Decision support for the planning of integrated wastewater reuse projects in South Africa

J.R. Adewumi[1*], A.A. Ilemobade[1] and J.E. van Zyl[2]

[1]*School of Civil and Environmental Engineering, University of the Witwatersrand, Johannesburg. South Africa*

[2]*Department of Civil Engineering, University of Cape Town, South Africa*

Abstract:

Wastewater reuse has become an attractive option for supplementing available water supplies. It also presents an opportunity for pollution abatement when it replaces effluent discharge to sensitive surface water bodies. Other benefits of reuse include the decrease in the use of freshwaters from sensitive ecosystems, replenishment of nutrients in agriculture, enhancement of groundwater recharge, delay in the future expansion of water supply infrastructure, and the sustenance of wetlands. This paper presents ongoing research in developing and testing of a decision support system (DSS) for assessing the feasibility of integrating wastewater reuse projects in South Africa. The database of the DSS contains 33 wastewater treatment unit processes with known information on performance, costs and qualitative criteria (technical & environmental) obtained from literature. Knowledge base contains a set of rules for standard combination of treatment units to form treatment trains and information on five groups of end users with maximum allowable water quality parameters. Multi-criteria qualitative assessment covers social, institution and water resource evaluation. Weighted average method was used to aggregate scores obtained from these analyses to generate an indicative value that could form the basis for decision making. Testing of the DSS was applied to the Parow wastewater treatment plant in Cape Town. The result of the analysis shows that only water resources evaluation score (1.0) is considered excellent for the reuse implementation while institutional evaluation score is very weak (0.35) to guarantee success. Although, 1.0 is the desirable aggregate for successful implementation of any reuse project, 7.5 obtained under social evaluation could still be considered adequate while necessary precautions are taken to address the shortfalls. If due considerations are given to the criteria highlighted in this model by the decision makers, success of reuse project in South Africa can be better enhanced.

Keywords: *Water scarcity, Wastewater reuse; Decision support, Multidisciplinary*

* Corresponding Author: Email: James.Adewumi@students.wits.ac.za, Tel: +27726835466

Introduction

A significant land area of South Africa is a semi-arid with a mean annual precipitation (MAP) of 450 mm, which is well below world average of 860 mm per annum (DWAF, 2004). The MAP is highly uneven across South Africa and accompanied with high evaporation rates. This makes the country's water resources extremely limited and scarce. Also, surface runoff is highly variable and stream flows in most South African rivers are at relatively low levels for most of the year. This limits the proportion of stream flow that can rely upon to be available for use without adverse effect on the ecosystem in many areas (DWAF, 2004).

The scarcity of water in South Africa is aggravated by regular pollution of surface and groundwater resources in many areas. An indication of the pollution pressure on South African freshwater resources can be found in the Vaal Barrage catchment that supplies freshwater to Gauteng province. The catchment receives 859 Ml/d of domestic effluent, 240 Ml/d of mine effluent and about 100Ml/d of industrial effluent (NSER, 2007). This has resulted in the increase in phosphates, chemical oxygen demand (COD), ammonium, suspended solids, faecal coliform, sulphate, metals (manganese, aluminium and iron) and a decrease in pH of the Vaal River (NSER, 2007). Also, in the City of Cape Town, algae blooms and geosmin in the raw water is increasingly becoming problematic, particularly at the following dams site: Theewaterskloof, Voelvlei, Steenbras and Constantia Nek. (CCT, 2007).

In evaluating the feasibility of implementing a water reuse project, decision makers are often faced with the responsibility of optimally considering multiple factors that often cut across the triple bottom line attributes of sustainability (i.e. environmental, technical/economic and social) (Ganoulis, 2003). Considerations of these factors are often onerous especially without a decision support tool that will assist.

Many authors have employed different techniques to solve wastewater treatment problems. Some of the techniques are: *Optimization computational technique* (e.g. Chang and Liaw, 1985; Gasso, *et al.*, 1992) used in the preliminary design of wastewater treatment systems to obtain a least cost design. The technique involves a systematic selection of different treatment unit processes to form treatment trains with minimum cost; *Expert system* has been used for the selection of optimal scheme in the treatment, disposal and reuse of wastewater (Wee and Krovvidy, 1990; Krovvidy, et al., 1994; Ahmed *et al.*, 2002; Economopoulou and Economopoulos, 2003; Dinesh and Dandy, 2003; Joksimovic *et al.,* 2006; Joksimovic, *et al.,* 2008). An expert system is a computer program that simulates the judgement and behaviour of a human being that has expert knowledge and experience in a particular field. The adopted approaches includes knowledge base containing accumulated experience, inference engine (thinking machine) solves the problem and a set of rules for applying the knowledge base to each particular situation that is described to the program; *Monte Carlos simulation* was used by Chen and Beck (1997) to generate and screen feasible wastewater treatment technologies and account for uncertainties in the performance of each treatment unit process This method relies on repeated random sampling and probability to compute their results and is useful for modelling physical conditions with significant uncertainty; Balkema *et al.* (2001) uses *Integer programming* to develop a decision support to identify sustainable treatment options for domestic wastewater using a weighted sum of sustainability indicators as objective. In integer programming, all variables (sustainability indicators in this case) are required to be integer before integer programming can be applied; *Analytical Hierarchy Process* (AHP) employed by Addou *et al*. (2004); Bick and Oron (2004) to select wastewater treatment technologies provides a comprehensive and rational framework for structuring a decision problem to overall goals and for evaluating alternative solutions. It first decomposes the problem into a hierarchy of grouped sub-problems that can be analyzed independently. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time. The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way; Hidalgo *et al.* (2007) uses *multi criteria analysis* to develop a decision support system to promote safe urban wastewater reuse. The analysis assigned weight to various indicators like treatment technology, costing factor, land availability, type of soil, type of crops cultivated and their water requirements, meteorological conditions and legislative requirements to score the safe reuse of wastewater effluent. Ellis and Tang (1990) and Tang and Ellis (1994) use 20 parameters that cut across technical, economic, environmental and socio-cultural factors to form a decision matrix to rank 46 wastewater treatment processes.

In general, most of these models based their evaluation on technical functionality and economic factors without detailed consideration of other important factors such as aridity, social perceptions and institutional capacity. These factors are crucial in wastewater reuse planning and can determine failure or success of a reuse project. This paper presents the methodology and preliminary testing results of the decision support system developed using a multicriteria analysis that cut across economic, environmental and social factors in assessing the feasibility of implementing integrated wastewater reuse project through the selection of appropriate treatment trains that will produce effluent of reuse quality. Employing this DSS tool is anticipated to enhance optimal planning of wastewater reuse schemes in South Africa communities and better empower water planners to take decisions that are economically, environmentally and socially justified.

Methodology

Features of the Decision Support System

The DSS has been developed for water planners and decision makers in water industry in South Africa. It was developed for PC computers in JavaTM programming language. A user-friendly interface has been design as a point and click to provide interactive access to input, output and action screen. The system includes the following modules and sub-modules:

i. *General information*: community name, province, water management area and population
ii. *Engineering/Technical evaluation*: treated effluent potential reuse estimation, quality of wastewater source, treatment train general costing information,

potential uses and maximum allowable water quality parameters, unit processes detailed information, treatment unit selection and result of evaluations.

iii. *Social perception evaluation*

iv. *Institutional perception evaluation*

v. *Water resources evaluation*

Each of these consists of many sub-modules which the user is guided through in sequential order to assist in decision making.

Evaluation of Potential Reuse

The use of treated wastewater varies from place to place depending on water availability and the quality of treated wastewater. In general, the main uses are for public and private irrigation (e.g. golf courses, playground and sport fields), agricultural irrigation (restricted and unrestricted), commercial and residential air conditioning, toilet flushing, car washing, building and street washing, fire protection, construction works including concreting and dust control, industrial processes, groundwater recharge, subsidence control and environmental enhancement (i.e. maintaining urban streams, wet lands, fountains and ponds) (Okun, 2002; Yang and Abbaspour, 2007). Quantitatively estimating the amount of non-potable water required in these different uses can be difficult because of the lack volumetric data as is the case in many developing countries. Where no data is available, non-potable water demand in each sector can be estimated using on various parameters which are described in the next section. The equations used in this research are modified version of the model presented by (Chu et al., 2004; Yang and Abbaspour, 2007). The equations were modified to allow direct computation of non-potable water need for each activity rather than depending on the fraction of water demand in various sectors which can be difficult to obtain if there are no historical water use data.

- ***Agricultural Irrigation, Landscape/ Recreational Irrigation***

The estimating equation used is presented as follows:

$$Q_A = 0.001 A_a V_a T_a \qquad 1$$

Where, Q_A = non-potable water use for agricultural irrigation (m_3)

A_a = area for the agricultural Irrigation (m^2)

V_a = crop water requirements (mm)

T_a = Number of irrigation days/ annum (days).

- ***Domestic Use***

Lazarova *et al.* (2003) reports that toilet flushing accounts for approximately 30% of in-door water usage and above 60% in commercial buildings. This indicates that a large volume of potable water could be saved with the use of non-potable water for toilet flushing and other water features like self contained recirculating water features, waterfalls and artificial streams in ground and above ground ponds as well as a range of garden accessories including grindstone birdbaths, animals and figurines with water recirculation. In this tool, domestic non-potable water use can be computed using the following predictive equation:

$$Q_D = \frac{365}{1000}(N_t V_t T_t P_t + W_F) \quad 2$$

Where, Q_D = Domestic non-potable water use (m^3)

N_t = total number of toilets in the area

V_t = volume of toilet cistern (L)

T_t = number of toilet flushing per person per day

P_t = total number of people using one toilet

W_F = volume of water required in other water features (L).

- ***Mining and Industry***

Demand for cooling power plants in the mining and industry is estimated as follows:

$$Q_I = C_e E_e K_e N_e \quad 3$$

Where, Q_I = Industrial non-potable water use (m^3)

C_e = the generating capacity of thermal power plants (kWh)

E_e = the water consumption of unit generating capacity of thermal power plants (m^3/kWh)

K_e = the ratio of circulating cooling water to total water withdrawal of thermal power plants.

N_e = number of thermal plants

- ***Other Uses***

Developing an accurate mathematical model that could be used to predict the volume of water required in other non-potable water use such as construction works, street flushing, fire protection, groundwater recharge etc could be problematic. However, an approximate value could be obtained using historical records of water consumptions for these activities. These values are imputed into the DSS by the user as a known value.

Details of the DSS interface for the evaluation of potential reuse is shown in Appendix A1

Treatment Train Evaluation

Treatment train evaluation criteria used in this research work were adapted from MOSTWATER (Dinesh and Dandy 2003) and WTRNet (Joksimovic, 2006) where the evaluation criteria for each unit process making the treatment trains is classified into technical, environmental and economic types. The technical criteria considered are performance, reliability, adaptability to upgrade, varying flow rate, change in water quality, ease of O&M and construction. The environmental criteria considered are power and chemical requirements, odour generation, impact on groundwater, land area requirements and sludge production, while economic criteria relates to the project costs (i.e. capital cost, annual operating and maintenance cost or lifecycle (cost incurred throughout the useful life of the project)). Of these criteria, the calculated are pollutant removal, cost, land area requirements and energy requirements, while the other items are considered as qualitative. These criteria are grouped into quantitative and qualitative criteria as shown in Table 1.

Table 1: List of treatment train and unit process evaluation criteria

Technical, Economic and Environmental Criteria	**Name of Criteria**
Quantitative Technical	Pollutant removal efficiencies Cost (Capital and O&M)

	Land requirements Energy production
Qualitative Technical	Reliability Adaptability to upgrade Adaptability to varying flow rate Adaptability to varying water quality Easy of Operation and Maintenance Easy of construction
Qualitative Environmental	Power Requirement Chemical requirements Odour generation Impact on groundwater

The methodologies for estimating quantitative technical, qualitative technical and qualitative environmental for wastewater treatment processes are numerous, but not easily comparable due to the assumptions used in their development. In this research, estimating quantitative and qualitative technical/economic information for the 33 unit processes in the knowledge base of the decision support tool were obtained from literature (Ahmed *et al.*, 2002; ESCWA, 2003; Metcalf and Eddy, 2003 and Joksimovic, 2006). Table 2 presents economic criteria used in developing the DSS tool. Decision support uses ***Nil, Low, Medium and High*** to quantify qualitative items with a positive value representing the technical items and a negative value representing environmental items.

Table 2: Cost functions used in quantitative economic estimation (Ahmed *et al*., 2002; ESCWA, 2003 and Joksimovic, 2006).

Unit Process	**Useful Life (years)**	**Capital Cost, CC (Rands)**	**Land Cost (Rands) (Value X cost/m2)**	**Labour Cost (Rands) (Value X cost)**	**O&M Cost (Rands)**	**Energy Cost (Rands)**	**Replacement Cost (Rands)**
Bar Screen	30	$1.21 \times 10^4 Q^{0.5138}$	$0.1262 Q^{0.9755} m^2$	6 person hrs/month	$1.31 \times 10^3 Q^{0.5138}$	0	0
Coarse Screen	30	$1.94 \times 10^4 Q^{0.5138}$	$0.1262 Q^{0.9755} m^2$	6 person hrs/month	0.10 X Capital Cost	0.01kwh/m3	0
Grit Chamber	30	$2.24 \times 10^4 Q^{0.4426}$	$4 \times 10^{-5} Q^2 + 0.0938Q + 67.5$	12 person hrs/month	0.10 X Capital Cost	0.01kwh/m3	0
Stabilization Pond: Anaerobic	15	$7.31 \times 10^3 Q^{0.6566}$	$1.04 \times 10^2 Q^{0.9607}$ m2	16 person hrs/month	$290 Q^{0.7977}$	0	0.5 CC
Equalization Basin	30	$5.04 \times 10^4 Q^{0.52}$	$\frac{Q}{SOR} = \frac{20 \times Q}{3} m^2$	14 person hrs/month	0.02 X Capital Cost	0	0
Sedimentation w/o coagulant	30	$1.5 \times 10^4 (20 \times Q)^{0.446}$	$\frac{Q}{SOR} = \frac{20 \times Q}{3} m^2$	14 person hrs/month	0.02 X Capital Cost	1.75 kwh/m3.yr	0
Sedimentation w coagulant	30	$2.7 \times 10^4 (20 \times Q)^{0.321}$	$\frac{Q}{SOR} = \frac{20 \times Q}{6} m^2$	14 person hrs/month	$1.4 \times 10^3 (20 \times Q)^{0.5146}$	1.75 kwh/m3.yr	0
Stabilization Pond: Aerobic	30	$5.6019 \times 10^0 Q^{0.6836}$	$1.11 \times 10^1 Q^{0.9453} m^2$	16 person hrs/month	0.20 X Capital Cost	0	0
Stabilization Pond: Facultative	30	$5.35 \times 10^3 Q^{0.6837}$	$1.11 \times 10^2 Q^{0.9453} m^2$	16 person hrs/month	0.20 X Capital Cost	0	0
Activated Sludge + Sedimentation	30	$9.1 \times 10^4 Q^{0.5184}$	$10.767 Q^{0.9705} m^2$	14 person hrs/month	0.10 X Capital Cost	300 kwh/m3.yr	0
Trickling Filter + Sedimentation	30	$4.7 \times 10^3 (20 \times Q)^{0.7361}$	$5.93 Q^{0.9581} m^2$	14 person hrs/month	$9.4 \times 10^2 (20 \times Q)^{0.82}$	75 kwh/m3.yr	0
Rotary Biological Contractors	30	$5.97 \times 10^3 Q^{0.8}$	0.6 Q m2	40 person hrs/month	$8.45 \times 10^2 Q^{0.9228}$	75 kwh/m3.yr	0
Membrane Bioreactors	30	$7.62 \times 10^3 (Q)^{0.75}$	7.2 Q m2	60 person hrs/month	$320 Q^{0.6928}$	0.6 kwh/m3	0
Biological Phosphorous Removal	30	$9.82 \times 10^3 Q^{0.5221}$	1.2 Q m2	0	$396 Q^{0.5959}$	2.5 kwh/m3	0

Unit Process	**Useful Life (years)**	**Capital Cost, CC (Rands)**	**Land Cost (Rands) (Value X cost/m_2)**	**Labour Cost (Rands) (Value X cost)**	**O&M Cost (Rands)**	**Energy Cost (Rands)**	**Replacement Cost (Rands)**
P – Precipitation	20	$1.13 \times 10^3 (20 \times Q)^{0.345}$	75 m_2	0	0.4 X Capital Cost	0.1 kwh/m_3	0.34 CC
Chemical Precipitation	20	$9.82 \times 10^3 Q^{0.554}$	85 m_2	0	0.4 X Capital Cost	7.0 kwh/m_3	0.34 CC
Denitrification	30	$9.82 \times 10^2 Q^{0.5221}$	1.2 Q m_2	0	$396Q^{0.5959}$	0.5 kwh/m_3	0
Constructed Wetland	30	$3.55 \times 10^4 Q^{0.3926}$	120 Q m_2	14 person hrs/month	0.40 X Capital Cost	0	0
Maturation Ponds	15	$3.6 \times 10^3 Q^{1.014}$	124 Q m_2	14 person hrs/month	$743.5Q^{0.7364}$	0	0.5 CC
Dual Media Filter	20	$5.54 \times 10^3 Q^{0.634}$	$0.4217 Q^{0.6029} m^2$	18 person hrs/month	0.20 X Capital Cost	1.0 kwh/m_3	0.34 CC
Micro Filtration	20	$5.36 \times 10^3 Q^{0.6}$	$0.4217 Q^{0.6029} m^2$	18person hrs/month	0.20 X Capital Cost	0.3 kwh/m_3	0.34 CC
Ultra Filtration	20	$5.36 \times 10^3 Q^{0.6}$	$0.4217 Q^{0.6029} m^2$	18 person hrs/month	0.20 X Capital Cost	0.3 kwh/m_3	0.34 CC
Nano Filtration	20	$9.4 \times 10^3 (Q)^{0.845}$	$0.3255 Q^{0.4311} m^2$	14 person hrs/month	0.20 X Capital Cost	2.5 kwh/m_3	0.34 CC
Reverse Osmosis	20	$9.4 \times 10^3 (Q)^{0.845}$	$0.3255 Q^{0.4311} m^2$	14 person hrs/month	0.20 X Capital Cost	1 kwh/m_3	0.34 CC
Soil Aquifer Treatment	40	180Q	$0.9065 Q^{0.969} m^2$	250 person hrs/month	2.2 X Capital Cost	0.24 kwh/m_3	0
Activated Carbon	20	$2.67 \times 10^3 (Q)^{0.8386}$	$0.365 Q^{0.423} m^2$	18 person hrs/month	0.09 X Capital Cost	0.5 kwh/m_3	0.34 CC
Ion Exchange	30	$4.9 \times 10^3 (Q)^{1.15}$	Q X 0.004 m_2	110 person hrs/month	0.10 X Capital Cost	175 kwh/m_3.yr	0
Advanced Oxidation Ponds	30	$1.4 \times 10^4 (Q)^{0.78}$	0.4 m_2/m_3/Hr	16 person hrs/month	$549(Q)^{1.1}$	2.5kwh/m_3	0
Electrodialysis	30	$5.8 \times 10^3 (Q)^{1.116}$	0.004 m_2/m_3	14 person hrs/month	0.10 X Capital Cost	175 kwh/m_3.yr	0
Chlorine Gas	15	$2.45 \times 10^4 (Q)^{0.5}$	15 m_2	30 person hrs/month	$0.1 \times$ Capital Cost	0	0.5 CC
Chlorine Dioxide	15	$3.85 \times 10^4 (Q)^{0.40}$	10 m_2	25 person hrs/month	0.1 X Capital Cost	0	0.5 CC
Ozone	15	$1.25 \times 10^4 Q^{0.7326}$	50 m_2	12 person hrs/month	$319Q^{0.8916}$	0.57kwh/m_3	0.5 CC

UV Radiation	20	$2.4 \times 10^{3} (20 \times Q)^{0.568}$	$2.4 \times 10^{3} (Q)^{0.3368}$ m^2	13 person hrs/month	0.198/m^3	0.043kwh/m^3	0.34 CC

The life cycle cost is obtained from the following expression:

$$LCC = \sum_{i=1}^{p} CC_i + 1.15(LanC_i) + LbC_{pwi} + O\&M_{pwi} + E_{pwi} + R_{pwi} \qquad 4$$

Where LCC = Life Cycle Cost of the treatment train

CC_i = Capital Cost of i_{th} unit process

$LanC_i$ = Cost of land for i_{th} unit process

LbC_{pwi} = Present worth of labour cost for i_{th} unit process

$O\&M_{pwi}$ = Present worth of operation and maintenance cost of i_{th} unit process

E_{pwi} = Present worth of energy cost of i_{th} unit process

R_{pwi} = Present worth of replacement cost of i_{th} unit process

p = Number of unit processes making treatment train

Numerical scores used for ***Nil, Low, Medium or High*** are 0, 1, 2 and 3 respectively. In the computation, another important factor included in the model as a fixed factor is a numerical weight ranging from 5 to 10 assigned to each criterion in order of importance with 10 as very important and 5 as least important.

The classification of the qualitative criteria shown in Table 1 is divided into technical and environmental which are positive and negative respectively. For positive (technical) criteria a score of HIGH indicates that the unit process is, for example, highly reliable based on operating experience or adaptable to varying conditions. On the other hand, a score of HIGH assigned to negative (environmental) criteria indicates that a unit process, for example, consumes large quantity of chemicals, generates a lot of odours, or has a high potential for groundwater pollution.

The process of determining the treatment qualitative criteria scores are as follows:

i. Calculate the average criteria score (equation 5)
ii. Normalise the score according to the criteria type i.e. positive(technical) and negative (environmental) (equations 6 and 7)
iii. Calculate the overall treatment train score (equation 8)

$$AEC_i^{TT} = \frac{\sum_{j=1}^{N} EC_{ij}^{up}}{N} \quad 5$$

$$NEC_i^{TT} = \frac{1}{3} AEC_i^{TT} \quad 6$$

$$NEC_i^{TT} = 1 - \frac{1}{3} AEC_i^{TT} \quad 7$$

$$QS_i^{TT} = \frac{\sum_{i=1}^{M} W_i . NEC_i^{TT}}{\sum W_i} \quad 8$$

Where

AEC_{iTT} = Treatment train average score for criteria i

AE_{ijUP} = Unit process score for criteria i

NEC_{iTT} = Normalise treatment train score for criteria i

QS_{TT} = Overall treatment train qualitative criteria score

N = Number of unit processes in the treatment train

W_i = Weight of criteria (user assigned)

M = Number of qualitative evaluation criteria

It should be noted that in equations 5 to 8, similar measuring criterion say for instance, adaptability to varying flow rates are summed together for all unit processes that forms the treatment trains and then aggregated to give the criterion score on a scale of 1.0 (Appendix A5).

Perception Survey Evaluation

- ***Social Evaluation Criteria Score***

All criteria used in the social evaluation are latent variables (variables that can not be measured directly). A potential user is expected to input an answer which is converted into a Boolean factor to determine the criteria score in accordance to Loetscher and Keller (2002). The user's input is in range $0 \le x \le 1$, where 0 equals the worst and 1 equals the best outcome. A fixed numerical weight ranging from 5 to 10 were assigned to each statement in order of importance with 10 as very important and 5 as least important. The result obtained by summation of all statements is then aggregated to obtain standardized outcome indices of social evaluation. Statements included as default in knowledge base of DSS that users must answer in social evaluation are outlined in Table 3. Each statement represents one criterion.

Table 3: Social evaluation Criteria

S/No	Criteria
1	Reclaimed water is acceptable to institutional users
2	Reclaimed water is acceptable to domestic users
3	Public are willing to eat fruits and vegetable irrigated with recycled water
4	Public trust the authority to provide safe recycled water
5	Public are not concern about the perceived health implications
6	public are not concern about the physical quality of the reclaimed water

- ***Institutional Evaluation Criteria Score***

In other not to compromise public health and environment, Laws, policies, rules, and regulations that affect reuse project must be well spelt out by the government agency to enable all stakeholder understand and play their roles effectively. The valuation of institutional criteria is done in the same way as social evaluation from the set of statements indicated in Table 4

Table 4: Institutional evaluation criteria

S/No	Criteria
1	Survey has been conducted to assess public opinion
2	All community leaders, pressure group etc have been consulted
3	Reuse project has been incorporated to form part of IWRM
4	People are aware of water scarcity
5	There is National regulations guiding reuse
6	There is local regulations guiding reuse
7	There is capacity measure to monitor and enforce the regulations
8	There are strong communication links between planners and the community
9	Public are willing to participate in reuse project
10	Funding is available for the project

- ***Water Resources Evaluation Criteria***

Table 5 shows the statements included in the knowledge base which the users must be provided with answer under this Section.

Table 5: Water resources evaluation criteria

S/No	Criteria
1	There are history of water restriction in the past
2	There is **low** potential for further sustainable exploration of surface water
3	There is **low** potential for further sustainable exploration of groundwater
4	There are cases of surface water pollution in the area.
5	The area is water stress

Input to statement 1-5 is Boolean: $x = f(yes) = 1, x = f(no) = 0$. Arithmetic mean is used to aggregate the standardized value obtained in statements contained in Table 3 to 5. The expression used is as follows:

$$a_j = \frac{1}{m}\sum_{i=1}^{m} x_{ij} \quad (9)$$

Where a_j = aggregation result for evaluation criteria j (j = 1, 2, 3, 4…n), $0 \le a_j \le 1$

x_{ij} = merit of criteria j with regard to statement i (i = 1, 2, 3, 4…m), $0 \le a_j \le 1$

Loetscher and Keller (2002) argued that where arithmetic mean is used to aggregate many criteria in evaluating sanitation technology alternatives, another coefficient doubles the weight of the resulting factor on the next higher level thereby resulting in a poor sensitivity analysis. In the qualitative analysis of this DSS, alternatives are not our evaluation focus but the critical factors that could lead to the success or failure of non-potable water reuse project, hence, the value obtained through arithmetic mean is only an indicative value that shows how low or high the evaluating criteria are. It is desirable that values obtained in this analysis should be as close to 1.0 as possible. If the value obtained in any perception criterion is zero, it is highlighted in red to indicate that a priority attention is needed on that criterion to facilitate reuse success.

Treated Wastewater End Users Classification

The end users category contained in the knowledge based of the decision support system is shown in Table 6. Information stored as default in the knowledge based specifies the maximum contaminant concentrations for each end user type (Appendix A2). The pollutants considered in this research are Turbidity (Turb), Total Suspended Solids (TSS), Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Total Nitrogen (TN), Total Phosphorus (TP), Faecal Coliforms (FC) and Total Coliforms (TC). Considerations were not given to heavy metals concentration because of the stringent Department of Water Affairs and Forestry (DWAF) regulations on the disposal of complex industrial wastewater into urban sewage system. It is mandatory under law (DWAF, 1998) that all wastewater emanating from industries with toxic chemicals must be treated on-site to specified pollutants limit before discharged to municipal sewer while compliance is enforced through regular monitoring and sanction.

Table 6: Classification of treated wastewater end users

Reuse Type	Description of Reuse
Domestic	Toilet flushing, garden/ lawn irrigation, home air conditioning systems, car washing and cleaning
Landscape and Recreational Irrigation (Urban)	Open access landscape areas like school fields, parks, golf courses, sport fields, etc
Industrial	Industrial cooling, boiler feed and process water except for food industries
Other Activities	construction works, street flushing, fire protection and groundwater recharge
Agricultural Irrigation (unrestricted)	Irrigation of raw consumed food crops, fruit trees sprinkler irrigation, greenhouse crop irrigation, etc.
Agricultural Irrigation (restricted)	Irrigation of pasture for milking or meat animals, fodder, cereals, fibres, seed crops and other areas where public access is prohibited.

Since South Africa guidelines for wastewater reuse promote the concept of "No potential risk" without specifying the maximum allowable concentration of pollutants, the stringent conditions suggested in USEPA (2004) guidelines are used to develop the maximum contaminant concentrations for each end user type as shown in Appendix A 2.

Methodology for Generating Treatment Trains

The combination of unit processes shown in Appendix A3 to form treatment train is not a very simple design process. Therefore, a selection has to be made among the treatment unit processes to form standard treatment trains for reuse purposes.

Rules taken into consideration when developing the knowledge base for assembling treatment trains are (Joksimovic, 2006; Kubik and Hlavinek, 2005):

i. rules that dictate possible starting points depending on the influent water quality,
ii. rules that prohibit the formation of unacceptable process configuration that violate sound engineering practice, and
iii. rules to check if the required pretreatment or the maximum allowable quality requirement for unit processes are met.

A typical example of the first rule: if raw wastewater is used as the source, it has to receive preliminary treatment prior to application of any additional treatment, unless lagoon systems are used. The second type of rule could be that Membrane Bioreactor can be used only for effluents from one of the primary treatment processes, excluding anaerobic ponds. The third type rule uses the maximum allowable pollutants content of treated effluent to match reuse activity with the treatment trains.

Other considerations in the generation of treatment train assembly process were its overall simplicity and tractability, and they were handled by other researchers typically by introducing a series of rules (Joksimovic, 2006). In this DSS, all unit processes are classified under category. The category specific rules guide the selection of unit processes classified into technology categories, and specify processes from the same or different categories that are allowed or forced to coexist in a treatment train.

The general structure of the rules can be summarized with the following expression: ***IF (unit process A / unit process(es) from category X) IS (present / absent) THEN (unit process(es) B / unit process(es) from category Y) (can / must / cannot) be present.***

The first set of treatment train rules, dealing with possible starting unit processes, are addressed simply by specifying the quality of wastewater source to be treated to meet any reuse purpose as the starting point.

Case Study

Preliminary testing of this decision support system has been applied to the effluent from Parow wastewater treatment works (WWTW) in the City of Cape Town (CoCT). This WWTW has a design capacity of 1.2 ML/day. The existing treatment process consists of the following configuration:

> ***Bar screen → grit chamber → aerated activated sludge → maturation pond → gas chlorination.***

Using the existing treatment trains configuration, the decision support system was used to simulate the treatment performance in term of pollutant removal when all the treatment units that form the treatment are performing at average pollutant removal efficiency (Appendix A3) and compare the result with the average value obtained in 2006 (CCT, 2007). The result is shown in Table 7 (detailed outputs of the decision support model are shown in appendix A3 – A10).

Table 7: Pollutant values obtained in the Parow WWTW in 2006 compared with values obtained from the decision support tool.

Pollutants	Units	Average values in 2006			Decision support model		
		Min	**Ave**	**Max**	**Min**	**Ave**	**Max**
Turbidity (Turb)	NTU	-	-	-	5.82	11.68	17.82
Total Suspended Solids (TSS)	mg/L	2.0	14.0	59.0	12.6	31.5	73.5
Biochemical oxygen demand (BOD)	mg/L	-	-	-	15.3	33.0	60.0
Chemical oxygen demand (COD)	mg/L	31.0	65.0	165.0	27.5	59.2	120.0
Total Nitrogen (TN)	mg/L	0.2	4.9	28.0	0.36	1.3	3.42
Total Phosphorus (TP)	mg/L	1.7	8.1	15.3	3.3	4.9	6.0
Faecal Coliforms (FC)	No/100mL	0	10	200000	0	100	150000
Total Coliforms (TC).	No/100mL	-	-	-	0	100	150000

Due to an increase in wastewater flow into the WWTW and high potential of effluent reuse in the area, the CoCT is proposing an upgrading of the existing treatment processes to include additional unit process in order to meet the irrigation quality requirements. The proposed upgrading has the following treatment trains:

Bar screen → aerated activated sludge → maturation pond → dual medial filter → gas chlorination.

Using the decision support tool, the generated treated wastewater quality effluent for the selected treatment trains are shown in Table 8.

Table 8: Pollutant values obtained in the proposed upgrading of Parow WWTW using decision support model.

Pollutants	Units	Decision support model		
		Min	**Ave**	**Max**
Turbidity (Turb)	NTU	2.9	11.8	35.6

Total Suspended Solids (TSS)	mg/L	0.6	3.1	14.7
Biochemical oxygen demand (BOD)	mg/L	3.0	8.2	21.0
Chemical oxygen demand (COD)	mg/L	6.8	17.7	51.2
Total Nitrogen (TN)	mg/L	0.3	1.17	3.2
Total Phosphorus (TP)	mg/L	2.8	4.4	5.6
Faecal Coliforms (FC)	No/100mL	0	20	100
Total Coliforms (TC).	No/100mL	0	20	100

The result of the qualitative analysis as shown in Table 9 indicated that the treatment unit processes for both existing and proposed upgrading has good qualitative scores. Also, the social and water resources evaluation score with a score of good and excellent also favour the implementation of wastewater reuse in the City of Cape Town. However, the result of the analysis reveals that much still needed to be done to improve institutional capacity for successful implementation of wastewater reuse.

Table 9: Summary of qualitative analysis result (scores were aggregated to 1)

S/No	Items	Score	Comment
1	Existing treatment trains score	0.76	good
2	Proposed upgrading treatment trains score	0.75	good
3	Social evaluation score	0.76	good
4	Institutional evaluation score	0.35	poor
5	Water resources evaluation score	1.0	excellent

Conclusion

Water scarcity in South Africa and other parts of the world has fuelled the need for alternative water supplies with reuse now considered an important option by many water resource planners. The selection of an efficient treatment trains to achieve the desired effluent quality using multidisciplinary approach that cut across technical, economics, social and environmental attributes are not easily achievable. The developed DSS provide a framework for structuring water reuse problem into technical (pollutant % removal and unit process performance), economic (costs), social (perception survey) and institutional (legislation and resources) criteria that are analyzed independently. The result obtained under various criteria will enable water planners and decision makers in water industry to make a better judgement in evaluating the feasibility of implementing wastewater reuse project in South Africa. The benefit of using this model will be significant as it will eliminate the use of unsubstantiated methods of evaluation which often result in poor feasibility planning and project failure.

Acknowledgement

Funding from the Water Research Commission project K5/1701 is gratefully acknowledged.

References

Addou, M., Benhammou, A., and Ouazzani, N. (2004). "A decision aid model for selecting the appropriate wastewater treatment plant." *IWA 4th World Water Congress and Exhibition*, Marrakech, Morocco.

Ahmed, S. A., Tewfik, S. R. and Talaat, H. A. (2002). "Development and verification of a decision support system for the selection of optimum water reuse schemes", *Desalination,* (152) 339-352

Balkema, A. J., Preisig, H. A., Otterpohi, R., Lambert, A. J. D. and Weijers, S. R. (2001). "Developing a model based decision support tool for the identification of sustainable treatment options for domestic wastewater", *Water Science and Technology* 43(7) 265-269

Bick, A. and Oron, G. (2004). "Optimal treatment selection for wastewater upgrading for unrestricted reuse and environmental control." *Operations Research Society - Israel Meeting*.

City of Cape Town (2007): The City of Cape Town Water Service Development Plan, City of Cape Town

Chang, S. Y. and Liaw, S. L. (1985). "Generating designs for wastewater systems", *Journal of Environmental Engineering,* 111(5), 665-679

Chen, J. and Beck, M. B. (1997). "Towards designing sustainable urban wastewater infrastructure: A screening analysis", *Water Science Technology,* 35(9*)*, 99-112

Chu, J. Y., Chen, J. N., Wang, C. and Fu, P. (2004). „Wastewater reuse potential analysis: implications for China's water resources management" *Water Research* 38, 2747-2756

Dinesh, N., and Dandy, G. C. (2003). "A Decision Support System for Municipal Wastewater Reclamation & Reuse." *Water Supply*, 3(3), 1-8.

DWAF, Department of Water Affairs and Forestry (2004). "National water resource strategy" Pretoria, South Africa

DWAF, Department of Water Affairs and Forestry (1998). "National water Act 36" Pretoria, South Africa

Economopoulou, M. A. and Economopoulos, A. P. (2003). "Expert system for municipal wastewater management with emphasis on reuse" *Water Science and Technology: Water Supply* 3(4) 79-88

Ellis, K. V. and Tang, S. L. (1990). "Wastewater treatment optimization model for developing world, I model development, *Journal of Environmental Engineering* (117) 501-518

Economic and Social Commission for Western Asia (2003): Waste-water Treatment Technologies: A general review, Publication of United Nation, New York

Ganoulis, J. (2003): "Evaluating alternative strategies for wastewater recycling and reuse in the Mediterranean area" *Water Science and Technology: Water Supply* 3(4) 11-19

Gasso, S., Baldasano, J. M. and Celades, C. (1992). "Plant design and economic for wastewater treatment plant via the CAD/CAE system SIMTAR, *Water Science Technology*, 25(4/5), 411-412

Hidalgo, D., Irsuta, R, Martinez, L., Fatta, D. and Papadopoulos, A. (2007). "Development of a multi-function software decision support tool for the promotion of the safe reuse of treated urban wastewater", *Desalination,* (215) 90-103

Joksimovic, D. (2006). "Decision support system for planning of integrated water reuse project" PhD Thesis, University of Exeter, United Kingdom.

Joksimovic, D., Kubik, J., Hlavinec, P., Savic, D. and Walters, G. (2006). "Development of an integrated simulation model for treatment and distribution of reclaimed water", *Desalination,* (118) 9-20

Joksimovic, D., Savic, D., Walters, G., Bixio, D., Katsoufidou, K. and Yiantsios S. G. (2008). "Development and validation of system design principles for water reuse systems", *Desalination,* (218) 142-153

Krovvidy, S., Wee, W. G., Suidan, M., Summers, R. S., Coleman, J. J. and Rossman, L. (1994). "Intelligent sequence planning for wastewater treatment systems". *IEEE Expert: Intelligence System and their Application* 9 (6) 15-20

Kubik, J. and Hlavinek, P. (2005). "Evaluation and selection of unit processes for treatment trains using water reuse simulation model", in *Integrated Concepts in Water Recycling*, Khan, S. J., Schafer, A. I. and Muston, M. H. (Eds) ISBN 1741280826.

Lazarova, V., Hills, S., and Birks, R. (2003). "Using recycled water for non-potable, urban uses: a review with particular reference to toilet flushing" *Water Science and Technology: Water Supply* 3(4) 69-77

Loetscher, T., and Keller, J. (2002). "A decision support system for selecting sanitation systems in developing countries." *Socio-Economic Planning Sciences*, 36(4), 267-290.

Metcalf, and Eddy, I. (2003). "Wastewater engineering treatment and reuse" 4th edition McGraw-Hill, New York.

National State of Environmental Report on freshwater systems and resources http://www.environment.gov.za/soer/nsoer/issues/water/pressure.htm#climate accessed 11 November 2007

Okun, D. A. (2002). "Water reuse introduces the need to integrate both water supply and wastewater management at local regulatory levels." *Water Science & Technology.* 46 *(6 - 7)* 273 – 280

Tang, S. L. and Ellis, K. V. (1994): "Wastewater treatment optimization model for developing world, II model testing, *Journal of Environmental Engineering Vol. (120)* 610-624

USEPA. (2004). "Guidelines for Water Reuse." EPA/625/R-04/108, United States Environmental Protection Agency

Wee, G. W. and Krovvidy, S. (1990). A knowledge based planning approach for wastewater treatment system" *Proceedings of the 3rd international conference on Industrial and engineering applications of artificial intelligence and expert systems Charleston, South Carolina, United States*, 991-998, ISBN:0-89791-372-8

Yang, H., and Abbaspour, K. C. (2007). "Analysis of wastewater reuse potential in Beijing" *Desalination (*212) 238-250

Appendix

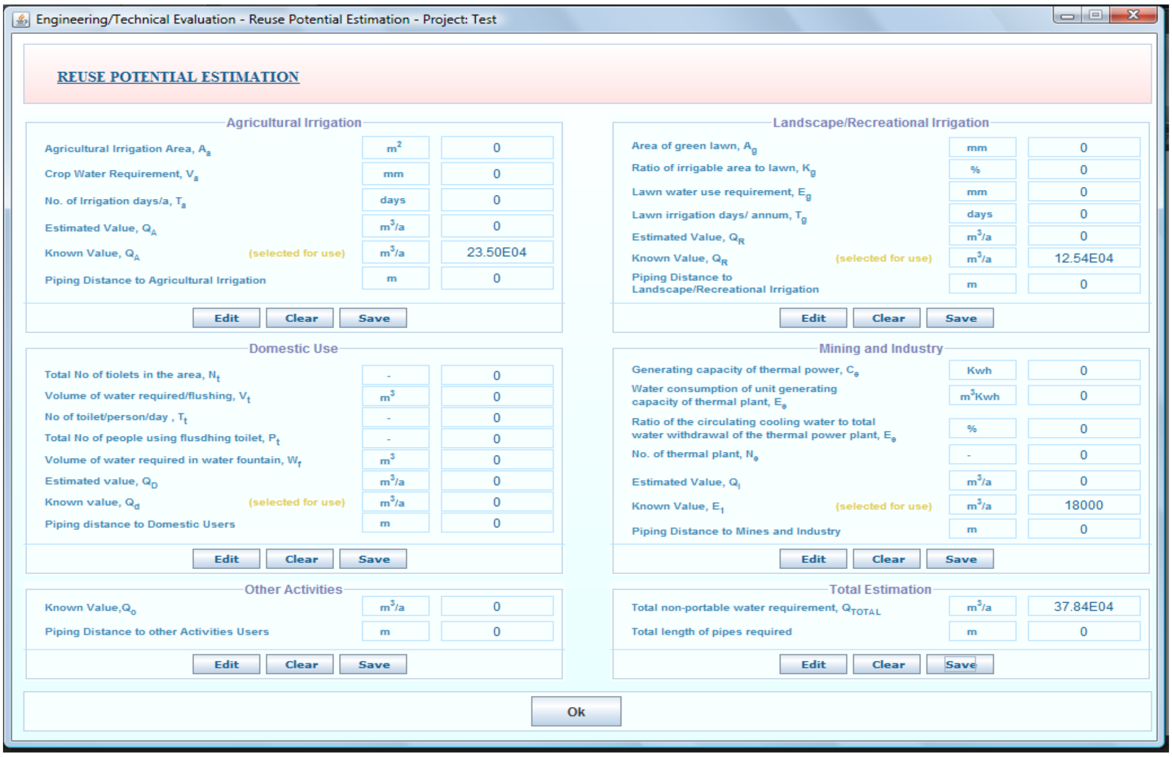
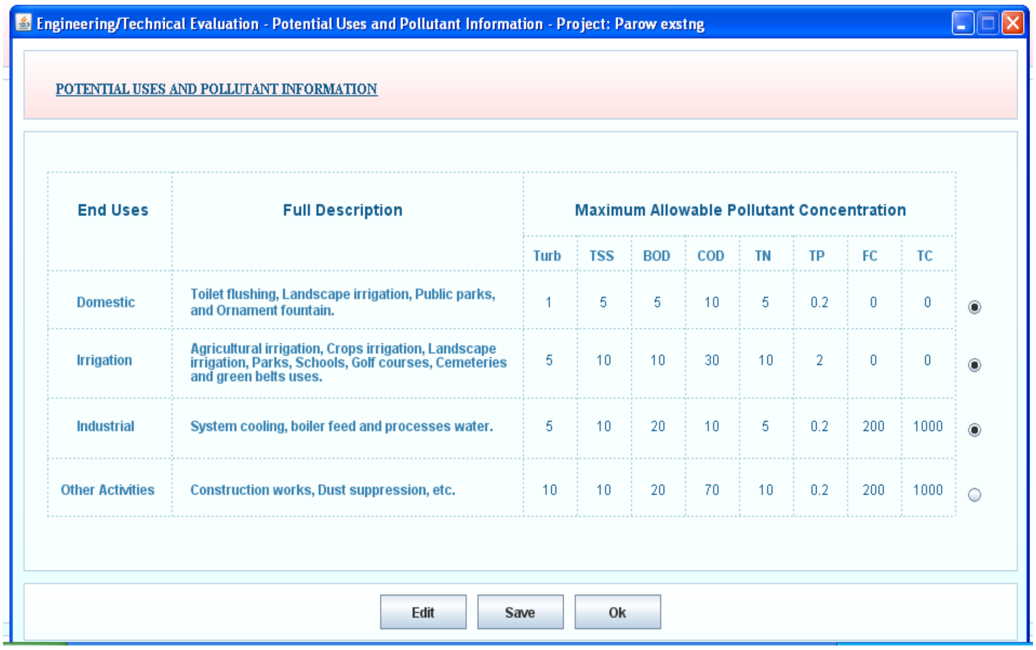


Fig A1: Reuse potential estimate interface



End Uses	Full Description	Maximum Allowable Pollutant Concentration							
		Turb	TSS	BOD	COD	TN	TP	FC	TC
Domestic	Toilet flushing, Landscape irrigation, Public parks, and Ornament fountain.	1	5	5	10	5	0.2	0	0
Irrigation	Agricultural irrigation, Crops irrigation, Landscape irrigation, Parks, Schools, Golf courses, Cemeteries and green belts uses.	5	10	10	30	10	2	0	0
Industrial	System cooling, boiler feed and processes water.	5	10	20	10	5	0.2	200	1000
Other Activities	Construction works, Dust suppression, etc.	10	10	20	70	10	0.2	200	1000

Fig A3: Potential uses and maximum allowable water quality parameters

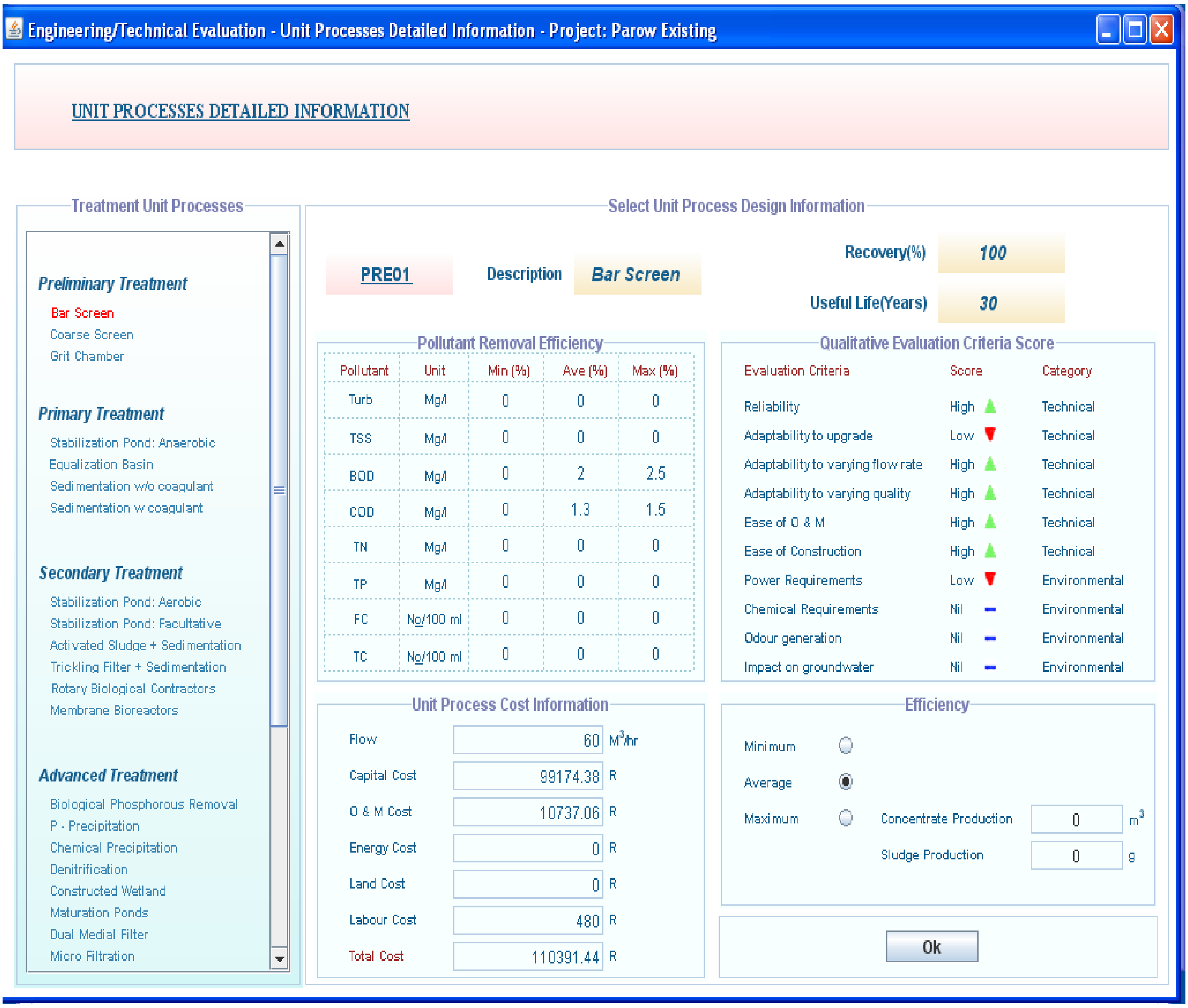
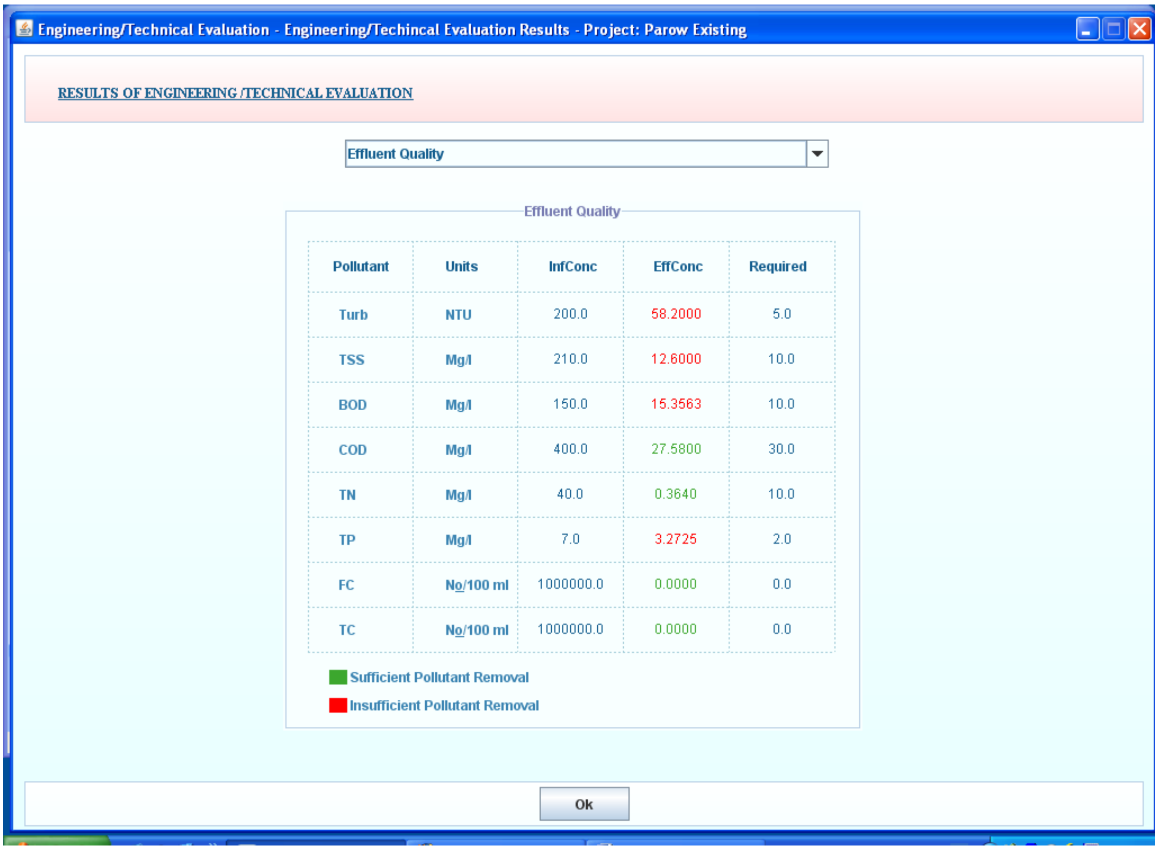
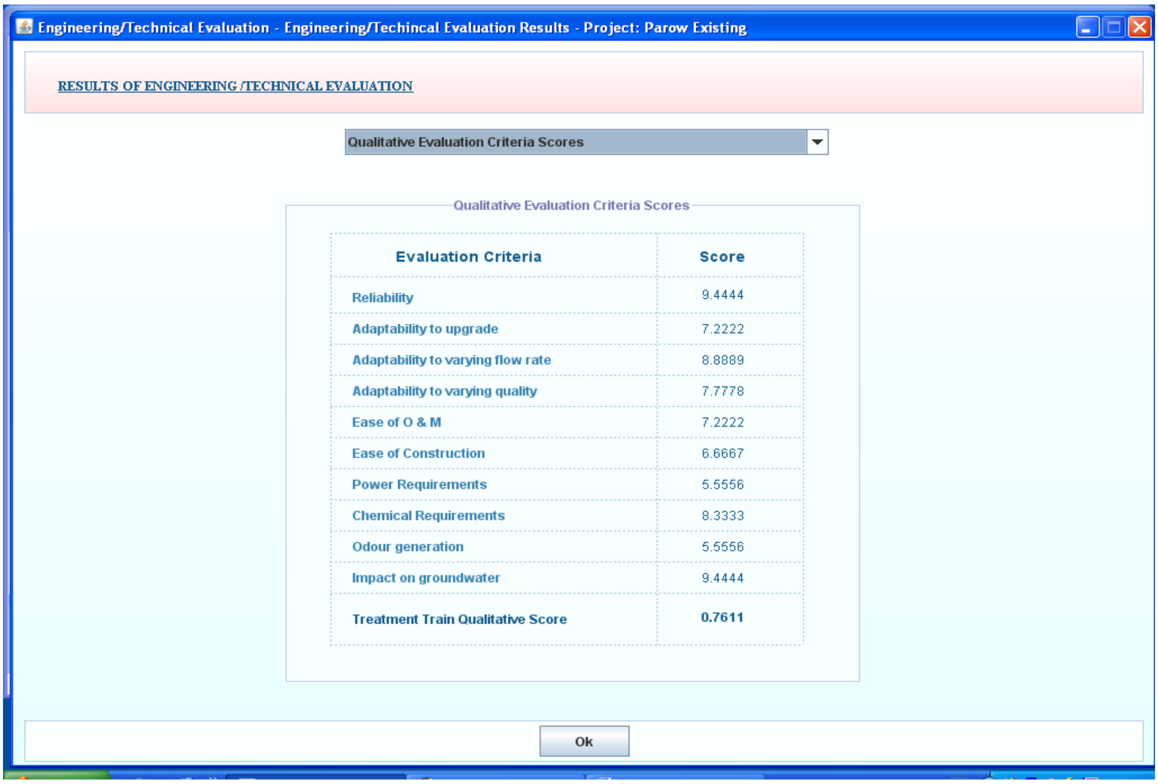


Fig A3: Unit processes detail information – Bar screen



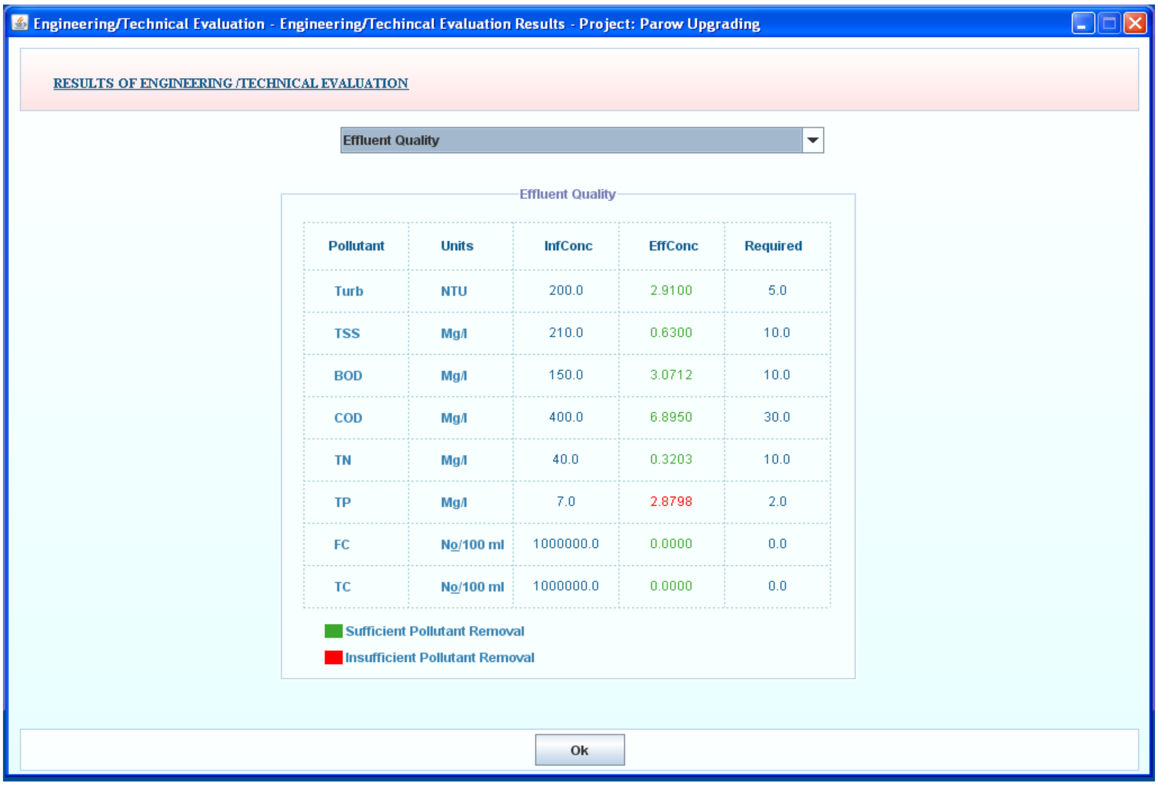
Pollutant	Units	InfConc	EffConc	Required
Turb	NTU	200.0	58.2000	5.0
TSS	Mg/l	210.0	12.6000	10.0
BOD	Mg/l	150.0	15.3563	10.0
COD	Mg/l	400.0	27.5800	30.0
TN	Mg/l	40.0	0.3640	10.0
TP	Mg/l	7.0	3.2725	2.0
FC	No/100 ml	1000000.0	0.0000	0.0
TC	No/100 ml	1000000.0	0.0000	0.0

Fig A4: Result of the model effluent quality for the existing Parow WWTW



Evaluation Criteria	Score
Reliability	9.4444
Adaptability to upgrade	7.2222
Adaptability to varying flow rate	8.8889
Adaptability to varying quality	7.7778
Ease of O & M	7.2222
Ease of Construction	6.6667
Power Requirements	5.5556
Chemical Requirements	8.3333
Odour generation	5.5556
Impact on groundwater	9.4444
Treatment Train Qualitative Score	0.7611

Fig A5: Result of the model qualitative evaluation for the unit processes of the existing Parow WWTW



Engineering/Technical Evaluation - Engineering/Techincal Evaluation Results - Project: Parow Upgrading

RESULTS OF ENGINEERING /TECHNICAL EVALUATION

Effluent Quality

Effluent Quality

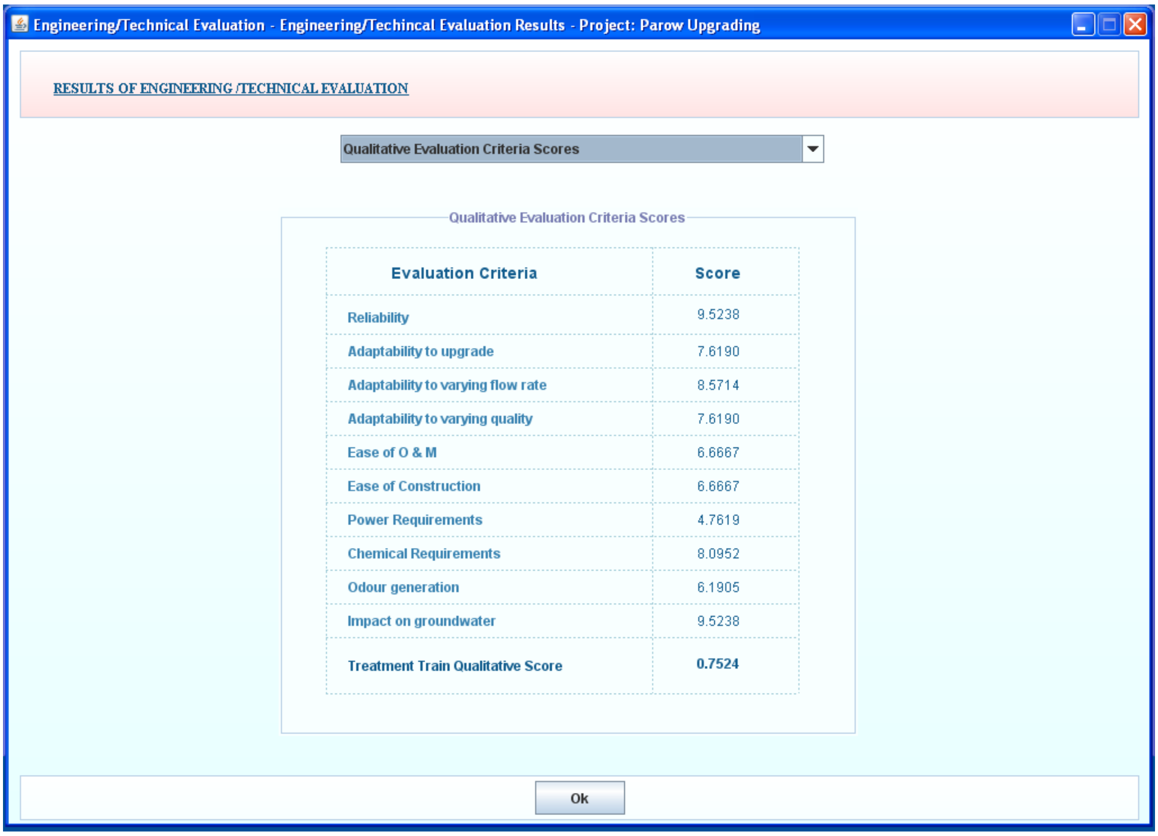
Pollutant	Units	InfConc	EffConc	Required
Turb	NTU	200.0	2.9100	5.0
TSS	Mg/l	210.0	0.6300	10.0
BOD	Mg/l	150.0	3.0712	10.0
COD	Mg/l	400.0	6.8950	30.0
TN	Mg/l	40.0	0.3203	10.0
TP	Mg/l	7.0	2.8798	2.0
FC	No/100 ml	1000000.0	0.0000	0.0
TC	No/100 ml	1000000.0	0.0000	0.0

Sufficient Pollutant Removal

Insufficient Pollutant Removal

Ok

Fig A6: Result of the model effluent quality for the proposed upgrading in Parow WWTW



Engineering/Technical Evaluation - Engineering/Techincal Evaluation Results - Project: Parow Upgrading

RESULTS OF ENGINEERING /TECHNICAL EVALUATION

Qualitative Evaluation Criteria Scores

Qualitative Evaluation Criteria Scores

Evaluation Criteria	Score
Reliability	9.5238
Adaptability to upgrade	7.6190
Adaptability to varying flow rate	8.5714
Adaptability to varying quality	7.6190
Ease of O & M	6.6667
Ease of Construction	6.6667
Power Requirements	4.7619
Chemical Requirements	8.0952
Odour generation	6.1905
Impact on groundwater	9.5238
Treatment Train Qualitative Score	0.7524

Ok

Fig A7: Result of the model qualitative evaluation for the unit processes of the proposed upgrading in Parow WWTW

Social Evaluation - Project: Parow Existing

SOCIAL EVALUATION

Evaluation Criteria	Weight	Score	Weighted Average
Reclaimed water is acceptable to institutional users	10	1	10
Reclaimed water is acceptable to domestic users	1	0	0
Public are willing to eat fruits and vegetables irrigated with recycled water	10	1	10
Public trust the authority to provide safe recycled water	10	1	10
Public are not concerned about the perceived health implications	10	0	0
Public are not concerned about the physical quality of the recycled water	5	1	5
Total	46	4	35
Average Score	0.7609		

Save | Ok

Fig A7: Result of the social qualitative evaluation for the City of Cape Town

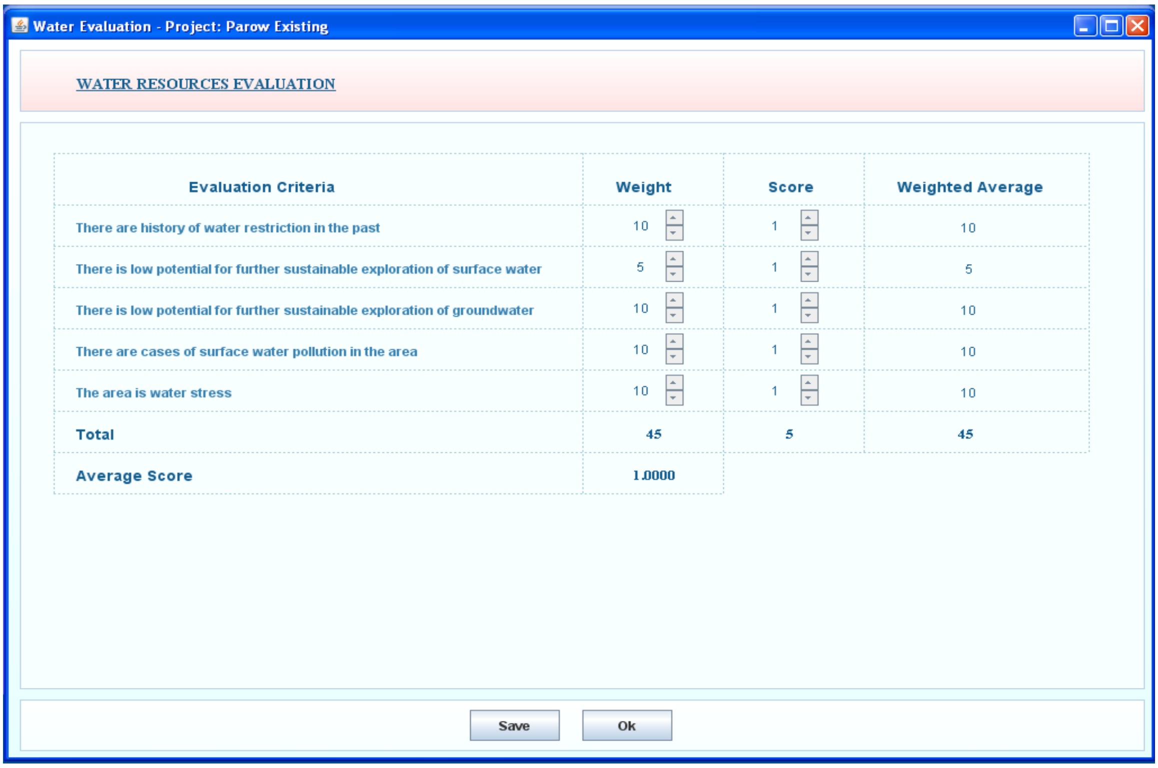
Institutional Evaluation - Project: Parow Existing

INSTITUTIONAL EVALUATION

Evaluation Criteria	Weight	Score	Weighted Average
Survey has been conducted to assess public opinion	10	0	0
All community leaders, pressure groups, etc, have been consulted	10	0	0
Reuse project has been incorporated to form part of IWRM	5	1	5
People are aware of water scarcity	10	1	10
There is National regulations guiding reuse	10	0	0
There is local regulation guiding reuse	5	1	5
There is capacity measure to monitor and enforce the regulations	5	0	0
There are strong communication links between planners and the community	10	0	0
Public are willing to participate in reuse project	10	0	0
Funding is available for the project	10	1	10
Total	85	4	30
Average Score	0.3529		

Save | Ok

Fig A9: Result of the institutional qualitative evaluation for the City of Cape Town



Evaluation Criteria	Weight	Score	Weighted Average
There are history of water restriction in the past	10	1	10
There is low potential for further sustainable exploration of surface water	5	1	5
There is low potential for further sustainable exploration of groundwater	10	1	10
There are cases of surface water pollution in the area	10	1	10
The area is water stress	10	1	10
Total	45	5	45
Average Score	1.0000		

Fig A10: Result of the water resources qualitative evaluation for the City of Cape Town