	0.03	2.44	12.00	9	0.39	0	0	216	0	19.90	21.03
295	17.00	2.04	11.70	105.00	0.41	0.03	2.31	4.00	9	0.39	0	101	51	0	22.82	19.90
296	17.00	1.85	12.00	136.00	0.44	0.02	2.25	15.20	9	0.89	0	0	25	0	24.19	22.82
297	17.60	2.61	9.84	102.00	0.42	0.02	2.47	10.80	9	1.94	8	0	17	0	21.55	24.19
298	17.70	2.48	15.00	65.10	0.41	0.02	2.40	9.60	9	0.35	0	0	17	0	23.11	21.55
299	18.50	2.27	8.41	58.10	0.33	0.02	2.30	2.00	9	1.05	0	208	416	0	22.58	23.11
300	18.20	2.30	10.20	109.00	0.44	0.02	2.23	8.40	8	0.23	0	0	8	0	20.09	22.58
301	20.30	2.58	11.60	105.00	0.44	0.02	2.34	18.00	8	0.90	0	0	8	0	24.68	20.09
302	18.60	1.82	16.50	156.00	0.58	0.02	2.48	19.60		0.30	0	0	34	0	31.83	24.68
303	20.10	1.32	19.10	152.00	0.76	0.03	2.72	18.00	8	0.10	0	0	59	0		31.83
304	20.50	1.53	15.90	78.30	0.77	0.03	2.86	18.40	8	0.16	0	0	126	0	24.72	
305	20.70	1.66	14.50	80.70	0.65	0.02	2.79	4.00	8	0.16	0	0	42	0	25.64	24.72
306	22.20	1.65	19.80	160.00	0.89	0.04	2.84	27.80	9	0.10	0	0	42	0	29.11	25.64
307	22.10	1.68	13.00	93.50	0.74	0.02	2.90	16.00	9	0.24	0	0	17	0	25.37	29.11
308	22.40	1.73	18.70	128.00	0.90	0.03	3.82	14.00	8	0.86	84	0	118	0	29.96	25.37
309	23.80	0.84	68.20	571.63	0.92	0.03	3.60	32.40	8	0.40	0	0	8	0	34.62	29.96
310	22.40	1.43	54.40	1473.0	1.30	0.04	5.25	42.00	9	0.24	0	0	42	0	38.96	34.62
311	23.40	1.36	45.70	592.00	0.72	0.04	5.30	24.80	8	0.82	0	0	98	0	37.02	38.96
312	23.00	0.63	38.20	740.00	0.89	0.06	7.00	22.00	8	0.97	0	0	8	0	46.16	37.02
313	23.15	0.41	105.00	856.00	2.14	0.08	5.14	47.60	7	1.65	0	0	21	0	57.02	46.16