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Costs of Eutrophication at the Vaal River System: An Integrated Economic Model

By

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Abstract

Currently 35 per cent of the total water storage available in South African dams has deteriorated in water quality due to excessive nutrient loading. Eutrophication poses a significant threat to freshwater resources in South Africa. Although there are policies in place to deal with this threat, the problem of eutrophication still persists.

The main goal of this study was to investigate the existence of tradeoffs between the different economic costs associated with eutrophication in the Vaal River System. This was done with the aim of understanding the water quality management policy implications that follow as a result of the existence of tradeoffs between the different economic costs associated with eutrophication in the Vaal River System.

This study contributed to the understanding of the current and historic impact of eutrophication on the Vaal River System. Using Seemingly Unrelated Regressions (sample period 1996 – 2006), similar to De Villiers (2009) and Mostert (2009), this study revealed that the impact of eutrophication on property prices in the study areas was not discernible. This study further confirmed that eutrophication had an economic impact on agriculture and water treatment.

Future research is necessary to estimate coefficients in the case of extreme eutrophication level changes. Estimation techniques such as System Wide Dynamic Modelling, which combines traditional data and expert opinion, can capture the impacts of extreme eutrophication level changes.

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Chapter 1: Introduction

Currently 35 per cent of the total water storage available in South African dams has deteriorated in water quality due to excessive nutrient loading (Van Vuuren, 2008:14). Eutrophication poses a significant threat to freshwater resources in South Africa. Although there are policies in place to deal with this threat, the problem of eutrophication still persists (Department of Water Affairs and Forestry, 2003).

The persistence of the problem of eutrophication can be attributed to the fact that quantitative knowledge of the eutrophication problem in South Africa informing policy is limited. Walmsley (2000:52) stated that for South Africa to develop effective national eutrophication control strategies it is important to have quantitative knowledge of:

- The extent and trends of the national eutrophication problem;
- The sources of nutrients entering freshwater resources;
- The actual economic and social costs that flow from the problem of eutrophication on a national scale.

The analysis of economic costs for the management of freshwater resources broadens the base for rational decision making in conserving water ecosystems (Stow et al., 1998:68).

Previous research identified the different cost associated with eutrophication (Pretty, Mason, Nedwell, & Hine, 2002; Rast & Thornton, 1996).In South Africa Mostert (2009) and De Villiers (2009) conducted research to identify different costs associated with eutrophication in the Vaal River System. Previous studies revealed that the non market nature of water ecosystems raises the need for particular pricing methods (Bateman & Turner, 2001; Gibbs, Halstead, Boyle, & Huang, 2002; Zylicz et al., 1995). These studies are summarised in Appendix A. Previous studies revealed the evolution of eutrophication policy in South Africa since the 1980s (Department of Water Affairs and Forestry, 2003; Grobler & Silberbauer, 1985; Quibell, Van Vliet, & Van der Merwe, 1997; Walmsley, 2000).

Problem Statement

The Vaal River is South Africa's most important river. The Vaal River has been described as South Africa's hardest working river and is the backbone of the South Africa's economy since it provides water services to the economic hub of South Africa, the Gauteng Province (Tempelhoff, 2006:433). The Vaal River contributes 25 per cent to the Gross Domestic Product of South African economy and has over 12 million people who directly depend on it for water (Tshwane University of Technology, 2009:37).

However, it has become apparent that the Vaal River is increasingly under threat of pollution. Tempelhoff, Munnik and Viljoen (2007:116) summarised the pollution threat to the sustainable use of the Vaal River as follows:

- The industries in and around the Vaal River provided arms and ammunition to the apartheid government under increasingly difficult circumstances. As a result environmental concerns were place on the backburner and the Vaal River suffered;
- The extent of the pollution became increasingly apparent as a new democratic dispensation came into power. The new government placed these industries under scrutiny and it became apparent that the water pollution was the order of the day since the 1960s;
- In the 1980s the then government lifted influx control into urban areas. This placed significant pressure on sanitary services and eventually led to their collapse. The influx of population in to the Witwatersrand led to the establishment of informal settlements and with the lack of sanitary services, the Klip River came under increasing pressure. The Klip River flows in the Vaal River (South of the Vaal River Barrage).

- The lack of sanitary services and therefore the threat of water pollution caused the establishment of the East Rand Water Care Company in 1992. This body is responsible of treating of water waste for the population of the eastern parts of Gauteng.
- The transition to democracy saw a change in the structure of municipal sanitary services. This saw white officials move into the private sector or into early retirement. This left a critical shortage of human resources which this persist even today.

In 2003, the Department of Water Affairs and Forestry recorded the trophic status of the Vaal dam, Bloemhof dam, and Grootdraai dam as mesotrophic, hypertrophic, and oligotrophic respectively. The Grootdraai dam, Vaal dam, and Bloemhof dam represent the upper, middle, lower Vaal River areas respectively. Data from the Department of Water Affairs and Forestry suggested that the aforementioned trophic status of the Vaal dam, Bloemhof dam, and Grootdraai still continues. The problem of eutrophication is well established in the Vaal River and significant intervention is needed to reverse this trend.

The Department of Water Affairs and Forestry established policies in response to problem eutrophication. In the 1980s the government promulgated the 1 mg/ℓ Phosphorus standard in terms of the 1956 Water Act (Quibell et al., 1997:194). This standard was applied to sensitive catchment (including the Vaal River System). The phosphorus standards were not widely observed and the Department of Water Affairs and Forestry moved to Receiving Water Quality Objectives which, unlike the phosphorus standards, recognised the assimilative capacity of freshwater bodies (Quibell et al., 1997).

Walmsley (2000:38) noted that since 1985 eutrophication was a low priority in South Africa, and that there was a significant need for eutrophication research in South Africa to inform water quality management policy. One of the areas noted was research into the actual economic costs associated with eutrophication. Therefore the Water Research Commission recognised this and new impetus has been placed on eutrophication research (Walmsley, 2000:10).

Mostert (2009) and De Villiers (2009) conducted studies in the Vaal River System quantifying the economic costs associated with eutrophication. Mostert (2009) and De Villiers (2009) found that economic costs of eutrophication in the Vaal River System affected recreational users, industry, property prices and agriculture. The magnitudes of the economic costs were however not significant. An explanation for this is that since the different users of the Vaal River System all observe the same eutrophication problem there are tradeoffs between the different economic costs observed. Dam specific information is crucial to understanding tradeoffs between economic costs associated with eutrophication. For example, property prices in a specific site can be affected by low quality of the water that is available in a specific property which is near a specific dam; that is potential property buyers include water quality in their purchase decision, indicating tradeoffs between the economic costs due to eutrophication (such tradeoffs are dam specific).

An extensive search of SABINET (available literature) revealed that no integrated economic model quantifying the cost associated with eutrophication exists in South Africa. Therefore this study attempted to bridge this knowledge gap by building an integrated economics model quantifying the tradeoffs between different economic costs of eutrophication in the Vaal River System.

It then follows that the research question is: what are the tradeoffs between the different economic costs associated with eutrophication in the Vaal River System?

Purpose Statement

The main goal of this study was to investigate the existence of tradeoffs between the different economic costs associated with eutrophication in the Vaal River System. This was done with the aim of understanding the water quality management policy implications that follow as a result of the existence of tradeoffs between the different economic costs associated with eutrophication in the Vaal River System.

Research Objectives

The specific research objectives for this study were:

- To determine whether tradeoffs exist between the different economic costs associated with eutrophication in the Vaal River System;
- To analyse the existing tradeoffs between the different economic costs associated with eutrophication in the Vaal River System.

Study Area

The Vaal River is 1300 kilometres long and it stretches from the Drakensberg plateau to the arid Karoo region. Historically the Vaal River has been used as communication route for humans and animals moving across the interior of South Africa, and it has served as a boundary line between the then independent states of the British and indigenous communities of South Africa (Tempelhoff, 2006:433). More recently the Vaal River has become a vital part of the South African economy providing water services mainly to Gauteng (the economic hub of South Africa).

This study separated the Vaal River into three parts: the Grootdraai dam situated in the upper area of the Vaal River, the Vaal dam situated in middle of the Vaal River, and Bloemhof dam situated in the lower area of the Vaal River. The separation is done to distinguish the impact of eutrophication on these three parts of the Vaal River. This study collectively referred to these three areas as the Vaal River System.

The Grootdraai dam is situated 10 kilometres from the town of Standerton in the Mpumalanga province of South Africa. Grootdraai dam was completed in 1982 and has a full supply capacity of 364 million cubic metres. The Grootdraai dam primarily suppliers water to municipal users and industrial users located in the Secunda area of the Mpumalanga province of South Africa.

The Vaal dam is located 56 kilometres south of the city of Johannesburg in the Gauteng Province of South Africa. The Vaal dam was completed in 1938 and at full supply capacity can store up to 2536 million cubic metres. The Vaal dam is critical to the water supply infrastructure of Gauteng province and to other surrounding provinces, and supplies water to municipal users and industrial users.

The Bloemhof dam is situated 2 kilometres from the town of Bloemhof in the North West province of South Africa. The Bloemhof dam was completed in 1970 and has a full supply capacity of 1269 cubic metres. The Bloemhof dam supplies water to the lower Vaal River area for both industrial and municipal users.

Limitations of the Study

This study had the several limitations related to the context, theoretical perspectives, and sampling units of the study. The context of the study is limited to the economic aspects of eutrophication and not the scientific study of the biological/ecological aspects of eutrophication. This study focused on the costs that were associated with eutrophication that accrue to residential property owners, industrial and agricultural users Vaal River System. The economic use value associated with recreational users was not quantified due to a lack of data. This study did not be use System modelling. System modelling is concerned with changes in levels of activity of observed phenomena, which was not the focus of this study. This study did not collect new data and used existing data (secondary data analysis).

Assumptions

This study assumed the following essential conditions:

- The three study areas were assumed to have a problem of eutrophication;

- The first order relationships of eutrophication and factors that affect it were established.

Definition of Key Terms

The main terms that are used in this study are the defined as the following:

Eutrophication: is defined as "the enrichment of water bodies with plant nutrients which may result in excessive growth of phytoplankton (free floating algae) and rooted macrophytes" (Rossouw, 2000:1). This can result in increased water treatment costs, taste and odour problems in treated water, and interference with recreation.

Water quality: is defined as the usefulness of water for anthropocentric uses (Bergstrom, Boyle, & Gregory, 2001:1). This water quality can be adversely affected by chemical contamination and bacterial contamination.

Chapter 2: Literature Review

Problem of Eutrophication

The primary causes of eutrophication are increased nutrient loads from discharges from sewage plants and increased nutrient runoff from agriculture, urban populations and industry. The trophic status of surface water bodies can be classified by the level of nutrient enrichment as oligotrophic, mesotrophic, eutrophic and hypertrophic (ranging from minimum impact on water quality (oligotrophic) to maximum impact water quality (hypertrophic)). Figure 1 summarises.

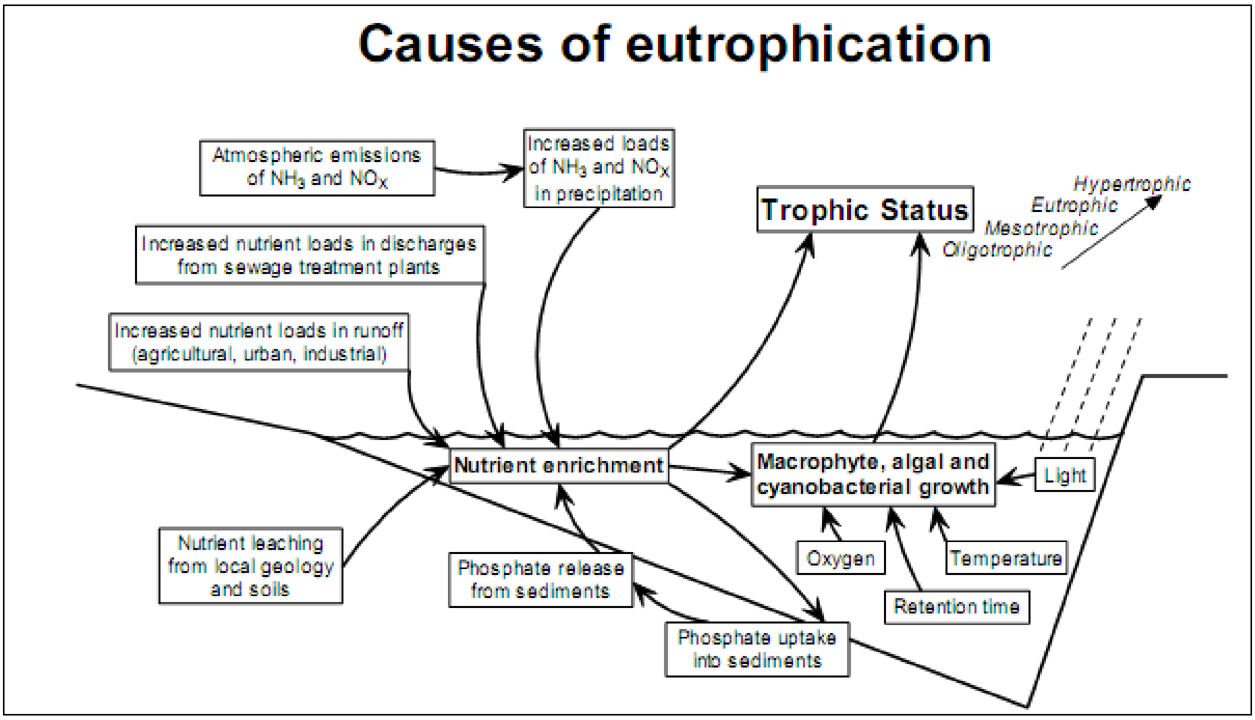

Figure 1. Negative impacts of eutrophication. From Department of Water Affairs and Forestry. (2003). *National eutrophication monitoring programme*. Pretoria: Department of Water Affairs and Forestry. Retrieved from www.dwaf.gov.za.

According to the Environmental Protection Agency (2000:30) the primary variable driving the nutrient criteria development in surface waters are total *Phosphorus*, total

Nitrogen, *Chlorophyll a*, and *Transparency*. Table 1 illustrates that the trophic status determination in South Africa was based the same primary variables.

Table 1

Trophic Status determination

		Trophic Status			
Variable	Unit	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic
Mean annual chlorophyll a	µg/ℓ	0<x≤10	10<x≤20	20<x≤30	>30
% of time chlorophyll a > 30 µg/ℓ	%	0	0<x≤8	8<x≤50	>50
Mean annual Total Phosphorus	mg/ℓ	x≤0.015	0.015<x≤0.047	0.047<x≤0.130	>0.130

Note. From Department of Water Affairs and Forestry. (2003). *National eutrophication monitoring programme*. Pretoria: Department of Water Affairs and Forestry. Retrieved from www.dwaf.gov.za.

The Department of Water Affairs and Forestry (1986:46) summarised the problems that were caused by eutrophication as follows (these are also summarised in Figure 1):

- *Problems with portable water treatment plants*: eutrophication increased costs associated with the treatment of water. The increased costs lay in the installation of additional processes such as micro-screening for the physical removal of algae. This was the case in treatment plants in Roodeplaat dam, Shogweni dam and the Vaal Barrage;

- *Health effects*: toxic algae can cause livestock and fish deaths. The effect on human health can be in the form of gastro enteritis caused by toxins from microcystis.
- *Interference with Recreation*: problems occurred with water hyacinth of dams used for recreation such as the Hartebeespoort and Roodeplaat dams. The financial impact of this can be significant;
- *Interference with water supply systems*: the control of algae has an economic costs associated with it. For example in 1982 R600 000 was set aside for the Vaal River;
- *Interference with irrigation*: excessive algae which grow in distribution canals can place restrictions on water supply of government water schemes. This was the case in the Hartebeespoort dam;
- *Aesthetic problems*: dying algae can cause odour and aesthetic problems. This can increase pressure from the public for corrective action;
- *Effect on values surrounding the land*: consequences of eutrophication can affect the surrounding land as promising development no longer becomes viable.

Economic Costs Associated with Eutrophication

In accordance with the OECD's Pressure State Response framework, the economic costs of eutrophication emanate from the sources of eutrophication which are point sources and non point source (Pretty et al., 2002:11). Point source costs were the costs that can be traced back to the specific source of originality. The point source costs included runoff from sewage treatment plants, runoff from industrial plants, and runoff from power plants. Conversely, non point source costs were the costs that cannot be traced back to their specific source of originality. These included runoff from the agriculture industry, runoff and emissions from the transport industry, and atmospheric nitrogen products from the transport sector.

The economic costs that flow from point and non point sources were (Pretty et al., 2002:13): 1) damage costs which were divided into social damage costs and ecological costs, and 2) policy response costs which were divided into compliance costs of adverse effects of eutrophication and direct costs to monitoring, investigating and enforcement agencies.

Damage Costs

These costs arise as a result of continued nutrient loading. Ecological costs were due to damage to the ecosystem structure as a result of increased nutrient loading. This can be presented as a change in species composition and/or loss of key species. Social costs included the following:

- reduced value of surrounding dwellings,
- reduced value of water bodies for commercial use,
- drinking water treatment of costs,
- cleanup costs of waterways,
- net economic losses to formal tourism industry,
- and human costs to human beings, livestock and pets.

Policy Response Costs

Policy response costs were divided into compliance costs of adverse effects of eutrophication and direct costs to monitoring, investigating and enforcement agencies. Whilst direct costs were monitoring costs of air and water, costs of developing, and implementing eutrophication control policies and strategies (essentially the cost that resource managers incur in controlling eutrophication). Compliance costs included the following:

- sewage treatment costs to remove phosphorus from point sources,
- costs of treatment of alga blooms in waters,

- and cost of adopting new farming practices to emit fewer nutrients.

Review of Previous Studies

Eutrophication of water bodies has proven to be a serious problem in South Africa and therefore it becomes essential to understand the implications of this economically (Walmsley, 2000). As mentioned in the introduction in South Africa there has been two recent studies in the area of quantifying the economic costs associated with eutrophication. These studies are Mostert (2009) and De Villiers (2009). These are discussed below. For a review of international studies please see Appendix A.

Mostert (2009)

Mostert mainly focused on quantifying economic costs due to property prices adjacent to the study areas that may be affected by eutrophication in the study areas (Bloemhof dam, Grootdraai dam and Vaal dam) and the effect of eutrophication on recreational activities in the study areas. The methods of inquiry were a panel data econometric model (Seemingly Unrelated (SUR) panel model) for property prices and a survey (Contingent Variation Method (CVM) – see Appendix A) for the recreational activities.

The results of Mostert are summarised in Table 2 below. The 1st lag model was the best fit model with and R^2 of 78 per cent. The results from Table 2 revealed contradictory marginal elasticities which could be attributed to data limitations. The direction of the relationships was at times contradictory, indicating that perhaps the environmental nature of the variables was not fully explored. In other words, the a priori expectations may not have been the same as one would expect with traditional economic variables.

Table 2

SUR panel property model[1]

Independent Variable/Statistic	Dependant Variable: *UNIT PROPERTY PRICES*		
	Level	1st lag	2nd lag
	Bloemhof Dam		
CHLOROPHYLL_B	0.869605	0.298965	-1.350005
	(0.0342)	(0.4625)	(0.0069)
AMMONIUMNITRATE_B	-1.066140	1.388566	0.030505
	(0.0081)	(0.0017)	(0.9427)
NITRATE-NITRITE _B	0.123928	0.731224	-1.222402
	(0.7613)	(0.1249)	(0.0266)
	Grootdraai Dam		
CHLOROPHYLL_G	0.374521	0.114163	-0.772480
	(0.1998)	(0.6924)	(0.0077)
AMMONIUMNITRATE_G	-0.455180	-0.097121	0.005697
	(0.0462)	(0.6768)	(0.9821)
NITRATE-NITRITE _G	-0.030130	0.378773	0.057987
	(0.9019)	(0.1141)	(0.8262)
	Vaal Dam		
CHLOROPHYLL_V	0.096599	0.128293	0.012792
	(0.0574)	(0.0027)	(0.8403)
AMMONIUMNITRATE_V	-0.259852	-0.320249	-0.092074
	(0.0469)	(0.0032)	(0.5684)
NITRATE-NITRITE _V	0.449625	0.583234	0.045344
	(0.0068)	(0.0000)	(0.8079)
	Diagnostics (Weighted Statistics)		
R^2	0.68	0.78	0.75
F statistic	2.91	5.86	5.74
Durbin Watson	1.99	2.23	2.61

Note. B= Bloemhof dam; G= Grootdraai dam; V= Vaal dam. Estimated in logs. [1] See Research Design and Methods section for description of variables. P values in parenthesis. Adapted from Mostert, D. (2009). *A generic model to assess the cost associated with eutrophication on property values and recreation applied to the Vaal River.* (Unpublished Masters Dissertation). University of Pretoria, Pretoria.

The results revealed that eutrophication had an impact on property prices – although marginal. The impact of eutrophication was appropriately explained by the variables included in the model, since the majority where statistically significant. The models were statistically robust (a good fit and no strong serial correlation).

Figures 2 – 4 summarise the results of the CVM survey. The survey in essence sought to establish the preferences of the recreational users of the study sites with regard to improved water quality. The survey asked the question: "how much are the respondents willing to pay to either keep the water quality in the site as is, or to improve the water quality on the site?" (Mostert, 2009:66). The survey was conducted on the three study sites in December of 2008. The survey covered 90 respondents (Bloemhof dam = 40, Vaal dam = 30 and Grootdraai = 20) across the three dams.

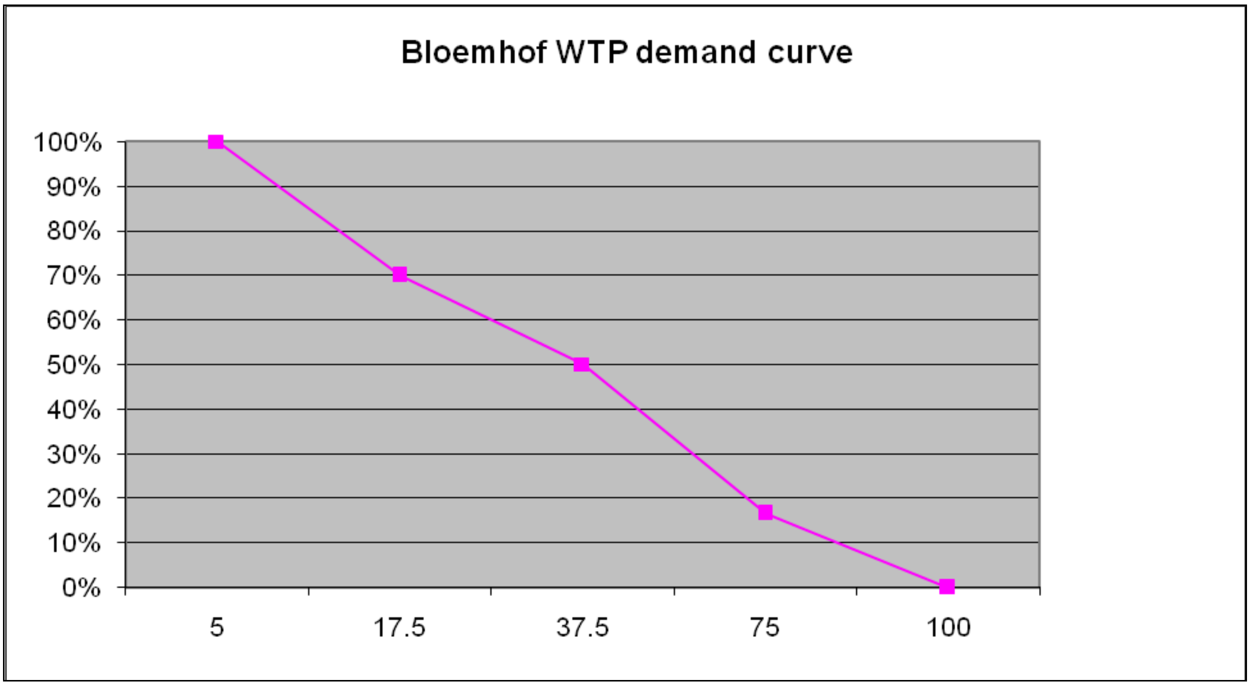

Figure 2. Willingness to pay (WTP) demand curve for Bloemhof dam. The y axis represents the percentage of respondents who responded positively on and the x axis represents the WTP in South African rands. Adapted from Mostert, D. (2009). *A generic model to assess the cost associated with eutrophication on property values and recreation applied to the Vaal River.* (Unpublished Masters Dissertation). University of Pretoria, Pretoria.

The final average WTP for each site was R36 for Bloemhof dam, R66 for Grootdraai dam and R53 for the Vaal dam. This represented strong evidence on the preference of the respondents towards good water quality. The confidence band for Bloemhof dam was R25 < Bloemhof < R47, Grootdraai dam was R46 < Grootdraai < R86, and Vaal dam was R37< Vaal < R69.

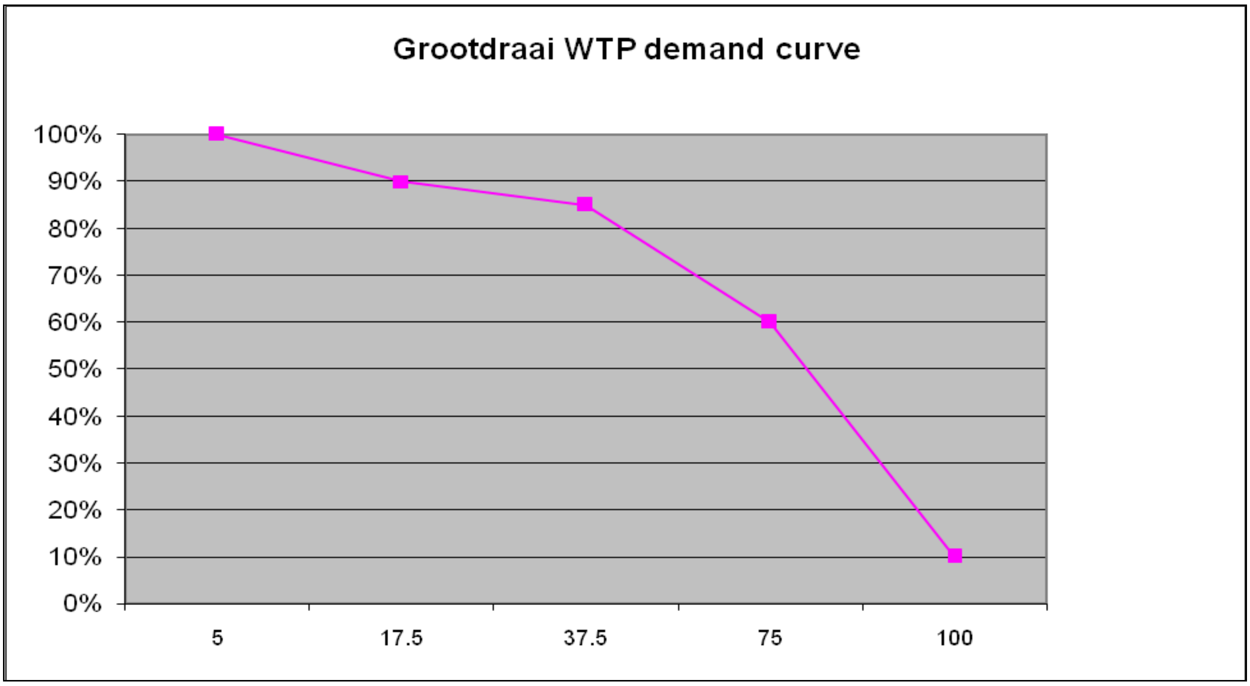

Figure 3. Willingness to pay (WTP) demand curve for Grootdraai dam. The y axis represents the percentage of respondents who responded positively on and the x axis represents the WTP in South African rands. Adapted from Mostert, D. (2009). *A generic model to assess the cost associated with eutrophication on property values and recreation applied to the Vaal River.* (Unpublished Masters Dissertation). University of Pretoria, Pretoria.

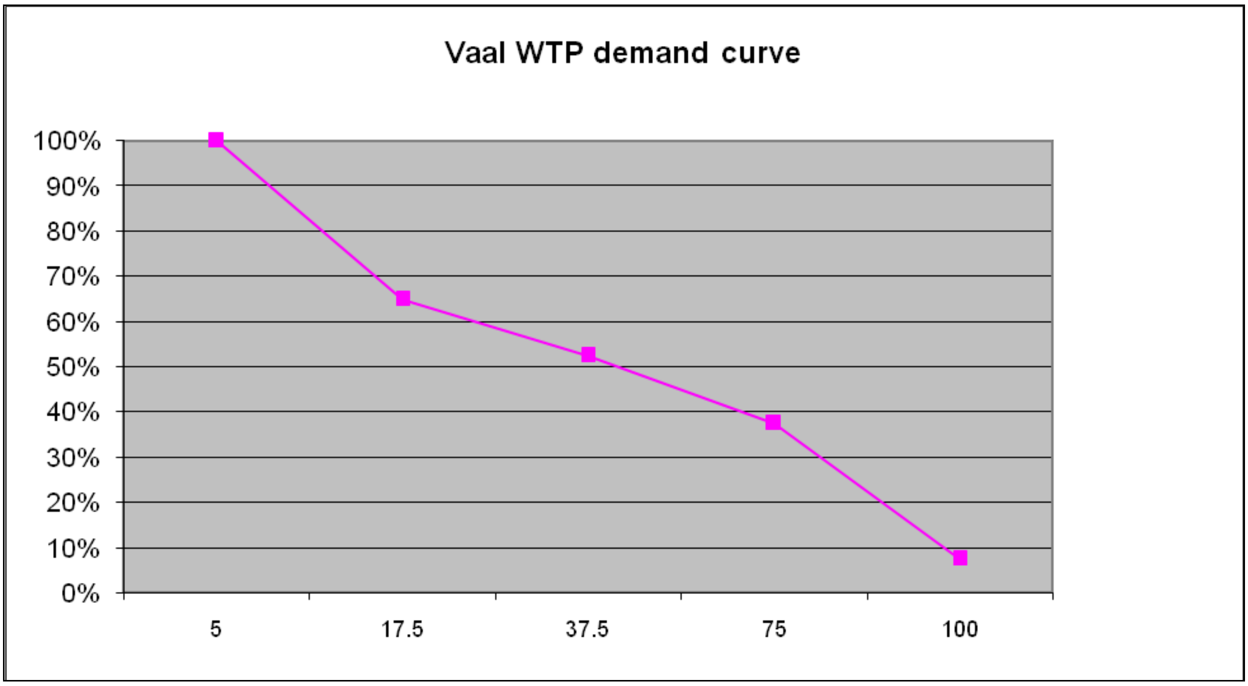

Figure 4. Willingness to pay (WTP) demand curve for Vaal dam. The y axis represents the percentage of respondents who responded positively on and the x axis represents the WTP in South African rands. Adapted from Mostert, D. (2009). *A generic model to assess the cost associated with eutrophication on property values and recreation applied to the Vaal River.* (Unpublished Masters Dissertation). University of Pretoria, Pretoria.

De Villiers (2009)

De Villiers (2009) mainly focused on quantifying the economic costs associated with eutrophication in the study areas due to agricultural activities and to industries (in particular the water treatment industry) that are surrounding the study areas. Similar to Mostert, De Villiers (2009) used a panel data econometric model (pooled least squares allowing for individual fixed effects) to for agriculture activities, but used ordinary least squares model for the industries. Table 3 summarises the results of the estimation.

Table 3

Pooled least squares model for agriculture[1]

	Dependant Variable: *TOTAL AGRICULTURAL COST*
Independent Variable/Statistics	Coefficients
Bloemhof Dam/Grootdraai Dam/Vaal Dam	
CONSTANT	0.57
	(0.00)
INTERMEDIATE COSTS	0.74
	(0.00)
CAPITAL COSTS	0.27
	(0.00)
PHOSPHORUS	-0.01
	(0.19)
NITROGEN	0.01
	(0.00)
Diagnostics	
R^2	0.99
F statistic	53646.32
Durbin Watson	0.62

Note.[1] See Research Design and Methods section for description of variables. P values in parenthesis. Adapted from De Villiers, L. (2009). *Development of a model to estimate the cost on agriculture and industry due to eutrophication in the Vaal system.* (Unpublished Masters Dissertation). University of Pretoria, Pretoria.

The results of the pooled least squares model revealed that the impact of eutrophication on agricultural costs was small (0.01 per cent) for both *Phosphorus* and *Nitrogen*. *Phosphorus* proved to be insignificant and excluding it from the model did not change the variables significantly.

Interaction with various industries such as SASOL (the petro chemical company) revealed that not significant information could be gathered to contribute towards the understanding of the impact of eutrophication on industries. De Villiers (2009:46) used ordinary least squares to estimate the effect of eutrophication on the water treatment cost faced by Rand Water (largest water treatment plant in the Vaal River System). The estimation revealed that a 1 per cent increase in the level of *Phosphorus* in the study sites indicates a 0.22 per cent increase in the water treatment costs per litre, and a 1 per cent increase in the level of *Nitrogen* in the study sites caused a 0.144 per cent increase in the water treatment cost per litre.

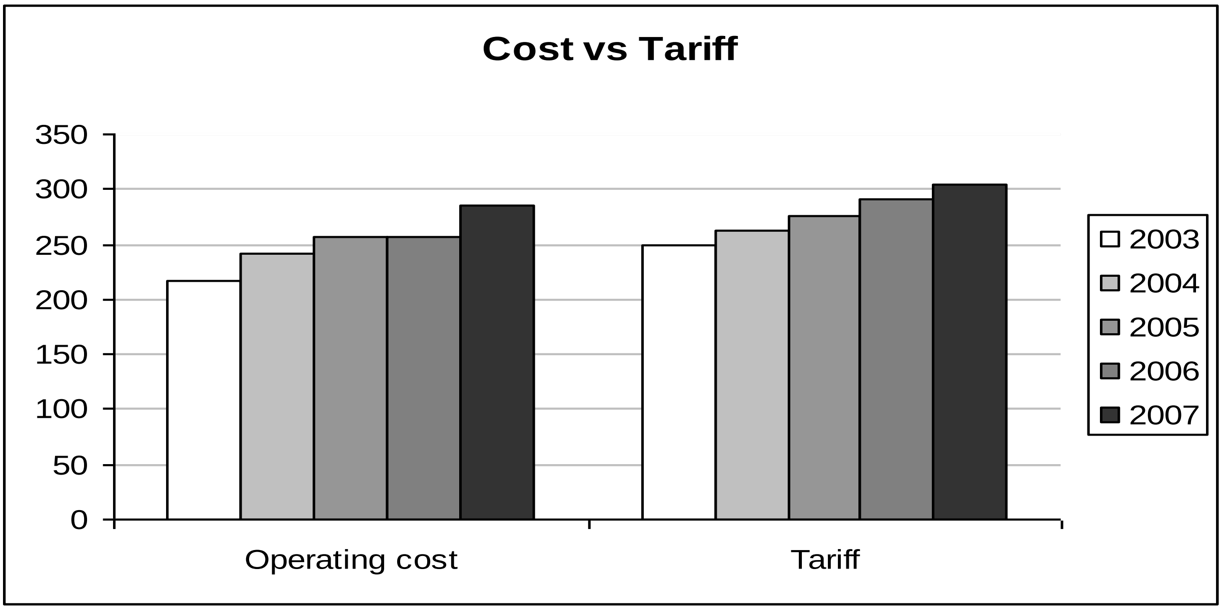

Figure 5. Cost versus Tariff. . Adapted from De Villiers, L. (2009). *Development of a model to estimate the cost on agriculture and industry due to eutrophication in the Vaal system.* (Unpublished Masters Dissertation). University of Pretoria, Pretoria.

Figure 5 illustrates that the increases in water treatment costs per litre were directly passed on to water consumers through the water tariff structure. This showed that eutrophication had a significant (though small) negative impact on the provision of clean water and access to clean water.

Eutrophication Management

General Framework

The estimation of environmental benefits has evolved to provide resource managers with a framework within which to base decisions. Lund (1972:371) noted that eutrophication was emphasised as an artificial and undesirable addition of plants to waters, and this emphasis had a particular shortfall in that what is undesirable to one body of water may be desirable to another. This was among the reasons for the continued need of resource managers for a coherent decision making framework.

Resource managers responsible for decision making with regard to the management of environmental resources do not operate in a vacuum. Resource managers make their decisions in the context of competing national interests and objectives. An illustration of the cycle of management for eutrophication under adaptive management of environmental resources (Stow et al., 1998:68) (Figure 6 illustrates):

- Under the canalisation phase the agencies focus on a narrowly defined set of issues and they excel in what they do;
- However as agency issues become fixed the societal objectives change and policies become irrelevant;
- Activists agitate social change and the alternative explanations arise;
- New more effective leaders arise and there is reorganisation and formulation of new paradigms;
- This leads to a new phase of exploitation.

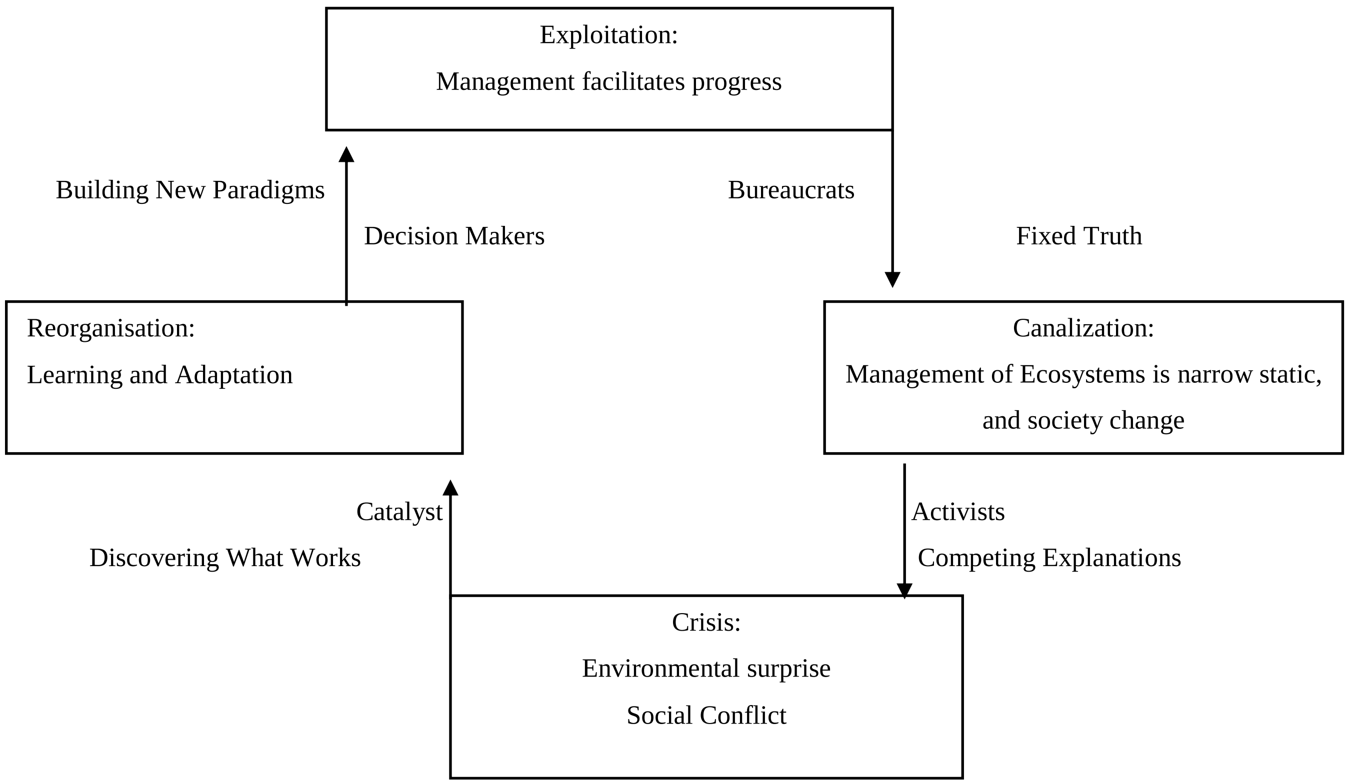

Figure 6. Cycles of management of eutrophication. From Stow, C. A., Bolgrien, D., Lathrop, R. C., Carpenter, S. R., Wilson, M. A., & Reed, T. (1998). Ecological and economic analysis of lake eutrophication by nonpoint pollution. *Australian Journal of Ecology*, *23*(1), 68-79.

Eutrophication Management Policies in South Africa

Water quality management in South Africa has been ongoing since the early 1900s. The realisation that surface waters would be vital to the economic success of South Africa is not new. For example, the Union Health Act of 1919 gave the Chief Health Officer the power to control pollution by using best practices (Quibell et al., 1997:194). This granted the Chief Health Officer the power to prevent the disposal of effluent from sewage treatment into water courses.

The Water Amendment Act of 1984 (an amendment of the 1956 Water Act) allowed for the Uniform Effluent Standard (UES) approach. The UES required the control of water pollution from point source by requiring effluent discharge to meet uniform effluent standards, which were set at economically and technologically feasible levels (Van der Merwe & Grobler, 1990:49). The UES was simple and straightforward for regulators to apply.

Van der Merwe and Grobler (1990:49) further noted that the UES failed due to several drawbacks:

- UES focused largely on effluent and largely ignored the impacts of effluent discharges on receiving waters;
- UES required that all effluent comply to the same standards regardless of the assimilative capacity of receiving waters and this was not cost effective;
- UES provided no framework for the control of non point sources and consequently did not guarantee that the quality objectives of receiving waters could continue to be met.

The continued deterioration of water quality despite the application of UES prompted a change in policy. This change was the Receiving Water Quality Objectives (RWQO) approach. The main difference between UES and RWQO is that RWQO recognised the assimilative capacity of receiving waters. RWQO approach required the specification of water quality needs in receiving waters for the control of point and non point source pollution. The RWQO was introduced in 1988 with an objective of obtaining 130 ug/ℓ total phosphorus for sensitive catchments (Walmsley, 2000:39). The sensitive catchments included the Vaal River upstream including Bloemhof dam, Pienaar and Crocodile Rivers upstream, and Umgeni River upstream.

The RWQO approach combined with the Pollution Prevention (PP) approach, which dealt with hazardous pollutants, had been widely viewed as the predominant policy approach towards water quality management in South Africa in the late 1980s to early 1990s. The overarching principle of the RWQO and PP is the “precautionary principle”. The “precautionary principle” placed an emphasis that the assimilative capacity of receiving waters must not be allocated to dischargers. Instead dischargers must prove that they have explored all other options before allocation can take place (Quibell et al., 1997:194). In the absence of the “precautionary principle” RWQO could lead to further deterioration of water quality in South Africa.

The promulgation of the National Water Act of 1998 expanded the definition of RWQO by introducing the concepts of Resource Quality and Resource Quality Objectives (www.dwaf.gov.za). Resource Quality meant the quality of all aspects of water (including water quantity and aquatic ecosystem quality. Resource Quality Objectives were the requirements of the receiving waters to maintain water quality.

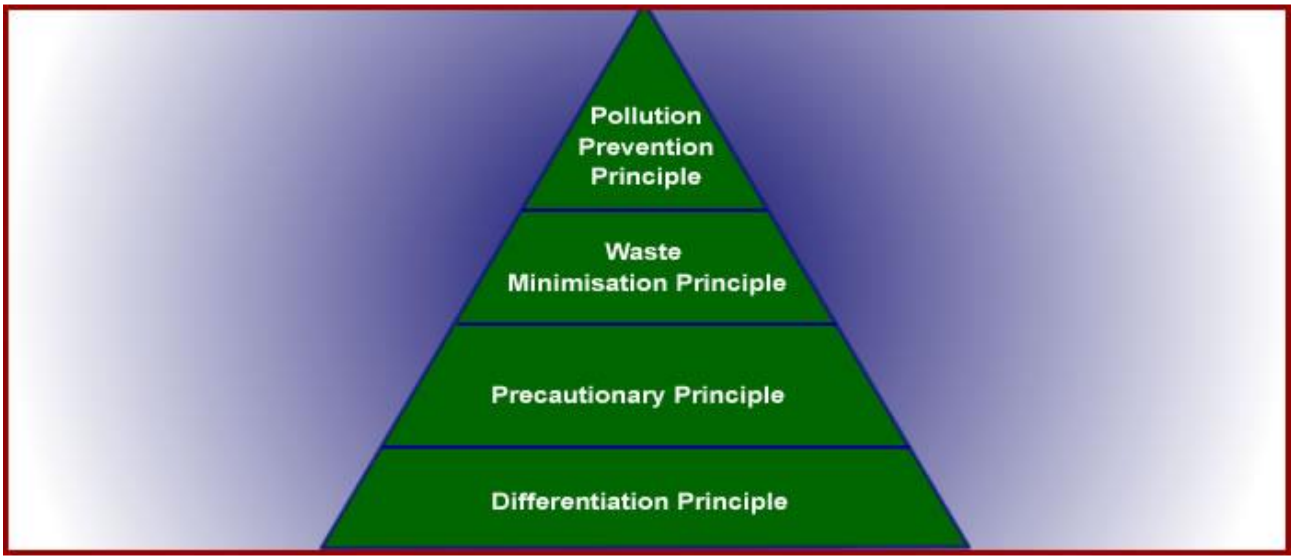

Figure 7. Decision Making Framework. From www.dwaf.gov.za

Figure 7 summarises the current decision framework of the Department of Water Affairs and Forestry. The pyramid shows the different approaches that have been adopted in South Africa in one coherent framework that is currently applied. The pollution prevention principle is informed by the initial approach promulgated by the Union Health Act of 1919. The waste minimisation principle informed the UES promulgated under the Water

Amendment Act of 1984. The precautionary principle falls under the RWQO approach and this has been extended by the National Water Act of 1998. The differentiation principle flows directly from the precautionary principle in the case of dischargers who have demonstrated that they have no other choice but to release pollutant into the environment (with the permission of the Department of Water Affairs and Forestry).

Chapter 3: Research Design and Methods

Introduction

The strategy of inquiry used in this study is secondary data analysis. This study follows on the works of Mostert (2009) and De Villiers (2009) who conducted research to identify different costs associated with eutrophication in the Vaal River System. This study distinguishes between the three dams that constitute the Vaal River System as separate "economies". This study sought to quantify the economic costs associated with eutrophication in each dam.

In essence SUR is system estimation when the individual equations in a system are related. In the context of this study this means that the determination of the different costs associated with eutrophication are related. For example, property prices in a specific site can be affected by low quality of water that is available for consumption in a specific property which is near a specific dam, that is, potential property buyers include water quality in their purchase decision. This indicates tradeoffs between the economic costs due to eutrophication that affect property prices and water quality (and such tradeoffs are dam specific. Tradeoffs infer that the same fresh water body serves different uses (for example water services and agriculture) and therefore the costs faced by different water users are related. The theoretical aspects of SUR followed by a description of the integrated model to be estimated are discussed in this chapter.

Seemingly Unrelated Regression (SUR) Estimation

SUR in General

SUR model is important because it has enabled the use of multivariate regression in a number of applications. These applications include demand systems and panel data which have proven to be indispensible to the current practice of econometrics. Zellner (1962) speaks on the general use of SUR:

- It can be applied to temporal cross-section data, for example annual macro data;
- It can be applied to single cross-section budget studies when regressions for several commodities are to be estimated;
- It can be applied in time-series regressions of the demands for a variety of consumption and investment goods;
- Finally it can also be applied to regression equations in which each equation refers to a particular classification category and the observations refer to different points in space.

Significant emphasis has been placed on demand systems because of their contribution to the understanding of economic development of the household. Work done includes Parker and Wong (1997), Taljaard, Almeu and van Schalkwyk (2004), Carson (1978), amongst others. To understand the essence of SUR, the case of a multivariate regression is considered. Thereafter the theoretical foundations of the SUR models are considered.

Multivariate Regression Model

Consider this form of a multivariate regression:

$$\begin{bmatrix} y_1 \\ y_2 \\ \cdots \\ y_H \end{bmatrix} = \begin{bmatrix} X_1 & 0 & \cdots & 0 \\ 0 & X_2 & \cdots & 0 \\ 0 & 0 & \vdots & 0 \\ 0 & 0 & 0 & X_H \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \cdots \\ \beta_H \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \cdots \\ \varepsilon_H \end{bmatrix} = X\beta + \epsilon$$

where **y** is a TH x 1 matrix; **X** is a TH x M block diagonal matrix of non-stochastic variables (also known as a data matrix); $\boldsymbol{\beta}$ is an M x 1 matrix of coefficients and $\boldsymbol{\epsilon}$ is a TH x 1 matrix of disturbance terms. The transpose of the disturbance terms is given by $\epsilon' = [\varepsilon_1{}', \varepsilon_2{}', \cdots, \varepsilon_n{}']$, leading to the mean and variance given by $E[\epsilon | X_1, X_2, \cdots, X_n] = 0$ and $E[\epsilon\epsilon' | X_1, X_2, \cdots, X_n] = \Psi$ respectively.

Assuming a sample size of T observations used to estimate H equation and K_H regressors in each equation of the multivariate regression model the variance covariance matrix Ψ (H x H) takes on this form:

$$\mathbf{\Psi} = \begin{bmatrix} \sigma_{11}\mathbf{I} & \sigma_{12}\mathbf{I} & \cdots & \sigma_{1H}\mathbf{I} \\ \sigma_{21}\mathbf{I} & \sigma_{21}\mathbf{I} & \cdots & \sigma_{2H}\mathbf{I} \\ \vdots & \vdots & \cdots & \vdots \\ \sigma_{H1}\mathbf{I} & \sigma_{H1}\mathbf{I} & \cdots & \sigma_{HH}\mathbf{I} \end{bmatrix}$$

where **I** is an identity matrix (T x T) with σ_{ij} representing the relationship of the disturbance terms, that is, $E[\epsilon_{it}\epsilon'_{js}|X_1, X_2, \cdots, X_n] = \sigma_{ij}$, if $t = s$ and 0 otherwise. This is to be consistent with one of the assumptions in the classical linear case, that the disturbance terms are uncorrelated across observations.

SUR Estimator

Keeping the initial matrix form of the multivariate regression and following Zellner (1962) the variance covariance matrix:

$$\mathbf{\Sigma} = \begin{bmatrix} \sigma_{11}\mathbf{I} & \sigma_{12}\mathbf{I} & \cdots & \sigma_{1H}\mathbf{I} \\ \sigma_{21}\mathbf{I} & \sigma_{21}\mathbf{I} & \cdots & \sigma_{2H}\mathbf{I} \\ \vdots & \vdots & \cdots & \vdots \\ \sigma_{H1}\mathbf{I} & \sigma_{H1}\mathbf{I} & \cdots & \sigma_{HH}\mathbf{I} \end{bmatrix} = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1H} \\ \sigma_{21} & \sigma_{21} & \cdots & \sigma_{2H} \\ \vdots & \vdots & \cdots & \vdots \\ \sigma_{H1} & \sigma_{H1} & \cdots & \sigma_{HH} \end{bmatrix} \otimes \mathbf{I}$$

where the **I** is still an identity matrix (T x T), Σ is a H x H variance covariance matrix, and ⊗ represents the **Kronecker product.** While **Σc** is the first part of **Σ** before ⊗.However, and more importantly, the disturbance terms are now correlated. More formally $E[\epsilon_{it}\epsilon'_{jt}|X_1, X_2, \cdots, X_n] = \sigma_{ij}$ for all t = 1, 2,...,T.

Solving for the SUR estimator:

$$\mathbf{\Omega} = \mathbf{\Sigma c} \otimes \mathbf{I}$$

and

$$\boldsymbol{\Omega}^{-1} = \boldsymbol{\Sigma}\mathbf{c}^{-1} \otimes \boldsymbol{I}$$

Denoting the elements of $\boldsymbol{\Sigma}^{-1}$ as σ^{ij} and therefore the SUR estimator is given by:

$$\boldsymbol{\beta}^{hat} = [\boldsymbol{X}'\boldsymbol{\Omega}^{-1}\mathbf{X}]^{-1}\boldsymbol{X}'\boldsymbol{\Omega}^{-1}\boldsymbol{y} = [\boldsymbol{X}'(\boldsymbol{\Sigma}\mathbf{c}^{-1} \otimes \boldsymbol{I})\mathbf{X}]^{-1}\boldsymbol{X}'(\boldsymbol{\Sigma}\mathbf{c}^{-1} \otimes \boldsymbol{I})\boldsymbol{y}$$

Expanding:

$$\boldsymbol{\beta}^{hat} = \begin{bmatrix} \sigma^{11}\boldsymbol{X}_1{}'\boldsymbol{X}_1 & \sigma^{12}\boldsymbol{X}_1{}'\boldsymbol{X}_2 & \cdots & \sigma^{1H}\boldsymbol{X}_1{}'\boldsymbol{X}_H \\ \sigma^{21}\boldsymbol{X}_2{}'\boldsymbol{X}_1 & \sigma^{22}\boldsymbol{X}_2{}'\boldsymbol{X}_2 & \cdots & \sigma^{2H}\boldsymbol{X}_2{}'\boldsymbol{X}_H \\ \vdots & \cdots & \cdots & \cdots \\ \sigma^{H1}\boldsymbol{X}_H{}'\boldsymbol{X}_1 & \sigma^{H2}\boldsymbol{X}_H{}'\boldsymbol{X}_2 & \cdots & \sigma^{HH}\boldsymbol{X}_H{}'\boldsymbol{X}_H \end{bmatrix}^{-1} \begin{bmatrix} \Sigma_{j=1}{}^{H}\sigma^{1j}\boldsymbol{X}_1{}'\mathbf{y}_j \\ \Sigma_{j=1}{}^{H}\sigma^{2j}\boldsymbol{X}_2{}'\mathbf{y}_j \\ \vdots \\ \Sigma_{j=1}{}^{H}\sigma^{Hj}\boldsymbol{X}_M{}'\mathbf{y}_j \end{bmatrix}$$

$\boldsymbol{\beta}^{hat}$ has all the properties of an efficient estimator, that is, it the best linear unbiased estimator. The coefficients are only linked by their disturbance terms – seemingly unrelated regressions.

Gain in Efficiency

Taking the first part of $\boldsymbol{\beta}^{hat}$

$$\begin{bmatrix} \sigma^{11}\boldsymbol{X}_1{}'\boldsymbol{X}_1 & \sigma^{12}\boldsymbol{X}_1{}'\boldsymbol{X}_2 & \cdots & \sigma^{1H}\boldsymbol{X}_1{}'\boldsymbol{X}_H \\ \sigma^{21}\boldsymbol{X}_2{}'\boldsymbol{X}_1 & \sigma^{22}\boldsymbol{X}_2{}'\boldsymbol{X}_2 & \cdots & \sigma^{2H}\boldsymbol{X}_2{}'\boldsymbol{X}_H \\ \vdots & \cdots & \cdots & \cdots \\ \sigma^{H1}\boldsymbol{X}_H{}'\boldsymbol{X}_1 & \sigma^{H2}\boldsymbol{X}_H{}'\boldsymbol{X}_2 & \cdots & \sigma^{HH}\boldsymbol{X}_H{}'\boldsymbol{X}_H \end{bmatrix}^{-1}$$

The following can be observed (Greene, 2003):

- If $\sigma_{ij}=0$ for all $i \neq j$ (no relationship between the equations) then there is no pay off and SUR estimation is the same as equation by equation OLS;
- If $\boldsymbol{X}_i = \boldsymbol{X}_j$ - identical explanatory variables - then SUR estimation is identical to OLS estimation;
- If regressors in one block are linearly dependant on regressors in another block of equations, then SUR estimation is identical to OLS estimation;

- Therefore the greater the correlations of the disturbance terms and less the correlation between the **X** matrices, results in higher efficiency gain from SUR estimation.

Model and Data Collection

This study postulated the following three part model comprising of property, agriculture, and water services equations for each study site. The three sites are denoted by i = 1, 2, 3 (Bloemhof dam = 1, Grootdraai dam = 2, and Vaal dam = 3). The specification of the model is as general as the available data allowed. This is to ensure that the available data is used to its maximum, and significant variables can be detected for each dam. The aspects of the model are discussed below.

The sample period is from 1996 to 2006 due to data availability and the main data sources are the Knowledge Factory (property price data; www.knowledgefactory.co.za), the Department of Water Affairs (eutrophication data), and Rand Water (water treatment data). The classification of the data is both cross sectional and time series. The data is cross sectional in that it is collected from all three sites and time series in that it is collected over time. All data manipulation was done in Excel while Eviews 7 software was used for empirical estimation.

Property Equation

$$\boldsymbol{Unit\ Property\ Price_i = p_{1i} + p_{2i}Eut_{-1i} + e_{pi}}$$

$\boldsymbol{Unit\ Property\ Price_i}$ is the unit property prices for property surrounding dam *i (UNIT PROPERTY PRICE* in the model*).*

$\boldsymbol{Eut_{-1i}}$ is the eutrophication level for a specific dam *i*. Under the property model eutrophication is given by *Chlorophyll a* present in the water (*CHLOROPHYLL* in the model), *Ammonium Nitrate* present in the water (*AMMONIUM-NITRATE* in the model), and

Nitrate and *Nitrite* present in the water (*NITRATE-NITRITE* in the model). This follows Mostert (2009).

e_{pi} is the error term for a specific dam *i*

Agriculture Equation

$$Total\ Agriculture\ Cost_i = a_{1i} + a_{2i}Eut_i + e_{ai}$$

$Total\ Agriculture\ Cost_i$ is the change to total cost of agriculture for a specific dam *i* due to eutrophication (*TOTAL AGRICULTURE COST* in the model).

Eut_i is the eutrophication level for a specific dam *i*. Under the agriculture model eutrophication is given by *Phosphorus* (*PHOSPHORUS* in the model) present in the water, and *Nitrogen* (*NITROGEN* in the model) present in the water. This follows De Villiers (2009).

e_{ai} is the error term for a specific dam *i*.

Water Services Equation

$$Total\ Water\ Treatment\ Cost = \ i_{1i} + i_{2i}Eut_i + e_{ii}$$

$Total\ Water\ Treatment\ Cost$ is the total water treatment costs. According to De Villiers (personal communication, 2009), this is not site specific since Rand Water is the only major water extractor from the Vaal River System and other extractors could not provide significant data (*TOTAL WATER TREATMENT COST* in the model)

Eut_i is the eutrophication level for a specific dam *i*. This is similar to the agriculture equation.

e_{ii} is the error term for a specific dam *i*

System to Estimated with SUR

For each i= 1, 2, and 3 (Bloemhof dam=1; Grootdraai dam = 2; Vaal dam = 3) the following three equation system was estimated using SUR:

$$\boldsymbol{Unit\ Property\ Price_i = p_{1i} + p_{2i}Eut_{-1i} + e_{pi}}$$

$$\boldsymbol{Total\ Agriculture\ Cost_i = a_{1i} + a_{2i}Eut_i + e_{ai}}$$

$$\boldsymbol{Total\ Water\ Treatment\ Cost = i_{1i} + i_{2i}Eut_i + e_{ii}}$$

Under SUR coefficients were estimated taking into consideration the relationships between equations.

Calculation of Total Costs

The parameters estimated for each site were used to calculate the total costs in each site. The model was estimated in log linear form and therefore coefficients can be interpreted as elasticities, that is, a one percentage change in an explanatory variable in the model leads to an x percentage change in the specific cost associated with that particular equation. In other words, how much of the percentage change in a specific cost can be attributed to a one percentage change in eutrophication? The total cost in rand value can be calculated by taking this percentage change and multiplying by the rand value of this cost at a specific time.

Chapter 4: Empirical Results and Discussion

Model Results

SUR models have a stringent requirement in that the random errors of each equation in the models must be white noise (constant variance and no serial correlation). This is essentially a requirement of cointegration. The models were estimated will all explanatory variables lagged one period. All dependant variables were not lagged. In other words Eutrophication affects the economic costs associated with eutrophication with a one year lag. Initial models for Grootdraai and Vaal dams presented with first order positive serial correlation for some equations. As a result the certain equations were estimated correcting for first order positive serial correlation. See Appendix B for detailed test for cointegration.

The results of the three models are presented in Table 4 -6. The direction of the relationship between the costs variables and eutrophication variables was expected to be negative for the property price equations signalling that eutrophic waters were expected to have a negative impact on riverside property demand. The relationship was expected to positive/negative for both the agriculture and water treatment services equations demonstrating that eutrophic water was expected to increase/decrease total agriculture costs faced by agriculture and also increase /decrease treatment costs faced by water treatment services, in all the dams.

The goodness of fit for the different equations was good. This is due to correcting for serial correlation. The Durbin Watson test statistic indicated that some of the equations indicate some positive serial correlation; however this is at times contrary to the cointegration tests.

Table 4

Parameter estimates for Bloemhof Dam

	Bloemhof dam Model		
	UNIT PROPERTY PRICE_B	*TOTAL AGRICULTURE COST_B*	*TOTAL WATER TREATMENT COST_B*
CONSTANT_B	10.61*** (0.00)	10.22*** (0.00)	15.49*** (0.00)
CHLOROPHYLL_B	0.22 (0.63)		
AMMONIUM-NITRATE_B	1.15*** (0.01)		
NITRATE-NITRITE_B	0.92** (0.08)		
PHOSPHORUS_B		0.63*** (0.04)	0.72*** (0.02)
NITROGEN_B		-0.32*** (0.00)	-0.37*** (0.00)
Diagnostics			
R^2	0.44	0.55	0.62
Durbin-Watson Statistic	2.01	1.64	1.93

Note. p values in parenthesis: *** denotes significance at 1%;** denotes significance at 5%;* denotes significance at 10%. Estimated in logs**.** All explanatory variables lagged one period. B= Bloemhof dam.

Table 5

Parameter estimates for Grootdraai Dam

	Grootdraai dam Model		
	UNIT PROPERTY PRICE_G	*TOTAL AGRICULTURE COST_G*	*TOTAL WATER TREATMENT COST_G*
CONSTANT_G	5.76*** (0.00)	11.34*** (0.00)	15.57*** (0.00)
CHLOROPHYLL_G	0.005** (0.06)		
AMMONIUM-NITRATE_G	-0.003 (0.12)		
DUMMY_G	1.45*** (0.00)		
NITRATE-NITRITE_G	0.0005 (0.78)		
PHOSPHORUS_G		0.79** (0.06)	0.55 (0.18)
NITROGEN_G		-0.048 (0.70)	-0.13 (0.29)
Diagnostics			
R^2	0.99	0.88	0.92
Durbin-Watson Statistic	1.48	0.81	0.90

Note. p values in parenthesis: *** denotes significance at 1%;** denotes significance at 5%;* denotes significance at 10%. Estimated in logs. All explanatory variables lagged one period. G= Grootdraai dam.

Table 6

Parameter estimates for Vaal Dam

	Vaal dam Model		
	UNIT PROPERTY PRICE_V	*TOTAL AGRICULTURE COST_V*	*TOTAL WATER TREATMENT COST_V*
CONSTANT_V	13.72*** (0.00)	10.02*** (0.00)	14.80*** (0.00)
CHLOROPHYLL_V	-0.51** (0.08)		
AMMONIUM-NITRATE_V	1.67*** (0.04)		
NITRATE-NITRITE_V	1.11 (0.25)		
PHOSPHORUS_V		0.65*** (0.00)	0.54*** (0.01)
NITROGEN_V		-0.50*** (0.00)	-0.47*** (0.02)
Diagnostics			
R^2	0.59	0.83	0.85
Durbin-Watson Statistic	1.49	1.30	1.24

Note. p values in parenthesis: *** denotes significance at 1%;** denotes significance at 5%;* denotes significance at 10%. Estimated in logs**.** All explanatory variables lagged one period. V= Vaal dam.

Table 7

Comparing results for the property price model

Variable	Mostert (2009)	Own Analysis
	Bloemhof Dam	
CHLOROPHYLL	0.30	0.22
	(0.47)	(0.63)
AMMONIUM-NITRATE	1.39***	1.15***
	(0.01)	(0.01)
NITRATE-NITRITE	0.73	0.92**
	(0.13)	(0.08)
	Grootdraai Dam	
CHLOROPHYLL	0.11	0.005**
	(0.70)	(0.06)
AMMONIUM-NITRATE	-0.097	-0.003
	(0.68)	(0.12)
NITRATE-NITRITE	0.38	0.0005
	(0.11)	(0.78)
	Vaal Dam	
CHLOROPHYLL	0.13***	-0.51**
	(0.01)	(0.08)
AMMONIUM-NITRATE	-0.32***	1.67***
	(0.00)	(0.04)
NITRATE-NITRITE	0.58***	1.11
	(0.00)	(0.25)

Note. P values in parenthesis: *** denotes significance at 1%;** denotes significance at 5%;* denotes significance at 10%. Figures all in logarithm. All at the first lag. From Own analysis and Mostert, D. (2009). *A generic model to assess the cost associated with eutrophication on property values and recreation applied to the Vaal River.* (Unpublished Masters Dissertation). University of Pretoria, Pretoria**.**

Comparing parameter estimates from Mostert (2009) with the results of this study revealed that majority of the parameter estimates share the same sign (except for *Ammonium Nitrate*), indicating consistency in estimated parameters. Magnitudes of estimates differed, for example *Nitrate-Nitrite* (Grootdraai dam) is 0.38 per cent in Mostert (2009) as compared to 0.005 in this study. The comparison also revealed that the parameter estimate significance changes from Mostert (2009) to the model in this study for a few of the variables. For example at Vaal dam *Nitrate-Nitrite* is significant in Mostert (2009) but insignificant in this study.

Table 8

Comparing results for agriculture and water services equations

Variable	De Villiers (2009)	Own Analysis
	Bloemhof Dam	
Agriculture Equation		
PHOSPHORUS	-0.01	0.63***
	(0.19)	(0.04)
NITROGEN	0.01***	-0.32***
	(0.00)	(0.00)
Water Treatment Services Equation		
PHOSPHORUS	0.21**	0.72***
	(0.05)	(0.02)
NITROGEN	0.15***	-0.37***
	(0.03)	(0.00)
	Grootdraai Dam	
Agriculture Equation		
PHOSPHORUS	-0.01	0.79**
	(0.19)	(0.06)
NITROGEN	0.01***	-0.048
	(0.00)	(0.70)
Water Treatment Services Equation		
PHOSPHORUS	0.21**	0.55
	(0.05)	(0.18)
NITROGEN	0.15***	-0.13
	(0.03)	(0.29)
	Vaal Dam	
Agriculture Equation		
PHOSPHORUS	-0.01	0.65***
	(0.19)	(0.00)
NITROGEN	0.01***	-0.50***
	(0.00)	(0.00)
Water Treatment Services Equation		
PHOSPHORUS	0.21**	0.54***
	(0.05)	(0.01)
NITROGEN	0.15***	-0.47***
	(0.03)	(0.02)

Note. P values in parenthesis: *** denotes significance at 1%;** denotes significance at 5%;* denotes significance at 10%. Figures all in logarithm. All at the first lag. From Own analysis and De Villiers, L. (2009). *Development of a model to estimate the cost on agriculture and industry due to eutrophication in the Vaal system.* (Unpublished Masters Dissertation). University of Pretoria, Pretoria.

Focusing on the remainder of the models (De Villiers (2009) compared to this study) revealed a similar picture to the property model. However this must be taken in context since De Villiers (2009) estimated a pooled OLS model meaning that all the study sites have the same parameter estimates.

Cost Associated with Eutrophication

In this section the costs associated with eutrophication were calculated for each industry, in each dam. The models were estimated in log linear form and therefore coefficients can be interpreted as elasticities. Figures 8-13 illustrate the costs associated with eutrophication in Bloemhof, Grootdraai, and Vaal dams. The costs associated with eutrophication in the property sector were not calculated.

Figures 8, 10, and 12 indicate a positive net effect of eutrophication on rand per hectare cost in all dams. The impact of eutrophication on rand per hectare cost was significantly different from zero, averaging R10 per hectare for all dams. The positive impact of phosphorus on rand per hectare cost outweighed the negative impact of nitrogen on rand per hectare cost.

The impact of eutrophication on water treatment services rand per kilo litre cost is similar to that of eutrophication to agriculture rand per hectare cost. However the magnitude of the impact was smaller in rand terms per kilo (R0.005). The positive impact of phosphorus on rand per kilo cost also outweighed the negative impact of nitrogen on rand per kilolitre cost. Analysis of variation (ANOVA) revealed that there was a significant increase in the

Phosphorus costs for the period 2001 to 2006 as compared to 1996 to 2000 in the study sites (see Appendix B).

Costs Associated with Eutrophication Bloemhof Dam

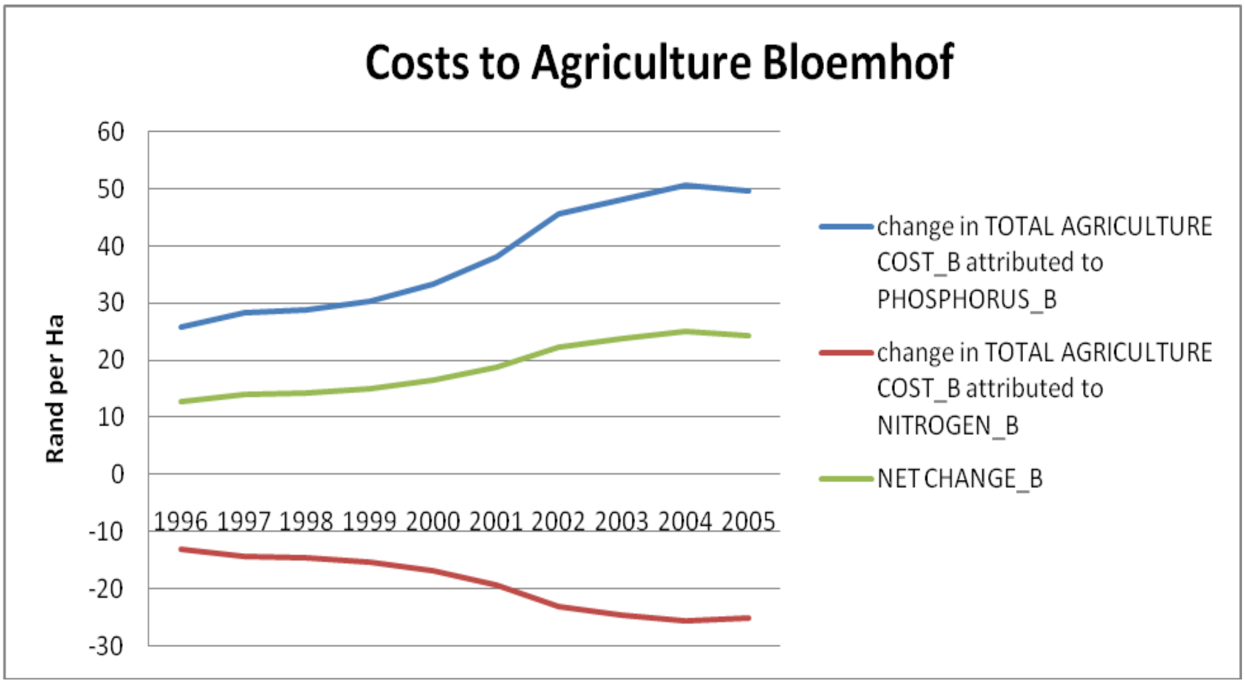

Figure 8. Costs to Agriculture Bloemhof dam.

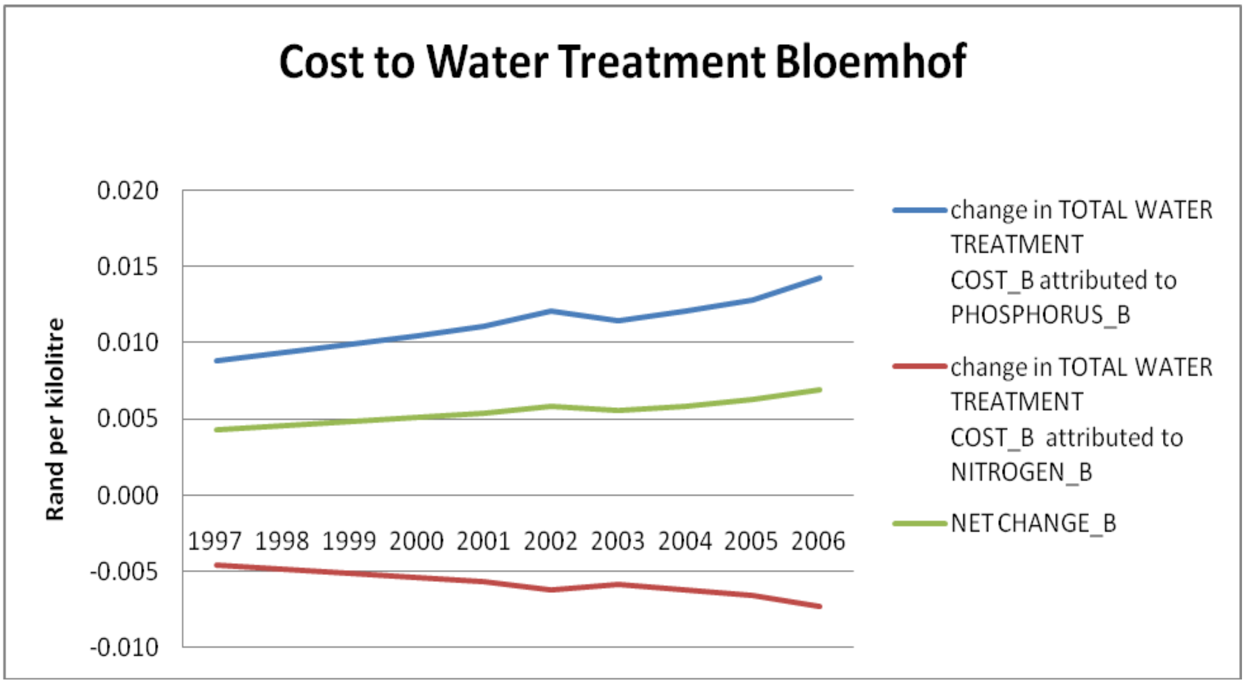

Figure 9. Costs to Water Treatment Bloemhof dam.

Costs Associated with Eutrophication Grootdraai Dam

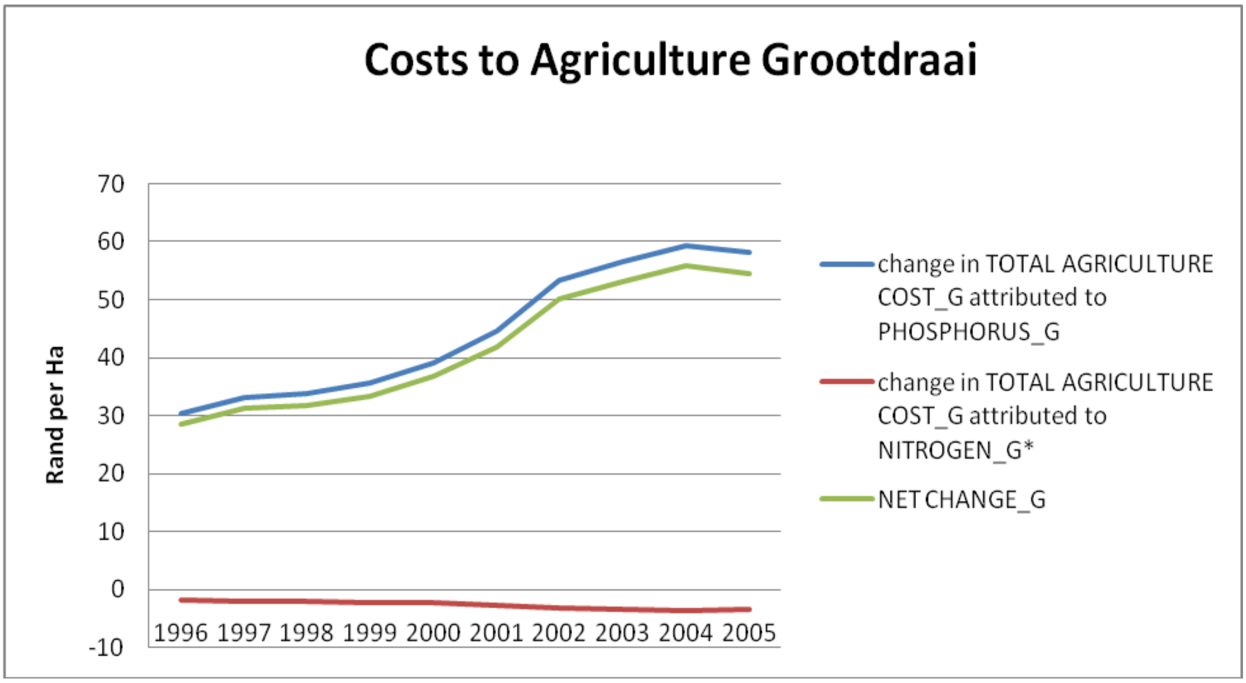

Figure 10. Costs to Agriculture Grootdraai dam. *Note.* * indicates insignificant variable or including insignificant variable.

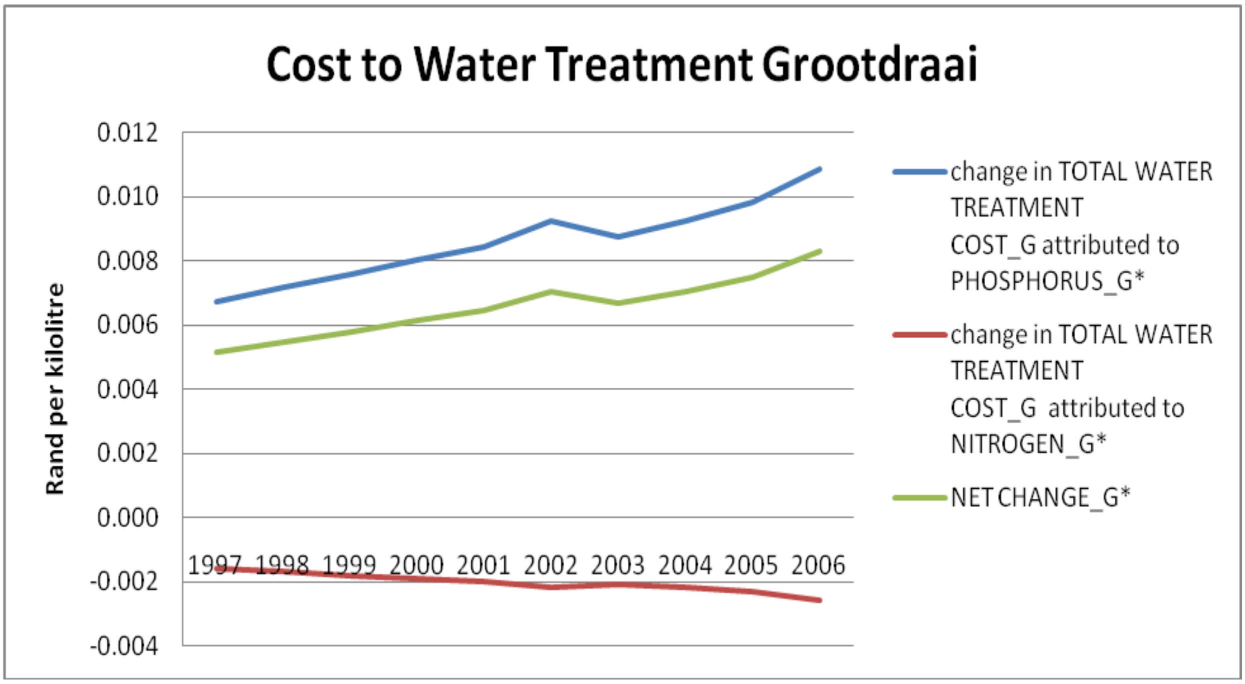

Figure 11. Costs to Water Treatment Grootdraai dam. *Note.* * indicates insignificant variable or including insignificant variable.

Costs Associated with Eutrophication Vaal Dam

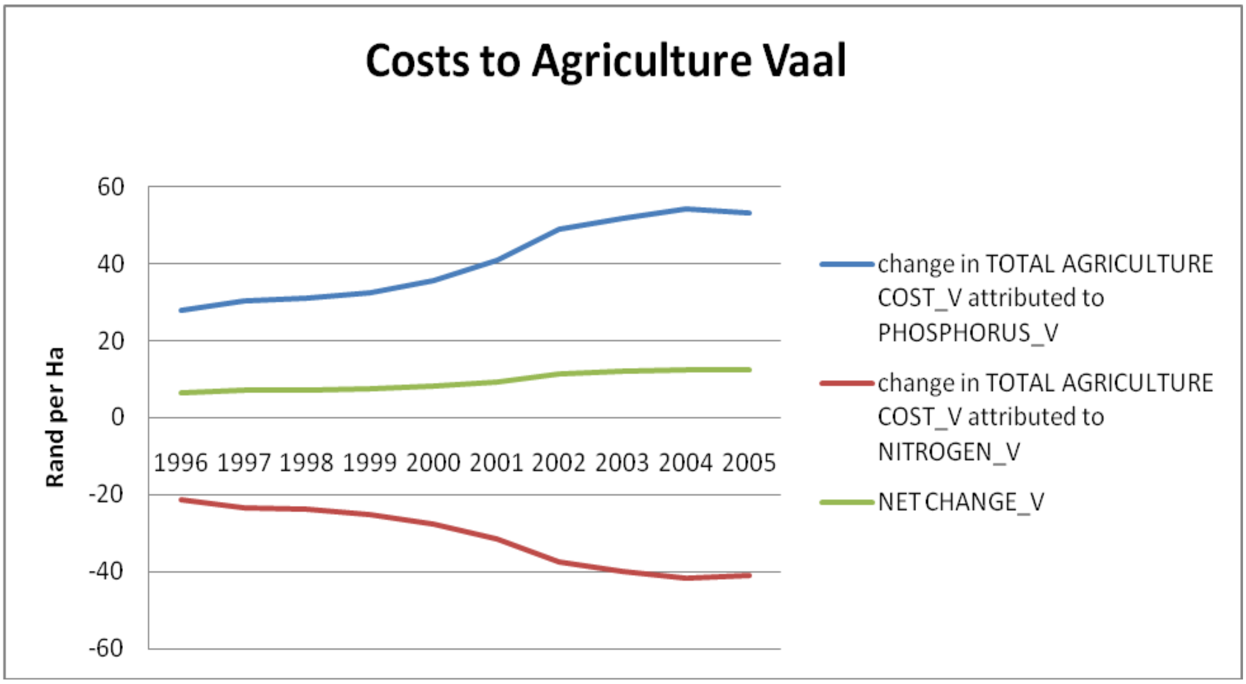

Figure 12. Costs to Agriculture Vaal dam**.** *Note.* * indicates insignificant variable or including insignificant variable.

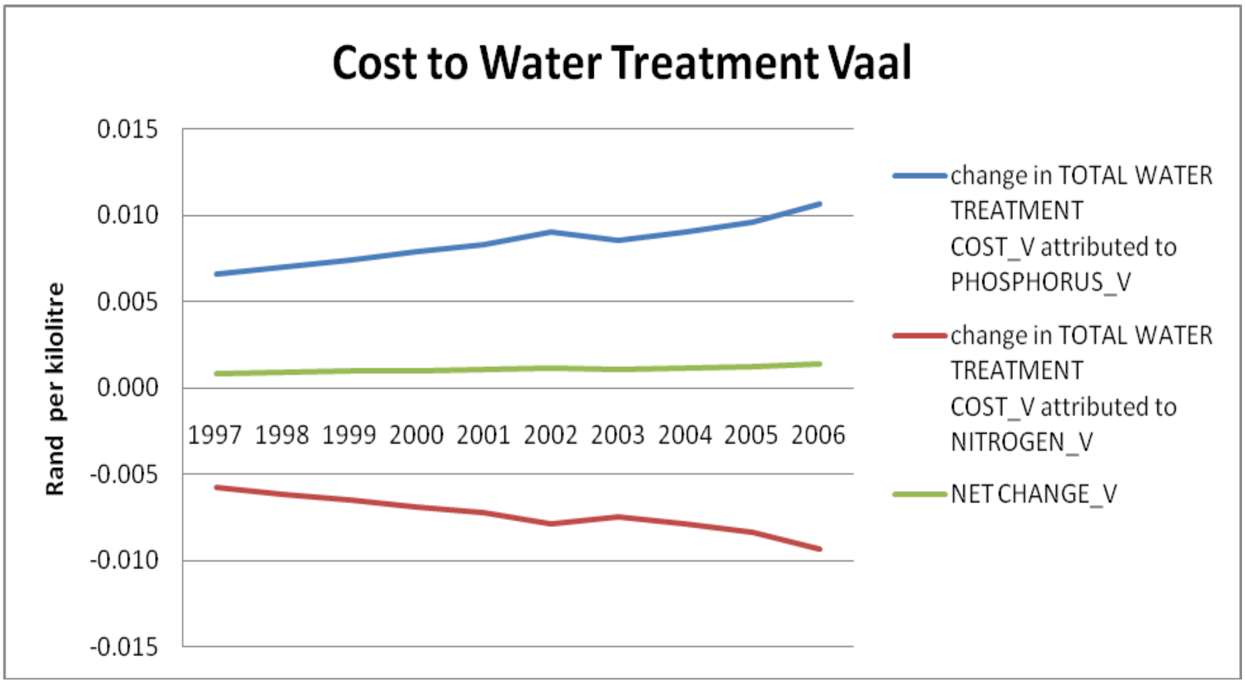

Figure 13. Costs to Water Treatment Vaal dam. *Note.* * indicates insignificant variable or including insignificant variable.

Chapter 5: Conclusion

This study contributed to the understanding of the current and historic impact of eutrophication on the Vaal River System. This study followed De Villiers (2009) and Mostert (2009) to illustrate the tradeoffs in costs associated with eutrophication. The results showed a historic (from 1996 to 2006) presence of such tradeoffs confirming the hypothesis posed in this study.

Similar to De Villiers (2009) and Mostert (2009), this study revealed that the impact of eutrophication on property prices in the study areas was not discernible. The estimates proved contradictory to theory and were not robust. The impact of eutrophication on property prices is small in comparison to other exogenous factors, and therefore proved difficult to estimate. However, it could not be ruled out that eutrophication had no impact at all on property prices. This study further confirmed that eutrophication had an economic impact on agriculture and water treatment.

SUR estimation is limited in the presence of rapidly changing estimates (i.e. level changes in the data). The nature of eutrophication is such that rapid level changes are possible, for example, increased runoff from sewage into rivers. Future research is necessary to estimate coefficients in the case of extreme eutrophication level changes. Estimation techniques such as System Wide Dynamic Modelling, which combines traditional data and expert opinion, can capture the impacts of extreme eutrophication level changes.

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Appendix A: Methods of Quantifying Eutrophication

Introduction

Below is a summary of literature specific to the quantification of the economic costs of eutrophication.

Methods for Quantifying Economic Cost of Eutrophication

Ecosystems are generally non market goods. This implies that the traditional methods of evaluating value in economics – market based methods - cannot be applied. Wilson and Carpenter (1999:772) are of the view that value in the sense of non market goods means that value is defined in the restricted sense – the economic behaviour of supply and demand of the good and service. The individual is the best judge of tradeoffs that are most valuable to him/her.

This is broadly defined as willingness to pay (WTP) and willingness to accept (WTA) compensation. These form the bedrock of the environmental methods of estimating economic benefits (costs). These are discussed below.

Travel Cost Method (TCM)

TCM is mostly applied to the estimation of economic costs associated with changes in water clarity and is the oldest of the methods. TCM uses a proxy for consumption costs such as gas mileage to estimate the demand for recreational sites.

The following framework to explain TCM set out (Wilson & Carpenter, 1999:772):

V_{ij} represents the number of trips to recreational site *j* by individual *i*

C_{ij} represents the travel costs for individual *i* to recreational site *j*

Q_j is the quality index of site *j*

M_i is person *i*'s income

All of these enter into a function where the number of trips to recreational site *j* by individual *i*, is a function of the other variables listed. This is given by:

$$V_{ij} = f\ (C_{ij}, Q_j, M_j)$$

An assumption of a positive relationship between the numbers of trips to recreational site *j* by individual *i* and the quality index of site *j*. This is essentially the Total Cost Method of estimation.

However, because TCM is conducted on an individual that continues to use the recreational site after an environmental change and not those who have stopped or potentially will use the site, the problem of information bias arises when inferences are made about the entire population (Ribaudo & Epp, 1984). This is known as sample discrimination. The authors suggest that a different sampling method be applied, that is, a sample that includes both current users and non users. Their results showed that this method of sampling actually produced better estimates of benefits.

Hedonic Pricing Method (HPM)

HPM is used to estimate the effect of environmental changes on surrounding goods that have an actual market. A typical application is mostly on housing surrounding water bodies. This is commonly estimated using statistical techniques such as ordinary least squares.

Again, the following framework is set out in explaining HPM (Wilson & Carpenter, 1999:772):

P_i represents the price of site *i* for which a market exists

S_i represents site *i*

N_i represents neighbourhood characteristics of the site *i*

Q_i represents environmental characteristics of site *i*

All of these enter into a function were the price of site *i* is a function of the other variables described.

$$P_i = f(S_i, N_i, Q_i)$$

Given this function, the marginal value of an environmental variant is dP/dQ. This is essentially the HPM method of estimation.

Empirical studies that have been conducted include Poor, Boyle, Taylor, and Bouchard (2001); Epp and Al-Ani (1979); Boyle and Kiel (2001); Gibbs et al. (2002). Table A 1 below summarises these empirical studies.

Table A 1

Summary of HPM empirical studies

Study and Publication Date	Freshwater ecosystem studied	Purpose of Paper	Sample units	Conclusion
Poor *et al.* (2001)	Lake	Examines and compares scientific measures of environmental quality with subjective measures of individuals obtained from survey information.	Property in four market areas: Lewiston, Augusta, Bangor and Northern Maine.	The results show that the subjective measures under reported the implicit price. Hedonic pricing method reported higher estimates.

Study and Publication Date	Freshwater ecosystem studied	Purpose of Paper	Sample units	Conclusion
Epp & Al-Ani (1979)	Small rivers and streams	To estimate the relationship between water quality in small rivers and property prices adjacent to the small rivers.	Property adjacent to small rivers and streams in Pennsylvania	The results show that water quality does have an impact on the property prices adjacent to the rivers and streams.
Boyle & Kiel (2001)		The study surveys previous hedonic studies. The studies of air quality, water quality and land usage are surveyed.		The studies on air quality are found to have statistically insignificant variables and are sensitive to other Water quality factors
Gibbs et al. (2002)	Lake	The paper aims to compare the impact of water quality on lake front property prices.	Property adjacent to lakes in New Hampshire	The results show that water quality negatively affects property prices in New Hampshire. The decrease ranges from 0.9 per cent to over 6 per cent.

Contingent Variation Method

The CVM is essentially a survey method. The main aim of CVM is to measure either compensating variation or equivalent variation. If the individual must purchase a good, then the compensating variation is the appropriate measure. This is the amount the individual is willing to pay to keep their utility constant. Conversely, if the individual has a good that might be taken away from him/her, then equivalent variation is appropriate. This is the amount that an individual needs to stay at the original level of utility before that good is taken away.

The main of CVM is to directly elicit willingness to pay or willingness to accept compensation directly from the respondents. A CVM survey must have the following essential elements (Portney, 1994:3):

- The survey must contain a scenario or description of the hypothetical or real policy program the respondent is being asked to vote upon;
- The survey must contain a mechanism for eliciting value of or a choice from a respondent;
- The survey must elicit information on the socioeconomic characteristics of the respondents, as well as information about their attitudes.

However, the willingness to pay as elicited by CVM, is based on the geographical boundary of the good in question (Pate & Loomis, 1997). The study uses a 15 page questionnaire to survey San Joaquin Valley (outside California in the United States America) residents, Washington State residents, Oregon State residents, and Nevada residents. A logit model is built and the hypothesis that the probability that an individual will answer yes to willingness to pay, decreases as distance increases, was tested. Although the results were not conclusive, there is some evidence that willingness to pay declines with distance.

Studies conducted include Zylicz, Bateman, and Georgiou (1995); Greene, Söderqvist, and Wulff (1997); Lipton (2003); Sale, Hosking and Du Preez (2009). Table 10 below summarises these empirical studies.

Table A 2

Summary of CVM empirical studies

Study and Publication Date	Freshwater ecosystem studied	Purpose of Paper	Sample units	Conclusion
Zylicz et al. (1995)	Sea	To use contingent valuation method to estimate the economic value of eutrophication in the Baltic Sea Region	Polish beach users	The results reveal that the polish Baltic Sea users are willing to pay for the sake of protecting the sea region.
Gren et al. (1997)	Sea	To present the costs and benefits of reducing phosphorus and nutrient loads in the Baltic Sea.	Baltic Sea Countries	The results reveal that a 50 per cent reduction in phosphorus and nitrogen loads results in a total cost of SKr 30000 million a year.
Lipton (2003)	Bay	To determine the perceptions of boaters on the water quality at Chesapeake bay. In doing so determine their willingness to pay for improvements	Maryland registered boat users	The boaters revealed a median willingness to pay of $17.50 per year. On the aggregate the boaters were willing to pay $7.3 million per year.
Sale et al. (2009)	Estuary	To determine the willingness to pay to secure increased water of recreational users of the Kowie and Kromme estuaries	Recreational users of the Kowie and Kromme estuaries	Total willingness to pay was estimated at R938 296 for Kowie, and R974 019 for Kromme.

Appendix B: Stationarity Tests and ANOVA Tests

Table B 1

Stationarity tests for residuals

Series	Model	ADF			PP	
		Lags	τ_τ, τ_μ, τ	φ_3, φ_1	Lags	
			Bloemhof dam			
Residuals property equation	None	2	-4.27***	NA	2	-2.94***
Residuals agriculture equation	None	0	-2.05**	NA	2	-2.01**
Residuals water treatment equation	None	0	-2.87**	NA	2	-2.91**
			Grootdraai dam			
Residuals property equation	None	0	-2.19**	NA	2	-2.14**
Residuals agriculture equation	None	0	-1.38	NA	2	-1.32
Residuals water treatment equation	None	0	-1.87*	NA	2	-1.86*
			Vaal dam			
Residuals property equation	None	0	-2.15**	NA	2	-2.12**
Residuals agriculture equation	None	0	-1.99**	NA	2	-1.96*
Residuals water treatment equation	None	0	-2.23*	NA	2	-2.22**

Note. McKinnon response surface critical values used. P values in parenthesis: *** denotes significance at

Table B 2

ANOVA: Single factor tests on phosphorus costs

Source of Variation	Sum of Squares	Degrees of freedom	Mean Square	F-value	P-value	F-critical
Bloemhof dam (agriculture sector)						
Between Groups	726.9949	1	726.9949	43.89223	0.000165	5.317655
Within Groups	132.5054	8	16.56318			
Total	859.5004	9				
Bloemhof dam (water treatment sector)						
Between Groups	1.69E-05	1	1.69E-05	17.66092	0.002986	5.317655
Within Groups	7.65E-06	8	9.56E-07			
Total	2.45E-05	9				
Grootdraai dam (agriculture sector)						
Between Groups	997.8995	1	997.8995	43.89223	0.000165	5.317655
Within Groups	181.8817	8	22.73522			
Total	1179.781	9				
Grootdraai dam (water sector)						
Between Groups	9.85E-06	1	9.85E-06	17.66092	0.002986	5.317655
Within Groups	4.46E-06	8	5.58E-07			
Total	1.43E-05	9				
Vaal (agriculture sector)						
Between Groups	836.0392	1	836.0392	43.89223	0.000165	5.317655
Within Groups	152.3803	8	19.04754			

Source of Variation	Sum of Squares	Degrees of freedom	Mean Square	F-value	P-value	F-critical
Total	988.4196	9				
			Vaal (water sector)			
Between Groups	9.5E-06	1	9.5E-06	17.66092	0.002986	5.317655
Within Groups	4.3E-06	8	5.38E-07			
Total	1.38E-05	9				