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PART 1

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Making Knowledge Usef

AN INTEGRATIVE SYSTEM THINKING APPROACH TO CLUSTER RESEARCH IN THE VAAL AND UMGENI BASINS, SOUTH AFRICA

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EXECUTIVE SUMMARY

A tendency to deal with one sector in isolation fails to recognise that the strategy for sustainable development is integration of economic and ecological considerations in decision-making. For complex river basins like the Vaal in South Africa, recent research findings imply that futuristic systems thinking and a visionary approach may be applied to manage and/or mitigate growing threats of environmental pollution.

South Africa is water-scarce and it is viewed as promoting sustainable management, that water provision should be considered in terms of socio-ecological and economic benefits accruing from various contributions. A major challenge is to manage and implement available fragmented solutions which are meant to model current scenarios based on historic data for predicting future impacts, in order to improve water quality and to extend availability of water resources. Various research reports indicate that the problem is getting more complex than in previous years. This proceeding describes cluster research that is being implemented in the Vaal and Umgeni basins in South Africa as an integrative systems thinking approach to develop solutions for challenges resulting from pollution of natural water courses by mine and sewage effluent. While specific methods are being applied to individual topics, hybrid evolutionary algorithms are being employed overall to develop tools that will support process optimisation for water boards in those basins, among other applications. Overall, the multidisciplinary research will contribute directly to sector tools in order to enhance sustainable basin management.

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INTRODUCTION

A tendency to deal with one sector in isolation fails to recognise that the strategy for sustainable development is integration of economic and ecological considerations in decision-making (Tippett 2005). Recent research findings imply that there is a new paradigm shift towards futuristic and multidisciplinary systems thinking to promote a visionary approach especially for managing and mitigating pollution in complex environments, and for river basins like the Vaal, various water uses may even compete due to pollution and/or limited availability (Dzwairo *et al.* 2010).

South Africa is water-scarce and water provision may be considered in terms of socio-ecological and economic benefits accruing from various contributions. On the other hand, successful implementation of the National Water Act No. 36 of 1998 is dependent on having proper models to support decision-making and competent people to apply sector tools. An example is research in the Vaal basin in South Africa, where raw water quality is variable and extremely impacted in places by poor quality sewage effluent and/or raw sewage, in addition to acid mine drainage (Akcil and Koldas 2006; Hallberg 2010).

The result is a complex pollution scenario spanning over more than 100 years back (Winde and Stoch 2010), for which is the subject of various research activities to try and extend current forecasts of water availability in the basin and at acceptable quality. A paper by Dzwairo *et al* (2010) mapped the Ecological Functionally of Upper and Middle Vaal Management Areas and zoned specific water quality monitoring hot spots: these points could be targets for source catchment protection especially on Blesbokspruit, Suikerbosrant, Rietspurit Waterval and Rietspruit Lochvaal Rivers. Mitigation of pollution at highlighted hotspots will attenuate pollution in the Vaal River, for both acid mine drainage (AMD) and sewage effluent.

On-going and future research topics within the cluster include hydro-climatic sequences of the drainage system upstream of Vaal dam, Vaal dam profiles and the dam's dilution rule for downstream uses, impacts of water quality variability on potable water treatment technologies and potable water chemical dosage prediction. Research is also on-going to develop a pricing model for raw water, which could be incorporated into South Africa's water pricing strategy in order to support current (2013) pricing reviews.

In Umgeni basin, which for the cluster is also acting as a test and validation site, an existing water quality index (WQI) is being expanded by incorporating determinants for key drivers to potable water treatment costs. Another research in that basin aims to optimise reservoir operation rule curves for Inanda dam which lies along uMngeni River.

METHODOLOGY

An adaptation from Elshorbagy and Ormsbee (2006) provides for seven specific characteristics which must be fulfilled in order to develop a structured modelling approach and simulation tools within a complex basin. The cluster research topics were chosen to fulfil that approach:

Simulating the hydrologic system

Research topics on hydro-climatic sequences of the drainage system upstream of Vaal dam, Vaal dam profiles and the dam's dilution rule will fulfil this characteristic. Selected Umgeni reservoirs are also being modelled in order to optimise rule curves for abstraction to multiple uses.

Model dynamics, adequacy and data-driven modelling

A WQI developed by Dzwairo (2011) forms a platform to refine potable water chemical dosage prediction models in the Vaal basin while the approach is being adapted to upgrade an existing WQI in Umgeni basin, using determinants for key drivers of potable water treatment cost. The resultant models should be dynamic and able to cope with nature of the hydrologic systems and pollution scenarios. Umgeni basin provides a test and validation site for some of the tools that are currently available or being developed in the Vaal basin. Examples are chemical dosage prediction models which were developed for a conventional potable water treatment plant, in Dzwairo (2011).

Models and simulation processes are being dictated to by availability of data from the Department of Water Affairs (DWA), Water Boards and South African Weather Services, in addition to other more specific sources like consulting companies, Trans-Caledon Tunnel Authority and Water Research Commission. Evolutionary algorithms using Bootstrapping is being adapted for specific scenarios. These algorithms allow for expansion if more data become available.

Simulating linear and nonlinear processes

The hydrological basin is borne out of hydro-climatic processes which are both linear and nonlinear. Research to profile Vaal dam and another to optimise Umgeni reservoir operation rule curves will allow for these using simulations. The last three characteristics involve feedback mechanisms to handle counter-intuitive processes, ability to model human and other environmental shocks, and testing for different policy/management scenarios, especially for developing a raw water pricing model which will eventually feed into a national raw water pricing strategy. Dzwairo *et al.* (2010) suggest that since initial node points of the system thinking Sensitivity Model (Figure 2) were done for the study area in earlier research (Dzwairo 2011), partial scenarios, simulation and cybernetic evaluation will be done during the current cluster research focus, a systems thinking approach. Specific approaches are being adapted from various techniques like those by Kalin and Caetano Chaves (2003), Benzaazoua *et al.* (2004) and Burford *et al.* (2007), among others, to reflect the variable basin settings. While specific methods are being applied to individual topics, hybrid evolutionary algorithms are being employed specifically to model chemical dosage prediction as well as to determine key drivers for potable water treatment cost. Hybrid Evolutionary Algorithm modelling will run parallel to an Artificial Neural Networks to compare outputs.

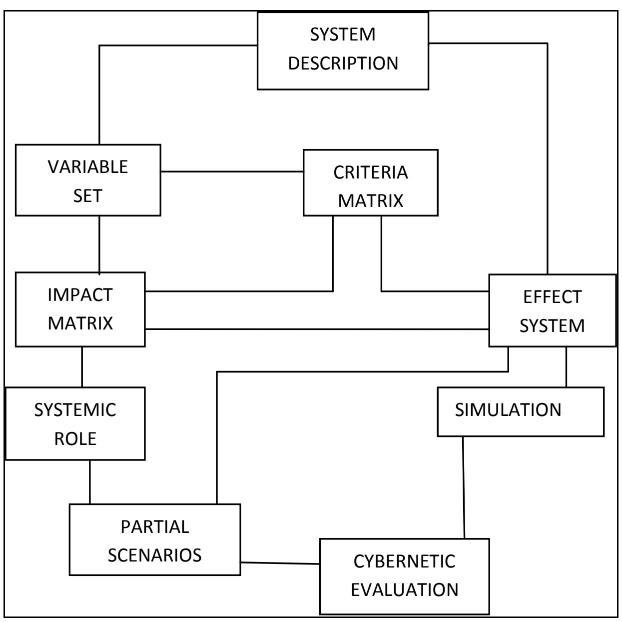

Figure 1 Node points for sensitivity model

Source: (Dzwairo *et al.* 2010)

1. POTABLE WATER CHEMICAL DOSAGE PREDICTION MODELS FROM HYBRID EVOLUTIONARY ALGORITHMS

1.1 BACKGROUND

The water industry is facing increased pressure to produce higher quality treated water at a lower cost (Lind 1994). This is a result of the population which is continuing to grow at an alarming rate. Water treatment processes involve physical, chemical and biological changes that convert raw water into potable water (Mirsepassi *et al.* 1997). The quality and nature of raw water determine the treatment process to be employed for purification purposes. Water utilities' primary objective is to safeguard the consumer's drinking water, as a result drinking water must be of quality that aligns with many water safety plans (Ho *et al.* 2012). This involves removing contaminants of concern, whether they be biological or chemical, a range of water treatment methods that have been developed over the years to eliminate the incidence of water-borne diseases for other public health measures, and to improve the quality of potable water (John and Trollip 2009).

Adverse effects on human health such as cancer may be caused by abundance of organic compounds, toxic chemicals, radionuclides, nitrite and nitrates in potable water (Ikem *et al.* 2002). It is observed that human activities are a major factor that is contributing to deterioration of surface and groundwater quality through atmospheric pollution, effluent discharges, use of agricultural chemicals, eroded soils and land use (Sillanpaa *et al.* 2004). It is therefore, of utmost important to have a constant monitoring of water quality used for drinking purposes. Zhao *et al.* (2002) indicated that potable water contaminated with heavy metals has a significant impact on people's health. These impacts indicate the level of contamination in the whole drinking water supply system.

In order for the domestic water supply to be considered safe for human consumption in South Africa it should be monitored for compliance using South African National Standards (SANS 241). This is after it has been treated with a wide range of drinking water treatment chemicals (John and Trollip 2009).

These chemicals are used for:

- Coagulation and flocculation
- Softening
- Precipitation
- Sequestering

- PH adjustment
- Corrosion control
- Scale control
- Disinfection/oxidation

Not all of these added chemicals are anticipated to be present after the water has been treated but some are. The very chemicals added for water treatment are not subjected to any form of regulation and control which poses lots of questions. As a result various stakeholders have raised concern that should these chemicals be continuously added in the treatment of natural water in order to enhance its quality, this might contribute to unhealthy levels of pollutants in the final product, causing potentially high risk to the community. The South African National Department of Health (SANDOH) admits this fact, and as a result they tried to manage and mitigate the risks by initiating an extensive consultative process with the major stakeholders. The main goal was to attain individual opinions on the need for development and implementation of a scheme for the approval and registration of drinking water treatment chemicals. In the consultation process that took place in 1999 to 2000, water services authorities (WSAs), industries and government were unanimous in support of this proposal. It is however, unfortunate that this initiative did not yield any tangible results since no further progress was reported in this area.

Benefits

According to the Water Quality and Health Council, prior to use of chlorinated drinking water at the turn of the century, waterborne diseases such as cholera, typhoid fever, dysentery and hepatitis claimed thousands of lives each year. As at 2013, for example, chlorination is still the most common disinfection method for public drinking water and swimming pools. Not only does chlorination help prevent the spread of infectious organisms such as Escherichia coli, it also destroys bacteria, algae and mould that can grow on walls of water storage systems. It also removes unpleasant tastes and odours from drinking water. While chlorination is effective at sanitizing drinking water, it can be difficult to handle without expertise and experience. The chlorination of water used for showering, laundering and swimming can dry out the skin and hair and may cause eye irritation.

Hard water contains high levels of dissolved minerals, which can build up in water pipes and internal systems to cause obstruction and permanent damage. Water softeners made with hydrated lime can treat water quality to improve hard water and also reduce the levels of toxic arsenic in drinking water. Lime also alters the water pH and works to destroy the environment required for growth of bacteria and viruses. In some cases, the pH levels become too high with lime softening. When lime is added to chlorinated water, the resulting formation of hypochlorite is a disinfectant that's inferior to other free chlorine residuals.

General Objective of Project:

To improve the quality of potable water within the Johannesburg Metropolitan

Specific Objectives:

- ❖ To simulate potable water production for a Water Board in Gauteng province, using a pilot plant
- ❖ To model chemical dosages of the pilot plant using hybrid evolutionary algorithms
- ❖ To optimise the Water Board's chemical dosage prediction model using a forced function

Constraints and Assumptions:

Water industry is facing increased pressure to produce higher quality treated water at a lower cost. This is a result of the population which is continuing to grow at an alarming rate. Water treatment processes involve physical, chemical and biological changes that convert raw water into potable water. The quality and the nature of raw water, determine which treatment process to be employed for purification purposes.

Deliverables:

1. Simulation of potable water production**.**

❖ Methodology

Water Management Systems (WMS) data extraction processes will be employed. WMS data collected from different monitoring points will be analysed using graphs and tables. Plant processes will then be simulated at a pilot plant

2. Chemical dosage prediction models.

❖ Methodology

Data on drinking water treatment chemicals used for potable water at a specific Water Board will be analysed using Matlab.

3. Forced function

- ❖ Methodology

These will be done to optimise the models for enhanced prediction accuracy

Key Stakeholder Organisations:

- ❖ Rand Water Board
- ❖ Tshwane University of Technology
- ❖ Department of Water Affairs
- ❖ Water Research Commission.

Key Project Management Staff and Authority Levels:

- ❖ Prof J Okonkwo, Dr B Dzwairo, Prof FAO Otieno, Mr MK Mabaso

Preliminary Summary Milestone Schedule:

Milestone (To be revised)	Deadline
1. Research Proposal	30-Sep-12
2. Data collection	28-Feb-13
3. Data analysis	30-June-13
4. Completed Draft Thesis	31-Dec-13
5. Completed Final Thesis	30-Jan-14

Preliminary Resource Requirements (Data/ Software/ etc.):

- ❖ Laptop, Transport, Sampling kit

Preliminary Budget Requirements:

- ❖ To be submitted.

Project Supervisor and co-Supervisors Approval:

2. VAAL AND UMGENI BASIN RESERVOIR PROFILES: IMPLICATIONS FOR WATER BOARD ACTIVITIES

2.1 BACKGROUND AND PROJECT JUSTIFICATION

Provision of sufficient and good quality potable water to communities is a challenge being faced by water service providers (Water Boards) in South Africa. Rainfall over much of South Africa is seasonal and as a result freshwater is a scarce resource (Schumann and Pearce 1997: 124). Studies show that many of South Africa's rivers are highly regulated by impoundments, in order to conserve water for domestic use, industry and agriculture (Roos and Pieterse 1994: 1; Bath *et al.* 1997: EX11; Schumann and Pearce 1997: 124; Oberholster and Ashton 2008: 2). The Vaal and uMngeni river basins are examples of some of the highly regulated river systems in South Africa and large populations rely on these river systems for their domestic water supply (Tollow 2004: 504; Mckenzie and Wegelin 2009: 171; Dzwairo 2011: 5). The Vaal dam on the Vaal River system was chosen for this study because the Vaal River system is widely recognised as the most important basin in South Africa as it supports the bulk of industrial water demands in the Gauteng and adjacent provinces (Mckenzie and Wegelin 2009: 168). The Inanda dam on the uMngeni River system also supplies a large proportion of South Africa's population (Tollow 2004: 504).

The quality of raw water in impounded reservoirs is influenced by stratification, and pollution generated by human activities. According to Bath *et al.* (1997: 2), stratification influences water quality of impoundments which in turn impacts on treatment of water abstracted from these reservoirs. Besides stratification, these reservoirs are also recipients of pollutants from urban and metropolitan areas as most of the reservoirs are located downstream of these areas (Oberholster and Ashton 2008: 2). According to (Dzwairo 2011: 2), a major threat to water availability in South Africa is pollution of water bodies, particularly from mining and industrial effluents as well as from partially treated effluent or sometimes raw sewage from domestic wastewater treatment plants. Water quality distribution in a reservoir is also significantly influenced by the change of hydrodynamic conditions in a reservoir (Yu *et al.* 2010: 910).

Nutrient enrichment of tributaries of the Vaal River Barrage reservoir resulted in associated algal related water purification and quality problems (Steynberg *et al.* 1996: 292). Rand.Water (2011) state that the two most significant water quality challenges experienced in the barrage catchment are biological (faecal pollution) and chemical (gold mining and industrial impacts through sulphates, sodium, iron, manganese and heavy metals). In the UMngeni basin, issues of concern regarding water quality include eutrophication; faecal contamination and pathogen risk; suspended solids (Tiba and Hodgson 2008: 1). Water pollution problems continue to prove costly, both for human needs as well as for environmental sustainability (Dzwairo 2011: 2).

The quality of raw water abstracted from a reservoir varies according to season, water depth and flow dynamics at that point. Predictive tools are required to support decision making in selective abstraction of raw water for drinking production. Water quality models have been found to have predictive qualities that can be useful in water quality management (Bath *et al.* 1997; van der Helm and Reitveld 2002; Westphal *et al.* 2003; Rietveld and Dudley 2006; McCartney 2007). For forecasting water quality, a model must be designed to take into account the complexities of the processes governing the water quality (Walter *et al.* 2001: 97). Reservoir profiles of different water quality parameters are used to characterise the water quality of impounded lakes. Walter *et al.* (2001: 97), points out that hydrological, geochemical and ecological processes govern water quality conditions of freshwater lakes. For a comprehensive characterisation, the spatial variation of the water quality in reservoirs must be profiled both along the stretch of the reservoir as well as the depth of the reservoir. This profiling is essential for the location of abstraction points of the best quality raw water as well as optimising treatment processes for potable water production.

Research Problem

Water quality management problems arise from the effects of the raw water quality on the intended uses of the water resource. The quality of raw water abstracted for potable water production influences the cost of treating that water to the set standards. For optimal treatment, there is need to abstract raw water of the best quality at the point in time. The abstraction point with raw water of the best quality has to be determined for different climatic conditions so that the water service provider is able to plan and budget for the treatment of that water for potable use. Selected previous studies have managed to characterise the quality of raw water in river systems and reservoirs (Roos and Pieterse 1994; Bath *et al.* 1997; Schumann and Pearce 1997; Boyacioglu 2007; Oberholster and Ashton 2008; Ochieng *et al.* 2010; Dzwairo 2011). The changes in the physical and chemical characteristics provide useful information about the quality of water in the reservoir and their impacts on the functions of the reservoir (Mustapha 2008: 309). Not enough work has been done to predict the impact of the variability of the raw water abstracted on production of potable water. This study seeks to develop a decision support tool that would aid the Water Boards (WBs) to predict and plan for impacts of variable raw water quality abstracted from the reservoirs on the production of potable water.

Benefits

For potable use, assessing the quality of the raw water in the reservoirs without linking it to the production of potable water is not enough for the management of the water quality of the reservoirs for this use. The Water Research Commission (WRC) conducted a study to investigate the applicability of hydrodynamic reservoir models for water quality management of stratified water bodies in South Africa. The study managed to select and adapt models to the South African conditions, as well as determine the optimum abstraction depth in Inanda reservoir (Bath *et al.* 1997: EX1). Recent studies have also linked the variability of raw water quality within river systems to the cost of potable water production, for example Dzwairo (2011). The significance of this study is the development of a tool that will inform WBs on abstraction points for raw water of optimum quality. The tool will be tested on two river systems with different catchment characteristics.

General Objective of Project:

To develop a decision support tool that would aid the WBs to predict and plan for impacts of variable raw water quality abstracted from the reservoirs on the production of potable water based on particular reservoir profiles.

Specific Objectives:

- To profile the temporal and spatial variability of the surface raw water quality in the Vaal dam and Inanda dam reservoirs.
- To analyse the impacts of specific reservoir profiles on potable water production.
- To develop a tool that models optimum abstraction points on the reservoirs

Constraints:

- Availability of data from the water boards

- ❖ Availability of meteorological and hydrological data
- ❖ Limitations of the models to be used.

Assumptions:

- ❖ It is assumed that effects of climate change are negligible
- ❖ It is assumed that land use patterns in the catchments of the dams will remain constant for the study period.

Deliverables:

1. Reservoir profiles showing the temporal and spatial variability of the surface raw water quality in the Vaal dam and Inanda dam reservoirs.

Methodology

The temporal and spatial profiles of the reservoirs will be modelled by use of data collected from the Water Boards as well as data collected and analysed during the course of the study. Temporal variations will be investigated climatically season by season. Primary data will be collected over a period of one year to cover all the seasons of the year. For spatial variability, two aspects will be considered; the vertical space (along the depth of the reservoir) as well as the horizontal space (along the stretch of the reservoir). Sampling points will be selected to coincide with the two most prominent stratification zones (that is the epilimnion and hypolimnion zones) in the reservoirs as well as the existing abstraction points for drinking water supply. Dissolved oxygen, temperature, turbidity, suspended solids and dissolved solids are some of the parameters that will be profiled. Selection of profiling parameters to be used will be based on the knowledge of the data requirements of existing models as well as availability of data from the Water Boards.

2. Analysis of the impacts of specific reservoir profiles on potable water production

Methodology

Hydrologic, hydraulic and ecological simulations will be integrated to investigate the effect of the temporal and spatial variability of the raw water on the production of potable water. The choice of production processes will be limited by the raw water quality parameters investigated. The reservoir profiles determined initially will be modelled against the cost of production of potable water as well as against optimization of selected treatment processes. The systems to be modelled will include abstraction points and chemical dosage requirements. The most appropriate model will be selected from the following models; DYRESM, CE-QUAL-W2, MINLAKE. These hydrodynamic models have been applied to South African reservoirs in previous studies and have been found to be applicable, for example Bath *et al.* (1997).

3. Decision support tool.

Methodology

The raw water quality will be characterized using a water quality index developed by Dzwairo (2011). The reservoir profiles will be mapped across the extent of the reservoir using a geographical information system (GIS) showing the variability of the raw water. A tool will be developed that models the location of an abstraction point with the optimum raw water characteristics. This will be achieved by simulating the abstraction process at points represented by the reservoir profiles and predicting the quality of raw water abstracted to identify the point with optimum water quality.

Key Stakeholder Organisations:

- ❖ Umgeni Water
- ❖ Rand Water Board
- ❖ Tshwane University of Technology
- ❖ Durban University of Technology

Key Project Management Staff and Authority Levels:

- ❖ Project Leader: Professor G M Ochieng (Supervisor)
- ❖ Principal Researcher: Doctor B Dzwairo (Post Doctoral Fellow)
- ❖ Research Student: Mrs. A Chinyama DTech student
- ❖ Mentor : Professor I Nhapi (Co- supervisor)
- ❖ Mentor: Professor F A O Otieno (Co- supervisor)

Preliminary Summary Milestone Schedule:

Milestone	Deadline
1. Data Collection	30-Apr-14
2. Data Analysis	30-Jun-14
3. Model development, testing and validation	30-Sept-14
4. Decision support tool	30-Sept-14
5. Completed Draft	31-Oct-14
6. Completed Final	31-Dec-14

Preliminary Resource Requirements:

- Laptop
- Data storage devices for back up
- Software purchases and licensing

Preliminary Budget Requirements:

Line item	Units	Quantity	Unit cost (Rands)	Amount (Rands)
Travel for data collection	Return Trips	15	1800	27000
Accommodation and subsistence	nights	36	1500	54000
Laptop for data capturing and analysis	No.	1	6500	6500
Software purchases and licensing	Lump sum		15000	15000
Data Storage devices (external hard drive)	No.	1	800	800
Laboratory analysis including laboratory	lump sum		250000	250000

Line item	**Units**	**Quantity**	**Unit cost (Rands)**	**Amount (Rands)**
consumables				
Conferences	No.	2	15000	30000
Production of final report	Copies of report	5	200	1000
TOTAL				**384300**

Quality/ Peer Review Process:

- Progress reports,
- Final thesis report
- Papers submitted to peer reviewed journals

3. INCORPORATING A WATER QUALITY INDEX TO DEVELOP AN EQUITABLE RAW WATER PRICING MODEL: VAAL CASE STUDY

3.1 BACKGROUND

Physical and economic scarcity of water resources tended towards critical examination of the different water demand and allocation polices and guidelines by various countries in the world. Under these circumstances, a raw water pricing strategy was developed by the South African government principally to improve effectiveness, efficiency and economic allocation and preserving of water resources.

Following the White Paper on a National Water Policy for South Africa (DWAF 1997) and National Water Act (DEAT 1998), the initial pricing strategy was gazetted in 1999 (DWAF 1999). Upon dynamic consultations and deliberations, the 1999 pricing strategy was reviewed and gazetted for comments in 2005. Organizations such as Business Unity South Africa (BUSA) and SAAWU significantly commented on the draft but relevant inputs were neglected (SAAWU 2004; BUSA 2005). The revised raw water pricing strategy; which strategy is subject to this study was gazette by the South African government in 2007.

The current strategy was analysed and it was noted that; economic benefits are being achieved at the expense of environmental degradation. Water resources are polluted at the expense of the environment and other Water Boards (WBs) withdrawing water of diminished quality. Furthermore, the term "monitoring", is mainly emphasizing on the quantity not quality of the water resources hence neglecting the effects of utilising water of diminished quality.

Raw water quality variability is a key issue that was omitted in the gazetted raw water pricing strategy of 2007, March 16th for South Africa. Previous papers targeting Upper and Middle Vaal Water Management Areas in South Africa also concluded that incorporating water quality variability into the cost chain for water services had the impact of trading pollution among upstream-downstream. This study provides practical methods towards restructuring the strategy to reflect integrated water resources approach as envisaged in the South African National Water Act, Act 36 of 1998 (DEAT 1998).

Purpose of the Study

The purpose of the study is to incorporate the water quality index into the current raw water pricing strategy of South Africa; henceforth, developing an equitable raw water pricing model. The pricing model will be structured in such a way that it incorporates a water quality index; which index represents quality variability among various water use locations.

Significance of the project

The pricing model is a virtual tool that will be used to predict realizable cost of raw water; attaching the true value of raw water depended upon the quality of the abstracted water. This will ultimately intensify the effectiveness and proficiency of the raw water pricing strategy; thereby achieving greater economic efficiency. Above all, this model will balance the water supply pricing chain; through optimization of the end product value.

Specific Objectives

The specific objectives of this study are framed towards achieving and equitable and sustainable raw water pricing strategy and they are defined as follows;

- To incorporate the water quality index into the current raw water pricing strategy.
- To develop a pricing model that will be used to predict the true value of raw water in recognizance of the raw water quality.
- To promote regular water resource monitoring which activity will support the utilization of the proposed pricing model.
- To predict water treatment costs; which will support the determination of the true value of raw water based on the quality restoration cost.

Constraints and Assumptions

The constraints and assumptions do not devalue the significance of this study and they are defined as follows;

- Assume all water boards are using the same treatment technology.
- Assume the cost of treatment is based on conventional water treatment method; which means that the prediction of the raw water cost may vary if deferent treatment method is followed.

- The pricing model will be built using Visual Basic Programming powered by Microsoft Excel; hence limiting the application to the use of Microsoft Office Suite.
- The Model should be updated frequently to reflect the correct amount of effort and cost required to restore the water quality at different level of pollution based on the class of water.

Methodology

WQI developed by Dzwairo (2011) will be adapted and reformed to accommodate the proposed pricing model. Data from three water quality monitoring points' will be processed and analysed using Microsoft Excel. The monitoring points refer to the abstraction points for Rand Water Board (RWB), Midvaal Water Company (MWC) and Sedibeng Water Board (SWB); which corresponds to Dzwairo (2011)'s monitoring points as V2, V17 and V19 respectively. The WQI will be analysed using hybrid evolutionary algorithm.

The water quality data range from January 2003 until November 2009 of the three monitoring/abstraction points will be used since it conforms to the WQI that will be adapted for this study. RWB is located within Upper Vaal Water Management Area whereas MWC and SWB fall under Middle Vaal Management Area; which defines the study area, thus Vaal Basin. The pricing model will be developed using Microsoft Excel (Visual Basic Programming), supported by the Water Quality Index (WQI) by Dzwairo (2011) and water treatment cost prediction based on conventional method of treating portable water. The model design will incorporate a Data Input Sheet with selected water quality parameters and an Output Sheet which will bear the predicted raw water price.

Literature Review

Pricing Strategy: Economic definition

Pricing strategy refers to method organisations use to price their products or services. According to Johnson and Scholes (2002: 10), strategy is the direction and scope of an organisation over the long-term; which achieves benefit for the organisation through its structure of resources within a stimulating environment, precisely to meet the needs of the markets and to fulfil stakeholders expectations. Almost all organisations, regardless of their magnitude; they base the price of their products and services on direct and indirect expenses.

Furthermore, depending on their operational objectives they can add a certain substantial percentage as profit mark-up.

Raw water pricing strategy definition

In the context of the research, it refers to a framework and policy used for the purpose of pricing use of raw water in South Africa (DWAF 2007b: 4). The strategy is established on the basis of guidelines and terms stated in the National Water Act (SA 1998: 36). Beyond pricing of raw water, the strategy also defines water resource management and protection practices. Comparable to any other pricing strategy, the South African raw water pricing strategy is governed by direct and indirect costs for water resource management and repayment of off-budget projects to achieve social, ecological and economic balance (DWAF 1999: 5).

Objectives of Establishing Pricing Strategy

General objectives

According to Williams (2008: 1), pricing objectives are the overall goals that describe the role of price in an organisation's long-term plans. The objectives provide decision makers with guidelines when developing pricing strategies that can establish profit base and revenue growth.

Raw Water Pricing Strategy Objectives

Raw water pricing strategy objectives targets to achieve efficient and cost-effective allocation of water, equity and fairness in the allocation mechanism, and long term sustainability of the natural environment (DWAF 1999: 7). Considering water resources from a large perspective, an economic raw water pricing strategy will improve overall allocations and encourage sustainable use. Although it is complex to treat water as both an economic and a social good, Dinar and Subramanian (1997: 1) highlight that on both individual and social levels, if price reflects the value of the resource, water use efficiency will improve. Savenije (2002: 742) outlines several characteristics of water which combined, they illustrate how water is not an ordinary economic good. Such water characteristics lead it to behave differently from any ordinary economic commodity. Henceforth, to be effective; water pricing strategies must be able to handle and address such complexities.

Broadly, though, raw water strategy objectives are governed by such characteristics and DWAF (1999: 4) and DWAF (2007b: 4) outline these objectives as; social equity, ecological sustainability, financial sustainability and economic efficiency. These objectives are drafted to promote sustainable, equitable and balanced water use as well as to protect and improve the aquatic environment.

Raw Water Pricing Structure

The structure of the strategy is defined by various components of charges and different sectors to be billed. Water uses are generally categorised under three groups as follows; abstraction related uses, non-consumptive uses and waste discharge uses. In most countries, abstraction related uses are grouped as; domestic (household use), industrial, agricultural (irrigation) and stream flow reduction. In the case of South Africa, domestic and industrial uses are considered as one sector while most countries separate the two sectors. Stream flow reduction can be combined together with the earlier three sectors depending on the purpose for which the stream flow is abstracted. Waste discharges differ based on the quality of waste being disposed. Hence this sector is normally handled differently. For as of allocation of funds, DWAF (2007b: 14) differentiate the sector based on the type of pollution; which are point source discharges, marine outfalls, waste disposal to facilities and land as well as irrigation with contaminated water.

Structure of the raw water charge depends on abstraction and waste discharge taking cognisance of the objectives to be achieved. With the aim of preserving of resource quality, the Polluter Pays Principle (PPP) for waste discharge was adopted in the South African raw water pricing strategy (DWAF 2007b: 5). The principle is widely adopted by various European countries as pollution charge (Roth 2001: 6). The PPP has its shortcomings; economic benefits will be achieved at the expense of environmental degradation (Dzwairo *et al.* 2011a: 6751). The system allows organisations to pollute the resource at the expense of the environment and other water bodies and authorities withdrawing water at the downstream of the pollution point. This is the case of Vaal basin, where the Middle and Lower Vaal basins are bearing the expense of water pollution by the Upper Vaal basin.

Polluter Pays Principle application only considers the concentration of the polluting agent without recognizing the environmental damage costs; which brings some difficulties on defining a pricing strategy that addresses financial sustainability. Worse still if the damage involves loss of aquatic species, the evaluation of such damage is not always feasible. Hence it creates a financial gap considering the PPP income revenue and the expenditure requirements to rectify such environmental damages. Polluter Pays Principle application does not consider the marginal expenditure required to restore unforeseen environmental damages other than the predicted, whilst the User Pays Principle does not incorporate the marginal costs required for utilising water of diminished quality.

Inter-basin transfer's schemes are there to augment water supplies in another area, for the purpose of meeting the deficit of supply to sustain ecological and economic user's requirements. Depending on the deficit, private and inter-boundaries transfer schemes could be implemented for the same purpose. The Trans-Caledon Tunnel Authority (TCTA) being a practical example. The raw water strategy is then a vital tool for the purpose of ensuring ecological sustainability through revenue collection that will successively cover water resource management and development expenditure.

Raw water quality variability due to negative environmental alteration is the key matter that was not considered in the pricing strategy. Diminishing of water quality ultimately cost the downstream user more resources in an effort to restore the raw water quality. The study will incorporate quality variability, balancing the marginal costs required for utilising water of diminished quality. it was also noted that aquatic plants develops more with the increase of waste concentration as a result of additional salts and phosphorus loads, hence the need for determining a more feasible ratio of allocating the costs of resource management (weed control) between the abstraction and waste discharge users (SAAWU 2004: 3; BUSA 2005: 5). The foregoing arguments thus validate the development of a raw water pricing strategy that will address the raw water quality variability due to environmental damages. The diminishing of water quality can be incorporated in the User Pays Principle (UPP), balancing the marginal costs required for utilizing water of diminished quality.

Stakeholder Organisation

The stakeholders targeted through the implementation of this study are;

- Department of Water Affairs
- Water Boards in Gauteng Province

- Domestic water user's other than the Water Boards

Resource Requirements

The resources required for the execution of this study includes;

- Treatment cost data (from water boards) and Raw water quality data (Dzwairo 2011)
- Raw water quality index (Dzwairo 2011)
- Laptop, Printer and Stationary
- Voice recorder
- Internet facilities (Modem and data bundles)
- Travelling and accommodation funds

Project Budget

The estimated project amount is **R 193,800.00** inclusive of VAT. The calculation of the professional fees and disbursements amount is included under table below.

PROJECT BUDGET [Preliminary Budget; actual budget to be determent upon secondary research phase]					
DESCRIPTION	**UNIT**	**QUANTITY**	**RATE**	**AMOUNT**	**% TO PROJ. COST**
Laptop	Sum	1.00	14,000.00	14,000.00	7.22%
Microsoft Office Suite	Sum	1.00	5,000.00	5,000.00	2.58%
Voice Recorder	Sum	1.00	3,000.00	3,000.00	1.55%
Stationary, Text Books and Documentation	Sum	1.00	80,000.00	80,000.00	41.28%
Travelling (Data Collection & Progress Meetings)	km	15,000.00	3.80	57,000.00	29.41%
Accommodation (Data Collection & Progress Meetings)	Nights	40.00	600.00	24,000.00	12.38%
Internet Facilities (Modem & Data Bundles)	Month	36.00	300.00	10,800.00	5.57%
TOTAL AMOUNT FOR STUDY EXPENSES [Including VAT]:				**193,800.00**	**100.00%**

Project Schedule

The project schedule is represented in the table below;

PROJECT SCHEDULE				
ITEM	**TASK**	**DURATION**	**START DATE**	**END DATE**
A	**OVERALL RESEARCH DURATION (Start - End)**	**466 days**	**2012/02/29**	**2014/01/22**
1	**RESEARCH ADMINISTARTION**	**242 days**	**2012/02/29**	**2013/02/21**
2	**PREPARING FOR RESEARCH**	**43 days**	**2012/04/12**	**2012/06/11**
3	**RESEARCH PROPOSAL**	**108 days**	**2012/05/28**	**2012/10/24**
4	**RESEARCH DISSERTATION**	**367 days**	**2012/05/28**	**2013/11/12**
5	**PROJECT TRANSFER**	**41 days**	**2013/12/11**	**2014/02/26**
5.1	Presentation to Stakeholders	20 days	2013/12/11	2014/01/28
5.2	Workshops (End-users)	20 days	2014/01/29	2014/02/25
5.3	Publications	1 day	2014/02/26	2014/02/26

4. DETERMINANTS OF KEY DRIVERS FOR POTABLE WATER TREATMENT COSTING IN UMNGENI BASIN

4.1 BACKGROUND AND PROJECT JUSTIFICATION

The water industry is currently facing increased pressure to produce higher quality potable water at a lower cost. Production of potable water is however determined by quality of raw water used, among other factors like utility technology and government standards. Potable water has the highest compulsory standards, thus stimulating need for continuous monitoring of raw water sources. Furthermore, water quality monitoring has been characterised by huge data sets, which are not being fully utilised for pollution trend analysis and decision making.

Retrospective data collection will be employed in this study because data already exists in databases, charts, records, etc. of Umgeni Water. Data sets for 31 water quality parameters (e.g. coliform, algae, BOD, COD, etc.) from 2005 to 2011 from uMgeni Water's monitoring program and for monitoring points that will be selected using purposive sampling as informed by point and non-point source pollution, and significance of sampling points to Umgeni's raw water abstraction patterns, shall be subjected to in-depth statistical trend analysis. Data will then be correlated to chemical dosages for determining treatability of such raw water. Student will attend selected Statistical and GIS-based training to enable him to carry out his own data analysis and presentation of results in various GIS formats, among other applicable environmentally-oriented software formats.

Derived significance parameters shall be assigned Weighted Factors (WF) according to importance of impacts to human health and these will be aggregated into a Water Quality Index (WQI). The WQI shall assist in providing an overview of the treatability of such water. Furthermore, Hybrid Evolutionary Algorithm Rule–Set functions and Bootstrapping, which use "if-then-else" logic to predict scenarios, shall be employed to model treatment chemical dosage in order to forecast raw water treatability.

Umgeni Water will benefit in terms of numerical understanding of parameters that significantly impact on production of potable water. An upgraded WQI shall be used to continuously assess quality variability of the raw water that is abstracted for treatment to potable use. Furthermore, incorporating the upgraded WQI into an adapted chemical dosage predictive model could help Umgeni Water in forecasting treatment cost, thus minimising under or over-budgeting of chemicals, both of which could be detrimental to a utility's smooth operation.

Literature Review

While studies (Huntley *et al.* 1982; Herold 2009: 2; Muller *et al.* 2009) have cited water as a principal limiting natural resource in South Africa, pollution has continued to aggravate the situation by deteriorating the quality of water resource making it either unusable or expensive to treat. Rampant urbanisation, industrialisation and population growth have been pointed as key drivers for the cause of water pollution in South Africa according to Coetzee (1995).

Water quality determines the 'goodness' of water for a particular purpose. Such fitness is measured by the concentration of particular parameters such as nitrates, Faecal coliforms, algae, manganese, calcium, turbidity, BOD, COD, pH, etc (DWAF 1996). For potable use, water should be free from harmful concentrations of chemicals or micro-organisms, and should ideally have a pleasant appearance, taste and odour (DWAF 2005). The treatment processes is meant to transform raw water to acceptable quality standard such as SANS 241 for drinking purposes in South Africa and the treatment costs are the associated expenses (Dennison and Lyne 1997; Pretty *et al.* 2002). For example, in most countries including South Africa, potable water guidelines (e.g. SANS 241 in South Africa) stipulates zero tolerances on the presence of the bacterium *Escherichia coli (E. coli)* (DWAF 1996).

E. coli is generally used as an indicator for faecal pollution since they originates from the intestines of warm blooded animals and its presence shows unfitness for drinking purposes (DWAF 1996; Dzwairo *et al.* 2011b). Algae on the other hand influence the organisms in a catchment and furthermore affect treatment processes (Graham 2004, Raw Water Quality 2006). During treatment, algae tend to increase energy consumption, as well as the amount of flocculants and coagulate in a conventional treatment process which ultimately increases the treatment cost, according to Environmental Protection Agency. In addition, the breakdown of algal cells release hepatotoxin which causes liver diseases and furthermore causes tastes and odours problems, which render the water less acceptable for domestic us according to DWAF (1996). Because of such effects of the parameters, chemicals such as coagulants, disinfectants and pH adjusters are used in a normal conventional treatment process to make the water fit for domestic use as indicated by Dearmont *et al.* (1998: 5).

Whereas humans have developed coping mechanisms for living in polluted environments, such options are not available for aquatic animals such as fish due to the vast volumes of water in a river, dam, etc. Polluted water has been known as an important vehicle for the spread of diseases (e.g. typhoid, cholera etc) causing death of 1.8 million people according to a report by WHO (2004). Also, besides increasing treatment costs, poor quality water can increase risk of compromising the quality of the final treated water, according to (Tiba and Hodgson 2008). Categorisation of parameters into those impacting treatment costs and affecting river quality could help in future development of a river WQI.

A WQI is a mathematical equation that incorporates data of multiple water quality parameters into a number that rates the health of a water body, according to Akoteyon *et al.* (2011: 264).. The report further refers to it as a useful tool for communicating information on overall quality of water to the general public and policy makers. Cude (2001), however, described a WQI as a tool for determining the appropriateness of the quality of water for the purpose of use such as potable, agriculture, etc. As pointed by Cude (2001), the proposed WQI shall serve in determining the appropriateness of raw water of a given quality for potable treatment.

Studies in the Vaal basin (DWAF 2007a; Dzwairo 2011: 2) notes that there has been significant deterioration of surface raw water quality downstream mainly due to pollution from mines and other industries. In cases like in the Vaal basin where price of raw water contributes about 50% of the total production cost as indicated by Van Wyk (2001: 3), raw water quality variability becomes a significant cost factor among WBs that abstract upstream-downstream of each other within a basin. Such a situation might also mean that water tariffs for downstream users are either incorporating the cost due to diminishing quality or WBs are operating at a loss as noted by (Dzwairo *et al.* 2011a).

uMngeni Basin is no exception to both water scarcity and pollution. A report by DWAF (2003b) states that water quality was fair upstream of the uMngeni River, but generally deteriorated downstream. In addition, direct discharge of sewage effluent into the uMngeni River was significantly increasing pollution levels (*Fresh water resources : State* 1999).

Studies in the uMngeni Basin have also cited water quality as a significant factor influencing treatment cost. A study by Dennison and Lyne (1997: 40) on DV Harris treatment plant in Pietermaritzburg recognises water quality variability as the major factor causing high treatment cost at that plant. However, although that study was performed in the same catchment as the proposed, there is now a need for review because water quality is not static. Graham (2004) conducted a similar study on dams in the basin and indicated algal variability as the key parameter deriving treatment cost. Following Graham (2004)`s approach, the study shall determine the significance of each water parameter monitored on treatment cost but will further incorporate such parameters into a WQI in order to make it specific for usage in determining the quality of raw water intended to be treated for potable use.

General Objectives:

To determine key parameters impacting production of potable water along uMngeni Basin

Objectives:

1. To analyse surface water quality monitoring data in order to determine spatial and temporal quality trends.
2. To correlate raw water quality with chemical dosages for the purpose of determining parameters significantly affecting treatment cost.
3. To upgrade an existing WQI and make it more oriented toward determining quality of raw water intended for producing potable water.
4. To adapt a chemical dosage predictive model for forecasting treatment cost.

Research Questions

1. Are there significant spatial and temporal surface raw water quality trends in uMngeni Basin?
2. Which parameters significantly determine chemical dosage during treatment of surface raw water to potable standard along uMngeni Basin?
3. Which parameters of significance to treatment can be incorporated into an existing WQI in order to make it more oriented towards representing key drivers for potable water treatment?
4. Can the upgraded WQI be further incorporated into an adapted chemical dosage predictive model for the purpose of forecasting treatment cost?

Constraints

- The budget allocation will allow for travel and purchase of required software

Assumption

- Sampling, preservation and analysis of surface raw water was done according to EPA and DWA guidelines
- For historic data, this is adequate for the modelling processes
- Data to be provided by Umgeni Water is raw, i.e., has not been pre-processed for other purposes.

Limitation

- The study will only analyse surface raw water data from uMngeni basin, which factors out other sources of raw water such as ground water.
- The study will trend water quality variability as a significant variable in treatment costing thus factoring out other elements such as electricity and wages which might also have an effect on portable water treatment costing, but which do not form part of this study.

Deliverables

Water Quality Trends

Upgraded Umgeni Water Quality Index

Chemical dosage model for Umgeni Water

Methodology

The study will use the quantitative research design approach. This approach, allows for statistical analyses of data sets. Data sets for 31 water quality parameters (e.g. *Escherichia coli*, Biochemical Oxygen Demand, Chemical Oxygen Demand, etc.) for 2006 to 2011, and for strategic monitoring points along UMngeni Basin, shall be statistically analysed and correlated to chemical dosage using statistical package software.

Deliverable 1: Water Quality trends

Method:

The Exploratory Data Analysis (EDA) approach shall be used for full visual, spatial, dynamic and interactive analysis of monitoring data (Helsel and Hirsch 1992: 17; Maasdam 2000: ii). The approach allows for in-depth analysis of data without an assumption (Mozejko 2012: 97). Spatial and temporal water quality trends shall be produced for analysis of the pollution changes in uMngeni Basin. Scatter plots, time series, etc., will be produced for the interpretation of water quality trends in the Catchment. Furthermore, Kendal (regional and seasonal) test shall be performed for significant testing of the relationship between surface water quality variability with space or time respective (Hirsch *et al.* 1982; Helsel and Hirsch 1992: 327).

Deliverable 2: Upgraded Water Quality Index

Method:

Pre-processed data sets shall be reduced using multivariate methods such as factor analysis. Weighted average of the parameters will then give the overall WQI of water intended for potable treatment.

Deliverable 3: Chemical dosage model

Method:

The upgraded WQI shall be incorporated into an adapted chemical dosage predictive model (Dzwairo 2011: 208).

Importance:

With the development of cost predictive models, WBs will be able to forecast water treatment chemical dosage. This will help combat under budgeting chemical dosage expense which can vary according to raw water quality.

3. **Journals articles**

   Shall be produced during the course of the research.

4. Reports and conference papers

5. Thesis

Key Stakeholders Organisations:

- Department of Water Affairs
- Water Boards e.g. Umgeni
- Catchment Management Agency
- Industries
- Water User Associations
- Local Authority e.g. eThekwini

Key Project Management Staff and Authority Levels

- Durban University of Technology
- Umgeni Water
- eThekwini Municipality
- Pietermaritzburg Municipality
- uMngeni Water User Association

Preliminary Summary Staff and Authority Levels:

Prof F.A.O. Otieno, Dr B. Dzwairo, Mr G.J. Barratt, Dr P. Reddy, Ms K. Hodgson

Preliminary Summary Milestone Schedule:

Milestone	**Deadline**
Topic formulation, preliminary reading, review any similar applications	July - August 2012
Submission and approval of thesis proposal. Literature review	September - December 2012
Data collection, processing and analysis	January - August 2013
Interpretation of results	August – December 2013
Write up and submission of draft thesis	January - March 2014
Write up and submission of completed final thesis	April – June 2014

Preliminary Resources Requirements

- SPSS and Matlab

Preliminary Budget Requirements:

Section A: Budget		**(Motivate below)**	
1.	Consumable Details (Motivate)	Purchase and maintenance of MATLAB software.	R20 000
2.	Outside Specialist Services (Motivate)	GIS tutor for mapping the study area and spatial analysis	R5 000
3.	Books/Journal/Documents	Access for relevant journal not in the institution database.	R500
4.	Library Charges	Printing and photocopying	R500
5.	Equipment (Motivate)	External Hard disk for data backup	R1 000
6.	Travel Costs (Motivate)	Data collection Local and international conference/ symposium	R35 000
7.	Other (Motivate)	Printing of draft and final thesis copies	R1 000
	TOTAL		R63 000

Quality / Peer review Process:

- Shall be done through use of library and internet. Databases such as Sciencedirect and JStor will facilitate the research with literature in line with the research. There will be continuous consultation with stakeholder and interaction at workshops and conferences.

Project Supervisor and co- supervisors' Approval:

1. Supervisor: Dr B. Dzwairo, Co- Supervisor: Mr G.J. Barratt, Co-Supervisor: Prof F.A.O. Otieno

5. SURFACE RAW WATER PRICING MODEL FOR SOUTH AFRICA: VAAL AND UMNGENI BASINS CASE STUDY

5.1 BACKGROUND

The National Water Act (NWA) No. 36 of 1998 (DEAT 1998) provides for progressive establishment of Catchment Management Agencies (CMAs) throughout South Africa. The intention is for CMAs to be largely financed at a WMA scale, mainly through appropriate “user charges”. This approach would enable CMAs financial self-reliance and sustainability (Pegram and Palmer 2001). One of the key issues raised by the Pricing Strategy in terms of CMA financing, and which required greater attention was the differentiation of user charges and the need to address various issues such as assurance of supply and benefit obtained from water resources management (Pegram and Palmer 2001).

The White Paper on National Water Policy for South Africa (1997) under Section 6.5.3 recognizes that all significant water resources use will be charged for, regardless of where it occurs. Such will include use of water for effluent disposal or interception of water to the detriment of other users. The only exception will be in respect of the Reserve for basic human needs. This is also enshrined in the NWA No. 36 of 1998 Part 3. The Strategic Framework for Water Services for the year 2003 and for South Africa under Section 4.5 notes that setting of raw water tariffs and the responsibility of regulating such could be placed on DWA but subject to national Treasury oversight or by a Water Service Authority and water boards, where such organizations manage raw water systems.

A new approach is concerned with pricing use of water from South Africa’s water resources, and not with the pricing of water services. Water services, including the pricing thereof, have been dealt with separately in the Water Services Act, 1997. Both the NWA No. 36 of 1998 Chapter 5 Part 1 and the Water Research Act No. 34 of 1971, Section 11 recognize the need to set water pricing tariffs from time to time by the Minister of Water Affair and or a responsible authority as prescribed by the NWA. Both these are in line and or informed by the Section 24 of the Republic of South African Constitution (Act No. 108 of 1996). In other words, the new approach deals with first tier water, i.e. the use of water from the water resource. It does not deal directly with second and third tier water, i.e. water supplied in bulk (often by water boards) and distributed to households (usually via a municipality), except for water supplied by Government water schemes. The new approach deals with all first tier water: state and private schemes, as well as ground and surface water (DWAF 1997). It is at this first tier water level that this study is focusing at to consider water quality when modelling raw water pricing strategy.

The salinity of the surface waters of the world is highly variable and depends upon ionic influences of drainage and exchange from surrounding land, atmospheric sources derived from the land, ocean and human activity and equilibrium and exchange with the sediment within the water body (Wetzel 1983; *Observations on environmental change in south africa. Commission by the south african environmental observation network (saeon)* 2011). South Africa is diverse in climate, geomorphology, geology and soils and also in its terrestrial and aquatic biota, and so each region exhibits differences in water chemistry even when unaffected by human activities. A generalised methodology model to determine the generic impacts of changes in the total salt concentration found in South African rivers was determined using the Middle Vaal River as a case and the impacts were interpreted in financial, economic and social resources (WRC 2000). The results of the study identified the total economic effects of increased salinity levels for the Middle Vaal River area.

As may be expected, the international experience with charging for water use has focused on the costs of water resources infrastructure development and operation (including water services). These are by far the greatest costs associated with water management, with the administrative-management costs of managing water use representing a relatively small portion of the total cost (Dinar and Subramanian 1997; Rettig 2001).

In order to ensure financial sustainability adequate revenue must be generated to fund the annual cost related to the management of the country's water resources; the operations, maintenance and refurbishment of existing Government water schemes; and the development of augmentation schemes. The full financial cost of water resource management and supplying water should be recovered from water users, including the cost of capital. Water must be priced at levels consistent with efficient and effective delivery of services. This approach may be phased in by taking account of constraints of various sectors to adapt quickly to price increases.

Department of Water Affairs (DWA) has developed a Waste Discharge Charge System (WDCS) to promote waste reduction and water conservation. It forms part of the Pricing

Strategy and is being established under the NWA. 36 of 1998. The water quality based approach model will assist in minimizing costs of water where such disposed water and or any available water is of poor quality which has resultant high costs for water service providers to treat such water to portable levels.

In terms of Chapter 3 of the NWA, the water needs for the effective functioning of aquatic ecosystems must be protected. The water required for the ecological reserve must be safeguarded and the cost of managing the Reserve must be paid for by all registered and billable users in terms of Section 56(2) (a) (iv) of the NWA. The WDCS is based on the polluter-pays principle. Lack of sufficient water quality data in many places hinders efforts of surface water quality modelling, which subsequently affects the process of water quality management. On the other hand, the user-pays principle encourages costing raw water as a capital resource base (Dzwairo 2011). Hence, justification for a raw water pricing structure which incorporates raw water quality variability makes sense as well as development of a model that accounts for raw water quality variability when predicting cost of water treatment (Dzwairo 2011) .

From the previous study (Dzwairo 2011), the Water Quality Index (WQI) was compared to the surface raw water pricing trends for the Upper and Middle Vaal Water Management Areas and it was concluded that quality was not a consideration for one component of the tariff structure, the Water Resources Management Charge. Currently the DWA has initiated a new study to look a revising the Water Pricing Strategy and in its inception report, the physical attributes of water as referred to in the WSA, specifically the water quality, is not considered as a critical element to base the pricing on.

The main challenge for not considering water quality on the pricing could have huge cost implications to Water Services Authorities (WSAs) should water quality change as they will have to cover for the treatment. Budgeting for operations of water treatment plants is normally done well in advance and should the cost of treating water shoot well above contingencies that can put a WSA on financial deficit. Such may well be a factor that currently makes some of the WSA, especially where such role is assumed by Municipalities, to fail to an extent on supplying potable water and also on poor return flows, putting environment and people at a serious risk.

However, the Internal Strategic Perspective (ISP) for the Vaal Catchment which was completed in 2004 (DWAF 2004a) and the Reconciliation Strategy for the Vaal River System (DWA 2009) have both considered water quality in planning for the resource, a major move on ensuring water quality consideration on water resource allocation.

From previous studies, it was recommended that the user pays principle be employed where a user abstracting good quality water could pay more than a user abstracting bad quality water, based on the Water Quality Index (Dzwairo 2011). This would provide a good water management strategy for protecting good quality water courses from over-exploitation. It may also encourage more effective water treatment technologies where raw highly polluted water could be made available to water service providers at lower prices. The DWA is currently engaging and investigating various such technologies mostly from Asian countries to deal with various water quality problems faced by the country.

Benefits :

- ❖ Legislative implementation through sound scientifically informed thinking along with other considerations on raw pricing;
- ❖ Balances needs for cost-recovery, sustainable financing and institutional viability with imperatives for redress, equity, growth, affordability and sustainability;
- ❖ Enables effective infrastructure management and water governance, regulation and research;
- ❖ Sustainable environmental/resource protection through revenue generated through administration costs which will go back to the collector for catchment management;
- ❖ Catchment Management Agencies sustainability through Treasury's implicit revenue ring fencing;
- ❖ National Treasury revenue generation for state's fiscal resources;
- ❖ Sectoral interests and benefits on consideration of water quality in pricing, other than the traditional quantity based alone, of the resource;

- Improved monitoring and compliance of the resource which will benefit the sector on coordinated data that which is much needed for informed decision and policy making; and
- Also sound scientifically based water pricing strategy.

General Objective of Project

To develop a model for pricing surface raw water for South Africa using Vaal basin as case study and uMngeni basin as validation site.

Specific Objectives:

- To conduct an in-depth analysis of components that determine annual price of raw water for domestic, agricultural and industrial use;
- To analyse available models for pricing raw water; and
- To develop a surface raw water pricing model for South Africa's pricing strategy

Constraints and Assumptions:

- Availability of data from the study area and water services authorities to be identified;
- Clear decision on project scope refinement; and
- Studying part time with a full time demanding job.

Deliverables:

1. Doctor of Technology Thesis for the fulfilment of the academic requirements of the University
   - The research methods will be adapted from Dzwairo (2011), where specific refinements will be made for this specific project.

Key Stakeholder Organisations:

- DWA, Water Services Authorities, Water Research Commission, CMAs, SALGA, COGTA, National Treasury, DAFF, DTI, DME, SAAWU, DBSA

Key Project Management Staff and Authority Levels:

- To be advised

Preliminary Summary Milestone Schedule:

Milestone	Deadline
1. Project concept approval and academic registration	30-Sep-2012
2. Project proposal approval by the faculty	31-Mar-2013
3. All data needed for modelling obtained from sources	31-Oct-2013
4. Modelling of the cost implications of water treatment completed	31-Mar-2014
5. Draft project report completed	31-Mar-2014
6. Comments from editors incorporated onto the final draft	31-Jul-2014
7. Submission of the thesis for evaluation	20-Dec-2014
8. Presentation of the outcomes/findings of the thesis to the University	31-Mar-2015
9. Submit the final report and copies for the fulfilment of the qualification	31-Aug-2015

Preliminary Resource Requirements:

- Endnote software and refresher training for the use of the program
- Subscription and access to relevant information/journal sources
- Contact sessions for the finalization of the project proposal
- Data sources and sourcing
- Model software and crush course
- Conferences/symposia presentations

Preliminary Budget Requirements:

Table 1 Project Budget

Disbursements	**Year 1 Costs (R)**	**Year 2 Costs (R)**	**Year 3 Costs (R)**	**Year 4 Costs (R)**	**TOTAL Costs (R)**
***Academic**					
Application	300	300	300	300	1200
Tuition/registration	20 000	3000	3000	3000	29 000
Handling	200	200	200	200	800
Participation/Operational					
Transport	1000	4000	4000	1000	10 000

Disbursements	**Year 1 Costs (R)**	**Year 2 Costs (R)**	**Year 3 Costs (R)**	**Year 4 Costs (R)**	**TOTAL Costs (R)**
Running costs	1000	2000	2000	2000	7000
Subsistence	500	500	1000	2000	4000
Equipment					
Software requirement	5000	0	5000	0	10 000
Maps, data, printing, journal and book articles	1000	2000	1000	3000	7000
National/international conferences					
Meetings/seminars workshops	1000	2000	3000	5000	11 000
Local conference presentations	1000	1000	3000	5000	10 000
International conference presentations	0	0	0	30 000	30 000
TOTAL	**31 000**	**15 000**	**22 500**	**51 500**	**120 000**

*subjected to confirmation

Quality/ Peer Review process:

- Progress reports, etc.

Project Supervisor and co-Supervisors Approval:

The concept note is still subject to further refinement and scrutiny and should be final in early 2013.

6. OPTIMISING RESERVOIR OPERATION RULE CURVES FOR INANDA DAM: UMNGENI BASIN

6.1 BRIEF BACKGROUND

Effective water resources development and management is widely recognised as crucial for sustainable economic growth and poverty reduction in many developing countries such as South Africa. The contribution of large hydraulic infrastructure, particularly reservoirs, to development, remains controversial. This controversy stems from the fact that, too often in the past, construction of reservoirs has brought fewer benefits than envisaged and has resulted in significant social and environmental costs. Reservoir operation is a complex problem that involves many decision variables, multiple objectives as well as considerable risk and uncertainty (Oliveira and Loucks 1997).

On the other hand it often involves a variety of stakeholders with different objectives, such as domestic and industrial water use, irrigation, potable water, flood control and hydropower generation. The conventional methods of reservoir operation are based on empirical methods and often the managers of the reservoir system rely on their experience and judgment in taking correct operational decisions (Diment 1991). These conventional methods are often not adequate for establishing optimal operation decisions, especially when integrated operation of multipurpose multi-reservoirs is contemplated. Reservoir rule curves are used for guiding and managing the reservoir operation. These curves typically specify reservoir releases according to the current reservoir level, hydrological conditions, water demands and time of the year. Established rule curves, however, are often not very efficient for balancing the demands from the different water users. Moreover, reservoir operation often includes subjective judgments by the operators. Thus, there is a potential for improving reservoir operating rule curves and small improvements can lead to large benefits.

For previous optimisation of reservoir systems, procedures based on coupling simulation models with numerical search methods have been developed. Traditionally, the simulation-optimisation problem has been solved using mathematical programming techniques such as linear or non-linear programming. Application of these methods, however, puts severe restrictions on the formulation of the optimisation problem with respect to description of water flow in the system, and definition of control variables to be optimised and associated optimisation objectives. Recently, procedures that directly couple simulation models with heuristic optimisation procedures such as evolutionary algorithms have been proposed (Lund and Guzman 1999). These methods have proven to be effective for optimisation of reservoir systems.

The overall objective of the project is to minimise in real-time water losses from the Umgeni River System and ensure that potable and irrigation demands are met in terms of the water quality and the required quantity at the right time.

Inanda dam is suited at the valley of a thousand hills below hillcrest in KwaZulu-Natal. It is owned by Umgeni water. Umgeni Water, a state-owned entity, is one of Africa's most successful organisations involved in water management, and is the largest supplier of bulk potable water in the Province of KwaZulu-Natal, South Africa. The organisation was established in 1974, and has grown over the years to become an entity of strategic importance in the Province of KwaZulu-Natal and indeed South Africa. Umgeni Water has six municipal customers, namely eThekwini metropolitan municipality, ILembe district municipality, Sisonke district municipality, UMgungundlovu district municipality, UGu district municipality and Msunduzi local municipality. The organisation currently supplies 426 million cubic metres of potable water to its six municipal customers. South Africa is a semi-arid country and water resources are limited. The use of sustainable alternative methods are needed to minimise real-time water losses from the Inanda dam and ensure that potable water and irrigation demands are met in terms of the water quality and the required quantity at the right time.

Research Objectives

To optimise reservoir operation rule curves in order to minimise in real time, water losses from uMngeni River system and to ensure that potable and irrigation demands are met in terms of water quality and the required quantity.

Specific Objectives

- To model Inanda dam operation by optimisation of existing methods
- To evaluate technical adaptation options for current reservoir operating rule curves for Inanda reservoir.
- To develop a water quality sensitive framework for optimal operation of reservoirs in the uMngeni basin by simulating operation at Inanda dam

Literature Review

In South Africa, where the need for economic development is urgent, but many people continue to rely on natural resources and agriculture to sustain their livelihoods, the necessity of assessing all the implications of dams are needed, given the complexity of water resources systems (Wurbs 1993). Oliveira and Loucks (1997) note that defining effective operating rules for a particular water supply system is a challenging task, especially those that apply to multiple reservoirs serving multiple purposes and objectives. While pointing out that optimisation models are playing a minor role in identifying possible real-time reservoir operating rules, (Bower *et al.* 1962) reported that many reservoir systems are still managed based on fixed predefined operating rules.

Nevertheless, such models can be used for planning to help identify and evaluate alternative operating policies for fixed or predefined goals or objectives. They further state that in most cases, these predefined operating rules have been derived from operator experience or from trial-and-error simulation studies while most of these have become very efficient over time. However, in spite of considerable past research on multi-reservoir system operations, they also highlighted the need for a comprehensive negotiation and subsequent agreement among stakeholders for deriving improved and effective operating rules. Operating rules for multi-reservoir urban water supply systems should specify how the total demand of a system should be met with available supply of water in the system. For single purpose multi-reservoir systems, the operating policies are usually defined by rules that specify either individual reservoir desired (target) storage volumes or desired (target) releases based on the time of the year and the existing total storage volume in all reservoirs (Oliveira and Loucks 1997).

A comparison of the individual reservoir storage targets to the actual storage volumes in each reservoir identifies which reservoirs should release water to meet the total system release target. Oliveira and Loucks (1997) also claim that having both system-wide release functions as well as individual reservoir storage volume target functions define a multiple-reservoir operating policy that permits the coordinated operation of the entire system. Loucks *et al.* (1987) reported that for many reservoir systems in the United States, there exists a hierarchy of rules that regulate the operation of the system, and in general, these can be divided into three categories: (1) the rule curves, (2) a release schedule, and (3) operating constraints. The rule curves define the individual reservoir storage targets at different times of the year and a release schedule typically indicates the total release to be made from the reservoir system as a function of water available in the system and time of the year. There could also be other numerous system specific operating constraints that govern the operation of a water supply system. These could be detailed in terms of minimum river releases, hydropower commitments, meeting the minimum levels of service criteria (such as, supply reliability, duration and severity of restrictions), amounts of river diversions etc.

Bower *et al.* (1962) suggested two rules for determining releases over time; a Standard Operation Policy (SOP) and a hedging rule. The SOP calls for the release in each period of the target release, if possible. If insufficient water is available to meet the target, the reservoir releases all the available water and becomes empty; if too much water is available, the reservoir can fill and spill the excess water. The hedging rule applies whenever there is a shortage of water and the marginal value of water is a decreasing function of the amount of water supplied. The hedging rule highlights that it is advantageous to accept a small current deficit in order to decrease the probability of a more severe water shortage in the future (Shih and Revelle 1992).

Simulation models typically include mechanisms for detailed specification of operating rules (Wurbs 1993). Operating rules based on release rules and storage balancing rules are used in simulation models such as HEC-3 (Hydrologic Engineering Centre 1981), HEC-5 (Hydrologic Engineering Centre 1989) and IRIS (Loucks *et al.* 1987). The simulation models REALM (Perera and Codner 1996),(Perera and James 2003),(Perera *et al.* 2005), WASP (Kuczera and Diment 1988; Kuczera 1990) and WATHNET (Kuczera 1992) , hybrid evolutionary algorithm (base on their operating rules on ‘restriction rule curves’, ‘target storage curves’ and other operating constraints.

Evolutionary computation, offers practical advantages to the researcher facing difficult optimization problems. These advantages are multi-fold, including the simplicity of the approach, its robust response to changing circumstance, its flexibility, and many other facets. The evolutionary algorithm can be applied to problems where heuristic solutions are not available or generally lead to unsatisfactory results. As a result, evolutionary algorithms have recently received increased interest, particularly with regard to the manner in which they may be applied for practical problem solving. Usually grouped under the term evolutionary computation or evolutionary algorithms, we find the domains of genetic algorithms (Houck 1985), evolution strategies (Rechenberg 1973), (Paul 1977), evolutionary programming (Raoud 1992) and genetic programming. They all share a common conceptual base of simulating the evolution of individual structures via processes of selection, mutation, and reproduction. The processes depend on the perceived performance of the individual structures as defined by the problem. Compared to other global optimization techniques, evolutionary algorithms (EA) are easy to implement and very often they provide adequate solutions.

Research Methods

- To model Inanda dam operation by optimising existing methods- Current models will be applied to develop operation rule-curves at the dam.
- To evaluate technical adaptation options for current reservoir operating rule curves for Inanda reservoir- The developed reservoir operating rule curves at Inanda dam will be evaluated and analysed in order to assess for technical adaptation options for optimal quality raw water supply to potable water treatment processes.
- To develop a water quality sensitive framework for optimal operation of reservoirs in the uMngeni basin by simulating operation at Inanda dam-.The process requires developing a credibility factor and a credibility index which will be used to test on the possible scenarios for the operation of the reservoir.

Plan of Research Activities

Milestone	Deadline
1. Proposal approval	30-Sept.-12
2. First progress report	31-Nov 2012
3. Data collection	30-Feb.-2013
4. Second progress report	30-July- 2013
5. Modelling	31-Novermber- 2013
6. Third progress report	30- Feb.- 2014
7. Submission of Thesis	30- July - 2014
8. Correction of Thesis	30-January- 2015

STRUCTURE OF DISSERTATION

Chapter 1: Introduction

Chapter 2: Literature Review

Chapter 3: First specific Objectives Methods and Results

Chapter 4: Second specific objectives Methods and Results

Chapter 5: Third specific Objectives Methods and Results

Chapter 6: Discussion

Chapter 7: Conclusion and Recommendation**.**

7. VAAL DAM DILUTION RULE

7.1 BACKGROUND

As from 1990, South Africa has had far-reaching policy, legislation and institutional changes in water-related governance. Responsible leaders have ensured that a paradigm of integrated water resource management (IWRM) is firmly entrenched in the above policy, legislation and institutional arrangements. IWRM in turn demands a level of interaction between individuals; disciplines and organizations such that multi-sector, multi-level stakeholders can collectively, timeously, wisely and cost-effectively visit the consequences of their proposed, present and past actions. As a result a follow-up processes to implement the 1998 NWA required that South Africa be divided into sector groupings and Catchment Management Areas (CMAs) to democratically pursue IWRM within the constraints of the triple bottom line and under the oversight of the DWAF and the framework of the National Water Resource Strategy (NWRS) (Dent 2012)

Globally the major threat to water availability is pollution of water bodies, particularly from mining, sewage and industrial effluent. Within this context, joint participation by key stakeholders including the private sector could serve to ensure that water resource pollution costs are internalized within the economic benefits accruing from contributions by specific users. To that effect, South Africa's National Water Act No. 36 of 1998 recognizes that protection of basic human and ecological needs; economic efficiency and social equity are guiding pillars for water resource allocation (Hassan and Farolfi 2005). For South Africa, Water Management Areas (WMAs) are administrative structures which were established, among other reasons, to support the concepts of integrated catchment management within these guiding pillars (DWAF 2006).

Vaal Dam releases are a function of the downstream water demands, local tributary inflows and the system operating rules employed. MVWMA water quality and quantity rely heavily on the dilution rule for operating the Vaal Dam. Some analysis of this rule, however indicates that this option could only be feasible over the medium term (<8 years) (DWAF 2009). Other options, such as desalination, would have to be considered for the long term management of salinity, because the dilution rule could result in excess water in Bloemfontein Dam from about 2012 onwards.

The Vaal River has been described as one of Africa’s work horse rivers. Of the 1300 km-long Vaal River, the Vaal Barrage region is regarded as the hardest-working region river in South Africa (Tempelhoff 2009). The 63 km from the Vaal dam to the Barrage constitutes less than 5% of the total catchment but 10 million people reside in this catchment and the run-off water of three large metropolitan cities, some 13,600 wet industries and a number of gold mines flow into the Vaal River between the wall of the Vaal Dam and the Barrage. In the Vaal basin, the economic factor was one of the major drivers for development and management of the water resource (DWAF 2004b) the basin supports sprawling urban and industrial areas (DWAF 2003a).

The mentioned activities account for about 60% of the economic activities of South Africa. The Upper Vaal WMA (UVWMA) contributes nearly 20% of the GDP of South Africa and is considered an economically important WMA due to mining and other commercially related activities. Treated effluent return flows from mining, agricultural and industrial activities are discharged into the basin, creating significant impacts on water quality. These impacts have a cascading effect into the Middle Vaal WMA (MVWMA). Its economy is predominantly rural in nature and contributes about 4% of GDP of South Africa. MVWMA‟s most dominant economic activity is the mining sector which generates more than 45% of the GDP for the area. Due to continued degradation and pollution of the main tributaries such as the Klip, the water quality of the Vaal Barrage is seriously impacted. The deteriorating water quality of the Vaal Barrage resulted in an increasing number of mass fish mortalities; particularly yellow fish, occurring in the region of the Barrage (Tempelhoff 2009). Although degraded water quality conditions continue to pose the greatest threat to fish health in this system, additional impacts such as habitat alteration, flow regime modifications, barriers for migration, disturbance to wildlife and or the impact of non-endemic alien or introduced fishes may be affecting the fish communities in the Vaal River.

In the catchments upstream of Bloemhof dam effluents from urban, industrial and mining activities have resulted in a marked increase in total salinity of the Vaal River. In the lower catchment irrigation return flows are the major contributor to river salinity. Potential long-term "pollution threats to the important Vaal Dam catchment are atmospheric pollution, diffuse agricultural sources and further industrial development. Eutrophication is already a problem in the Vaal River, particularly in the Barrage and Bloemhof dam catchments where it is becoming an increasingly serious issue. The problem is partly contained because of the turbid nature of Vaal River water but, as has already been demonstrated for the middle Vaal River, increasing salinity and accompanying decreases in turbidity can enhance primary productivity.

Little research has been done to integrate hydrologic and water quality issues into mainframe water resources management in sub-Saharan Africa in order to determine the net impact of introducing any innovation into catchments, (Fatoki *et al.* 2001). Majority of the studies on water resources management have focused on either water quality and water quantity independent of anthropogenic activities. Total success in dam dilution assessment should entail systems modelling in which water managers seek to understand and predict the behaviour of complex systems that are characterized by non-linearity, time delays and feedbacks. Also, multi-scale databases should be constructed which make site and situation specific data available for enhanced up and out scaling.

The research proposes to come up with tools for sustainable dam dilution. Overall, the project will contribute to new knowledge by developing and testing a methodology of linking hydrology and water quality aspects in water resources management. It will also contribute to bridging the information and knowledge gaps in on-going attempts to reconcile productivity, efficiency and equity in water resources allocation and management in general. In addition, the research will help build mutual trust between stakeholders by providing a transparent decision support tools.

BENEFITS

- ❖ Opens up the water quality research fraternity for further scientific inquiry
- ❖ Informing policy on impacts and applicability of water quality management strategies
- ❖ Reduction in the cost of management of water resources
- ❖ Facilitate stakeholder understanding of catchment hydrodynamics

General Objective of Project

Over and above the many initiatives made in the Vaal Catchment, this study aims to develop an adaptive water quality management framework for the Vaal River System, downstream of

Vaal Dam and upstream of the Bloemhof Dam. The study seeks to change traditional water quality management approaches by combining real-time water quality data with historical data in order to optimize water quality management strategies, taking advantage of the rapid developments in computational techniques. Furthermore, hydrology and water quality issues will be integrated in a manner that facilitates decision making in this study.

Specific Objectives

- To assess the success factors of the integrated water quality management initiatives operational in the Vaal River system;
- To develop a tool that integrates water quality and river system hydrodynamics, and use the tool to develop water quality management decision scenarios;
- To develop a prototype decision support system based on water quality management decision scenarios for Vaal River System for optimizing water quality management decisions; and
- To evaluate the applicability of the decision support system in integrated water quality management in the Vaal catchment

Constraints And Assumptions

- Availability and access to relevant data
- It is assumed that auxiliary resources will be available throughout the study period

Deliverables

Deliver a decision support tool that can be readily applied for hydrological and water quality policy exercises in the Vaal river basin.

a. Methodology

Statistical methods such as Monte Carlo methods will be performed on the input data if possible and level of confidence will be specified for the output.

Experimentation and data validation.

Demonstration of the various management scenarios based on the dilution rule within the DSS

b. Methodology

Scenario assessments will be carried out

c. Run developed models under different operating conditions

Publications, methods, manual and guidelines and other information materials for knowledge delivery and enhanced understanding and awareness on decision support tools for integrated water resources planning and management.

d. Methodology

Compilation of research output into publications, methods, manuals and guidelines

e. Presentation of research outputs in different forums

Key Stakeholder Organizations

- ❖ Department of Water Affairs
- ❖ Universities and Research institutions with interests in water
- ❖ Catchment Management Agencies
- ❖ Water user associations

Key Project Management Staff and Authority Levels

- ❖ Dr Bloodless Dzwairo - Postdoctoral Fellow and Research Supervisor
- ❖ Professor F.A. Otieno Co- Supervisor
- ❖ Civil Engineering Department, DUT

Preliminary Resource Requirements (Data/ Software/ e.t.c.)

- ❖ MATLAB software
- ❖ ArcView GIS software
- ❖ Database for the Vaal River System (Water quality, water quantity, water use, etc.)
- ❖ Visual Basic software
- ❖ GPS (Global positioning system)
- ❖ Water quality variability atlas

Preliminary Summary Milestone Schedule

Milestone	Deadline
1. First progress presentation	30-Sep-12
2. Full proposal submission	30-Nov-12
3. First journal paper submission	31-Jun-13
4.Second progress presentation	15-Jul-13
5. Second journal paper submission	31-Dec-13
6. Final progress presentation	15-Nov-14
7. Third journal paper submission	31-Dec-14
8. Completed Draft	31-Mar-15
9. Completed Final	30-Jun-15

Preliminary Budget Requirements

Budget Component	Year				Total
	2012	2013	2014	2015	
Living Allowances	24 000	48 000	48 000	24 000	144 000
Book allowance	2 000	2 000	1 000	1 000	6 000
Equipment		10 000	7 000	6 000	23 000
Software		15 000			15 000
Conference attendance	5 000	5 000	5 000		15 000
Workshops/Seminars		15 000			15 000
Field work costs		6 000	4 000	2 000	12 000
Travel costs		8 000			8 000
Training courses		6 000	6 000	6 000	18 000
Contingencies				4 000	4 000
Total					260 000

Quality/ Peer Review Process

❖ Progress reports

- Progress presentations
- Journal Articles
- D Tech Dissertation

Project Supervisor and co-Supervisors Approval

Dr Bloodless Dzwairo

Prof Fred AO Otieno

CONCLUSION

It is envisaged that cluster research will focus basin needs and help develop sector capacity in order to negotiate products into policy. By implementing an integrated approach to the overall research, this will promote prioritisation where necessary in order to ensure that strategic research goals are aligned to the sector project portfolios, taking cognisance of the changing environment. A systems thinking approach is recommended because current fragmented research has failed to mitigate complex pollution issues in the Vaal basin, where in the following sections proposals specific to a particular research topic are presented.

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