Development of a Decision Support System for Optimum Selection of Technologies for Wastewater Reclamation and Reuse

by

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Doctor of Philosophy in Engineering

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April 2002

To my parents…

Sowbhagya and Shivarudrappa

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Abstract

Reuse of reclaimed wastewater is perceived as a sustainable option for water resources management in many countries including Australia. The current state-of-the art of reclamation technologies can produce water of any desired quality (including potable quality) and this has been demonstrated in a number of successful reuse schemes. Until recently, designers have used a “rule-of-thumb” approach to select the most appropriate treatment alternative. Such a conventional method of selection has many drawbacks as objective assessment and rational selection of alternatives is difficult due to the increasing number of efficient treatment processes. Hence, there is a need for a systematic and structured approach to assist decision-makers in the selection of treatment alternatives for a given reuse application before exhaustive simulation or pilot studies are conducted.

This study developed a computer-based decision support system named **MOSTWATAR** (which stands for **M**odel for **O**ptimum **S**election of **T**echnologies for **WA**stewater **T**reatment **A**nd **R**euse). MOSTWATAR has an easy-to-use interface linked to a database and a knowledge base. This model is intended to assist planners and decision-makers in the techno-economic assessment of reclamation technologies and aid in the selection of the best five treatment trains for given conditions such as end use, wastewater flow rate and characteristics. This study also investigated the use of an optimisation technique based on genetic algorithms for selection and sequencing of wastewater treatment processes for both new and upgrade of existing treatment plants.

MOSTWATAR was used to generate both new and upgrade treatment options for Victor Harbor wastewater treatment plant in South Australia. It was found that the genetic algorithms were effective in generation & optimisation and the best alternatives generated by this model have been previously overlooked. It can be concluded from this research that MOSTWATAR can be used effectively as a decision aid in the facility-planning stage, to evaluate treatment options for municipal wastewater reclamation and reuse schemes.

Statement of Originality

This thesis contains no material which has been accepted for the award of any other degree or diploma at any university or other tertiary institution and to the best of my knowledge and belief this thesis contains no material previously published or written by another person, except where due reference is made in the thesis text.

I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan.

Signed: Nirmala Dinesh   **Date**: 8th April 2002

Acknowledgments

The author wishes to acknowledge the immense support, guidance and comments of her supervisor Prof. Graeme Dandy, Professor and Head, Dept of Civil & Environmental Engineering of the University of Adelaide.

This research was funded by IPRS (formerly OPRS) and an Adelaide University Scholarship (UAS). The support and guidance provided by the lecturers and staff of the Department of Civil and Environmental Engineering at the University of Adelaide is gratefully acknowledged. Thanks to Dr Stephen Carr and Mr. Paul Carter for their computing support and to Ms. Kay Leverett for assistance with Library searches.

The technical inputs and critical comments from Ian Willshire, Daryl Bentley, Lester Sickerdick, Mark Biebrick, and Grant Lewis of the South Australian Water Corporation (SA Water) are gratefully acknowledged. A special thanks goes to Mr. Mike Stevens for his time patience and support during the development of the model. The author is grateful to Mr. Kevin Read and family for their support and friendship.

The author would like to thank a number of manufacturers (Tema Engineers, USF filters, UVTA, HydroAustralasia), Government agencies/ departments and reuse experts (Prof Asano, Dr John Anderson, Dr. Peter Dillon, Ms. Lyndel Stone) who have shared process information and their reuse experience, without which this research would not have been possible. A freeware (kbmMemTable) developed by Mr Kim Bo Madsen has been used to store data during genetic algorithm runs.

Thanks to Drs Krishnan & family for rendering moral support during the conduct of this research. Also thanks to Dr John Vitkovosky for the useful discussions on GAs and thanks to fellow postgraduates who helped the author reach the goal – Lie Ping Yaun, Rebecca Gravina and Lamia Salhane. Finally, the author is grateful for the encouragement and support of her husband Dinesh Karachur, parents and family.

Chapter 1 Introduction

Wastewater reclamation, reuse and recycling are a common occurrence in nature where upstream communities discharge their partially treated wastewater into rivers, which serve as the water source for downstream communities. In recent years, this natural reclamation and reuse of wastewater has been affected by excessive pollution caused by effluent discharges from industries and communities. On the other hand, many communities in arid and semi-arid regions in the world are facing severe water shortages due to an unequal distribution of rainfall, high evapo-transpiration and increasing demands for water. Furthermore, regulatory agencies are imposing stringent discharge regulations to minimize the impact on the environment and this has lead to an increase in treatment and disposal costs.

Thus increasing water demand, growing concern about environmental pollution and stricter regulations has required water managers to consider efficient management of water resources such as wastewater reuse, recycling & conservation and discharge reduction strategies. Among these options, wastewater reuse is being considered as a sustainable alternative as it minimizes the impact on water bodies by conserving or supplementing the available water sources in addition to reducing the pollution of water bodies. Furthermore, it can defer the need to establish new reservoirs and water treatment plants thus reducing associated costs. In addition to the above, reuse in agricultural irrigation can save fertilizer costs as nitrogen and phosphorous present in the wastewater act as natural fertilizers (Dean and Lund, 1981; Asano, 1998b; USEPA, 1992, http://www.siwi.org).

For the above-mentioned reasons, engineered reuse schemes are becoming an integral part of present day water resources management. Currently, there are a number of technologies available to treat wastewater to any required level. However, an increasing number of novel technologies and often-conflicting objectives such as minimising the cost and impact on the environment and maximising performance has made the selection of appropriate technology a complex task for planners and wastewater managers. The current "rule of thumb" technique is inadequate as objective assessment of alternatives is difficult and many options may be overlooked. This illustrates the need for a systematic approach using decision aids or models and aid in selection of most appropriate treatment train(s) for a given reuse(s).

Previous research has been focused on the evaluation and selection of appropriate treatment trains from the treatment alternatives suggested by the user. Until now there has been limited attempts to optimise the selection based on the type of reuse, reuse criteria, location and given unit processes. Hence, the objective of this study was to first develop a decision aid for selection of appropriate treatment trains given the reuse type, criteria and other local conditions such as climate and depth of ground water table. Secondly, this study examined the application of genetic algorithms, an optimisation technique based on Darwin's theory of natural selection, for the optimisation of treatment train alternatives.

In this chapter, firstly the importance of wastewater reclamation and reuse from an Australian perspective is presented. Secondly, the research problem and the need for decision support systems (DSS) to optimise treatment selection are discussed. Thirdly, objectives and scope of the research and terms used are defined. An outline of the methodology adopted to address each research question is highlighted. Finally, the layout and content of the thesis is presented.

1.1 Wastewater Reuse - An Australian Perspective

Australia is the driest inhabited continent on earth and its water resources are stretched to the limit as two thirds of the population lives in the five largest cities (Harris, 2000). Once known for its natural diversity, Australia is now facing the extinction of species due to pollution and water scarcity. Major rivers basins, which are serving both urban and agricultural sectors, are affected by salinity. To meet the urban water demand, large quantities of water is imported from surrounding catchments and surface water sources (Mitchell, 1996) and the availability of water per capita has fallen by more than 50 % in the last three decades (Williams, 1997).

Despite this, Australians used more than 1 million litres of fresh water per person during 1996-97 (ABS, 2000) and rank second in the world in per capita water usage next to North Americans (Crosscurrent, 2000a). The current water consumption pattern in most Australian states is unsustainable and calls for effective water resources management to sustain economic growth (Thomas *et al.*, 1999, cited in Dillon, 2000). Until the mid 1980's water was a 'one through' use product in Australia and reuse was not common in spite of (a) the first reuse scheme as early as 1898 in Werribee; Victoria, and (b) the enormous potential for reuse in the agricultural sector (which accounts for 70 % of water use) and the domestic sector (which accounts for 60 % of the total urban water use, Webster, 1987).

Apart from effective water management measures such as rainwater harvesting and water conservation, the reuse of wastewater has received some attention in recent years. In the last couple of years there has been steady increase of reuse in most Australian States mainly due to (1) public awareness of the importance of water conservation and the pollution of rivers, coastal and estuarine waters and (2) an integrated approach to encourage reuse through research and demonstration projects.

Reuse is now being emphasized in many new water resources management schemes in Australia as the current focus is on now on sustainability and effective use of reclaimed water (Hartley, 1998). This has resulted in radical changes in the design approach of wastewater collection, treatment and disposal. Most of the new wastewater treatment plants are being designed to produce effluent suitable for local non-potable reuse applications. While many of the existing treatment plants, which consist mainly of lagoons, activated sludge process or trickling filter and sludge systems are being upgraded to include tertiary treatment facilities, to meet stringent standards (Biebrick, 2000).

Currently about 11 % of reclaimed water is being reused (Dillon, 2000) and there are about 52 reuse schemes operating throughout Australia (pp 48, Civil Engineers Australia, Oct 1999). Some of the well-known reuse schemes include Rouse Hill development and Taronga Zoo in Sydney; Virginia pipeline scheme in Adelaide and Eraring power station near Newcastle (Williams, 1997,1998) and more recently Homebush Bay in Olympic village at Sydney.

1.2 Research Problem

The planning of any wastewater reclamation and reuse scheme involves a feasibility investigation of treatment alternatives and reuse options. Wastewater reclamation and reuse schemes are capital intensive. Hence, it requires a systematic methodology to study various aspects of water reuse such as water quality and quantity, and to help select the most preferred treatment alternative. The current research focuses on the feasibility investigation of wastewater treatment alternatives for given reuse(s) and guidelines. The following questions are addressed in this research.

- What are the criteria to be considered for selection of appropriate process for a given reuse at a given location?
- How to synthesize acceptable and feasible treatment trains?
- How to optimise the selection of treatment trains appropriate for reuse?
- How to incorporate the selection and optimisation of the processes into a user-friendly decision support system to aid planners and engineers?
- What are the available upgrade options for an existing treatment plant given reuse application(s)?

The implementation of any reuse scheme requires the selection and evaluation of appropriate process from a large number of highly efficient processes. The selection of type of process is dictated by the required effluent quality, which is in turn based on the intended reuse application such as landscape irrigation, toilet flushing and so on. However, the selection and sequencing of the wastewater treatment process is made difficult as different combinations of treatment processes can achieve more or less the same effluent quality at various costs.

The selection of an appropriate treatment train is no longer based on a single objective of minimum cost but multiple objectives such as maximizing performance and reliability, minimizing sludge production and so on. This indicates that cost benefit ratio alone cannot help the decision-maker in selecting the most appropriate technology. Added to this development of several innovative and novel technologies has made the selection process even more difficult.

Consequently the selection of the most appropriate combination of wastewater reclamation process in terms of efficiency, cost, and other factors such as reliability for a given situation is a complex task for planners or decision-makers. One of the major factors influencing the success of wastewater reclamation and reuse projects is the selection of an appropriate treatment technology. The use of inappropriate technologies has lead to failure of reuse schemes (Tchobanoglous, 1996; Finney and Gearheart, 1998). Thus careful evaluation and selection of treatment alternatives is necessary to (1) select the most appropriate technology for a given situation, (2) instil public confidence in the appropriateness and reliability of the technology, and to (3) ensure selection of the least expensive alternative to achieve the required reuse criteria (Chen and Beck, 1997; Finney and Gearheart, 1998).

Until today, the selection of reclamation and reuse technologies for pre-feasibility studies has been based on the experience of wastewater experts using heuristic techniques or a "rule of thumb" approach. There are many drawbacks of this approach including:

- a limited number of alternatives are considered as it is time consuming to evaluate a large number of options and hence the best alternative may be overlooked.
- the selection of processes is highly dependent on the expert's knowledge; and
- more promising configurations may be overlooked as donor agencies have vested interest in promoting a particular technology (Finney & Gearheart, 1998)

Thus it is difficult to assess alternatives objectively using the conventional "rule of thumb" approach. To overcome these limitations there is need for scientific and objective assessment tools (i.e. models) to aid planners in the selection of appropriate treatment technologies. Many researchers have worked on the development of mathematical models, which can provide structured approach to the generation, evaluation, and optimisation of reclamation alternatives and assist in making informed decisions. In the past, researchers have developed several techniques to generate feasible alternatives from a limited number of unit processes.

Since many non-quantifiable criteria such as reliability and adaptability are now being considered, reuse is no longer viewed as a single objective problem of selecting the least cost alternative. A number of criteria such as cost, performance and land requirement have been used to evaluate and compare alternatives. However, very little work has been done to integrate these techniques and mathematical models in to a decision support system, which can facilitate rational decisions and provide an effective framework for rapid testing and evaluation of reclamation technologies appropriate for a given reuse application(s).

Decision support systems (DSS) incorporate the experience of designers and provide reasoning support through database and mathematical optimisation (Newell *et al.*, 1998). Although some argue that such DSS require many simplifications and assumptions for a complex problem such as process selection, these models are meant to assist decision makers and are not intended to replace human judgment. There are many advantages of using DSS for treatment train selection. Some of these include: (1) DSS can be used to analyse "what if" scenarios by changing parameters such as removal efficiencies, (2) they are more structured and systematic than the traditional "rule of thumb" approach, and (3) consistent and objective assessment of a large number of alternatives can be carried out in a short interval of time.

Extensive literature search and discussions with wastewater reclamation experts has indicated that there is only one model (named WAWTTAR) currently in use to perform such process selections based on the desired end use and other local conditions. This model developed by Finney and Gearheart (1998) is primarily aimed at selecting appropriate water and wastewater technologies in developing countries and rural areas. It has a number of limitations. In particular: (a) it requires the user to specify the treatment trains to be considered which means that the number and type of alternatives are limited by the user's knowledge, and (b) it also does not consider upgrade options for existing plants which is an important aspect of present day wastewater resource management in Australia.

1.3 Research Objectives

As discussed in the previous section, there is a need for a screening tool, which provides an effective methodology to objectively assess a large number of treatment trains (TTs) capable of meeting desired reuse criteria. Therefore the principal objective of this study was to develop a decision support system (DSS) to assist facility planners and decision makers in evaluation a wide range of alternative treatment trains and identify the best and or near-optimal treatment train based on criteria such performance, cost and environmental impact for given reuse application (s) in a community. The model developed called MOSTWATAR, which stands for Model for the Optimum Selection of Technologies for WAstewater Treatment And Reuse.

In summary the fundamental objectives of this research are to:

(1) develop a database of unit process, their design criteria and cost estimates for South Australia.

(2) develop assessment criteria to evaluate the appropriateness of reclamation technologies

(3) incorporate these criteria to develop a user-friendly computer-based decision support system for evaluation and selection of the most appropriate treatment train for municipal wastewater reclamation and reuse

(4) investigate the use of genetic algorithms (an optimisation technique) for generation and sequencing of unit processes for both new and upgrade of existing plants, and to

(5) assist facility planners in rapidly testing and evaluating different treatment alternatives within the framework of prefeasibility studies.

This study is important for the following reasons. Firstly, this model provides technical assistance and serves as a decision aid for local planning agencies, state-planning bodies and planning and engineering firms involved in the assessment of technologies for wastewater reclamation and reuse. Secondly, it provides a comprehensive database of different reuse criteria applicable in Australian states and process selection criteria. Thirdly, a systematic methodology developed to evaluate reclamation technologies will eliminate the problem of overlooking potential processes that can occur in less systematic approach. Finally, the contribution of this research to the methodology for the selection of appropriate wastewater reclamation and reuse technologies is going to be significant, as very few models have been developed so far to assist decision-makers in this area.

1.4 Definitions and Scope

In the context of this research the term *wastewater* refers to municipal wastewater, which mainly comprises of wastewater from domestic households. The term *reclamation* has been used to describe treatment of wastewater and is synonymous with the word *treatment* while the term *reuse* refers to the beneficial use of reclaimed wastewater. A single unit or group of parallel or series of units of the same type, capable of removing one or more of the pollutants is referred to as a *unit process* (UP) or *treatment unit* or *treatment technology*. (examples of unit processes are a bar screen, grit chamber, and primary clarifiers).

A logical sequence of such unit processes put together where the effluent of one process becomes the influent of the next process is referred to as a *treatment train (TT)*. The following example represents a typical TT: bar screen + grit chamber +primary sedimentation +activated sludge process + chlorination. The terms *treatment alternatives* or *treatment options* or *treatment trains* (TTs) are used interchangeably in this thesis. The term synthesis has been used to refer to generation of such TTs. The individuals responsible for decision making and carrying out feasibility analysis are referred to as *decision makers, facility planners* or *wastewater managers*. The term 'user' is used throughout this thesis to refer to these individuals.

The following simplifications and assumptions have been used.

- This research focuses on small-scale, centralized municipal wastewater management as most of the treatment facilities in Australia, have been centralized facilities with an average treatment plant size of 20,000 equivalent population (EP) (Hartley, 1998). This model looks at plant sizes ranging from 5,000 to 50,000 EP.
- The model developed does not integrate regional water resources as integrative models can be quite enormous and jeopardize the depth of the research. However this model could be modified into a regional model to consider total water system in a region.
- Only municipal wastewater was considered as industrial effluents vary widely in type, flow and characteristics. The inclusion of different industries would mean a specific study of the flow and characteristics and is therefore outside the scope of this research.
- MOSTWATAR is intended for preliminary feasibility investigation of different treatment alternatives and is intended as a planning tool for facility planners and decision makers.

- A preliminary cost estimate has been developed for South Australian conditions. Reclaimed water storage, transportation and distribution costs are not included in the project cost as it is common to all the treatment alternatives assessed.
- Steady state performance data has been used for the performance evaluation of different unit processes.
- Since it is not possible neither is the objective of this research to collect data on all the unit processes applicable in Australia, unit processes representative of each treatment category have been included in the database. The database has both wastewater treatment and sludge handling processes.
- This model is based on non-potable reuse applications such as irrigation; industrial reuse, ground water recharge and various urban uses, as regulatory authorities in Australia currently do not approve potable reuse.

1.5 Methodology

This section briefly explains the methodology and techniques that has been used to address the questions stated in the research problem.

1. What are the suitable processes and reuse guidelines applicable to Australian States?

A questionnaire was sent out to leading manufacturers and consultants to collect information on the different unit processes commonly used for reclamation schemes in Australia. A review of literature and interviews with the local water industry was also carried out to select representative processes. A numerical database was set up to include performance, costs and qualitative criteria for different unit processes commonly used in Australia. Simple mathematical models for each unit process with design strategies and cost equations were developed using data from design handbooks, manuals, quotations, vendor information, published catalogues and in conjunction with the SA Water Corporation, a local water authority.

The reuse guidelines applicable in NSW, QLD, TAS, SA, VIC and ACT are included. Further, the national guideline for use of reclaimed water is also included. Since there was significant difference between the categories of reuse and associated guidelines it was difficult to compare the guidelines when more than one type of reuse was selected Hence, the non-potable applications are all categorized into 33 types of reuse.

2. *What are the criteria to be considered for selection of appropriate process for a given reuse at a given location?*

Many researchers have used qualitative and quantitative criteria to compare alternatives but there has been no structured approach. Thus a framework for evaluation of alternative wastewater systems was developed using 13 criteria. These selection criteria were selected using the contributions from local consultants, wastewater engineers, and water reclamation experts and the literature. In this model, a qualitative scale of evaluation for environmental criteria such as odour, groundwater impact has been developed.

3. *How to synthesize acceptable and feasible treatment trains?*

Alternative treatment trains can be generated (or synthesized) either by the user or by the model. The formation of alternative TTs by the user as in WAWTTAR will have limitations. On the other hand, rule- based generation of treatment trains by the model can encourage more favourable treatment trains to be evaluated. MOSTWATAR will include both these features to allow the user to compare their selection with the model output.

In the past, researchers have used various techniques such as efficient random generation, generation & screening and heuristics to synthesize acceptable TTs and have acknowledged the fact that it is a very challenging task due to large search space. This model utilizes a random search technique coupled with heuristic technique to generate acceptable configurations of TTs. The selected unit processes will be combined to generate treatment train alternatives based on the defined rules as rule-based selection encourages more favourable treatment trains to be formed and evaluated.

The alternate treatment trains formed will be first evaluated based on technical criteria (i.e. the ability to achieve the required performance or reuse requirement) to eliminate infeasible treatment trains. The parameters of interest such as BOD, SS and Faecal coliforms are tracked in each of the unit processes in the alternate treatment trains. The treatment trains not capable of achieving the required effluent quality will be discarded.

Further, feasible treatment trains that have the ability to achieve the reuse criteria will be subjected to comparative evaluation with respect to technical, economic and socio-environmental criteria.

4. *How to optimise selection of treatment trains appropriate for reuse?*

A number of optimisation techniques including linear programming, heuristics, dynamic and integer programming have been used in the past to optimise the treatment train selection for a conventional wastewater treatment plant. Limitations of these techniques have been reported and are discussed in chapter 3. This model examines an application of optimisation technique called genetic algorithms based on Darwin's theory of evolution to assist the user in selection of five near-optimal solutions for given conditions.

5. *How to incorporate these selection & optimisation of process in to a user-friendly decision support system to aid planners, engineers?*

The MOSTWATAR model includes evaluation and selection of optimum treatment train for reclamation and reuse at centralised wastewater treatment facilities. This model development involved integration of important stages of decision support namely, database management, optimisation of treatment selection and model validation. There are about 8 different modules, which are integrated in to a user-friendly tool for interactive decision support using Borland Delphi™ 4.0. All these modules have been written in object PASCAL language.

6. *What are the available upgrade options for an existing treatment plant given a reuse?*

Evaluation of upgrade options requires a detail study of the existing plant facilities. The upgrade of existing plants is carried out for many different reasons. But this model assumes that the existing facility is in full working condition and requires additional unit processes to meet the required quality. The user will be able to input the site-specific aspects such as existing processes in addition to population, wastewater quality and quantity generated, land cost, local environmental/climatic and hydro geological conditions in the community. The costs incurred in upgrading the existing treatment plant will be evaluated by isolating the unit processes that have been added to the existing system.

1.6 Thesis Outline

This thesis is organised in to 8 chapters, They are: (1) Introduction, (2) Wastewater reclamation and reuse, (3) Review of reuse models and techniques, (4) Development of MOSTWATAR, (5) Generation and Optimization of TTs using Genetic Algorithms, (6) Salient features of the MOSTWATAR, (7) Case study: Victor Harbor WWTP, and finally (8) Conclusions and Recommendations.

Chapter 2 introduces the concept and classification of wastewater reuse. In this chapter, current reuse practices in America, Asia, Australia and Middle Eastern countries are discussed. An overview of reclamation technologies from Australian perspective is presented. The various issues of concern in terms of environment and public health are discussed. The guidelines applicable in different states of Australia are presented. Finally, a discussion of need for planning stage models in reuse schemes is presented.

Chapter 3 presents a review of current wastewater reuse models and techniques used for evaluation and selection of TTs. Firstly the history of wastewater reuse models is presented. Secondly, models on TT synthesis, and selection of appropriate TT are discussed. Current optimisation models and techniques are discussed. Finally current decision support systems (DSS) and their limitations are presented.

In Chapter 4, the methodology used to develop MOSTWATAR is described. This includes an outline of methodology for development of the database, knowledge base and user interface. The database structure is explained and the reclamation technologies, design criteria, performance and cost of these technologies are presented. Further, the evaluation and selection criteria used in this thesis are described. Different indices used in the evaluation of treatment processes are also described in this chapter.

Chapter 5 introduces the optimisation theory used in the process selection based on genetic algorithms (GA). In this chapter rationale for the use of GAs to optimise the treatment train selection is presented. The formulation of the objective function and the design variables, penalty costs and GA operators used in the model are described.

Chapter 6 focuses on the salient features of the MOSTWATAR model. In this chapter, system requirements to run the software are presented. It includes a description of the different modules and the graphical user interface developed for this model. The different modules such as TT formation, criteria evaluation, performance evaluation and optimisation module are described. The user input requirements and default values used are explained in this chapter.

In Chapter 7, the profile of the case study area namely Victor Harbor in South Australia, is presented. Victor Harbor was selected to validate this model for the selection of both new and upgrade options of an existing wastewater treatment plant. A general description of the study area, reuse applications & reuse criteria selected and the treatment alternatives generated by MOSTWATAR are presented in this chapter. Further, the results and discussions based on the case study area are also presented. Finally, summary and conclusions from this research are presented in Chapter 8. This chapter also presents recommendations for future extensions of the model.

1.7 Conclusions

Many communities worldwide cannot afford to have "once through" water use systems any more because of increasing water demand, growing concern about environmental pollution and stricter regulations. Over the last few years, an increased interest in sustainable management of water resources has led to wastewater reuse in many countries around the world including Australia. New wastewater treatment plants are being designed with reclamation and reuse facilities as an integral feature while existing plants are being upgraded to meet the reclaimed water quality criteria for various reuse applications.

There are a number of treatment technologies available to meet any reuse criteria and this has made the selection process more difficult for facility planners and decision-makers. Present models and methodologies to select appropriate reclamation technologies are inadequate. The only model developed for this purpose is WAWTTAR and it has a number of limitations. In particular (a) it is intended primarily for developing countries and (b) it requires the user to specify the treatment trains to be considered.

The need for decision support systems to evaluate and optimise treatment alternatives for different reuse conditions in Australia has been established. The MOSTWATAR was programmed to evaluate and select best alternatives from a wide range of reclamation technologies applicable to reuse schemes in Australia. In this research, an optimisation technique called Genetic Algorithms has been applied for the first time to wastewater treatment optimisation.

Further this model has a database of (1) performance, cost and qualitative scale for comparing unit processes and (2) reuse guidelines applicable in different states of Australia has been developed. The knowledge base consists of rules for (1) screening unacceptable TT, (2) design and allowable influent quality. This model is focused on evaluation and optimisation of TT alternatives for municipal wastewater reclamation and reuse. It is perceived that this model will assist planners in technical and economic evaluation of treatment technologies in a scientific and objective manner compared to the existing "rule of thumb" techniques. The economic and environmental benefits of using this model are likely to be significant.

Chapter 2 Wastewater Reclamation and Reuse

2.1 Introduction

Wastewater reclamation and reuse refers to the treatment or reclamation of wastewater to make it suitable for beneficial purposes such as irrigation or recreational use (Asano *et al.*, 1992). In the early 1900's wastewater reclamation and reuse (henceforth referred to as reuse) was driven by necessity for additional sources of water while in the late 1950's, reuse was considered in the interest of protecting the environment. On the contrary, reuse came to be accepted as a sustainable approach in the late 1980's. Since then reuse is becoming an integral part of present day water resources management in many countries including USA, Middle East, Japan, Namibia and Australia (Asano, 1998b; Christen, 1998; Shuval, 1998, Hartley, 1998; Fordham *et al.*, 1981;Williams, 1997 & 98).

The research on wastewater reuse has been quite diversified and includes contributions from water and wastewater treatment experts, health professionals, economists, psychologists and modeling experts. In spite of the interdisciplinary approach, planning of reuse schemes is still a complex task, as various issues such as reclaimed water demand, regulations, selection of appropriate treatment and above all public acceptance require careful consideration. The purpose of this chapter is to review how some of these issues have been addressed in the past and the importance of planning stage models. While different models developed for planning reuse schemes have been reviewed in the next chapter.

This chapter begins with a brief note on wastewater reclamation processes and explains the importance of tertiary treatment processes in reuse schemes. The factors affecting their selection are discussed in Chapter 3, while reclamation processes currently in use in Australia is presented in Section 2.4.3. The treated wastewater can be reused in many different ways. The background information on different reuse applications and reuse schemes in leading countries including Australia is presented next. Since the current research is focussed on evaluation of reclamation processes in South Australia, an insight in to current South Australian reuse initiatives is presented. Next, reuse guidelines applicable in different countries are reviewed while a detailed discussion of the Australian State guidelines is presented in Chapter 4. The fundamental issues of reuse such as technical, societal, economic and legal issues are discussed to present a holistic view of the problem. The importance of planning reuse schemes and, in particular feasibility study of treatment alternatives and the role of planning models to assist managers in their decisions are discussed in this chapter. Finally a summary and conclusions of this review are presented.

2.2 Wastewater Reclamation Processes

Wastewater reclamation processes refer to processes in which contaminants such as biochemical oxygen demand (BOD), suspended solids (SS); Faecal coliforms (FC) and nutrients such as nitrogen (N) and phosphorous (P) are removed by biological, chemical and physical action. These processes are currently grouped in to primary, secondary and tertiary treatment processes as shown in Table 2.1.

Table 2.1 Types of Wastewater Reclamation Processes

Type of Treatment Process	Major Pollutants Removed	Method of Removal	Commonly Used Unit Processes
Primary	Floating, settleable solids	Physico-chemical	Screens, primary clarifiers
Secondary	Suspended and dissolved solids	Biological and chemical	Activated sludge process (ASP), trickling filter (TF), waste stabilization pond, sequencing batch reactor (SBR)
Tertiary	N, P, SS, DS, BOD, refractory organics, heavy metals and pathogens	Physico-chemical, biological	Filtration, disinfection, flocculation and sedimentation

(Source: Metcalf and Eddy, 1991)

The discussion in this section will be based on these three types of treatment processes, although the clear distinction between these groups of processes is fast disappearing due to introduction of package plants (which combine two or more type of the treatment processes). Further since most environmental protection agencies have strict regulations for handling and disposal of sludge, one or more of the sludge treatment processes shown in Table 2.2 are used. A detail account of different treatment processes their design and, performance characteristics can be obtained from the following references (Metcalf and Eddy, 1979 & 1991; WEF Manual of Practice No.8, 1998; USEPA, 1992).

Table 2.2 Types of Sludge Treatment Processes

Type of Treatment Process	Method of Treatment	Commonly Used Unit Processes
Sludge thickeners	Physical, chemical	Gravity thickener,
Sludge stabilization	Aerobic, anaerobic	High rate two stage anaerobic digester, aerobic digester,
Sludge drying	Mechanical or physical	Belt filter press, sludge drying beds
Sludge disposal	Filling or spreading	Land filling, land spreading (bio-utilisation)

(Source: Metcalf and Eddy, 1991)

A conventional (also referred to as typical) wastewater reclamation plant consists of primary, secondary and sludge treatment processes as shown in Figure 2.1.

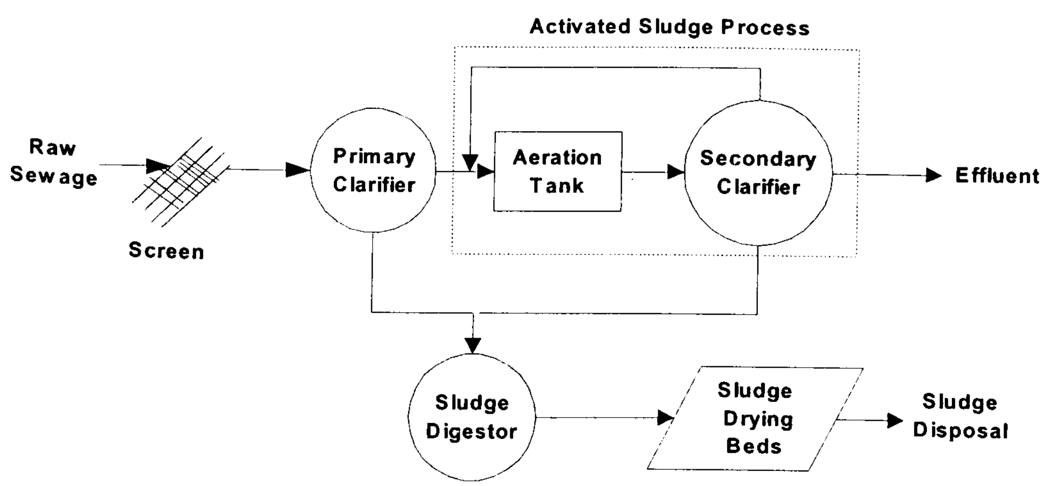


Figure 2.1 Conventional Wastewater Treatment Plant

The effluent characteristics from a conventional plant vary depending on the influent concentration of pollutants as shown in Table 2.3. This table also shows that the pathogens and dissolved organics remain in secondary treated wastewater at levels higher than most of the upper and lower limits of the reuse goal posing potential risk to human health. This if further discussed by Olivieri *et al*, (1997), Hamilton, (1996) and Yates & Gerba, (1998). Due to this potential health risk, primary treatment is seldom approved for reuse applications except for applications where there is no human contact like tree lot irrigation.

Table 2.3 Comparison of Wastewater Characteristics

Parameter	Typical range in raw sewage	Approximate range in secondary treated wastewater	Treatment goal for reclaimed wastewater reuse*
BOD, mg/L	110-440	10-30	1-20
Turbidity, NTU	--	1-30	0.1-10
Nitrogen, mg/L	20-85	10-30	1-30
Phosphorus, mg/L	4 -15	1-3	0.5-2
FC, No/100mL	10^6-10^9	10^2-10^5	0-10^3

*Treatment goal depends on the reuse application (Source: Metcalf and Eddy, 1991; Qasim, 1998)

However, in developing countries where treatment is considered expensive, raw or primary treated wastewater has been directly applied for agriculture or aquaculture thus exposing workers and consumers to great risk (WHO, 1989). In most countries including Australia, secondary treated wastewater with disinfection has been approved for restricted crop irrigation. On the other hand, many regulatory agencies insist on additional treatment to make the reclaimed water safe for reuse applications such as urban reuse with potential exposure routes to human. This additional or polishing treatment is referred to as tertiary treatment, and is described next.

2.2.1 Overview of Tertiary Treatment Processes

Tertiary treatment is an additional step applied after secondary treatment to reduce suspended and dissolved solids, BOD, refractory organic, heavy metals and pathogens. The term tertiary treatment is often used as a synonym for advanced wastewater treatment and although similarities exist between the two they are not precisely the same. Advanced treatment is used after or before conventional treatment to remove nutrients like ammonia, nitrates and phosphates. Whereas the term tertiary treatment process is used to refer to treatment processes used after secondary and includes advanced treatment as indicated by Metcalf and Eddy (1991, pp 2).

There are a number of tertiary treatment technologies (or processes) available to meet the required performance objective. They are more or less similar to water treatment processes as they consist of filtration, chemical coagulation, sedimentation and disinfection. The types of tertiary treatment processes that are applied to remove specific contaminants are listed in Table 2.4. A combination of one or more of the tertiary treatment processes listed in the Table below is required in practice to achieve the desired reclaimed water quality. Hence selection criteria need to be established to aid in the selection of the most appropriate treatment technology for reuse schemes and is further discussed in detail in chapter 3 (Section 3.4.1).

Table 2.4 Types of Tertiary Treatment Processes

Contaminant to be Removed	Tertiary Treatment Process Employed
Dissolved solids	Reverse Osmosis; Electrodialysis; Distillation
Suspended solids	Chemical coagulation (alum, polymers); Filtration (single media -activated carbon, sand, anthracite; dual media; membrane filtration)
Organics and metals	Carbon adsorption
Phosphorous	Chemical precipitation; Biological phosphorus removal
Nitrogen	Nitrification/denitrification; Selective ion exchange Break point chlorination; Air stripping
Coliforms / viruses	Disinfection- UV, chlorination, ozonation
Parasites (Helminth eggs)	Waste stabilization ponds/lagoons; wetlands; storage reservoirs

(Source: Rowe and Abdel-Magid, 1995)

Until recently the approach was to provide tertiary or advance treatment to secondary treated effluent to meet reuse criteria. But of late, there have been attempts to reduce or replace the number of complex, multiple treatment units with more efficient single treatment processes in new wastewater treatment plants. One such example is use of bioreactors with membrane units, which are highly reliable and require low energy compared to conventional bioreactors such as activates sludge process (ASP) (Kimuara, 1991; Cote *et al.*, 1997; Dijk and Roncken, 1997; Peng *et al.*, 1995).

Many researchers have carried out research on several modifications of the processes listed in Table 2.4. To name a few are pulsed bed sand filters in Florida (US Filters, Zimpro product News, 1998), gravel bed hydroponic constructed wetlands in Egypt (Stott *et al.*, 1997) and use of water hyacinth for secondary treatment. The technology required to produce safe water has been studied extensively since the late 1970's to overcome many socio-technical and economic barriers in wastewater reuse projects (Asano and Levine, 1996). A number of researchers have studied various aspects of tertiary treatment processes and have presented reviews on full-scale wastewater reclamation plants in operation in USA, Australia, UK, and South Africa (Tchobanoglous, 1996; Rowe and Abdel-Magid, 1995; Cote *et al.,* 1997; Dijk and Roncken, 1997; Williams, 1997 & 1998; van Leeuwen, 1996).

The reclaimed wastewater can be reused in many different ways. The various types of reuse and current practices in leading countries are described in the following sections.

2.3 Classification of Reuse

Wastewater reuse is classified based on either the nature of reuse or reuse applications. These are described below.

2.3.1 Based on Nature of Reuse

(a) Direct reuse and indirect reuse

Direct reuse refers to direct use of reclaimed wastewater for various purposes such as agriculture & landscape irrigation, industrial applications, urban applications such as dual water systems. *Indirect reuse* refers to mixing, dilution and dispersion of reclaimed wastewater by discharge into an impoundment, receiving water or aquifer prior to reuse such as in groundwater recharge (Asano and Levine, 1998).

(b) Planned and unplanned reuse

Planned reuse is deliberate reuse of reclaimed wastewater and is being adopted by many cities as a sustainable approach to water resources management. *Unplanned reuse* is discharge of treated effluent into water bodies for assimilation and withdrawal by downstream communities. This latter type of reuse has been in practice for centuries (Asano and Levine, 1998).

2.3.2 Based on Reuse Application

Reclaimed wastewater has been used for both potable and non-potable applications. However, the principal focus has been on non-potable applications especially agricultural & landscape irrigation, groundwater recharge and urban uses (Table 2.5) and is described in the following sections.

Table 2.5 Types of Municipal Wastewater Reuse

Type of reuse		Applications
Potable reuse	Direct	Pipe to pipe supply
	Indirect	Blending in water supply or water bodies
Non potable reuse	Irrigation	*Agricultural irrigation* Food crops, pastures, nurseries *Landscape irrigation* Parks, school yards, freeway medians, cemeteries, greenbelts, golf courses
	Industrial	Cooling, boiler feed, construction, process water, stack scrubbing
	Groundwater recharge	Recharge of potable aquifer, storage, subsidence control, salt water intrusion control
	Recreational & Environmental	Stream flow regulation, fisheries, marshes and wetlands, recreational areas, snow making
	Urban uses	Fire protection, toilet flushing, air conditioning, street washing/ car washing, dust control

(Source: Tchobanoglous, 1996; Asano, 1998; Metcalf and Eddy, 1991)

(a) Potable reuse

Direct potable reuse is very rare and is limited to extreme conditions because of lack of public acceptance. Many communities have raised their concern on long-term effects of toxic chemicals and their by-products (Angelakis *et al.*, 1997). Lack of public acceptance has been the key factor hindering the implementation of direct potable reuse projects in many countries. There is only one full-scale, *planned direct potable reuse* scheme in the world, which has been in practice for more than 25 years at Windhoek, Namibia (Haarhoof and Van der Merwe, 1996). There are many *indirect potable reuse* demonstration projects in USA where reclaimed water is blended with surface or groundwater sources as discussed in Section 2.4.1.1.

(b) Non-potable reuse

Non-potable reuse is more common because it is economically feasible, reliable and acceptable to the public (Asano, 1996). Different types of non-potable reuse applications are given in Table 2.5. Agricultural irrigation is by far the oldest (as it dates back to the Minoan civilization 5000 years ago) and largest non-potable reuse application for the following reasons: (a) it requires large quantity of reclaimed wastewater, (b) it requires a relatively lower level of treatment and (c) it reduces the use of fertilizers (Asano and Levine, 1998; Oron *et al.,* 1996a; Haruvy, 1997). The guidance manual edited by Pettygrove and Asano (1990) has a detailed account of various aspects of municipal wastewater irrigation.

The use of reclaimed wastewater for landscape irrigation is gaining importance in many cities around the world as the water demand for irrigating green belts, medians, parks and golf courses is growing. Industrial reuse is more common in Japan and USA where it has been successfully used for cooling, scrubbing and as boiler feed. Groundwater recharge and recovery is being given consideration in many countries including USA, Israel and Australia for many applications listed in Table 2.5. Urban uses such as toilet flushing, fire protection are becoming common in major cities around the world. A brief account of reuse practices in Australia and other leading countries is presented in the following Section.

2.4 Current Reuse Practices in Australia and Other Countries

The purpose of this section is to provide an overview of reuse practices in the world and its importance in the present day water resource management. A brief account of reuse in major countries and regions involved in reuse is presented first before describing the reuse schemes of Australia. A comprehensive insight in to the history and evolution of reuse practices around the world can be found in Asano and Levine (1996).

2.4.1 Reuse Practices in Various Regions

A brief summary of reuse practices in regions such as USA, Middle East, Asia, Africa is presented in this section. A detailed account can be found in Williams (1997 & 98), Asano (ed, 1998b); Rowe and Abdel-Majid (1995, pp 3-11); Odendaal (1992), USEPA (1992, pp 107-115).

2.4.1.1 United States of America

The Unites States of America (USA) leads other countries not only in terms of volume of wastewater reused but also in terms of framing regulations, research & demonstration projects to evaluate the safety and reliability of reuse applications. Water reuse in USA dates back to 1926 when a dual system was first installed in Grand Canyon tourist resorts (Williams, 1997). Since then a number of reuse schemes have been commissioned in many states including California, Florida, Colorado and Texas to overcome water scarcity and pollution of streams & oceans (Asano and Tchobanoglous, 1991 & 1995).

The first reuse regulation for wastewater irrigation was formulated in 1918 in the State of California (known as Title 22; Shuval, 1996) and many countries around the world have based their regulation on Title 22. In March'2001 the State of California passed a new edition of its Title 22 regulations entitled '*Water Recycling Criteria*', which has set a new benchmark in terms of permitted applications (http://www.dhs.ca.gov). On the other hand, in 1994 the first groundwater recharge regulation was proposed in this State (Asano and Levine, 1996).

Direct potable reuse was implemented for the first time in 1956 at Chanute in Kansas State, to overcome drought (Asano, 1996). After this scheme there have been no direct, pipe-to-pipe potable reuse schemes in USA. However, planned indirect potable reuse systems are in operation and these include Whittier narrows & Water Factory 21 in California; El Paso in Texas; and Occoquan in Virginia (Law, 1998).

On the other hand non-potable reuse applications such as agricultural reuse and landscape irrigation is more common in USA. The state of California leads all other states with 8 % reuse and is mainly driven by periodic droughts and scarce water supplies (Asano and Levine, 1998). The City of San Diego is planning to use 86 Mm^3 of reclaimed water by the year 2010 (Bailey *et al.*, 1992). In Florida about 3126 Mm^3/d is being reused as against 3785 Mm^3/d in California. Industrial reuse is less common and only 5% & 2 % are being reused in Florida and California respectively (Asano *et al.*, 1998).

Groundwater recharge accounts for 14 to 15 % (170 Mm^3/d) of reuse in California and is being carried out in Montebello Forebay and Whittier Narrows both in Los Angeles County (Crook, *et al.*, 1990). The City of St. Petersburg in Florida has the worlds largest closed loop dual distribution system covering 250,000 inhabitants (Lazarova *et al.*, 2001).

Since the late 1980's, demonstration projects have been carried out in USA to investigate the safety and reliability of agricultural reuse and indirect potable reuse (such as in San Diego, Tampa, the Potomac estuary, and Water factory). These studies on agricultural reuse showed that (a) yield of salad crops irrigated were significantly higher than yield from local well water and (b) no plant tissues showed any contamination. It was concluded that using water from tertiary treatment as a raw water supply posed equivalent or reduced health risks when compared to water from an existing water treatment plant (Asano and Levine, 1996).

Further, detail toxicological investigations of indirect potable reuse demonstration projects have showed no adverse health effects on animals consuming reclaimed water (Asano and Levine, 1996; Mc Ewen *et al.*, 1997; NRC, 1998 Cited in Cole, 1998). Further, the National Research Council (1998) of USA has concluded that it is safe and reliable to use reclaimed wastewater for potable water supply and that implementation of potable reuse projects is a matter of public acceptability.

2.4.1.2 Middle East

Since the 1930's, Israel has been using reclaimed wastewater for agricultural and landscape irrigation and is the leader in reuse schemes in the Middle East. Due to severe water scarcity Israel has a national policy to reuse secondary effluent for crop irrigation

(Shelef *et al.*, 1994). Currently about 65% of the municipal wastewater (about 260 Mm^3/yr) is reused mainly for agricultural irrigation (Eran, 2000). It is predicted that by the year 2010, one fifth of the total water supply and about one third of agricultural demand will be supplied from reclaimed wastewater (Rebhun and Engel, 1988) while by the year 2040, it will be the main source of water for irrigation (Haruvy, 1997). The Dan region-Third Line is one of the largest integrated urban sewerage schemes with a 190 Mm^3/d groundwater recharge project (Rowe and Abdel-Majid, 1995) and an agricultural reuse scheme serving about one third of the population of Israel (Shelef *et al.*, 1994).

In 1999, Ali has reported religious beliefs as one of the main objection to reuse of reclaimed water in the Middle Eastern region. Countries including Jordan, Saudi Arabia, Tunisia, have developed many strategies to promote reuse (Shuval, 1998, Rowe and Abdel-Majid, 1995) by educating communities to overcome religious and psychological barriers. In Jordan, water authorities have issued a policy, which requires all new wastewater treatment plants to have reuse components (Gur and Al Salem, 1992). In view of this policy, about 75% of the urban wastewater was reused for agricultural irrigation in 1993. In Egypt, a field scale study for restricted irrigation using gravel hydroponic beds was carried out (Stott *et al.*, 1997 a & b).

In 1995-96, reclaimed wastewater provided 0.8 % (335 ML/d) of the total water demand in Saudi Arabia (Al-Rehaili, 1997) and by the year 2000 it is estimated that 9 to 11 % of the water demand will be met by reclaimed wastewater (Rowe and Abdel-Majid, 1995). Since 1976 extensive non-potable reuse has been in practice in United Arab Emirates, (U.A.E). According to 1991 data, about 85 % of the reclaimed water was used for landscape irrigation while 15 % was used for the camel tracks at Abu Dhabi in U.A.E. In the Sultanate of Oman, reuse was initiated in the year 1987 (USEPA, 1992; pp 198) and in 1995 about 10.8 – 17.3 ML/d was reused (depending on the season) for landscape irrigation (Rowe and Abdel-Majid, 1995, pp476, Table 10.28).

2.4.1.3 Asia

In Japan, urban wastewater reclamation and reuse projects have been in place since 1964, to overcome disposal problems as well as water scarcity (Ogoshi, *et al.*, 2001). In contrast to the major agricultural reuse trend in many countries, Japan uses 206 Mm^3/yr (1998 data) of reclaimed water mainly for industries and non-potable urban reuses. Closed loop water recycling systems with on-site wastewater reclamation systems in office and apartment complexes are common in Japan (Asano *et al.*, 1996). Similar to Japan's industrial reuse, Singapore is practising the reclamation of sewage effluent for industrial use since 1960 (Chin and Ong, 1991).

Wastewater fed aquaculture and horticulture has been common in many parts of India and China. In India, land disposal of raw or primary treated wastewater has been in practice for over 160 years (Rowe and Abdel-Majid, 1995). Calcutta alone has over 70,000 ha of wastewater fed fishponds (WHO, 1989). The National Environmental Engineering Research Institute (NEERI) has published data on various reuse schemes and their environmental and public health significance in India (Rowe and Abdel-Majid, 1995).

In China, agricultural reuse schemes are in practice since 1950 with very minimal treatment leading to pollution of irrigated lands. It is estimated that there is a potential demand of 2.8×10^{10} m^3/yr of reclaimed water in China and by the year 2000, 18 – 20% of total urban water consumption is expected to be from reclaimed water (Pinjing *et al.*, 2001). Peng *et al.*, (1995) has reported a pilot plant scheme that has been initiated to overcome growing water demand and pollution of water resources in China.

2.4.1.4 Europe

Water reuse is growing steadily in Belgium, England and Germany and more rapidly in coastal areas and islands with tourist influx. Golf course irrigation is by far the fastest growing reuse application in Europe (Lazarova *et al.*, 2001). In Germany, about 25% of primary treated sewage from the City of Munich was used for cultivating common carp (WHO, 1989). In France, although reuse is not crucial it has been practiced in Paris from as early as 19^{th} century to irrigate more than 2000 ha. In tourist areas and islands (where there is limited fresh water supply) reclaimed water is used for landscaping and golf courses (Bontoux and Courtois, 1996 and Vedry *et al.*, 2001).

In England, planned indirect reuse is very common and is estimated that 25 % of the flow in Thames River consists of treated effluent in summer (Rowe and Abdel-Majid, 1995). The first indirect potable reuse scheme in Europe called Chelmer augmentation scheme was implemented in 1997 at Essex (Lazarova *et al.*, 2001). Water Authorities in UK are now investigating reuse of treated wastewater in industries and grey water reuse in households to overcome recent droughts and inadequate supplies (Williams, 1997).

2.4.1.5 Africa

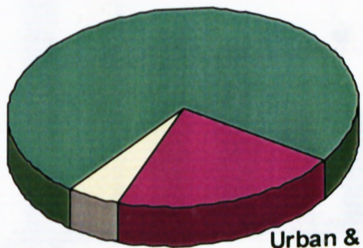
In 1969, a planned direct potable reuse scheme was adopted in Windhoek, Namibia due to severe water scarcity and failure of other alternatives to meet the water demand in an economical manner. Since then this is the 'only' direct potable reuse scheme in operation in the world. Experience of over 25 years indicate that potable reuse is a viable option and success has been attributed to a holistic approach with respect to the water supply, collection and treatment of wastewater and above all public participation (Haarhoff and Van der Merwe, 1996). This project has proven that reuse schemes can be a viable option even in developing countries.

Following Namibia's success, South Africa carried out research on suitable design and performance criteria of range of technologies in 1970. In the year 1982, the Water Research Commission of South Africa, published a guidance manual incorporating the experience of reclamation plants in South Africa and other parts of the world (Law, 1998). According to Williams (1997), planned indirect reuse (i.e. discharge to surface streams to be withdrawn by downstream communities) is the preferred management approach in South Africa as there is scarcity of water

In other African countries such as Morocco, Libya, Algeria and Egypt, reuse is practiced on a small scale. In Morocco about 16% (60 Mm ^{3}/yr) of the collected wastewater is reused which represent only 5% of the water used in agriculture while in Libya about 3100 ha is irrigated using reclaimed wastewater (Angelakis, *et al.*, 1997).

2.4.2 Reuse Schemes in Australia

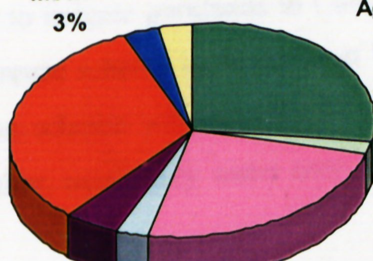
The first reuse scheme in Australia was initiated in 1898 in Melbourne's Werribee Sewage farm to overcome the incidence of water borne diseases (Hartley, 1998). Since then there are about 52 reuse schemes operating throughout Australia (Civil Engineers Australia, 1999). As discussed in Chapter 1, reuse is gaining importance in Australia, as it is the driest inhabited continent with an average runoff of 50 mm per year (Anderson, 1996 a & b). In Australia, agriculture is a major consumer of water resources (approximately 74%) as shown in Figure 2.2.



(Anderson, 1996b)

Figure 2.2. Average Annual Water Usage in Australia

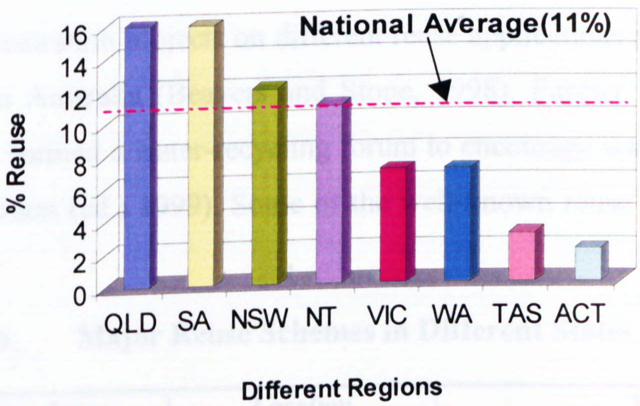
In spite of this enormous potential for reuse of wastewater for irrigation, less than 10 % of water used for urban and industrial uses is being recycled for irrigation. The reuse of reclaimed water in different economic sectors in Australia is presented in Figure 2.3.



(ABS, 2000)

Figure 2.3. Percentage Reuse in Different Sectors in Australia

Currently potable reuse is not approved by Australian Authorities (Anderson, 1996 a). Water reuse has been growing steadily in Australia from 7 % in 1998/99 (Dillon, 2000) to as much as 11% in the year 2000 (ABS, 2000). The percentage reuse in different regions and on a national level in Australia is presented in Figure 2.4.



(Source: Dillon, 2000)

Figure 2.4 Percentage Reuse in Different Regions of Australia (1999-2000)

Anderson (1996a) has presented a comprehensive discussion on Australian recycling initiatives. Many individual household level treatment and recycling schemes have been in place in many rural areas but these are not popular in urban areas due to space and technological considerations. Since 1995, onsite neighbourhood treatment and recycling systems using membrane technologies have been initiated in many places including a 375 m^3/d water-mining scheme to irrigate parklands in Canberra. The State of Victoria has the prestige of having the first reuse scheme in Australia at Werribee, as early as 1898. In June 2000, a 20-year water reuse scheme was initiated for an 18-hole golf course at Geelong (Crosscurrent, 2000b). Further, many grey water recycling schemes are being investigated in Victoria.

In Queensland, about 39 Mm^3/yr (12 %) out of 325 Mm^3/yr of secondary effluent is currently being reused (White, 1998). Irrigation is the predominant form of reuse while industrial reuse comprises less than 0.5 % (Draft report on industrial reuse, DNR, QLD, 1999). In 1997, the Queensland Department of Natural Resources initiated the Queensland water recycling strategy in order to promote reuse of reclaimed water in Queensland and address issues pertaining to sustainable water recycling (White, 2000). In late 1999, advanced water recycling demonstration plant consisting of nine separate treatment modules each demonstrating a particular process such as DAF, filtration, ozonation, activated carbon, MF, RO and UV disinfection was commissioned in Queensland (White, 1999). Water reuse is being seen as an increasingly valuable resource in Western Australia too and the major reuse schemes are summarized in Table 2.6. As in many countries, research and demonstration projects on different reuse applications are being carried out to encourage reuse in Australia (Beavers and Stone, 1998). Further in 1999, the Australia Water Association formed a water-recycling forum to encourage water recycling and reuse in Australia (Anderson (ed.) 1999). Some of the well-known reuse schemes are presented in the Table 2.6.

Table 2.6 Major Reuse Schemes in Different States of Australia

Name of the reuse scheme	Location	Remarks
Sewage farms[1]	Werribee, VIC	First sewage farm implemented in 1898
Tannery process water [2]	Toowoomba, QLD	Currently uses 2.2 ML/d
Meat works industrial wash down water[2]	South Burnett, QLD	Utilises 240 ML/yr
Australian steel mill[3]	Port Kembala, NSW	20 ML/d for quenching slag
Sithe energies cogeneration plant	Kurnell, NSW	Uses about 140 ML/d and is the largest industrial reuse in Australia.
Rouse Hill development[3]	Sydney, NSW	First domestic non-potable reuse scheme in Australia commissioned in 1994
Albury*, Branxton, Wagga Wagga, Mildura[3]	NSW	Irrigation of wood lots
Eraring power station	Hunter region, NSW	4 ML/d for boiler feed water
Taronga Zoo	Sydney, NSW	Reused for landscape irrigation, water features & moats in the animal exhibits
Dubbo	WA	Irrigating eucalyptus plantation for feeding Koalas in Dubbo Zoo
Industrial cooling water	Perth, WA	Demonstration project at Woodman Point
Bolivar	Adelaide, SA	150 ML/d is available for reuse in agriculture and this is the largest reuse scheme in Australia
Loxton	SA	Irrigation of wood lots
Mawson Lakes, New Haven – residential developments	SA	Domestic non potable reuse scheme

(Source: [1]Hartley, 1998; [2] Draft Report on Industrial Reuse, 1999; [3]Gregory, 1999; [4] Anderson, 1996; [5] Law, 1996b; [6] QLD water recycling strategy; [7] Civil Engineers Australia, 1999)

2.4.2.1 Reuse Schemes in South Australia

As early as 1890, Adelaide, the capital City of South Australia, was fully sewered (Hartley, 1998). However, the reuse of reclaimed water started only in the mid 1970's (Kayaalp, 1996). Since then many reuse schemes have been implemented including the Bolivar reuse scheme, the largest reuse scheme in Australia where 150 ML/d is available for reuse in horticulture (Huijbregsen *et. al.*, 1998) without any restrictions on application method or marketing of the produce (Marks *et al.*, 1998). Recently a dual reticulation system has been incorporated into two new residential developments in Adelaide namely Mawson Lakes and New Haven for toilet flushing and irrigation of gardens & recreational spaces (Water Recycling News, 2000).

In 1998, about 86 Mm^3/yr of sewage effluent was discharged from 22-wastewater treatment plants out of which, only 8% i.e. 6.8 Mm^3/yr was recycled for non-potable applications including landscape and agricultural irrigation (Leahy *et al.*, 1998). Whereas in 2000, the total volume of effluent reused increased because of Virginia pipeline scheme and the percentage reuse also increased to 16% as shown in Figure 2.4.

The main reuse applications in South Australia include irrigation of ovals, golf courses, parks, and reserves as shown in Table 2.7. Research on groundwater storage and recovery of reclaimed water has been carried out at Bolivar to evaluate environment, public health and social aspects (Dillon, 2000). A review of the reuse schemes in South Australia is presented in Table 2.7 and the details of the same can be found in Attwood (1997; cited in Leahy *et al.*, 1998).

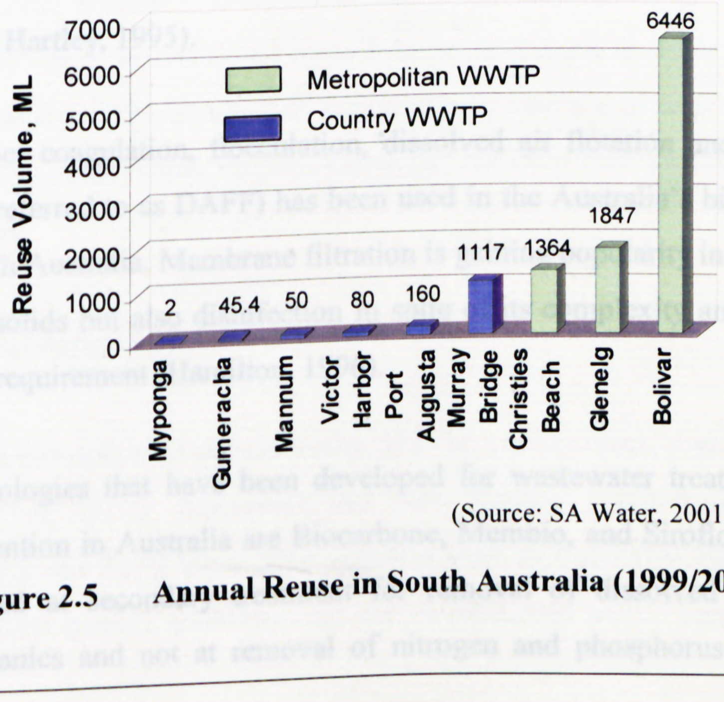
Table 2.7 Wastewater Reclamation and Reuse Plants in South Australia

Name of the Plant	Types of Reuse	% Reuse	Treatment Processes Employed [3]
Gumeracha[1]	Pine plantation	100%	IT +TF+LG+CHL
Mannum[1]	Golf course	100%	IT + LG+CHL
Murray Bridge[1]	Constructed wetlands	100%	IT +TF+LG
Myponga[1]	Irrigation of pastures	100%	IT +LG
Port Augusta West[1]	Golf course	72%	ALG+SLG
Victor Harbor[1]	Golf course	9.3%	IT+TF+LG
Bolivar[2]	Irrigating Lucerne, vines, vegetables and for recreation	6%	S+GC+PS+TF+LG+CF+DAF F+ CHL
Christies Beach[2]	Landscaping and recreation	3%	S+GC+PS+ASP+CHL
Glenelg[2]	Landscaping and recreation	11%	S+GC+PS+ASP+CHL

(Source: Biebrick, 1998)

Note: [1]Country wastewater reclamation plant; [2]Metropolitan wastewater reclamation plant; [3]IT: Imhoff tanks; LG: Lagoons; S: Screening; GC: Grit chamber; PS: Primary Sedimentation; ASP: Activated sludge process; TF: Trickling filter; CF: Coagulation and Flocculation; DAFF: Dissolved Air Flotation and Filtration; ALG: Aerated Lagoon; SLG: Settling Lagoon; CHL: Chlorination.

Currently the State planning authority (SA Water) is aiming for 30 % reuse from the metropolitan plants and 24 % reuse from its country WWTPs. This has been partly achieved by upgrades of the metropolitan WWTPs (http://www.sawater.sa.gov.au/). The annual reuse volume is different WWTPs in SA is shown in Figure 2.5.



(Source: SA Water, 2001)

Figure 2.5 Annual Reuse in South Australia (1999/2000)

2.4.3 Wastewater Reclamation Processes Currently Used in Australia

Presently there are about 1000 sewerage treatment plants with average plant size of under 20,000 persons in Australia and most of them use lagoons, TF and sludge handling systems (Hartley, 1998). Until recently tertiary treatment in many treatment plants in many states of Australia including South Australia (see Table 2.3) has been mainly related to ponding to reduce nutrients and use of chlorine for disinfection prior to agricultural use. Secondary waste stabilization ponds have been used in both large (Bolivar, SA) and small (Port Pirie, SA) treatment plants to reduce nitrogen, phosphorus, BOD and bacteria (Cooper *et al.*, 1974).

But since 1990, with the introduction of a number of international water utilities in Australia, a wide range of tertiary treatment processes are being adopted including dissolved air flotation, microfiltration, activated carbon, reverse osmosis and biological nutrient removal (BNR) and sequential batch reactors (SBR) (Dillon, 2000). BNR and SBR plants are becoming popular in Australia owing to their performance and one-step treatment approach (Hartley, 1998).

From 1985-1990, plant upgrades using BNR process have been commissioned in Penrith, South Windsor and Albury (in New South Wales), Ballaret (Victoria), Brendale (Queensland) and Port Adelaide (South Australia). Whereas in the early 1990's, new BNR plants were commissioned at Rouse Hill (New South Wales), Bendigo and West Wodonga (both in Victoria, Hartley, 1995).

Alum and polymer coagulation, flocculation, dissolved air flotation and granular multi-media filtration (referred to as DAFF) has been used in the Australia's biggest reuse plant at Bolivar in South Australia. Membrane filtration is gaining popularity in Australia for not only removal of solids but also disinfection in spite of its complexity and high operation and maintenance requirement (Hamilton, 1996).

Alternative technologies that have been developed for wastewater treatment and which have received attention in Australia are Biocarbone, Membio, and Sirofloc. Each of these processes is aimed at secondary treatment for removal of dissolved and suspended, carbonaceous organics and not at removal of nitrogen and phosphorus (GHD Pty Ltd, 1992). Jayawardene *et al.*, (1996) have proposed a novel technique for land treatment of sewage effluent known as FILTER technique, which eliminates the need for wet weather storage.

Another novel technique called Electro-coagulation has been field tested in Australia, which reduces phosphorus by 98 % in 37 seconds and minimizes sludge production and is reported to be cheaper than coagulation (www.dnr.qld.gov.au/reourcenet/water/ wastewater-reuse/archives). The CRC for Waste Management and Pollution Control is involved in a project at South Windsor, NSW where micro filtration (MF) and reverse osmosis (RO) processes have been pilot tested for reuse up to potable quality and boiler feed (Fergus, 1999).

The natural treatment systems such as constructed wetlands are becoming popular as it can preserve open spaces, enhance wild life habitats, and augment stream flow in addition to stabilizing the wastewater. The Byron Bay wastewater wetlands in New South Wales (The constructed wetlands manual, Vol.1, pp.11) and 71 ha wetland systems at Murray Bridge in South Australia are well known examples (www.sawater.sa.gov.au/wastewater reuse).

A critical review of the disinfection process from an Australian perspective by Hamilton (1996) indicates that Ultraviolet (UV) disinfection is gaining popularity especially when the environmental flow is to be augmented. Although use of chlorine has been very popular it is not being favored in recent times due to the harmful effects of disinfection by products especially when the reclaimed water is to be discharged to water bodies (Biebrick, 2001). On the other hand chorine dioxide is not popular because of high O & M costs and the need for constant supervision. Further, ozone has not been used for disinfection process to date in Australia.

2.5 Reuse Guidelines

In order to ensure protection of public health and the environment, regulatory authorities such as the USEPA, WHO, Australian and New Zealand Environment Conservation Council (ANZEEC) and many local state agencies such as California Health Department have developed water quality guidelines for use of reclaimed water. The first wastewater reuse standard was developed by WHO in 1973 (Shuval, 1991) while the first wastewater reuse regulation knows as Title 22 was developed by State Health Department of California in 1977 (Levine *et al.*, 1997). In 1989, WHO published its guidelines based on epidemiological and technological data, to provide a rational health basis for the microbial standards for wastewater irrigation (Shuval *et al.*, 1997). This WHO guideline and Title 22 has formed the basis for the development of reuse standards for agricultural irrigation in many countries around the world.

Further, some countries and states have formed their own reuse guidelines (for a wide range of non-potable reuse applications) based on the past experience, economic factors and above all the protection of public health (Anderson *et al.*, 2001) as shown in Table 2.8. There are no set guidelines for direct potable reuse application and any potable reuse schemes would have to satisfy the relevant drinking water standards.

Table 2.8 Reuse Standards Adopted in Different Countries

Type of Reuse Standard	States /Countries	Specification for High Risk Category
Title 22	California, Israel, Saudi Arabia	TC < 2.2/100mL
WHO	France, Tunisia, Oman	FC < 1000/100mL and H. Eggs < 1 /L
USEPA	Some States in America	
New/ Miscellaneous	Australia*, South Africa, some States in America (eg: Arizona, Texas Florida, Oregon, Colorado)	More stringent than WHO and have been based on Title 22 or USEPA and is specific to the country or state
No Standards	Turkey, Morocco	Not yet adopted any standards but practice wastewater reuse

(*see Sections 2.5.1 and 4.5.5 for details, Source: Levine *et al.*, 1997)

2.5.1 Reuse Guidelines in Australia

Until recently there was no national guideline for use of reclaimed water in Australia. In 2000, the National Water Quality Management Strategy Guidelines was released for use of reclaimed water in places where no local or state guidelines exists. Many states such as South Australia, Victoria, New South Wales, Queensland, Tasmania, and Australian Capital Territory have formulated guidelines based on their local experience and the guidelines are presented in Appendix G.

2.5.2 Comparison of Reuse Guidelines

The reuse regulations vary between countries and within each country from state to state with respect to type of application, microbial quantification & monitoring and perception of health risk resulting in different water quality and wastewater treatment requirements. For instance, according to the WHO guidelines for agricultural reuse, helminth eggs are to be monitored in addition to faecal coliform whereas Title 22 relies on the treatment systems and monitoring of total coliforms (TC) only (Table 2.8). Further, WHO emphasizes a series of stabilization ponds while Title 22 stipulates conventional biological wastewater treatment followed by tertiary treatment (filtration & chlorine disinfection) to meet the microbial quality. Anderson *et al.*, (2001) have attributed this inconsistency to lack of a unified position on health effects and they suggest that it has lead to an unnecessarily conservative approach to water reuse.

The direct comparison of different guidelines is made difficult by the fact that each guideline has its own set of categories (Class A, B, C and D) indicating different levels of risks (Levine *et al.*, 1997). For example Class A of the WHO guidelines are the most stringent category while for Israel, Class D is the most stringent category. In addition guidelines consider median or mean values of indicator organisms like E.coli or faecal coliforms. Hence it is necessary to carefully consider the scope and type of reuse application before making a comparison.

The variation in guidelines for the same scope and type of application exists not only from country to country but within the states in the same country. An excellent comparison of different national and state guidelines for agricultural irrigation has been presented by Levine *et al.*, (1997) while WHO, USEPA and Title 22 regulations for irrigation has been compared by Asano and Levine (1996) & Shuval (1996). In 1997, Shuval *et al.*, developed a risk assessment approach to compare USEPA and WHO guidelines. Based on the preliminary results of this study, authors have questioned whether huge additional investments (of the order of $ 3-30 million) to provide additional risk reduction is justifiable when WHO guidelines can provide a very low level of risk.

Currently, most guidelines specify guideline values for BOD, SS, FC or TC and turbidity while some guidelines suggest values for trace organic compounds, viruses, chlorine residual, helminth eggs as shown in Table 2.9. Further limits for nitrates and phosphates are normally determined on site-specific basis (Australian States –SA, VIC, and QLD).

Even though many studies have suggested that potential risk of using reclaimed wastewater is much lesser than the perceived risk, most developed countries have adopted cautious approach and have chosen criteria similar to the state of California as WHO guidelines is considered too limited. A variety of approaches such as water quality parameters, treatment requirements, and method of application based on significant case studies have been considered by different agencies to regulate water quality for wastewater reclamation systems (Angelakis *et al.*, 1997). Many researchers such as Anderson *et al.*, (2001) and Lazarova *et al.*, (2001) have recommend an international guideline to reduce the discrepancies in the current standards and to induce confidence in public about safety and reliability of reuse schemes.

Table 2.9 Parameters Used in Different Reuse Guidelines

Type of Parameter	Parameter		Reuse Guidelines of States/ Countries/Organizations using this parameter
Biological parameters	*Bacteria*[1]	TC	USA (California, Colorado, Hawaii, Oregon)
		FC	WHO, USA (Florida, Arizona, Nevada, New Mexico), Australia (New South Wales, Queensland, Victoria, Australian Capital Territory, Tasmania), Israel
		E.Coli	Australia (South Australia)
	Viruses[2]	Hepatitis, Entero Virus	USA (Arizona, Hawaii), Australia (Victoria)
	Helminth[3]	Helminth eggs	WHO, Australia (Victoria)
	Protozoa[4]	Giardia, Cryptosporidium	USA (Arizona)
Physico-chemical parameters	Turbidity		USA (Arizona, California, Oregon, Nevada, Texas), Australia (South Australia, Victoria, Queensland)
	BOD		Most guidelines in the States of USA & Australia, Israel
	SS		USA (Florida, Georgia, Utah, Maryland), Australia (all the state and national guidelines)
	Cl_2 residual		USA (Florida), Australia (Victoria)
	pH		USA (Wyoming, Arizona), Australia (Victoria, Australian Capital Territory)

(Source: Lazarova, *et al.*, 2001; USEPA, 1992, pp 204-244)

Note: [1] measured in terms of median, mean values per 100 mL; [2] no indicator, each virus to be monitored; [3] mainly Ascaris, Trichuris, Ancylostoma; [4] no indicator, presence of one could indicate the presence of the other.

2.6 Issues in Reuse Schemes

Although reuse has been widely acknowledged as the most suitable and sustainable alternative in water resources management, there are several technical, economical, societal and legal issues still to be resolved. Some of the major issues include public acceptability & perception of aesthetics, religious beliefs, concerns about long term effects on environment and humans, safety and reliability of tertiary treatment, the method of application and so on. In spite of over four decades of reuse practice, communities are still trying to find answers to the following questions.

- How reliable and safe are the reclamation technologies?
- What are the most cost effective & efficient technologies to remove trace metals, pathogens and carcinogens from the wastewater?
- What is the potential long-term impact after implementation of reuse schemes?
- Which is more appropriate scale of treatment: centralized or decentralized schemes?
- What is the best approach to address timing & quantity to match the water demand?

The basic concerns for reuse of reclaimed water includes its physical (color, odour, turbidity), chemical (pesticides, organics, DBPs, surfactants, pharmaceutical by products), biological (pathogens– bacteria, viruses, helminths) and radiological (radon, radium) characteristics (Rowe and Abdel-Majid, 1995). The public is concerned about the long-term effects of trace metals such as Cd, Cr, Cu, Zn, Ni and chemicals, which can accumulate and pose long-term hazards to plants, animals and human beings (as result of consuming such plants and animals). A state of the art review on human health risks associated with the reuse of wastewater has been presented by Shahalam (1989).

There has been increased interest and heated debate over the long-term effect of trace organics and recalcitrant chemicals on public health and environment. One of the main technical challenges in water reuse schemes is to achieve operational reliability of not only treatment technologies but also distribution system and storage reservoirs (Lazarova *et al.*, 2001). A number of field studies have been carried out to investigate the safety & reliability of treatment technologies and long term effects of reuse in countries such as

Namibia (Haarhoof & Van der Merwe, 1996), USA (National Research Council, 1998) and Israel (Oron, 1996).

These studies have proven that wastewater reuse is safe and reliable and poses no greater health risk than those associated with fresh water supply (Olivieri *et al.*, 1996). Further, Gerba *et al.*, (1981) and Lance *et al.*, (1982) have shown that reclaimed water when applied for irrigation undergoes further treatment as soils have high potential for removal of bacteria & viruses.

There is also the question of, which is the most appropriate technology to reduce color, odour and turbidity among the available technologies. There is no simple answer to this as there are a number of factors, which influence the selection, and one of the objectives of the present investigation is to study these factors and incorporate them in to a decision support system.

Social factors play a major role in deciding the feasibility & sustainability of reuse projects. Seaton *et al.*, (1998) have researched the concept of 'receptivity' to evaluate the extent of willingness to accept and utilize a given technology. The most severe objection to the use of reclaimed water in Islamic countries has been that of religious and cultural beliefs (Ali, 1999) which has now been overcome by community education and mandatory recommendations to use reclaimed water. Issues such as reclaimed water quality, health risks, price of reclaimed water, retrofit costs, reliability of supply and liability are of major concern to users (USEPA, 1992).

Economics play a major role in the implementation of any projects. This is particularly so for a reuse project as non-monetary benefits cannot be defined accurately. Some of the questions that concerns public, decision makers and planners are listed below:

- What are the cost and benefits of using reclaimed water?
- How should reuse projects be financed?
- How should the reclaimed water be priced?
- Who should pay for the treatment cost: polluters and /or consumers?

Many a times the actual value of reuse schemes is under estimated due to a comparison of only the monetary terms with other alternatives. This excludes the non-monetary benefits of reuse such as improved environmental quality and conservation of habitats. The success of reuse projects depends on continued demand for reclaimed water and the willingness of the community to pay for the reclaimed wastewater. Unfortunately public look at reclaimed water as a cheap source of water (Mills and Asano, 1998) and expect it to be sold at a very cheap rates compared to fresh water. However in any reuse schemes, major cost components apart from the reclamation costs include (1) distribution costs which can be as high as 70 % of overall cost depending on the distance of consumers from the reclamation site (Lazarova *et al.*, 2001), and (2) cost involved in retrofitting the distribution system at consumer level (i.e. on site modifications).

There is still a debate as to who should bear these costs in order to make reuse schemes more sustainable. Most communities are generally not willing to pay true costs of reuse, which includes the treatment & distribution costs, and on site modifications. Many times the reclaimed water has to be supplied at highly subsidized rates to promote reuse and reap long-term benefits such as environmental protection. As in case of Bolivar, Australia's biggest reuse scheme farmers have to be persuaded to pay for the extra cost of pipeline to their fields through community consultation and political will (Biebrick, 2000). Further, it is also necessary to ensure the interest and willingness of the community to use reclaimed water even after the project completion (USEPA, 1992; Mills and Asano, 1998) to guarantee the reclaimed water demand.

Another school of thought is that the polluters should pay for the price and reclaimed water should be supplied at subsidized rate for the consumers. Water pricing strategies for reclaimed water has been discussed by Young (1996) while various alternatives and steps to be taken for financing reuse schemes along with case studies have been discussed in USEPA manual (1992, pp 151-163).

As discussed in Section 2.5, many countries have legislation in place for proper implementation of reuse schemes. This includes regulations or standards to be met to protect public health and environment, national and state legislations for water rights (USEPA, 1992, pp141-148). Discussion as to who is liable when the water quality is not met, control measures for cross connection controls, irrigation limitations, and penalties for violation of laws have been presented in detail in the above mentioned references.

2.7 Planning of Wastewater Reuse Schemes

Although there are many advantages of reuse such as water pollution control and additional water supply, the actual cost analysis of reuse projects in a number of cities have turned out to be more expensive than supplying water from a distant source (Dean and Lund, 1981). On the other hand the reclaimed water can represent low cost supply only if the reclamation facility is located near large industrial or agricultural users as otherwise distribution costs can be very high (Asano and Mills, 1990). Further, many projects have failed to meet their objectives mainly due to insufficient planning and socio- economic factors (Mohorjy, 1987; Lazarova *et al.*, 2001).

Therefore detailed systematic planning is necessary to determine the appropriateness of the wastewater reclamation and to analyze different alternatives of (a) treatment (b) conveyance and (c) reuse application so as to deliver reclaimed water at minimum cost and health risks to users in addition to offsetting fresh water demands (Asano and Mills, 1990).

Planning of reuse projects differs from that of water supply projects in two ways: (1) water supply projects demand is projected and supplies are developed while the reverse is true in reuse projects and (2) the main objective in reuse projects is to minimize potential public health risks and environmental impacts associated with the reuse. Researchers such as Mohorjy (1987) and Turner (1981) have worked on development of a planning methodology based on analysing proposed and existing water reuse projects and identifying financial & regulatory requirements.

2.7.1 Planning Stages

Planning of any reuse scheme typically involves three stages namely (1) the conceptual level of planning, (2) preliminary feasibility investigation and (3) facilities planning and these are discussed in detail by Asano and Mills (1998). In this review, a brief account of each stages of planning is presented to highlight where the model developed in the current research will fit in.

(a) *Conceptual planning* is the first stage in planning where a preliminary design & construction plan and rough cost estimate are prepared based on the study area, site evaluation, environmental review & assessment (Metcalf and Eddy, 1991; Crites, 1990; Asano and Mills, 1990; Kontos and Asano, 1996).

(b) *Feasibility investigation* is the second stage of planning, which includes (1) systematic, retrospective assessment of consumer demand for reclaimed water (in terms of water quality and pricing), (2) evaluation of techno-economic feasibility, (3) environmental and (4) institutional feasibility. The evaluation of technical-economic feasibility involves defining customer demands, development of alternative treatment and distribution systems for reclaimed water, storage system siting and design to match supply & demand (Tanik *et al.,* 1996).

The preliminary screening of technical alternatives suitable to meet the planned end use application and health related requirements is carried out at this stage. The environmental feasibility of reuse projects is checked by studying the local environmental conditions such as climate, groundwater surface water quantity & quality, and geology of the area to overcome possible long-term effects of salts, nutrients and trace elements on soils and plants (Metcalf and Eddy, 1991). The institutional feasibility is carried out to provide a basis for justification of reuse projects and assess alternatives for financing reuse projects (USEPA, 1992).

(c) *Facilities planning is* the third stage in planning and is based on the actual field data obtained from the study area as shown in Table 2.10 and is discussed in detail by Asano and Mills (1990). Implementation of reuse projects is capital intensive and requires a detail analysis of all the financing alternatives (USEPA, 1992). Normally the government grants or developers contribute to the capital costs while O & M cost are normally generated by number of sources such as user charges, connection fees, and property taxes. Several cost recovery instruments such as increasing the demand for reclaimed water to enhance the sustainability of reclamation projects have been suggested by Doughman *et al.*, (1996).

Table 2.10 Outline Plan for Wastewater Reclamation and Reuse Facilities

1. ***Study area characteristics***

   geography, geology of the area, climate, hydrogeology – groundwater basins, surface water, land use pattern, population growth

2. ***Water supply facility***

   water supply source, quality and treatment; water use trends & customer price; ground water management; present and future water supply costs; future facility needs, fresh water alternatives if any

3. ***Wastewater characteristics***

   quality & quantity of wastewater generated and treated effluent; description of treatment facility; seasonal & hourly flow and quality variations; description of wastewater reuse if any; disposal practices or storage

4. ***Treatment requirements***: standards for discharge and reuse
5. ***Reclaimed water market assessment***
6. ***Project alternate analysis***

   water reclamation & pollution control alternatives; other water supply alternatives; pipeline route alternatives

7. ***Recommendation plan***:

   description of proposed facilities, preliminary design criteria, projected cost, potential users and their commitments, implementation & operation plan

8. ***Construction financing plan and revenue program***

   source and timing of funds, pricing policy and reclamation project costs.

(Source: Asano and Mills, 1990; Metcalf and Eddy 1991)

The current research is focused on the treatment alternatives feasibility study which is part of the 6th step i.e. project alternate analysis shown in the Table 2.10. The different steps involved in the treatment alternative feasibility study are discussed next while the different approaches taken by researchers for the same are discussed in Chapter 3.

2.7.1.1 Steps Involved in Treatment Alternatives Feasibility Study

In any wastewater reclamation and reuse scheme, treatment alternatives feasibility study includes three steps: (1) generation or synthesis of treatment alternatives, (2) evaluation and screening of these alternatives in terms of criteria such as cost, performance, reliability & so on and finally (3) selection of an optimum or sub-optimal alternatives for further evaluation in pilot plants.

Experienced design engineers have always carried out the first step i.e., generation of alternatives. The limitations of this would be that (1) the generation of alternatives can be biased as it is highly dependent on the designers knowledge, and (2) sometimes donor agencies have vested interest in promoting a particular technology (Finney & Gearheart, 1998) and thus more promising configuration can be overlooked (Rossman, 1989).

The second step involves evaluation where the alternatives are normally evaluated in terms of cost and performance. The alternatives that do not meet these criteria are removed in screening. The alternatives that pass this stage are then optimized to select the best and or next best options and this forms the third and final step in treatment alternative feasibility study. It is clear from the literature that several combinations of treatment technologies are capable of treating wastewater to any desired quality (Lazarova *et al.*, 2001). The selection of these technologies is dependent on many factors and is discussed in section 3.4.1 Screening several combinations to select an optimum alternative is an enormous task, as number of combinations needs to be evaluated for their performance, cost and other factors.

Researchers such as Lazarova *et al.*, (2001) have indicated that such optimization of integrated water management and planning requires new tools such as techno-economic models and decision-making tools to compare reuse options and treatment alternatives. It is at this stage that decision support systems such as the one developed under current study can assist decision makers in the selection of appropriate technologies for a given study area, and is further discussed in subsequent chapters.

2.8 Summary and Conclusions

Wastewater reclamation and reuse is becoming an integral part of many water resources management schemes allover the world to overcome water demand, pollution and discharge issues. Conventional treatment (i.e. primary and secondary) has been reported to be incapable of removing contaminants (including coliforms, parasites, dissolved solids like nitrates and phosphates, trace organics, and heavy metals) to levels suitable for reuse. Hence, tertiary treatment is necessary to render the wastewater suitable for most reuse applications.

The perusal of literature indicates that there are many technologies available for reducing the concentration of pathogens and other harmful constituents to acceptable levels and a number of systems have demonstrated that high quality of water can be produced. The evaluation and selection of appropriate treatment processes is very critical to the success of any wastewater reclamation projects as the treatment technologies are capital intensive. The reclaimed water could be used in many different ways. Reuse schemes are becoming popular in USA, Australia, Israel, Japan and Middle East as it can supplement the expensive seawater desalination plants and depleting ground water resources. The direct potable reuse project in Namibia has proven that reuse schemes can be a viable option even in developing countries.

Although some concerns about the safety of reclaimed water usage has been expressed by sections of the public in recent years; epidemiological and toxicological studies have shown that it is absolutely safe to use reclaimed water for both potable and non-potable applications. Researchers have concluded with proper management practices, health risk could be reduced to minimum.

Many countries have reuse regulations in place. The two main regulations that have been used as a basis for the formulation of local guidelines are WHO guidelines and Title 22. The perusal of different state and national guidelines has indicated that there is wide disparity in terms of the guideline values used, indicator organisms and the classification of different types of reuse. In Australia most states have set their own guidelines while a national guideline was released in 2000.

Most of the times the environmental benefits are overlooked and reuse schemes are mainly evaluated in terms of costs. Although reuse projects may be technically, environmental and economically feasible, it is necessary to determine the appropriateness of various components such as treatment process to ensure the success of the project. Hence, careful planning of wastewater reuse projects is necessary to deliver reclaimed water at a minimum cost and at minimum health risks to consumers.

Planning methodology involves the assessment of reuse opportunities, alternate treatment technologies and identification of potential consumer demand, and financial and regulatory requirements. Planning of reuse projects is carried out in three stages, which includes detailed study at conceptual level, feasibility and planning of facilities. One of the main objectives of the present study was to develop a decision support system to assist planners and wastewater managers in technical feasibility investigation i.e. preliminary screening of alternatives based on technical, economic and environmental aspects.

Water reuse projects involve interaction between various entities such as collection, treatment, distribution of wastewater, supplier of fresh and reclaimed water and the user. From the point of view of sustainability, holistic approach to regional water supply and wastewater management is to be given utmost priority. However there is a need for many more demonstration projects to induce confidence in public and to show that tertiary treatment are cost effective on a long-term basis and are reliable too. It can be concluded that a systematic planning approach is necessary for the success and sustainability of reuse projects.

In the next chapter a review of different models and techniques used for evaluation and selection of treatment processes are presented. While the following chapters describe how the current model was developed to carry out feasibility investigation of various treatment alternatives, which is one of the important steps in systematic planning of reuse schemes.

Chapter 3 Review of Reuse Models & Techniques

3.1 Introduction

The review of literature presented in Chapter 2, indicates that wastewater reclamation and reuse is a safe and environmentally friendly way of reducing pollution in addition to meeting water demand. As discussed in the last chapter, before using water for any reuse application it is necessary to treat wastewater to the criteria set by the local regulatory bodies. Currently there are a number of treatment sequences or configurations that can produce water of any desired quality water suitable for reuse.

With the growing number of efficient and innovative treatment processes, evaluation and selection of the appropriate sequence or configuration of treatment processes is a challenging task for designers, wastewater managers and planners (Yang & Kao, 1996). In addition to this, one can obtain enormous number of treatment combinations by changing various design or model parameters as illustrated by Chen & Beck (1997). On the other hand, there are growing concerns about how to handle the qualitative decisions made and multiobjective nature of the wastewater treatment system design (Liaw, 1987). Therefore, the question as to what is the most suitable treatment configuration for given conditions is a complex one.

Models are increasingly being used to plan and design many complex systems including wastewater treatment systems as they provide an effective framework for systematic and rapid evaluation & screening of alternatives (Orlob, 1992; Oron, 1996b). For over four decades, the system analysis approach, which includes modelling and mathematical and numerical optimisation techniques, has been developed for preliminary design and costing of wastewater treatment systems (Rossman, 1980 & 1989; Chen & Beck, 1997; Finney and Gearheart, 1998; Archer, 1982). Such models can enhance the designer's capability to objectively assess large number of alternatives in terms of performance and cost to find the best design parameters for a specific treatment alternative (Chang and Liaw, 1990). The use of these models can result in a reduction in the time and cost involved in the preliminary selection of processes appropriate for reuse (Evenson *et al.*, 1969). In addition they can be used to carry out sensitivity analyses of different design parameters (Liaw, 1987).

The selection and design of appropriate alternatives can be considered as a three-stage approach (Rossman, 1989). The first stage (also referred to as selection of treatment alternatives or techno-economic feasibility study) includes development of a list of feasible treatment trains that meet the required criteria and evaluation of the performance and cost of each alternative. The second stage involves pilot plant studies of the preliminary treatment schemes obtained. The third stage involves selecting the preferred alternative in order to carry out the detailed design. Since the model developed in the current study is focused on the first stage i.e. techno-economic feasibility investigation of treatment alternatives, models reviewed in this chapter will be primarily on this approach.

The purpose of this chapter is to present a review of models and techniques for generation, evaluation and optimisation of treatment alternatives. This chapter begins with an overview of reuse models, which are based on various issues such as the quantity, quality & cost of reclaimed water as well as planning and integrated water management. Next, reuse models developed for the techno-economic feasibility investigation of treatment alternatives are reviewed. For better understanding of the models & techniques developed and their limitations, they have been reviewed under the following headings: (1) models for synthesis of treatment alternatives, (2) different selection criteria and techniques, (3) models for optimisation of treatment alternative and different optimisation techniques used so far, and (4) a review of existing decision support systems and their limitations. Finally, summary and conclusions from this review is presented.

3.2 Overview of Reuse Models

Wastewater reclamation and reuse models integrate one or more of the different planning steps outlined in the previous chapter (Table 2.10). In this Section, an overview of the reuse models which encompasses the broad objectives of wastewater reuse planning such as quantity, quality and transportation issues are discussed while the models that are developed to generate and evaluate treatment options are discussed in Sections 3.3 to 3.6.

Bishop and Hendricks (1971), applied systems analysis for the first time to a water reuse problem. Later in the same year these authors outlined a methodology to assess the range of alternatives including water reuse in water supply development. Taur (1984) has reviewed works of several researchers on water planning models in the 1970's. Notable of them all was the application of modelling to evaluate a reuse scheme in Utah, USA by Bishop *et al.*, (1975).

Reuse models developed between the 1970's and early 1980's looked at transporting reclaimed water through the system at minimum total cost using linear cost function and ignoring the factors such as flow rate, demand growth rate (Fordham *et al.*, 1981) and water quality parameters. To overcome some of these limitations, Yang (1981) developed a hypothetical water reuse-planning model with BOD and TDS as critical components while Fordham *et al.*, (1981) incorporated time sequential decision process, hydrologic variability and seasonal demands into reuse planning. Further, Taur (1984) developed a large-scale deterministic (non-linear optimisation) model based on successive linear programming and generalized Benders decomposition. He determined the optimum (minimum cost) allocation of water and wastewater reuse on a regional basis using water quality and quantity constraints.

Thus reuse models developed up to late 1980's looked at various issues such as quantity, quality and minimization of costs as the major objectives of reuse. These models have proven that economic analysis has always been a strong driving force in decision-making as the main objective of optimisation studies has been to minimize the cost.

Until the early 1990's researchers had overlooked environmental and social factors, which also influence the success of reclamation projects in the optimisation process (Ellis and Tang, 1991). But in mid to late 1990's, a shift in paradigm occurred and an integrated management approach to reuse models was applied by researchers such as Edwards (1994), Chen and Beck (1997), Butler and Parkinson (1997), Newell *et al.*, (1998) and Oron (1996).

On the other hand, models were also developed for evaluating health risks associated with reuse (Mustafa, 1987and Tanaka *et al.*, 1998) and public perceptions of reuse schemes

(Rao, 1985). In 1980's researchers such as Turner (1981) and Mohorjy (1987) presented models with the objective of comprehensive water reuse planning to evaluate water reuse options.

Newell *et al.*, (1998) proposed to develop simple models from which complex integrated system models can be constructed for simulation and optimisation of sustainable urban water systems. These authors claimed that the key issue is defining a realistic objective function, which not only considers minimizing cost but also includes intangible factors such as public perception, acceptance, health risks, which are yet to be quantified and evaluated. Oron (1996) has used a similar integrative approach to wastewater treatment and reuse and has illustrated the different steps involved in the development of such models. He has suggested that reuse models are to be based on defining an objective function (generally the cost) to be optimised subject to technical (such as water quantity and quality), social, and environmental constraints. He has applied linear programming and has concluded that evaluation of a linear objective cost function against a series of technical, social, health, and environmental constraints can result in an optimal solution.

However, the integrative approach is a very broad overview of all the factors responsible for water resources management in a location. Such an approach does not deal in depth about treatment alternative feasibility, which is an important step in planning of reuse schemes (See Section 2.7.1.1). Hence the review and discussion in the following sections will be focused on models developed for treatment alternative feasibility study.

As discussed earlier in this chapter (Section 3.1), there are three stages involved in the wastewater treatment alternative study. The first stage i.e. treatment alternatives feasibility study includes three major steps namely: (1) generation or synthesis of treatment alternatives, (2) evaluation and screening of these alternatives in terms of criteria such as cost, performance, reliability & so on and finally (3) selection of an optimum or sub-optimal alternatives for further evaluation in pilot plants. The different steps involved in treatment alternative study are illustrated in Figure 3.1.

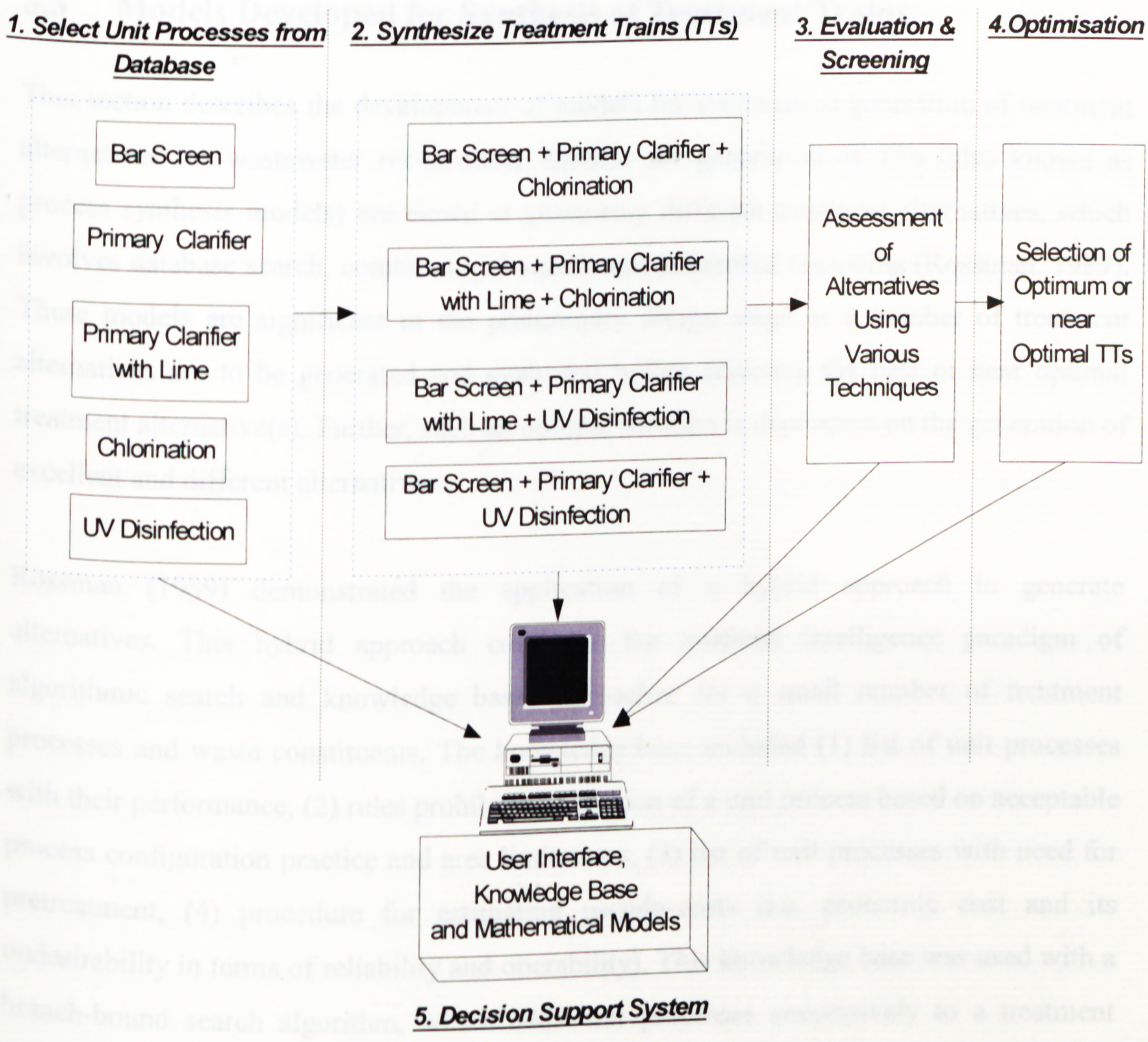


Figure 3.1 Steps Involved in Wastewater Treatment Alternative Study

Since the objective of this study is to integrate these different steps into a decision aid, the models developed for each of these steps as well as their merits and demerits are discussed next. Firstly the models developed for synthesis of treatment trains is discussed. Next, the criteria and techniques used for evaluation and screening of alternatives is reviewed. This is followed by a review of the models developed for optimisation of wastewater treatment systems and finally discussion on existing decision support systems and their limitations is presented.

3.3 Models Developed for Synthesis of Treatment Trains

This section describes the development of models for synthesis or generation of treatment alternatives for wastewater reclamation. Models for generation of TTs (also known as process synthesis models) are aimed at generating different treatment alternatives, which involves database search, combinatorial search and inferential reasoning (Rossman, 1989). These models are significant in the preliminary design stage as a number of treatment alternatives are to be generated and evaluated before selecting the best or near optimal treatment alternative(s). Further, such an optimal solution is dependent on the generation of excellent and different alternatives.

Rossman (1989) demonstrated the application of a hybrid approach to generate alternatives. This hybrid approach combines the artificial intelligence paradigm of algorithmic search and knowledge base approaches for a small number of treatment processes and waste constituents. The knowledge base included (1) list of unit processes with their performance, (2) rules prohibiting selection of a unit process based on acceptable process configuration practice and area limitations, (3) list of unit processes with need for pretreatment, (4) procedure for estimating pseudo-costs (i.e. economic cost and its undesirability in terms of reliability and operability). This knowledge base was used with a branch-bound search algorithm, which adds unit processes successively to a treatment alternative until the treatment goals are met. Further, a bounding condition was applied to prevent further addition of unit processes to alternatives whose psuedo costs exceeded the specified cut off level. The main drawback of this approach is that the user needs to specify a cut off level for the psuedo costs, which requires a prior knowledge of the same.

In 1991, Krovvidy *et al.*, applied a similar heuristic search approach to synthesize treatment trains using a new heuristic search function based on cost. An algorithm was used to construct decision trees and extract knowledge rules from the database. In addition, external rules from experts (such as 'IF ASP is in the TT then never use aerated lagoon in the same TT') were also integrated in to the system in order to include the interaction between different processes. The choice of the least cost technology was based on the heuristic cost function and the cost per unit removal of target toxicity by process 'j' was estimated using the following equation.

$$= \frac{Cj}{\sum_{k=1}^{n} w_k \alpha^{j}} \quad \text{.........(3.1)}$$

where a^j = certainty factor of the j^{th} unit process given by $(a_1 + a_2 + a_3 + ...+ a_n)/n$, where n is the number of compounds to be removed

C_j = cost incurred due to option j

w_k = weight factor of the k^{th} compound given by $(E_{ki} - E_{ki+1})$, where E_{ki} concentration of compound after i^{th} stage and E_{ki+1} concentration of compound k after j^{th} treatment option

The certainly factor 'a ' has been included to indicate the confidence on the unit process to remove a compound from the effluent stream and thus a higher certainty factor indicates higher certainty of its performance and greater the chance for its selection. Furthermore, they compared this heuristic search with Hopfield neural networks in terms of optimality of the solution and the process time taken and concluded the following: (1) heuristic approach produces optimal solution faster for smaller size problem while for large number of compounds or the high strength wastewater neural network produces quicker solution, and (2) it is difficult to identify the correct set of coefficients in neural network approach.

Another interesting application of knowledge based approach to selection and sequencing of hazardous wastewater treatment systems has been carried out by Evenson and Baetz (1994). They have used commercially available software Nexpert® to develop a DSS to assist facility designers and managers with generation of treatment sequences. They have considered 15 contaminants, 10 treatment processes and about 82 process screening rules to demonstrate their approach. The steps used by Evenson and Baetz in the selection and sequencing of alternative treatment systems are discussed next.

A list of candidate treatment processes is first prepared based on their capability to remove a contaminant present in the waste. Since one single process can treat one or more contaminants, repeated processes are deleted from the list. Further, the screening rules are used to evaluate and sequence the selected processes. The processes that do not meet these rules are deleted form the list. If after pruning there are no processes available in the list then that waste is said to have no complete treatment. It is worth noting here that hazardous waste streams differ from domestic waste in that hazardous waste streams (which come from different unit operations) are not usually combined and this model generates treatment sequences for different waste streams separately.

Chang and Liaw (1995) have compared two modelling-to-generate-alternatives (MGA) methods namely 'Efficient Random Generation' (ERG) and the generating and screening (G&S) method to generate 'good' and 'different' alternatives. In the ERG method, firstly the decision space is defined by considering the constraints (such as feasibility) and targets (such as total annual cost) of the objective function. Then a solution from this feasible and good decision space is located by randomly selecting unit processes (decision variables) and maximizing the objective function (i.e. sum of these variables) subject to constraints and targets. Next, reasonable approximation criteria were used to distinguish good alternatives from the poor ones. On the other hand, different alternatives were obtained by randomly selecting different objective functions to be maximized. This ERG method is different from simple random generation and has numerous advantages over the same. They are: 1) it always generates design alternative that are feasible, (2) it meets targets on modeled objectives & satisfies all constraints and (3) it can also generate unexpected solutions to a design problem.

The same authors have also applied the generating and screening (G & S) method, which first generates as many candidate solutions as possible. These solutions are then screened to select the best alternative by ranking them based on their relative difference. The relative difference was identified with respect to (1) unit process (i.e. two TTs may have different unit process like activated sludge process (ASP) & trickling filter) and (2) difference in level of treatment (i.e. two TTs may have the same unit process for example ASP with two different designs parameter such as mixed liquor suspended solids concentrations). The relative difference between two alternatives was calculated using the following equation:

$$\sum_i \left| x_{ij} - x_{ij+1} \right| + \sum_k w \left| x_{kj} - x_{kj+1} \right| \qquad (3.2)$$

where x_{ij} = i^{th} decision variable related to a unit process in the j^{th} solution

w = weight of the treatment level differences

x_{kj} = k^{th} decision variable related to level of treatment in the k^{th} solution

The weight of the treatment level difference was set lower as the differences in unit process are more significant. Chang and Liaw have concluded that for the example problem considered in their study, the G & S method was more efficient in generating 'different' alternatives than the ERG method. Further they have also shown that G & S and ERG methods are more efficient than the conventional constraint method and the EXEC /OP program developed by USEPA.

Computational screening is especially important for judging the potential effectiveness of a unit process within the wastewater treatment train. Chen and Beck (1997) have used Monte Carlo simulation to generate & screen different combinations of conventional (wastewater) unit processes with the emphasis on sustainability. Instead of considering one unique optimal solution, these authors have worked on identifying a relatively small number of good (but sub optimal) combinations of technologies. They have identified two hurdles for a screening analysis and they are: (1) an overwhelming multiplicity of technological combinations, and (2) gross uncertainty of performance, cost characteristics and criteria of sustainability for preferring one processes to the other.

3.4 Evaluation and Screening of Treatment Trains

As described in the previous section, the formation of TTs involves selection of unit processes to form acceptable process configurations. Factors such as reliability, cost, quality of effluent required and desired reuse application and standards are to be considered before selecting any unit processes (Metcalf and Eddy, 1991, pp 168, WEF Manual of Practice No. 8, 1998; and Qasim, 1999). Once the treatment alternatives are generated, it is necessary to evaluate and select the optimum or near optimal TTs for a given reuse and other local conditions. The traditional cost – benefit analysis alone cannot be applied to evaluate TT alternatives, as a number of factors such as reliability and ease of operation cannot be easily expressed in monetary units. Therefore, evaluation and screening of alternatives needs to be based on wide variety of criteria with emphasis on sustainable development.

In this section, different criteria normally considered for the evaluation and selection of treatment trains are first described. Next, the criteria that have been used by other researchers to evaluate treatment trains are discussed. Finally the techniques used for evaluation of TTs are discussed in Section 3.4.3.

3.4.1 Selection Criteria for Treatment Trains

Most of the research conducted up to the early 1990's was focused on least cost process evaluation indicating that cost has been the most important selection criteria. In recent years with emphasis on sustainability and protection of the environment more than 20 criteria have been used, although cost still remains as one of the most important selection criteria. In developing countries, the number of criteria used for the evaluation of TTs is large as a number of factors such as the availability of finance and resources such as skilled personnel are to be evaluated. Whereas in developed countries these factors are usually present and therefore the number of criteria used for TT evaluation may be less. Since the model in this research is developed for Australian conditions, the most widely used criteria in developed countries have been addressed in this Section and are listed in Table 3.1.

Table 3.1 The Most Common Criteria Used for Evaluation and Selection of TTs

SlNo	Selection Criteria
1	Cost of treatment
2	Effluent quality achieved and intended reuse application
3	Reliability
4	Land required
5	Ease of operation and maintenance
6	Resource requirement
7	Quantity and quality of sludge produced
8	Impact on environment
9	Adaptability

(Source: Adapted from Table 5.5, pp 168, Metcalf and Eddy, 1991)

A discussion on the above criteria and the methodology used to evaluate the same is presented in the following sections.

3.4.1.1 Cost of Treatment

As discussed earlier in this chapter, cost has been the single most commonly used criterion for selecting alternatives. The cost of a TT is estimated by adding the construction cost and annual operation & maintenance cost of all the unit processes in the TT as highlighted by Richard (1998) and are shown below.

- Capital costs = Σ cost of unit process + Σ [standby unit costs + storage costs + site development costs + costs for (process piping + liquid stream conduits linking units) + administration building costs + standby generator costs].
- O & M costs = Treatment plant operator salary + distribution facility operator salary + Power costs + chemical costs + equipment repair & maintenance* (* typically around 5 % of equipment initial costs and 2 % of capital costs for pipeline and storage tanks.)

Cost estimation has been the subject of study for over four decades and several researchers have developed cost equations to estimate unit process cost (Middlebrooks *et al*, 1982; Qasim *et al.*, 1992, Qasim, 1999, Gumerman *et al.*, 1986; Benjes, 1980; Finney and Gearheart, 1998; Richard, 1998).

All these researchers use more or less same methodology to estimate the cost. However, it is not possible to compare these costs as they all have either different design or cost assumptions or different types of equipment for a process and so on. Further, there is also inconsistency in the terminology used. For instance Qasim (1999) uses capital cost to indicate total construction cost plus the site facility cost and this does not include land cost. Whereas Benjes (1980) computes capital cost based on construction cost and land cost.

The cost estimation of treatment processes is a difficult task as it involves commercially sensitive information and it is hard to obtain cost information. As a number of local factors influence the cost, the equations developed are to be modified with local cost indices and or other appropriate factors.

3.4.1.2 Effluent Quality Achieved and Intended Reuse Application

The effluent quality achieved by a TT is dependent on many factors such as the type of process involved, removal efficiency and influent wastewater quality (Tchobanoglous, 1996). The intended reuse application dictates the quality of effluent required and is the basis for setting the reuse criteria.

While evaluating TT alternatives, the effluent quality achieved is to be compared with the reuse criteria to eliminate or identify TTs, which do not meet the same. For instance, in residential non-potable use, pathogens have to be removed to a level less than or equal to 10 No/100mL (based on SA reclaimed water guidelines, 1999). Hence focus is on the removal of SS and turbidity to enhance disinfection apart from improving the aesthetic quality of reclaimed water. For residential non-potable use, a combination of coagulation + flocculation or filtration + disinfection can be employed. On the other hand, for turf irrigation where the quality of effluent required is 10,000 FC /100mL or less, primary sedimentation with lagoons is found to be adequate.

Regulatory agencies like WHO, USEPA and many water authorities around the world have specified standards for the water quality parameters such as BOD, SS, FC, TN, TP and so on depending on the local environmental conditions and past reuse experiences (see Section 2.5). For instance, USEPA specifies BOD =10mg/L for urban reuse (such as vehicle washing, toilet flushing) whereas for the same reuse application, the South Australian reclaimed water guideline specifies a BOD value of < 20 mg/L. Hence, a urban reuse scheme in USA and South Australia may have different combination of treatment processes. Thus local regulations play a major role in the selection of treatment alternatives.

3.4.1.3 Reliability of Treatment Processes

The primary concern in reclaimed wastewater reuse is the reliability of treatment processes. The reliability is defined as the ability of the treatment system to consistently achieve a specified level of treatment, which is set as the basis for risk assessment (Metcalf and Eddy, 1991). The reliability of treatment processes should be an important part of the planning and design of wastewater reuse projects (Eisenberg *et al.*, 2001). This is to prevent the distribution of any inadequately treated wastewater due to process upset, power outrage or equipment failure, which poses potential health risk to consumers (USEPA, 1992). Hence highly reliable and proven technologies are to be selected in reuse schemes. In addition, novel technologies are to be selected only after extensive field studies.

It is difficult to quantify the reliability of processes, as accurate data on mechanical reliability and plant performance is often unavailable. Some researchers have worked on developing mathematical relationships for this (Metcalf and Eddy, 1991; Eisenberg *et al.*, 2001). In the absence of accurate data, it is quite common to rate the reliability of processes on an ordinal scale i.e. high, medium and low (Martin and Martin, 1991, pp 3-7; Qasim, 1999, pp.83). These reliability scores have been used to compare different TTs in this study as discussed in section 4.5.7.

3.4.1.4 Land Requirement

It is obvious that different unit processes will have different footprints and therefore the TTs, which contain different combinations of unit processes, will have different land requirements. In most urban areas the land availability is the most important factor next to cost (Metcalf and Eddy, 1991). Availability of land will affect the selection of land-based treatment processes such as aerobic lagoons, facultative pond, and wetlands and some conventional treatment processes such as trickling filters, as they require comparatively large area. However if land is available at reasonable cost, stabilization ponds and lagoons are the preferred treatment processes (USEPA, 1992; WHO, 1989). Therefore when evaluating TTs it is necessary to evaluate the land required and the land available at the WWTP site.

3.4.1.5 Ease of Operation and Maintenance

Many treatment processes such as biological nutrient removal and microfilters are complex to operate. Ease of operation and maintenance is a vital criterion; as most authorities would want trouble free operation conditions and minimum maintenance. Since it is difficult to quantify conditions for ease of operation and maintenance, this criterion is treated in a similar way to reliability and is normally rated on an ordinal scale.

3.4.1.6 Resource Requirements

Treatment trains require various types of resources for the construction, operation and maintenance phases. Resources can be broadly classified as human resources, material and equipment and these include chemicals, power and skilled personnel. Traditionally, in developed countries resources such as skilled personnel are assumed to be available and TTs are evaluated based on their chemical and power requirement. Further, the requirement of these resources for each unit process can vary widely and since data is not always available, it is common practice to use a qualitative scale for evaluation (Martin and Martin, 1991; Qasim, 1999).

3.4.1.7 Quantity and Quality of Sludge Produced

The quantity and quality of sludge produced is dependent on many factors including the type of processes involved and the influent wastewater quality. As the volume of sludge produced can significantly affect the overall cost of the treatment, it has been considered as one of the important criteria in TT alternative evaluation. Sludge handling and disposal costs varies depending on the volume, water content and the carbon (C), nitrogen (N) & phosphorus (P) content of sludge. The quantity of sludge is calculated by the sum of sludge produced by all the individual unit processes while the quality of sludge in terms of C, N and P is determined by a mass balance approach.

The quantity & quality of sludge produced varies in a TT and from one TT to the other TT, as some processes are more efficient in stabilizing sludge than others. This criterion is of significance especially in urban situations where land available for sludge disposal may be limited and odour caused by unstabilised sludge is considered as a nuisance.

3.4.1.8 Impact on Environment

This encompasses many sub criteria such as impact on surface and groundwater and air pollution due to odour generation. This criterion is important for reasons such as public health, aesthetics and protection of environment. An ordinal scale similar to reliability and ease of operation is also used to measure the impact on environment.

3.4.1.9 Adaptability

Adaptability of a TT to conditions such as varying influent quality, varying flow rate and upgrade are an important criterion to assess flexibility of a TT. Normally an ordinal scale or indices are developed to rate adaptability of different unit processes, which are then used to calculate the total adaptability score for a TT.

3.4.2 Selection Criteria Used by Other Researchers

Rossman (1980) has used the following evaluation criteria to compare alternatives: (1) cost, (2) energy requirements, (3) total land requirement and (4) subjective rating for different processes in terms of reliability, environmental impact, and public acceptance. On the other hand Ellis and Tang (1990,1994) have used 20 parameters including technical, economic, environmental and socio-cultural factors to rank treatment options for developing countries. Out of these 20 parameters only some parameters such as flow characteristics, influent and effluent quality, land cost, land availablity are of importance to developed countries like Australia. Other parameters like skilled personnel, training, power availability and reliability are all assumed to be present in countries with well developed infrastructure and education.

Chen and Beck (1997) have used a set of screening criteria to select appropriate primary and secondary wastewater treatment technologies and these included the following: (a) land area requirement, (b) capital and O & M costs, (c) odour emissions, (d) impact of process output on the environment, (e) robustness, (f) the volume and water content of sludge produced and (g) the amount of C, N, P in solid products. The authors have concluded that the above screening analysis has two main difficulties. They are the overwhelming multiplicity of technological combinations and the gross uncertainty of performance, cost characteristics and sustainability of the candidate technologies.

Mels *et al.*, (1999) have used criteria derived from a life cycle assessment methodology to evaluate sustainability of different processes. The criteria included energy usage, sludge production, effluent quality and chemicals & space requirements. The actual values of these criteria were compared for two test TT alternatives developed using a spreadsheet model called DEMAS (a Dutch abbreviation for designing and evaluation model for wastewater treatment scenarios). Although this approach provides a systematic approach for evaluation, the authors have not considered all of the technical and environmental criteria for evaluation.

Loetscher (1999) has used 50 technical, social and economic criteria to select appropriate sanitation alternatives in developing countries. An examination of these criteria indicated that they are more appropriate for developing countries as most of the criteria such as skilled personnel, expertise are hard to come by in developing countries whereas they are assumed to be present in most developed countries and socio –cultural factors.

Recently Balkema, *et al.,* (2001) developed a DSS, which used four sets of sustainability indicators for evaluation and screening of alternatives, and they are as follows:

1. functional criteria: included performance in terms of BOD, TS, TSS, N, P, FC and heavy metals, adaptability, durability, flexibility, maintenance and reliability
2. economic indicators: included cost, cost effectiveness and labor intensity
3. environmental indicators: included use of resources such as land, energy and emissions in terms of sludge and effluent quality achieved
4. socio- cultural indicators such as institutional requirements and acceptance.

On the other hand, Aramaki *et al.*, (2001) have used only cost as the criterion for evaluating reclaimed water reuse system as they consider it as the most important factor for implementation.

3.4.3 Screening and Ranking Techniques

As seen from the previous Sections 3.4.1 and 3.4.2, TT evaluation and selection involves multi-objective decision-making, as the objective is to select the best TT, which satisfies many criteria. Prior to the advent of multi objective decision-making, benefit cost analysis was used to compare alternatives. Drobny *et al.*, (1971) have provided an explanation on the use of benefit cost analysis and its limitations. As stated by these authors, it is obvious that benefit cost analysis cannot be applied whenever there are criteria that cannot be converted in to monetary units. In such instances there is a need to perform a trade off on multiple evaluation criteria while taking into account the users preferences or judgment (Goicoechea *et al.*, 1982).

An excellent review on the classification of multi-criteria decision making and the approaches used by many researchers for multi criteria problems have been highlighted by Malczewski (1999). The two most commonly used techniques to deal with multi criteria decision-making are the weighting and the constraint methods. Normally weights are assigned to express the relative importance of the criterion over other criteria. A number of criterion weighting procedure are in use and they are discussed in Section 4.8.2. Some freeware (Web-HIPRE, WINPRE, developed in University of Technology, Helsinki, Finland, http://www.hipre. hut.fi) and commercial software like Expert Choice ® (Expert Choice Inc., 1993), LOGICAL DECISIONS (Smith, 1994) and Which &Why (Arlington Software Inc., 1994, cited in Malcewicz, 1998) are available to express preferences or weights for a wide range of alternatives.

Although there are obvious advantages of multi-objective techniques, researchers have used singe objective function to evaluate TT alternatives, as they are simple and easy to implement. The different techniques used by researchers have been summarized in the following paragraphs.

Rossman (1980) used cost, energy and land requirements to carry out a quantitative comparison. Furthermore, a subjective system rating was given for non-quantifiable factors such as reliability, environmental impact and public acceptance by simply adding the subjective scores. As stated by Rossman this is a very crude approach to incorporate non-quantifiable factors. In 1996, von Sperling used a comparative analysis for selection of most frequently used treatment technologies in developing countries. His analysis was based on qualitative (1 to 5 star scoring), quantitative (per capita values) and schematic comparison. He has identified the following criteria as important for the selection of treatment technology: efficiency, reliability, sludge disposal, land requirement, environmental impacts, O & M costs, capital cost, sustainability and simplicity of construction. But such a comparative analysis is unsuitable for the current model development, as it is necessary to have one quantifiable score with which the genetic algorithms can work through a large number of iterations to get best solutions.

On the other hand, Okubo *et al.*, (1994), Ellis & Tang (1991) and Tang & Ellis (1994) have used a more structured approach based on the analytic hierarchy process (AHP, developed by Saaty, 1977). Okubo *et al.*, have developed a DSS for selecting the most appropriate small-scale (on-site) wastewater treatment plant process for given conditions such as population and budget. The evaluation parameters included pollutant removal efficiency, O & M and capital costs, reliability with respect to influent variations, temperature reliability, environmental impacts, and topography applicability. The AHP was used to rank the treatment processes.

Ellis and Tang (1991) & Tang and Ellis (1994) have considered AHP to optimise the treatment selection in developing countries. Twenty decision parameters such as flow, wastewater quality and the nature of site were used in this study. Decision variables included 46 sets of alternative treatment processes and using pairwise comparison a decision variable matrix for each of the decision parameters was developed. The AHP was used to obtain final ranking of treatment alternatives. However, the following disadvantages of the AHP technique has been identified: (1) pairwise comparison of each decision variable can become cumbersome when the alternatives considered are numerous, and (2) the use of AHP in the case of multiple copies of alternatives or irrelevant alternatives may cause rank reversal.

Finney and Gearheart (1998) have shown how the Delphi selection process can be used to rank TTs. The selection is based on six selection criteria namely: construction cost, O & M cost, land requirement and three adaptability indices such as adaptability to varying influent quality, hydraulic head and upgrade. The user can specify up to 7 water quality parameters to be tracked in each TT. For each criterion the decision maker can select a weight and for each criterion the model ranks the TTs from 0-10. Each of these criterion scores is then multiplied by the weights. The maximum point value for each TT is then calculated by the sum of all criterion weights multiplied by 10. For instance, if 3 is the sum of all the criterion weights for a TT then the point value is 30.

Bengtsson *et al.*,(1997); Emerson, *et al.*,(1995); Hellstrom, (1997); Lundin *et al.*, (1999); Mels *et al.*, (1999) and Otterphol, *et al.*, (1997) have all described different techniques that can be used for comparison of alternatives. However, only a few researchers have developed a methodology, which can be used to compare large number of alternatives, based on a multi disciplinary set of criteria. Loetscher (1999) has developed multi level amalgamation technique to compare sanitation alternatives in developing countries based on 50 socio-technical and economic criteria. According to Loetscher, the conventional method of combining number of criteria using the arithmetic mean can diminish the effect of an individual criterion when the number of criteria increases.

In the next section, models which incorporate one or more of these criteria to optimise the wastewater treatment selection, is presented.

3.5 Models for Optimisation of Wastewater Treatment Systems

In the past, optimisation models have been applied in the field of wastewater treatment under two main categories namely fixed system optimisation and system synthesis (Chang and Liaw, 1990). The fixed system optimisation involves determination of the optimum design parameters for unit process or a given wastewater treatment plant configuration whereas, system synthesis includes selection of the optimal treatment train from a set of alternatives. A number of optimisation techniques are reported to have been used for the above two categories and these include: (1) Linear programming, (2) Non-linear programming, (3) Dynamic programming, (4) Enumeration techniques, (5) Heuristic or rule-of-thumb technique, and (6) Fuzzy Logic.

Rossman (1980) has presented an excellent review of some of the optimisation techniques used in early 1960's to late 1970's. While Chang and Liaw (1990) have presented a complete review of different programming techniques and their limitations for both fixed system and system synthesis optimisation.

3.5.1 Models for Optimisation of Unit Process and WWTP design

Traditionally, optimisation techniques have been applied to obtain optimum design and they are referred to as fixed system optimisation techniques (Liaw, 1987). Almost all of the fixed system optimisation models reported so far are based on optimising the activated sludge process (ASP). Several models such as BIOWIN® are commercially available for modeling different design parameters of unit processes. A list of researchers who have worked on fixed system optimisation models can be found in Chang & Liaw (1990).

Dynamic programming (Evenson *et al.*, 1969) and stochastic dynamic programming (Ellis *et al.*, 1986) have been applied to optimise the selection of least cost unit process. Gall and Patry (1989) developed an expert system based on heuristic technique to optimise the operation of the activated sludge process. However, researchers in the late 1980's felt the need to develop optimisation models to consider all the unit process in the treatment plant as the unit processes should be considered in conjunction with other processes in the treatment train and not in isolation (Rossman 1980, Chen and Beck, 1997).

The majority of research on WWTP design optimisation has been on the application of different optimisation techniques to a conventional (secondary) treatment plant consisting of ASP. Uber *et al.*, (1990 a & b) has presented an excellent review of the minimum cost designs developed (between late 1960's to early 1990's) using different optimisation techniques for a conventional ASP plant consisting of primary clarifier, aeration tank and secondary clarifier.

Tyteca and Smeers (1981) applied nonlinear programming using the generalized reduced gradient algorithm for optimizing the design of a wastewater treatment plant with six treatment processes namely primary clarifier, ASP, secondary clarifier, sludge thickener, anaerobic digester and vacuum filter. Tang *et al.*, (1987a, b) have reviewed optimisation techniques such as geometric programming, decomposition and the generalized reduced gradient method for developing minimum cost design of a conventional plant which is same as the one used by Tyteca and Smeers (1981).

Traditionally the focus has been on minimum cost design of WWTP for a steady state condition. Such WWT systems are expected to perform consistently over a wide range of operating conditions while in practice it is not so. To overcome this uncertainty, Uber *et.al.*, (1990b) suggested a new design approach called as robust optimal design which included robustness measures to explicitly consider the effects of uncertainty on effluent values. This robust optimal design was used to generate alternative designs that represent the trade offs between total cost and robustness.

3.5.2 Models for Optimisation of Treatment Train Selection

In recent years number of computer-based models have been developed to aid in the selection of optimum or sub optimal treatment trains. They are discussed in this Section.

3.5.2.1 Linear Programming

Linear programming is used to determine the optimal solution for a linear objective function where all the constraints are linear functions of the design variables. Lyn *et al.*, (1962) were the first to apply a linear optimisation technique to select a TT alternative to minimize cost. Balkema *et al.*, (2001) has used the integer linear programming technique (where design variables can have only discrete or integer values) to optimise treatment alternatives. The objective function was defined as the weighted sum of the sustainability indicators such as adaptability, flexibility, cost, performance and land area requirement. Linear programming was found inadequate for the following two reasons: (1) a different formulation is required for each TT configuration and therefore it is not efficient when a number of alternatives are present and (2) wastewater treatment includes non-linear functions such as wastewater quality and flow rate (Chang and Liaw, 1990).

3.5.2.2 Non-Linear Programming

Non-linear optimisation models were developed between 1975 to the mid 1980's. These models were based on linear quantity constraints and non-linear quality constraints. Nonlinear 0-1 integer programming was applied by Rossman (1982) to develop a methodology for planning cost-effective pretreatment programs for integrated industrial and publicly owned municipal treatment works (POTW). Implicit enumeration has been applied to generate options and the steps involved in this technique are discussed below.

To begin with a very large optimal solution cost (V*) is assumed. A list of candidate solutions is formed by selecting the cheapest pre-treatment choices (available for all the industrial sources). After every selection of pretreatment choices, the solution is evaluated in terms of cost (V) and its feasibility in terms of effluent and sludge criteria for both industrial and POTW. If V = V* then last industrial source added is removed (referred to as last in first out - LIFO rule) and the pre-treatment option of some other source is assigned to its next highest cost level.

On the other hand, if the candidate solution is feasible and its cost is less than the assumed initial cost ($V < V^*$), this solution becomes the new optimal solution and the master list is updated. However if $V < V^*$ and the solution is infeasible then either (1) the highest level of pretreatment for that source is selected to make the solution feasible. If this doesn't yield a feasible solution then pretreatment choice for some source is raised to next higher cost level, or (2) a new source is added with its pretreatment choice set at lowest cost level.

When all the sources have been considered the next higher cost POTW option is used to form the next candidate solution. After all the POTW options are exhausted the algorithm terminates. Rossman (1982) has concluded that this technique is superior to complete enumeration as a good upper bound on the optimal solution is obtained quickly without compromising on the potential choices. However, Chang and Liaw (1990) have argued that nonlinear programming may not be efficient, as the global optimum may not be obtained.

3.5.2.3 Dynamic Programming

Shih and DeFilippi (1970) applied the decision inversion method in dynamic programming to identify the optimum types and combination of unit treatment processes that meet a specified performance level at minimum annual cost. Taur (1984) has reported that dynamic programming to water reuse planning was applied by Schwartz and Mays in 1983. The model developed by Schwartz and Mays looked at minimizing the treatment allocation cost and find least expensive combination of treatment alternatives. Although dynamic programming overcomes the disadvantages of linear programming it looses its efficiency when there are a large number of variables (Fordham *et al.*, 1981) as computational time increases exponentially with an increase in number of variables (Dandy and Warner, 1989).

3.5.2.4 Enumeration Techniques

Enumeration techniques are based on evaluating all possible treatment combinations from a given set of unit processes. Several types of enumeration techniques such as total enumeration (TE) and implicit enumeration (IE) have been used to eliminate infeasible treatment train and identify least cost treatment systems and they are discussed next.

The model developed by US Army Corps of Engineers and USEPA (1978) by name CAPDET (Computer Assisted Procedure for the Design and Evaluation of Wastewater Treatment Systems) used total enumeration algorithm to select feasible alternatives that meet given effluent standards and to rank the alternative based on present worth. This is one of the very popular models, which has been successfully used in facility planning. However CAPDET model has number of limitations and McGhee *et al.*, (1983) have discussed this in detail. One of the major limitations of CAPDET is that it requires large computation time when a large number of combinations of treatment are available. Therefore complete or total enumeration of alternatives for problems with large search space (such as wastewater treatment optimisation; Rossman, 1980) is not computationally efficient although it guarantees achieving an optimal result (Dandy *et al.*, 1993).

Further, in May 2001 a commercial, user-friendly version of CAPDET knows as CAPDET Works™ (www.hydromantis.com) was released by Hydromantis, Inc. This model is intended for design and costing of new wastewater treatment plants. Although this model can be used for Australian conditions with appropriate cost indices, it does not contain generation or optimisation modules nor different reuse options and guidelines applicable to Australian States.

Rossman (1980) applied implicit enumeration to develop treatment alternatives for liquid wastes and sludge handling. An application called EXEC/OP was developed to implement this technique, which interfaced with a treatment simulation package, developed by USEPA. On the other hand, Chang and Liaw (1990) have used bounded implicit enumeration to show that it requires less computer time and storage when compared to total enumeration technique. However, the main drawback of the implicit enumeration techniques is that such methods can exclude optimum solution from the search space although intuition and experience used may reduce computation time.

3.5.2.5 Heuristic Techniques

As discussed in Section 3.3, Rossman (1989); Krovvidy *et al.*, (1991) have applied heuristic search techniques to search for an optimal solution from several alternatives in the presence of many constraints. Since the solution search space is large, Krovvidy and Wee (1993) applied case-based reasoning (CBR) in conjunction with a heuristic search technique. The basic idea of CBR approach is to make use of old solutions while solving new problems to reduce the time taken to find the optimal solution. But the key problem for the CBR system is identifying the old solutions, which are similar to the current case. As some optimal solutions share partial solutions (i.e. some part of the TT may be common to two optimal solutions. for example: bar screen + grit chamber + primary clarifier) the cost of maximally difficult problem or a predetermined cost bound has been used to identify such solutions.

These authors have reported that the search effort is significantly reduced for CBR (as compared to A* search algorithm) and was found to perform well as the number of solutions solved increased. The time taken to find solutions improved with the number of cases in the case base (i.e. a database where the solutions are stored). They concluded that research needs to be carried out to identify how to forget old cases to control the growth of the case base.

3.5.2.6 Fuzzy Logic

A preliminary Fuzzy logic approach has been applied by Yang and Kao (1996) to develop an Expert system for selecting and sequencing unit processes with greater flexibility for the user to specify treatment objectives. These authors used the analysis and synthesis approach suggested by Krovvidy *et al.*, (1991). Similar to that defined by Krovvidy *et al.*, Yang and Kao have also considered a certainty factor, which allows the user to express the level of confidence or uncertainty of information provided by the performance database. In addition to this, the user can specify his or her preference for a particular process. The steps used in the fuzzy logic approach by Yang and Kao are explained below.

Using the information regarding the type and initial concentration of the contaminant, a list of candidate treatment units is generated by the system. Next, the user preference for a particular process is obtained through fuzzy rules. The fuzzy rules are basically IF-THEN statements and a typical rule is represented as follows: IF x is *high* AND y is *low* THEN z is *high*, where x, y, z stands for performance efficiency, construction cost and preference to the treatment technique. Based on the preference suggested by the user, the system selects a suitable process for each waste contaminant under each specified concentration level. The effluent concentration of the selected process is taken as the influent to the next process.

The above-mentioned steps are repeated until all the concentrations of waste contaminants meet their desired criteria. Finally, the optimal TT is established. The main drawback of this expert system is that the user can provide preference only in terms of cost, performance and also the certainty factor, but it overlooks important factors such as land area requirement, environmental impact and reliability criteria. Furthermore, as suggested by the authors, this model needs an improved knowledge base and cost estimation tools.

A comprehensive review of the optimisation techniques applied so far to wastewater process optimisation, WWTP design and system synthesis is summarized in Table 3.2 (a to d).

Table 3.2a Summary of Optimisation Techniques Applied for Wastewater Treatment

Researcher	Model Name	Type of Model	Technique Used			Integrates Wastewater and Sludge Treatment	Programming Language / Database Used	Objective
			Generation	Screening	Optimisation			
Lynn *et al*., (1962)*	-	CBS, WWR	-	-	LP	No	-	First application of optimisation techniques
Evenson *et al*., (1969)	-	CBS, IWWR	-	-	DP	Yes	-	To determine the treatment system with minimum annual cost among alternatives for cannery wastes
Shin & Krishnan (1969) and Shih & DeFilippi (1970)*	-	CBS,WWR	-	-	DP	Yes	-	Decision inversion method to identify optimum types and combination of unit processes meeting requirement at minimum cost
Ecker & McNamara(1971)*	-	CBS, IWWR	-	-	GP	No	-	To find least cost design
Mishra *et al*., (1973)	-	CBS,WWR	-	-	NLP using GKCHEN	-	-	To obtain best value of parameters for a given process configuration
CIRIA,(1973) & Bowden *et al*.,(1976)*	STOM	CBS, WWR	-	-	NLP	Yes	-	Model to find the least cost alternative from all possible feasible combinations
US Army Corps of Engineers, (1976)	CAPDET	CBS,WWR	TE	-	-	Yes	-	Model to assist in design, cost estimation and evaluation of wastewater treatment facilities at planning level
Rossman (1979,1980)	EXEC/OP	CBS,WWR	IE	-	-	Yes	FORTRAN	To generate alternatives using Implicit Enumeration to find optimal design and next best designs
Tyteca and Smeers (1981)	-	CBS,WWR	-	-	GRG	-	-	Optimal design of preselected TT configuration (primary clarifier + ASP + digester + vacuum filter + thickener)

Table 3.2b Summary of Optimisation Techniques Applied for Wastewater Treatment (Contd.)

Researcher	Model Name	Type of Model	Technique Used			Integrates Wastewater and sludge treatment	Programming Language / Database Used	Objective
			Generation	Screening	Optimisation			
Rossman (1982)	-	CBS,WWR	IE	-	NLIP (0-1)	Yes	FORTRAN	To develop cost effective pretreatment program for removal of toxic pollutants in municipal wastewater systems
Camara *et al*, (1985)	TREAT	CBS, WWR	Heuristic	-	DP	-	FORTRAN IV	To generate treatment alternatives
Taur (1984)	-	CBS, WWRR	-	-	SLP and GBD	-	NA	Regional scale water reuse model to determine optimum allocation of water and reuse
Ellis *et al*., (1985)	-	CBS, IWR	Monte Carlo Simulation	heuristic based on max. permissible influent concentration	SDP	-	-	To delineate least cost industrial wastewater treatment sequences
Chang & Liaw (1985)	-	CBS,WR	MGA methods namely ERG, G& S	rank solutions based on relative differences like different unit process	EXEC/OP v. 1.2	-	EXEC/OP - FORTRAN,	Evaluate two MGA methods for generating good and different preliminary designs for a typical wastewater treatment plant
Rossman (1989a)	-	CBS, WWR	Heuristic	-	-	-	PROLOG	Generation of alternative treatment configurations using AI approach
Williams (1990)	-	DSS, IWWR	-	-	NLP, GAMS	-	-	Development of multiple objective decision technique to select the 'best' option for water & wastewater reuse for an industry
Ellis & Tang (1991)	-	CBS,WWR	-	AHP	-	-	-	Use of intangible factors apart from cost and performance in the selection of optimal or most appropriate system

Table 3.2c Summary of Optimisation Techniques Applied for Wastewater Treatment (Contd.)

Researcher	Model Name	Type of Model	Technique Used: Generation	Technique Used: Screening	Technique Used: Optimisation	Integrates Wastewater and sludge treatment	Programming Language / Database Used	Objective
Krovvidy *et al*., (1991)	-	CBS, WWR	Heuristic	-	Hopfield neural network	No	LEX, YACC and C language with interface to dbase III	An artificial intelligence approach for generating and optimising wastewater treatment systems
Uber et al., (1992)	-	CBS,ADWR	MGA, robust optimal design	-	-	-	-	Use of MGA and robust optimal design for generating alternative techniques
Krovvidy and Wee (1993)	-	CBS, WWR	CBR for heuristic search	-	-	-	-	Application of case based reasoning approach to expedite the search for wastewater treatment alternative.
Mendes (1994)	IWM	DSS, IWWR	heuristic	-	-	-	MS Visual C v1.0 and Pascal for multicriteria decision algorithms	A DSS for the management of industrial wastes treatment and disposal
Evenson (1992) and Evenson & Baetz (1994)	HAZ-MAN	CBS, HWR	heuristic search	82 screening rules based on heuristics	-	-	Nexpert® written in C	A knowledge based approach to selection and sequencing of hazardous waste treatment processes, number of alternatives dependent on number of hazardous waste streams
Okubo *et al*., (1994)	-	DSS, WWR	-	AHP	-	-	-	DSS for selecting an appropriate small scale wastewater treatment process from a list of processes using pairwise comparison (AHP technique)
Oron(1996)	-	CBS, WWRR	-	-	LP	Yes	-	Management modelling for optimal wastewater treatment , disposal and reuse
Chen & Beck (1997)	-	CBS, WWR	Monte Carlo Simulation	Ranking using objectives & criteria	-	-	-	Generating and screening of alternatives

Table 3.2d Summary of Optimisation Techniques Applied for Wastewater Treatment (Contd.)

Researcher	Model Name	Type of Model	Technique Used			Integrates Wastewater and sludge treatment	Programming Language / Database Used	Objective
			Generation	Screening	Optimisation			
Finney & Gearheart (1998)	WAWTTAR	DSS, WWRR	-	Delphi process	-	Yes	Visual Basic® and MS Access®	Appropriate selection of technologies for wastewater reuse in developing countries, Number of alternatives dependent on user
Loetscher (1999)	SANEX®	DSS, DT	-	Multilevel amalgamation Technique	-	-	Visual Basic* and MS Access®	DSS containing over 80 sanitation alternatives and assessment based on 50 criteria including technical, social and economic criteria using multi level amalgamation
Balkema *et al*., (2001)	-	DSS, IM	-	-	IP	Yes	Matlab simulink, Spreadsheet	DSS to compare wide variety of domestic water systems using a multi disciplinary set of sustainability indicators, user to generate options
Hydromantis Corporation (2001)	CAPDET Works ™	CBS,WWR	-	-	-	Yes	C	Assist in design of Wastewater treatment plants, user to generate options

Note:
* Cited in Rossman(1980)

ADWR: Alternative designs for wastewater reclamation
AHP: Analytic Hierarchy process
BIE: Bounded implicit enumeration
CBR: Case based reasoning
CBS: Computer based system
DP: Dynamic programming
DT: decentralized treatment
ERG: Efficient random generation
ES: Expert system
EXEC/OP : program developed by USEPA
G & S: Generating and screening
GAMS: General algebraic modelling system
GBD: Generalized benders decomposition
GKCHEN: Optimization subroutine package developed by Chen
GP: Geometric programming
GRG: Generalized reduced gradient
HWR: Hazardous waste treatment
IE: Implicit Enumeration
IM: Integrated model of water supply and domestic water use
IP: Integer Programming
IWM- Industrial Waste Management System
IWWR: Industrial wastewater reclamation
LP: Linear programming
MGA: Modelling to generate alternatives
NA- No Information Available
NLIP: Non linear integer programming
NLP: Non linear programming
SDP: Stochastic dynamic programming
SLP: Successive linear programming
TE: Total Enumeration
WWR: Wastewater reclamation
WWRR: Wastewater reclamation Reuse

It is clear that selection of appropriate treatment for wastewater reclamation and reuse is a complex problem, which requires consideration of different unit processes, generation and optimisation of large number of alternatives. Due to advances in computer technology and understanding of the complex systems like wastewater treatment design, mathematical models such as those discussed in the previous sections are now being applied to assist decision makers.

One or more of the different steps involved in the TT feasibility study namely generation, evaluation and optimisation are combined along with knowledge base and interactive user interface in to one computerized system known as decision support systems (DSS). The DSS provide comprehensive and structured approach to complex problems making the evaluation process more explicit. In the next section a brief introduction to the DSS and its application in wastewater reuse systems is presented. Then, a description of the existing decision aids and their limitations are discussed.

3.6 Decision Support Systems for Wastewater Reclamation & Reuse

Decision support systems (DSS) have been defined as interactive computer based systems, which facilitate complex decision-making by providing reasoning support through database & mathematical optimisation based on the strengths of human designers (Davis, 1998; Orlob, 1992; pp 301; Newell *et al.*, 1998). The supporting role of DSS is highlighted by the definition of Janssen (1990, Cited in Loetscher, 1999) below:

> '*A computer program that assists individuals or groups of individuals in their decision processes, supports rather than replaces judgment of these individuals and improves the effectiveness rather than the efficiency of a decision process*'.

DSS have been applied to many complex environmental problems by several researchers (Rossman, 1989). These include feasibility assessment of different wastewater reclamation alternatives. The different components of a decision support system are illustrated in Figure 3.2.

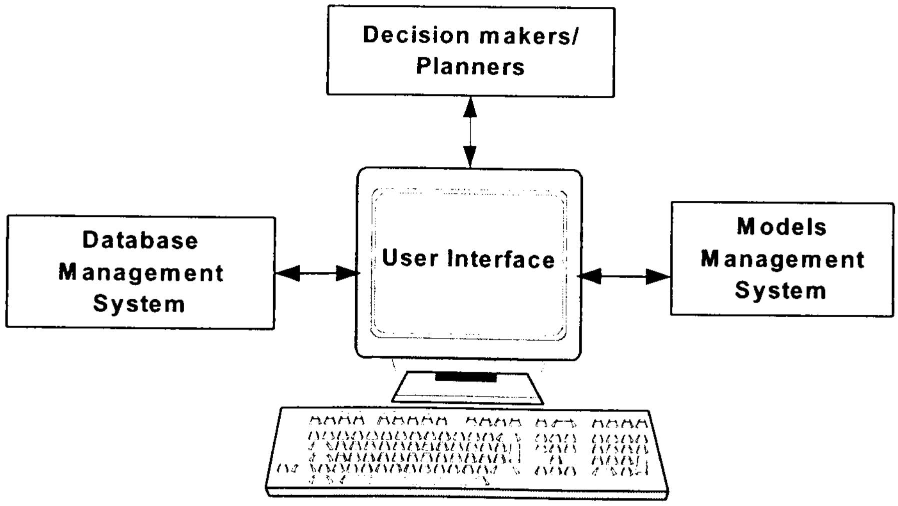


Figure 3.2 A Typical Decision Support System

A DSS can aid planners and engineers in answering questions such as 'what are the possible alternatives?'; 'which is the best alternative for given conditions?' and 'what are the performance and cost of a TT if an alternative process is used?'. There are many advantages of using a DSS for generation, evaluation and optimisation of TTs. They are listed below:

1. It can be used for analysis of "what if" scenarios
2. The user can change assumed design parameters or removal efficiencies and see the difference in cost and performance almost immediately.
3. It has a knowledge base that the user can access and update easily through user interface.
4. An increased number of alternatives can be examined using DSS.
5. It has a structured approach to generation, evaluation and optimisation and results will be consistent.
6. It can be used for ad-hoc analysis of TTs.
7. It can be less time consuming than the traditional "rule of thumb" approach.
8. It can be used to optimise TT selection

DSSs developed for wastewater reclamation are discussed in the following paragraphs. Okubo *et al.*, (1994) developed a DSS for selecting the most appropriate small-scale (on-site) wastewater treatment plant process for given conditions such as population and a budget using analytic hierarchy process (AHP, developed by Saaty in 1977). Further in the same year Mendes (1994) reported the development of a DSS for industrial waste management named IWM (Industrial **W**aste **M**anagement system) by the Joint Research Center, European Commission. The main objective of this model was to reduce the overall impact on man, environment and economy caused due to industrial waste disposal and treatment facilities in the region. In this model different alternatives were evaluated using heuristic algorithms.

A DSS named SANEX ® was developed by Loetscher (1999) to evaluate appropriate low cost sanitation alternatives for developing countries using a novel approach called multi-level amalgamation. Recently, Balkema *et al.*, (2001) has developed a DSS for selection of sustainable small-scale treatment options for domestic wastewater treatment using sustainability indicators. The unique feature of this model is that the user can decide to implement either a wastewater treatment system, a sanitation system or a complete water system (supply, sanitation, transport and treatment). This model has an evaluation and an optimisation model based on integer programming. However this model includes only basic processes such as settling, biodegradation and chemical reactions and the user has to generate treatment options.

Water resources planners and engineers have acknowledged the need for a decision support system that would evaluate different reclamation technologies and assist in the selection of appropriate technology for a given reuse application. Archer (1982) developed a DSS for water reuse assessment called 'Waste.Val' which can be used to assess relative costs and energy implications of municipal treatment and disposal alternatives. With the objective of evaluating reclamation technologies, various researchers (Davis *et al.*, 1998, Newell *et al.*, 1998, and White, 1998) have initiated model development.

Recently Loetscher and Keller (2001) have developed a DSS named WaterGuide ™ as part of Queensland Water Recycling Strategy (an initiative of the Queensland EPA, Australia). This DSS aims at assisting planners, beneficiaries and the public in assessing suitability of water reuse alternatives. This model is unique in its approach, as an attempt has been made to integrate the public/beneficiaries in to the decision-making processes to enhance the success rate of reuse schemes. However, this model does not include the generation and optimisation of treatment alternatives.

An extensive literature search was carried out for DSS that integrates the three steps of feasibility study namely generation, evaluation, and optimisation of TTs (discussed in Section 3.3) for various reuse applications. Review of published literature has indicated that no DSS has been developed so far with all the three steps for evaluation of treatment options for wastewater reclamation and reuse. However there is only one DSS named WAWTTAR (developed by Finney and Gearheart, 1998) in which the user can generate TT options and the model will evaluate and display the feasible alternatives appropriate for water, wastewater reclamation and reuse. The salient features and attributes of this model are discussed in the next section.

3.6.1 WAWTTAR

Finney and Gearheart (1998) developed WAWTTAR for the environmental health project (sponsored by US Agency for International Development). WAWTTAR stands for **W**ater **A**nd **W**astewater **T**reatment **T**echnologies **A**ppropriate for **R**euse. This model was developed with the aim of assisting planners in improving sanitation coverage in rural and developing areas. In this model user needs to generate alternatives and the model will evaluate and select the best alternatives appropriate for reuse. WAWTTAR evaluates the technologies based on local materials, manpower and resource capabilities of rural areas and developing countries and thus mainly includes low cost sanitation alternatives. The Visual Basic™ programming language was used to develop this model with a graphic interface for interactive usage.

The analysis in this model includes following steps:

1. User inputs performance standards, material costs, raw water and wastewater quality, community needs and capabilities, planning horizon.
2. User then constructs several possible treatment trains from the database.
3. WAWTTAR screens these treatment trains based on needs, resources, and capabilities and discards infeasible alternatives.
4. This model calculates the performance, costs of the feasible treatment trains.
5. The selection criteria in WAWTTAR are based on construction costs, O & M costs, land requirements, adaptability to influent quality, varying hydraulic head, and adaptability to upgrades.

6. The values of any seven water quality parameters (listed in database) are tracked through each treatment train.
7. The output of the model contains (1) the feasible treatment train's indices of adaptability to upgrade, varying flow rate and changes in influent quality, (2) solids production rate of each unit process, (3) final effluent quality of the requested constituents for each of the feasible TT.

3.6.1.1 Limitations of WAWTTAR Model

The following limitations of WAWTTAR model have been identified.

1. The model doesn't select treatment trains to be optimised. The user must select processes and arrange them in a logical order. While this allows the flexibility for the user to select the TT, the number and types of alternative treatment trains evaluated is limited by the users knowledge.
2. The model doesn't directly analyze the response of treatment systems to variable influent conditions. However, sensitivity can be explored by multiple trials of treatment systems with different influent quality.
3. The model doesn't evaluate treatment technologies for the upgrade of existing plants.
4. The model is intended primarily for developing countries.

3.7 Summary

The feasibility investigation of any wastewater reclamation and reuse schemes involve a study of treatment alternatives appropriate for a given reuse application(s). Such analyses involves three steps namely generation, evaluation and optimisation of alternatives. This chapter presents an overview of the mathematical models and optimisation techniques developed for each of these steps. In the past, optimisation techniques have been applied to a limited number of conventional treatment processes either for single process design or design of optimum TT. The existing wastewater treatment optimisation models apply techniques such as linear programming, non-linear programming, dynamic programming, enumeration, heuristics and fuzzy logic to select optimum TT. The salient features of the model developed by different researchers including the optimisation techniques used are summarized in Table 3.2 (a to d). Furthermore, the perusal of literature indicates that so far genetic algorithms have not been applied for wastewater treatment optimisation.

Researchers until early 1990's did not consider the intangible factors such as ease of construction and adaptability to varying flow rate in modelling and selection of alternatives. As the concern for reused wastewater increased, it raised several issues such as level of treatment, reliability, transportation, storage costs, and associated health risks. In summary, the research carried out in the preliminary selection of TT alternatives has laid the groundwork for the development of decision aids for wastewater reclamation and reuse. Very few researchers have used models for wide range of technical, economic and social aspects of wastewater reclamation and reuse (Okubo *et al.*, 1994; Finney and Gearheart, 1998).

There is only one decision support system developed so far with the objective of selecting appropriate treatment train for wastewater reclamation and reuse. This system is named WAWTTAR and has several limitations. In this model TT alternatives are to be generated by user and thus alternatives are limited to the users knowledge. Further this model does not include upgrade or generation and optimisation modules.

3.8 Conclusions

Several limitations of the current research and models developed are summarized below.

- The models in the past have used a very limited number of conventional treatment processes and pollutants for testing hypothesis of generation, evaluation and optimisation.
- The data such as performance, cost and other criteria are not readily available and hence many researchers have used the USEPA treatability database for testing. The limitations of the development of cost database have been identified by many researchers.
- The heuristic rules used for the generation of alternatives are neither reported nor discussed in the literature.

- Important intangible factors such as public acceptance, health risks, and environmental impacts associated with reuse have received attention, but are yet to be quantified and evaluated.
- WAWTTAR - the only DSS available for evaluation of wastewater reclamation alternatives does not include optimisation and upgrade modules
- None of the models discussed except WAWTTAR has included evaluation of reclamation technologies for various reuse applications as an important decision variable in their studies.
- No model has been developed yet which considers upgrade options for existing plants.
- In recent years researchers have pointed out that cost should not be the only criteria for the evaluation and selection of TTs as other intangible factors need to be considered.
- There is wide variation in the type and number of criteria used for the evaluation of TTs and until now there is no standardized methodology to evaluate TTs.
- An optimisation technique based on genetic algorithms has not been applied so far to generate and optimise TTs.
- None of the models discussed so far have combined generation, evaluation and optimisation of wastewater reclamation technologies appropriate for a given reuse.
- A DSS with the objective of generation, evaluation and optimisation of wastewater reclamation alternatives has not yet been developed for Australian conditions

Therefore the current research is focused on combining generation, evaluation and optimisation of wastewater reclamation technologies into a DSS. In the following chapters the development of such a DSS incorporating all the three components namely generation, evaluation and optimisation of reclamation technologies for various reuse applications is presented. In Chapter 4, an overview of the development of the DSS with the database design (consisting of reuse applications and guidelines of Australian states, cost, performance and sustainability criteria values for selected unit processes), and evaluation techniques are discussed. While in Chapter 5, the generation and optimisation of alternatives using genetic algorithms is discussed.

Chapter 4 Development of MOSTWATAR

4.1 Introduction

Wastewater reclamation and reuse schemes are complex, capital intensive projects the success of which depends on many factors including the quality of reclaimed water, the reliability of the treatment processes and, above all, public acceptance. In order to increase the public acceptance and satisfy the required water quality criteria at minimal cost, a holistic approach to the evaluation of alternative treatment technologies is necessary. Traditionally, the evaluation of treatment alternatives was based on economic considerations alone (Qasim, 1999) and economics were often over emphasised in the evaluation process (Martin and Martin, 1991).

However in recent years with an increased interest in the sustainability of treatment alternatives and environmental protection, the evaluation of alternatives is now based on a combination of the economics and effectiveness of treatment alternatives (Qasim, 1999). As many measures of effectiveness cannot be expressed directly in monetary terms, the traditional approach of cost benefit analysis cannot be applied. In such a case, decision makers (DM) must make a rational choice of alternatives by weighing many diverse factors.

In the past, the selection of the most suitable treatment technology for a given site has been based on experience and judgement. This process has grown more complex and time consuming due to an increase in the number of innovative and effective technologies available. This has created the need for a systematic methodology to select effective treatment alternatives. As discussed in the previous chapter, decision support systems (DSS) can aid in a systematic and rational approach to the selection of effective treatment processes. In addition, DSS have been identified to combine the knowledge of experienced planners and the DM with computer technology to improve the quality of decisions made.

The two main objectives of this research were to develop a DSS named MOSTWATAR to: (1) assist the user to generate and evaluate treatment alternatives for both new and upgrade of existing plants for a given reuse(s) & location and (2) to generate and select the best five (near optimal) treatment alternatives using an optimisation algorithm.

The purpose of this chapter is to present the methodology used to develop the MOSTWATAR model. Firstly, an introduction to the MOSTWATAR model and its structure is presented. Secondly, the rationale behind the selection of the software language for model development is discussed. Thirdly, the salient features of the database and methodology adopted for the development of the same are presented. Fourthly, the criteria and the technique used for techno-economic evaluation of treatment trains are presented. At the end of this chapter an example calculation and results from the model for two simple treatment trains (TTs) are presented. Finally, discussion and conclusions based on this chapter are presented.

4.2 MOSTWATAR Model and its Objectives

MOSTWATAR is a reuse facility planning model with a user-friendly interface developed to assist a DM in the techno- economic evaluation and optimisation of treatment options for given reuse and other local conditions. MOSTWATAR stands for Model for Optimum Selection of Technologies for WAstewater Treatment And Reuse.

The model developed includes both liquid and sludge treatment processes. An important and unique feature of this model is that it has an optimisation module which can be used to generate and optimise treatment trains for given conditions. This feature enables users to compare the alternatives that they generate with those generated by the model. The MOSTWATAR model is based on non-potable applications, as regulatory authorities in Australia currently do not approve potable reuse (Anderson, 1996a).

The specific goals of this research are to develop the following.

1. A database consisting of
   (a) steady state estimate of the removal efficiencies of unit processes

(b) qualitative criteria or effectiveness measures (such as reliability and ease of operation & maintenance) for each of the unit processes

2. A knowledge base consisting of
   (a) different non-potable reuse types and guidelines applicable in different states of Australia
   (b) equations for determining the size requirements of selected unit processes.
   (c) equations for estimating the cost of selected unit processes
   (d) rules for generation of alternative treatment trains (TTs)
   (e) screening rules to ensure that the influent quality to certain unit processes does not exceed the maximum allowable quality.
3. A methodology for the evaluation of user specified TTs in terms of cost, performance and effectiveness measures for both new wastewater treatment plants (WWTP) and their upgrade.
4. An optimisation module based on genetic algorithms for
   (a) generation, evaluation and optimisation of treatment train alternatives for given local conditions.

Therefore, MOSTWATAR model can be used to address the following five primary questions:

1. Which is the best treatment train out of the alternatives specified by the user for a given influent, type of reuse and other local conditions?
2. What are the acceptable treatment alternatives that can be formed with the available database of unit processes for a given influent, type of reuse and other local conditions?
3. What is the best combination of processes for upgrade out of the options specified by the user to meet the reuse criteria?
4. What are the best five treatment trains for a given influent, type of reuse and other local conditions?
5. What are the optimum combinations of processes that could be added on to an existing treatment plant to meet the reuse criteria?

In this chapter the first three questions concerning the methodology developed to evaluate user generated options are addressed while the remaining questions regarding generation and optimisation are addressed in the Chapter 5. The software used to develop this model and the structure of the program is described in the following sections.

4.3 Software Used

MOSTWATAR has been developed as a single user desktop application with a user-friendly interface. The selection of an appropriate development tool or programming language is not straight forward as it depends on the objective, type of features required and intended use of the application The two commonly used rapid application development tools are Borland Delphi™ and Microsoft Visual Basic™.

Borland Delphi™ 4.0 was chosen as it is considered to be a powerful and superior development tool (because of its better compiler and more efficient use of resources) compared to Microsoft Visual Basic™ (D'Spirito, 2001). Furthermore, Delphi™ has an in built flexible database called Paradox. Therefore, the graphical user interface and the database for this model were developed using Delphi™ 4.0. However, MOSTWATAR doesn't require the user to have Delphi™ on the system to run the application. The minimum system requirements and the instructions for the installation of the model are discussed in the Chapter 6 and are presented in Table H.1 (See Appendix H).

4.4 Structure of MOSTWATAR

A simplified structure of the MOSTWATAR model is presented in Figure 4.1. MOSTWATAR consists of the following basic components.

1. User interface- Input /Output
2. Knowledge base
3. Database, and
4. GA model base

Each of the above components is briefly described in the following sections.

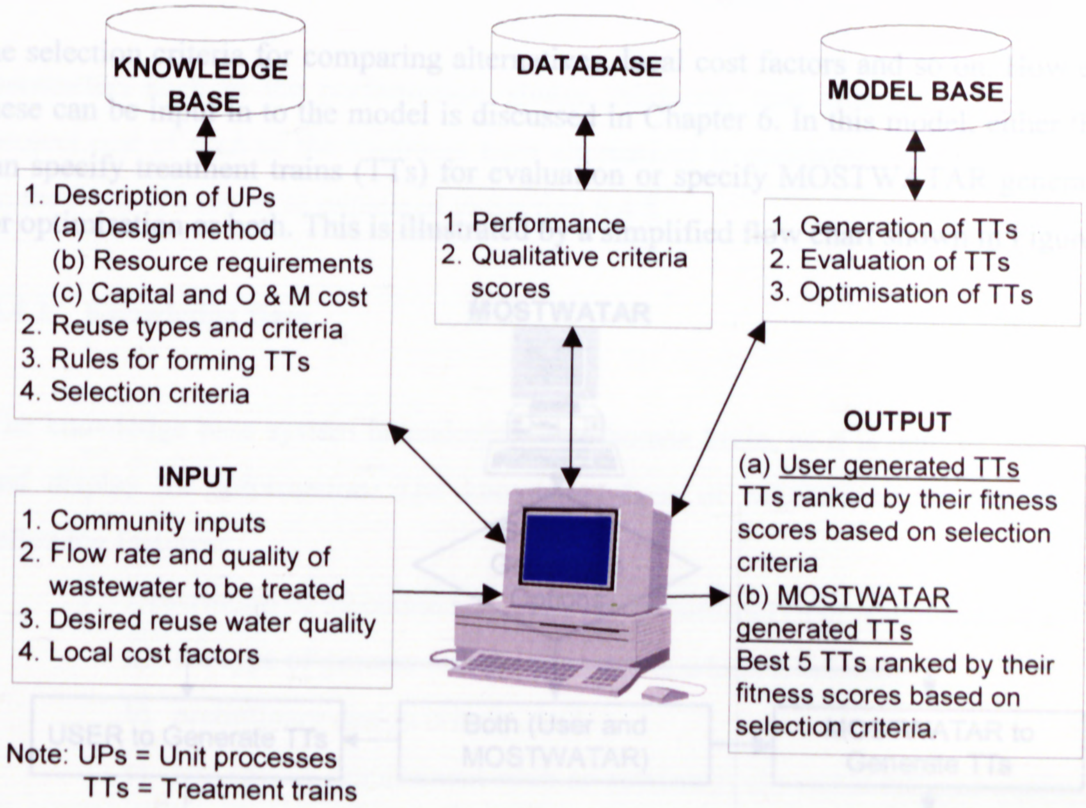


Figure 4.1 Structure of the MOSTWATAR model

4.4.1 User Interface

A graphical user interface has been developed to enable the user to input site-specific conditions such as type of plant, wastewater characteristics, desired reuse and so on. The key to the success of any DSS lies in having a user-friendly interface. In order to increase the acceptance by users it is necessary to develop a user interface, which is easy to use and understand (Turban, 1993). MOSTWATAR has been developed with a user-friendly interface to enable users even with limited computer knowledge to use this model successfully. It is developed as a "point and click" type or a "wizard like" application as it is known to have high user preference. The hints and the directions are provided in each screen and further information can be obtained from clicking on the help button.

4.4.1.1 Input

MOSTWATAR requires the user to input site specific parameters such as type of plant (new or upgrade), estimated design population, influent wastewater quality, per capita wastewater generation, desired reuse(s), reuse guidelines to be used, relative weights for the selection criteria for comparing alternatives, local cost factors and so on. How each of these can be input in to the model is discussed in Chapter 6. In this model, either the user can specify treatment trains (TTs) for evaluation or specify MOSTWATAR generate TTs for optimisation or both. This is illustrated by a simplified flow chart shown in Figure 4.2.

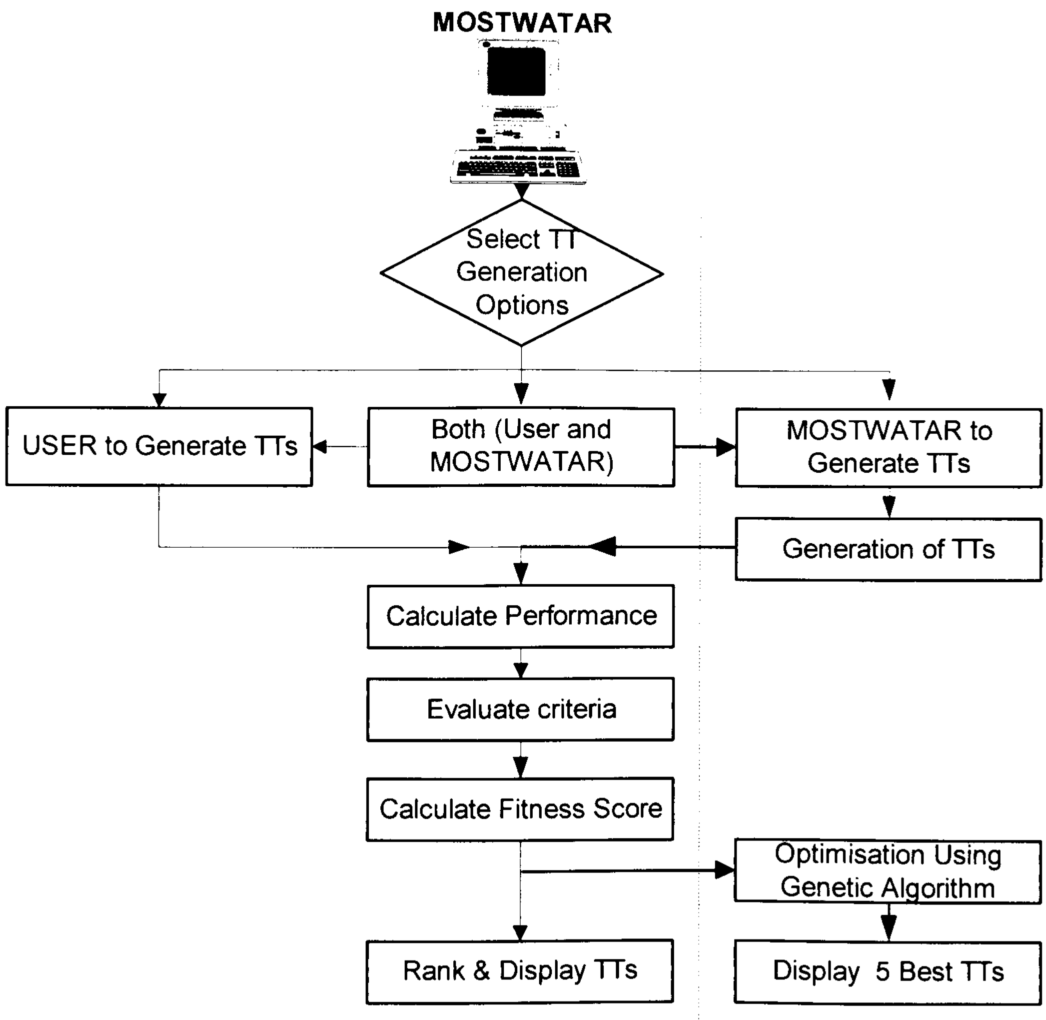


Figure 4.2 A Simplified Flow Chart Depicting the Options for TT Formation

4.4.1.2 Output

The output of MOSTWATAR depends on the types of options used to generate TTs. The output from user specified TTs includes the TTs ranked by their fitness score or any other criteria such as maximum performance or minimum land area selected by the user. On the other hand, the output from the MOSTWATAR generated TTs includes the best five treatment trains ranked by their fitness score. If the user selects both the above options then both the outputs described above are displayed to the user for comparison. The various parameters such as the performance, sludge produced, land area requirement and total project cost of each of the treatment train alternatives is presented and this can be printed in the form of a report as explained in Section 6.4.8.

4.4.2 Knowledge Base

The knowledge base system is analogous to a human brain, as it is used to store, retrieve and display the information. The knowledge base of MOSTWATAR consists of the following features:

1. Description of 40 commonly used unit processes (UPs) which consist of
   a) the type of process and the category to which it belongs,
   b) preliminary design criteria, and
   c) any special requirement such as maximum allowable influent quality, depth of ground water or maximum allowable rainfall for the proper functioning of the unit processes.
2. Various types of non-potable reuse applications (such as landscape irrigation, golf course irrigation) and reuse criteria or guidelines applicable to different Australian states (see Appendix G).
3. Rules for the formation of acceptable treatment train (TT) alternatives.
4. Selection criteria to evaluate and select the best TT alternatives.

4.4.3 Database

The MOSTWATAR database consists of the following features.

1. performance of individual unit processes in terms of minimum, maximum and average removal efficiencies,
2. capital and operation & maintenance (O & M) cost of each unit process as a function of hydraulic or organic loading for different capacities ranging from 1,000 to 10,000 m^3/d (equivalent to 5,000 to 50,000 population based on average wastewater generation rate of 200 litres per capita per day, lpcd), and
3. qualitative scores for each unit process in the database for criteria such as reliability, adaptability to upgrade and so on.

4.4.4 GA Model Base

The genetic algorithm (GA) model base is a generation and optimisation module developed using an algorithm based on Darwin's theory of natural selection. The GA model base consists of the following four basic components:

1. generation of TT alternatives using the rules for the formation of acceptable process configurations
2. evaluation of TT alternatives for performance, cost and effectiveness measures
3. calculation of fitness scores
4. selection of the best five TT alternatives for given conditions using genetic algorithms

In the next chapter a brief background on genetic algorithms and the methodology used for the development of algorithm is presented. While the user interface development is discussed in Chapter 6. In the following sections, the methodology used to develop the knowledge base and database is discussed in detail.

4.5 Knowledge Base Development

This section focuses on the development of the following: (1) types and categories of wastewater reclamation processes, (2) preliminary design criteria, (3) cost estimation methodology, (4) reuse types and guidelines, (5) rules for forming TT alternatives, and (6) criteria for evaluation and selection of TTs.

4.5.1 Wastewater Reclamation Processes

The most commonly used wastewater reclamation processes in South Australia have been included in the knowledge base as it is not practical nor the objective of this study to develop a knowledge base of the entire range of available unit processes. These processes were selected in consultation with SA Water with due consideration to (1) processes that are applicable to South Australian conditions, (2) novel processes which appear to be promising, and (3) processes for which design, cost and performance data were available. In order to collect data on the performance, design and cost of unit processes, a questionnaire was sent out to leading wastewater equipment manufacturers in Australia. A copy of the questionnaire along with the list of companies who responded is presented in Appendix C. In addition to this, information was gathered through a wide variety of sources including :(1) text books such as Metcalf & Eddy (1979 & 1991), Qasim (1999), WEF Manual of Practice (1998), (2) published papers and reports such as Qasim *et al* (1992), Mara (1992) and (3) personal communications with SA Water personnel & reuse experts.

Wastewater reclamation processes (referred to as unit processes or UPs) have been classified into the six basic types shown in Table 4.1. Each type of process has a unique process type identification number (abbreviated as PTID) such as 1,2,..to 6. For instance, PTID 1 represents primary process while PTID 2 represents secondary process. Each of these process types is further classified into categories as shown in Table 4.1. For example a disinfection process is divided in to 4 categories namely natural, chemical, physical, and post disinfection process.

A unique category identification number (CatID) is assigned to each of these categories. For example, CatID of 11 represents the first category in the primary process type (whose PTID is 1) while CatID 12 represents the second category in the primary process type. Under each of these categories, one or more type of unit processes is included. Since the idea was to develop a framework and demonstrate the methodology for generation, evaluation and optimisation, not all the categories have unit processes in the current database as shown in Table 4.1. The framework was developed to enable users to update the database at a later time.

As stated earlier in Section 4.2, one of the objectives of this study was to generate acceptable TTs, which can be optimised. Therefore the order of these categories and type of process is very important in the formation of acceptable TTs. Although it is obvious that tertiary processes should follow secondary and primary treatment, the order of the process within each type of process is dependent on the designer's choice. For instance some designers use break point chlorination before lime treatment while others use it after lime treatment.

Table 4.1 Classification & Type of Unit Processes Included in Database

PTID	Process Type	CatID	Type of Category	UIDNo	Process Name
1	*Primary Process*	11	Screens – Coarse, Medium & Fine	1100	Bar Screen (BS)
				1101	Fine Screen (FS)
		12	Grit chamber	1200	Grit Chamber (GC)
		13	Preliminary package unit	-	-
		14	Flotation	-	-
		15	Gravity sedimentation	1500	Primary Clarifier (PC)
		16	Chemical assisted sedimentation	1600	Primary Clarifier w lime (PCwlime)
		17	Fine screen	-	-
		18	Primary package units	-	-
2	*Secondary Process*	21	Attached growth reactors	2100	TF, Rock Media, w Clarifier (TFR)
				2101	TF, Plastic Media, w Clarifier (TFP)
		22	Suspended growth reactors	2200	Conventional ASP, w Clarifier (ASP)
				2201	ASP w Ni and Clarifier (ASP w Ni)
		23	SBR and package plants	2300	SBR (SBR)
		24	Ponds / Lagoon	2400	Anaerobic Lagoon (An L)
				2401	Facultative Pond (FP)
				2402	Aerobic Lagoon (A L)
				2403	Aerated Lagoon (Aer L)
		25	Sedimentation ponds/ Secondary clarifiers /polishing lagoons	2500	Secondary Clarifier (SC)
				2501	Sedimentation Pond (SP)
3	*Natural Treat–ment Process*	31	Constructed wetlands	3100	SSF Wetland (SSF, BOD)
				3101	FWS Wetland (FWS, BOD & Ni)
				3102	FWS Wetland (FWS, BOD)
4	*Tertiary Process*	41	N & P removal	4100	Continuous Flow BNR (BNR)
		42	P removal	4200	Single Stage Lime Treatment (SSLT)
				4201	Two Stage Lime Treatment (TSLT)
		43	N removal	4300	Break Point Chlorination (BPChl)
		44	Coagulation and flocculation	4400	Coagulation & Flocculation (CF)
				4401	Coag, Flocc & Sedimentation (CFS)
		45	Sand filters	4500	Sand Filter (SF)
				4501	Dual Media Filter (DMF)
		46	Microstrainers/ micro screens	-	-
		47	Membrane filters	4700	Microfiltration (MF)
		48	Carbon adsorption	4800	Granular Activated Carbon (GAC)
		49	Desalination using membranes	4900	Reverse Osmosis (RO)
5	*Disinfection*	51	Natural disinfection	5100	Maturation Pond (MP)
		52	Chemical disinfection	5200	Chlorination (Chl)
		53	Physical disinfection	5300	Ultraviolet Disinfection (UV)
		54	Post disinfection	5400	Post Chlorination (PostChl)
6	*Sludge Treatment Process*	61	Sludge thickeners	6100	Gravity Thickener (GT)
		62	Sludge digesters	6200	Anaerobic Digester (AnDig)
		63	Sludge drying	6300	Belt Filter Press (BFP)
				6301	Sludge Drying Beds (SDB)
		64	Sludge disposal	6400	Land Spreading of Sludge (LSS)
				6401	Land Filling of Sludge (LFS)

In this study since the aim was to generate acceptable configurations the order of processes was arrived at based on the most commonly used configurations (Biebrick, 2001 & Lewis 2001) and based on treatment flow diagrams presented in references such as Richard (1998, pp1344-1354), Metcalf & Eddy (1979 & 1991) and Tchobanoglous (1996).

A unit process can have a number from 00 to 99 and thus each category can have a maximum of 100 unit processes. A unique unit process identification number (abbreviated as UIDNo) is given for each unit process to identify the type of process and the category to which it belongs. For example a UIDNo of 1100 represents the first process (i.e. bar screen) under screen category and a type of primary process in the database.

The first two digits therefore indicates process type ID and category ID respectively while the last two digits represent the number of the process, which can vary from 00 to 99. In Table 4.1, the abbreviations used for each of these unit processes are indicated within brackets after each process name.

4.5.1.1 Primary Processes

These include processes, which are typically the first step in treating wastewater, and are based on physical processes such as sedimentation. In the current study the preliminary processes such as screening (for removal of large objects), grit removal (for removal of abrasive material such as grit and shells), have been included under primary process type. In addition to these processes, primary processes also include primary sedimentation, with or without chemical addition.

Since the late 1990's, fixed or rotary fine screens are also being used after or in place of primary sedimentation to enhance the removal of suspended solids (SS) in USA (WEF, 1998; Vol.1). Although use of fine screens after primary sedimentation is not yet popular in Australia they may be considered in future for new WWTP. Hence a category of fine screens has been included after primary sedimentation. The categories and different types of unit processes included in the database are listed in Table 4.1.

4.5.1.2 Secondary Processes

Secondary processes also known as biological processes follow primary processes. The most commonly used biological processes are waste stabilization ponds, activated sludge process (ASP) and trickling filter (TF). In recent years biological nutrient removal (BNR) and sequential batch reactors (SBR) are becoming popular in Australia due to higher discharge requirements (Hartley, 1998). Eleven different types of secondary processes have been included in the database as shown in Table 4.1. There are many types of ASP based on the operational characteristics as discussed in Metcalf and Eddy (1991, pp 549). However in the present database the most commonly used processes such as conventional ASP with mechanical aerator and ASP with nitrification (i.e. single stage nitrification) are considered.

In the current database, the ASP and TF unit processes include a secondary clarifier. However a secondary clarifier is included as a separate process in the database to enable the user to include it with new processes. In recent years, nutrient removal is becoming part of secondary treatment and some designers consider BNR as a secondary process as it is replacing ASP in many WWTP. However in the current database BNR is considered as a tertiary process under the category of removal of nitrogen (N) and phosphorus (P). Nevertheless a rule is set up in such a way that BNR could also be used as a secondary process (See Rule No.7, Section 4.5.5.1). The different types of lagoons included are anaerobic, facultative, aerobic and aerated lagoon. They have been commonly used in most of the existing plants in South Australia. In addition to these, a sedimentation pond is included which can be used as a polishing lagoon.

4.5.1.3 Natural Treatment Processes

Natural treatment systems include constructed wetlands. These systems are regarded as an environmentally friendly alternative to energy intensive processes for treating municipal & industrial wastewater and even stormwater. Constructed wetlands are capable of removing pollutants such as SS, BOD, nutrients, pathogens, heavy metals and other toxic pollutants by physical (settling), chemical (oxidation) and biological (micro and macro fauna and flora) processes. Wetlands are becoming popular in Australia because of their advantages over other conventional processes in terms of lower operating cost and greater intangible benefits such as habitat creation and public interest (Mitchell *et al.*, 1998). Thus, constructed wetlands can be used for both wastewater treatment and habitat creation.

In the current study the constructed wetlands are considered as a secondary wastewater treatment system and are classified as natural treatment system. The two main types of wetlands are subsurface flow (SSF) and free water surface (FWS) wetlands. SSF are more appropriate for treating primary wastewater while FWS are more appropriate for polishing secondary and tertiary effluent and for habitat development. The design of these wetlands can be based on BOD and nitrification and accordingly three types of wetlands (as shown in Table 4.1) are considered.

4.5.1.4 Tertiary Processes

There are 11 tertiary processes in the database and are considered as the principal unit processes for tertiary treatment. As discussed earlier, BNR is becoming popular for both new plants and the upgrade of existing plants in Australia. There are many different types of BNR processes (such as 3 stage and 5 stage processes) and proprietary systems such as Bardenpho™ are available. BNR is a highly complex process and needs a detailed design. However for this planning level estimate, design and cost data reported in UWRAA report on BNR plants (Report No.94, Hartley, 1995) and Hartley (1998) have been used.

Single and two stage lime treatment processes have been included for the removal of phosphorus while the most commonly used process for removal of nitrogen namely break point chlorination, is also included. Coagulation, flocculation and sedimentation (CFS) using alum is commonly used as a pre-treatment to media filtration process as they require influent SS to be less than 30 mg/L. This process has been included under the coagulation and flocculation category.

Two types of media filter, namely single and dual media filters, are included as they are commonly used for tertiary filtration of wastewater. Although micro filtration (MF) and reverse osmosis (RO) are not common in Australia for wastewater treatment due to high capital and operating costs, they are being evaluated for new treatment plants as well as upgrade of some existing plants (Willshire, 1999). Therefore these processes have been included in the database. The use of granular activated carbon (GAC) for wastewater treatment is not popular Australia. But this process has been included as it is commonly used in most reuse demonstration plants in USA and is also being pilot tested in a demonstration plant in Queensland.

4.5.1.5 Disinfection

As discussed by Hamilton (1996) the most commonly used disinfection processes in Australia include chlorination and UV disinfection and these have been included in the current database. Furthermore, most of the existing plants have maturation ponds or polishing lagoons to enhance disinfection. Therefore, a maturation pond is also included. Since residual chorine may be preferred for reticulation systems post chlorination has also been included in the database.

4.5.1.6 Sludge Treatment Processes

Sludge treatment processes have been categorised as discussed in Section 2.2. The two commonly used processes namely gravity thickener and single stage high rate anaerobic digesters are included under the thickening and stabilisation categories respectively. Until recently, sludge disposal alternatives were not considered for TT evaluation and a lump sum provision was made for the same.

In South Australia, utilisation of biosolids (also known as land spreading) is becoming popular to improve the quality of soil for a range of agricultural and landscaping applications. Currently any biosolids utilisation has to be approved by the South Australian EPA after soil surveys and analyses (http://www.sawater.sa.gov.au/About_SA_Water/index.html). Since sludge handling and disposal was not the main objective of this study, it is assumed that necessary guidelines/licence conditions are met and that there is sufficient land available for land spreading and land filling of sludge.

For each of the unit processes described above, design criteria, capital costs and O & M costs were developed and they are discussed in Sections 4.5.3 to 4.5.5. As discussed previously, MOSTWATAR model has three options for the generation of TTs i.e. the user can specify or request MOSTWATAR to generate TTs or use both the options to generate

TTs. In the next section, rules set up in the knowledge base for the generation of TTs by the model are discussed.

4.5.2 Rules for Generation & Evaluation of TT Alternatives

Rules for TT generation and evaluation form a major part of the knowledge base development in the MOSTWATAR model. The rules are necessary for the following reasons: (1) to prohibit the formation of absurd or unacceptable process configurations, (2) to configure TTs based on site specific factors, and (3) to check if the required pre-treatment or the maximum allowable influent quality requirement for a unit process are met.

For these reasons, three sets of rules were developed. The first set of rules i.e. rules based on acceptable process configurations apply to TTs, that are generated by MOSTWATAR. While, it is assumed that the user will form acceptable TTs for evaluation. The remaining two rules, namely rules based on site-specific factors and maximum allowable influent quality, are applicable for both user and MOSTWATAR generated TTs. The development of these rules is discussed in detail in the following sections.

4.5.2.1 Rules Based on an Acceptable Process Configuration

In order to prevent formation of unacceptable or illogical treatment trains (i.e. TTs that are not practical) it is necessary to check each TT string after generation with the rules set up in the database. The definition of what constitutes an acceptable process configuration differs widely from designer to designer. For instance a TT with series or parallel combinations of SSF and FWS wetlands is said to be acceptable to enhance the treatment (Mitchell *et al.*, 1998, pp 258) while some designers consider two types of wetland in a single TT as unnecessary and therefore as unacceptable. Hence it is difficult to develop rules that can satisfy every designer's perspective.

One alternative for such a situation is to allow the user to specify what combinations are acceptable to him or her. This is accomplished in the model by allowing the user to form TTs for evaluation. But since the objective of this study was to demonstrate the application of GAs for generation and optimisation of TTs, it was necessary to form as many acceptable combinations as possible. Such combinations were then optimised based on cost and other factors using GAs as described in Section 5.4.

The rules for this study were developed with the aid of the literature (Metcalf and Eddy, 1991; Qasim, 1999; Benjes, 1980) and in consultation with SA Water and equipment manufacturers. In order to have greater flexibility when new processes are added, rules were developed based on unit process category and process specific rules (for sensitive processes such as RO and MF). These rules are described below.

Category Specific rules:

Rule No.1: TTs cannot have more than ONE process from any category except screen, lagoons and constructed wetlands.

Implication: a). a TT cannot have both TFR and TFP in the same TT

b). both coarse and fine screens can be present in the same TT

c). a TT can have series of lagoons such as AnL and FP.

Justification: As described in Section 4.5.1, unit processes have been categorized based on their primary function, i.e. removal of SS, BOD, TN, TP and so on. Therefore there is no need to have two processes from the same category except when processes from screens, lagoons and wetlands are involved. It is a common practice to use one or more type of lagoons and or natural treatment processes (SF and FWS wetlands) in series to enhance the pollutant removal capabilities.

Rule No.2: If fine screen is present then a bar screen must also be present in a TT.

Implication: a) If fine screen is present in a TT then a bar screen must precede fine screen.

Justification: WEF Manual of Practice (1998, pp 10-57) indicates that a coarse (bar) screen must be present prior to a fine screen in order to protect the fine screen. In addition to this, coarse screens are essential in bypass channels to protect the downstream process equipment in case of mechanical failure.

Rule No.3: TTs must have a process selected from either screens or preliminary package unit but they both cannot coexist.

Implication: a) a TT must have either bar screen or bar screen & fine screen or preliminary package unit but cannot have all of them.

Justification: It is necessary for all TTs to have preliminary treatment i.e. screening and/or grit removal to protect the downstream equipment. Therefore either separate units or proprietary preliminary package units (which combines screening and grit removal) must be present in all TTs.

Rule No.4: TTs can have a process from either grit removal or preliminary package unit both they cannot have both.

Implication: a) If a TT has a grit removal unit then that TT cannot have package unit based on screen and grit removal.

Justification: Same as in Rule No.3

Rule No.5: All TTs generated must have only ONE of the following processes: PC, PClime, primary package unit or SBR

Justification: All TTs must have one primary sedimentation process except when SBR is present. SBR processes are single reactor processes, which normally do not require sedimentation as pre-treatment.

Rule No.6: If secondary processes namely TF, and/ or ASP or ASP w Ni is present then ONE of the following must be present: .PC, PClime, primary package unit

Implication: a) a TT must have a primary sedimentation process if it has either TF and/ or ASP or ASP w Ni process.

Justification: Secondary processes must precede primary processes in any TT.

Rule No.7: BNR can be selected instead of a secondary process (TF or ASP) or can be selected in conjunction with one of the secondary processes such as TF.

Implication: a) BNR can be used both as a secondary process and as a tertiary process

Justification: As discussed in Section 4.5.1.2, BNR processes are replacing the traditional TF or ASP process, to meet the stringent N & P discharge requirements. Therefore it could be used in place of secondary process or in addition to the other secondary processes to enhance the N & P removal.

Rule No.8: If only lagoons are present then secondary clarifier cannot exist.

Implication: a) a TT with AnL, FP and a secondary clarifier is not acceptable

Justification: There is no need for secondary clarifier when lagoons are selected. If polishing of effluent is necessary then sedimentation ponds can be used as post treatment to lagoons.

Rule No.9: If a post chlorination process is present then ONE of the processes from: physical or natural disinfection process categories must be present

Implication: a) a TT can have PChl only if it has processes such as MP or UV

Justification: Post chlorination as the name suggests is used to provide residual disinfection and therefore can be used in conjunction with other disinfection processes and but cannot provide sufficient disinfection on its own. Furthermore, the Chl process does not require PChl as the chlorine dosage used is quite high.

Rule No.10: If sludge digesters are selected then one of the following must be present: PC, PC wLime, TF, ASP, BNR, or SBR.

Implication: a) If a TT has a digester then one of the above-mentioned process is to be selected.

Justification: The sludge generated in lagoons and natural systems are designed to be removed once in 3-5 yrs (frequency may be less in practice) and further, more the sludge is usually stabilized dried and disposed of. Therefore processes such as PC, PClime or TF must be present.

Rule No.11: TTs must have ONE process each from the sludge drying and sludge disposal categories except when only lagoons or wetlands are selected in a TT.

Implication: a) a TT without any sludge drying or disposal process is not acceptable except when only lagoons or wetlands are present in a TT.

Justification: Since all TT alternatives generate sludge it is necessary to include sludge drying and disposal process as a default. As discussed in Section 4.5.1.6, sludge drying and disposal alternatives are to be considered for evaluation. This rule will be overruled if a TT consists of only lagoons or wetlands where sludge removal frequency is between 3-5 years.

Rule No.12: If a TT has PC or PC w lime then SBR is not allowed

Implication: a) a TT with PC and SBR is not acceptable

Justification: SBR is a single reactor treatment and therefore there is no need to have TF or ASP.

Rule No.13: If a TT has a process selected from the sand or membrane filtration or granular activated carbon category then TTs cannot have maturation pond as a disinfection process.

Implication: a) TTs in which sand filter is followed by maturation pond is not acceptable

Justification: Sand or membrane filtration produce high quality water and therefore disinfection by chlorination or UV is preferred.

Process Specific Rules:

Rule No.14: If TFR, TFP or ASP is present then SBR cannot exist.

Implication: a) a TT with TFR or TFP and SBR process is not acceptable

Justification: SBR is a complete treatment in itself, that replaces TF and ASP, and therefore the presence of these processes in a TT is not necessary.

Rule No.15: If TFR or TFP or ASP or ASP w Ni is present then secondary clarifier cannot be present.

Implication: a) a TT with TFR or TFP and a secondary clarifier is not acceptable

Justification: As these processes in the current database include a secondary clarifier

Rule No.16: If ASP or ASP w Ni is present then AnL cannot be present.

Implication: a) a TT with ASP and An L or ASP Ni and An L is not acceptable

Justification: The wastewater treated in ASP or ASP Ni is of higher quality and there is no need to treat it in AnL.

Rule No.17: If AnL is present then either FP, AL, or AerL must be present.

Implication: a) a TT with AnL & FP is acceptable

Justification: It is common practice to treat wastewater in series of lagoons to achieve better effluent quality.

Rule No.18: If FP, AL is present then secondary clarifier cannot be present.

Implication: a) a TT with FP and a secondary clarifier is not acceptable

Justification: There is no need for secondary clarifier if FP is selected, as the wastewater will be in quiescent condition in FP.

Rule No.19: If AerL is present then SP must be present.

Implication: a) a TT with AerL must have a SP.

Justification: The effluent from AerL needs to be settled to remove SS.

Rule No.20: SSF and FWS wetlands can be present in series.

Implication: a) a TT with either SSF or FWS or SSF and FWS is acceptable

Justification: SSF and FWS wetlands can be constructed in series to enhance treatment capability (Mitchell *et al.*, 1998)

Rule No.21:If SBR is present then secondary clarifier cannot be present.

Implication: a) a TT with SBR and a secondary clarifier is not acceptable

Justification: SBR is complete treatment in itself and has a settling zone.

Rule No.22: If RO is selected then MF cannot exist.

Implication: a) a TT with RO and MF is not acceptable

Justification: MF is not necessary if RO is selected as cross membrane filters are included as a pre-treatment to commercially available RO systems

Rule No.23: If chlorination process is present then UV cannot exist in the TT.

Implication: a) a TT with Chl and UV is not acceptable

Justification: It is not necessary to have both these types of disinfection.

Rule No.24: If UV is present then post chlorination can exist

Implication: a) a TT with UV and PostChl is acceptable

Justification: PostChl is desirable when the UV treated effluent is distributed and residual disinfection is desired.

Rule No.25: If CF is present then ONE process from either SF or MF or GAC categories must be present.

Implication: a) A TT with CF must have either SF, MF or GAC.

Justification: The flocculants formed in CF must be removed either by SF, MF or GAC before disinfection.

It has been reported that programs such as PROLOG or LISP which use logical statements require enormous dynamic memory (Evenson, 1992) and this will increase the computation time in genetic algorithms. Thus logical rules listed above are represented as numerical rules in the database. These numerical rules are shown in Table 4.2 (a, b & c). In these Tables, the category specific rules are represented first (SlNo.1 to 83). The rest of the records (SlNo. 81 to 123) represent process specific rules.

Table 4.2a Rules to Check for Acceptable Process Configuration

Sl. No	Row UID	Col UID	Value	Operator Value
1	11		3	A
2	11	11	1	
3	11	13	0	
4	12	12	0	
5	12	13	0	
6	13		3	A
7	13	13	0	
8	14	14	0	
9	15		3	B
10	15	15	0	
11	15	16	0	
12	15	18	0	
13	15	23	0	
14	16		3	B
15	16	16	0	
16	16	18	0	
17	16	23	0	
18	17	17	0	
19	17	18	0	
20	18		3	B
21	18	18	0	
22	21	15	4	C
23	21	16	4	C
24	21	17	4	C
25	21	18	4	C
26	21	21	0	
27	21	23	0	
28	22	15	4	D
29	22	16	4	D
30	22	17	4	D
31	22	18	4	D
32	22	22	0	
33	22	23	0	
34	23		3	B
35	23	25	0	
36	24	24	1	
37	24	61	0	
38	24	62	0	
39	25	21	4	E
40	25	22	4	E
41	25	24	4	E
42	25	25	0	
43	41	41	0	
44	42	42	0	

Table 4.2b Rules to Check for Acceptable Process Configuration (Contd.)

Sl. No	Row UID	Col UID	Value	Operator Value
45	43	43	0	
46	44	44	0	
47	45	44	1	
48	45	45	0	
49	45	51	0	
50	47	51	0	
51	48	51	0	
52	49	47	1	
53	49	51	0	
54	51	51	0	
55	52	53	0	
56	52	54	0	
57	53	52	0	
58	53	54	1	
59	54	51	4	F
60	54	52	0	
61	54	53	4	F
62	54	54	0	
63	61	61	0	
64	62	15	4	G
65	62	16	4	G
66	62	21	4	G
67	62	22	4	G
68	62	23	4	G
69	62	41	4	G
70	62	62	0	
71	63	15	3	H
72	63	16	3	H
73	63	18	3	H
74	63	21	3	H
75	63	22	3	H
76	63	23	3	H
77	63	41	3	H
78	63	63	0	
79	64	15	3	I
80	64	16	3	I
81	64	18	3	I
82	64	21	3	I
83	64	22	3	I
84	64	23	3	I
85	64	41	3	I
86	64	64	0	
87	1101	1100	2	
88	2100	2300	0	
89	2100	2500	0	
90	2100	2501	0	
91	2101	2300	0	
92	2101	2403	1	
93	2101	2500	0	
94	2101	2501	1	
95	2200	2300	0	
96	2200	2400	0	
97	2200	2403	0	
98	2200	2500	0	
99	2200	2501	0	
100	2201	2300	0	
101	2201	2400	0	
102	2201	2403	0	
103	2201	2500	0	
104	2201	2501	0	
105	2201	5100	0	
106	2400	2401	4	J
107	2400	2402	4	J
108	2400	2403	4	J
109	2400	2500	0	
110	2401	2500	0	

Table 4.2c Rules to Check for Acceptable Process Configuration (Contd.)

Sl. No	Row UID	Col UID	Value	Operator Value
111	2401	2501	0	
112	2402	2500	0	
113	2402	2501	0	
114	2403	2500	0	
115	2403	2501	2	
116	3100	3101	1	
117	3100	3102	1	
118	3101	3102	0	
119	4400	4500	4	K
120	4400	4501	4	K
121	4400	4700	4	K
122	4400	4800	4	K
123	4500	5100	0	

(Note: For representations of values see Table 4.3).

In Table 4.2 (a, b & c), the second column referred to as RowUID, represents the category or process specific rules identified by their CatIDNo or UIDNo respectively. The third column represents the rules for the corresponding CatIDNo or UIDNo and is referred to as ColUID. The fourth column represents the logical conditions represented by values as shown in Table 4.3.

Table 4.3 Representation of Values in Rules Table

Value	Logical condition
0	Cannot coexist
1	Can coexist
2	Must be present if a process is present
3	One of the process must be present from the group of operators as a default in a TT
4	One of the process must be present from the group of operators if RowUID process is present

The last column in Table 4.2 is referred to as "operator value". This column has values such as A, B, C and so on, which are used to represent the logical conditions along with value of 3 and 4. For instance, the rule no 3 i.e. a TT must have a process selected either from screens or preliminary package unit is represented by sl No 1 & 6 with a value of 3 and an operator value of A in Table 4.2 (a). Based on operator values, the RowUID are grouped together and are used to check the configuration of TTs. The methodology adopted to check the TT configuration using these rules is discussed in Chapter 5 (see Section 5.4.4).

4.5.2.2 Rules Based on Site – Specific Factors

The site-specific factors such as depth of groundwater, local climatic conditions, amount of rainfall, land available and location of WWTP site are also important in determining the applicability of TTs. For instance land-based systems such as lagoons may not be suitable for sites that is close to urban areas due to aesthetic and odour reasons. Furthermore, land based treatment systems require relatively large land area and may exceed the land available or allotted for WWTP construction.

On the other hand, if the depth of ground water table is less than 2 m then the there is a possible danger of groundwater contamination. The effective functioning of some unit processes such as sludge drying beds can be affected due to high rainfall. Therefore such site-specific factors needs to be considered for the configuration and evaluation of TTs. A penalty factor is introduced for TTs that violate any of these site-specific factors. This is discussed in Section 4.8.2.3 (ii).

4.5.2.3 Rules Based on Maximum Allowable Influent Quality

Each unit process can work efficiently in a range of wastewater characteristics. Some processes such as reverse osmosis and UV disinfection are more sensitive and have limitations on their applicability when the influent quality exceeds the maximum specified level. The maximum allowable influent quality is the level beyond which the unit processes fails to function efficiently and are presented in Table 4.4.

Table 4.4 Rules Based on Maximum Allowable Influent Quality

UIDNo	Parameter*	Max Influent Value	Source**
2101	BOD	50	1
2101	SS	50	1
2401	BOD	1,000	1
3100	BOD	100	1
3100	SS	150	1
3101	BOD	75	1
3101	NH3-N	30	1
3101	ON	35	1
3101	SS	75	1
3101	TN	40	1
3102	BOD	75	1
3102	NH3-N	30	1
3102	ON	35	1
3102	SS	75	1
3102	TN	40	1
4201	BOD	40	1
4201	SS	40	1
4201	Turbidity	10	1
4500	BOD	30	2
4500	SS	30	2
4501	BOD	30	2
4501	SS	30	2
4700	BOD	50	2
4700	SS	30	2
4800	BOD	50	1
4800	SS	30	1
4900	BOD	20	1
4900	SS	20	1
5200	BOD	20	3
5200	SS	20	3
5200	Turbidity	10	3
5300	BOD	20	3
5300	SS	20	3
5300	Turbidity	5	3

*All units in mg/L except turbidity, NTU, **1- Finney & Gearheart (1998), 2- Manufacturer, 3- Hamilton (1996)

For instance influent turbidity greater than 5 NTU can affect the disinfection process as the turbidity prevents penetration of the UV radiation. Although UV may seem a better process compared to Chl, high influent turbidity may actually preclude the use of UV disinfection process. Therefore it was necessary to set up rules based on the allowable maximum influent quality to unit processes.

Some of the rules based on acceptable process configuration are actually based on the experience that a TT combination will not work efficiently as the influent quality exceeds the maximum allowable quality. For example, UV process will not work efficiently when it treats effluent from lagoons, as the algal levels are quite high (which increases the turbidity levels). Similarly, SF cannot be applied to primary treated wastewater unless the influent BOD and SS are < than 30 and 30 mg/L respectively. To achieve this influent quality one or more of the secondary processes must be selected. Therefore TTs in which the influent SS to sand filter is greater than 30 mg/L will be unacceptable. Thus these rules actually filter out any infeasible combinations based on the influent value.

4.5.3 Design of WWTP

The design of wastewater treatment plant is complex due to large variations in the quantity and quality of wastewater flows and highly site-specific design parameters. Many references including Metcalf & Eddy (1991), WEF Manual of Practice No.8 (1999), Qasim, (1999) and USEPA design manuals (1998) give guideline values for the design of various wastewater treatment processes. Furthermore, the design assumptions reported in these references is quite varied, as some designs are more conservative than others.

For example the detention time for maturation ponds suggested by Mara (1998) for a temperate climate is 3 days while for same conditions, Arthur (World Bank Technical Report, No7, 1983) suggests a minimum detention time of 5 days. Similarly the BOD loading rate of 280 kg/ha.d and a detention time 20-50 days is suggested for an anaerobic lagoon by Metcalf and Eddy (1991) while Mara (1998) suggests BOD loading rate of 0.29 kg/m^3 and a detention time of 1.5 days to be sufficient for wastes with BOD up to 400 mg/L. Hence an AnL designed with these two approaches will yield significantly different sizes. Therefore the design parameters have to be careful evaluated before selecting them.

Although many reference texts are available, most of these designs are based on US WWTP and are not available for Australian conditions. Most of the designers in Australia use the above mentioned design references along with their local experience to carry out design. However, these design assumptions are not widely reported. Therefore, where possible, the data has been taken from the available design reports (like UWRAA report on BNR) and from the references mentioned above. As stated earlier, MOSTWATAR is a planning tool and therefore a planning level design and cost estimates are included in the model. In this model, reclaimed water storage and distribution systems is not considered, as they would be common to all the TT alternatives for a given situation.

Currently, the user can view the design assumptions used in this model. Since the variation in design parameters can affect the cost estimation, the user is not allowed to modify this data. However with few changes like the development of wider range of cost data, the user will be allowed to make changes in the future. Simple mathematical models have been developed for each treatment processes using equations for sizing and calculation of performance, sludge production, land area requirement, capital and O & M cost. In the following sections, the methodology adopted to calculate the hydraulic loading, land requirement and sludge production are described.

4.5.3.1 Wastewater Characteristics and Hydraulic Loading

The typical wastewater parameters used for sizing various unit processes in this model are given in Table 4.5.

Table 4.5 Typical Wastewater Characteristics Used for Sizing Unit Processes

Parameter	Units	Symbol Used	Typical Value
5 day Biological Oxygen Demand	mg/L	BOD	230
Suspended Solids	mg/L	SS	220
Total Nitrogen	mg/L	TN	65
Total Phosphorus	mg/L	TP	12
Ammonia Nitrogen	mg/L	NH_3-N	45
Organic Nitrogen	mg/L	ON	20
Faecal Coliforms	No/100mL	FC	10^6

(Source: Metcalf and Eddy, 1991; Richard, 1998, pp 1356; Biebrick, 2001)

The description and equations used to calculate the hydraulic loading are given in Table 4.6. The average per capita wastewater generation was assumed to be 200 litres per capita per day (Lewis, 2001). The range of values for hydraulic and organic loading peaking factors displayed for the user are discussed in Chapter 6 while the default values used for the same are given in Table I.1 (Appendix I).

Table 4.6 Equations Used to Calculate Hydraulic Loading

Type of Flow	Equation Used	Remarks
Average flow, Q_{av}	Q_{av} = Population * Av per capita wastewater generation	Av per capita wastewater generation assumed as 200 lpcd
Average dry weather flow, Q_{avdwf}	$Q_{avdwf} = Q_{av} * 0.85$	Average dry weather flow (with minimum infiltration), assumed as 85 % of average flow
Peak monthly flow, Q_{pm}	$Q_{pm} = Q_{av} * P_{fm}$	The average of the peak flows sustained for a month, Pf_m=monthly peak factor
Peak daily flow, Q_{pd}	$Q_{pd} = Q_{av} * P_{fd}$	The average of the peak flows sustained for a day Pf_d = daily peak factor
Peak hourly flow, Q_{ph}	$Q_{ph} = Q_{av} * P_{fh}$	The average of the peak flows sustained for a period of an hour Pf_h = hourly peak factor

(Adapted from Crites & Tchobanoglous, 1998,Table 4.17, pp 185)

4.5.3.2 Design Criteria for Unit Processes

The criteria used for sizing different unit processes for both new and upgrade of treatment plants are given in Table 4.7. The design values of the parameters used for each of the unit process are presented along with references in cost data sheets presented in Table F.2 to F.43 (Appendix F). Further more these data sheets also include the land required, sludge produced and economic life of the processes. In the following sections, the methodology used to estimate land and sludge production is discussed while the cost estimation methodology is discussed in Section 4.5.5.

Table 4.7 Design Criteria Used For Sizing

Unit Process	Criteria Used for Sizing
Screens, grit chamber, primary clarifier, chemical assisted sedimentation, sand filters, UV, chlorination, RO, coagulation & sedimentation, activated carbon, membrane filters, raw sewage pump,	Hydraulic loading rate (HLR) at Q_{ph}
TF, ASP, SBR, Thickener, digester, belt filter press, sludge pump	Detention time at Q_{avdwf}, aeration equipment at peak daily organic loading
Secondary clarifier	HLR at Q_{ph}, solids loading rate at Q_{avdwf} with 100% recycle
Ponds, maturation pond, ASP w Ni, wetlands	Peak daily organic loading
Sludge disposal	Peak daily sludge flow
Chlorine contact tank	Q_{pd}
Chemical storage tanks	Q_{pm}

(Source: Adapted from Metcalf & Eddy, 1991, pp178; Crites &Tchobanoglous, 1998 and Richard 1998, pp 1360)

4.5.3.3 Land Requirements

The land area for WWTP is calculated by adding land area required for individual unit processes. An additional allowance is made for administrative buildings, fencing, landscaping & access and site wide facilities such as pumps, controls and other inter process facilities. The Table 4.8 shows the methodology adopted to calculate the land area of unit processes in MOSTWATAR.

Once the individual land areas were determined using the values described in Table 4.8, the total land area of the TT alternative was calculated using Equation 4.1.

$$\text{L.R for TT}_i = [\sum_{j=1}^{N} (\text{L.R for each UP}_j)] \times 1.15 \quad \textbf{(4.1)}$$

where LR = land required in hectares for construction of i^{th} TT

UP_j = j^{th} unit process in the i^{th} TT

N = total number of unit processes in the i^{th} TT

Table 4.8 Methodology Used for Land Area Calculations

Type of Process	Methodology	Remarks
Minor processes, eg: Bar screen, fine screen, grit chamber	Add 4 m perimeter area around the diameter or the equipment plan area, i.e. (diameter + 8 m)^2	To allow for base construction and access
Major processes eg: Clarifiers, biological reactors	The land area calculated as 2 times plant capacity	To allow for future expansion
Lagoons eg: Anaerobic lagoons, aerobic lagoons	The approximate area is calculated as 1.7*surface area	Based on L: W of 1: 3 and 4 m perimeter all round, to allow for access.
Rapid mixing tank and storage building	Assumed as 100 m^2.	

As shown in Equation above, the total land area was considered the sum of the land required for each unit process in the treatment train plus the additional area required for the site wide facilities such as access, landscaping, administration buildings and buffer distance for odour control and future expansion. This additional area is taken as 15 % of the land requirement for unit processes. USEPA (1998 pp 1-6) suggests an additional 20-foot (i.e. 6.2 m) perimeter around each unit process to accommodate the site wide facilities. However, 4 m perimeter was considered in this model as it is found adequate and a total land area of the TT was enhanced by 15 % as shown in Equation 4.1.

Furthermore, in case of land required for sludge disposal, it is assumed that the land is available for either land spreading or land filling within 10 km of the WWTP site. Therefore no provision is made in the total land area required for land spreading or land filling.

4.5.3.4 Sludge Production

It is necessary to estimate the sludge produced by each unit process in order to arrive at the total sludge produced by a TT. This in turn is used to determine the size of the various sludge treatment processes such as thickeners and digesters. The sludge composition and its production rate vary widely from day to day and hour to hour (WEF Manual of Practice, 1998; Vol.3, pp17-24 to 17-31). Several empirical equations have been developed (Koch *et* *al*, 1990 and Metcalf and Eddy, 1991) to estimate the sludge production. But these equations require assumptions of many constants and therefore in the current study, simple equations based on a mass balance approach were used to estimate the sludge produced. The equations used to calculate sludge produced in each unit process are given in the cost data sheets in Appendix F (Table F.2 to F.43). The total sludge produced in a TT was calculated using the following Equation.

$$\text{S.P by TT}_i = \sum_{j=1}^{N} \text{S.P by UP}_j \qquad \textbf{(4. 2)}$$

where S.P = sludge produced in kg/d

UP_j = j^{th} unit process in the i^{th} TT

N = number of unit process in the i^{th} TT

Further, sludge is removed once in 3 –5 yrs or even longer in land based treatment systems such as lagoons and wetlands. Therefore sludge generated by such processes is not displayed in the estimate of the total sludge generated per day in a treatment train.

4.5.4 Upgrade of WWTP

As stated in Section 4.2, one of the objectives of this research was to generate suitable upgrade options for given local conditions such as reuse & criteria. As discussed by Diagger and Buttz (1998) the upgrade of treatment plants can be a result of one or more of the following reasons:

- population growth resulting in increase in plant capacity,
- more stringent standards leading to higher removal efficiencies of treatment plants for pollutants such as nitrogen and phosphorus,
- obsolete equipment and or technology such as imhoff tanks resulting in an increase in operation cost and or lower reliability.

The wastewater treatment plant upgrade involves the steps as shown in Table 4.9. The upgrade investigation requires review of field data and analysis of background studies before evaluation and selection of suitable upgrade options.

Table 4.9 Step by Step Approach to WWTP Upgrade

Steps Involved	Brief Description
1. Desktop analysis	Historical data analysis, hydraulic calculations, review of operation and maintenance.
2. Identification of performance limiting factors	Field testing and evaluation
3. Identification of upgrade options	Engineering evaluations, workshops
4. Evaluation of upgrade Options	Field testing, pilot testing, surveys, engineering calculations
5. Selection of upgrade option	Cost effective analyses, qualitative evaluations
6. Implementation	Construction, training and procedure development

(Source: Diagger and Buttz, 1998, Table 1.3, pp 9)

In the current research, the following assumptions were made in the development of the upgrade module in MOSTWATAR:

- it was assumed that the existing plants are to be upgraded to meet stringent standards for reuse and that it requires addition of unit processes.
- the existing unit processes are assumed to be in good working condition and require no rehabilitation.

MOSTWATAR was developed to evaluate and select upgrade options based on cost-effective analysis. The design of unit processes for upgrade is similar to design of a new WWTP. The additional land requirement and sludge produced due to new processes is calculated in case of upgrade options. While qualitative analysis is carried out for all the unit processes i.e. both existing and new processes in order to establish the overall criteria score. The cost estimation for both upgrade and new wastewater treatment plant are discussed in the following section.

4.5.5 Cost Estimation

The most important evaluation criterion for TT alternatives is a comparison of the costs (Benjes, 1980). In this section, firstly background information about cost estimation is presented to explain why cost curves had to be developed in this model in spite of abundant cost data. Next the methodology adopted to develop the cost curves is described for both new plants and plant upgrades. Finally, the cost functions developed for comparison of TTs is described.

Wastewater reclamation costs include construction costs, equipment costs and annual O & M costs (Richard, 1998). These costs are dependent on many factors such as: (1) plant capacity, (2) reuse option selected, (3) design criteria, (4) treatment process configuration, (5) site conditions like type of soil and depth of rock, (6) land costs, (7) climate, (8) competition among bidders and suppliers and (9) general local and nation wide economic conditions (Richard, 1998, pp 1370, Qasim *et al.*, 1992). On the other hand, reuse costs includes the reclaimed water storage and distribution network costs. The distance between source and demand can influence these reuse costs. However, in the current model, the reuse costs are not considered for the economic comparison, as they would be common to all the TT alternatives considered for a given situation. Therefore, the cost estimation includes only wastewater reclamation costs.

Despite decades of research on cost estimation methodologies several issues such as the evaluation of social and environmental benefits/costs, standardized cost data for individual treatment components and sensitivity of design criteria to cost are still unresolved. Estimation of the cost of treatment processes is generally carried out at five different levels as shown in Table 4.10. This table shows various types of cost estimation methods and their level of accuracy.

Table 4.10 Cost Estimation Categories

Type of estimate	Basis	Accuracy
Ratio estimate	Similar historical cost data	≥ ± 30%
Factored/preliminary estimate	Based on cost of major equipment items	± 30%
Concept estimate	Based on preliminary studies	± 20%
Design estimate	Based on detailed design	± 10 %
Detailed/ tender /contract estimate	Drawings and specifications	± 5%

(Source: Bauman, 1964; Cited in Loetscher, 1999 and Willshire, 1998)

The following procedure described by Benjes (1980) is frequently used to estimate the costs of the facilities, which do not have significant historical cost background

1. Define the unit processes by dimension, construction material, equipment piping and valve requirements.
2. Estimate the cost of the major components using rules of thumb is applied to derive quantities.
3. Estimate the major cost components including concrete equipment, piping, valves, excavation, housing and so on.
4. Add miscellaneous cost components that are not included in the major cost items like contingencies. Apply an appropriate discount rate per year for the design period.

Using similar procedures, cost curves have been developed by several researchers (Benjes, 1980; Qasim *et al.*, 1992; Qasim, 1999; USEPA reports, 1978, 1976, 1998; Richard, 1998). However, the cost data from these references could not be used directly in the MOSTWATAR for the following reasons:

1. different standards & design assumptions used for cost calculation,
2. combined costs are reported for one or more type of process; for example: Qasim (1999) provides cost estimate for bar screen & grit removal,
3. type of equipment used varied,
4. most of these cost are reported in US $ and are applicable to US conditions
5. cost data for South Australian conditions have not been widely reported, and
6. cost data was not available for all the unit processes considered in the model.

Hence, it was necessary to develop a cost estimate of the unit processes with the help of these references, manufacturer quotations and historical costs from SA Water. Further as MOSTWATAR is a planning tool and preliminary cost estimates was developed as it is widely used for comparing the economics of the process alternatives (Qasim *et al.*, 1992). As indicated in Table 4.7, the level of accuracy of such preliminary cost estimation method is ± 30 %.

4.5.5.1 Methodology Used for Cost Estimation

The methodology used to develop cost curves is similar to that described by Qasim (1999, pp 1037-1049) and Martin & Martin (1991, pp 4-7). As a first step the preliminary cost estimates were developed for each of the unit processes at capacities ranging from 1,000 to

10,000 m^3/d (equivalent to 5,000 to 50,000 population). The historical data from similar treatment plants in South Australia was collected from SA Water. Further the cost data supplied by manufacturers, suppliers and published data for Australian conditions were used. In instances where no local information was available for unit process cost, cost data from the sources such as Qasim (1999) and Finney & Gearheart (1998) was used with appropriate currency conversion rates and consumer price index (CPI). This is further discussed in Appendix F.

The construction cost of each unit process included the following: (a) manufactured equipment/ process module, (b) civil works, (c) piping, (d) mechanical, (e) electrical and controls, and (f) process specific excavation and site work. Using the construction cost data for various capacities, cost curves were developed in Excel spreadsheets. Generalized construction cost equations were developed by regression analysis. Different trend lines such as linear, polynomial, power, and logarithmic trends were tried until the regression coefficient 'R^2' value was highest. The cost equations developed for each of the unit processes are presented in Appendix F (see Table F.2 to F.43).

Using these cost equations, the total TT construction cost can be developed for any treatment configuration by adding the corresponding unit process and common facility construction cost such as inter process piping and electrical as shown in Table 4.11. The user can define common facility construction cost as a percentage of the unit process construction cost. The capital cost of TTs was then computed by applying necessary percentages for engineering cost and contingencies.

On the other hand, the operation and maintenance cost were estimated as a function of operating labour, electrical power, repair and maintenance and consumables like chemicals. Where no data was available, O & M cost was assumed to be between 5 and 10 % of unit process construction cost. Further more, to compare the cost of alternative TTs, the total project cost or equivalent annual cost or life cycle costs were computed as described in Section 4.5.5.5. In the following sections the methodology used to estimate the capital and O & M cost for new and upgrade of existing plants is presented in detail.

4.5.5.2 Estimation of Capital Costs for WWTP

4.5.5.2 (i). New Plants

As a first step the construction cost is calculated for each unit process in the treatment train using the cost equations outlined in the previous section. Next, the total unit process construction cost is calculated by adding all the unit processes in the treatment train plus the miscellaneous cost. The common facility cost such as site works and plant piping are estimated as a percentage of total unit process construction cost. While the total TT construction cost is obtained by adding common facility costs to the unit process construction cost. Finally the capital cost of the TT is calculated by adding the engineering and contingency cost which are estimated as a percentage of total TT construction cost as shown in Table 4.11.

Table 4.11 Estimation of Capital Cost of New WWTP

Description	Calculation
Sum of UP construction cost	Σ UP Construction Cost
Miscellaneous cost	A*
Sub total 1	***Total UP construction cost***
Piping (inter process piping)	8% of sub total 1
Control and instrumentation	8 % of sub total 1
Site electrical	9 % of sub total 1
Site development (landscaping, roads, drainage)	8 % of sub total 1
Site works (excavation, base preparation)	6 % of sub total 1
Sub total 2	***Total TT construction cost***
Engineering & construction supervision	12 % of sub total 2
Contingency	15 % of sub total 2
Sub total 3	***Total TT capital cost***

(Adapted from USEPA report, 1998, p1-2 and Martin and Martin, 1991,
*cost for facilities such as inlet structure, raw sewage pumping, and rising main)

4.5.5.2 (ii). Plant Upgrades

Capital cost estimation for the plant upgrades are similar to that of new plants except that the cost for new processes is only estimated. It is assumed that the existing facility is in good working condition and does not need any rehabilitation. Furthermore, an additional allowance is made for the construction of common facilities as a percentage of total construction cost. These percentages are usually higher than those for the new plants and percentages commonly used are shown below (Willshire, 2000).

1. Site electrical: 9 %
2. Controls and instrumentation: 6 %
3. Plant piping: 10 %
4. Site excavation: 8 %
5. Site development: 6 %

4.5.5.3 Estimation of O & M Costs

The operation and maintenance cost are defined based on energy requirement, labour, repair and maintenance and consumables such as chemicals. The unit cost assumed for estimating the O & M cost are given in Table F.1 in Appendix F.

4.5.5.3 (i). New Plants

The operation and maintenance (O & M) cost for new plants are calculated using the following equation.

$$\text{OM TT}_i = \sum_{k=1}^{N} \text{OM UP}_k \quad \textbf{(4.3)}$$

where OM TT_i = O & M cost for i^{th} TT

OM UP_k = O & M cost for the k^{th} unit process

N = number of unit processes in i^{th} TT

4.5.5.3 (ii). Plant Upgrade

The O & M cost for plant upgrades is the additional O & M cost incurred for the new processes. Hence it is determined by adding only the O & M cost of the additional processes using Equation 4.3.

4.5.5.4 Estimation of Land Costs

Land cost can vary from location to location and is obviously higher in urban areas. Based on SA Water estimates the land costs in South Australia for urban and rural areas are \$20,000 and \$10,000 per hectare respectively (Bentley, 2001). In addition to this cost, a land acquisition cost of $250,000 is included for purchase of land to construct the treatment facility and for council approval fee. As shown in Table 4.11, land costs are not included in the capital cost of TTs.

4.5.5.4 (i). New Plants

After calculating the land area required for TTs as described in Section. 4.5.3.3, the land cost for each treatment train was calculated using the following Equation.

$$\text{TLC for TTi} = (\text{TL} \times \text{ALC}) + \text{LAF} \quad \textbf{(4. 4)}$$

where TLC = total land cost for i^{th} TT in 1000s of dollars

TL = total land area required in hectares for the i^{th} TT

ALC = appropriate land cost based on urban or rural area, $1000s per ha

LAF = land acquisition fee, (assumed as $ 250,000, Bentley, 2001)

4.5.5.4 (ii). Plant Upgrades

In case of plant upgrades the land cost is calculated by considering the land requirements for the additional unit processes. The Equation 4.4 is used to calculate the additional land costs.

4.5.5.5 Cost Functions Used in MOSTWATAR

The three types of cost functions developed to form a basis for comparison of TTs are: (1) total project cost, (2) equivalent annual cost and (3) life cycle cost. The total project cost is used as a default method to compare TTs. But the user can specify any one of these cost functions for comparison. All costs are in 2001 Australian Dollars ($) and are annualised over 25 years using a discount rate of 8 %.

4.5.5.5 (i). Total Project Cost

$$\text{Total } Project \text{ Cost}^y = \text{TTcap}\cos\text{t}^y + \text{TLC}^y + \frac{\text{AnOM}^y}{\text{CRF}} \quad \text{.................(4. 5)}$$

where $TTcapcost^y$	=	Total capital cost of TT in the Y year
TLC^Y	=	Total land cost in the Y year
$AnOM^y$	=	Annual O&M for the Y year
CRF	=	Capital recovery factor given by Dandy & Warner (1989, pp 79)

$$CRF = \frac{i}{(1-(1+i)^{-n})} \quad \text{..(4. 6)}$$

where i	=	discount rate in decimals (assumed as 0.08)
n	=	planning period in years (assumed as 25 yrs)

4.5.5.5 (ii). Equivalent Annual Cost or Annualised Project Cost

The equivalent annual cost is given by sum of equivalent annual capital cost, land cost and O & M costs as shown in the Equation below.

$$Annualised\ Pr oject\ Cost = AnCap\cos t + AnLC + AnOM \quad \text{..............(4. 7)}$$

where AnCapCost, AnLC and AnOM are annual capital, land and O & M cost respectively calculated using following equations.

$$\text{AnCapCost} = \text{TTcap}\cos\text{t}^y \ (\text{CRF}) \quad \text{...(4. 8)}$$

$$\text{AnLC} = \text{TLC}^y \ (\text{CRF}) \quad \text{...(4. 9)}$$

AnOM is calculated using Equation 4.3

4.5.5.5 (iii). Life Cycle Cost

As indicated by Richard (1998) life cycle costs are useful for economic evaluation. The life cycle cost is calculated using the following Equation. The facility capacity is obtained by multiplying the average daily treatment plant capacity in m^3/d by 365 days.

$$Life\ Cycle\ Cost\ (\$ / m^3) = \frac{Annualised\ Pr oject\ Cost\ (\$ / yr)}{Facility\ capacity\ (m^3 / yr)} \quad \text{.........(4. 10)}$$

4.5.6 Reuse Types and Guidelines

As discussed in Section 2.5.2, there is a wide variation in the reuse regulations and the type of application between countries and within each country from state to state. This has resulted in different water quality and wastewater treatment requirements. Therefore, it was necessary to first establish a common basis for comparison of different guidelines and reuse types.

Thirty-three different types of reuse were identified based on the type of reuse application (such as restricted & unrestricted access and so on). They are listed in Table G.1 (see Appendix G). Each of these reuse types was classified into 4 types of reuse classes namely A, B, C & D based on the SA reclaimed water guidelines. These classes were represented by reuse ID of 3, 2, 0, & 1 respectively in the model. In addition to these 33 different types of reuse, the user can also specify any other type of reuse and the corresponding criteria values to be used with the model. The guidelines included in the MOSTWATAR are shown in Table 4.12.

Table 4.12 List of Guidelines Included in MOSTWATAR

Reuse Guideline ID	Name of the Guideline
1	National Water Quality Management strategy guidelines (NWQM)
2	SA reclaimed water guidelines, April 1999
3	NSW State guidelines
4	QLD: Interim guidelines for reuse, April1996
5	Victoria State guidelines, March 1996
6	ACT Wastewater reuse for irrigation, July1999
7	Tasmanian State guidelines, 1999 draft
8	USEPA, 1992
9	WHO

Apart from 5 Australian State guidelines, two commonly used international guidelines namely USEPA and WHO are also included in the model. In 2001, a national guideline for use of reclaimed water in Australia was released (NWQM, 2001). The Northern Territory and the State of Western Australia do not have set guidelines and the reuse schemes are evaluated on a case-by-case basis (Murphy, 1999).

About 199 guideline values have been incorporated against the 33 different types of reuse. A unique ID referred to as Reuse guideline ID was used to identify each of these guidelines. Further, the reuse criteria value specified for BOD, SS, FC, turbidity, residual chlorine, helminth eggs, enteric viruses and pH are included for each of these guidelines. Since TN, ON, NH_3-N and TP values are based on site-specific conditions, the user can specify limits on these criteria. Faecal coliforms (also known as thermotolerant coliforms, guidelines for wastewater reuse, State of Victoria, 1996, pp 8), which chiefly consist of E.coli, were used to represent the bacteria although different guidelines use different counts such as thermotolerant coliforms, total coliforms and methods of measurement, average, mean and median.

For each of the above guidelines, the minimum recommended treatment specified by the guidelines was included. This information will be displayed to the user to enable them to form feasible treatment train alternatives. The specific comments such as the type of application, nutrient control and so on provided by each of the guidelines are also included in the database.

4.5.7 Selection Criteria

Ideally the best treatment alternative is identified as the alternative with the greatest net present value of benefits minus costs. However, benefits and costs of alternative TTs are incommensurable as many intangibles such as adaptability to upgrade, ease of construction cannot be expressed in dollar terms. Therefore, the selection will have to be based on the alternatives, which meets not only the treatment standards at the lowest possible cost but also meet other objectives such as reliability, low minimum odour generation and so on. Thus the TT selection is a multi-objective task and selection of TTs is no longer based on least cost configuration.

An inductive approach as explained by Biermann (1998, pp 204) was used for identifying the different selection criteria. In this model, in addition to performance and cost, other technical and environmental criteria are also considered. Social criteria such as impact on human health due to use of a particular treatment process and acceptability of a process to stake holders have not been included, as they are too difficult to quantify.

The selection of the user generated TTs in MOSTWATAR was carried out in two stages (see Section 4.8) while the selection of TTs generated in the GA module is discussed in Chapter 5. The first stage involved the evaluation & selection of TTs based on performance criteria. The TTs, which meet the specified reuse criteria, are passed on to the second stage. Further no undue weight was given to TTs, which were able to perform better than the specified reuse criteria, as the objective was to meet the reuse criteria. Therefore as long as TTs meet the reuse criteria, they were allowed to be evaluated in second stage. In this second stage, 13 criteria listed in Table 4.13 were used to evaluate and select TTs.

Table 4.13 Selection Criteria Used in MOSTWATAR Model

Evaluation & Selection Stage	Type of Criteria	Name of the Criteria	
STAGE 1	***Technical Criteria***	*1.*	*Performance*
STAGE 2	***Technical Criteria***	2.	Reliability
		3.	Adaptability to upgrade
		4.	Adaptability to varying flow rate
		5.	Adaptability to change in quality
		6.	Ease of operation and maintenance (O &M)
		7.	Ease of construction
	Environmental Criteria	8.	Power requirements
		9.	Chemical requirements
		10.	Odour generation
		11.	Impact on groundwater
		12.	*Land area requirement**
		13.	*Sludge production**
	Economic Criteria	*14.*	*Total project cost or Equivalent annual cost or Life cycle cost**

Note: *2-11 criteria are considered as qualitative while the rest shown in italics are quantifiable.

** 1- 7 are considered as positive attribute while the rest of the criteria are considered as negative attribute for a TT

The selection criteria in the model have been broadly classified in to three categories namely (1) technical criteria, (2) environmental criteria, and (3) economic criteria.

Fourteen criteria including performance and cost were included in the model and they are listed in Table 4.13. The selection of TTs can be either based on total project cost or equivalent annual cost or life cycle cost as specified by the user.

As shown in the Table above, criteria 2 to 11 are considered as qualitative criteria and are also referred to as effectiveness measures. Due to lack of data on chemical and power requirements of all the unit processes it was necessary to consider them as qualitative criteria rather than quantitative criteria. Further criteria 1 to 7 are considered as a positive attribute while the remaining are considered as negative attributes The methodology used to integrate these qualitative and quantitative criteria in to a common scale of measurement is explained in Section 4.8.2.

4.6 Database Development

The database of MOSTWATAR consists of performance and qualitative criteria for each of the 40 unit processes considered in the model. In this section the methodology adopted to develop a database of performance and qualitative criteria scores for the different treatment processes is described while the steps involved in the criteria evaluation is described in Section.4.8.2.

4.6.1 Performance of Unit Processes

Performance of unit process is an important measure, which decides the effluent quality achieved by a treatment combination. The performance is measured in terms of removal efficiency and is defined by the following Equation.

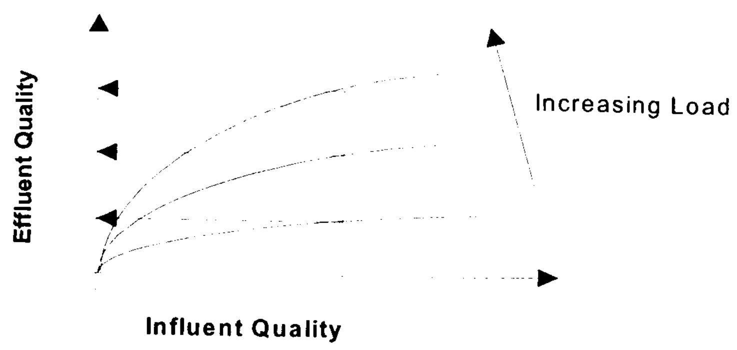
$$\eta = \frac{100(S_{in} - S_{eff})}{S_{in}} \qquad \textbf{(4. 11)}$$

where η = % removal efficiency

S_{in} = influent wastewater parameter concentration

S_{eff} = effluent wastewater parameter concentration

Performance of unit processes is usually reported in terms of minimum, average or maximum removal efficiencies. It can vary widely based on (1) plant location, (2) influent characteristics, (3) environmental conditions (4) loading and (5) condition of the plant. Thus, ideally the performance relationship should be established for each treatment process for an optimal design as illustrated by Tebbutt (1989).



(Source: Tebbutt, 1989)

Figure 4.3 Illustration of Performance Relationship

This Figure shows how the effluent quality is dependent on the influent quality and the process loading. There are several reports in the literature on performance of treatment plants, but the lack of information on loading and wastewater characteristics make it hard to compare the performance results (Kroiss, 1994).

On the other hand, performance of the individual unit processes is not monitored in most of the treatment plants due to high monitoring costs. In almost all the WWTP in South Australia, monitoring of the treatment performance was aimed at determining the treatment plants ability to meet the discharge requirements rather than to study the individual performance of the individual unit processes. This hindered the inclusion of the performance of unit processes from the existing WWTP in South Australia. Where possible the data has been taken from the historical plant performance while other data has been based on the literature and manufacturer's catalogues. In some cases, where specific information was not available, removal efficiencies were estimated based on similar processes.

Although a number of parameters including BOD, COD, SS, nutrients, trace organics, and heavy metals are to be considered for the suitability of reuse applications, all of these parameters are not always monitored. The performance of each unit process is tracked for the parameters listed in Table 4.14.

Table 4.14 Wastewater Parameters Evaluated in MOSTWATAR

Parameter	Units	Symbol Used
5 day Biological Oxygen Demand	mg/L	BOD
Enteric Viruses	No/50L	EV
Faecal Coliforms	No/100mL	FC
Grit	kg/m^3	Grit
Helminth Eggs	No/50L	Heggs
Ammonia Nitrogen	mg/L	NH_3-N
Organic Nitrogen	mg/L	ON
Suspended Solids	mg/L	SS
Total Nitrogen	mg/L	TN
Total Phosphorus	mg/L	TP
Turbidity	NTU	Turb

(Source: Biebrick, 2001; Metcalf and Eddy, 1991)

The steady state performance for individual unit processes expressed as a percentage removal of each of these parameters is given in Table D.1 (a to i) of Appendix D. A detailed list can be found in Metcalf and Eddy (1991), Qasim (1999) and Martin and Martin (1991).

4.6.2 Qualitative Criteria

It is necessary to develop a common scale of measurement in terms of raw scores for qualitative criteria and quantitative criteria. A number of references are available which give a rating of unit processes for some or all the criteria and unit processes listed in Table 4.13 (Qasim, 1999; Martin & Martin, 1991). Each of these authors has used different rating methods. For instance Qasim (1999) has used *minimum, moderate, maximum, poor, fair & good*, while Martin & Martin (1991) has used *nil, low, medium and high* to rate the unit processes. Furthermore there is discrepancy in the ratings used. This is because the measures of effectiveness depend on individual perceptions.

In the current study, a raw score of 0 to 3 was set up for all the qualitative criteria (2 to 11 listed in Table 4.13) using the above-mentioned references and the manufacturers input. In the case of discrepancies in the reported ratings, an average value was considered. This ordinal scale of 0 to 3 was chosen because in most of the literature, the unit processes were given a rating of nil, low, medium and high. Thus 0, 1, 2, 3 were selected to represent NIL, LOW, MEDIUM and HIGH ratings respectively. The scores were set up for each unit process as shown in Table E.1 (see Appendix E) by comparing the unit processes in that process category.

Out of the 13 criteria considered in the second stage of evaluation, some contributed positively to the TT while others were negative attributes. The two ways of developing raw scores for these attributes are discussed next. One method would be to develop raw scores in the same direction i.e. higher scores for positive and lower scores for negative attribute to represent better suitability. For example, a score of 3 represents the highest reliability while the same score would represent the lowest odour generation potential.

An alternate method would be to develop scores based on positive and negative attributes i.e. a higher score for a positive attribute represents better suitability while the higher score for negative attribute represents lower suitability. Thus a score for 3 in this method would represent the highest reliability and the highest odour generation potential as well. This method is adopted in the current study to develop raw scores for all the qualitative criteria. In order to get the same direction of scoring i.e. the higher the score greater the suitability, the negative criteria scores were subtracted from one as explained by Biermann (1998, pp 208). The Equations developed for the calculation of criteria scores are described in Section 4.8.2.2 (i).

4.7 User Specified TT Generation

As shown in Figure 4.2, MOSTWATAR has three options for generation of TTs. In this section different step involved in the user generated TT options are presented while in Chapter 5 the MOSTWATAR generated options are discussed. Further more when user selects both options, the user is asked to specify the options first. The steps involved in the user generated TT evaluation are shown in Figure 4.4. As a first step the community data such as design population, desired reuse type(s) and criteria, climatic conditions are input by the user. The user interface developed for the same is discussed in detail in Chapter 6.

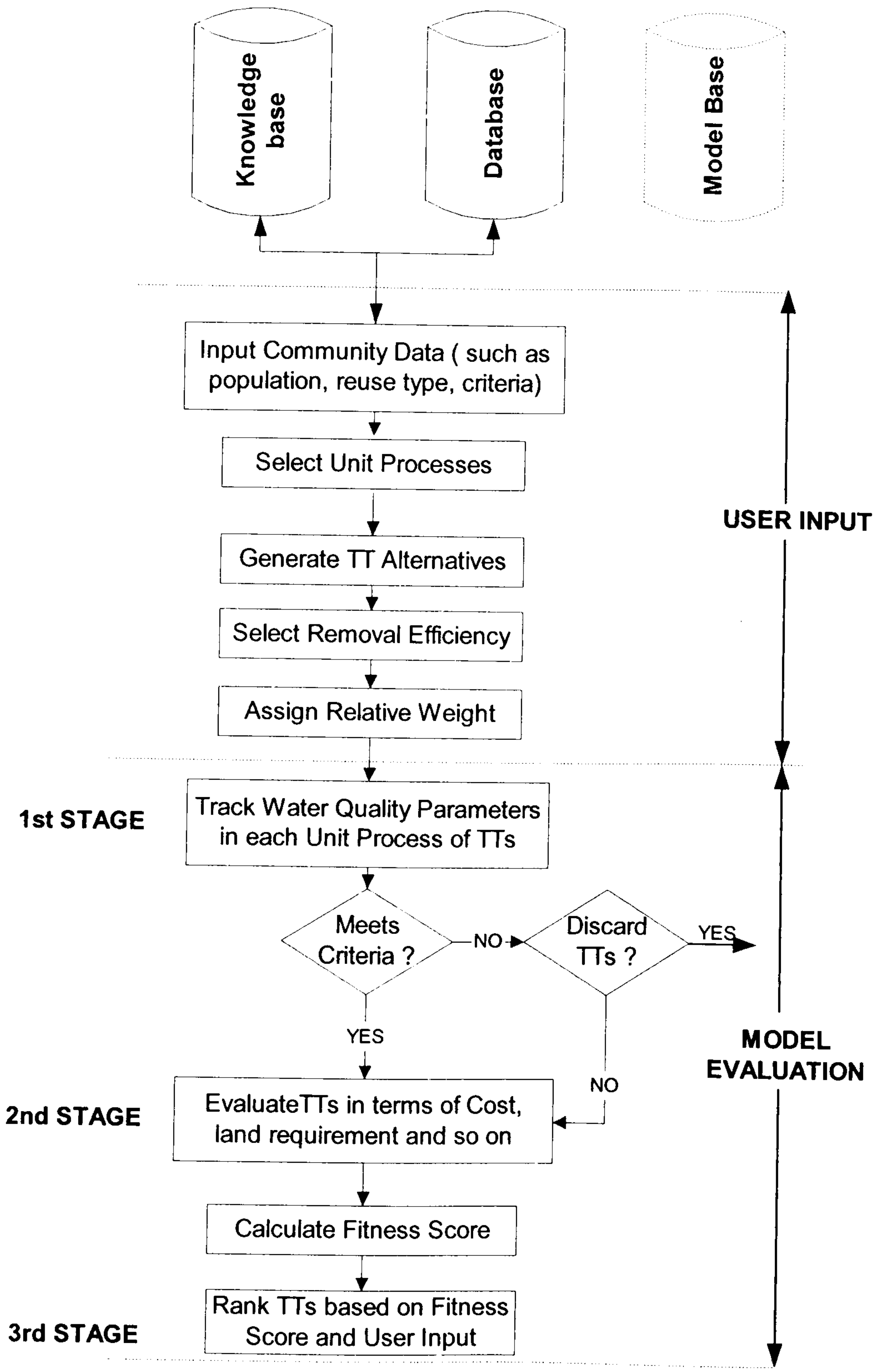


Figure 4.4 Steps Involved in the Evaluation of User Generated TTs

The user then selects the unit processes to form TT alternatives for evaluation. The user specifies removal efficiency level (minimum, average, maximum) in order to evaluate the performance against the reuse criteria. The relative weights for each criterion are specified to express his or her emphasis on the selection criteria. This is explained in detail in Chapter 6. With the above inputs the model evaluation is carried out in three stages as described in the following sections. At the end of this chapter a sample calculation to illustrate the steps involved in the selection of TTs is presented.

4.8 Evaluation and Selection of User Generated TTs

As shown in Figure 4.4, the three important stages in user generated TT evaluation are: (1) performance evaluation, (2) evaluation based on technical, economic and environmental aspects, and finally (3) ranking of TT alternatives. These stages are described in the following sections.

4.8.1 Stage 1: Performance Evaluation

The first stage of model evaluation is to determine whether the treatment train (TT) alternatives formed are able to meet the specified reuse criteria. The alternate treatment trains formed are evaluated based on their removal efficiencies. The user can specify either minimum, average or maximum removal efficiencies for the calculation of TT performance. The parameters of interest (for example; BOD, SS and faecal coliforms) are tracked in each unit process in the treatment trains by rearranging Equation 4.11.

$$S_{eff} = S_{in} \times (1 - \frac{\eta}{100}) \qquad \textbf{(4. 12)}$$

The effluent quality of each TT in the community is compared with the specified reuse criteria. The TTs that meet the criteria for all the parameters of interest are passed onto second stage of evaluation as shown in Figure 4.4. The TTs that do not meet criteria can either be discarded or selected (where one or two parameters exceeds the reuse limits by up to 10 %) by the user for further evaluation. This option is included in order to allow for any discrepancies in the reported removal efficiencies of the unit processes. The TTs that have the ability to achieve the reuse criteria or those that TTs that have been selected by the user will be passed on to second stage of evaluation.

4.8.2 Stage 2: Techno-Economic and Environmental Evaluation

The second stage of evaluation involves comparative evaluation of TTs that meet the reuse criteria and of those TTs that have been selected by the user. Traditionally, benefit cost analysis was used to compare TT alternatives. However, benefit cost analysis is no longer applicable as there are a number of important objectives, which cannot be converted to dollars. Thus the TT evaluation & selection is a multi-objective decision problem as a number of criteria and conflicting objectives are involved as described in Section 4.5.7. It is a common practice to convert such multi-objective problems to single objective problems. Although such conversions can oversimplify the multi-objective nature of the problem it may be preferred in situations where simplicity and ease of use is necessary.

Weighting and constraint techniques are commonly used to transform multi-criteria problems to single criterion problem. Since not all criteria listed in Table 4.13 play an equal role in the TT evaluation, it is necessary to achieve a trade off between various criteria by assigning weights to them. These weights indicate the importance of the criteria relative to each other (Kirckwood, 1997). Several methods listed in Table 4.15 have been used to assess the criterion weights.

Table 4.15 Different Methods for Assessing Criterion Weights

Features	**Ranking**	**Rating**	**Pairwise comparison**	**Trade off analysis**
Response scale	Ordinal	Interval	Ratio	Interval
Hierarchical	Possible	Possible	Yes	Yes
Underlying theory	None	None	Statistical/Heuristic	Obvious/deductive
Ease of use	Very easy	Very Easy	Easy	Difficult
Trustworthiness	Low	High	High	Medium
Precision	Approximations	Not precise	Quite precise	Quite precise

(Adapted from Malczewski, 1998; Table 2.1, pp 24)

Of these methods pairwise comparison and trade off analysis are quite precise. However pairwise comparison can be very cumbersome when a number of alternatives (such as in the current problem) are involved, while trade off analysis is difficult to use. Furthermore, techniques based on pairwise comparison such as the analytic hierarchy process (AHP) has limitations if there are multiple copies of alternatives or irrelevant alternatives, which causes rank reversal. Based on the pairwise comparison and trade off analysis procedures several commercial software products such as Expert Choice™ (Expert Choice Inc., 1993), Which & why (Arlington software, 1995) and LOGICAL DECISIONS (Smith, 1994) are available. Apart from being expensive these products would be difficult to integrate into the current model.

On the other hand, out of the two simple techniques of ranking and rating, ranking was used for the current study, as an ordinal scale could be easily set up for the qualitative criteria. Malczewski (1998) suggests that when ease of use is important, the time and cost involved in generating a set of weights are the major concerns then ranking or rating must be used.

It was therefore necessary to develop a systematic methodology where in the user can enter his or her preferences and carry out a sensitivity analysis by varying the weights assigned to the criteria. In the following sections the methodology developed for evaluation is described.

4.8.2.1 The Weighted Average Technique

In the current investigation, the weighted average technique was used, as it is simple, the most widely used and understood by the decision-makers to express preferences. Decision weighting models have been criticized in the past as decisions can vary as a result of variations in the weightings used (Drobny *et al.*, 1971). The greatest limitations are that it is an ad hoc method and has very little theoretical foundation. To use the technique, it is necessary for the user to express preference and weigh diverse factors before making a final choice.

In this technique numerical weights are assigned to each criterion to represent the relative importance or preference. A total score is obtained by multiplying the scaled or normalized scores by the assigned weights and then summing the products of all the criteria. In this model the user can assign weights to express his or her views about the importance of each criterion relative to the other criteria. For each of the criteria, the relative weights can be varied from 0 to 10. The larger the weight the greater is its importance in overall score. A weight of '10' indicates that the criterion is extremely important while a weight of '1' indicates that the criterion is relatively unimportant.

The user can also exclude any criterion from evaluation by assigning a '0' weight to that criterion. Since cost of treatment is normally considered more important than all other criteria, it was necessary to give a separate weighting for the cost. The weighting given for cost indicates by how much more it is important compared to all other criteria. The relative weights to cost can also be varied from 0-10. For instance, a weight of '2' indicates that the cost is 2 times more important than all other criteria combined.

The aim is then to rank the TT alternative in the descending order of their overall scores. This technique is further explained with fitness functions described below. The calculation of individual criteria scores and scaled or normalized scores for unit processes with respect to each criterion is presented next.

4.8.2.2 Calculation of Normalized Scores

Each criteria needs to be scaled in order to evaluate the degree to which the objective is met by an alternative. Linear scale transformation is the most commonly used deterministic method for transforming input data in to commensurate criterion (Malczewski, 1998). In order to carry out comparative evaluation the first step is to convert all of the criteria to a common measurement unit. A scale of 0 to 1 was selected and all the criteria were normalized to this scale using the linear functions presented in Equations 4.13 to 4.16.

This is done in order to arrange the alternatives in the order of their suitability for each criterion. For all criteria a score of '1' indicates the best level of the criterion and '0' the worst. For instance a TT with '0' score for reliability indicates that it is least reliable TT among the compared alternatives. On the other hand a TT with '0' score for odour represents that this TT has the highest odour generation potential among the alternatives considered.

Since the criteria listed in this section include both quantitative and qualitative criteria, the following sections describe the different methods of normalisation for the scores.

4.8.2.2 (i). Qualitative criteria

The scores for both positive and negative attributes of TTs were calculated using the following Equation.

$$P'_{ik} = \frac{\left[\sum_{j=1}^{N} P'_{ikj}\right]}{N} \quad \text{.......(4. 13)}$$

where P'_{ik} = average qualitative criteria score for i^{th} TT

k = k^{th} criterion (for k = 2-11, see Table 4.13)

P'_{ikj} = qualitative criteria score for k^{th} criteria for the j^{th} unit process in i^{th} TT

N = total number of unit processes in i^{th} TT

Once the criteria scores are established, these scores are normalized using the following Equations.

(a) Positive Attribute (Criteria 2-7 in Table 4.13)

$$P_{ik} = \left(P'_{ik}\right) \times \frac{1}{3} \quad \text{.......(4. 14)}$$

where P_{ik} = normalized quantitative score for k^{th} criteria of i^{th} TT

(b) Negative Attribute (Criteria 8-11 in Table 4.13)

The calculation of normalized score for negative attributes is similar to the positive attributes except those scores are subtracted from one '1' so that all the scores are formulated in the same direction.

$$P_{ik} = 1 - \left[\left(P'_{ik}\right) \times \frac{1}{3}\right] \quad \text{.......(4. 15)}$$

The notation used is same as in the previous case except that k value is from 8-11.

4.8.2.2 (ii). Quantitative criteria

In order to normalize quantitative criteria scores to a scale of 0 to 1, the interval scale score method described by Biermann (1998) was used. In the current study the quantitative criteria considered for evaluation are cost, land requirements and sludge production. The costs of all the treatment train alternatives for a given community were calculated based on the type of cost function suggested by the user. As a default, total project cost is used for evaluation. On the other hand land required and sludge produced by each TT is calculated using Equations 4.1 and 4.2 respectively. Next the maximum and minimum cost, sludge produced, land required of the user generated TTs were determined. Finally, using the Equation 4.16, the normalized scores for quantitative criteria were calculated.

$$P_{ik} = 1 - \left[\frac{P'_{ik} - min\,P'_{ik}}{max\,P'_{ik} - min\,P'_{ik}} \right] \qquad \textbf{(4. 16)}$$

where, P_{ik} = normalized criterion scores for k = 12-14(see Table 4.13)

P'_{ik} = criterion scores for k = 12-14

min P'_{ik} = minimum criterion score for all the user generated TTs for k^{th} criteria

max P'_{ik} = maximum criterion score for all the user generated TTs for k^{th} criteria

Since cost, sludge and land requirements are all negative attributes; scores are actually subtracted from one. The above Equation sets the treatment train for instance with lowest capital cost to a score of '1' while the TT with highest cost among all the other alternatives gets a score of '0'. In the application of this method, it was found that, in order to compare TTs generated by the user and MOSTWATAR, it was necessary to fix min P'_{ik} and max P'_{ik} as estimated values at the start of each modelling run.

Using these normalized scores for both quantitative and qualitative criteria, the fitness score for each TT is calculated as discussed in next section.

4.8.2.3 Fitness Function

The fitness function is a measure for establishing how good or bad a solution is. Linear fitness functions are established for each TT in order to compare the alternatives. The mathematical formulation of the fitness function implemented for user generated TTs in MOSTWATAR is as follows.

$$Maximise\ f(_{TTi})$$

$$\text{where } f(_{TTi}) = O(_{TTi}) - \alpha_{(TTi)} \quad \text{(4. 17)}$$

$f(_{TTi})$	=	fitness function for i^{th} TT
$O(_{TTi})$	=	objective function to be maximized
$a(_{TTi})$	=	penalty function which depends upon the constraint violations given by Equation 4.21

4.8.2.3 (i). Objective Function

The objective score of a TT string is the weighted summation of its normalized scores. The weighted score for each TT was obtained by multiplying the normalized score (calculated as described in the previous sections) by the user assigned relative weights and summing over all the criteria as shown in Equation 4.18. The performance was not considered in the second stage of evaluation and therefore in the objective function. This is because the basic requirement is to meet the reuse criteria specified by the guidelines and therefore no undue advantage was given to TTs, which have higher performance than others.

$$\text{Objective Score for TTi} = \left\{ \frac{\sum_{k=2}^{k=14} W_k P_{ik}}{\Sigma W_k} \right\} \quad \text{(4. 18)}$$

where P_{ik}	=	scaled scores for TTi for k^{th} criteria.
k	=	criterion such as total project cost, reliability shown in Table 4.13, (criteria 2 to14)
W_k	=	user assigned weight for k^{th} criteria

4.8.2.3 (ii). Penalty Function

The penalty function for the i^{th} TT was calculated using the following Equation.

$$\alpha_{TTi} = \rho \begin{pmatrix} (PsL \times \delta_1) + (PsNMDGW \times \delta_2) + \\ \sum_{i=1}^{l} \{[(PsRC \times \delta_3)] + [(PsMaxInfq \times \delta_4)]\} \end{pmatrix} \qquad (4.19)$$

where ρ = constant penalty weight assigned for exceeding constraints (set as 25)

PsL = penalty score for exceeding land available

δ_m = $\begin{cases} 1, & \text{if the } m^{th} \text{ constraint is violated} \\ 0, & \text{if the } m^{th} \text{ constraint is satisfied,} \end{cases}$

where m = 1 to 4

$PsNMDGW$ = penalty score for selecting land based treatment systems when depth of groundwater table is less than or equal to 2 m

$PsRC$ = penalty score for exceeding reuse criteria (1 to l, where l = number of wastewater treatment parameters exceeded)

$PsMaxInfq$ = penalty score for exceeding maximum allowable influent quality.

An explanation of each of these penalties and the Equations used to calculate the same are described below.

a) Penalty for Exceeding Reuse Criteria (PsRC)

PsRC was calculated by estimating the amount by which the effluent quality in terms of BOD, SS, and so on exceeds the limit specified by the reuse criteria. Equation 4.20 was used to compute this.

$$PsBOD = \frac{BODeff - BOD\,c}{BOD\,c} \qquad (4.20)$$

where $PsBOD$ = penalty score for exceeding BOD criteria

$BODeff$ = effluent BOD achieved by TT in mg/L

BOD_c = reuse criteria value for BOD in mg/ L

Similarly the penalty score for exceeding SS, TN, TP, EV, FC, turbidity and helminth eggs were calculated and they are represented as PsSS, PsTN, PsTP, PsEV, PsFC, PsTurb, and PsHeggs respectively. To obtain the penalty score for exceeding reuse criteria (PsRC) the penalty scores for each of the performance parameter is summed up as shown in Equation 4.21.

$$\mathrm{PsRC} = (\mathrm{PsBOD} + \mathrm{PsSS} + \mathrm{PsTN} + \mathrm{PsTP} + \mathrm{PsTurb} + \mathrm{PsHeggs} + \mathrm{PsEV} + \mathrm{PsFC}) \quad \text{......(4. 21)}$$

where PsRC = penalty score for exceeding the reuse criteria

b) Penalty for Exceeding Land Available (PsL)

The land required for each TT in the population is compared with the land available in the community. The penalty for exceeding the land available (PsL) for each TT was calculated using equation 4.22.

$$PsL = \frac{Lr - La}{La} \quad \text{......(4. 22)}$$

where PsL = penalty for exceeding land available at the site

L_T = land required by TT,

L_a = land available at the site

c) Penalty for Exceeding Maximum Allowable Influent Quality (PsMaxInf)

It is obvious that the performance of unit processes is dependent on the influent quality. Some of the processes like sand filters, micro filters, RO, activated carbon are very sensitive to the influent quality and require a specified range of values for their proper functioning. For instance the sand filters require the influent SS to be less than 30 mg/L. If the influent SS exceeds 30 mg/L then the sand filters may not function properly and thus the final quality achieved (actual value) will be inferior to the calculated value. To overcome this, a penalty factor for exceeding the allowable maximum influent quality was used and was calculated using Equation 4.23.

$$PsMaxInf = \frac{S_{in} - S_{max}}{S_{max}} \quad \text{.......(4. 23)}$$

where PsMaxInf = penalty for exceeding maximum allowable influent quality

S_{in} = influent quality parameter such as BOD, SS to UP in mg/ L *

S_{max} = maximum allowable influent quality parameter such as BOD, SS in mg/L*

*(except for FC in No/100 mL)

d) Penalty for Not Meeting Depth of Groundwater Criteria

This penalty is applied to TTs if land based treatment systems are selected when depth of groundwater table is less than 2 m.

$$PsNMDGW = \mu \quad \text{.......(4.24)}$$

where PsNMDGW = penalty score for not meeting depth to groundwater

μ = +1 if violated

0 if satisfied

4.8.3 Stage 3: Ranking of TT Alternatives

Once the fitness scores of the TT alternatives are evaluated, the TTs can be ranked by the user based on any one of the 11 criteria listed in Table 4.16. As default the TTs are ranked based on their maximum fitness score.

Table 4.16 Criteria for Ranking TTs

Sl No	Ranking Criteria
1	Maximum fitness score
2	Minimum project cost
3	Minimum annualised cost
4	Minimum life cycle cost
5	Minimum O & M cost
6	Minimum land requirement
7	Minimum sludge produced
8	Maximum upgrade
9	Maximum BOD removal
10	Maximum SS removal
11	Maximum FC removal

4.8.4 Sensitivity Analysis

Sensitivity analysis is an approach to deal with uncertainty of the criterion weights. In some situations decision-makers may not be able to precisely judge the criteria weights. In such circumstances the sensitivity of the weights on the TT alternatives can be investigated by varying the weights. This is explained with respect to the case study in Chapter 7. Next a numerical example is provided to describe the three major steps (shown in Figure 4.4) involved in the user-generated evaluations.

4.9 Numerical Example

In this section a simple example is considered to demonstrate the steps involved in the evaluation of user generated TTs in the MOSTWATAR model. Consider a hypothetical community with an estimated design population of 5000 in country region of South Australia. Let us assume the community intends to irrigate golf course with Class B quality reclaimed water. In order to treat the wastewater in the community let us consider two treatment alternatives (represented as TT1 and TT2) consisting of the following unit processes.

TT1: Bar screen + Grit chamber + Primary clarifier + ASP w clarifier + Chlorination + *Anaerobic digester* + *Sludge drying beds* + *landfilling of sludge*

TT2: Bar screen + Grit chamber + Primary clarifier w lime + ASP w clarifier + Chlorination + *Anaerobic digester* + *Sludge drying beds* + *landfilling of sludge*

(Note: The sludge handling processes are indicated in Italics)

To keep the problem simple only the type of primary clarifier employed is varied in the two TTs shown above. Let us consider 5 wastewater parameters assuming all other contaminants to be within the specified criteria. The influent wastewater characteristics, criteria values and the average percentage removal efficiencies of the unit processes present in the example TTs are presented in Table 4.17.

Table 4.17 Input Data for Example TTs

Parameter	Influent Value	Reuse Criteria	% Average Removal Efficiency						Maximum Allowable Influent Value for Chlorination
			Bar Screen	Grit Chamber	Primary Clarifier	Primary Clarifier w lime	ASP w clarifier	Chlorination	
BOD, mg/L	250	20	2.5	4.0	35.0	55.0	87.5	0.0	20.0
SS, mg/L	230	30	7.5	5.00	57.5	65	85.0	0.0	20.0
TN, mg/L	65	-	0.0	0.0	7.5	25	20.0	0.0	-
TP, mg/L	15	-	0.0.	0.0	15.0	80	17.5	0.0	-
FC, No/100mL	10^6	100	0.0	0.0	0.0	40.0	70.0	99.95	-

Further the maximum allowable influent quality in terms of BOD and SS for chlorination are listed in the last column while for all other processes maximum limit was not specified (see Table 4.4). The first step is to calculate the performance followed by calculation of criteria values such as cost, land requirement and qualitative criteria scores and finally the calculation of fitness scores. Each of these steps is described in the following sections.

4.9.1.1 Calculation of Performance

The effluent quality achieved in each unit process is calculated using Equation 4.12. For example effluent BOD value from bar screen for TT1 is calculated as follows:

Bar screen effluent BOD = Influent BOD * (1 - % fraction BOD removal efficiency for bar screen)

Since bar screen is the first unit process in TT1, the influent wastewater BOD is taken as the influent BOD for this process. i.e.

$$(250)*(1-0.025) = 243.7 \text{ mg/L}$$

Similarly the effluent values for SS, TN, TP and FC are calculated for bar screen. Since grit chamber follows bar screen, the effluent coming out of bar screen becomes the influent for the grit chamber. The effluent quality achieved in grit chamber is calculated in a similar manner and this is continued until the last liquid waste treatment process is reached. Similarly the effluent quality for TT2 is calculated. The final effluent quality achieved in

TT1 and TT2 is the effluent quality from chlorination process since it is the last liquid waste treatment process in both the treatment alternatives considered. The effluent quality achieved in each of the unit processes for TT1 and TT2 are tabulated in Table 4.18.

As seen from this Table, the influent BOD and SS (i.e. 19.0 and 13.2 mg/L respectively) for chlorination is within the maximum influent quality allowed. Further the final effluent quality achieved for the three parameters namely BOD, SS and FC in TT2 is within the specified reuse criteria and hence TT2 is said to be a feasible treatment train. On the other hand, TT1 alternative does not meet the FC criteria and therefore is said to be an infeasible alternative.

Table 4.18 Final Effluent Quality Achieved in the Example TTs

Parameter	Influent Value	Reuse Criteria	Effluent value achieved after each unit process							
			Bar Screen (TT1&TT2)	Grit Chamber (TT1 & TT2)	Primary Clarifier (TT!)	Primary Clarifier w lime (TT2)	ASP w clarifier (TT!)	ASP w clarifier (TT2)	Chlorination (TT1)	Chlorination (TT2)
BOD, mg/L	250	20	243.7	234.0	152.1	105.3	19.0	13.2	19.0	13.2
SS, mg/L	230	30	212.7	202.1	85.9	70.7	12.9	10.6	12.9	10.6
TN, mg/L	65	-	65.0	65.0	58.5	48.7	46.8	39	46.8	37.1
TP, mg/L	15	-	15.0	15.0	12.7	3.0	10.5	2.5	10.5	2.5
FC, No/100mL	10^6	100	10^6	10^6	10^6	$6x10^5$	$3x10^5$	$1.8x10^5$	150	90

(Note: Green & red colour in the above table indicates whether the final effluent value is within the specified criteria are not)

4.9.1.2 Calculation of Criteria Scores

The next step is to determine the qualitative and quantitative criteria scores. The total project cost, sludge produced and land area required by the TTs are calculated using the Equations displayed in Table F.2 to F.43. The normalized criteria score (for example: adaptability to upgrade) for TT1 and TT2 (represented as P_{11} and P_{21}) is calculated using

Equation 4.14 & 4.15 and criteria values from Table E.1 in Appendix E. The sum of criteria scores for both TT1 and TT2 are divided by 8, since each TT has 8 unit processes.

$$P_{11} = \frac{3+3+3+3+1+2+3+3}{8} \times \frac{1}{3}$$

$$\Rightarrow P_{11} = 0.88$$

$$P_{21} = \frac{3+3+3+3+1+2+3+3}{8} \times \frac{1}{3}$$

$$\Rightarrow P_{21} = 0.88$$

The normalised criteria scores are calculated similarly for all the other criteria and are displayed in Table 4.20. Further, land required and sludge produced by each unit processes is calculated using Equations provided in the respective unit processes cost data sheet in Appendix F and Equations 4.1 and 4.2. The calculated values are displayed in Table 4.20.

4.9.1.3 Calculation of Total Project Cost

As a first step the individual unit process construction cost is calculated using cost equations presented in Table F.2 to F.43. The total construction cost for TT1 is shown in the Table below.

Table 4.19 Construction and O & M Cost for Example TT1

Unit Process	Construction Cost, 1000s $	O & M Cost, 1000s $
Bar Screen	56.58	4.87
Grit Chamber	74.22	6.485
Primary Clarifier	200.56	20.06
ASP w clarifier	768.51	76.85
Chlorination	80.62	70.74
Anaerobic Digester	293.97	29.40
Sludge drying beds	54.33	5.43
Land filling of sludge	161.68	19.13
Total, 1000s $	***$1,690.47***	***$232.97***

Using the above total construction cost and the percentages given in Table 4.11, the total project, annualised and life cycle costs for the TT1 are calculated. These costs are summarized in Table 4.20.

4.9.1.4 Calculation of Fitness Score

The fitness scores for the example TTs are calculated using Equation 4.17 as follows. Each of the criteria scores calculated as discussed in the previous section is then multiplied by the corresponding default weights shown in Table I. 1(Appendix I).

Table 4.20 Summary of Evaluation for the Example TTs

Description	Reuse Criteria	TT1	TT2
BOD, mg/L	20	19.0	13.2
SS, mg/L	30	12.9	10.6
TN, mg/L	-	44.5	37.1
TP, mg/L		10.5	2.5
FC, No/100mL	100	150	90
Meets Criteria (Yes/No)	-	NO	YES
Adaptability to upgrade		0.88	0.88
Adaptability to varying flow rate		0.75	0.71
Adaptability to varying influent quality		1.00	1.00
Ease of O & M		0.79	0.75
Ease of construction		0.67	0.67
Reliability		0.88	0.83
Odour generation potential		0.21	0.25
Impact on ground water		0.83	0.83
Power requirement		0.88	0.75
Chemical requirement		0.54	0.50
Total land required, ha		0.49	0.53
Total sludge produced, kg/d		218	225
Total project cost*		$6,13	$6,228
Annualised project cost**		$573	$583
Life cycle cost***		$1.57	$1.60
Fitness score		-26.338	0.855

(* 1000s $, ** 1000s $/yr, ***$/m^3)

4.10 Summary & Conclusions

In this chapter the structure of MOSTWATAR and the methodology used to develop the knowledge base and database are described. A framework has been developed for the categorization of types of unit processes and their identification. Perusal of literature has indicated that there is a wide variation in the design parameters and cost of the unit processes. There is also lack of accurate information on the criteria such as reliability and performance, which makes the comparison of different process configurations difficult. As indicated by Kroiss (1994) due to probabilistic nature of wastewater flow and composition it is difficult to develop a database, which can characterize every problem. In an effort to develop a realistic database in reference to South Australian conditions, a questionnaire was developed to identify and collect data for the unit processes. 40 unit processes have been selected to demonstrate the methodology for comparative evaluation. The preliminary design and cost for these unit processes have been developed based on the input from SA Water, manufacturer's and data from literature.

The primary goal of this model was to assist users in developing a series of treatment trains (TTs) to treat domestic wastewater to the required reuse criteria. Since the order of the unit processes in a treatment train is important, over 120 rules were developed. In addition to the order of the unit processes, it is also necessary to check if the influent entering these unit processes in a TT are within the maximum limit, as they fail to function effectively beyond this limit. Maximum allowable limits for sensitive unit processes were developed. In order to form TTs based on site-specific factors such as location of WWTP, penalty factors have been developed. More than 30 reuse types have been identified and corresponding guidelines from five Australian states, one territory and a national guideline have been included. In addition to these, two widely used international guidelines have been included.

Several criteria have been used in the literature to evaluate TTs. However 14 technical, economic and environmental criteria were identified to be most important in the current study. A fitness function with an objective and penalty component was developed for the comparative evaluation of TTs. The weighted average technique was used to develop the objective function, as it is the simplest, most commonly used and widely understood technique. A description on how the user can rank the TTs based on the fitness score or on any of the 11 criteria is presented.

In this chapter, the first three objectives namely: development of database, knowledge base and evaluation methodology have been addressed. In the next chapter, an algorithm developed to generate and optimise TTs for given conditions is described. While the salient features of the user interface developed in discussed in Chapter 6.

Chapter 5 Generation and Optimisation of TTs Using Genetic Algorithms

5.1 Introduction

In the previous Chapter, the development of MOSTWATAR model and how the user can use it to evaluate treatment train (TT) options was described. In this chapter the methodology used to develop an algorithm for MOSTWATAR to generate and optimise TT options is described. The generation and optimisation of treatment trains (TTs) is an important step in the planning of wastewater reuse schemes as discussed in the previous Chapters. This can be a very tedious task for planners especially, as there are many unit processes to choose from. Several researchers such as Chang and Liaw (1990), Ellis *et al.*, (1986), Taur (1984), Rossman (1980), Ellis and Tang (1991), Chen and Beck (1997) have studied generation techniques such as enumeration and optimisation techniques including linear, dynamic, non-linear and integer programming. These optimisation approaches have been found to have limitations as discussed in Section 3.5.2.

The present study investigated the use of genetic algorithms (GAs) for generation and optimisation of TT's for given reuse(s) and a guideline. Genetic algorithms are a set of guided search procedures based on Darwin's theory of natural selection. The algorithms originated from studies of cellular automata by Holland (Holland, 1975 cited in Buckles and Petry, 1994). Goldberg (1989) extended this study to search for optimal solution in many engineering applications with enormous solution spaces.

Since then several researchers have applied GAs to a number of combinatorial optimisation problems such as pipe network optimisation (Simpson *et al.*, 1994, Dandy *et al.*, 1996), image processing, pipeline controls systems (Goldberg and Kuo, 1987), water resources planning (Connarty, 1995), water supply pump schedule (Rodin, S.I, 2002), structural optimisation (Sved *et al.*, 1991; Rodin, S.I 2002), aerospace applications (Krishnakumar and Goldberg, 1990) and musical compositions (Horner and Goldberg, 1991, Cited in

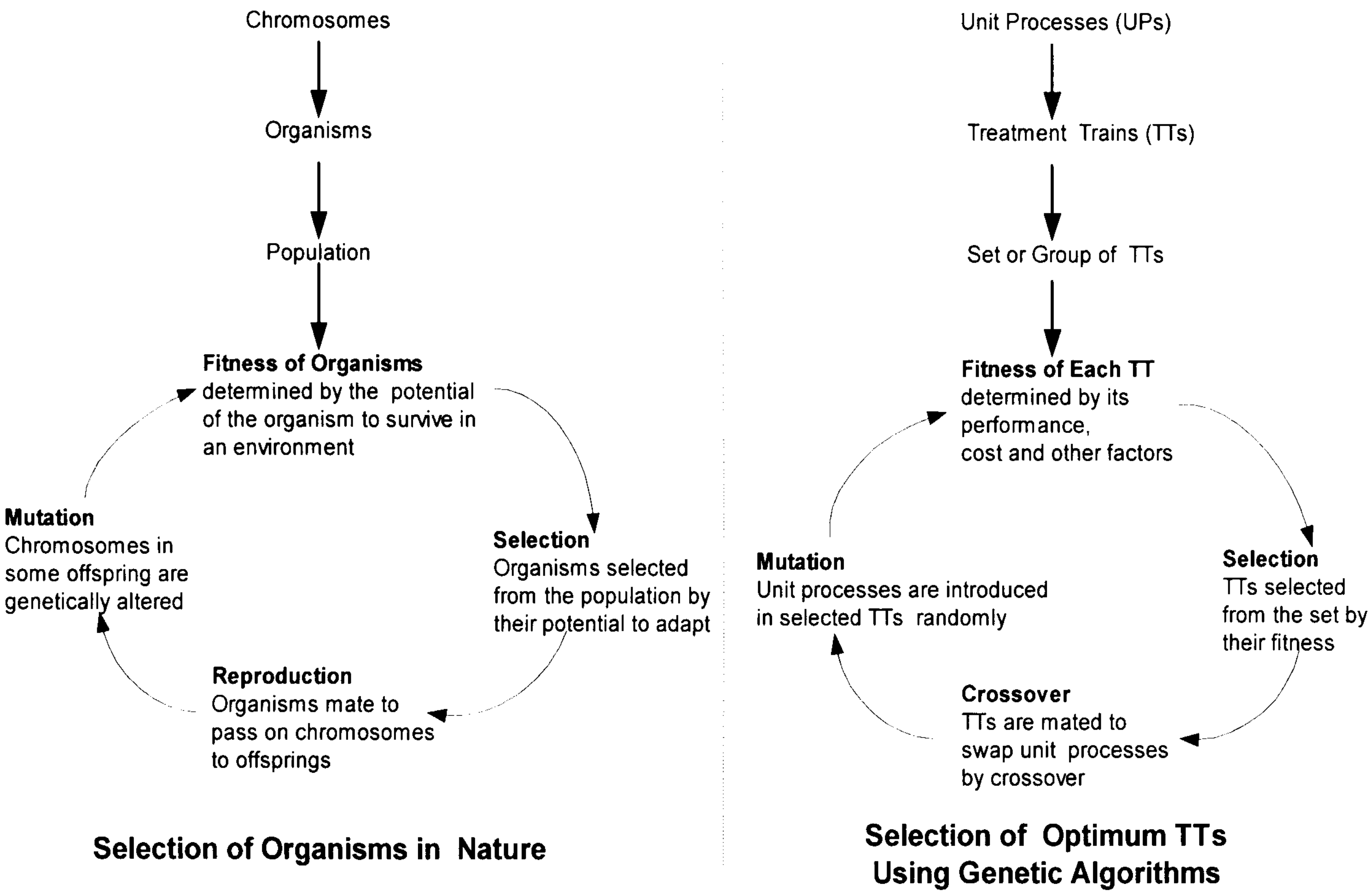
Simpson *et al.*, 1994). Although they have been used to solve wide-ranging optimisation problems, GAs have not been applied so far for generation and optimisation of TTs.

The purpose of this chapter is to introduce GAs and present the methodology used to develop a simple GA for the generation and optimisation of TTs for given local conditions such as reuse(s), guidelines, influent characteristics and so on. To begin with, an overview of GAs and the basic components of GAs are presented based on Goldberg (1989). Secondly, the merits and demerits of GAs and why simple GAs was chosen for TT generation and optimisation are discussed. Thirdly, the methodology adopted for the algorithm development is described in Section 5.4. Since the generation of an initial population of possible solutions is the first step in GAs, this is discussed along with the GA development. Finally, the steps involved in the algorithm are summarized in the flow chart and conclusions based on the use of GAs for generation and optimisation of TT options are presented.

5.2 An Overview of Genetic Algorithms

Genetic algorithms (GAs) are a set of stochastic optimisation techniques based on Darwin's theory of natural selection (Begon *et al.*, 1990). GAs are used for guided search of large combinatorial problems and they are discussed in depth by Goldberg (1989). The basic idea of GAs is to maintain a set of solutions, which evolve over time through process of survival of the fittest similar to the population genetics in nature. This is as shown in Figure 5.1. This figure also outlines a simple GA adapted from Grefenstette and Baker (1994).

In nature each organism will have a fixed number of chromosomes and a number of organisms (of the same kind) are grouped to form a population. The probability of an organism surviving and reproducing in a population is determined by its potential to survive in the environment and is referred to as fitness.



(Source: Adapted from Hewitson,1999)

GA Procedure
begin

```
  Generation (Gen), Gen = 0;
  Initialize to randomly/ heuristically
   select population P (Gen);
  Evaluate fitness function in P(Gen);
  Repeat;
   Gen = Gen + 1;
   Select P (Gen) from P (Gen-1);
   Apply genetic operators in P(Gen);
   Evaluate the fitness of P (Gen);
   Until Gen >= max Gen;
```

end.

(Source: Grefenstette & Baker, 1994).)

Figure 5.1 Analogy between Population Genetics and Optimization of TTs with an Outline of a Simple Genetic Algorithm

The organisms most capable of surviving in the environment reproduce to form new organisms (referred to as offspring). Sometimes mutation of genetic material occurs in some offspring thus affecting their fitness. This process of selection, reproduction and mutation continues over a large number of generations in nature. Genetic Algorithms emulate the principle of the survival of fittest and involve similar steps to that described above as illustrated in Figure 5.1.

In GAs, the candidate solutions (similar to organisms) are normally represented as strings. In the current problem, each candidate solution represents a TT consisting of a number of unit processes (which are similar to chromosomes). A number of TTs form a population. As shown in Figure 5.2, a simple GA involves three steps namely generation, evaluation and optimisation. Solutions are evaluated in terms of their performance, cost and effectiveness measures in order to measure their fitness value at the end of each generation. Several genetic operators such as reproduction, crossover, and mutation are used to manipulate solutions to obtain better solutions from the previous generation.

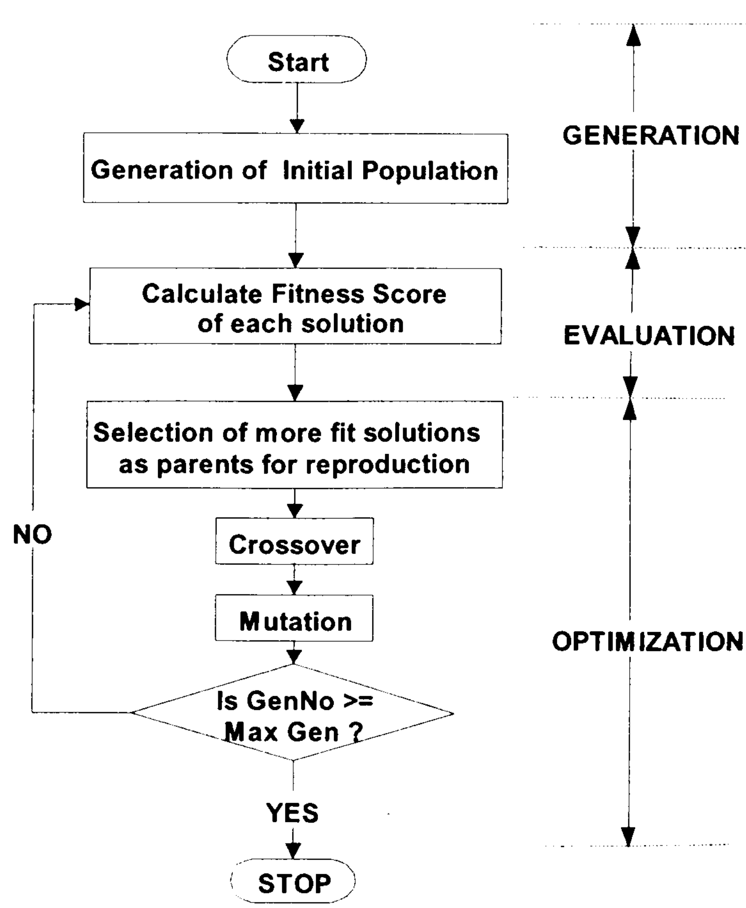
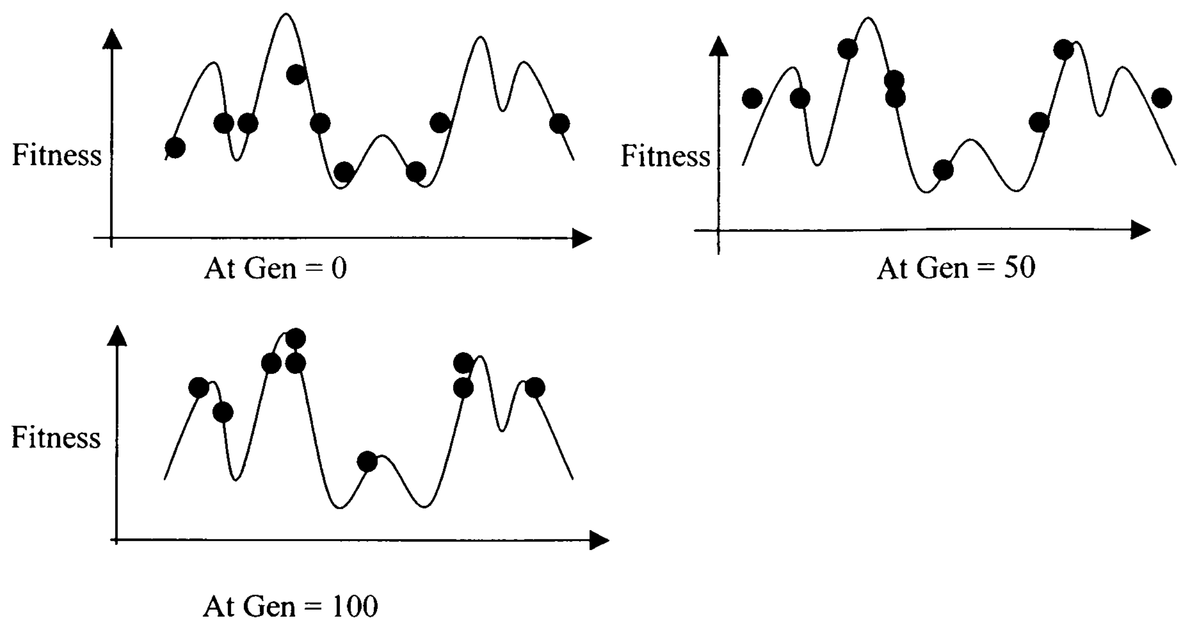


Figure 5.2 Flowchart of a Simple Genetic Algorithm

The improvement of solutions (which is measured by fitness) over generations is illustrated in Figure 5.3. In this Figure, the points on the curve show how the fitness of individuals in a population improves over 0, 50th and 100th generations (Gen) by moving towards the peaks. The generation of a new population is continued until convergence is achieved or a near optimal (or best) solution is found.



(Source: DeJong, 1994)

Figure 5.3 An Illustration of Improvement of Fitness Over Generations

GAs have been applied to a wide range of complex optimisation problems and many modifications to simple GAs (such as Messy GAs) have been made to suit such applications (Savic and Walters, 1994). In this chapter a brief description of simple GAs is presented as it consists of most of the important features of any modified GA. The description is based on Goldberg (1989). In the following sections background information on basic components of GAs and how they operate is provided before presenting the methodology adopted to develop this evolutionary algorithm.

5.2.1 Basic Components of GA

In general a GA must have the following five basic components to solve any optimisation problem.

1. a genetic representation of solutions to the problem referred to as the coding scheme

2. a way to create an initial population of solutions
3. an evaluation function to rate solutions in terms of their 'fitness'
4. genetic operators that alter the genetic composition of offspring during reproduction
5. values for GA parameters such as population size, probability of crossover, and mutation. (Davis, 1987 cited in Michalewicz, 1999)

Before discussing these components with reference to the present study, a discussion of the same as applied to any problem in general is presented in Sections 5.2.1.1 to 5.2.1.5.

5.2.1.1 Coding Scheme

The coding scheme refers to the genetic representation of a candidate solution, which is expressed as unique coded string of finite length (Dandy *et al.*, 1996). There are 4 types of coding schemes commonly used for representation of strings in GAs. They are (1) binary coding, (2) gray coding, (3) real coding and (4) continuous coding. Traditionally, GAs have used fixed length, binary coding to represent strings. The binary coded stings have dominated GA research, as there are theoretical results to show them to be the most effective and simple for implementation (Goldberg, 1991). Each string has a finite length and each bit can be either 0 or 1. Other non-binary representation of strings started after it was shown that GA properties are not because of bit strings (Radcliffe, 1992 cited in Herrera, *et.al*, 1998).

Gray coding also uses 0 or 1 to comprise the strings as in binary coding. The main difference between binary and gray coding is that in gray coding there is only one bit change between the adjacent strings while in binary coding there may be several changes in the bit (Caruana and Schaffer, 1998). This is illustrated in Table 5.1. On the other hand real coding refers to the use of integer numbers (e.g. 0,1,2,3) and continuous coding refers to the use of real or floating-point numbers (e.g. 0.11, 0.989, 0.345) (Connarty, 1995). The real coding has been used in number of applications such as parametric design of aircraft (Bramlette *et al.*, 1991 cited in Herrera, *et.al.*, 1998), pipe optimisation (Simpson and Goldberg, 1994) and optimisation of flood control (Chang and Chen, 1998).

Table 5.1 Comparison of Binary and Gray Coded Integers

Integer	Type of Coding Scheme	
	Binary	Gray
1	0001	0001
2	0010	0011
3	0011	0010

(Source: Goldberg, 1989, pp 100)

In many applications, real coded GAs have outperformed binary coded genetic algorithms (Davis, 1991; Michalewicz 1994) and the advantages of using real coded genetic algorithms has been discussed by Herrera *et al.*, (1998). Real, binary and gray coding have been compared for pipe optimisation by Simpson and Goldberg (1994) and they have concluded that there is no benefit from using any particular coding scheme if there was sufficient mixing within the GA process. While Chang and Chen (1998) have reported that a real coded GA performed better for optimisation of flood control reservoir model in terms of efficiency and precision than a binary coded GA. The coding scheme used in the current study is described in Section 5.4.2.

5.2.1.2 Generation of the Initial Population

The first step involved in running GAs is the generation of an initial population of solutions either randomly or heuristically. A random number can be generated using pseudo random number generators built in to many of the programming languages such as FORTRAN, Visual Basic™ and Delphi™. A sequence of random number between 0 and 1 will be generated (unless a different range is specified) to form strings (candidate solution). For binary coding these random numbers will be rounded to 0 or 1 depending on which is closer. Several such candidate solutions can be generated randomly to form a population.

On the other hand, an initial population can be generated based on experience and previous knowledge of the problem. For instance, all the solutions can be generated within the feasible solution space. Generating the initial population by this method (i.e. heuristically) has an advantage over random generation, as the search time will be reduced with the disadvantage that the search will not be as broad as with random generation. These two techniques are further described in Section 5.4.3

5.2.1.3 Fitness Function

The fitness function (also known as the evaluation function) is a means of rating how good or bad an individual is, as compared to others in the population. Better individuals have higher chances of survival and reproduction. Hence, the successful implementation of GAs depends on proper definition of the fitness function. Often it is taken for granted as it is implicitly defined by the problem (Michalewicz, 1999).

As discussed in Section 5.2, GAs alter solutions over generations through crossover and mutation to search for better solutions. This results in the generation of feasible and infeasible solutions. In order to encourage feasible solutions, three main approaches have been used. They are (1) repair algorithms, (2) special data structures and operators and (3) penalty functions (Coit and Smith, 1996; Michalewicz, 1999) and are discussed next.

The repair algorithms have been applied to problems such as traveling salesman where it is relatively easy to repair an infeasible individual by searching the closest feasible solution (referred to as learning) and evolving over generation. This learning and evolution is referred to as Baldwin effect (Whitley *et al.*, 1994 cited in Michalewicz, 1999). The two main drawback with repair algorithms are that (1) it is problem dependent and requires specific algorithm to be designed and (2) in some problems repairing the individuals is as complex as solving the original problem.

On the other hand the special data structures and operators is based on maintaining feasible population by one of the following approaches: (1) by using special representation and genetic operators, (2) by restricting the search to feasible solutions based on the idea of decoders, i.e. chromosomes give direction on how to build feasible solution, or by (3) exploring the boundaries between feasible and infeasible parts of the search space. The third and final approach namely the penalty function is the most common approach and is discussed further in Section 5.2.1.3 (i).

A typical fitness function consists of an objective function and a penalty function. For a single decision variable x, the fitness function is given by the following equation.

$$f(x) = O(x) \pm \alpha(x) \quad \textbf{(5.1)}$$

where $f(x)$ = fitness function for decision variable x

$O(x)$ = objective function of x

$a(x)$ = penalty function for x

The objective function and penalty function is similar to that described in Section 4.8.2.3 (i). The penalty function is added to the objective function for a minimization problem while it is subtracted for a maximization problem. A brief review of the type of penalty functions and different methods of penalty calculation used is discussed in this section.

5.2.1.3 (i). Penalty Function

The penalty function (*a*) is one of the most widely used approaches to penalize individuals that fail to satisfy the constraints. An individual may be penalized for (1) just being infeasible (sometimes referred to as "death penalty"), (2) the number of constraints violated regardless of magnitude, (3) the 'amount' by which it is infeasible or (4) for the 'ease of repairing' an individual (Michalewicz, 1999).

Michalewicz (1999) have presented an excellent review on the construction of a penalty function and form the basis for the discussion presented in this section. Siedlecki and Sklanski (1989) and Michalewicz (1999) explain that one should not eliminate infeasible solutions from the population as in most of the problems, the optimum solution lies on the boundary of feasible and infeasible parts of the search space. Retaining infeasible solutions allows an approach to the optimum from both infeasible and feasible directions thus reaching the optimum solution much faster.

The method of penalty calculation is important in a GA as a very harsh penalty discards all infeasible solutions while a very mild penalty fails to direct the search towards the feasible solution (Khuri *et al.*, 1994, Smith and Tate, 1993; Michalewicz, 1995). Thus an appropriate choice of the penalty calculation method should be based on the following. (1) the ratio between the size of the feasible to the size of the whole search space, (2) the type of objective function (maximize or minimize) (3) the type(s) and numbers of constraints, (4) the number of variables, (5) topological properties of the feasible search space and (6) the number of active constraints at the optimum (Michalewicz, 1999). Further, the design of the penalty function is problem dependent and an overview of the types of penalty functions studied by various researchers is presented in Table 5.2. The types of penalty functions can broadly be classified in to static, dynamic and adaptive approaches and these are discussed below.

Static penalty functions are constant penalty functions based on either the number of constraints violated or on the distance from the feasible region. Distance based static penalty functions are much superior to penalty functions based on the number of violated constraints and they have been studied by Olsen (1994), Richardson *et al.*, (1989), Le Riche *et al.*, (1995) (cited in Coit and Smith, 1996). However, the main drawback of static penalty functions is that it is difficult to determine the penalty constant for the i^{th} constraint (*Ci)* and it needs to be determined experimentally based on factors such as feasibility of the solutions (Coit and Smith, 1996).

To overcome this disadvantage, Smith and Tate (1993) modified the approach of Richardson *et al.,* (1989) by calculating the distance measure and altering the magnitude of the penalty dynamically, by scaling according to the fitness of the best solution yet found. Many forms of dynamic fitness scaling have been suggested (Grefenstette, 1986; Goldberg, 1989; Siedlecki and Sklanski, 1989; Smith and Tate, 1993 and Coit and Smith, 1996). Siedlecki and Sklanski (1989) have reported that GAs with dynamic (variable) penalty coefficients outperform the static penalty factor algorithm. In spite of incorporating the distance and the length of search, the dynamic penalty functions are known to ignore the search specific information (such as the best feasible or worst infeasible solution found in the previous generations).

Adaptive penalties were then proposed by Bean and Hadj-Alouane (1992) to consider search specific information as they can guide the search based on what is already observed or found. In this method, if 't' is the generation number, the penalty component for the (t+1) generation decreases if all the best individuals in the last '*t*' generations were feasible. On the other hand, the penalty increases if all the best individuals in the last '*t*' generations were infeasible. If there are some feasible and some infeasible solutions on the last '*t*' generations then the penalty component remains the same.

Table 5.2 Comparison of Penalty Functions

Type of Penalty Function	Basis	General Equation	Advantages	Disadvantages	References
Static penalty function	Number of constraints	$f_p(x) = f(x) - \sum_{i=1}^{m} C_i \delta_i$	None	Difficult to determine Ci value	Coit & Smith (1996)
	Distance from feasibility (i.e amount by which they are infeasible)	$f_p(x) = f(x) - \sum_{i=1}^{m} C_i d_i^{\ k}$	Better performers than the above	Difficult to determine Ci value	Olsen (1994); Richardson *et al.*, (1989); Le Riche *et al.*, (1995)
Dynamic penalty function	Variable penalty coefficients	$f_p(x,t) = f(x) - \sum_{i=1}^{m} s_i(t) d_i^{\ k}$	Increases severity of the penalty based on distance and length of search (i.e number of generations)	Ignores search specific information (such as best or worst infeasible solution in the previous generations)	Siedlecki & Sklansky (1989); Smith &Tate (1993); Khuri *et al.*,(1994)
	Variable penalty coefficients based on generation index	$f_p(x,t) = f(x) - V(g) \times A \times \sum_{i=1}^{m} (\delta_i w_i d_i \Phi_i) + B \times \delta_s$	Locates the general area of global optimum at the early stages of search	-	Referred to as Varying Fitness Function by Adamidis *et al.*, (1998)
Adaptive penalty function	Penalty coefficient updated every generation based on all previous generations	$fp(x,t) = f(x) - \sum_{i=1}^{m} \lambda_t d_i^{\ t}$	Guides search based on what is already observed or found (i.e best or worst solutions found so far)	-	Bean & Hadj-Aloune (1992)

Notation: i= constraints (1 to m), t = generation number, f(x) = unpenalised objective function, $f_p(x)$ = penalised objective function, A = Severity Factor, B = threshold penalty factor, C_i =constant imposed for violating i[th] constraint, d_i= amount by which constraint 'i' is violated, k = user defined exponent (normally 1 or 2 is used), w_i = weight factor for constraint 'i', ϕ_i = function of degree of violation, δ_i= 1 is constraint is violated and 0 if satisfied, δ_s= binary factor equal to 1 if x is feasible else 0, V(g) = g/G where g is the generation number and G is the maximum number of generations, $s_i(t)$ = monotonically non–decreasing in value with respect to 't'; λt = penalty component updated every generation 't',

$\lambda(t+1) = (1/\beta_1) \cdot \lambda(t)$, if previous generations have best feasible solution;

$\beta_2 \cdot \lambda(t)$, if previous generations have best infeasible solution;

else

$\lambda(t)$ otherwise,

where β_1, β_2=constants > 1& $\beta_1 \neq \beta_2$;

In order to study these different types of penalty functions and assess their suitability for the present problem, static, dynamic and adaptive penalty methods were investigated. Each of the penalty functions and the equation used is described in Section 5.4.5.2.

5.2.1.4 Reproduction

Reproduction is a process by which strings are copied to the next generation according to their fitness values. This implies that a string with higher fitness has a higher probability of reproducing in the next generation. Reproduction involves (1) selection of relatively fit parents (i.e. survival of the fittest), (2) crossover or exchange of chromosomes, and (3) mutation of chromosomes within an organism. This is discussed in the following sub-sections.

5.2.1.4 (i). Selection of Parents

Selection of parents is based on Darwin's theory of survival of the fittest (Murphy and Simpson, 1992). A randomized selection procedure is used to select new parents from the old population. Selection of new parents from the old population can be carried out by the following techniques. (1) roulette wheel selection (also known as proportionate or proportional selection), (2) tournament selection, (3) truncation selection, (4) linear ranking selection, and (5) exponential ranking selection. A good comparison of these different selection techniques is presented in Blickle and Thiele (1995) and Goldberg and Deb (1992). The most commonly used techniques namely roulette wheel and tournament selection are described next.

Roulette wheel selection is the original selection method proposed by Holland (1975). The selection probability of an individual is directly proportional to its fitness value as shown in Equation 5.2.

$$Pi = \frac{fi}{\sum_{i=1}^{n} fi} \qquad \textbf{(5.2)}$$

where P_i = probability of selecting i^{th} individual,

f_i = fitness of the i^{th} individual,

n = number of solutions in a population

The above Equation indicates that the roulette selection method will work only if all the fitness values are greater than '0'. Also, it has been shown that the selection probability strongly depends on the scaling of the fitness function. As illustrated by Blickle and Thiele (1995), the selection probability for the best and the worst individual is almost the same in the roulette selection method. This effect increases as the range of fitness values in the population decreases over generations. Therefore it doesn't not guarantee the best fit string being selected or the least fit string not being selected. Due to this lack of selection pressure a good solution is often lost (Simpson and Goldberg, 1994) and this is undesirable. To overcome this many scaling techniques have been proposed (Grefenstette and Baker, 1989).

On the other hand, tournament selection is based on randomly picking a fixed number of solutions, comparing them and retaining only the best. The number of strings selected from the population for comparison is referred to as *tournament size (ts)*. This technique can be implemented very efficiently and is preferred as it tends to converge faster than roulette wheel selection (Hewitson, 1999). The selection can take place either by replacing the selected individuals in the population (thus increasing the chance of them being picked again) or without replacement. This is further discussed next.

The first method (tournament selection with replacement) refers to the random selection of a set of strings equivalent to the tournament size and the fittest string being the parent string in the next generation. These strings are then replaced in the population and the next parent is selected using the same process. This is repeated until parent strings equal to the population size is generated. The main drawback of this method is that there is always a probability of some strings being selected as parents a number of times. By doing so, we may be overlooking other potentially fit strings and hence tournament selection with replacement is not preferred.

In tournament selection without replacement, first the entire population of the strings is shuffled (randomized) and then 'ts' strings are drawn from the shuffled population. The fittest string of the 'ts' number of strings is selected as new parent. The other strings are placed in a discard pile and the process is continued until all the strings are drawn. This will result in $n/_{ts}$ parent strings. The entire population is again reshuffled and the selection process is continued until the number of parent strings is equal to the population size 'n'. Thus in this process there is no replacement of strings in the population.

5.2.1.4 (ii). Crossover

Crossover is a mechanism used to exchange the genetic material of two parent strings. It is the primary mechanism by which breakage, partial exchange and reunion of corresponding segments of two parent strings takes place to produce two offspring (Simpson *et al.*, 1994). The probability of crossover (P_c) defines the frequency at which strings undergo crossover. In each new population, (P_c times n) strings undergo crossover 'n' is the population size. For example, if P_c is 0.4 and the population size is 100, then on average 40 strings undergo crossover in each new population.

Several types of crossover such as one-point, two-point, uniform, partially mated (PMX), cycle (CX) and r-OPT crossovers have been studied to suit different problems. In this section one point, two point and uniform crossover are discussed. A detailed description of other types can be found in Goldberg, (1989); Buckles, Petry *et al.*, (1994); Beasley *et al.*, (1993) while a comparison of different types of crossover can be found in Syswerda (1989); Eschelman, *et al.*, (1989); Spears and DeJong, (1991) and Connarty (1995).

A traditional GA uses one- point crossover where a random point is chosen along the two chromosomes. The chromosomes are separated at this point and recombined to form two new chromosomes. For instance, consider two treatment trains (1 and 2) represented by two binary strings each consisting of 8 decision variables (unit processes). The presence of the unit process is denoted by '1' while its absence is denoted by '0'. If a random crossover point is chosen at fourth bit (indicated by shaded region) then the one point crossover results in child strings shown below.

Parent 1: 1 0 0 1 1 0 0 1

Parent 2: **1 1 0 1 0 0 1 0**

After one point crossover,

Child 1: **1 1 0 1** 1 0 0 1

Child 2: 1 0 0 1 **0 0 1 0**

On the other hand two-point crossover has two random points chosen along the two strings and is reported to be superior to one-point (Goldberg, 1989). For the same two parent strings described above, two- point crossover results in the following child strings.

Parent 1: 1 0 0 1 1 0 0 1

Parent 2: **1 1 0 1 0 0 1 0**

After two-point crossover,

Child 1: **1** 0 0 **1** 1 0 0 1

Child 2: 1 **1 0** 1 **0 0 1 0**

Uniform crossover is radically different from the above two types as the number of crossing points is not fixed but is decided randomly by crossover operator referred to as probability of crossover (P_c). For each position in the string a random number between 0 & 1 is selected. If it is less than the probability of crossover, the corresponding bits are swapped between the two strings.

Spear and DeJong (1991) have presented the three important virtues of uniform crossover. They are as follows:

1. uniform crossover doesn't depend on the length of the strings and this implies that there is no defining length bias in uniform crossover.
2. disruption potential can easily be adjusted by varying the P_c.
3. when a disruption occurs, uniform crossover results in an exploration of the search space with a minimum bias.

Thus uniform crossover ensures strong mixing effect, which is sometimes helpful to overcome local optima (Khuri *et al.*, 1994). Further if we consider the same two parent strings described in one and two–point crossover, the uniform crossover at 2nd, 4th, 7th bit results in the following child strings.

Parent 1: 1 0 0 1 1 0 0 1

Parent 2: **1 1 0 1 0 0 1 0**

After uniform crossover,

Child 1: 1 **1** 0 **1** 1 0 **1** 1

Child 2: 1 0 **0** 1 **0 0 0 0**

Holland (1975) and DeJong (1975) suggested that one point and two-point crossover are preferred. This was later disproved by Syswerda (1989), Eschelman (1989), Spear and DeJong (1991) and Lin and Yao (1997). These researchers have reported that having a higher number of crossover points is beneficial and that uniform crossover outperforms one point crossover and two-point crossover.

5.2.1.4 (iii). Mutation

Mutation is considered as a secondary mechanism used to maintain any important information in a string, which may have been lost in crossover. Goldberg (1989) defines mutation as a simple random walk through the string space to change the bit values. Thus, mutation is carried out by randomly selecting a string in the population and then selecting the string position based on a probability of mutation 'Pm', where change in bit value occurs. This change in bit values enhances population diversity and prevents convergence to local optima (Coit and Smith, 1996).

Based on the type of random alteration of bit values, mutation is divided in to two main types and they are (1) bit-wise and (2) adjacency or creep mutation. In bit-wise mutation, a random alteration of a bit value (from 0 to 1 or vice versa) occurs at a string position based on a probability of mutation (P_m) (Dandy *et al.*, 1996). While in adjacency mutation, the bit value is changed to the adjacent sub string value. Simpson and Goldberg (1994) have applied this adjacency mutation to pipe network optimisation where the pipe size is changed to an adjacent pipe size (smaller or bigger).

5.2.1.5 GA Parameter Values

One of the difficult aspects of GAs is the determination of the GA parameter values, as they are highly problem dependent and need several test runs to establish the best values of the same. Several researchers such as Goldberg and Koza (1990), Simpson and Goldberg (1994) and Grefenstette (1994) have investigated appropriate values for these GA parameters.

Researchers such as Grefenstette (1994), Simpson and Goldberg (1994) and Goldberg (1994) have worked on optimising the population size. Simpson and Goldberg (1994) have presented an Equation shown below to estimate population size, which is based on many factors including cardinality of the coding, string length, difficulty of the problem, the standard deviation and error for a single trial.

$$n = 2c(1+\rho_T^2)\chi^k\gamma^2 \quad \text{..........} \quad \textbf{(5.3)}$$

where n = population size

c = square of standard normal deviate (z^2) corresponding to a probability α of making a error on a single trial

ρ_T^2 = relative additional noise due to sources other than just the variance of the fitness within the population

χ = cardinality of the alphabet used to represent the strings (eg: χ = 2 for binary coded string)

k = size of building blocks or number of bits

γ^2 = mean squared inverse overall signal to noise ratio

These authors have investigated large population sizes (100, 500, 1000) for 8 and 24 bit strings and found that large population sizes take longer time to converge. On the other hand Goldberg (1994) has indicated that faulty selection of the population size may lead to premature convergence. Goldberg and Kuo (1987) indicate that a population size of 35-200 is a good size for optimisation.

Goldberg and Koza (1990) have suggested that P_m should be greater than or equal to (1/n) and less than or equal to (1/*l*) where 'n' and '*l*' are population size and length of the string respectively. Typically P_m values range from 0.0 to 0.02. In relation to the probability of crossover P_c, the higher its value greater is the probability of new strings (offspring) being introduced in to the population. However, higher crossover can discard the high performance strings faster while lower P_c can cause stagnation due to lower exploration rate. The suggested range of values for Pc is between 0.5 and 1.0 (Grefenstette, 1986 and Goldberg, 1989).

Traditionally researchers have used tournament size of 2 as tournament sizes greater than 2 create more pressure on the selection of the fittest string and may lead to faster convergence. In problems where selection pressure or convergence rate needs to be slowed, one can use a probabilistic form of selection where the fitter string is selected based on the probability of selection pressure 'Ps'. The Ps value can range from 0.5 to 1. For a tournament size of 2 and Ps of 0.6, the selection pressure will be equal to 1.2 (i.e. 2 x 0.6) (Simpson and Goldberg, 1994).

5.3 Advantages of Using Genetic Algorithms

The limitations of deterministic optimisation techniques based on linear, non-linear and dynamic programming as applied to the generation and optimisation of treatment process selection have been discussed in the previous chapter (Section 3.5.2). The GA technique is particularly useful for large, complex search spaces (such as the present problem) where other classic search tools such as enumerative techniques have limitations. GAs provide a useful framework for simplifying the search for optimal solution in an adaptive way similar to theory of evolution. GAs have been applied to wide ranging complex, engineering optimisation problems because of the following advantages.

1. GA's are known to be more robust than gradient based algorithm and are based on the mechanics of natural selection and natural genetics.
2. GAs work from a rich database of points (a population of strings) simultaneously climbing many peaks in parallel, which is referred to as implicit parallelism (Grefenstette, 1994). Thus with probabilistic optimisation techniques (such as GAs) the probability of finding a false peak is reduced as compared with conventional methods such as the gradient based methods that go from point to point.
3. GAs examine a large but discrete solution space in order to find a global optimum (Poloni and Pediroda, 1997)
4. GAs use objective function information (fitness values) instead of derivatives or other auxiliary knowledge (Goldberg, 1989).
5. GAs can directly approach multi-objective optimisation problems without over simplification.

However, one of the main limitations of a simple GA is it tends to converge on a single solution for functions characterized by multiple peaks even though there may be several peaks that are equally fit (Goldberg and Wang, 1997). Simpson *et al.*, (1994) suggest that although GAs do not necessarily guarantee a global optimum solution, its application to wide range of problems has indicated that GAs provide near-optimal solutions after a reasonable number of evaluations.

This study investigated the use of Simple GAs for generation and optimisation of TTs for the two main reasons.

1. GAs have not been investigated so far for optimisation of TT selection. The possible number of TTs for a given condition such as reuse and influent characteristics is very large making it suitable for application of GAs. Each possible solution (TT) can then be tested for its ability to satisfy these criteria. An optimal solution (TT) can be found by allowing solutions (which do not violate the criteria) to evolve over subsequent generations.
2. GAs provide near optimal solutions which is ideal in relation to the present problem as in pre-feasibility analysis, it is intended to have the 3 or 5 best TT alternatives which are used to conduct further pilot plant studies to select the most suitable TT.

In fact, the optimisation of a TT is a multi objective optimisation problem, as it requires simultaneous evaluation of multiple conflicting objectives such as maximum performance, and minimum cost & land requirements (listed in Section 4.5.7) Normally multi-objective optimisation problems are reduced to a single objective optimisation by a weighted combination of the objective functions. It has been argued by Obayashi (1997) that the solution obtained by such a method is dependent on the arbitrary choice of the relative weights assigned and is often difficult to interrelate them. To overcome this limitation, many researchers (Goldberg, 1989; Fonseca and Fleming, 1993) have recommended several modifications such as artificial niche formation, sharing and crowding to simple GAs to help identify multiple optima reliably.

In spite of the above said limitations of converting a multi objective optimisation problem in to a single objective one, the present study investigated the use of a single objective GA for TT generation and optimisation for the following reasons.

1. As discussed in chapter 3, GAs have not been applied for TT generation and optimisation. As a first step it was necessary to determine whether GAs could be applied for generation and optimisation of TTs. Since the generation and optimisation of TTs is a complex problem, it was necessary to first develop a simple GA, which could later be modified to a multi objective optimisation algorithm.
2. Since MOSTWATAR is developed as user-friendly software, the user can carry out sensitivity analysis to understand the trade off between various criteria by varying the relative weights. This is further discussed in relevance to case studies in the chapter 7.

5.4 Development of GA for Generation and Optimisation of TTs

The current problem of generation and optimisation of TTs can be expressed in its simplest form as follows:

Find the combination of TTs (process configurations) for given local conditions such as reuse/s, criteria which results in a maximum fitness score subject to following constraints:

1. the TTs must meet the rules set out in the knowledge base.
2. the TTs must meet the reuse criteria specified by the user.
3. the TTs must have minimum cost (i.e. either total project or equivalent annualized or life cycle cost as suggested by user)
4. influent quality to unit processes in TTs must not exceed the maximum allowable influent quality described in the database.
5. land area required for TTs must not exceed the land available in the community.
6. the TTs must have high effectiveness measures such as reliability, ease of O & M, low chemical and power requirement and so on.

In this section, the methodology used to develop a simple GA for generation and optimisation of TTs is presented. This section begins with the explanation of total search space and the decision variables. Then an explanation of the coding scheme used to represent TTs and different methods used to generate the same are presented. The range of values used for various input parameters is discussed. The steps involved in determining whether the TT generated meet the rules are described with a simple example. Next, the construction of objective and penalty functions and the type of genetic operators used are described. Finally a flowchart, which summarizes the different steps involved in the GA developed, is presented.

5.4.1 Decision Variables and Search Space

Decision variables represent different options available to form a solution. In the present study, decision variables are different unit processes available in the database. These unit processes can form numerous combinations of TTs. The following equation suggested by Hewitson (1999) was used to determine the number of combinations (i.e. size of the search space) that can be generated.

$$\text{Size of the Search Space} = N_{oi}^{N_{di}} \quad \textbf{(5.4)}$$

where N_{di} = number of decision variables for type i

N_{oi} = number of options of type i

In each string a unit process can either be present or absent and thus, the decision process is made up of two options. In the present study, the total number of combinations available is 2^{40} (as 40 unit processes are present in the current database). This works out to about 1 trillion combinations (1.09×10^{12}). In the current database 40 unit processes were used to demonstrate the methodology. However in practice there may be 100s of unit processes, which means the actual total search space is much larger. Although the total search space is large, in practice the solution space is much smaller as not all of these combinations are feasible as illustrated in Figure 5.4.

Only some TTs formed out of these unit processes will meet rules and some meet the reuse criteria while a relatively smaller proportion meet both reuse criteria and rules. In the current study, TTs that meet both reuse criteria and rules are termed as *feasible TTs*. The number of feasible TT formed is dependent on many factors such as type of reuse, reuse criteria selected, type of unit processes present in the database and the acceptable process configuration rules (discussed in Section 4.5.2). An estimate of the number of combinations of TTs meeting rules, criteria and those that are feasible using the current database is presented in Section 5.4.3.1.

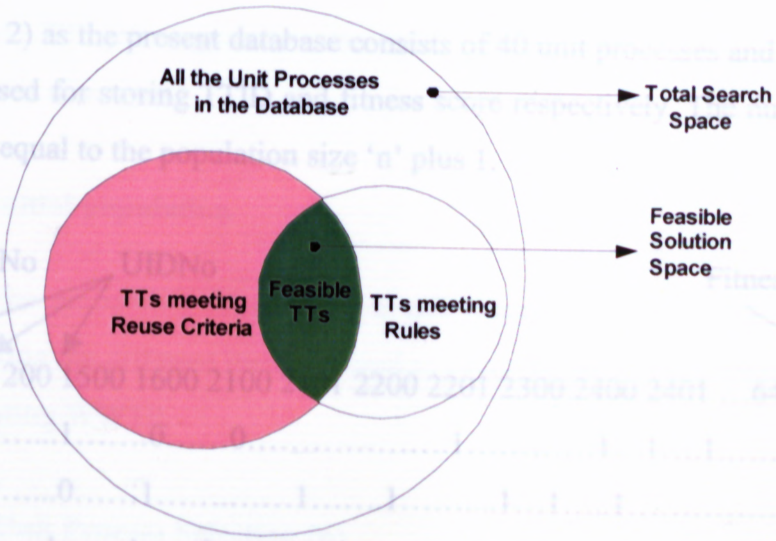


Figure 5.4 An Illustration of Search Space

5.4.2 Defining a TT Representation

In this section, the abstract representation of organisms, chromosomes and population as applied to the present problem is presented. A binary coded string was used to represent a TT (organism). The binary coding was used, as it is the simplest form of coding. The 1's and 0's in the TT string were used to represent the presence or absence of a particular unit process corresponding to the unit process in the database respectively.

Each TT string consisted of unit processes (chromosomes) represented by '1' while the absence of unit process was represented by a '0' as shown in Figure 5.5. A number of such TT strings represent a population. Since the sequence of unit processes in a TT string is important (i.e. primary process must precede secondary process in a TT) an order-based representation of TTs was necessary. An array was used to store the TT strings generated. The first row of the array consisted of all the unit processes in the same order as in the database (henceforth referred to as dummy string) and is as shown in Figure 5.5.

The first element in each row of the array was reserved for storing the identification number (TTID) of a TT string while the last element in each row was reserved for storing the fitness value of that TT string. The length of a TT string is dependent on many factors including type of reuse selected, recommended treatment and the method used for the initial generation of population as shown in Table 5.3. The maximum length of the TT string is however (40 + 2) as the present database consists of 40 unit processes and the first and last elements are used for storing TTID and fitness score respectively. The number of strings in the array was equal to the population size 'n' plus 1.

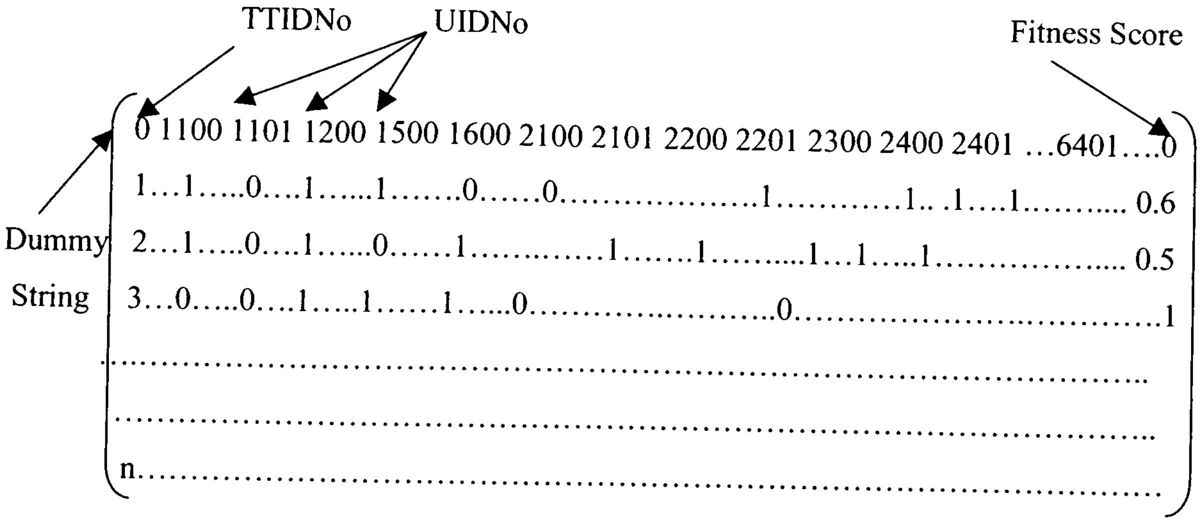


Figure 5.5 An Illustration of Order-Based Representation of TT Strings

In the following example a typical representation of TT string (maximum length of 29) is presented. Note that a symbol '|' has been used after each element in a TT string for ease of reading.

TT1: 1|1|0|1|0|1|0|0|0|0|1|0|0|0|0|0|0|0|0|0|0|1|0|0|1|0|1|0|1|0.6

TT2: 2|1|0|1|0|0|1|0|0|1|0|0|0|0|0|0|0|0|0|0|1|0|0|0|1|0|1|0|1|0.5

TT3: 3|0|0|1|0|1|1|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|1

TT 1 string represents a bar screen (1100)+ grit chamber (1200)+ primary clarifier (1500) ASP with Ni (2201)+ UV disinfection (5300) +anaerobic digester (6200)+ sludge drying beds (6301)+ land filling of sludge (6401) with a fitness score of 0.6. Similarly, TT2 represents a bar screen (1100)+ grit chamber (1200) + chemical assisted clarifier (1600) + ASP (2200)+ chlorination (5200) + anaerobic digester (6200) + belt filter press (6300) + land spreading of sludge (6401) with a fitness score of 0.5. The zeros indicate that the process (corresponding to this position in the database) is not present in these strings.

On the other hand TT3 represents an infeasible TT as it has no screens and has both gravity & chemical assisted sedimentation. As it does not meet the acceptable process configuration rules, this TT gets a penalty score of 1. In the following sections, the generation of TT strings is discussed.

5.4.3 Generation of initial population

In this section, firstly the probability of selecting a unit process to form a TT string is described before presenting the different methods used to generate the initial population for new and upgrade of existing WWTP.

5.4.3.1 Probability of Unit Process Selection (p)

The most common method to generate an initial population when using binary coding in GAs is to randomly generate strings of '0's and '1's with a probability 'p'. Normally a 'p' value of 0.5 is used to generate strings. However this was found not to be effective for the generation of TT alternatives as it meant that approximately half of the unit processes present in the database would be present in any particular TT. As the TTs needed to satisfy a number of rules for feasibility it was found that a lower value of 'p' gave a higher percentage of feasible TTs. In addition, the time taken to generate feasible TTs is higher for a higher value of 'p'.

After several test runs it was seen that a 'p' value of 0.2 produced highest number of feasible TT strings and therefore in all the future runs a 'p' value of 0.2 was used. It was also found that on an average 700 TTs had to be generated to get 1 TT meeting rules. The generation of initial population or the alternative treatment schemes is dependent on the type of plant i.e. new plant or upgrade of existing plant and they are discussed in the following sections.

5.4.3.2 Generation of TTs for a New Plant

The initial population can be chosen heuristically or at random (Grefenstette, 1994) or a combination of both. One can approach the feasible solution space starting from different search spaces (represented by symbols S, R1, R2 & R3) as illustrated in Figure 5.6 and described in Table 5.3.

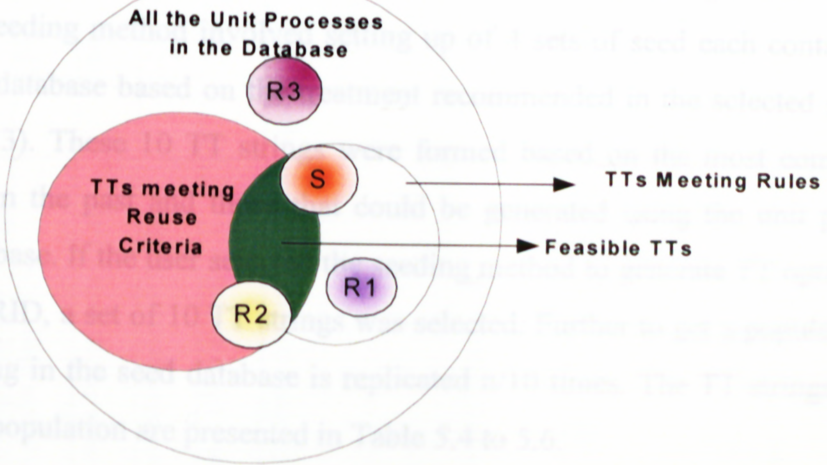


Figure 5.6 Pictorial Representation of Initial Population Generation Methods

Table 5.3 Different Methods Tested for Generation of Initial Population

Method	Symbol Used	Description*	Maximum Length of the TT String (y)**			
			RID0#	RID1	RID2	RID3
Seed	S	Seeding initial population with a set of TT strings that meet the rules	25	25	29	40
Random-1	R1	Random generation of TT strings from selected unit processes based on recommended treatment	25	25	29	40
Random-2	R2	Random generation of TT strings using all the unit process from the database and checking that they meet the rules	40	40	40	40
Random-3	R3	Random generation of TT strings using all the unit process from the database. Rules are not checked for the initial population	40	40	40	40

Note: * 100 % of the initial population generated meets the rules while only 30-80% of them are feasible (which meets both criteria and rules) in all the methods except R3. The actual percentage feasible depends on the reuse type and criteria selected.

** based on recommended treatment and method of generation of TTs

Recommended treatment ID (RID) 0,1,2,3 represent reuse class D, C, B, A respectively (See Table G.3 for recommended treatment processes)

As shown in the Figure 5.7, methods S, R1, R2 and R3 were used to generate the initial population. The seeding method involved setting up of 4 sets of seed each containing 10 TT strings in the database based on the treatment recommended in the selected guideline (RID 0, 1, 2 and 3). These 10 TT strings were formed based on the most common TT alternatives used in the past and those that could be generated using the unit processes present in the database. If the user selected the seeding method to generate TT options then depending on the RID, a set of 10 TT strings was selected. Further to get a population size of n, each TT string in the seed database is replicated n/10 times. The TT strings used in seeding the initial population are presented in Table 5.4 to 5.6.

The TT string for the seed was selected based on the type of reuse (i.e. their reuse ID). Accordingly three types of seed were selected as shown in Table 5.4 to 5.6. The type of process to be included in these strings was based on the recommended treatment by the guideline. For instance, if turf irrigation and SA reclaimed water guideline was selected then the TT strings consisted of primary and lagoons only or primary and secondary treatment based on RID 0. In such a case the seed strings listed in Table 5.4 will be selected. Similarly if residential non-potable uses were selected then TT strings listed in Table 5.6 (based on RID 3) will be selected as seed.

The above methodology was adopted to ensure that the seed reduces the time taken to reach the 5 best solutions. How the solutions from seed compared with other generation techniques is discussed in Chapter 7.

Table 7.31 Summary of the Best TT Options Generated by the User and MOSTWATAR

Method of Generation	Treatment Trains	Fitness Score
User	Bar screen + Grit Chamber + Primary clarifier + Continuous flow BNR + Coagulation, flocculation & Sedimentation + Sand filter + UV disinfection + Gravity thickener + Sludge drying beds + Land spreading of sludge	0.742
User	Bar screen + Primary Clarifier w lime + Continuous flow BNR + Coagulation & flocculation + Dual media filter + UV disinfection + Post chlorination + Gravity thickener + Anaerobic digester + Sludge drying beds + Land spreading of sludge	0.731
Seed (B^+)*	Bar screen + Primary Clarifier w lime + ASP w Ni & w clarifier + Two stage lime treatment + Dual media filter + UV disinfection + Sludge drying beds + Land spreading of sludge	0.655
R2(B^+, DPM1)*	Bar screen + Primary Clarifier w lime + Continuous flow BNR + Sand filter + UV disinfection + Sludge drying beds + Land spreading of sludge	0.801
R2(B^+, DPM2)*	Bar screen + Primary Clarifier w lime + Continuous flow BNR + Sand filter + UV disinfection +Post chlorination + Sludge drying beds + Land spreading of sludge	0.776
SA Water**	Bar screen + Grit chamber +Continuous flow BNR + Coagulation & Flocculation + Dual media filter + UV disinfection + Gravity thickener + Sludge lagoons + Sludge drying beds.	---

*Generated by MOSTWATAR, ** SA Water is currently evaluating this TT option for Victor Harbor. Since the current database does not include sludge lagoons the fitness score is not calculated.

Table 7.32 Comparative Evaluation of TTs Generated by the User and MOSTWATAR

Method of Generation	Total Land Required, ha	Sludge Produced, kg/d	Reliability Score	Adaptability to Upgrade Score	Life Cycle Cost, \$/m3	Final Effluent Quality		
						BOD, mg/L	SS, mg/L	FC, No/100mL
User (1)	1.68	2,331	0.87	0.80	0.83	3.1	1.5	4.5
User (2)	1.87	622	0.88	0.70	0.93	5.3	4.0	0
Seed (B^+)	1.66	1,613	0.79	0.83	1.19	2.3	1.8	0
R2(B^+,DPM1)	1.53	872	0.76	0.81	0.61	4.9	3.6	4.5
R2(B^+,DPM2)	1.59	872	0.79	0.75	0.70	4.9	3.6	0

Table 5.6 List of TTs used as Seed for RID 3

SlNo	Treatment Trains
1	bar screen + grit chamber + primary clarifier + TF, rock + BNR + coagulation and flocculation + sand filter + chlorination + Anaerobic Digester + belt filter press + land spreading of sludge
2	bar screen + grit chamber + primary clarifier w lime + ASP + single stage lime treatment + sand filter + granular activated carbon + UV disinfection + post chlorination + anaerobic digester + sludge drying beds + land spreading of sludge
3	bar screen + grit chamber + SBR + break point chlorination + coagulation & flocculation + Sand filter + UV disinfection + anaerobic digester + sludge drying beds + land spreading of sludge
4	bar screen + fine screen + primary clarifier + ASP w Ni + single stage lime treatment + micro filtration + UV + sludge drying beds + land spreading of sludge
5	bar screen + grit chamber + primary clarifier w lime + aerated lagoons + sedimentation pond + break point chlorination + coagulation and flocculation & sedimentation + granular activated carbon + RO + UV disinfection + anaerobic digester + sludge drying beds + land Filling of sludge
6	bar screen + aerobic lagoon + FWS (BOD & Ni) + maturation pond + post chlorination
7	bar screen + grit chamber + primary clarifier + BNR + coagulation &flocculation + sand filter + granular activated carbon + UV disinfection + sludge thickener + anaerobic digester + sludge drying beds + land filling of sludge
8	bar screen + fine screen + SBR + two stage lime treatment + break point chlorination + micro filtration + granular activated carbon + UV disinfection + anaerobic digester + sludge drying beds + land filling of sludge
9	bar screen + fine screen + primary clarifier w lime + ASP w Ni + two stage lime treatment + dual media filter + RO+ UV disinfection + gravity thickener + anaerobic digester + sludge drying beds + land filling of sludge
10	bar screen + grit chamber + primary clarifier + TF plastic + single stage lime treatment + maturation pond + post chlorination + sludge drying beds + land filling of sludge

If the user selects the random generation of TT strings (R1) to generate TT options then maximum length of the string is based on the treatment recommended in the relevant guidelines. Furthermore, the unit processes will be selected from this group of treatment processes. Depending on the probability of process selection 'p' (as discussed in Section 5.4.3.1) each unit process gets included in or excluded from a string. If the random number generated is less than 'p' then a unit process corresponding to the first process in the database is selected.

Once the TT is generated, the rules are applied so as to rule out any unacceptable treatment trains and to ensure the formation of good set of solutions in the subsequent generations. For example: bar screen + primary clarifier + chlorination +sludge drying beds + land spreading of sludge is an acceptable TT configuration while bar screen + chlorination is not acceptable. The elimination by rules is explained in the Section 5.4.4. Further, the initial generation of TT is continued until the number of feasible TT strings is equal to the population size specified by the user.

Similarly if the user selects the random generation of TT strings (R2) to generate TT options then the unit processes are selected form among all the processes present in the database. Therefore the maximum length of the TT string is equal to the total number of unit processes as shown in Table 5.6. The TT string is formed as explained in the case of R1. The only difference between the R1 and R2 method of generation is that R1 considers only processes based on the recommended treatment while R2 considers all the unit processes in the database.

Since the R2 method requires a considerable amount of time to generate TTs, which meet the rules, it was decided to test another method of generation where the TT strings were generated randomly using all the available unit processes without checking the rules. This method was denoted as R3 as shown in Table 5.3.

Further, the maximum length of the TT string is based on the recommended treatment and the initial population generation method. In case of R1 and RID 2, the treatment recommended by SA reclaimed water guidelines (1999) is full secondary and disinfection. Therefore the maximum length of the string will be 29 i.e. 5 primary process + 11 secondary process + 3 wetlands + 4 disinfection + 6 sludge handling process. In case of RID 1, full secondary treatment is recommended and therefore the maximum length of the string will be 25. On the other hand, for RID3 all the categories of treatment processes present in the database were considered and hence the maximum length of the string was 40.

5.4.3.3 Generation of TTs for Upgrade of an Existing Plant

The generation of TT alternatives for an existing plant is similar to the new plants, except that all the existing processes need to be included in all TTs. Additional unit process or processes are added to the existing plant based on the probability of process selection 'p'. It is assumed that the existing plant is in good working condition and doesn't require any rehabilitation.

For instance, if the user wants to upgrade an existing treatment plant (consisting of bar screen + primary clarifier + chlorination) to reclaim wastewater for urban irrigation, then each TT alternatives (upgrade option) will consist of the existing processes and suitable additional process or processes. One of the possible upgrade option generated can be: bar screen + primary clarifier + ***activated sludge process*** + ***single stage lime treatment*** + ***sand filter***+ chlorination + ***sludge drying*** + ***land filling*** (Note: The new processes added are shown in bold italics).

Once the possible upgrade options are generated, the TT will be checked to see if it meets the acceptable process configuration rule. However if the user enters an existing TT not meeting the rules then there is no chance of getting TTs with acceptable process configurations and hence an error message is displayed to the user. Further, as in the case of new plant, the initial generation of TTs is continued until the number of feasible TT strings is equal to the population size specified by the user.

5.4.4 Rules to Check Process Configuration of TTs

As discussed in section 4.5.2, it is necessary to check if the generated TT strings are acceptable in order to rule out any absurd TTs, which may have been formed either during initial population generation or during crossover or mutation. In this study a simple mathematical comparison of values and operators discussed in Section 4.5.2.1 was used. These rules can easily be updated if new processes are added without any major changes to the program. The steps designed to check if a TT string meets the rules are illustrated next by an example. For ease of understanding the rules corresponding to processes in the screen category are listed in Table 5.7 below while the complete rules developed are presented in Tables 4.2 (a, b & c).

Table 5.7 Rules Corresponding to Processes in the Screen Category

SlNo	RowUID	ColUID	Value	Operator
1	11		3	A
2	11	11	1	
3	11	13	0	
4	13		3	A

Let us consider the following TT string (TT1).

DS*	**0**	**1100**	**1101**	**1200**	**1500**	**1600**	**2100**	**2101**	**2200**	**...............0**
TT1	**1**	**1**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**.............0.6**

(*DS-Dummy string used for illustration)

1. The first unit process namely 1100 is selected and is then checked to see if there are any category specific and process specific rules in the Table above. First step is to check for category specific rules. The first two characters of the unit process ID that represents the category of unit process are taken. In this case 11 is taken and checked to see if RowUID column has a value of 11. Since there are three rows with category 11, it means that there are three category specific rules to be satisfied and TT1 is then checked to see if it meets these rules.
2. For each of these rows, the corresponding ColUID and value (0,1,2,3 or 4) are noted. Depending on the value, requirements of each of the rules are checked. For example in Table 5.7, the second row (SlNo.2) has ColUID equal to 11 and a value of one, which indicates that more than one process from category 11 can be present in the TT string i.e. bar screen and fine screen can coexist in a WWTP. Therefore TT1 string is said to pass this rule.
3. Next, the rows are grouped based on operator value. As shown in Table 5.7, categories 11 and 13 have value of 3 and operator value equal to A. This means process from either category 11 (screen) or 13 (preliminary process package plant)

must be present in the TT string. Since 1100 (bar screen) is present this TT string passes this rule.

4. The next step is to find out if any process specific rules for bar screen (1100) are to be met. This is done by checking if 1100 is present in RowUID column in Table 5.7. Since 1100 is not found, this means that this unit process does not have any process specific rules. Therefore next process in the TT string is selected.
5. In this TT string, second process is absent (0) and hence the pointer moves on to the next process, which is 1200. Steps 1 to 4 are repeated for this process.
6. Similarly steps 1 to 4 are repeated until the last process in the TT string is checked against the rules. If any one of the processes in the TT string does not match one or more of the rules then that string gets a penalty score of 1 and the next string in the population is considered.

5.4.5 Construction of Fitness Function

As discussed in Section 5.4, the optimisation problem is formulated as a maximisation problem; i.e. higher the fitness score the better the TT. The two basic differences between the fitness function used for user generated TT evaluation and GA optimisation are (1) the two penalty terms which are introduced in the GA module in addition to the four penalties discussed in Section 4.8.2.3(ii) and (2) modifications to the basic fitness function based on the method of penalty calculation. They are discussed in Section 5.4.5.3.

5.4.5.1 Objective Function

The objective function of MOSTWATAR model incorporates several objectives including cost, the land requirement, and other technical and environmental criteria such as reliability, adaptability to varying flow rate and so on as discussed in Section 4.8.3.2(i). The inclusion of these criteria with weights assigned by the user helps in understanding the trade offs among objectives. The objective score for TT strings in the GA module is calculated using the Equation 4.18 given in Section 4.8.3.2(i).

Once the criterion scores (P_{ik}) for TT strings are calculated, it was necessary to scale the objective score values of different TT strings in a population to ensure that all the components of the objective function are comparable. Bäck (1996) has discussed a number of objective score scaling techniques including linear static & dynamic scaling, logarithmic scaling, exponential scaling and sigma truncation. He has reported that empirical comparison of the different scaling techniques have not been carried out so far but recommends that linear dynamic scaling technique is preferable compared to other techniques. In this study linear static and linear dynamic scaling techniques were investigated to identify best TTs.

5.4.5.1 (i). Linear Dynamic Scaling in the Objective Function

The different steps involved in the linear dynamic scaling are as follows.

1. In every generation, maximum and minimum values of the criteria namely economic (either project cost or equivalent annual cost or life cycle cost suggested by user) and technical (land requirement and sludge production) were calculated for each treatment alternative in a population.
2. These values were then compared with the maximum and minimum from all the previous generations.
3. If the current generation maximum score for any criterion is the highest as compared to the previous generations, then this value becomes the maximum score for that criterion. Similarly the minimum criterion score for the current generation is determined.
4. Thus, for generations greater than one, the scaled scores were calculated using the maximum and minimum scores obtained from all the previous generations as shown in Equation 5. 7.
5. On the other hand, the scaled scores for other technical and environmental criteria listed in Table 4.13 (criteria no 2 to 11) were obtained by simply dividing the raw score by 3 (as the scale was set from 0 to 3) as shown in Equations 4.14 & 4.15.

The main advantage of linear dynamic scaling technique is it doesn't require prior knowledge about the minimum and maximum criterion values for TTs with given input parameters. However, after several test runs it was found that linear dynamic scaling has a major drawback i.e. the same TT string in different generations can have different fitness scores depending on the best and worst TT string up to that generation. This means that TT strings could not be compared on one unchanging scale. Therefore this method of scaling which kept changing with respect to generation was not suitable for the present problem.

Hence it was necessary to have the same maximum and minimum value for each criterion in all the generations and linear static scaling was used in all runs. This is explained next.

5.4.5.1 (ii). Linear Static Scaling in the Objective Function

Case 1: MOSTWATAR to generate options using either seed or R1 or R2.

1. Find maximum and minimum values for economic and technical criteria namely cost, land requirement and sludge production for the initial population.
2. For subsequent populations the minimum and maximum values are multiplied by factors shown below.

$$\min P'_{ik} = 0.1 * \min P_{ik} \quad \text{(5.5)}$$

$$\max P'_{ik} = 5 * \max P_{ik} \quad \text{(5.6)}$$

where $\min P'_{ik}$ = Minimum criterion value for generation >0

$\min P_{ik}$ = Minimum criterion value for 0^{th} generation

$\max P'_{ik}$ = Maximum criterion value for generation >0

$\max P_{ik}$ = Maximum criterion value for 0^{th} generation

The values of 0.1 and 5 in the Equations 5.3 and 5.4 respectively were chosen to span the range of likely values for the criteria.

3. The scaled score calculated using the following equation would set the TT with the lowest criterion score at 0 and the highest at 1 for that generation

$$Scaled\ criterion\ score(P_{ik})\ for\ TT_{ik} = \frac{P_{ik'} - \min P'_{ik}}{\max P'_{ik} - \min P'_{ik}} \quad \text{(5.7)}$$

where, $\min P'_{ik}$ = minimum criterion score for all the previous generations for k^{th} criteria

$\max P'_{ik}$ = maximum criterion score for all the previous generations for k^{th} criteria

Case 2: MOSTWATAR to generate options using R3

The initial test runs with R3 generation has shown that there are very few processes in the TTs generated in the initial population. As a result the criteria values for cost, land requirement and so on for such TTs were considerably less than the feasible TTs obtained in the subsequent generations. The steps used to scale the criterion values were same as in case 1 except that a higher scaling factor for the maximum value was used as shown below.

1. Find maximum and minimum values of economic and technical criteria namely cost, land requirement and sludge production for the initial population.
2. For subsequent populations, the minimum and maximum criterion values were calculated as follows.

$$\min P'_{ik} = 0.1 * \min P_{ik} \quad \textbf{(5.8)}$$

$$\max P'_{ik} = 20 * \max P_{ik} \quad \textbf{(5.9)}$$

Case 3: User and MOSTWATAR to generate TT options

In order to compare options generated by the user and MOSTWATAR it was found necessary to have same scaling for both. In this case Equations 5.9 and 5.10 were used with the min P_{ik} and max P_{ik} being the minimum and maximum value of the criterion obtained in the TT options generated by the user.

5.4.5.2 Penalty Function

As discussed in Section 5.2.1.3, it is necessary to assign a penalty function (a) in order to retain some infeasible solutions as optimal solutions often lie on the boundary of feasible solution space (Siedlecki and Sklanski, 1989). The different types of penalty calculation methods and equations developed are discussed next.

5.4.5.2 (i). Static Penalty Method

Static penalty method based on the amount by which they are infeasible is considered in this study as they are said to be better performers than those based on number of constraints (see Table 5.2). Two types of static penalty methods namely additive and multiplicative penalty methods were tested in this model. They are described below.

(a) Additive Penalty Method (APM):

APM is the simplest form of penalty function and has been widely used (Chan Hilton and Culver, 2000). In this method a penalty factor proportional to the total constraint violation is subtracted from the objective function (as the current optimisation problem is that of maximization). This is similar to the fitness function used for user generated options.

$$f_{TTi} = O_{TT\,i} - (\alpha_{TTi} + \sigma_{TTi}) \quad \text{...(5.10)}$$

where,
O_{TTi} = objective function given by Equation 4.18
α_{TTi} = penalty factor given by Equation 4.19
σ_{TTi} = additional penalty factor given by Equation 5.17

In this study a constant penalty weight was used. Initially a constant value of 5 was assumed for penalty weight 'ρ'. This resulted in optimal solutions being infeasible (i.e. violating constraints) and hence the penalty weight was increased by 10 times (ρ =50 was used) as discussed by Chan Hilton and Culver (2000). This is further discussed in Chapter 7.

(b) Multiplicative Penalty Method (MPM):

MPM differs from APM in that; the objective score is actually multiplied by the penalty factor. Chan Hilton and Culver (2000) suggest that the multiplicative method is superior to the APM as it converges to a near optimal solution in less search time and is capable of identifying feasible and near optimal solutions. These authors suggest that the fitness function using MPM method be given by

$$f_{TTi} = O_{TTi} \times (\alpha_{TTi} + \sigma_{TTi}) \quad \text{...(5.11)}$$

As the optimisation problem considered in this study is a maximization i.e. higher the fitness score the better the TT, the objective score was divided by the penalty factor as given in Equation 5.10. The notations used are same as in APM and the same equations for penalty calculations were also used in MPM.

$$f_{TTi} = \frac{O_{TTi}}{(\alpha_{TTi} + \sigma_{TTi})} \quad \text{...(5.12)}$$

5.4.5.2 (ii). Dynamic Penalty Method

A simplified form of the varying fitness function (VFF) method studied by Adamidis *et.al.*, (1998) based on the dynamic penalty method was used in this study. In this method penalty terms are kept low (after the 0^{th} generation) at the early stages of the search and increased gradually through the generations. This helps GA to carry out a broad search initially and converge to a feasible solution in the later generations.

$$f_{TTi} = O_{TTi} - \rho' \times (\alpha_{TTi} + \sigma_{TTi}) \quad \text{......(5.13)}$$

where α_{TTi} is given by Equation 5.8

ρ' = is the generation index given by

= 1, for t = 0

= $\frac{t}{t_{max}}$, for t >= 1

where t is the current generation number and t_{max} is the generation limit specified by the user.

5.4.5.2 (iii). Adaptive Penalty Function

This penalty function is based on the level of infeasibility in the previous generations. In order to establish the level of infeasibility it is necessary to determine by how much a particular TT is violating the constraints. The adaptive penalty function is considered for scaling as the difference in the penalty value between the best feasible solution in a particular generation and the overall best feasible solution is not known in advance.

$$f_{TTi(t)} = O_{TTi} - \lambda_{(t)} \times \omega \times (\alpha_{TTi} + \sigma_{TTi}) \quad \text{......(5.14)}$$

where α_{TTi} is same as in Equation 5.8

$\lambda(t)$ is a penalty component updated every generation 't' as follows.

$$\lambda(t+1) = \begin{cases} (1/\beta_1) \cdot \lambda(t), & \text{if previous generations have best feasible solution} \\ \beta_2 \cdot \lambda(t), & \text{if previous generations have best infeasible solution} \\ \lambda(t), & \text{otherwise,} \end{cases}$$

where β_1, β_2 = constants > 1 and $\beta_1 \neq \beta_2$

In addition a penalty factor (ω) based on generation number was used as it is reported to increase the selective pressure on GAs to find a feasible solution (Adamidis, *et al.*, 1998).

$$\omega = \rho \times t \qquad (5.15)$$

where, ρ = penalty weight assumed as 50

t = generation number.

The user can select any one of the above penalty methods. In this study the adaptive penalty method has been used as the default penalty method as it is reported to be superior to the static and dynamic penalty methods. Once the fitness scores are calculated using the objective and penalty components, some of the TTs strings may become infeasible for one or more of the following reasons: (a) TTs may not meet the rules, (b) TTs may not meet the reuse criteria, or (c) TTs may have land based systems when it is specified as unacceptable by the user. Rather than discarding such infeasible TTs, they were retained within the population as this is known to aid the search for the optimum solution (Smith and Tate, 1993; Siedlecki and Sklanski, 1989). After the fitness scores are evaluated, TT strings are selected using tournament selection as explained in the next section.

5.4.5.3 Fitness Function

It is assumed that the user will form TTs which meet acceptable process configuration /rules. On the other hand when the TTs are generated randomly or when they undergo crossover and mutation, this may result in TTs that do not meet the rules. On the other hand, some users may prefer mechanical systems over land based treatment systems and may not want TTs with processes such as lagoons and wetlands to be considered for optimisation. In such cases a penalty term for TTs not meeting rules (PsNMR) and an additional penalty term denoted as PsSLBT (penalty score for selecting land based treatment) are introduced in to the fitness function used for GAs. Thus the mathematical formulation of the fitness function implemented in the GA module is as follows.

Maximise $f(_{TTi})$

$$\text{where } f(_{TTi}) = O(_{TTi}) - \left[\alpha_{(TTi)} + \sigma_{(TTi)}\right] \qquad (5.16)$$

where $f(_{TTi})$ = fitness function for ith TT

$O(_{TTi})$ = objective function to be maximized (discussed in Section 5.4.5.1)

$a_{(TTi)}$ = penalty function which depends upon the constraint violations given by Equation 4.19

$s_{(TTi)}$ = additional penalty term given by

$$\sigma_{(TTi)} = ((PsNMR \times \delta_i) + (PsSLBT \times \delta_i)) \quad \textbf{(5.17)}$$

where PsNMR = penalty score for not meeting rules given by

$$PsNMR = \mu \quad \textbf{(5.18)}$$

where μ = +1, if the any of the rules is violated
0, if all of the rules are satisfied.

PsSLBT = penalty score for selecting land based treatments systems when it is selected as unacceptable by user given by.

$$PsSLBT = \psi \quad \textbf{(5.19)}$$

where ψ = +1, if land based treatment systems are selected when user specifies that they are unacceptable
0, otherwise.

5.4.6 Selection of TTs by Tournament Selection

In the current study, tournament selection without replacement was selected for the following reasons:

1. it is reported to be faster than roulette wheel selection,
2. its behaviour in terms of convergence is well known
3. there is potential for overlooking fit TTs in tournament selection with replacement (Espinoza, 2000),
4. it is possible for TTs to have fitness scores less than '0' when the solutions are infeasible due to the penalty scores while roulette wheel selection will work only if all the fitness values are greater than '0' (as indicated in equation 5.2)

Normally a tournament size (*ts*) of 2 or 3 is considered for selecting the parents from the population. A tournament size of 2 was considered as the default value in this study. The steps involved in tournament selection without replacement are explained below. These steps hold good for both new plant and upgrade of existing plant.

1. The population of strings is shuffled or randomised.
2. A number of strings equal to '*ts*' are drawn and the fittest string is selected as a parent. This is repeated for next '*ts*' strings to select the next parent.
3. Step 2 is repeated until (*n* **div** *ts*) parent strings are obtained.
4. Step 1 to 3 is repeated 'ts' times to get number of parent strings equal to '*n*'. If 'n' is not divisible by 'ts' then go to step 5.
5. Repeat steps 1 to 2 until the number of parent strings is equal to 'n'. For example, if a population size of 100 and tournament size of 3 is considered, number of parent strings selected after step 4 will be 99. The remaining 1 string will be obtained by repeating steps 1 and 2.

The implementation of such a tournament selection scheme described above resulted in premature convergence, as there was no improvement after 5 to 10 generations. One of the solutions discussed by Simpson and Goldberg (1994) is to decrease selection pressure on fitter TT strings using a probability of selection (P_s) ranging from 0.5 to 1.0. The fitter string is chosen with a probability of 'Ps' otherwise the less fit string is chosen as parent. These steps are summarized in the flow chart (see Figure 5.8 c).

5.4.7 Crossover

In the present study, uniform crossover was initially tested using the following steps for both new plant and upgrade of existing plants.

1. Two parent TT strings are randomly selected without replacement and a random number between 0 and 1 is generated.
2. If random number generated is greater than probability of crossover (P_c) then no crossover occurs and the pointer moves to the next bit position in the strings.
3. If random number generated is less than or equal to Pc then crossover occurs. The processes in the two bit positions are swapped over.

4. Steps 2 to 3 are repeated until the end of the TT strings.
5. Steps 1 to 4 are repeated (*n*/2) times.

The initial test runs showed that the percentage of feasible TTs decreased over generations even for Pc values of 0.5. The figure 5.7 illustrates how the % feasibility decreased from 40 % to 2 % in the case of R1 method for class B irrigation. This indicates that there is high disruption, resulting in addition or removal of unit processes from a TT string affecting the acceptable configuration rules. Therefore many TT strings became infeasible as illustrated in Figure 5.7.

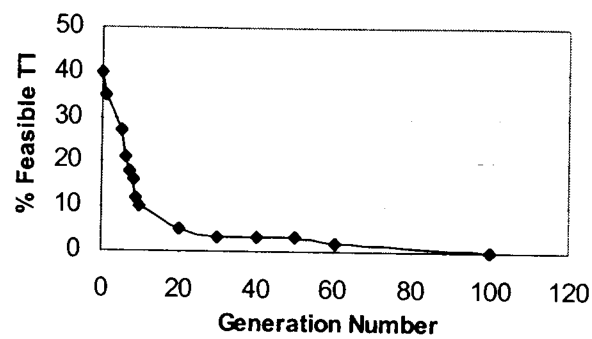


Figure 5.7 Illustration of Percent Feasible TTs Versus Generation Number for Uniform Crossover (Pc = 0.5)

To overcome the problem of infeasible solutions, single point crossover, which is less disruptive, was tested and the steps involved are illustrated in Figure 5.8 (c). As discussed in Section 5.2.1.4 (ii) the single point crossover occurs at one single point and the position of which is decided by the random number generated and the value of Pc.

5.4.8 Mutation

Bit-wise mutation was chosen for this study as adjacency mutation can (1) alter the order in which unit process can occur in a TT string and (2) also cause two unit processes of the same kind to be present in a string. This would lead to violation of the acceptable process configuration rule and hence adjacency mutation was unacceptable. The steps involved in the mutation process for a new plant and upgrade of existing plant are given below.

1. The first TT string is taken and a random number is generated between 0 and 1.

2. If the random number generated is greater than P_m then no mutation occurs in that string. Next TT string is selected.
3. If random number generated is less than P_m then mutation occurs. In order to determine the position of the mutation, a random number is generated from 1 to the maximum length of the string (see Table 5.3). In case of a new plant, a unit process (indicated as '1') is replaced by a '0' in this position and vice versa. However, if it is an upgrade of existing plant then it is necessary to check if the mutation position consists of an existing process. If so then it is not allowed to mutate and steps 1 to 3 are repeated for the next TT string. Otherwise the mutation occurs as in case of new plant described above.
4. Steps 1 to 3 are repeated for the entire population (*n*).

Thus mutation is carried out with a probability of mutation per string. After mutation the TTs are checked to see if they meet process configuration rules. TTs that violate any of the rules were assigned a penalty of 1.

5.4.9 Selection and Display of Best TTs

After the first generation (t =1) is completed, the top five unique, best TTs (based on fitness scores) are stored. It was found necessary to ensure that the TTs are unique in order to have wider choice of alternative treatment trains. In the subsequent generations, the TTs are sorted according to their fitness and the first TT (i.e. TT with highest score) is then compared with the five best TTs of the previous generation(s). If a TT from (t+1) generation has a fitness score greater than any one of the best five TTs from previous generations, then the TT from (t+1) will replace that TT. On the other hand if the TT from (t+1) generation has fitness score less than any of the best five TTs then there will be no replacement.

This comparison is continued until all the TTs of the five best TT have fitness score greater than TTs in (t+1). Once the generation reaches the maximum generation suggested by the user, the five best TTs are displayed along with their fitness score and the generation number. This is illustrated in Section 6.4.8.

5.4.10 Flow Chart

A summary of the steps involved in the simple GA developed is illustrated in the Figure 5.8 (a, b, c, & d). The notations used in the flow chart are presented below.

Gen	=	generation number
Maxgen	=	maximum number of generations
n	=	population size
ts	=	tournament size
Pc	=	probability of crossover
Pm	=	probability of mutation
Ps	=	probability of selection
y	=	maximum length of the string (refer to Table 5.2)
Rand	=	random number generated by the system
j,k	=	integer values used to denote the position on the TT string for crossover and mutation
i	=	integer value used to increment the number of strings (maximum value of i = n)

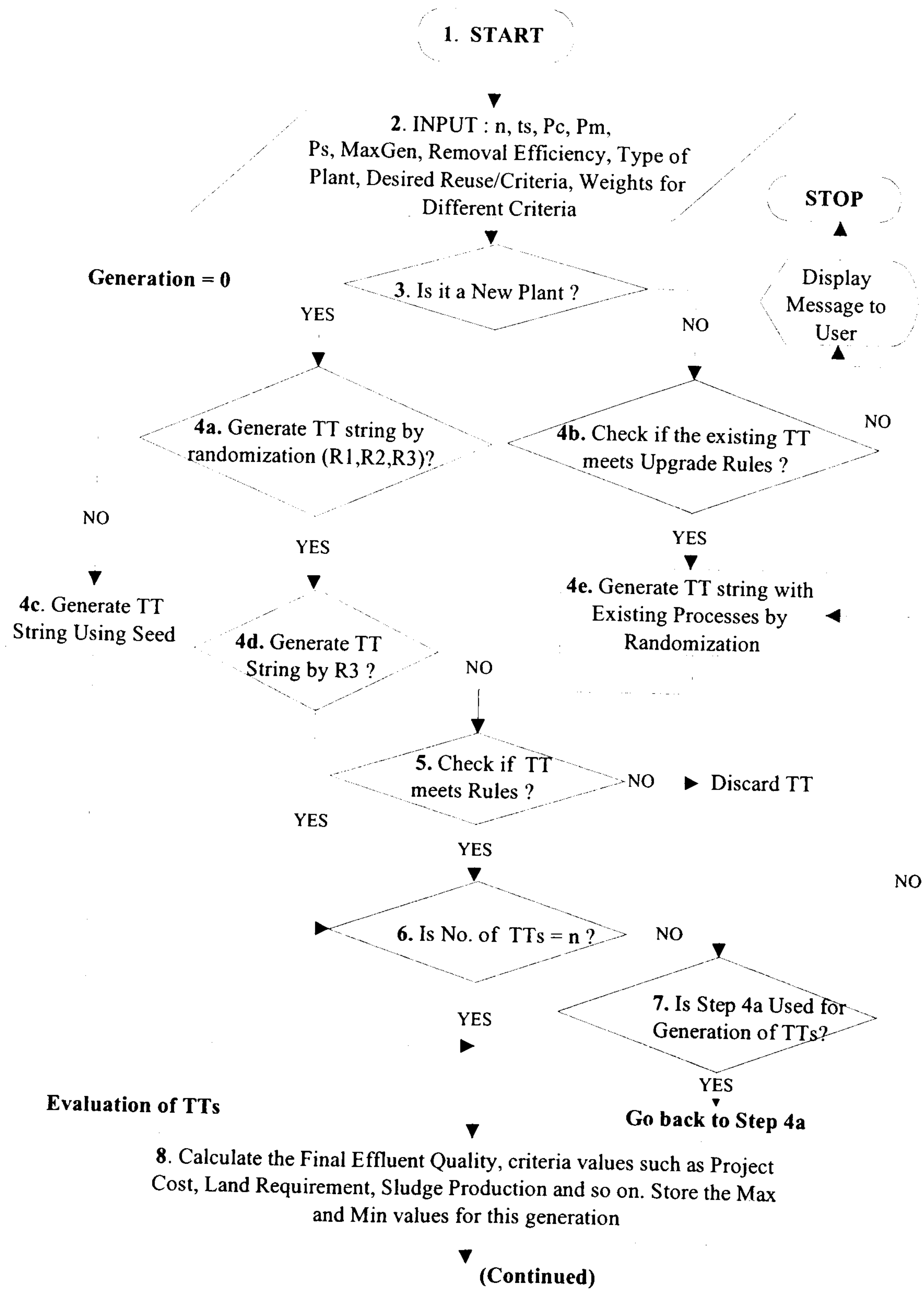


Figure 5.8a Flow Chart of Simple GA Developed

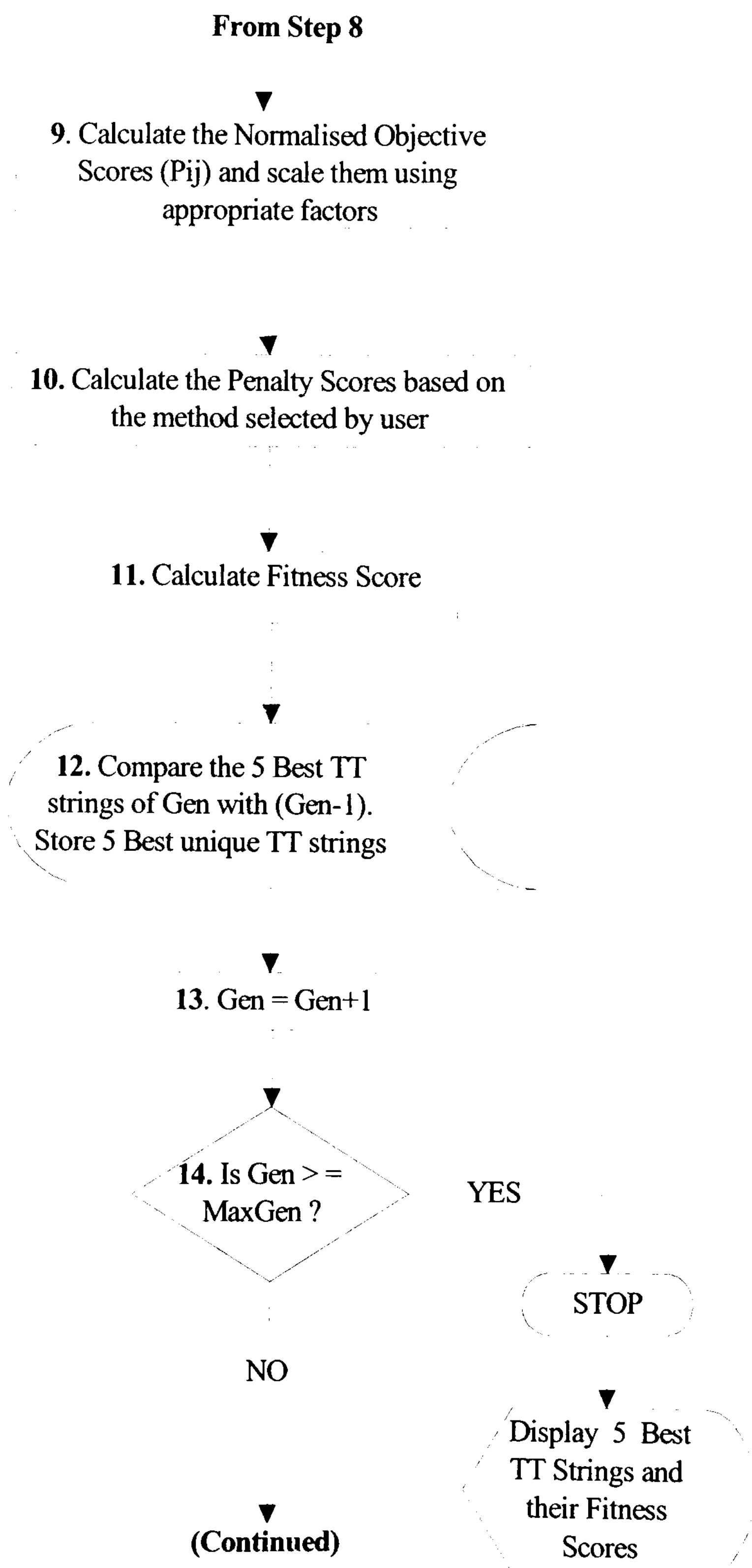


Figure 5.8b Flow Chart of Simple GA Developed (contd.)

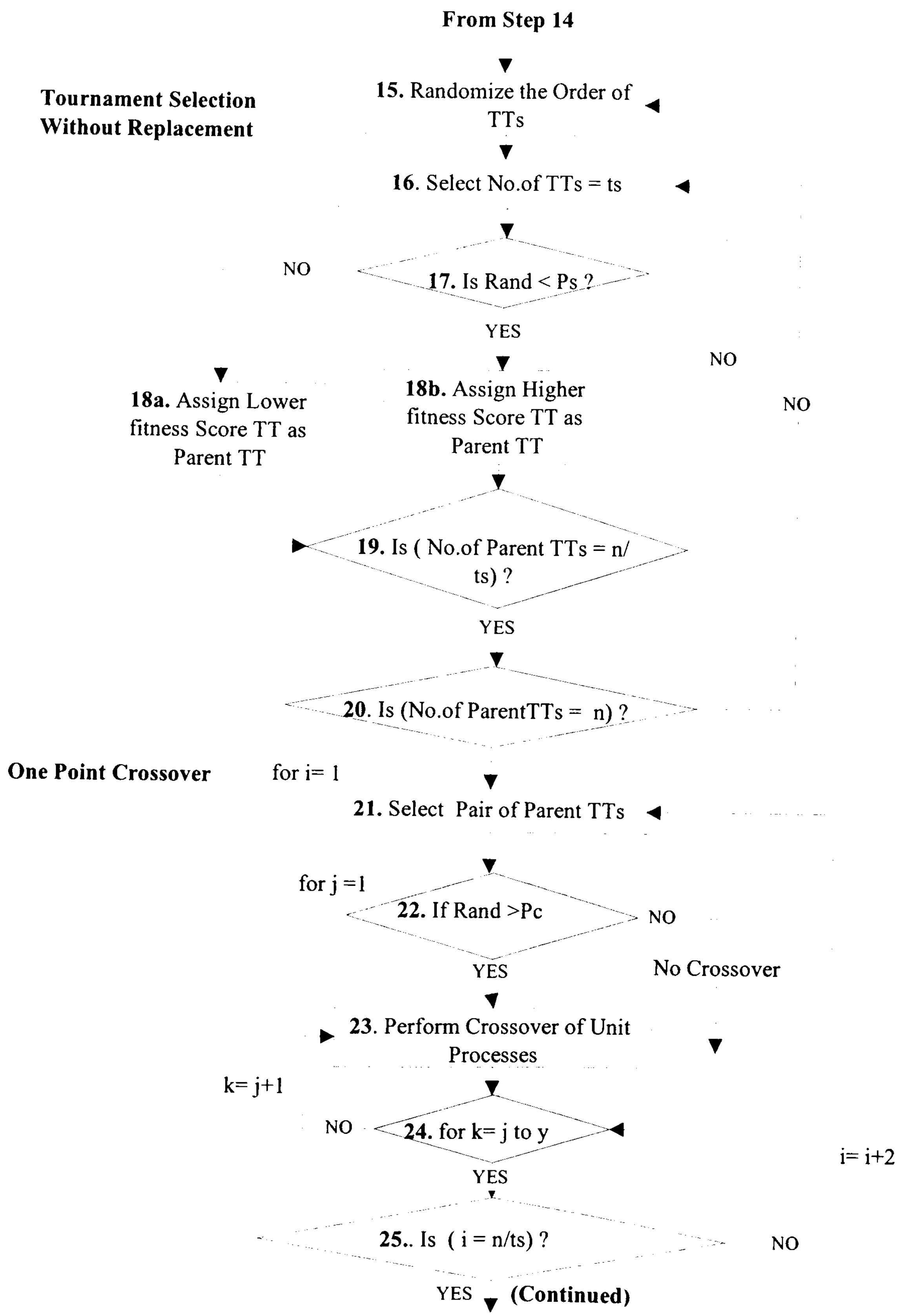


Figure 5.8c Flow Chart of Simple GA Developed (contd.)

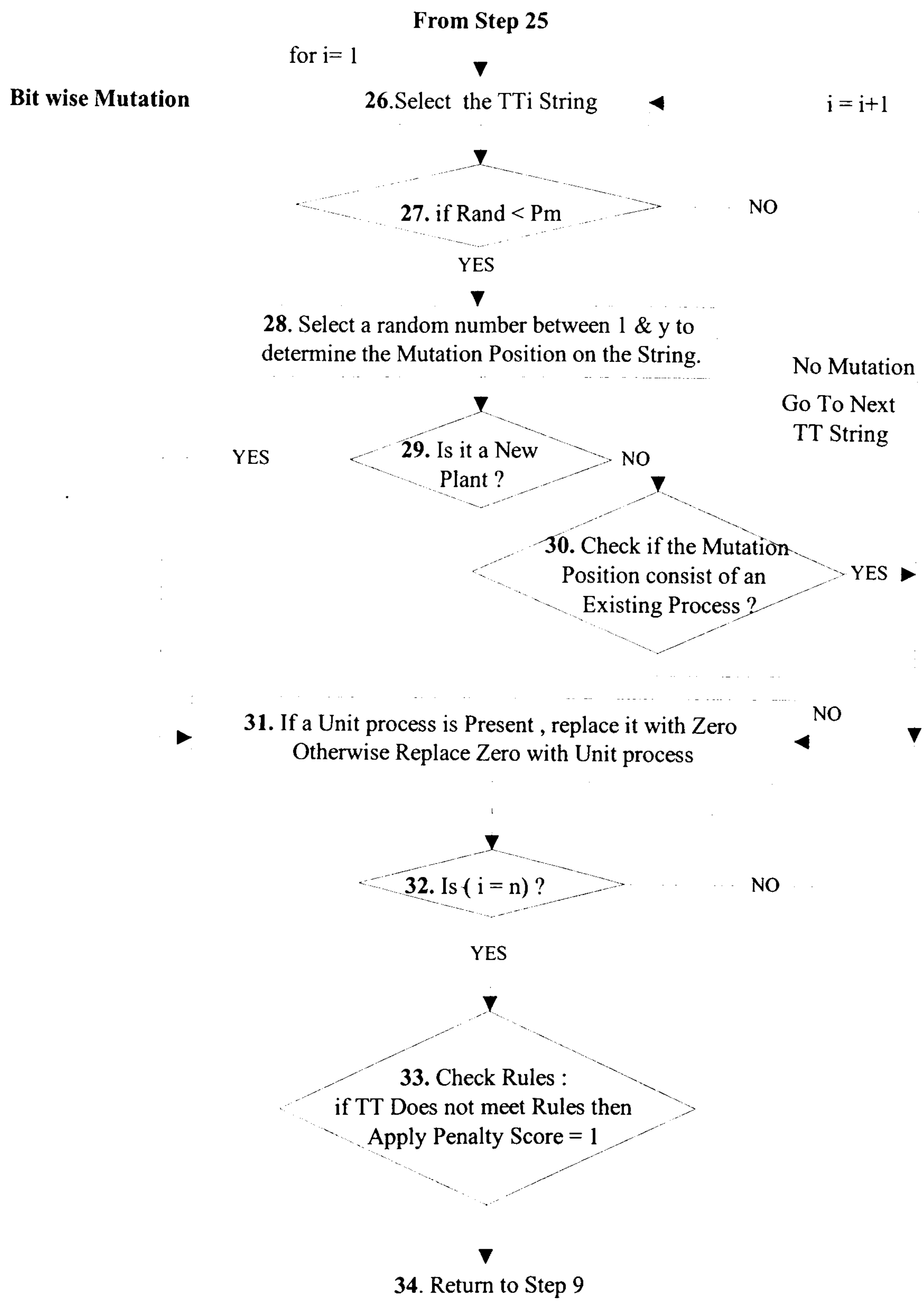


Figure 5.8d Flow Chart of Simple GA Developed (contd.)

5.5 Summary & Conclusions

The genetic algorithms are a set of guided search procedures, which are used for optimisation of large combinatorial problems. Several researchers have worked on optimising the wastewater treatment selection using linear, dynamic, and integer programming. But so far GAs have not been applied for generation and optimisation of TT alternatives.

In this chapter an introduction to GAs and its similarity between the population genetics and the current application of TT optimisation was presented. A simple GA was developed to generate and optimise TTs. Binary coding scheme was used to represent TT strings in a population. Four different methods were developed to generate initial population of TT strings. The rules developed as part of a knowledge base discussed in the Chapter 4 was applied to check whether the generated TT string is acceptable or otherwise. Further, to differentiate between feasible and infeasible solutions, four different penalty calculation methods have been incorporated in the algorithm and the comparison of the same is presented in Chapter 7.

It was observed that the current problem had a very high percentage of infeasible solutions. On an average just one treatment train in every 700-1000 randomly generated TTs met the rules. Because of the high percentage of infeasible solutions, uniform crossover and adjacency mutation were not found suitable as they cause high disruption to TT strings. Hence single point crossover and bitwise mutation were selected for this study. Further, bitwise mutation was carried out at one point on each string based on 'Pm'. Both static and dynamic linear scaling methods were tested. Linear static scaling was preferred as the comparison of TTs from different generations and penalty calculation methods was required. In addition to the above, methodology used to develop TT options for upgrade of existing plants was presented.

In the next Chapter the salient features of the user-friendly interfaces developed for entering the site specific details are described. In Chapter 7, the application of algorithm to develop both new and upgrade options for a case study in South Australia is presented.

Chapter 6 Salient Features of MOSTWATAR

6.1 Introduction

In the previous Chapters the methodology used to develop the knowledge base and database was described. In this chapter the salient features of the input and output modules of the MOSTWATAR model is presented. This chapter describes the structure of all modules and has information on how the user can use this model to evaluate treatment trains (TTs) for a given community. Firstly, the hardware and software requirements for installation and operation of this model are presented. Secondly, an overview of the model and various features of user-interface of each of the modules are presented. Thirdly, it presents how the genetic algorithm developed is incorporated in to the model. Finally, a description of the print module followed by a summary is presented at the end of this chapter.

6.2 System Requirements and Installation

MOSTWATAR is developed for the Microsoft Windows® operating system and the minimum and recommended system requirements are listed in Appendix H (Table H.1). The programming environment used was Borland Delphi™ 4.0. Installation of the MOSTWATAR model is simple and can be done by inserting the CD-ROM and double clicking the install button on the screen. On double clicking the install button, the MOSTWATAR program and the necessary database drivers will be installed on to the system. A dialog box with a message 'installation complete' appears after successful installation of the program.

6.3 An Overview of the Model

MOSTWATAR is a user friendly decision support system (DSS) for selecting the appropriate wastewater treatment train for given conditions such as flow rate, type(s) of intended reuse, guidelines and wastewater characteristics. This model as described in Chapter 4 is intended for decision-makers and planners to evaluate all treatment alternatives available. In this model the user can either (1) specify TTs for evaluation based on his or her experience and or (2) ask the model to generate optimal TTs based on GAs.

The MOSTWATAR model is developed as a point and click model using Borland Delphi™ 4.0 (standard edition). MOSTWATAR consists of the modules listed below and is illustrated in Figure 6.1.

1. Community data
2. Reuse criteria
3. Form TT
4. Design criteria
5. TT performance
6. Selection criteria
7. Optimise TT
8. Results.

The sub modules or sections under each of the above module are represented as multiple layers in Figure 6.1 and are described in the following sections.

6.4 Modules

The MOSTWATAR application starts with a first screen as shown in Figure 6.2. The MOSTWATAR logo is displayed in the center of the screen while buttons on the right hand side of the screen represents different modules. The user will have to enter the data as in the order of the modules (buttons) displayed. The user can start the application by clicking the first button namely, community data.

Each of the modules developed has a number of common user interface features (Figure 6.3). The header indicates the title of the module accessed while the tab sheet headings indicate the sub sections included in that module. The community name is displayed on the top right hand corner of the screen. On the right hand side of the screen, the eight buttons (as in the first screen) are displayed representing all the modules.

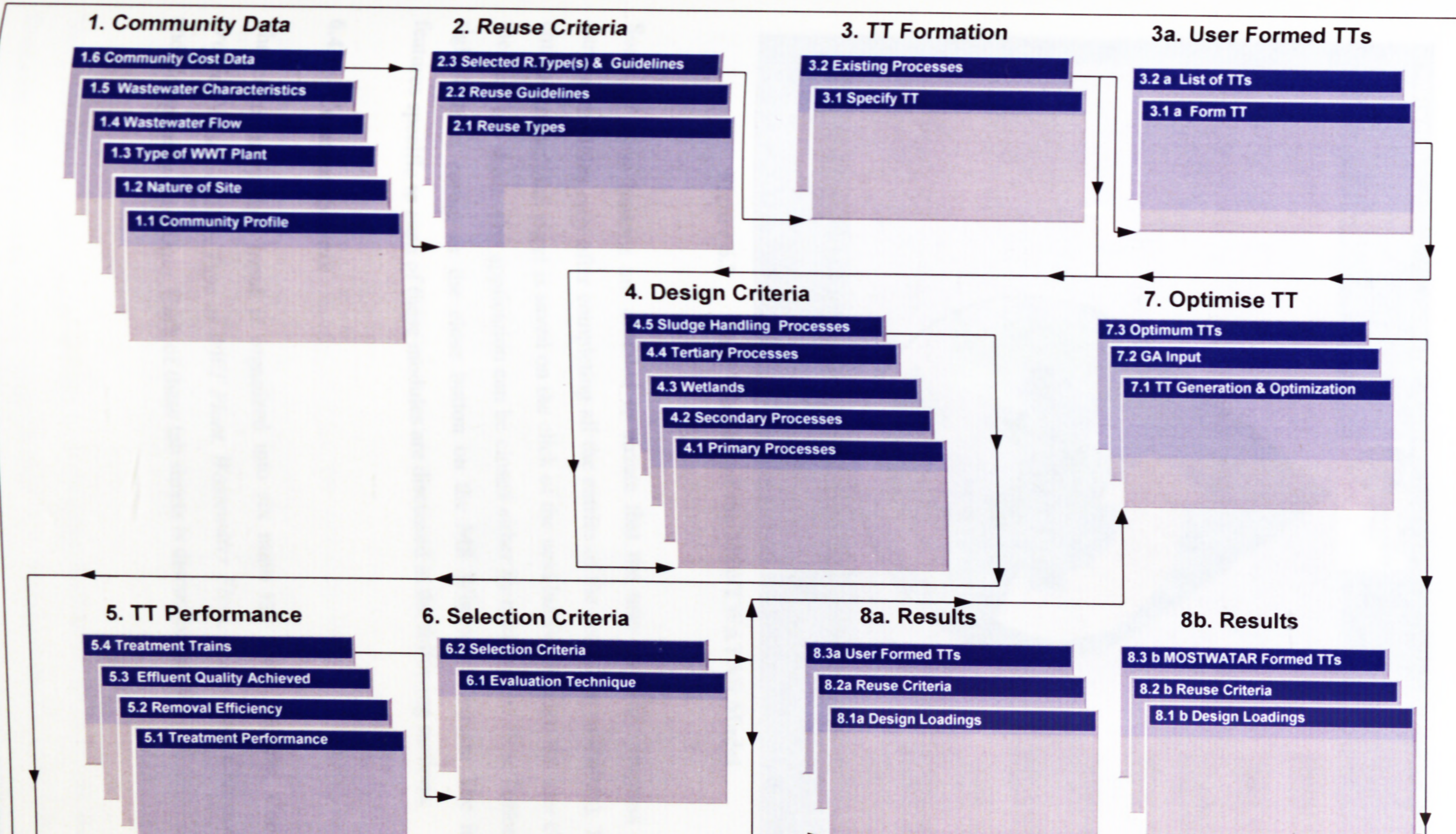


Figure 6.1 Overview of MOSTWATAR Modules

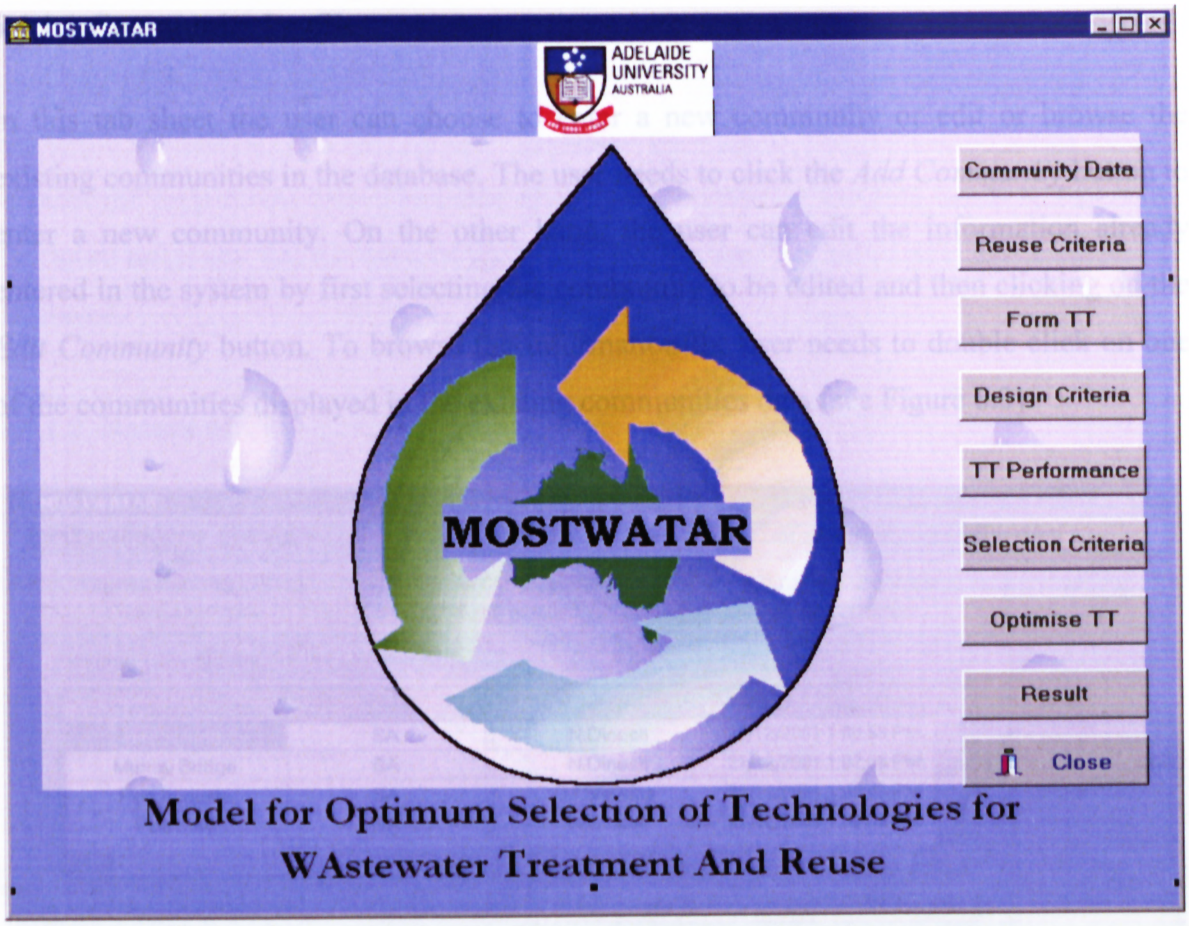


Figure 6.2 First Window of the MOSTWATAR Model

Some of these buttons are disabled to ensure that the user can only progress through various modules only after completing all the entries of the preceding module(s). The data entered in each tab sheet is saved on the click of the next button or when the user clicks on the next tab sheet. The application can be closed either by clicking the close button on the right bottom corner or the close button on the MS Windows® screen. The interface features specific to each of these modules are discussed in the following sections.

6.4.1 Community Data

The community data input is organized into six main tab sheets namely, *Community Profile, Nature of Site, Type of WWT Plant, Wastewater Flow, Wastewater Characteristics* and *Community Cost Data.* Each of these tab sheets is discussed below.

6.4.1.1 Community Profile

In this tab sheet the user can choose to enter a new community or edit or browse the existing communities in the database. The user needs to click the *Add Community* button to enter a new community. On the other hand, the user can edit the information already entered in the system by first selecting the community to be edited and then clicking on the *Edit Community* button. To browse the information the user needs to double click on one of the communities displayed in the existing communities data (see Figure 6.3).

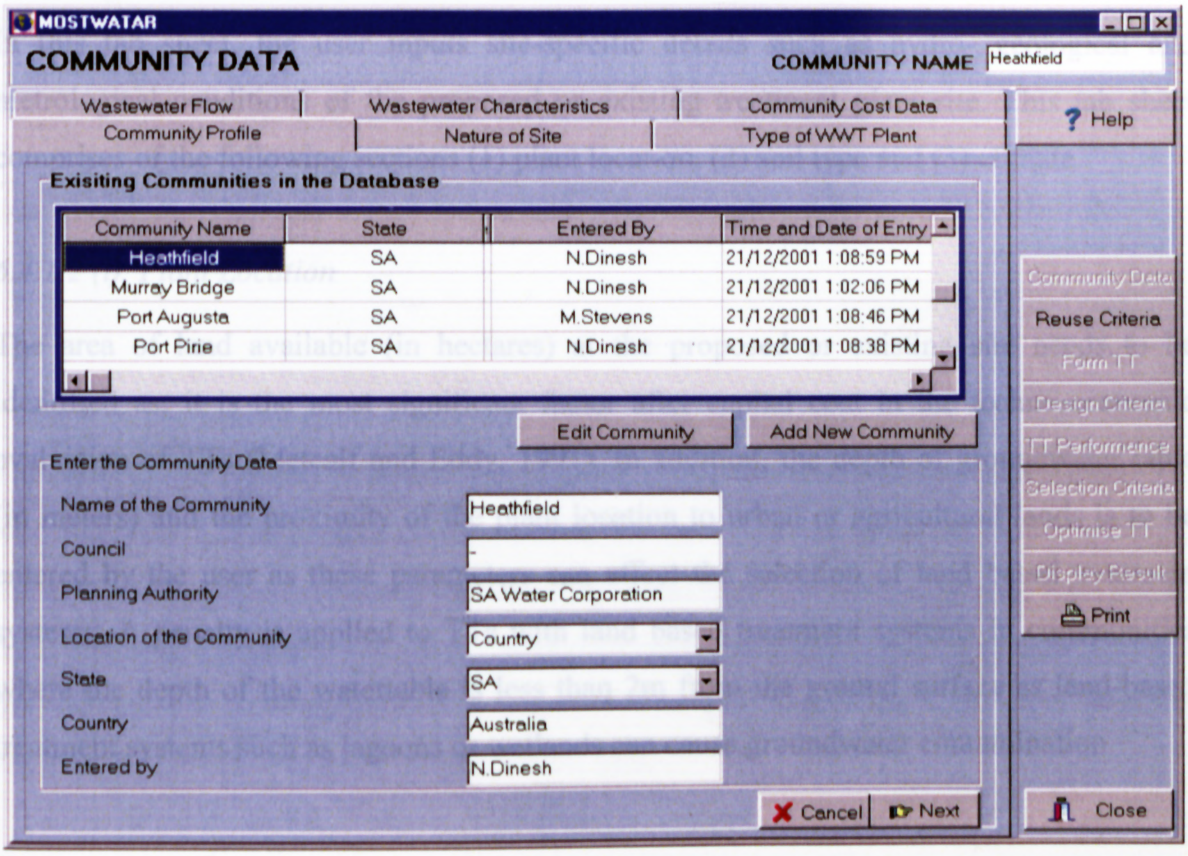


Figure 6.3 Community Data Module

To add a new community into the database, the user needs to enter the community name, against the input field provided. The user can either use enter key or tab key to move to the next input field. A unique community name has to be given by the user in order to prevent duplication of entries. The model gives a warning message if the user tries to add a community name, which already exists in the database.

Next, the name of the council and the local planning authority responsible for planning, financing and implementation of reuse schemes is to be entered by the user in the input fields. The location of the community i.e. country or metropolitan region, can be selected from the drop down list. The location identifies the cost factors to be added for the economic evaluation. The user should then select the state to which the community belongs to from the drop down list. The name of the person entering the data needs to be entered for future reference. On the click of the "Next" button the "Nature of Site" tab sheet will be displayed.

6.4.1.2 Nature of Site

In this tab sheet, the user inputs site-specific details such as hydro- geological and metrological conditions of the proposed or existing treatment plant site. This tab sheet comprises of the following sections (1) plant location, (2) soil type and (3) climate.

6.4.1.2 (i). Plant Location

The area of land available (in hectares) at the proposed or existing site needs to be identified as, it is the most significant factor after capital cost in the techno-economic evaluation of TTs (Metcalf and Eddy, 1991). In addition, the depth of groundwater table (in meters) and the proximity of the plant location to urban or agricultural lands is to be entered by the user as these parameters can affect the selection of land based treatment systems. A penalty is applied to TTs with land based treatment systems in communities where the depth of the watertable is less than 2m from the ground surface as land-based treatment systems such as lagoons or wetlands can cause groundwater contamination

6.4.1.2 (ii). Soil Type

Soil type in the region is a deciding factor for selection of land based treatment systems as absorption capacity is dependent on the soil type. Since it is easier for the user to enter the soil type rather than the absorption capacities, different soil types are listed in this model. The user can select any one of the following types: (1) coarse sand to gravel, (2) medium to coarse sand, (3) fine sand to loamy soil, (4) loam to silty soil, and (5) silty soil to clay. Once the user selects the type of soil the equivalent absorption capacity ($L/m^2/d$) based on USEPA (1980) will be calculated as shown in Table 6.1.

Table 6.1 Absorption Capacities for Different Soil Types

Type of Soil	Absorption Capacity, L/m²/d
Coarse sand to gravel	>50
Medium to coarse sand	50
Fine sand to loamy soil	33
Loam to silty soil	25
Silty soil to clay	15

(Source: USEPA, 1980)

6.4.1.2 (iii). Climate

The annual average precipitation and evaporation rates (mm/yr) and annual daily average minimum and maximum ground surface temperature (Deg C) are to be entered. This data is required as it affects the selection and sizing of natural treatment systems such as lagoons and wetlands.

6.4.1.3 Wastewater Treatment Plant

The MOSTWATAR can be used for evaluation of TTs for two types of plants namely, (1) new plants and (2) upgrade of existing plants. The user needs to select the type of plant for which the TT options are being evaluated by clicking on one of the options (see Figure 6.4). The option selected will be stored in the database and will be used to determine the cost percentages to be applied. The "Next" button will display the wastewater flow tab sheet where the user can enter the population data.

6.4.1.4 Wastewater flow

In this tab sheet all the information related to population, design period, wastewater generation rate and peaking factors are to be entered. This is described below.

6.4.1.4 (i). Design Population

The initial project year is the year in which the project is proposed and population corresponding to this year is the initial year population. For example, if the treatment plant is proposed for a community in the year 2001 with a population of 5900, then the initial project year is entered as 2001 and the initial project year population is entered as 5900.

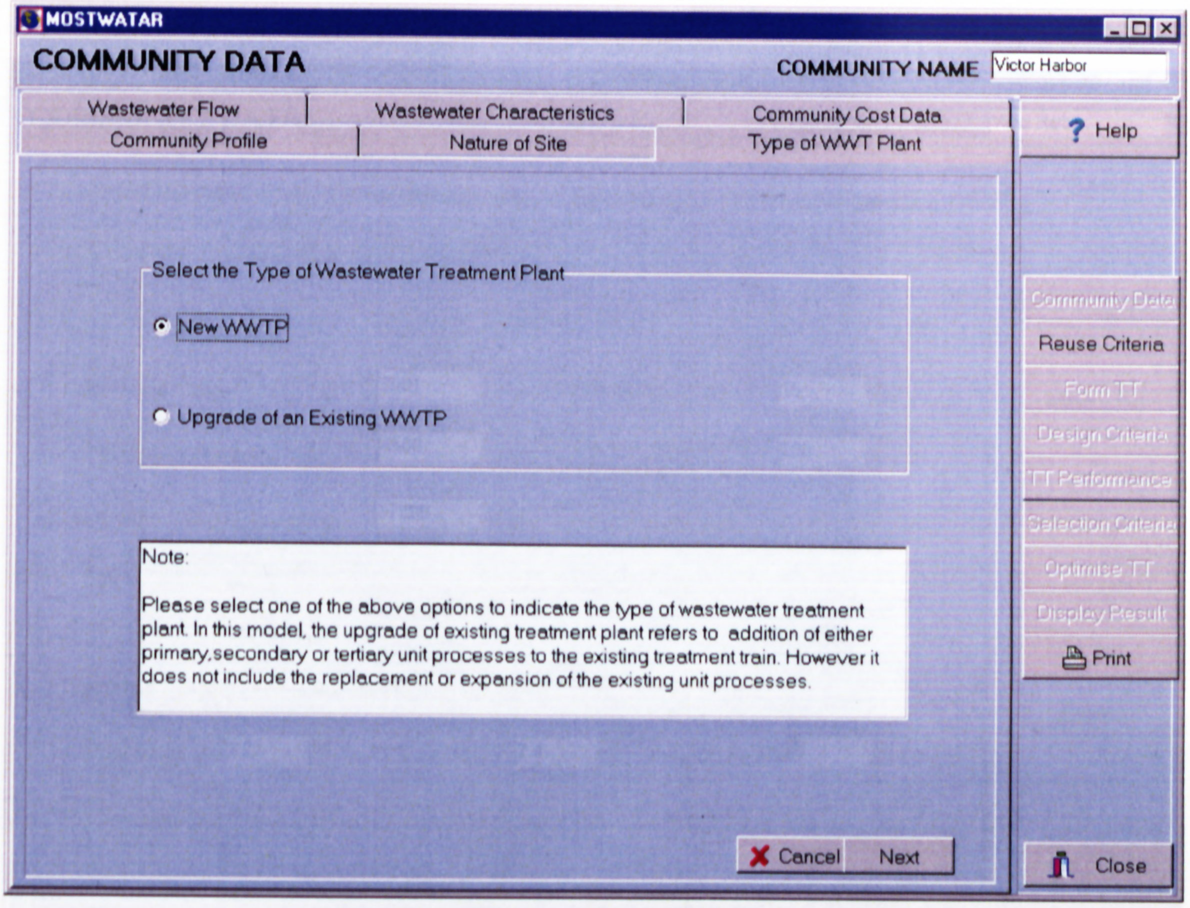


Figure 6.4 Form Showing Selection of WWTP

The design period is the time taken to reach design capacity of the plant in years and is normally taken as 20-25 years. The user can select the design period from the drop down list. The estimated design population is the design or projected population at the end of the design period.

The average per capita wastewater generation in liters per capita per day (lpcd) is used to calculate the total volume of wastewater generated in the community. The per capita wastewater generation can vary widely based on number of factors such as the number of persons per household, socio-economic grouping and the water supply system. A typical range of values can be selected from the drop down list. The average per capita value of 200 lpcd is displayed as the default value (normally used by SA Water). The cost model in MOSTWATAR is based on plant capacities ranging from 1,000 to10, 000 m^3/d which corresponds to a population of 5,000 to 50,000 (based on 200 lpcd). Thus, it is necessary that estimated design population be in this range. If design population is outside this range, an error message is displayed.

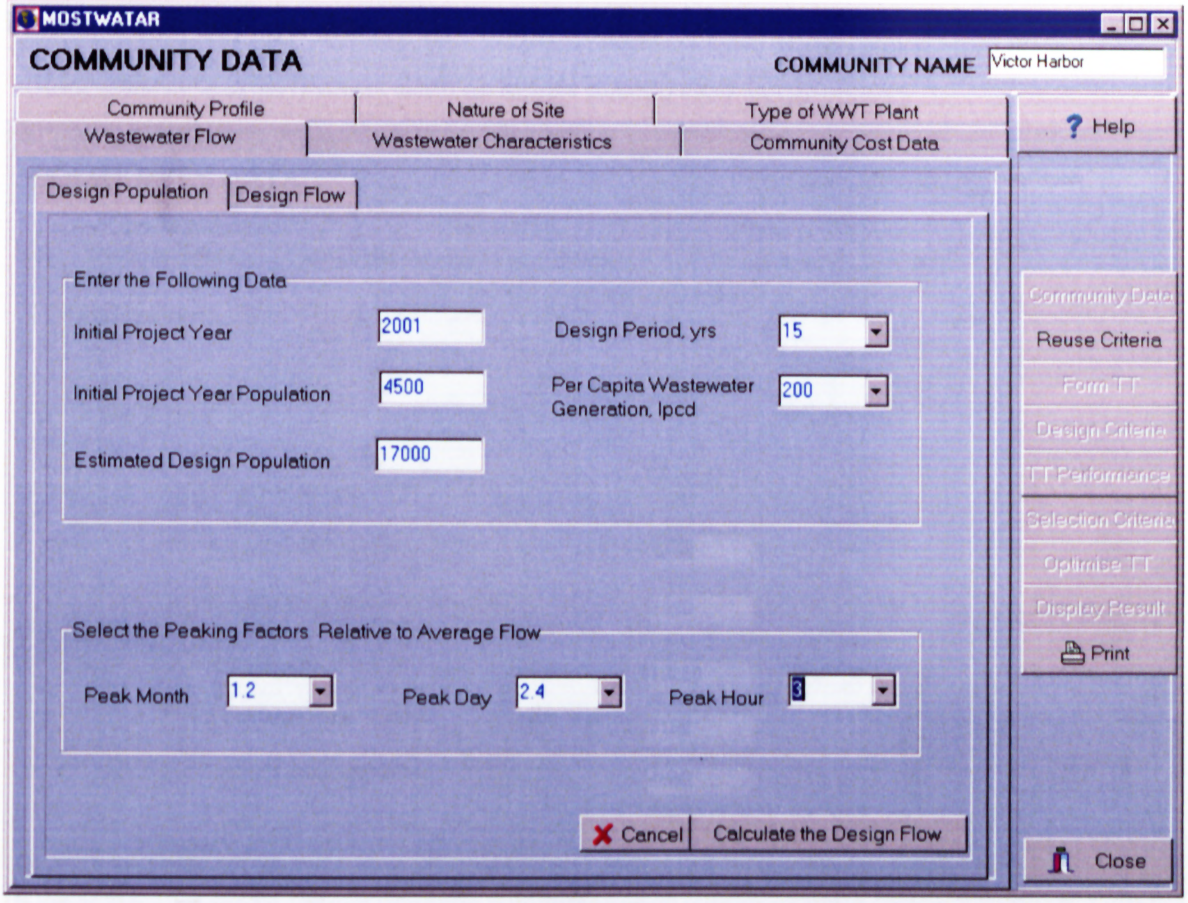


Figure 6.5 Form Showing Design Population Data

The peaking factors relative to the average flow are necessary for sizing unit processes and these can be selected from the drop down list. The three types of peaking factors considered in this model are peak monthly, peak daily and peak hourly. These are used to calculate the design peak monthly, peak daily and peak hourly flows to the treatment plant respectively. The calculated flows are displayed in the design flow tab sheet on the click of "calculate the design flow" button (see Figure 6.6).

6.4.1.4 (ii).Design flow

The annual average flow is calculated as a product of the estimated design population and average per capita wastewater generation while the average dry weather flow is calculated as 85% of the annual average flow. On the other hand the peak monthly, daily and hourly flows are calculated as a product of annual average flow and the respective peaking factors. The user can edit the peaking factors if the calculated flows are found to be different from the anticipated values. When the user is satisfied they can click on the next button, which displays 'wastewater characteristics' tab sheet.

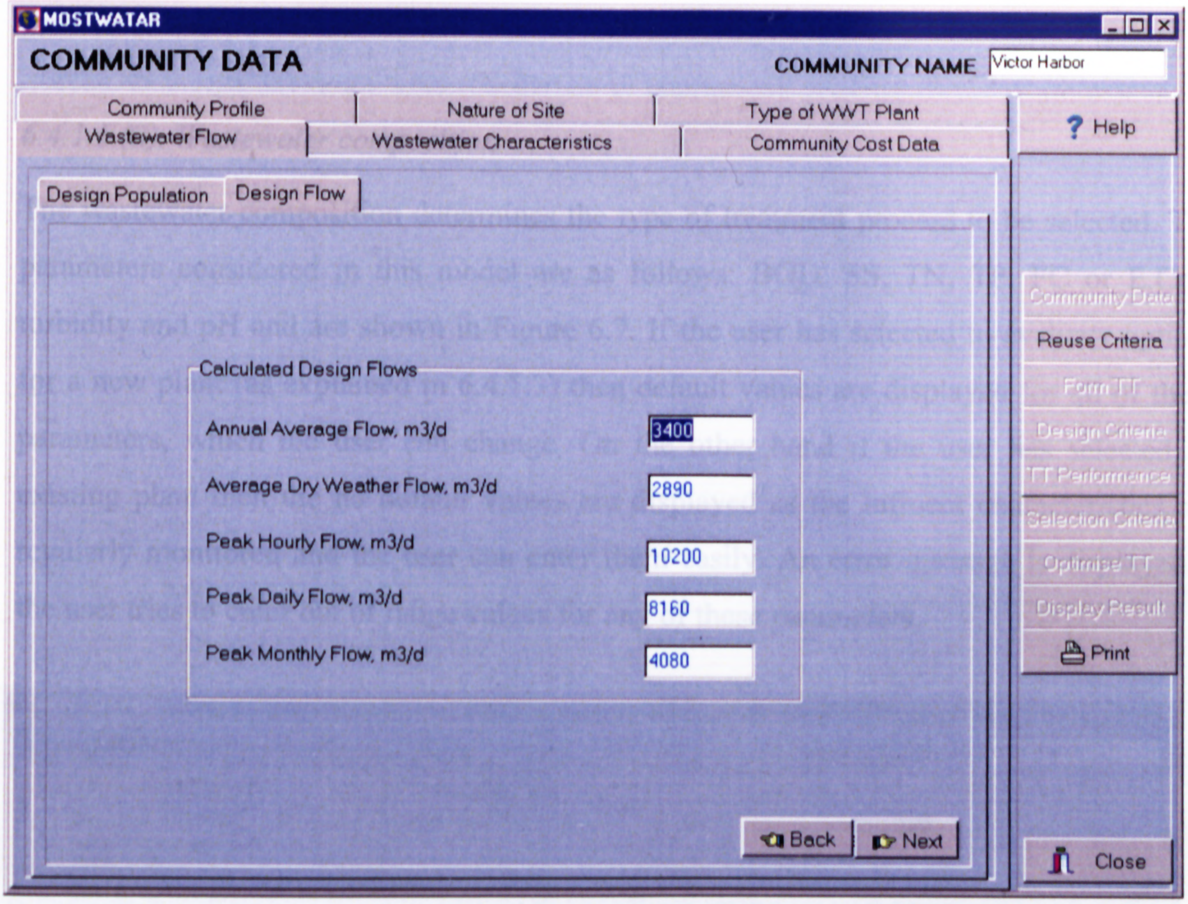


Figure 6.6 Form Showing Calculated Wastewater Flows

6.4.1.5 Wastewater characteristics

This module consists of 3 tab sheets namely: (1) wastewater sources, (2) wastewater composition and (3) design organic loading. These are described below.

6.4.1.5 (i). Wastewater source

This model is essentially meant for evaluating suitable technologies for treating domestic wastewater. However in many communities commercial and partially treated industrial wastewater reaches the municipal sewer. Furthermore, the quality of wastewater to be treated determines its suitability for different reuse applications. Hence the user has to designate any wastewater source(s) apart from domestic wastewater. The user can select one or more of the options displayed i.e. commercial and or industrial. If the user selects industrial wastes then he or she can also select the industries contributing waste. This information will be displayed in the result module, suggesting that a detailed evaluation of other wastewater pollutants such as heavy metals may be necessary before considering any form of reuse.

6.4.1.5 (ii). Wastewater composition

The wastewater composition determines the type of treatment process to be selected. The parameters considered in this model are as follows: BOD, SS, TN, TP, FC or E.Coli, turbidity and pH and are shown in Figure 6.7. If the user has selected to evaluate options for a new plant (as explained in 6.4.1.3) then default values are displayed for all of these parameters, which the user can change. On the other hand if the user has selected an existing plant then the no default values are displayed as the influent characteristics are regularly monitored and the user can enter them easily. An error message is displayed if the user tries to enter out of range values for any of these parameters.

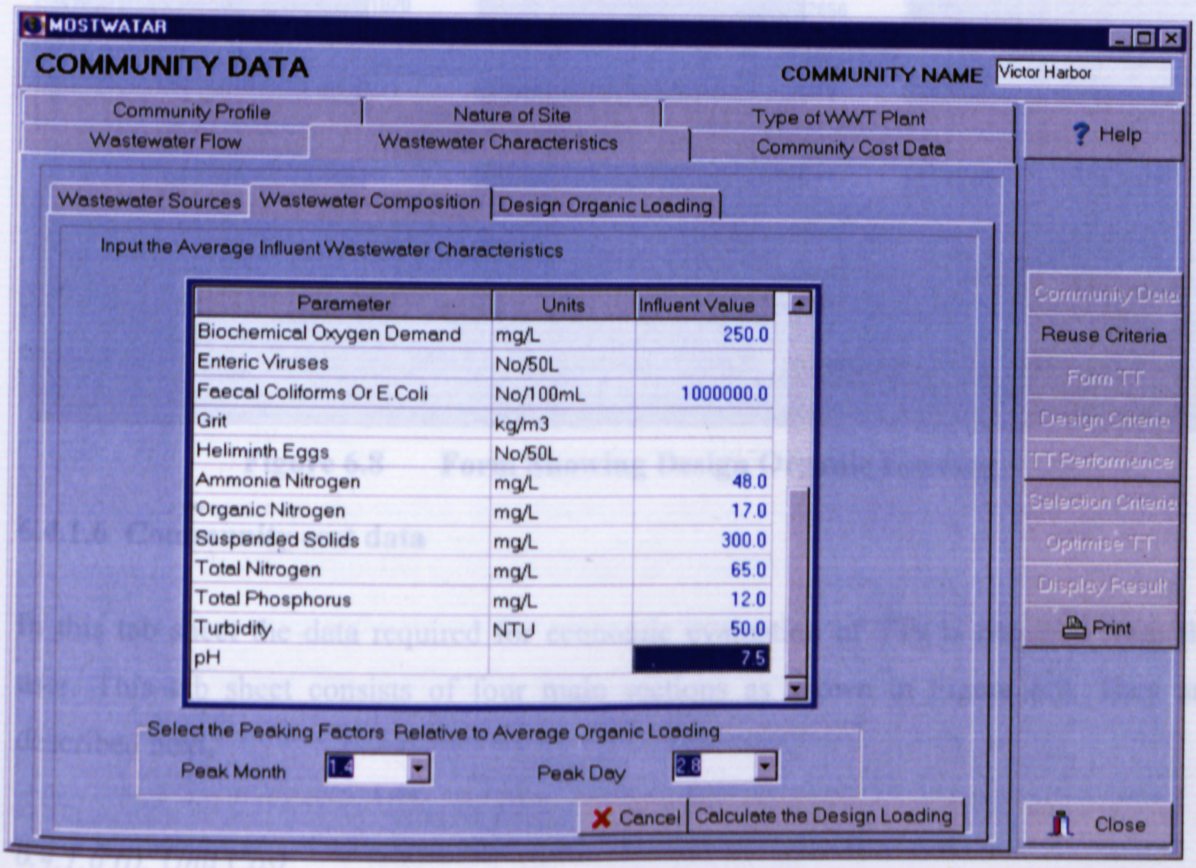


Figure 6.7 Wastewater Composition

6.4.1.5 (iii).Design Organic Loading

The peaking factors relative to average organic loading is to be selected from the drop down list as it is necessary to calculate the design organic loading for biological unit processes. The calculated organic loading is displayed to the user as shown in Figure 6.8. Similar to design flow, the user can decide to change the peaking factor if the calculated organic loading is found to be higher than expected.

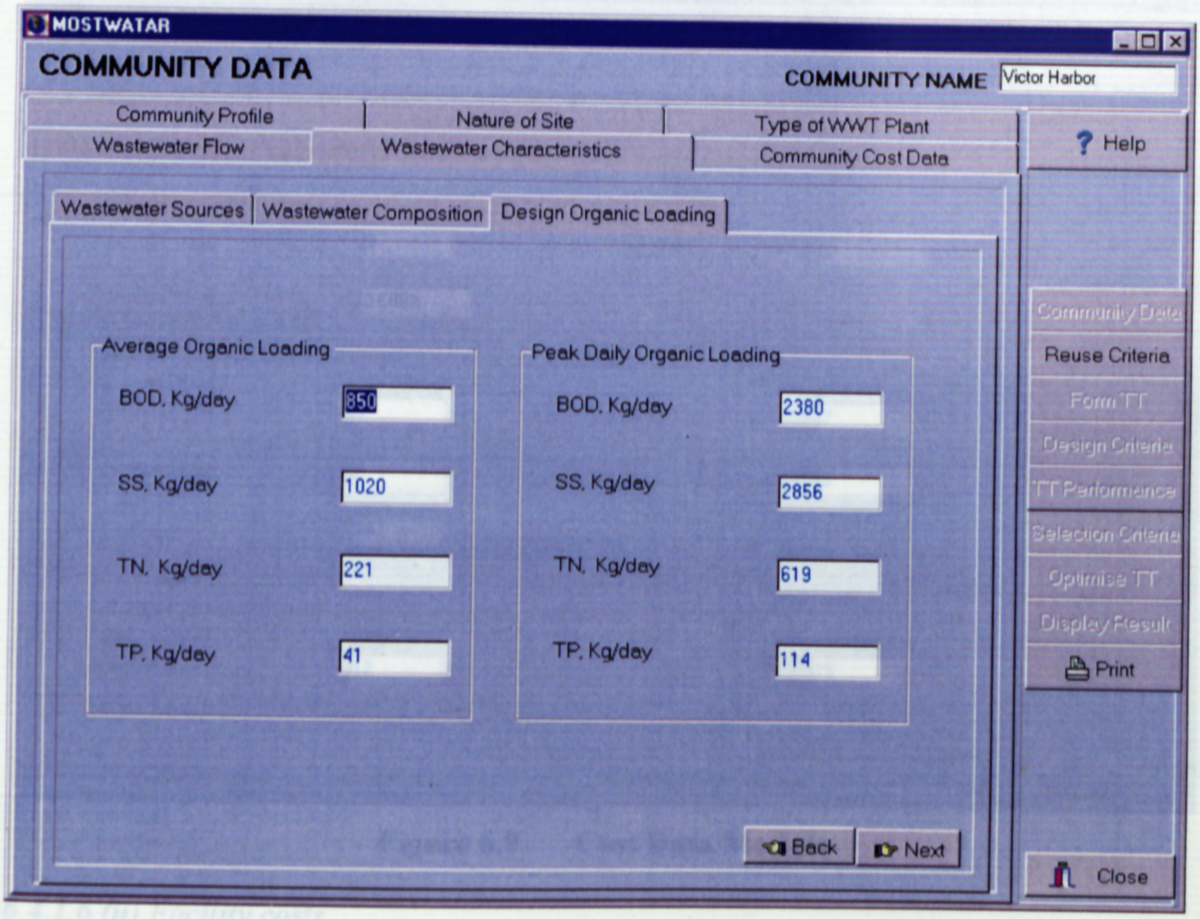


Figure 6.8 Form Showing Design Organic Loading

6.4.1.6 Community cost data

In this tab sheet the data required for economic evaluation of TTs is obtained from the user. This tab sheet consists of four main sections as shown in Figure 6.9. They are described next.

6.4.1.6 (i). Unit Cost

The cost of land per hectare can vary significantly from metropolitan to country regions. Based on the selection made by the user at the community profile (see Section 6.4.1.1), default values corresponding to a metropolitan or country region will be displayed which the user can change. The default values for metropolitan and country region land costs are $20,000 and $ 10,000 per hectare respectively. In addition to this $ 250,000 is added as land acquisition cost (Bentley, 2001). The cost of land is used to calculate the total project cost. The default values considered for sludge landfill costs, landfill tipping fee in $ per ton is also displayed.

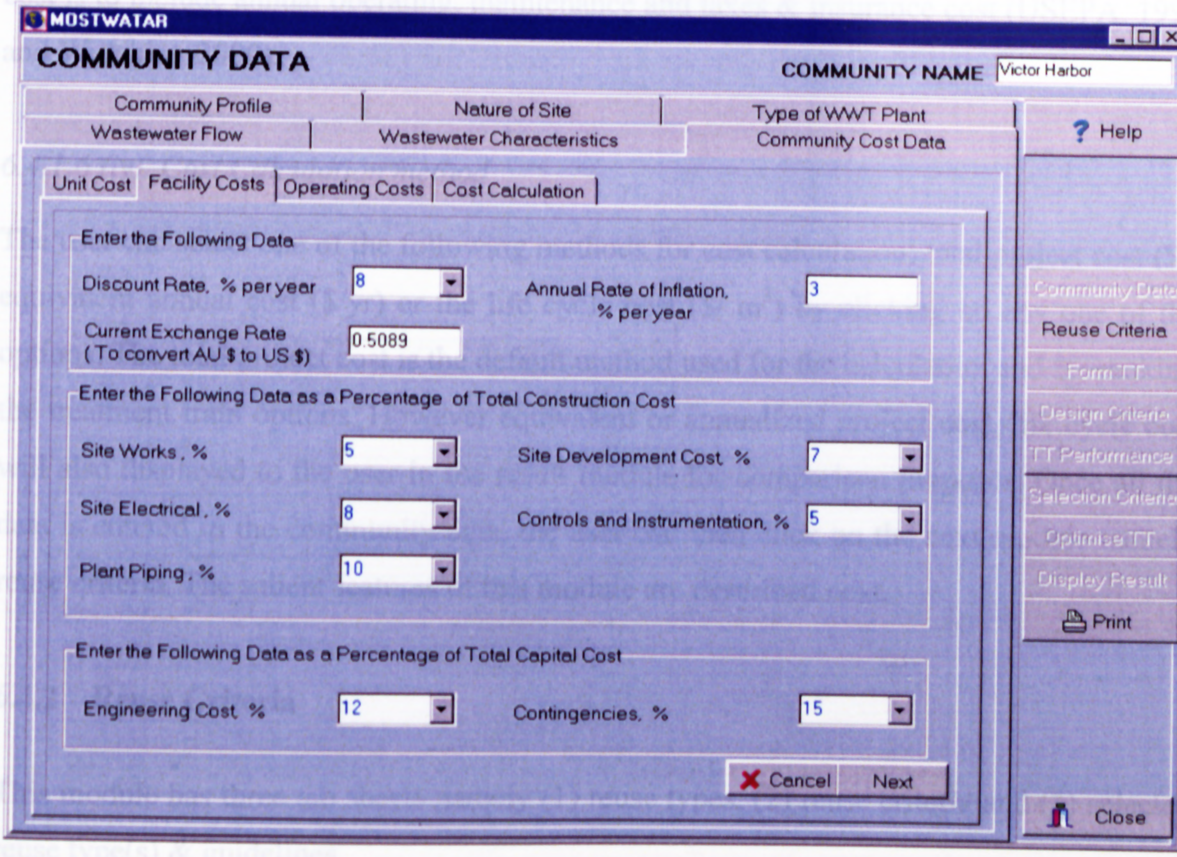


Figure 6.9 Cost Data Module

6.4.1.6 (ii).Facility costs

Facility costs such as site works, site electrical, piping, site development costs, control and instrumentation are computed as a percentage of total construction cost (as shown in Table 4.8). The engineering and contingency costs are further calculated as a percentage of total capital cost. The user has to select the percentages for the above works from the drop down list shown in Figure 6.9. Typical values used are displayed as default values. Further, a drop down list is provided for the user to select the discount rate (% per year), which is used for calculating the amortized costs. The annual rate of inflation is considered to update the project year costs from the year in which the cost estimation was made in this model (2001).

6.4.1.6 (iii). Operating Costs

The operating costs are calculated based on unit costs of labor, power, chemicals and building materials. However where there is lack of data on power, material and chemical requirements of individual treatment processes, the operation and maintenance (O & M) cost is estimated as 5 to 10 % of the total construction cost of the unit process. The O & M cost is to include annual operating, maintenance and taxes & insurance cost (USEPA, 1999 and Willshire, 2000).

6.4.1.6 (iv). Cost Calculation method

The user can select one of the following methods for cost calculation: total project cost ($), equivalent annual cost ($/yr) or the life cycle cost ($/ m^3) by clicking on any one of the options. The total project cost is the default method used for the calculation and for ranking the treatment train options. However equivalent or annualized project cost, life cycle cost will also displayed to the user in the result module for comparison purposes. Once all the data is entered in the community data, the user can then click on the next module namely reuse criteria. The salient features of this module are described next.

6.4.2 Reuse Criteria

This module has three tab sheets namely (1) reuse types, (2) reuse criteria and (3) selected reuse type(s) & guidelines.

6.4.2.1 Reuse Types

The reuse types tab sheet lists 33 different non-potable reuse applications that are practiced in Australia as shown in Figure 6.10. For a given community, the user can select one or more reuse applications from the list box by either double clicking the desired reuse type in the list box or by clicking the add button. The selected reuse type is then displayed at the selected reuse type box below. On the other hand, to delete the selection one can use either delete button or double click on the reuse type displayed in the 'selected reuse type' box. The user can select any number of reuse types for a given community. However the user can select only one reuse at a time as guideline values vary for different reuse applications. If the user wishes to select more than one reuse type then he has to select one of the guidelines before selecting the next reuse type. Further the user can enter any other type of reuse application not listed in the model by selecting the 'other' type from the list box and entering the guideline name and the reuse criteria values.

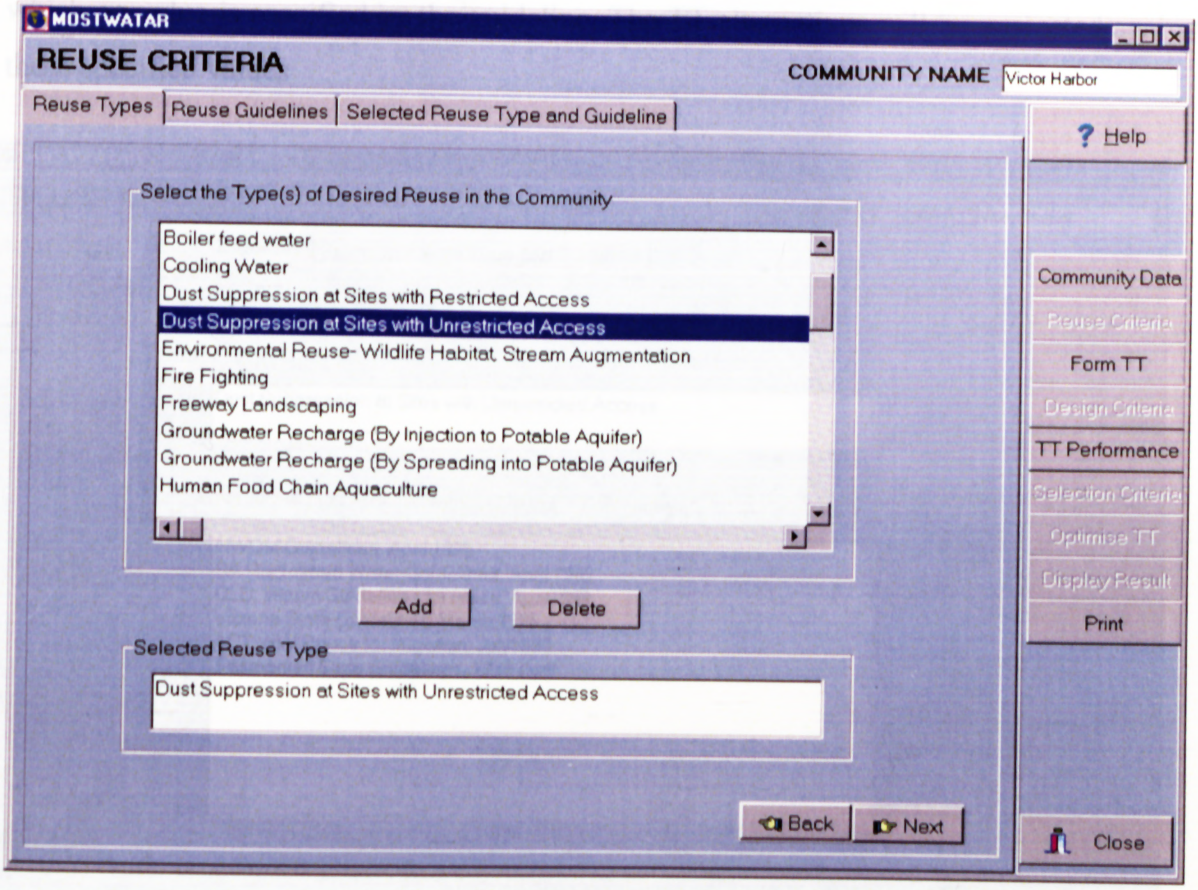


Figure 6.10 Reuse Criteria Module

6.4.2.2 Reuse Guidelines

Once the user selects a reuse type, different state reuse guidelines available for this selected reuse application will be displayed in the reuse guidelines tab sheet as shown in Figure 6.11. As discussed in Chapter 4, five State guidelines have been included in this model apart from NWQM, USEPA and WHO guidelines (see Appendix B for the list of guidelines). It should be noted that not all states have guidelines set out for all of the reuse types. Hence only available state guidelines for the selected reuse type are displayed. The user needs to select the reuse guideline by double clicking and the click of the "next" button displays the selected reuse type and criteria values.

6.4.2.3 Selected Reuse Type(s) and Guideline

The reuse criteria values for the selected guidelines are displayed in the boxes, which cannot be edited. However, the user can enter values for parameters (such as TN, TP) for which no value is specified by the guideline. The TT alternatives will be evaluated against these specified values

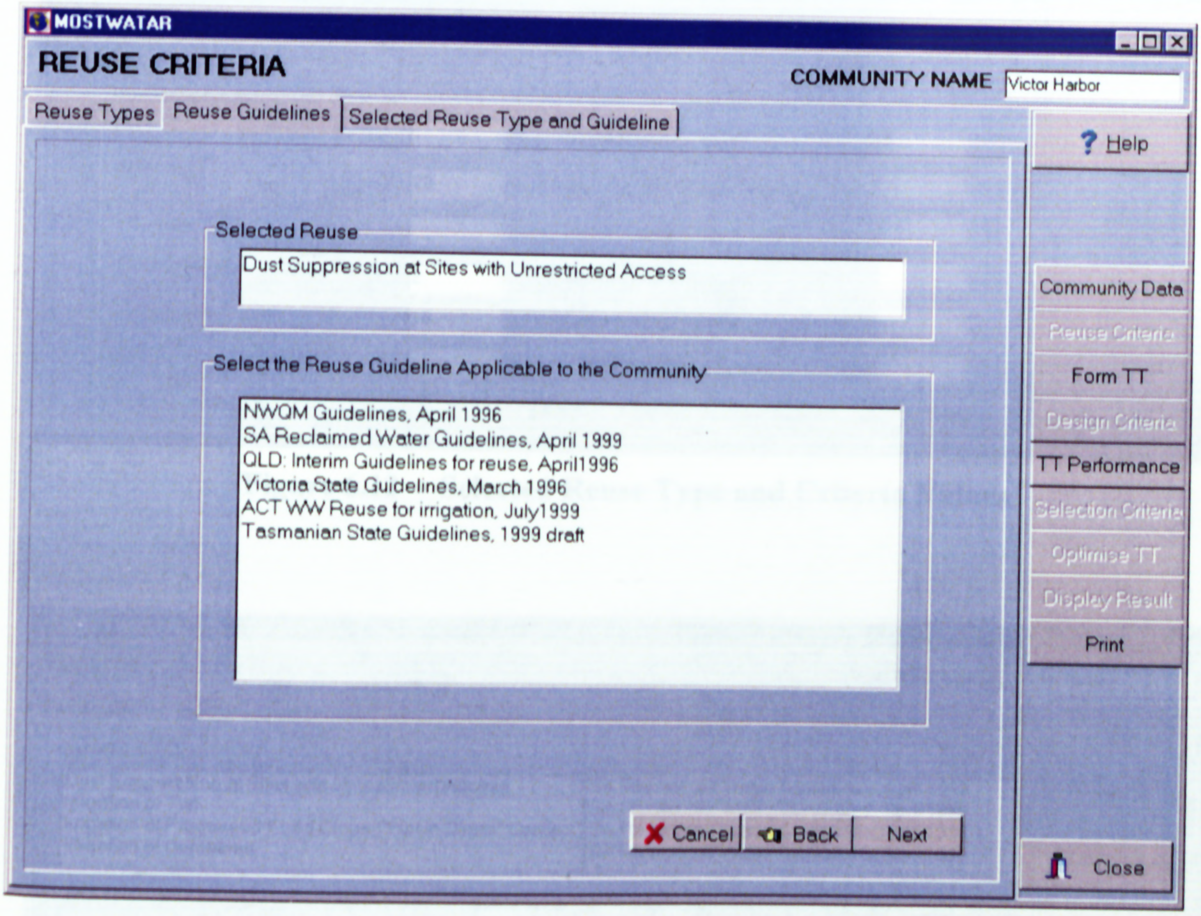


Figure 6.11 Selected Reuse and Corresponding Reuse Guidelines

Once the user finishes making the selection of reuse types, the selected reuse types and guidelines are displayed in the selected reuse & guideline tab sheet as shown in Figure 6.12. On the other hand, if more than one reuse is selected then reuse criteria values corresponding to the most stringent guideline based on faecal coliforms are displayed as shown in Figure 6.13. Further, TT alternatives are evaluated against the final effluent quality required by the most stringent reuse application.

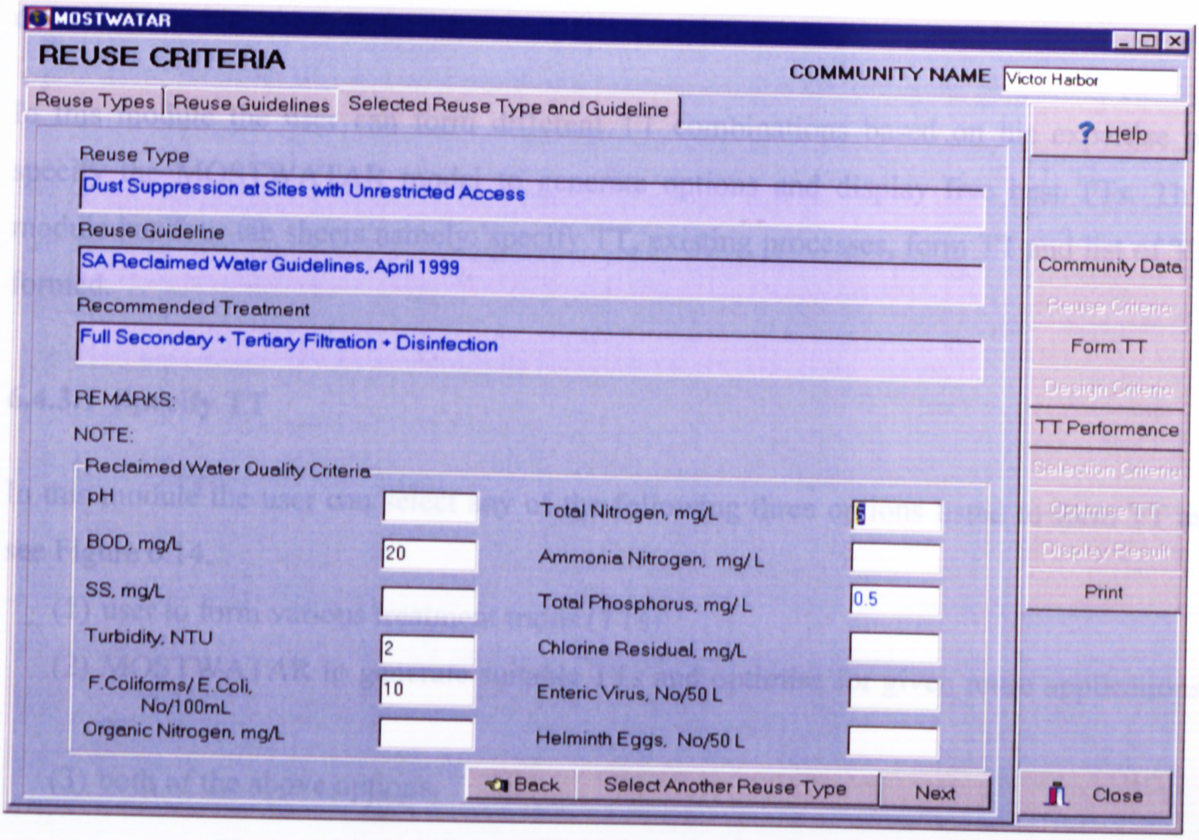


Figure 6.12 Selected Reuse Type and Criteria Values

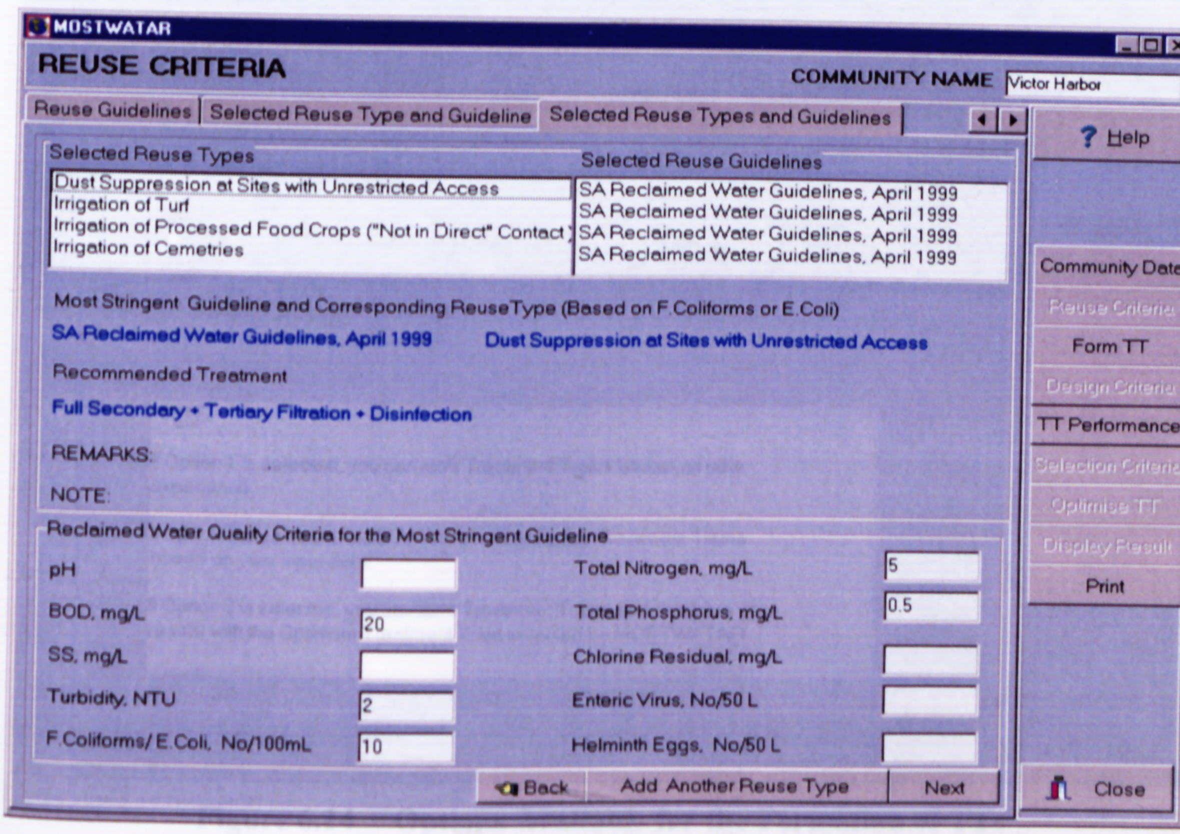


Figure 6.13 Form Showing the Most Stringent Guideline

6.4.3 Form TT

In this module the user can form different TT combinations based on his expertise or specify the MOSTWATAR model to generate options and display five best TTs. This module has four tab sheets namely: specify TT, existing processes, form TT and list of TT formed.

6.4.3.1 Specify TT

In this module the user can select any of the following three options listed to form TT as see Figure 6.14.

(1) user to form various treatment trains (TTs)

(2) MOSTWATAR to generate suitable TTs and optimise for given reuse applications or

(3) both of the above options.

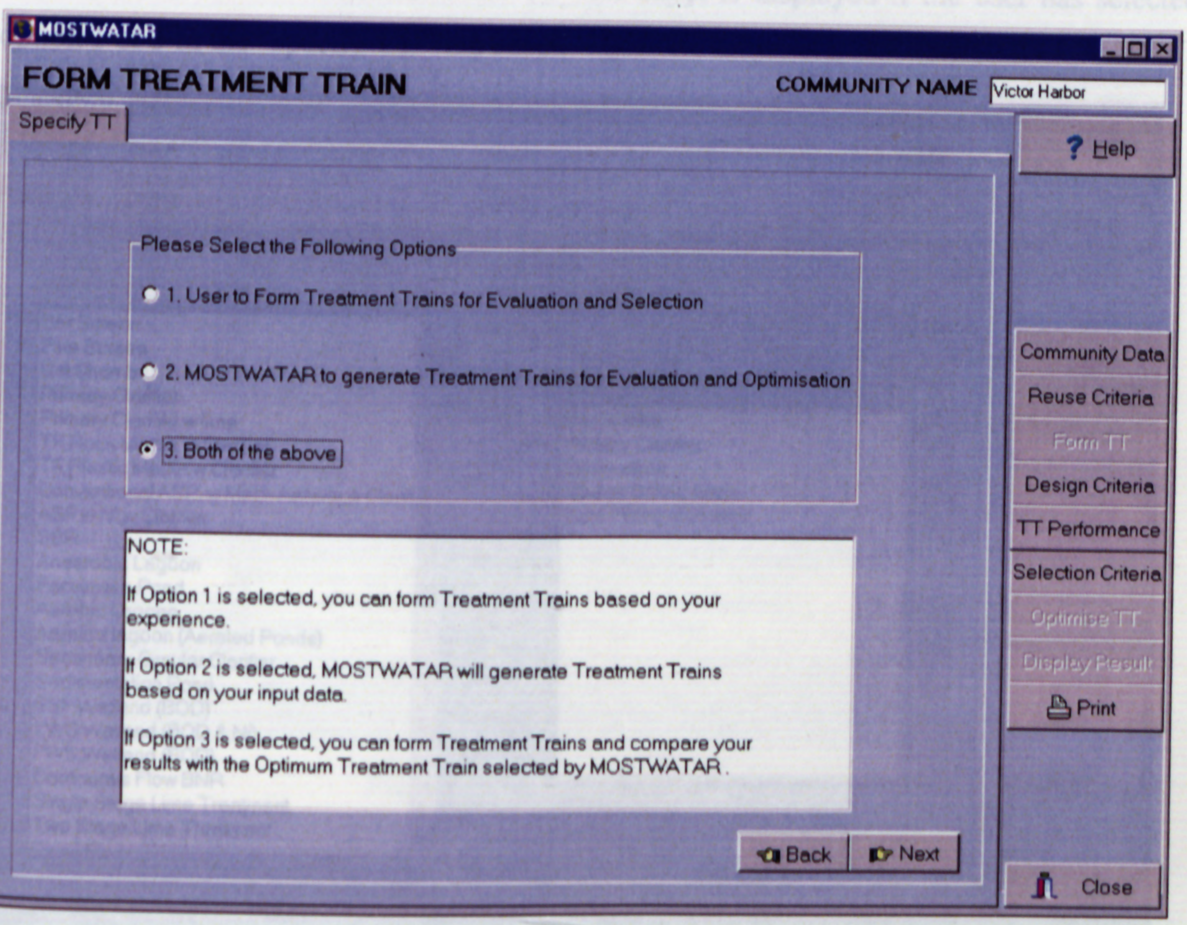


Figure 6.14 Options Available for the Formation of TTs

As a first step the model will check the type of wastewater plant selected by the user in the community module. If it is a new plant and the user selects the option to generate TTs then, the 'form TT' tab sheet is shown. If the user selects option 3 (i.e. both of the above), then the user must form TT first and then MOSTWATAR will generate and optimise TTs. On the other hand if the user has selected an existing plant upgrade option, irrespective of the options (1, 2, or 3) selected, the user is first asked to enter the existing processes in the 'existing processes' tab sheet shown in Figure 6.15.

6.4.3.2 Existing Unit Processes

The list of possible unit processes is displayed and user needs to double click or click on the add button to select the unit process. The selected unit processes are displayed in the right hand side list box as shown in Figure 6.15. The user can either double click on the unit process in this box or click the delete button to delete the selected processes. Once the existing processes are selected, "form TT" tab sheet is displayed if the user has selected option 1 or 3 in the "specify TT " tab sheet.

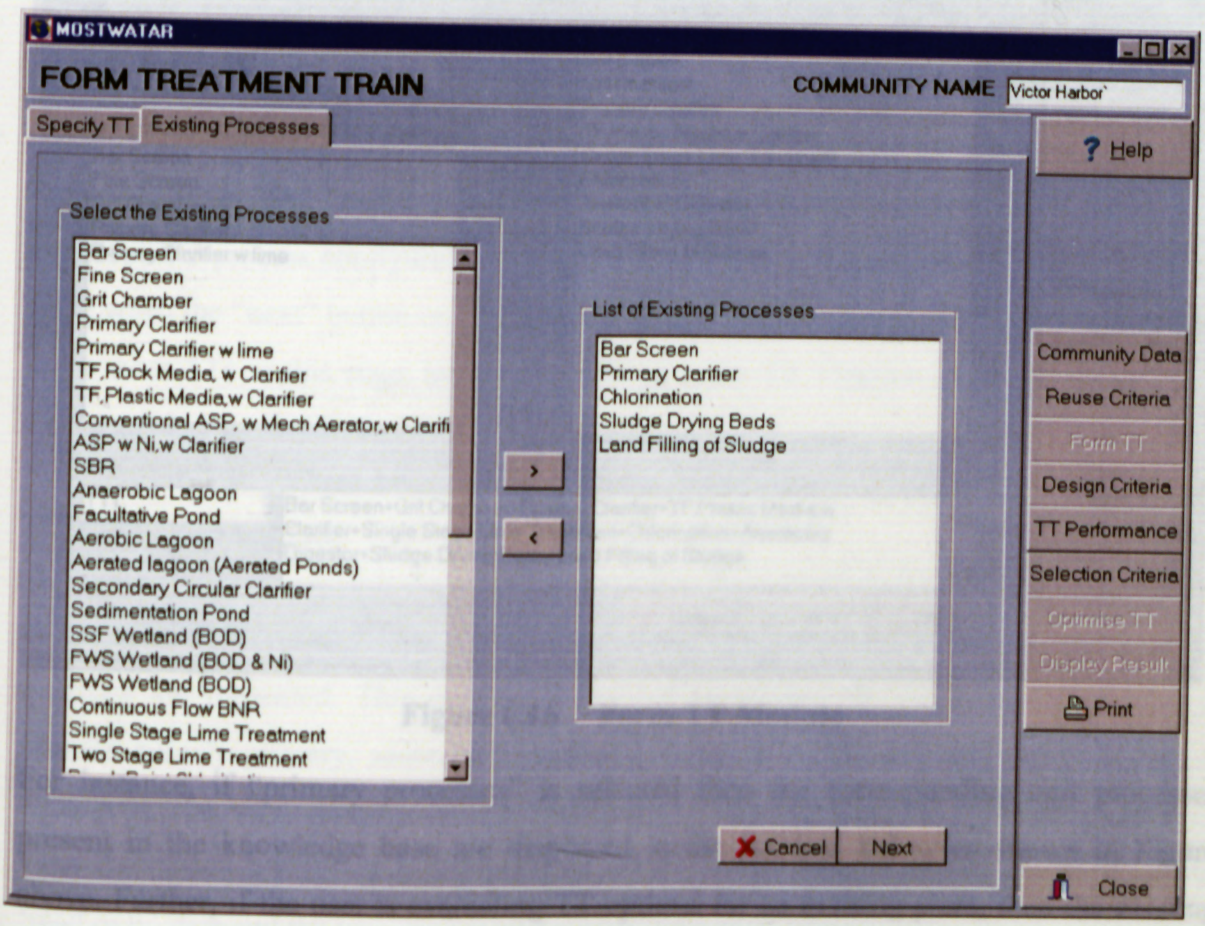


Figure 6.15 Selection of Existing Unit Processes

6.4.3.3 Form Treatment Train

The user can form new TT by first entering a name which can be a maximum of 10 characters long. The TT name has to be unique to prevent duplication. An error message is displayed if the user tries to enter a name, which already exists in the database. Further, the model will auto generate a unique treatment train identification number (TTIDNo) for easy identification. The user can then select the type of treatment process to be included in the TT from the drop down list as shown in Figure 6.16. The six categories of processes namely, (1) primary processes, (2) secondary processes, (3) natural systems, (4) tertiary processes, (5) disinfection and (6) sludge handling processes are displayed in the drop down list.

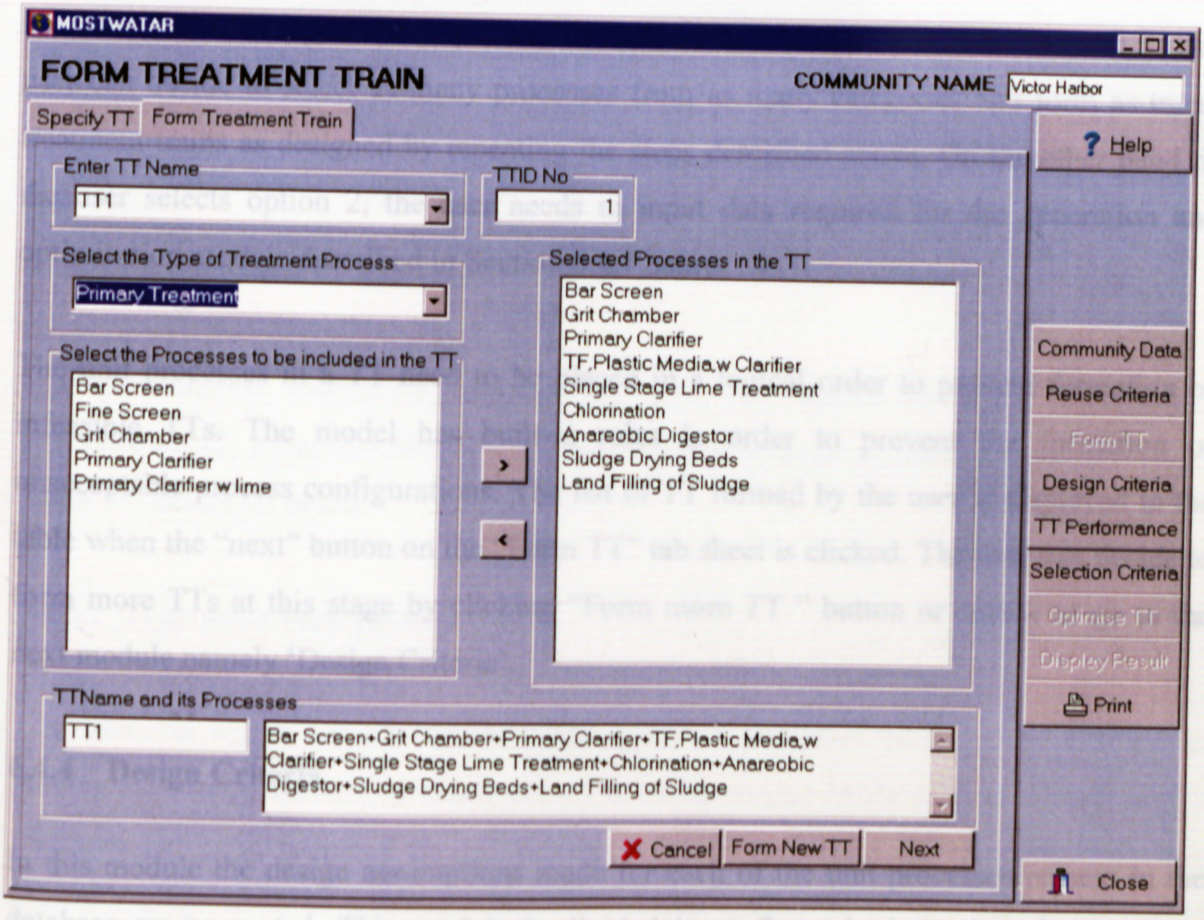


Figure 6.16 Form TT Module

For instance, if "primary processes" is selected then the corresponding unit processes present in the knowledge base are displayed in the list box below as shown in Figure above. Further, if the user is evaluating TT options for an existing plant, then the existing processes selected in the previous tab sheet will be displayed in the selected processes list box on the right hand side. To add processes to the existing plant or evaluate TT options for a new plant, the user needs to either double click on the process or select the process and then click on the add button.

The selected processes are displayed in the list box on the right side of the screen. If any processes needs to be removed from the TT then the corresponding process needs to be highlighted and can be removed either by double clicking or by clicking the delete button. The selected processes are displayed in the box at the bottom of the form to represent a treatment scheme as shown in Figure 6.16.

Similarly, other types of process namely secondary, tertiary processes can be selected and the corresponding unit processes are displayed in the list box to the left of the screen. The user then needs to repeat the steps described above to add more processes to the TT. The user can decide to select as many processes from as many categories and form as many treatment trains as designed by repeating the steps described above. On the other hand, if the user selects option 2, the user needs to input data required for the generation and optimisation module described in Section 6.4.7 below.

The unit processes in a TT need to be placed in a logical order to prevent formation of infeasible TTs. The model has built-in rules in order to prevent the formation of unacceptable process configurations. The list of TT formed by the user is displayed in the table when the "next" button on the "Form TT" tab sheet is clicked. The user can decide to form more TTs at this stage by clicking "Form more TT " button or decide to go to the next module namely 'Design Criteria'.

6.4.4 Design Criteria

In this module the design assumptions made for each of the unit processes present in the database are presented. This module is divided in to five tab sheets based on type of process namely primary, secondary, wetlands, tertiary, disinfection and sludge handling processes. The user can click on the corresponding unit processes in these tab sheets and view the criteria as shown in Figure 6.17. Currently the design criteria are displayed as 'read only' data and the user cannot edit any of the design criteria.

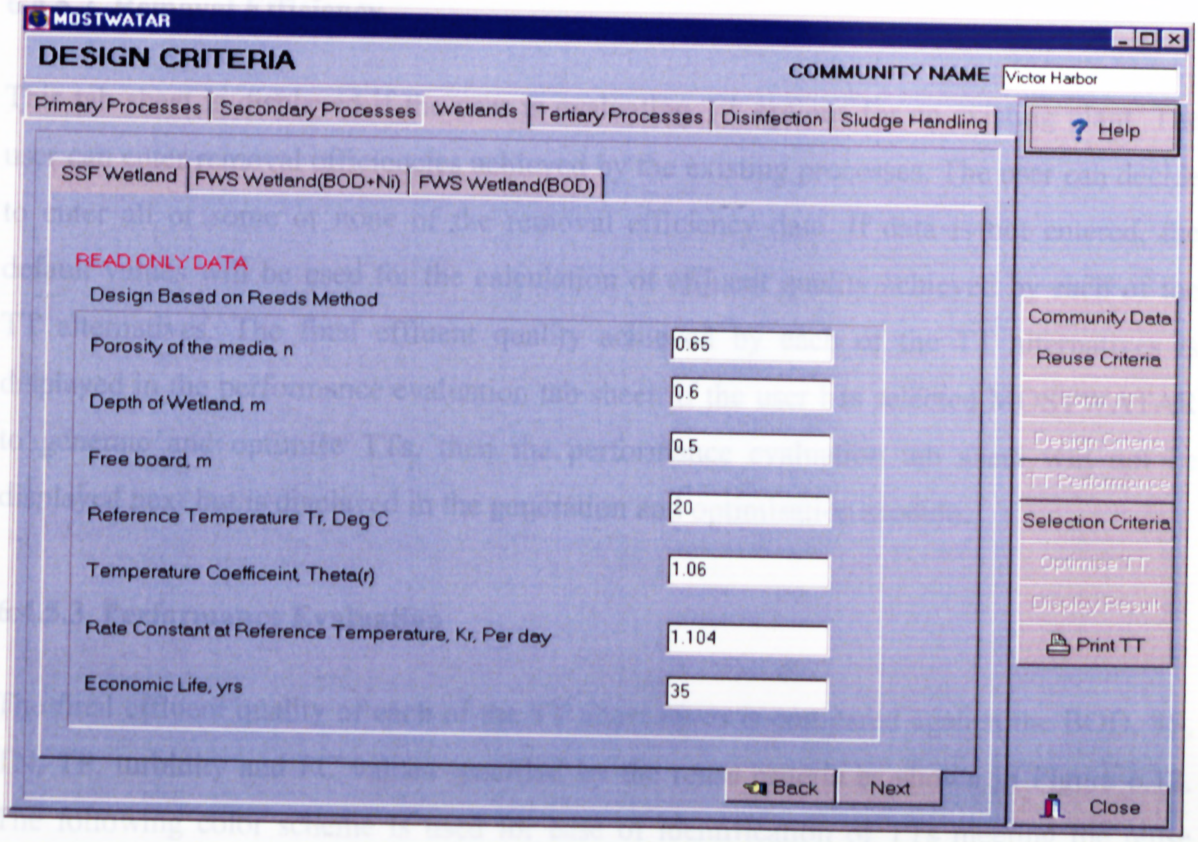


Figure 6.17 Design Criteria Module

6.4.5 Performance Evaluation

The performance evaluation module has four tab sheets namely, (1) treatment performance, (2) removal efficiency, (3) performance evaluation, and (4) treatment trains. These are described below.

6.4.5.1 Treatment Performance

The user can select any one of the three levels of treatment performance efficiencies namely minimum, average or maximum by clicking on one of the options. Based on this selection, the performance of the treatment train will be calculated. For example, if the user selects average removal efficiency then the effluent quality of all TTs will be calculated using the average removal efficiencies of the unit processes.

As a default the average removal efficiency is used to calculate the performance. Further, if it is an existing plant then the user can enter the removal efficiencies achieved by the existing processes as explained in the next section.

6.4.5.2 Removal Efficiency

This tab sheet is displayed if the user is evaluating TT options for an existing plant. The user can enter removal efficiencies achieved by the existing processes. The user can decide to enter all or some or none of the removal efficiency data. If data is not entered, the default values will be used for the calculation of effluent quality achieved by each of the TT alternatives. The final effluent quality achieved by each of the TT alternatives is displayed in the performance evaluation tab sheet. If the user has selected MOSTWATAR to generate and optimise TTs, then the performance evaluation tab sheet will not be displayed next but is displayed in the generation and optimisation module.

6.4.5.3 Performance Evaluation

The final effluent quality of each of the TT alternatives is compared against the BOD, SS, TN, TP, turbidity and FC values specified by the reuse criteria as shown in Figure 6.18. The following color scheme is used for ease of identification of TTs meeting the reuse criteria.

- Red – criteria values are NOT met.
- Green- criteria values are met
- Yellow- no criteria was specified for that parameter
- Pink- exceeds the maximum allowable parameter criteria for the influent to a unit process.

The user can select TTs that meet performance criteria for the next stage of evaluation by double clicking. Also the user can use his or her discretion to select the TTs, which fail to meet the reuse criteria values.

6.4.5.4 Treatment Trains

The list of TTs selected is displayed in the treatment trains tab sheet. These TTs are then passed on to further evaluation in the second stage.

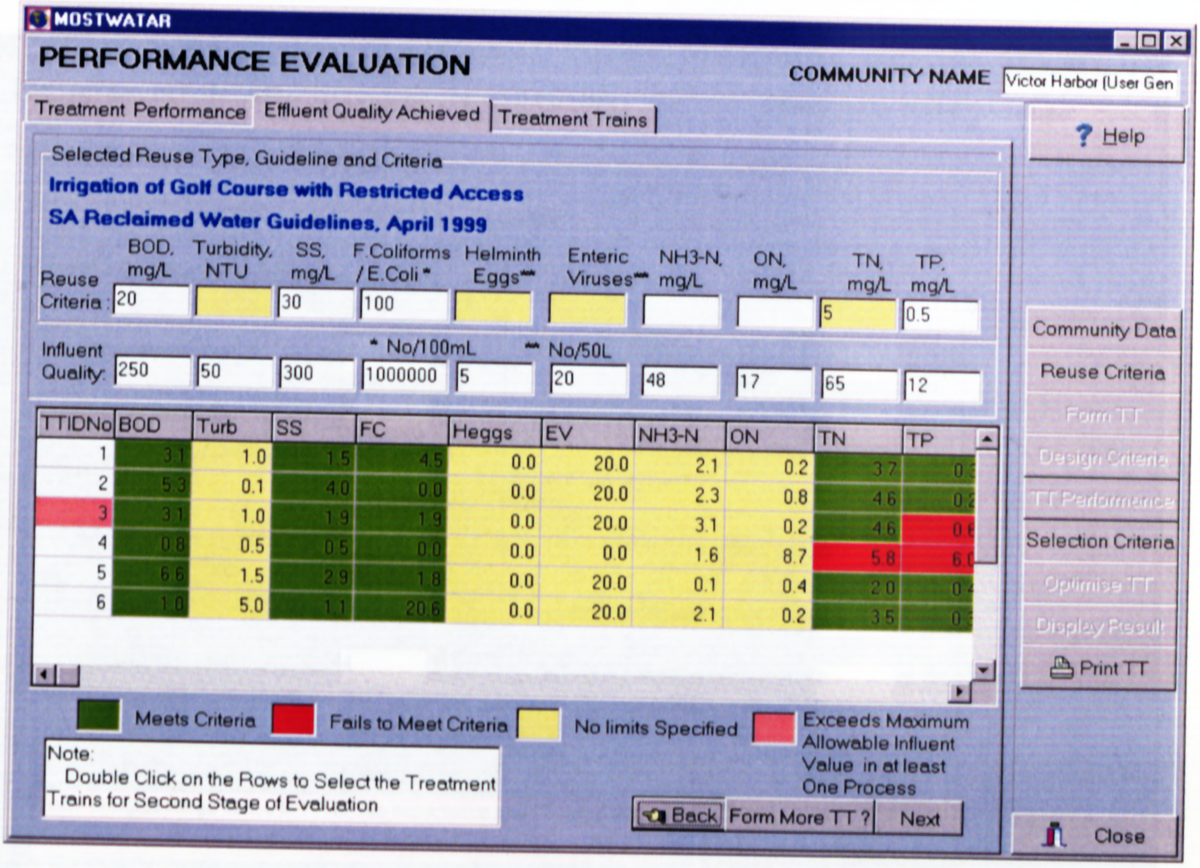


Figure 6.18 Performance Evaluation Module

6.4.6 Selection Criteria

This module has two main tab sheets namely, (1) evaluation technique and (2) selection criteria as shown in Figure 6.19. The evaluation technique tab sheet displays a brief note on the weighted average technique used in this model. The selection criteria module has three tab sheets, namely (1) relative weights, (2) relative weights for cost and (3) decision matrix.

The user can assign relative weights to the 12 criteria (as shown in Figure 6.19) within the range of 0 to 10. The weight zero '0' indicates that the criterion is of no importance while a weight of '10' indicates that the criterion is of highest importance. Since cost is considered separate to all other criteria, the user can assign weight of '0' to '10' as shown in Figure 6.20.

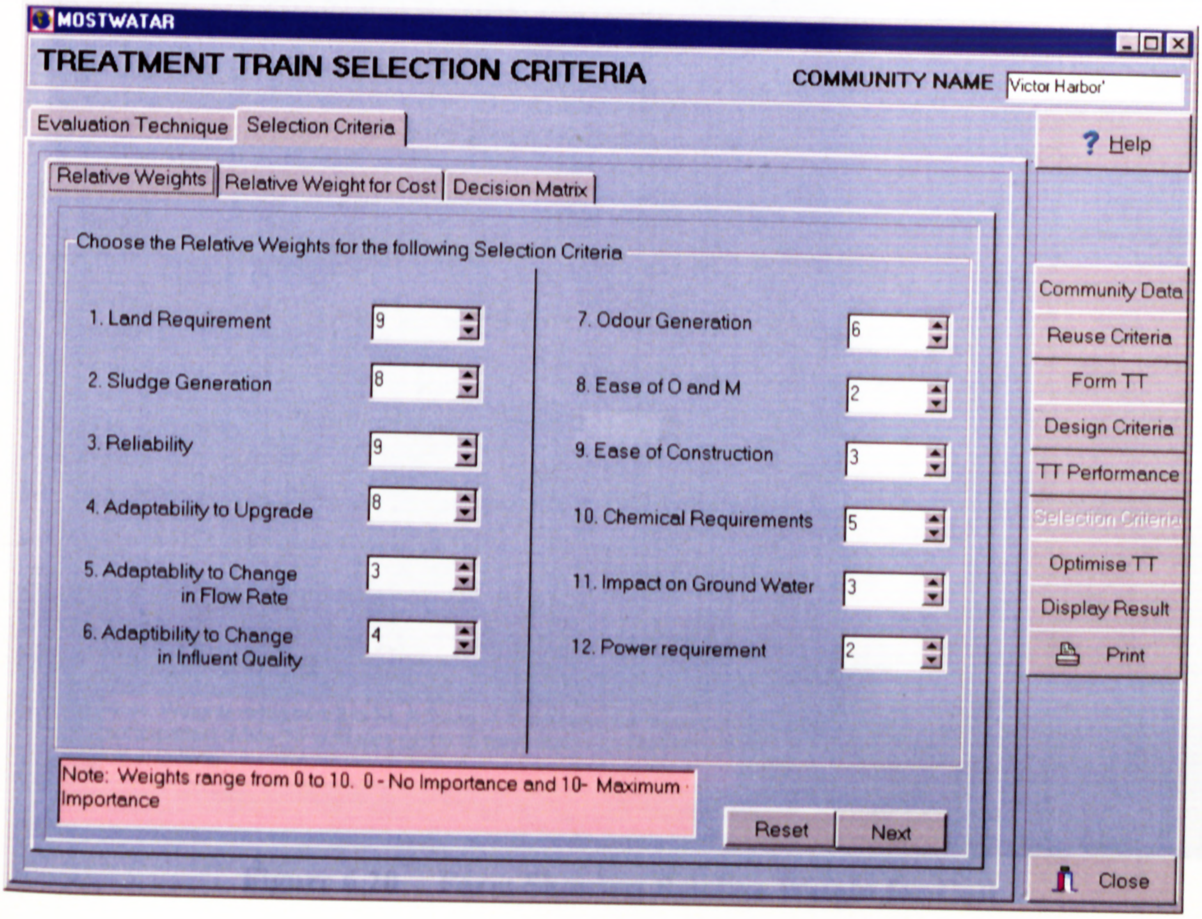


Figure 6.19 Selection Criteria Module

The user can change the default values in the display boxes by scrolling up or down arrows of the boxes. Further, the user can choose to ignore some of the criteria listed by assigning zero weight while equal weights can be assigned for two or more criterion of equal importance. The click of the "next" button displays decision matrix tab sheet with the normalized (linearly scaled) scores for the selected TTs as shown in Figure 6.21. This tab sheet also displays the relative weights selected by the user for each criterion. On the other hand if the user has specified that MOSTWATAR generate TT options then a click of the "next" button displays the generation and optimisation module.

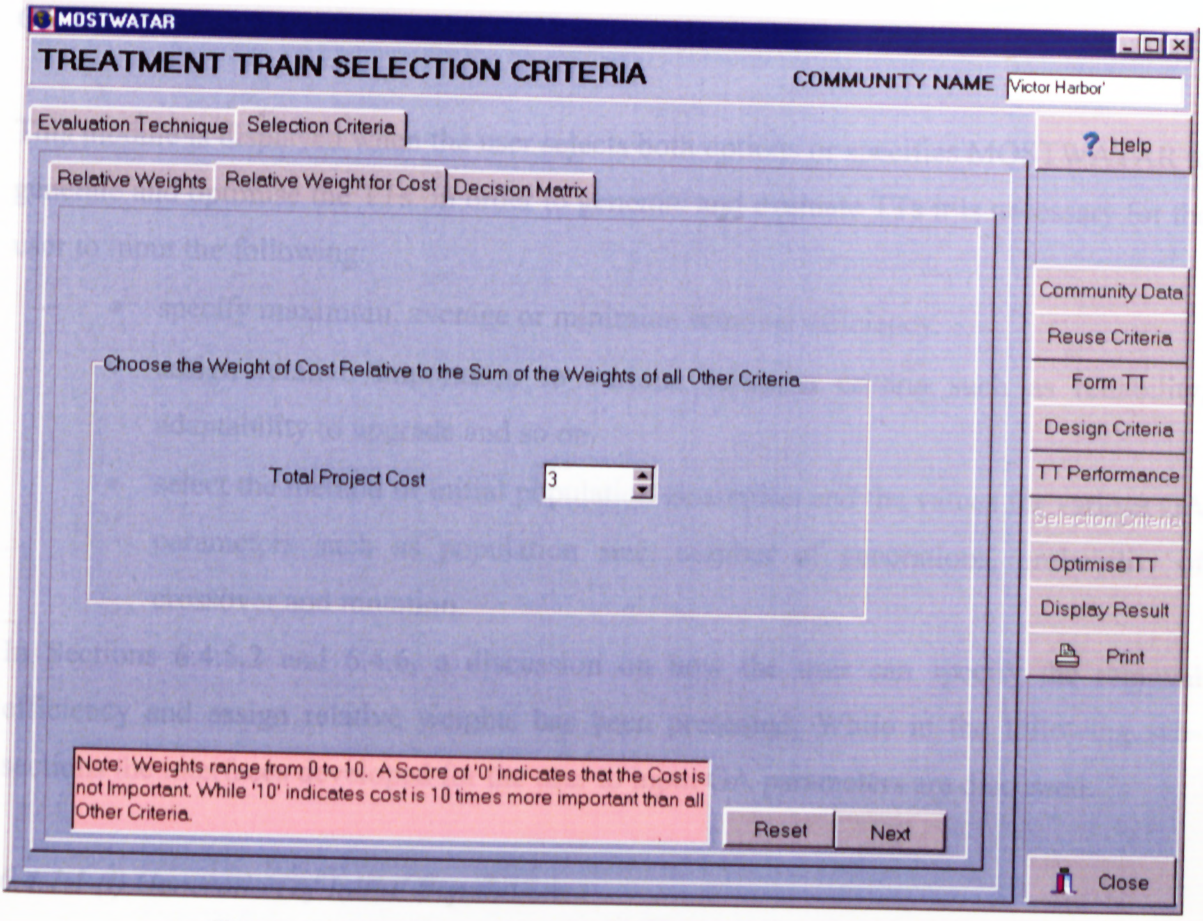


Figure 6.20 Form Showing Relative Weight for Cost

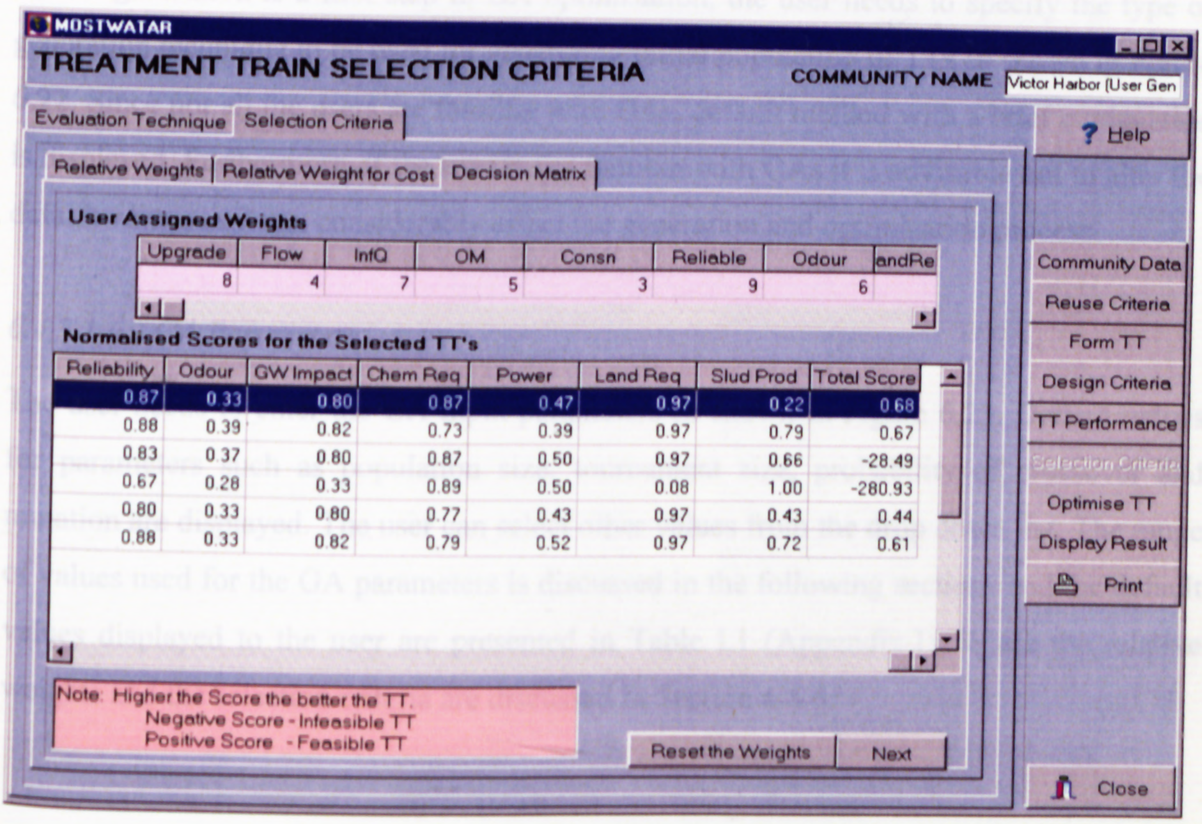


Figure 6.21 Form Showing Decision Matrix

6.4.7 Optimise TT

This module is displayed when the user selects both options or specifies MOSTWATAR to generate and optimise the TTs. In order to generate and evaluate TTs it is necessary for the user to input the following:

- specify maximum, average or minimum removal efficiency.
- assign relative importance to various selection criteria such as reliability, adaptability to upgrade and so on.
- select the method of initial population generation and the values for various GA parameters such as population size, number of generations, probability of crossover and mutation.

In Sections 6.4.5.2 and 6.4.6, a discussion on how the user can specify the removal efficiency and assign relative weights has been presented. While in the following sub-sections the interfaces developed for the user to input GA parameters are discussed.

6.4.7.1 (i). Generation of Initial Population

As TT generation is a first step in GA optimisation, the user needs to specify the type of generation technique to be used for generating initial population of TTs as shown in Figure 6.22. Since not all the users are familiar with GAs, default method with a brief explanation is displayed. Furthermore, if the user is not familiar with GAs it is advisable not to alter the default values as it can considerably affect the generation and optimisation process.

6.4.7.1 (ii). GA Parameters

The user needs to enter the GA input parameters as shown in Figure 6.23. Default values for parameters such as population size, tournament size, probability of crossover and mutation are displayed. The user can select other values from the drop down list. The range of values used for the GA parameters is discussed in the following sections and the default values displayed to the user are presented in Table I.1 (Appendix-I). While the relative weights and the selection criteria are discussed in Section 6.4.6.

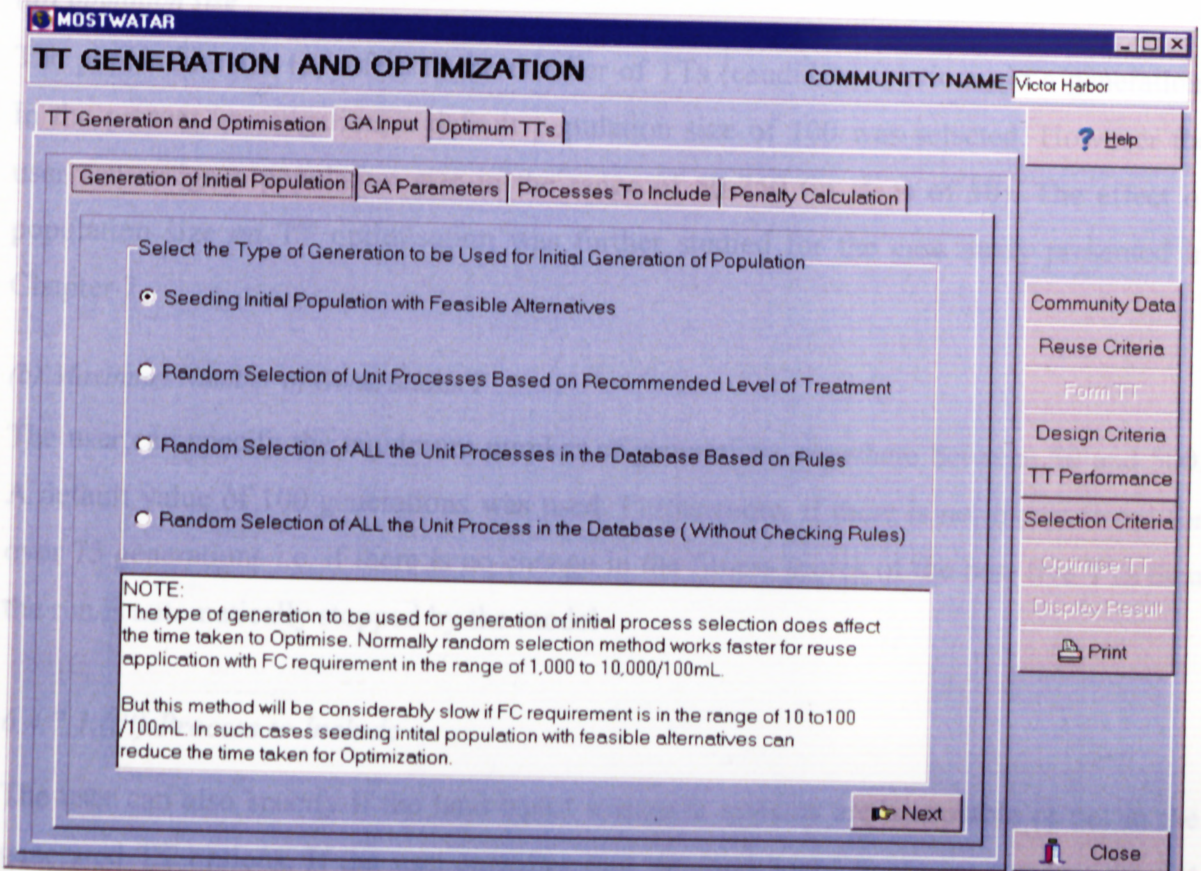


Figure 6.22 Different Methods of Initial Population Generation

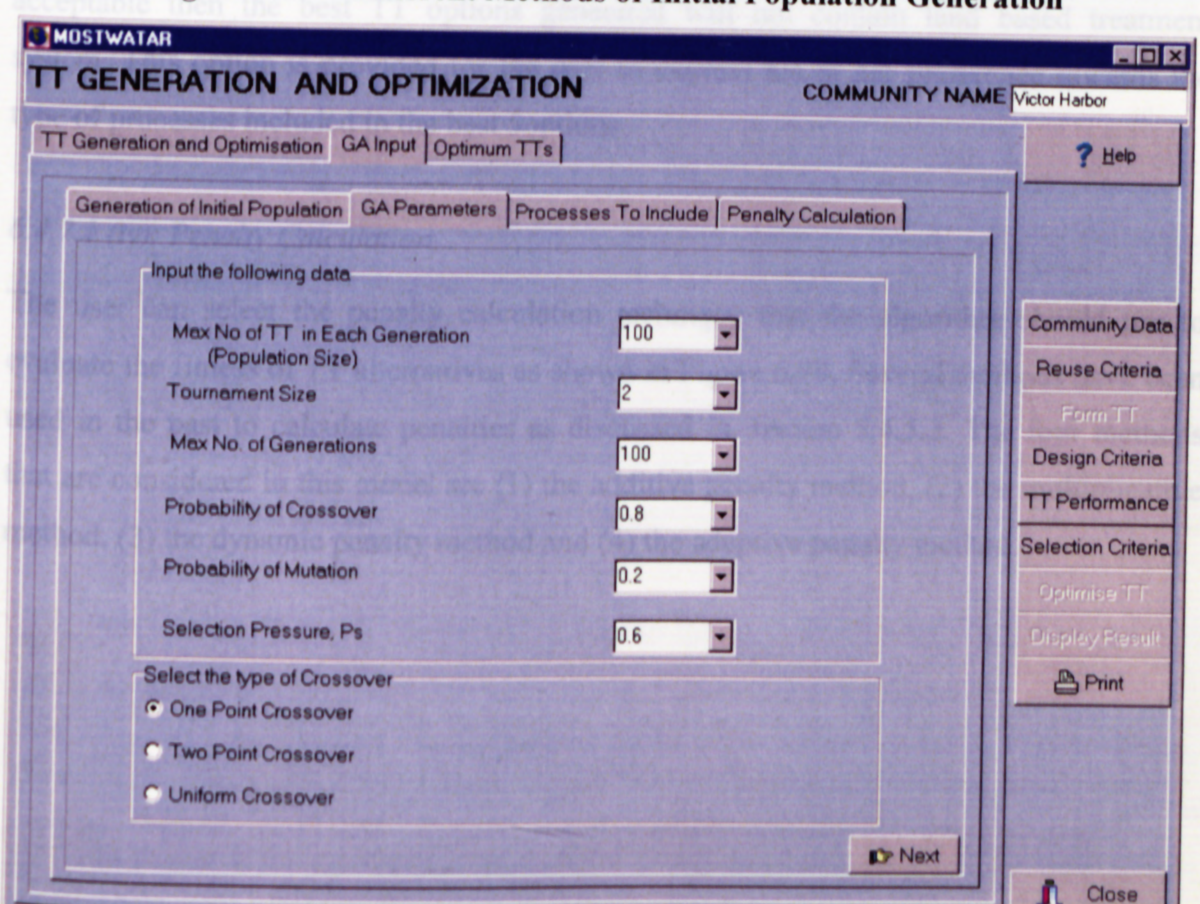


Figure 6.23 Form Showing GA Input Parameters

(a)Population size

The population size (n) refers to the number of TTs (candidate solutions) in a generation. In the present investigation, a default population size of 100 was selected. However the user can assign a population size in the range of 50-250 (in steps of 50). The effect of population size on TT optimisation was further studied for the case study presented in Chapter 7.

(b) Maximum Number of Generations T

The user can specify the maximum number of generations anywhere between 50 and 500. A default value of 100 generations was used. Furthermore, if there is no improvement for over 75 generations i.e. if there is no change in the fitness scores of the best five TTs then the run is automatically stopped by the model

6.4.7.1 (iii).Process to Include

The user can also specify if the land based treatment systems are acceptable or not in the generated TT options. If the user specifies that the land based treatment systems are not acceptable then the best TT options generated will not contain land based treatment system. This option is provided for the user to express his or her preference towards the type of processes included in the best 5options.

6.4.7.1 (iv). Penalty Calculation

The user can select the penalty calculation technique that the algorithm should use to evaluate the fitness of TT alternatives as shown in Figure 6.24. Several methods have been used in the past to calculate penalties as discussed in Section 5.4.5.2. The four methods that are considered in this model are (1) the additive penalty method, (2) the multiplicative method, (3) the dynamic penalty method and (4) the adaptive penalty method.

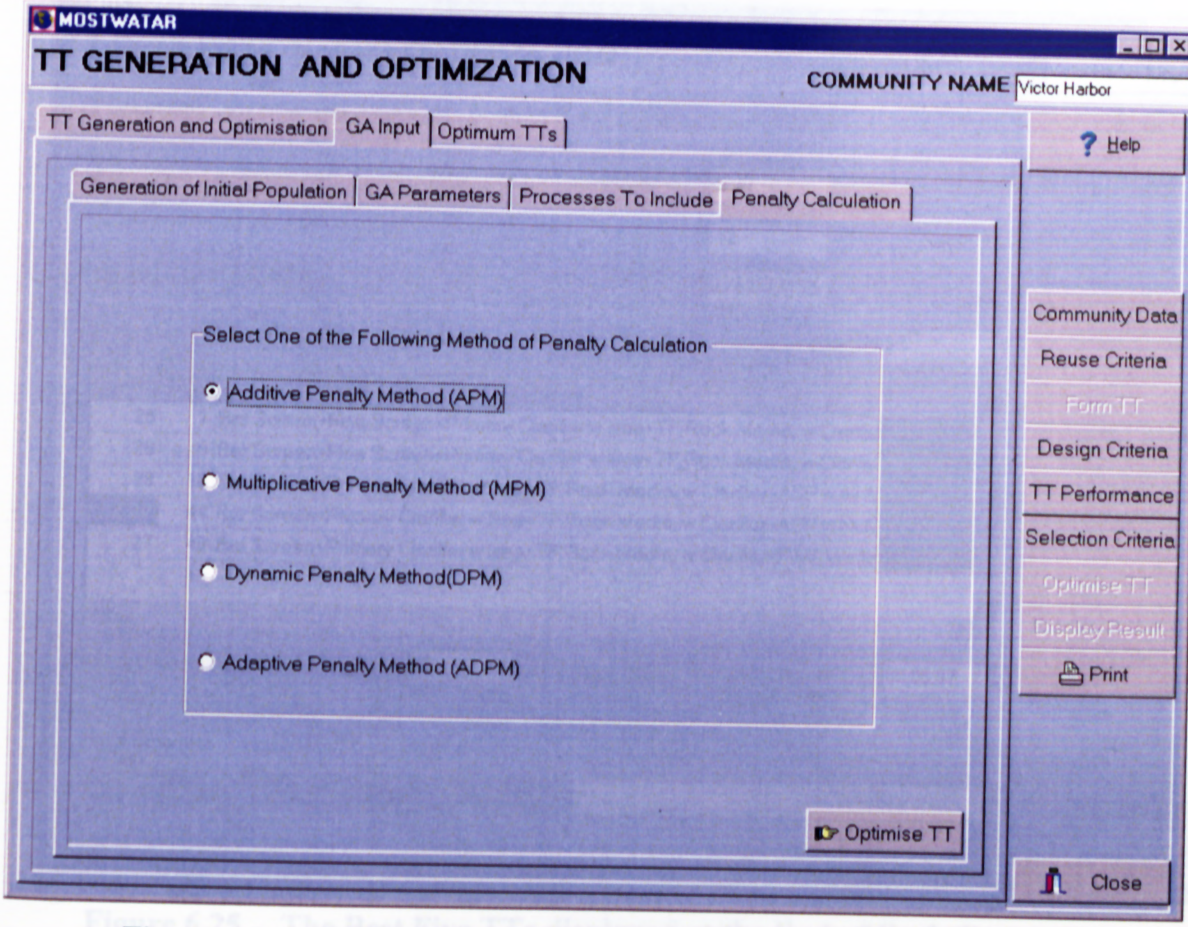


Figure 6.24 Form Showing Different Penalty Calculation Methods

Once the user clicks the "Optimise TT" button the TT optimisation is carried out using genetic algorithm as described in Chapter 5. The steps involved when the user clicks the optimise TT button are listed below.

1. Firstly, TTs are generated randomly. The generated TT is checked with the rules in the knowledge base to see if the configuration is acceptable. If a TT does not meet the rules criteria then it will be discarded and another TT is generated. This step is repeated until the number of TTs generated is equal to the population size specified by the user.
2. Evaluation of TTs is carried out similar to that described in the Sections 6.4.5 and 6.4.6 above.
3. The TTs are sorted in descending order based on their fitness and the best five, unique TT strings selected from this generation are stored and displayed as shown in Figure.6.25. The display includes the unit processes in the TTs, their fitness score and the generation number at which the TT was generated.

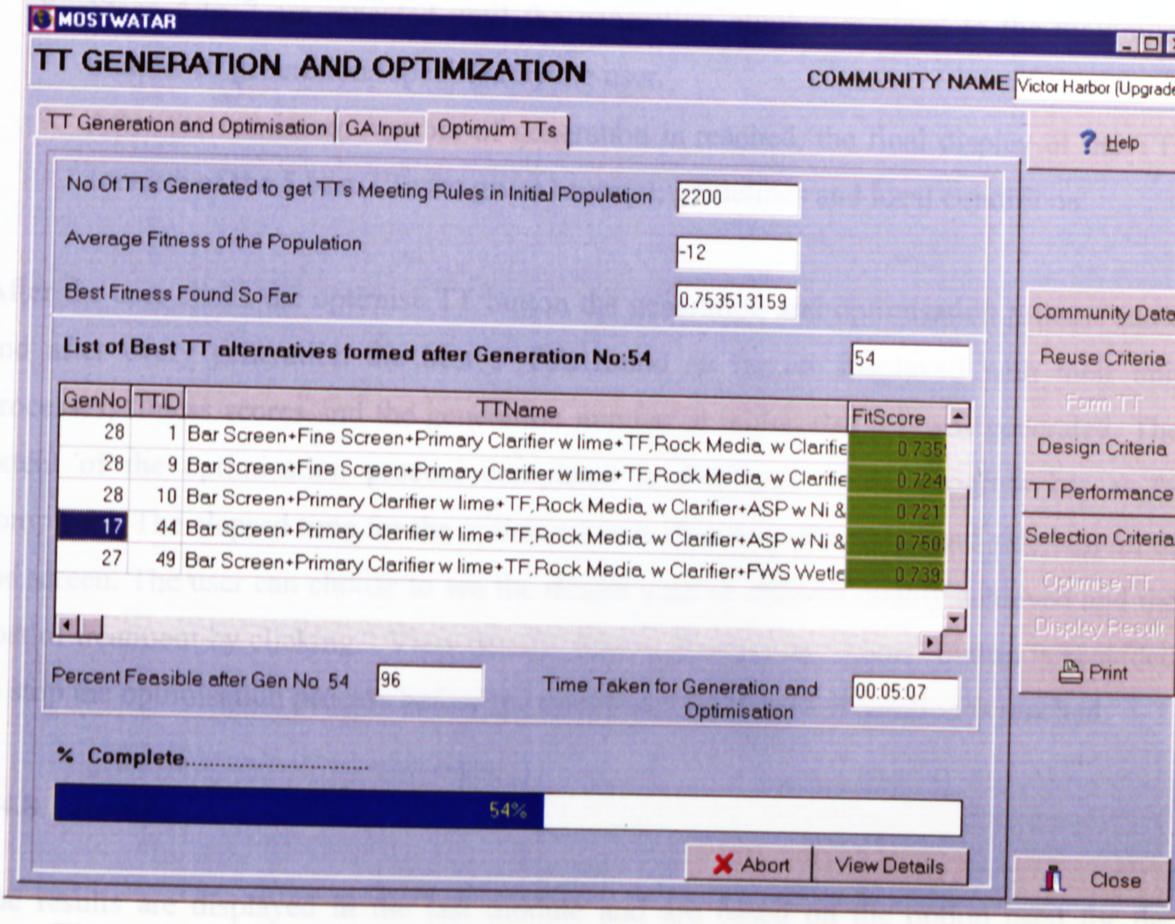


Figure 6.25 The Best Five TTs displayed at the End of Each Generation

4. Tournament selection is carried out to select fit parents. One point crossover and bit wise mutation then takes place as discussed in Section 5.4.7 & 5.4.8
5. The TTs formed after mutation are checked to see if they have an acceptable configuration and if they do not meet the rules criteria then a penalty of '-1' score is applied.
6. Step 3 is repeated and the TTs are evaluated.
7. The best 5 TTs of the previous generation are compared with TTs from the current generation in the following manner. First the TTs of the current generation are sorted in descending order based on their fitness scores. Then, the first TT of the sorted population is compared with the best five TTs. If any of the five best TTs has lower fitness score then that TT string is replaced by the first TT string of the current generation. Before replacing, a check is made to ensure that no other TT string in the best five group has same unit processes present as in the replacement string. If it does, then next best is compared and so on until a unique TT with higher fitness is found. This is done to prevent duplication of TT strings.

8. Steps 4 to 7 are repeated until the generation number is equal to the maximum number of generations specified by the user.
9. After the maximum number of generation is reached, the final display of the TTs consists of the 5 best TTs for given reuse(s), guidelines and local conditions.

After the user clicks the optimise TT button the generation and optimisation process starts and after every generation the best 5 TTs found so far are displayed with their unit processes, fitness scores and the generation number at which that TT was generated. The extent of the optimisation process completed is displayed in the progress bar as % completed. The elapsed time for the optimisation is shown on the right hand side bottom of the screen. The user can choose to see the details such as effluent quality achieved and the cost of treatment by clicking " View details" button. Further an "Abort" button is provided to stop the optimisation process before the maximum number of generation is reached.

6.4.8 Results

The results are displayed in the last module and are based on the option used for the formation of TT. If the user chooses to form TTs then the result module will consist of the TTs formed by the user and the list of infeasible & feasible TTs and their attributes such as cost, performance and adaptability criteria values as shown in Figures 6.26 to 6.28.

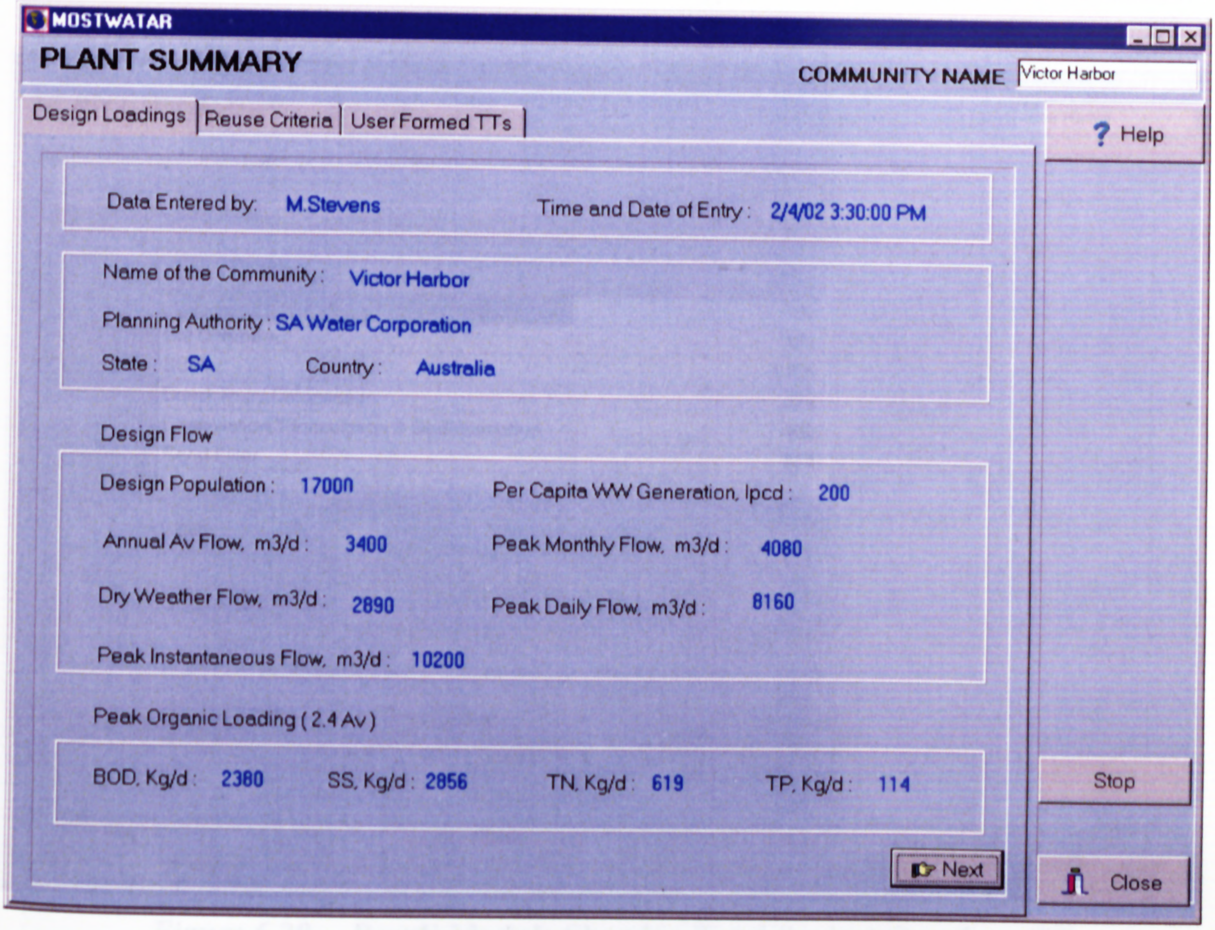


Figure 6.26 Form Showing Results Module

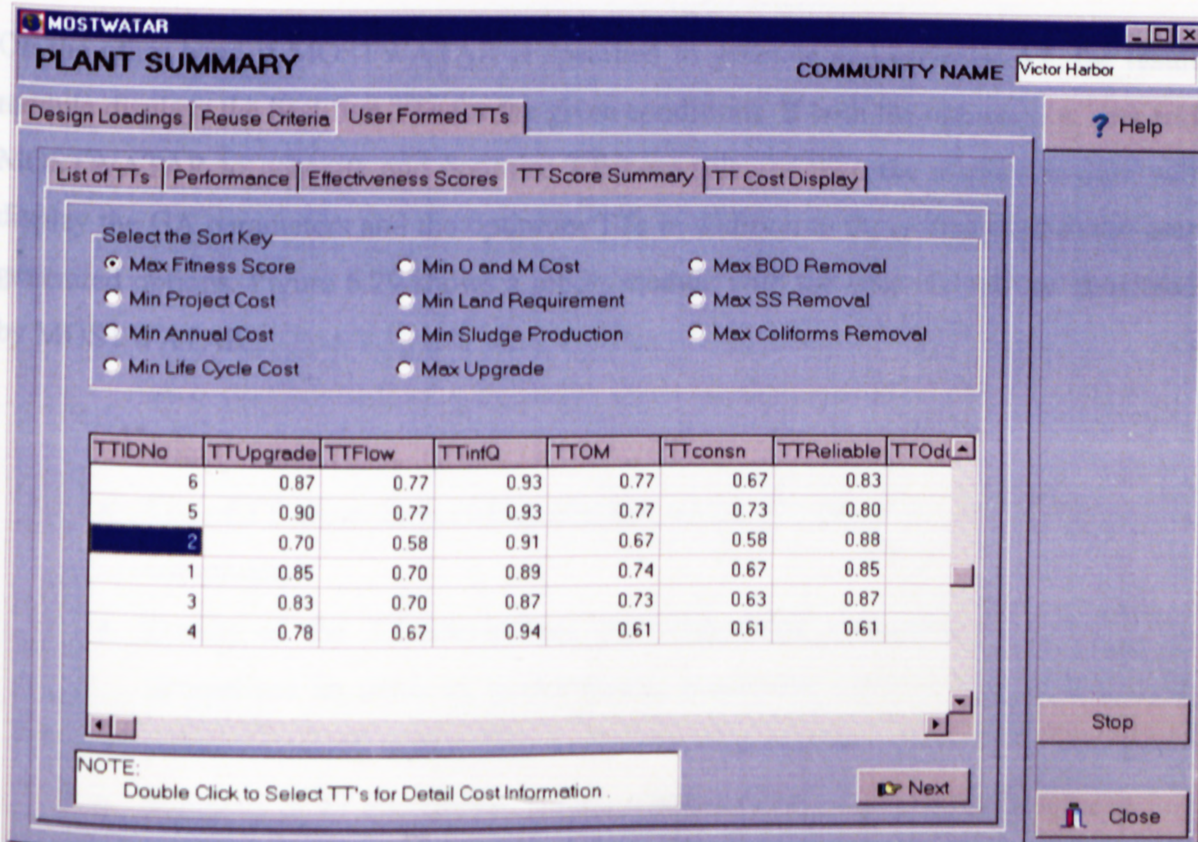


Figure 6.27 Results Module Showing TT Score Summary

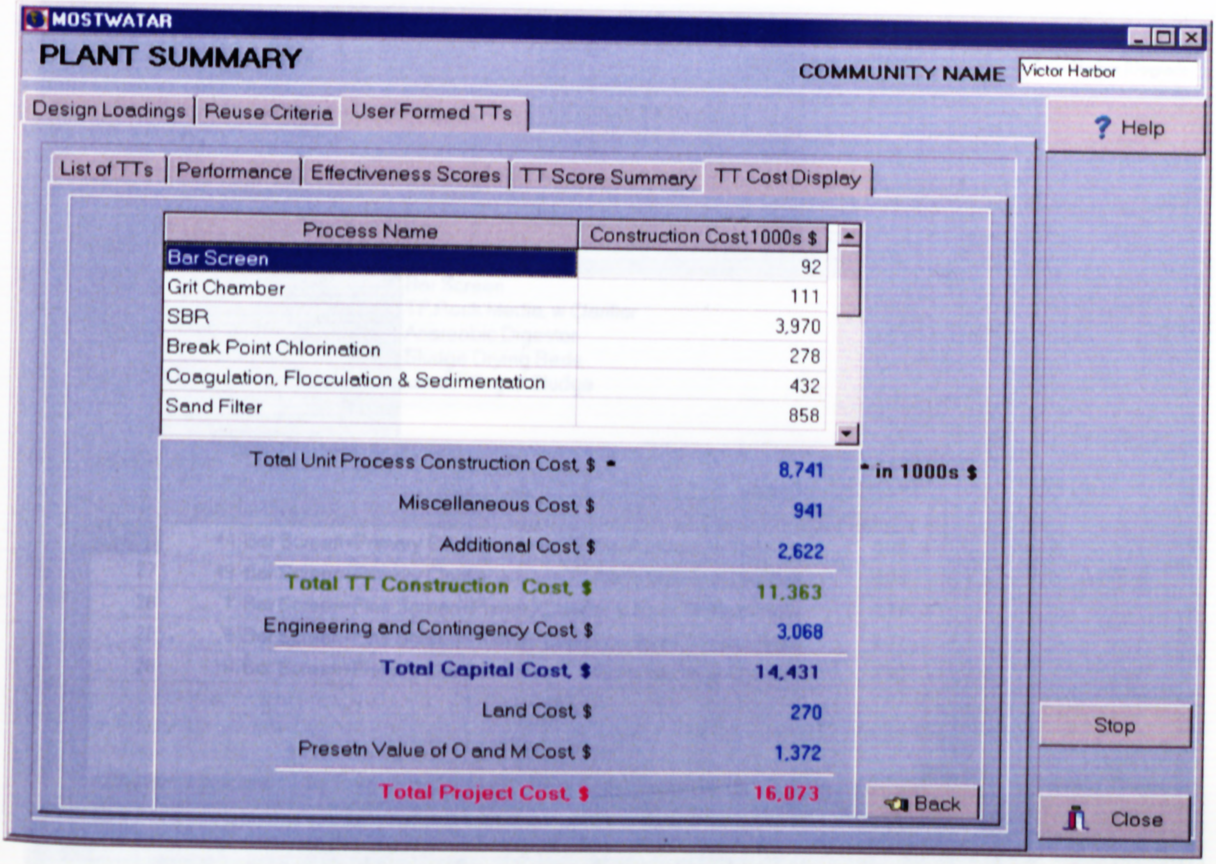


Figure 6.28 Result Module Showing Total Project Cost for a TT

On the other hand if MOSTWATAR is specified to generate and optimise TT, the result module displays the best five TTs for the given conditions. If both the options (i.e. user and MOSTWATAR to generate and optimise TTs) are selected then the display module will display the GA parameters and the optimum TTs in addition to those displayed in the user generated options. Figure 6.29 shows a report module with the upgrade options generated by MOSTWATAR.

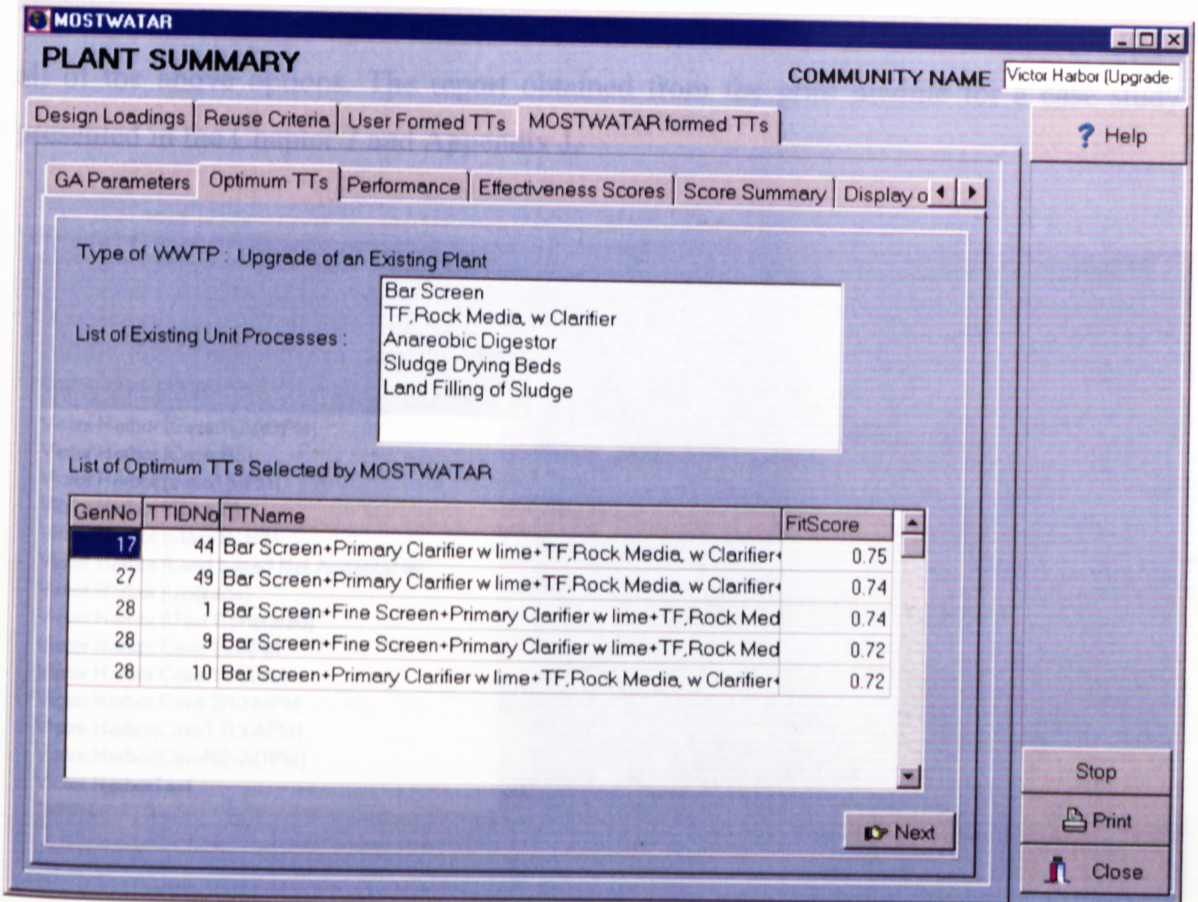


Figure 6.29 Result Module Showing Upgrade Options

6.4.8.1 Print Module

The user can print the details of the evaluation from MOSTWATAR using the "Print" button. The click of this print button displays a dialog box with the following 5 print options as shown in Figure 6.30.

- Community data (which displays important community input information such as design population, wastewater characteristics, desired reuse and criteria so on).
- List of TT alternatives (which displays all the TTs generated by the user for that community).
- Details of the TT alternatives (includes detail evaluation of each of the alternatives in terms of performance, qualitative criteria, cost of each unit processes present in that TT).
- Summary of TT alternatives (which summarizes all of the above information)
- All of the above.

The user can decide to print one or more of the options displayed above or decide to print all of the above options. The report obtained from the print module for a case study is presented in the Chapter 7 and Appendix J.

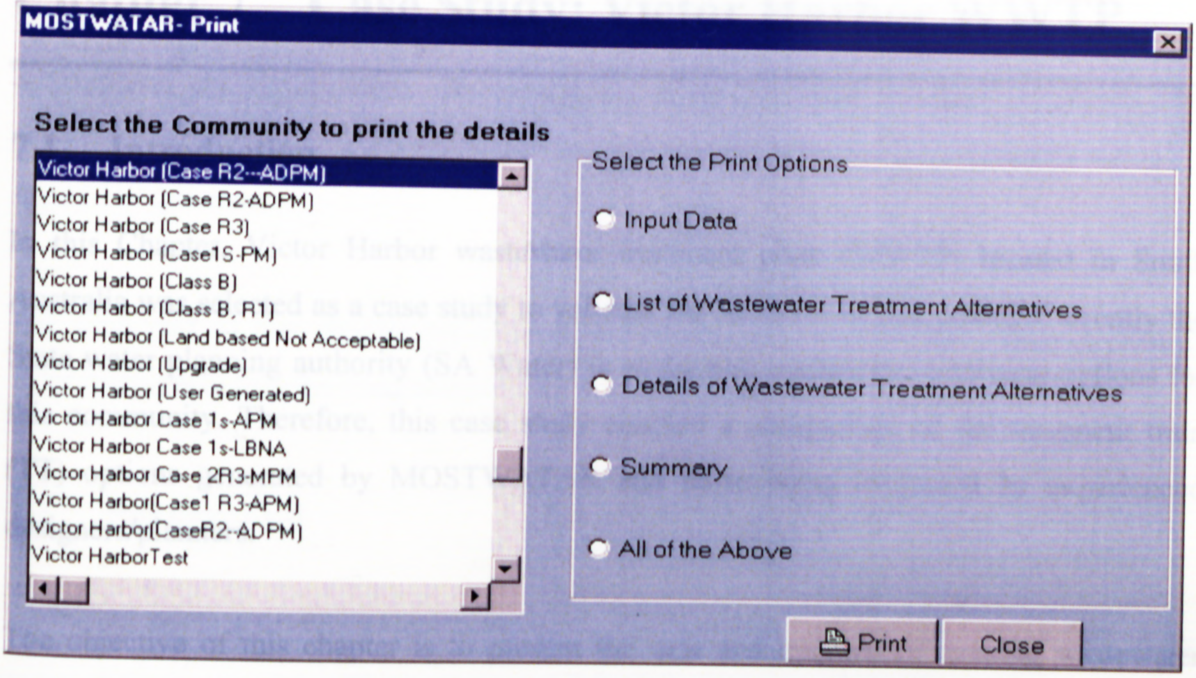


Figure 6.30 Print Dialog box in the Results Module

6.5 Summary

This chapter describes the salient features of MOSTWATAR model and explains how the user can enter community specific data using user-friendly interfaces. This chapter discusses various modules that have been developed to gather information regarding community, desired reuse and for the formation & evaluation of treatment trains. This chapter also describes how the GA has been incorporated into the model and steps involved in the generation and optimisation module. Finally, a print module was described to show how the user could print the results form the MOSTWATAR model.

In the next chapter a case study is presented to demonstrate how this model can be used to evaluate TT options while the conclusions drawn from this research are presented in Chapter 8.

Chapter 7 Case Study: Victor Harbor WWTP

7.1 Introduction

In this Chapter, Victor Harbor wastewater treatment plant (WWTP) located in South Australia was selected as a case study to validate the MOSTWATAR model. Currently the State water planning authority (SA Water) is evaluating wastewater treatment options for this community. Therefore, this case study enabled a comparison of the treatment train (TT) options generated by MOSTWATAR and those being evaluated by experienced designers/planners.

The objective of this chapter is to present the new and upgrade of existing wastewater treatment plant options evaluated for Victor Harbor. This chapter is divided in to four main parts. The first part deals with the background studies conducted since 1992 on Victor Harbor to evaluate treatment and reuse options. A summary of the short listed options by SA Water is presented in Section 7.2.1.

The second part focuses on the evaluation of new WWTP options and presents results and discussion based on this evaluation. This part begins with the design population, wastewater characteristics and reuse options assumed for the evaluation. This is followed by the input data used for Victor Harbor case study and the treatment options generated by the user and MOSTWATAR. Next, a comparative study of the options generated by the user, the MOSTWATAR model and those being evaluated by SA Water is presented. Results from a sensitivity analysis of relative weights for various selection criteria and GA parameters such as the probabilities of mutation (P_m), crossover (P_c) and treatment train selection (P_s) are also presented. Finally, comparative studies and a discussion on different penalty calculation methods are presented.

The third part presents the upgrade options for the wastewater treatment plant (WWTP) at Victor Harbor. Currently SA Water is evaluating new TT options for Victor Harbor. However, a hypothetical case where existing plant would be upgraded to meet Class A reuse quality was considered to demonstrate the methodology developed for upgrade of treatment plants. This part begins with the input data used in the evaluation of upgrade options and the assumptions used. First the user generated and the MOSTWATAR generated options are presented. Then a discussion is presented on how the methodology is applied to this case.

The final part of this chapter presents the comparison of the algorithm developed with other methods before drawing conclusions from this case study in Section 7.5.

7.2 Background

Victor Harbor is a popular tourist spot, located 80 km south of Adelaide (Australia) on the coast of Encounter Bay (Figure 7.1). In 1972, Victor Harbor WWTP was commissioned with a design capacity of 8,000 equivalent population (EP) to serve the township of Victor Harbor and an adjoining area of Port Elliot and Goolwa.

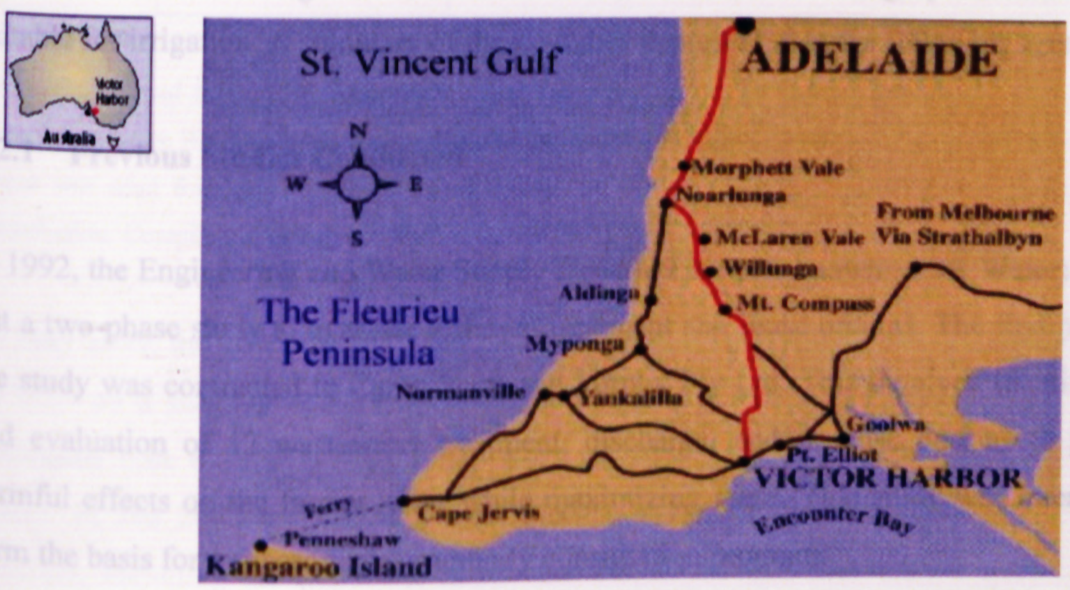


Figure 7.1 Map of Victor Harbor

The existing WWTP is spread over 37 ha of land and consists of the treatment processes shown in Figure 7.2.

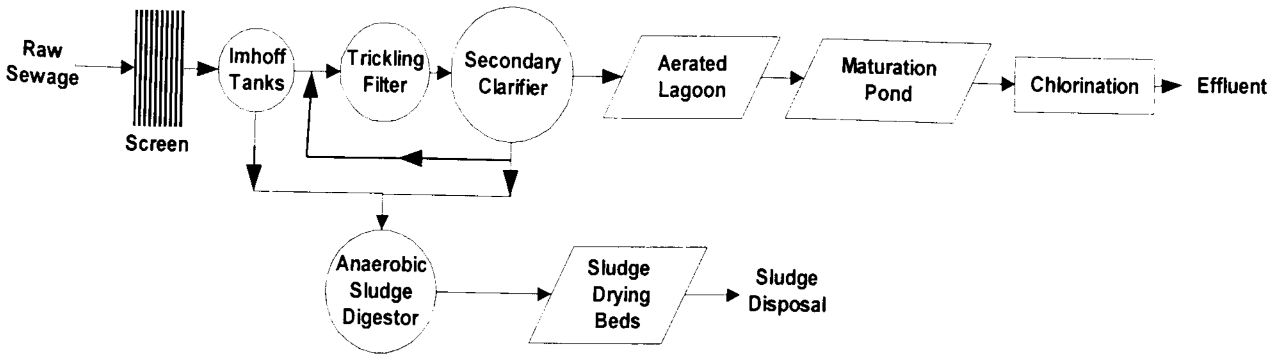


Figure 7.2 Existing WWTP at Victor Harbor

Currently, about 90 % of treated effluent is being discharged into the Inman River while the rest is reused for golf course irrigation. It has a year round population of 8,400 residents which rises to as high as 17,000 (EP) with day trippers and overnight tourists in the summer months due to its relatively mild, maritime climate. As a result of this increase in population, the existing WWTP is overloaded and the nutrient load in the effluent discharge to the Inman River is causing algal blooms. Since 1992, SA Water has conducted a number of studies through various consultants to evaluate treatment and reuse options. The main objective of these studies was to protect the Inman River and provide an alternative source of irrigation water as the Inman River water is highly saline and is not suitable for irrigation. A summary of these studies is presented in the following section.

7.2.1 Previous Studies Conducted

In 1992, the Engineering and Water Supply Department (now known as SA Water) carried out a two-phase study to evaluate different treatment and reuse options. The first phase of the study was contracted to Camp Scott and Furphy Pty Ltd. This involved identification and evaluation of 12 wastewater treatment, discharge, and/or reuse options to prevent harmful effects on the Inman River while maximizing reuse. This study was intended to form the basis for a subsequent community consultation program.

In 1997, SA Water contracted the second phase of the wastewater management options study to Egis Consulting Australia (ECA). In the second phase 4 options were short listed using multi-criteria analysis in consultation with community and representatives from SA

Water and they are given in Table 7.1. This Table also shows different treatment processes considered for these options.

Table 7.1 Different Options Considered for a New WWTP at Victor Harbor

Different Options	Description	Wastewater Treatment Level*	Treatment Processes**	Total Project Cost (NPV) 1000s $	Ranking
Option BC	Base Case- Winter discharge and summer reuse and WWTP located at remote site	B	BNR[1], SF, UV[2], MP[3], Sludge Lagoons	43,600	3
Option RC	Reference case- winter discharge and summer reuse, WWTP at existing site	B	BNR, SF, UV, MP, Lime stabilization of sludge	29,400	1
Option RU	Maximum reuse, WWTP at remote site	A	BNR, SF, UV, MP, Sludge Lagoons	43,700	4
Option RD	Wetlands with 100 % river discharge	B^+(TP <0.25 mg/L)	BNR, SF,UV, Wetlands, Sludge Lagoons	35,800	2

(*Wastewater treatment level based on SA Reclaimed water guidelines (1999), **BNR- biological nutrient removal, SF-Sand filter, UV- ultra violet disinfection, MP- maturation pond, [1] 5 stage BarDenPho process except for Option RU where it is 3 stage BarDenPho process, [2] chlorine added for all options where reclaimed water was used for Class B reuse, [3] maturation pond used for reclaimed water storage and as well as disinfection. Compiled from Egis Consulting Australia, 2001, pp. ii, 101-102,)

In May 1999, the Government of South Australia gave an endorsement to construct a new WWTP on a site remote from the town (3.5 km away from the existing WWTP) at an estimated cost of $20 million (http://www.sawater.sa.gov.au/ About_SA_Water /index. html). In Jan 2000, ECA carried out a concept design for different proprietary BNR reactors, including the immersed membrane bioreactor. The following treatment option was evaluated: *Bar screen + grit chamber + BNR+ coagulation & flocculation using alum + dual media filter + UV disinfection + gravity thickener + sludge lagoons + sludge drying beds.*

7.3 Evaluation of New WWTP Options

In this section the validation study carried out to evaluate the wastewater treatment options using the MOSTWATAR model is discussed. This section is divided in to three main sub sections. In Section 7.3.1 the input data used for both the user and MOSTWATAR generated options is presented. The user generated TT options and the assessment of these alternatives by the MOSTWATAR model is presented in Section 7.3.2. While in Section 7.3.3 the alternatives generated and optimised by the genetic algorithm are described. The detailed output from the model is presented in Appendix J while the summary is presented in Sections 7.3.3.3 to 7.3.3.5. Further, the comparison between the user and MOSTWATAR generated options is presented in Section 7.3.4.

7.3.1 Input Data for Evaluation of New WWTP Options

In this section, the input data used to evaluate treatment options for the Victor Harbor plant is presented. Firstly, the design population, wastewater characteristics and reuse criteria values used for the case study are discussed. Next, the input data used in MOSTWATAR is presented. These values are based on the previous studies conducted by consultants to SA Water (ECA, 2001).

7.3.1.1 Design Population and Influent Characteristics for the New WWTP

The new wastewater treatment plant at Victor Harbor is to be undertaken in two stages. It is envisaged that the first stage will be designed for 17,000 equivalent population (EP) will be covered in the first stage while 25,500 EP will be covered in the second stage. The design population and influent wastewater characteristics adopted for the current study are given in Table 7.2.

Table 7.2 Design Data for Victor Harbor WWTP

Description	Stage 1	Stage 2	Class B*	Class B^+
Design Year	2009	2023	-	-
Equivalent Population (EP)	17,000	25,500	-	-
Per capita wastewater generation, lpcd	200	200	-	-
Average annual flow, Q_{av} m^3/d	3,400	5,100	-	-
Average dry weather flow, Q_{avdwf} m^3/d #	2,900	4,300	-	-
Peak wet weather flow, Q_{ph} m^3/d #	10,200	15,300	-	-
BOD, mg/L	250	-	20	20
SS, mg/L	300	-	30	30
TN, mg/L	65	-	-	5**
TP, mg/L	12	-	-	0.5**
FC, No/100mL	10^6	-	100	100

(* Class B guidelines of SA Reclaimed Water Guidelines (1999) specifies values for BOD, SS and FC while TN, TP values are to be determined for the site conditions. In this study, Class B^+ is used to refer to guidelines where TN and TP values have been specified in addition to the Class B guidelines, **Designated values from ECA 2001, # $Q_{avdwf} = 0.85 \times Q_{av}$; $Q_{ph} = 3 \times Q_{av}$).

7.3.1.2 Reuse Options and Criteria for the New WWTP

In Jan 2000, Scholefield Robinson Horticultural Services Pty Ltd (SRH) carried out a detailed investigation into reclaimed water demand in the Victor Harbor area for SA Water. Potential demands for eucalyptus woodlot irrigation (756 ML/yr), pasture/lucerne irrigation (528 ML/yr), grass & turf irrigation water (356 ML/yr) and vineyards (776 ML/yr) were identified (ECA, 2001).

Currently Victor Harbor golf course is using reclaimed wastewater for irrigation. However, reduction in nitrogen levels and odour has been recommended to overcome excessive growth of grass and discomfort to golfers. Reduction in nitrogen is envisaged in the new treated effluent criteria as shown in Table 7.2. Since the reuse applications identified by the SRH study required reclaimed water of quality ranging from Class B^+ to Class D, the MOSTWATAR model selected the Class B^+ quality as it has the most stringent criteria (based on FC). Therefore the proposed treatment facility was designed to treat wastewater to Class B^+ quality. The complete user input data used for this case study is presented in Table 7.3 (a to c).

Table 7.3a Input Data for Victor Harbor

Module	Name of the Variable	Input Values
Community Data	*Community Profile* Name of the community	Victor Harbor
	Council Name	-
	Planning Authority	SA Water
	Location of the community	Country region
	State	SA
	Country	Australia
	Entered by	M. Stevens
	Nature of Site Land available for WWTP construction, ha	120
	Depth of water table below ground level, m	6
	Type of Soil	Fine sand to loamy soil
	Av monthly precipitation, mm/month	50
	Av monthly evaporation rate, mm/month	42
	Av daily min temperature, C	8
	Av daily max temperature, C	24.3
	Type of WWTP plant New Upgrade of existing Plant	New -
	Wastewater Flow Initial project year	2001
	Initial project population	8,400*
	Design period, yrs	25
	Estimated design population	17,000
	Per capita wastewater generation, lpcd	200
	Peaking Factors Relative to Average Flow: Peak monthly	1.2
	Peak daily	2.4
	Peak hourly	3.0
	Wastewater Characteristics *Peaking Factors Relative to Average Organic Loading:* Peak monthly	1.4
	Peak daily	2.8

Table 7.3b Input Data for Victor Harbor (Contd.)

Module	Name of the Variable	Input Values
Community Data	*Community Cost Data* Cost of land, $ per ha - Country region	10,000
	Sludge landfill tipping fee, $/ tonne	20
	Discount rate, % per yr	8
	Exchange rate (US $/A$)	0.5089
	Site works cost, % of total unit process construction cost for landscaping, drainage, roads	5
	Site electrical, % of total unit process construction cost for connection and power supply)	8
	Plant piping, % of total unit process construction cost for inter process piping	10
	Site development works, % of total unit process construction cost for excavation, pipe laying and base preparation	7
	Controls and instrumentation, % of total unit process construction cost for process controls, flow meters, SCADA systems	5
	Engineering cost, % of total WWTP construction cost for design and project management	12
	Contingencies, % of total WWTP construction cost for overheads and contingencies	12
	Cost calculation method to be used for Ranking	Total project cost
Reuse Criteria	*Type of reuse(s) desired*	Irrigation of turf; irrigation of pasture & fodder for diary animals; silviculture /non food crop irrigation; irrigation of non processed food crop; irrigation of golf course with unrestricted access
	Name of the guideline selected	SA Reclaimed Water Guidelines

Table 7.3c Input Data for Victor Harbor (Contd.)

Module	Name of the Variable	Input Values
Reuse Criteria	*Guideline Values* BOD, mg/L	20
	SS, mg/L	30
	FC, No/100mL	100
	TN, mg/L	5
	TP, mg/L	0.5
Form TT	*Specify TT* User MOSTWATAR Both of the above options	Both
Selection Criteria	*Relative weights assigned by user:*** Adaptability to upgrade	8
	Adaptability to varying flow rate	4
	Adaptability to varying influent quality	7
	Ease of O & M	5
	Ease of construction	3
	Reliability	9
	Odour generation potential	6
	Land requirement	5
	Sludge production	8
	Impact on ground water	3
	Power requirement	2
	Chemical requirement	5
	Total project cost	2
Optimise TT	*GA Parameters*** Population size, n	100
	Tournament size, ts	2
	Probability of crossover, P_c	0.8
	Probability of mutation, P_m	0.2
	Selection pressure, P_s	0.6
	Maximum number of generations	100

(*Source: SCH report, 2000, ** these parameter values are further varied)

The values in Table 7.3 (a, b & c) were input into the model using the user interfaces discussed in Chapter 6. The weights for the selection criteria and the GA parameters were varied in a sensitivity analysis, which is discussed in Sections 7.3.2.2(i) and 7.3.3.1. In addition to the above, an analysis was carried out to evaluate how much the TT options will vary for different classes of reuse such as Class B, Class B^+ and for guidelines specified by different state authorities. The results of this analysis are discussed in Section 7.3.2.2 (iii).

7.3.2 User Generated Options

As stated earlier, SA Water is investigating many treatment options for Victor Harbor. Based on these investigations, the treatment options listed in Table 7.1 (consisting of unit processes available in the MOSTWATAR database) were selected by the user as input to the model. These options were first evaluated in terms of performance and then fitness scores based on the criteria weights assigned were calculated.

Since one of the objectives of the case study was to compare different TT options generated by different methods (i.e. user and MOSTWATAR option) and those from different penalty techniques it was necessary to have the same scaling for objective function. For this case study, several test runs were carried out in order to determine the maximum and minimum values for scaling different criteria such as total project cost, land required and sludge produced as explained in Section 5.4.5.1(ii). These maximum and minimum values are listed in Table 7.4.

Table 7.4 Maximum and Minimum Values Used for Scaling

Type of criterion	Maximum Value	Minimum Value
Total Project Cost, 1000s $	40,000	2,000
Land Required, ha	40	0.1
Sludge Produced, kg/d	5000	0*

(*value of '0' is assumed as the minimum value as for TTs in which land based treatment systems are present the sludge is not removed every day but is instead desludged once every 3 to 5 years)

7.3.2.1 Output for User Generated Options

In MOSTWATAR, the report generated by the results module is divided in to 4 main sections namely (1) community data, (2) list of TT alternatives, (3) details of TT alternatives generated and (4) summary of the TT evaluation as described in Section 6.4.8.1. The result sheets obtained from MOSTWATAR for user-generated options using the input parameters for Victor Harbor (listed in Tables 7.2 and 7.3 a to c) are presented in the following Tables (7.5 to 7.8).

In Table 7.5, the report showing the input data such as design population and wastewater characteristics used for the case study is presented. While in Table 7.6, the report showing the user generated TTs with their fitness scores is presented. In the case of feasible TTs such as TT1, TT2, TT5 and TT6, fitness scores ranges from 0 to 1. Higher scores indicate a better treatment option. While infeasible TTs (i.e. those not meeting the reuse criteria or maximum allowable influent quality and or rules) such as TT3 and TT4 have negative scores.

The details of one of the TT alternatives namely TT1 is presented in Table 7.7 to illustrate the output sheet for 'details of TT alternatives' while the details for the remaining TTs is presented in Appendix J (See Tables J.1 to J.5a). The construction cost estimates for TT1 is summarized in the result sheet as shown in Table 7.7a. The summary report generated by the MOSTWATAR using default values for relative weights and removal efficiency is presented in Table 7.8. This Table presents the final effluent quality achieved by each of the user-generated TT options and how they compare with the reuse criteria selected by the user. The qualitative criteria scores, land required and sludge produced by each of the TTs are also presented in this Table.

Table 7.5 Report Showing Community Data Used for Victor Harbor WWTP

Printed on 18/03/2002

Community Data

Name of the Community	Victor Harbor (User Generated, Class B+)
Planning Authority	SA Water Corporation
State	SA, Country Australia
Entered By	M.Stevens

Design Information

Design Population	17000
Per Capita Wastewater Generation,lpcd	200
Average Annual Flow, m3/d	3400(3.40)*
Dry Weather Flow, m3/d	2890(2.89)
Peak Monthly Flow, m3/d	4080(4.08)
Peak Daily Flow, m3/d	8160(8.16)
Peak Wet Weather Flow, m3/d	10200(10.20)

* Note: The figures inside the brackets indicate flow in million litres per day, ML/d

Type of Wastewater Treatment Plant: New Plant

	BOD,mg/L	SS,mg/L	NH3-N,mg/L	ON,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Influent Wastewater Characteristics:	250	300	48	17	65	12	1000000	50

Peak Daily Organic Loading

BOD, kg/d	2380
SS, kg/d	2856
TN, kg/d	619
TP, kg/d	114

Desired Reuse Application(s)

Irrigation of Turf
Irrigation of Pasture and Fodder for Grazing Animals
Irrigation of Golf Course with Restricted Access
Silviculture /Non Food Crop Irrigation
Irrigation of Processed Food Crops ("Not in Direct" Contact)

Selected Reuse Guideline SA Reclaimed Water Guidelines, April 1999

Relative Weights Assigned for Different Selection Criteria:

Adaptability to Upgrade:	8	Odour Generation Potential:	6	Reliability:	9
Adaptability to Varying Flow Rate:	4	Land Requirement:	5	Chemical Requirement:	5
Adaptability to Varying Influent Quality:	7	Sludge Production:	8	Ease of O & M:	5
Ease of Construction:	3	Power Requirement:	2	Impact on Ground Water:	3
Total Project Cost:	2*				

(*This indicates that Total Project Cost is 2 times more important than the sum of all other criteria)

Table 7.6 List of TT Alternatives Generated by the User

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

Wastewater Treatment Alternatives Generated by: M.Stevens

TTIDNo	TTName	Treatment Processes	Fitness Score
1	TT1	Bar Screen+Grit Chamber+Primary Clarifier+Continuous Flow BNR+Coagulation, Flocculation & Sedimentation+Sand Filter+UV Disinfection+Gravity Thickener+Sludge Drying Beds+Land Spreading of Sludge	0.742
2	TT2	Bar Screen+Primary Clarifier w lime+Continuous Flow BNR+Coagulation & Flocculation+Dual Media Filter+UV Disinfection+Post Chlorination+Gravity Thickener+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge	0.731
3	TT3	Bar Screen+Primary Clarifier+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Sand Filter+UV Disinfection+Gravity Thickener+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge	-28.383
4	TT4	Bar Screen+Aerated lagoon+Sedimentation Pond+FWS Wetland (BOD & Ni)+Maturation Pond+Post Chlorination	-280.851
5	TT5	Bar Screen+SBR+Break Point Chlorination+Coagulation, Flocculation & Sedimentation+Sand Filter+UV Disinfection+Gravity Thickener+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge	0.567
6	TT6	Bar Screen+Grit Chamber+Primary Clarifier+Continuous Flow BNR+Single Stage Lime Treatment+Dual Media Filter+UV Disinfection+Gravity Thickener+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge	0.718

Table 7.7 Details of the User Generated TT Option -1

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

TT OPTION-1:TT1

Treatment Train: Bar Screen+Grit Chamber+Primary Clarifier+Continuous Flow BNR+Coagulation, Flocculation & Sedimentation+Sand Filter+UV Disinfection+Gravity Thickener+Sludge Drying Beds+Land Spreading of Sludge

Desired Reuse(s):
Irrigation of Turf
Irrigation of Pasture and Fodder for Grazing Animals
Irrigation of Golf Course with Restricted Access
Silviculture /Non Food Crop Irrigation
Irrigation of Processed Food Crops ("Not in Direct" Contact)

Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	30	5	0.5	100	-
Effluent Quality Achieved:	3.1	1.5	3.7	0.3	4.5	1.0
Meets Criteria (Yes/No): YES						

Effectiveness Measures

Upgrade:	0.80
Varying flow rate:	0.73
Varying influent quality:	0.90
Ease of O & M:	0.77
Ease of construction:	0.63
Reliability:	0.87
Odour:	0.33
Ground water impact:	0.80
Chemical requirement:	0.87
Power requirement:	0.47

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	1.68
Sludge produced,kg/day:	2331

Table 7.7a Construction Cost Estimate for TT Option 1

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

Summary of Construction Cost Estimate for TT Option-1:TT1

Item	Construction Cost 1000s $
Bar Screen	$106
Grit Chamber	$128
Primary Clarifier	$344
Continuous Flow BNR	$830
Coagulation, Flocculation & Sedimentation	$495
Sand Filter	$983
UV Disinfection	$142
Gravity Thickener	$390
Sludge Drying Beds	$147
Land Spreading of Sludge	$131
Miscellaneous Cost*	$530
Total Unit Process Construction Cost	**$4,226**
Additional Cost**	$1,268
Total Construction Cost for WWTP	**$5,494**
Engineering and Contingency Cost	$1,483
Total Capital Cost	**$6,977**
Total Land Cost	$267
PV O & M Cost	$3,730
Total Project Cost	**$10,974**
Annualised Project Cost* **	**$1,028**
Life Cycle Cost******	**$0.83**

*Miscellaneous cost includes: Cost for raw sewage pumping, rising main and sludge pumping station
**Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
1000s $/yr , * Life cycle cost is expressed as $/m3 of reclaimed water

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*Miscellaneous cost includes: Cost for raw sewage pumping, rising main and sludge pumping station
**Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
1000s $/yr , * Life cycle cost is expressed as $/m3 of reclaimed water

Table 7.8 Summary of TT Options Generated by the User

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

Design Population:17000

Design Average Flow,m3/d:3400

Design Peak Flow,m3/d:10200

Summary of Evaluation of Wastewater Treatment Alternatives

Items	R.Criteria	TT1	TT2	TT6	TT5	TT3	TT4
BOD,mg/L	20	3.1	5.3	1.1	6.6	3.1	0.8
SS,mg/L	30	1.5	4.0	1.2	2.9	1.9	0.5
TN,mg/L	5.0	3.7	4.6	4.2	2.0	4.6	5.8
TP,mg/L	0.5	0.3	0.2	0.1	0.4	0.6	6.0
FC,No/100mL	100	4.5	0.0	0.2	1.8	1.9	0.0
Turbidity,NTU	-	1.0	0.1	0.4	1.5	1.0	0.5
Meets R.criteria (Yes/No)		YES	YES	YES	YES	NO	NO
Upgrade		0.80	0.70	0.79	0.83	0.87	0.78
Varying flow rate		0.73	0.58	0.70	0.73	0.77	0.72
Varying influent quality		0.90	0.91	0.94	0.90	0.87	0.94
Ease of O & M		0.77	0.67	0.73	0.77	0.77	0.61
Ease of construction		0.63	0.58	0.61	0.73	0.63	0.67
Reliability		0.87	0.88	0.88	0.80	0.83	0.67
Odour		0.33	0.39	0.33	0.33	0.37	0.28
Ground water impact		0.80	0.82	0.82	0.80	0.80	0.33
Chemical requirement		0.87	0.73	0.88	0.77	0.87	0.89
Power requirement		0.47	0.39	0.45	0.43	0.50	0.50
Total land required, ha		1.68	1.87	1.79	1.50	1.74	36.97
Total sludge produced,kg/d		2331	622	827	1707	1009	--*
Total capital cost**		$6,977	$6,934	$7,398	$13,370	$11,980	$8,413
Total land cost**		$267	$269	$268	$265	$267	$620
PV O & M cost**		$3,730	$5,077	$5,845	$7,663	$6,741	$5,906
Total project cost**		**$10,974**	**$12,279**	**$13,510**	**$21,298**	**$18,989**	**$14,938**
Annualised project cost***		**$1,028**	**$1,150**	**$1,266**	**$1,995**	**$1,779**	**$1,399**
Life cycle cost****		**$0.83**	**$0.93**	**$1.02**	**$1.61**	**$1.43**	**$1.13**
Fitness score		**0.742**	**0.731**	**0.718**	**0.567**	**-28.383**	**-280.851**

NOTE: Alternatives sorted by :Max Fitness Score. Fitness score scaled from 0 to 1, a negative score indicates an infeasible treatment train.
* Sludge produced is removed once in 3 to 5 years, sludge handling cost is accounted in O & M Cost; **1000s $, *** 1000s $/yr,**** $/m3.

As shown in Table 7.8, TT1 was selected as the best TT as it had higher criteria scores than the next best TT i.e. TT2. Further TT1 had the lowest total project cost out of the 6 TTs generated by the user. The sludge produced by TT4 (which has land based treatment systems such as lagoons and wetlands) is indicated as '--', as the sludge produced is removed once in 5 years or more as against daily wasting of sludge in other TTs. The sludge handling costs is accounted for in the annual O & M cost as detailed in the cost data sheets in Appendix F.

Furthermore, the total capital cost, land cost and present value of O & M cost is also displayed. As indicated in Section 4.5.5.5, all the three types of costs namely total project cost, annualized project cost and life cycle cost are displayed. While the cost calculation method selected by the user (i.e. total project cost) is used for fitness score calculations and ranking. As a default TTs are sorted by their fitness score. However, the user can sort the TTs in terms of maximum BOD removal, maximum FC removal and so on as indicated in Table 4.16.

7.3.2.2 Sensitivity Analysis

Sensitivity analysis was performed for the following parameters: (1) relative weights for selection criteria, (2) removal efficiency of unit processes and (3) reuse guidelines. The results are discussed below.

7.3.2.2 (i). Relative Weights

The user can vary the relative weights assigned for one or more of the selection criteria. This is carried out in order to indicate the user's preference for a selection criterion and to analyse their effect on the fitness of the TT options. Further the user can also select '0' weight for one or more criteria to indicate that they are not important in the evaluation. As a first step, a sensitivity analysis for cost was carried out by varying the weights for cost from 0 to 10 while the weights for all other criteria were kept constant. The results from this sensitivity analysis are given in Table 7.9.

Table 7.9 Sensitivity Analysis for Cost

Ranking	Relative Weight for Cost (Wc)			
	Default Case: Wc = 2	**Case 1:** Wc = 0	**Case 2:** Wc = 1	**Case 3:** Wc = 10
Decreasing fitness score	**TT1** (0.742)*	**TT6** (0.760)	**TT1** (0.732)	**TT1** (0.758)
	TT2 (0.731)	**TT2** (0.733)	**TT6** (0.731)	**TT2** (0.730)
	TT6 (0.718)	**TT5** (0.716)	**TT2** (0.729)	**TT6** (0.703)
	TT5 (0.567)	**TT1** (0.699)	**TT5** (0.604)	**TT5** (0.513)
	TT3 (-28.383)	**TT3** (-28.245)	**TT3** (-28.349)	**TT3** (-28.433)
	TT4 (-280.851)	**TT4** (-280.847)	**TT4** (-280.850)	**TT4** (-280.853)

* Numbers within the brackets indicate fitness scores

As shown in Table 7.9, Case 1 represents zero '0' weight for cost. Although this is seldom true in practice, some planners would like to evaluate the TTs for all other criteria independent of cost. This case shows that such an evaluation is possible in MOSTWATAR. Due to change in the weight on cost as compared to default case, there is a change in the ranking of TTs. In this case, TT6 with a total project cost of $13.51 million was selected in preference to TT1 with the lowest total project cost $10.97 million (See Table 7.8). This is because the values of other criteria for TT6 are higher and the sludge production is lower compared to TT1 as shown in Table 7.8.

In Case 2, the weight for cost was set to '1' indicating that the cost is equally important as any other criteria combined. TT1 ($10.97 million) was selected as the best TT as it had higher criteria values and lowest cost. On the other hand in Case 3, the cost was considered 10 times more important than all other criteria and the TT with the lowest project cost ($10.97 million) namely TT1 was selected. For all the cases represented in Table 7.9, the default weights listed in Table 7.3c are used for all the other criteria.

Another set of analysis was carried out where relative weights for the most important criteria were varied while the weights for all the other criteria (listed in Table 7.3c) were set to zero '0'. This was carried out to identify the influence of most important criteria and to show their effect on ranking of the TTs. The results are given in Table 7.10.

Table 7.10 Relative Weights Used for Selected Criteria

Criteria	Relative Weights*						
	Default Values	Case 4: Wc = 1	Case 5 Ws = 2	Case 6: Wo = 2	Case 7: Wr = 10	Case 8: $W_L = 2$	Case 9: $W_U = 10$
Total project cost	2	**1**	2	2	2	2	2
Sludge production	8	8	**2**	8	8	8	8
Odour	6	6	6	**2**	6	6	6
Reliability	9	9	9	9	**10**	9	9
Land requirement	5	5	5	5	5	**2**	5
Adaptability to upgrade	8	8	8	8	8	8	**10**

(Note: *weights for all other criteria (listed in Table 7.3) have been set to zero '0', Wc = weight for total project cost, Ws = weight for sludge production, Wo = weight for odour, Wr = weight for reliability, W_L= weight for land requirement, W_U = weight for upgrade).

In Table 7.10, the figures in bold indicate changed weights of the criteria compared to the default values indicated in the 2nd column. In these analyses cost was considered equally important as compared to all other criteria put together and therefore a weight of '1' was used. A weight of '10' was used for reliability and upgrade to indicate that they are highly important in the selection and evaluation of TTs in the current study.

A weight of '2' was used for land requirement and odour, as in the current case study the proposed plant is to be located on a remote site with more than 120ha. Since most plants generated by the user requires land area between 1 and 40 ha, a weight of two was used to indicate that land requirement is not important in the current evaluation. Similarly a weight of '2' was used for sludge production to indicate that sludge production is not critical to current evaluation, as there is sufficient demand for biosolids utilization in the area. The results from this sensitivity analysis are presented in Table 7.11.

Case 4 is different from Case 1, 2 and 3 in that weight used for cost is '1' while all other criteria weights (apart from those given in Table 7.10) are set to zero '0'. In Case 4, TT2 is selected as the best TT of the 6 TTs generated by the user while it is the second best when weights of '0' and '10' were used (i.e. in Case 1 & 3 respectively).

Table 7.11 Sensitivity Analysis for Selected Criteria

Ran-king	Case4: Wc = 1	Case 5 Ws = 2	Case 6: Wo = 2	Case7: Wr = 10	Case8: $W_L = 2$	Case 9: $W_U = 10$
	TT2 (0.740)	**TT1** (0.748)	**TT2** (0.751)	**TT2** (0.738)	**TT2** (0.730)	**TT2** (0.736)
	TT6 (0.721)	**TT2** (0.734)	**TT6** (0.733)	**TT1** (0.723)	**TT1** (0.710)	**TT1** (0.724)
	TT1 (0.699)	**TT6** (0.715)	**TT1** (0.730)	**TT6** (0.714)	**TT6** (0.707)	**TT6** (0.714)
	TT5 (0.582)	**TT5** (0.568)	**TT5** (0.566)	**TT5** (0.553)	**TT5** (0.543)	**TT5** (0.555)
	TT3 (-28.357)	**TT3** (-28.383)	**TT3** (-28.373)	**TT3** (-28.388)	**TT3** (-28.395)	**TT3** (-28.386)
	TT4 (-280.874)	**TT4** (-280.893)	**TT4** (-280.853)	**TT4** (-280.867)	**TT4** (-280.851)	**TT4** (-280.864)

* Numbers within the brackets indicate fitness scores

In Case 5, the weight of '2' for sludge production resulted in TT1 as the best TT, which produces the highest sludge of 2331 kg/d. The next best TT in this case is TT2, with the lowest sludge production of 622 kg/d while TT6 has been selected as the 3rd best TT, which produces 827 kg/d.

In Case 6, TT2 has the least odour generation potential (0.39 i.e. qualitative score for odour) while TT4 has the highest odour generation potential (0.28). It is to be noted here that odour being a negative attribute, a higher calculated score indicates a lower odour generation potential (see Section 4.8.2.2 (i)). In Case 7, TT2 and TT6 had the highest reliability score of 0.88 while TT4 had the lowest reliability score of 0.67 among the 6 TTs. Although TT2 and TT6 had the same reliability score, TT2 was selected as the best by the model as it was a better TT mainly in terms of cost and sludge generation.

In Case 8, TT2 with a land requirement of 1.87 ha was selected the best as against TT5 with the lowest land requirement of 1.50 ha as the assigned weight for land was only 2. Finally, in Case 9 the weight for the adaptability to upgrade was set '10' in order to select the TTs with maximum adaptability to upgrade. Among the feasible TTs namely TT1, 2, 5 and 6; TT5 had the highest score for upgrade (0.83). However TT5 was not selected as the best TT because of higher cost and TT2 was found to be the best TT for these values of weights.

As shown in Table 7.11, the ranking of TTs does vary based on the relative weights assigned except for the ranking of TT5, TT3 and TT4. This is because the TT5 had the lowest score overall due to its high cost while TT3 and TT4 were infeasible as they did not meet the reuse criteria. This analysis has shown that the user can vary weights for different selection criteria and then decide the best 3 or 5 TTs to be used for pilot plant studies.

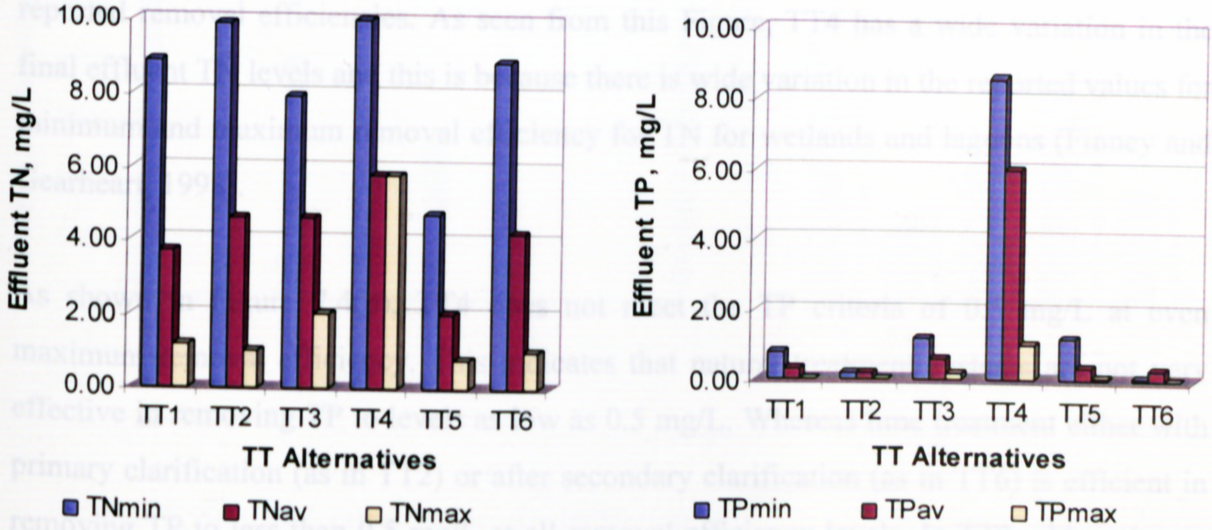
7.3.2.2 (ii). Removal Efficiency

As a default the TT options were evaluated based on average removal efficiencies. However, the user can select either minimum or maximum removal efficiencies to see the variation in the quality of the effluent produced in each of the TT options. The selection of minimum efficiency indicates to the user whether the plant can meet the reuse criteria set by the regulatory agency under one or more of the following conditions (1) when it is not operating efficiently due to poor operation, (2) malfunction of one or more of the treatment processes and or (3) due to wide variation in the influent wastewater quality. Since reliability of the plants is very important in reuse schemes, the variation in the removal efficiency can indicate its acceptability for a reuse scheme.

In addition to this variation in final quality due to different removal efficiencies selected, there is also a difference in the quantity of sludge produced, land required and, therefore, the cost. This is because the design of some of the unit processes such as lagoons and wetlands are based on the influent organic load and this load varies with the removal efficiency. The variation in the final effluent quality due to variations in removal efficiencies is shown in Figures 7.3 to 7.5.

The minimum, average and maximum effluent BOD (represented as BODmin, BODav, BODmax respectively) achievable by each of the TTs generated by the user is shown in Figure 7.3a. All the TTs meet the BOD criteria of 20 mg/L even at the lowest removal efficiencies. Further, TT4 and TT6 have relatively lower BOD effluent value compared to the rest of the TTs generated by the user.

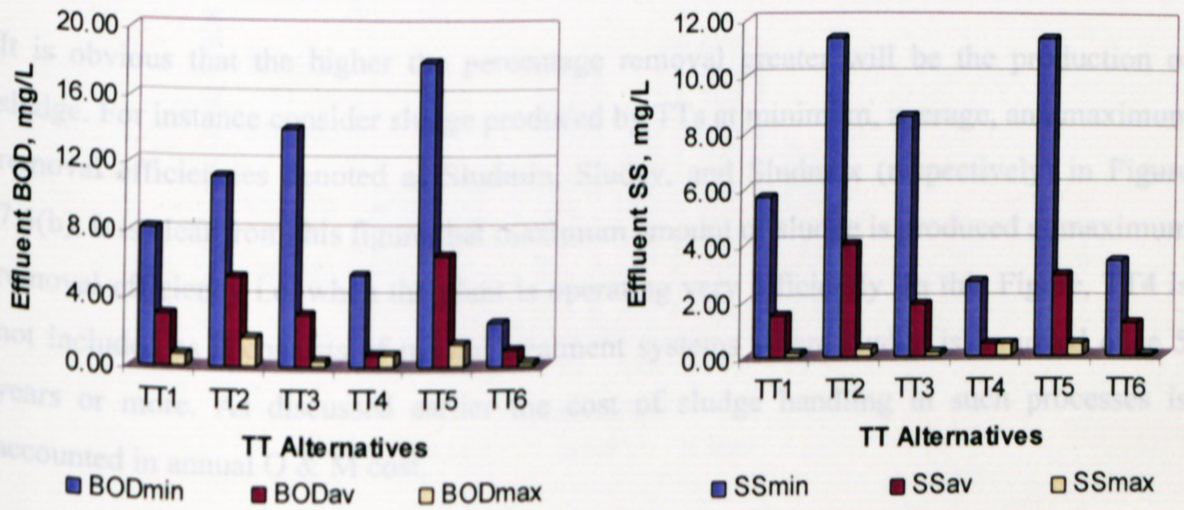
Similarly the minimum, average and maximum effluent quality achievable for parameters such as SS, TN, TP and FC in the user generated TTs are shown in Figures 7.3 (b) to 7.5. As is the case with effluent BOD, all the TTs generated by the user meets the SS criteria as shown in Figure 7.3(b). This Figure shows that TT4 is very efficient in removing SS.



(a) BOD mg/L (allowable level = 20 mg/L) (b) SS mg/L (allowable level = 30 mg/L)

Figure 7.3 Variation of BOD and SS based on Removal Efficiencies

However, many treatment plants with lagoons have very high algal growth in South Australia, resulting in higher SS and turbidity than what is reported in the literature and used in this study. Therefore due consideration to the increase in SS due to algal growths in the lagoons should be given during TT evaluation. Among thee 6 TTs, TT5 consisting of SBR and break point chlorination is efficient in removing TN to relatively lower level at all the three levels of removal efficiencies as shown in Figure 7.4(a).



(a) TN mg/L (allowable level = 5 mg/L) (b) TP mg/L (allowable level = 0.5 mg/L)

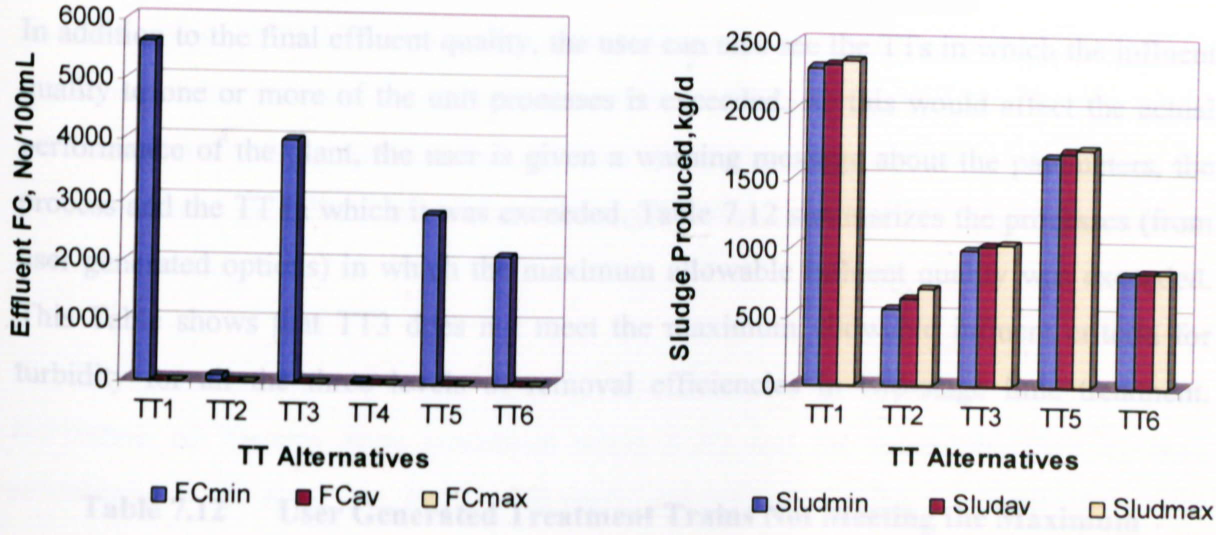
Figure 7.4 Variation of TN and TP based on Removal Efficiencies

In fact, TT5 is the only TT that achieves the standard in relation to TN for the lowest reported removal efficiencies. As seen from this Figure, TT4 has a wide variation in the final effluent TN levels and this is because there is wide variation in the reported values for minimum and maximum removal efficiency for TN for wetlands and lagoons (Finney and Gearheart, 1998).

As shown in Figure 7.4(b), TT4 does not meet the TP criteria of 0.5 mg/L at even maximum removal efficiency. This indicates that natural treatment systems are not very effective in removing TP to levels as low as 0.5 mg/L. Whereas lime treatment either with primary clarification (as in TT2) or after secondary clarification (as in TT6) is efficient in removing TP to less than 0.5 mg/L at all removal efficiency levels. In TT3, although two stage lime treatment was used with ASP w Ni, the TP levels at minimum removal efficiency was much higher compared to the TTs such as BNR and coagulation, flocculation & sedimentation (TT1) and BNR and single stage lime treatment (TT6).

Figure 7.5(a) shows the final effluent FC levels at minimum, average and maximum removal efficiency in TTs. As seen from this figure only TT2 and TT4 meet the FC criteria of 100 No/100mL at minimum removal efficiencies. Whereas all the TTs generated by the user meets FC criteria at average and maximum removal efficiencies. Therefore, it is essential that the reclamation plants are operating reasonably well to ensure the effluent FC meets the specified reuse criteria value.

It is obvious that the higher the percentage removal greater will be the production of sludge. For instance consider sludge produced by TTs at minimum, average, and maximum removal efficiencies denoted as Sludmin, Sludav, and Sludmax (respectively) in Figure 7.5(b). It is clear from this figure that maximum amount of sludge is produced at maximum removal efficiency i.e. when the plant is operating very efficiently. In this Figure, TT4 is not included as it consists of natural treatment systems where sludge is removed once 5 years or more. As discussed earlier the cost of sludge handling in such processes is accounted in annual O & M cost.



(a) FC No/100mL (allowable level = 100No/100mL) (b) Sludge produced, kg/d

Figure 7.5 Variation of FC and Sludge Produced based on Removal Efficiency

The Figure 7.6 shows that the total project cost for a TT depends on the desired removal efficiency. The removal efficiency affects the sizing of individual unit processes and consequently results in varying costs. This can be noted very clearly in the case of TT4, which reflects that minimum removal efficiency has the lowest project cost due to the least land requirement while for maximum removal efficiency the project cost is highest due to higher land requirement.

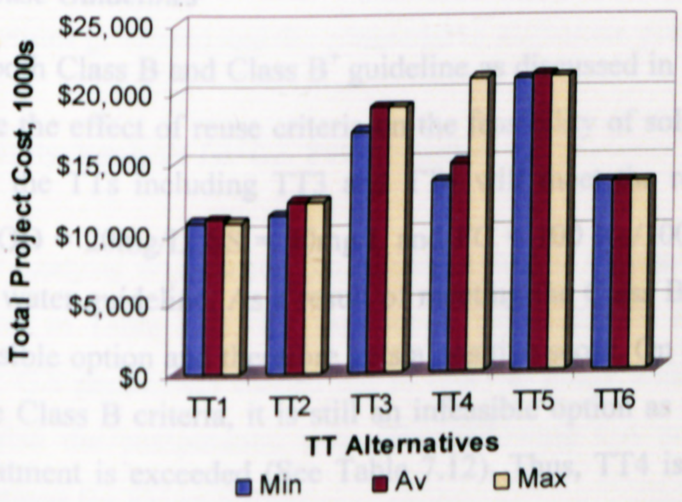


Figure 7.6 Total Project Cost Based on Removal Efficiency

In addition to the final effluent quality, the user can also see the TTs in which the influent quality to one or more of the unit processes is exceeded. As this would affect the actual performance of the plant, the user is given a warning message about the parameters, the process and the TT in which it was exceeded. Table 7.12 summarizes the processes (from user generated options) in which the maximum allowable influent quality was exceeded. This Table shows that TT3 does not meet the maximum allowable influent criteria for turbidity for all the three levels of removal efficiencies in two-stage lime treatment.

Table 7.12 User Generated Treatment Trains Not Meeting the Maximum Allowable Influent Quality

Type of Removal Efficiency	TT Name	Parameter	Name of the Process	Influent Value	Maximum Allowable Influent Value
Average	TT3	Turbidity, NTU	Two stage Lime Treatment	20.0	10
Maximum	TT3	Turbidity, NTU	Two stage Lime Treatment	12.5	10
Minimum	TT3	SS, mg/L	Two stage Lime Treatment	42.8	40
		Turbidity, NTU	Two stage Lime Treatment	25.0	10
	TT4	TN, mg/L	FWS (BOD +Ni)	41.6	40
	TT5	Turbidity, NTU	UV	6.0	5.0

7.3.2.2 (iii). Reuse Guidelines

In this study both Class B and Class B$^+$ guideline as discussed in Section 7.3.1.2 was used to demonstrate the effect of reuse criteria on the feasibility of solutions. As seen from the Table 7.8, all the TTs including TT3 and TT4 will meet the reuse criteria of Class B quality (i.e. BOD = 20mg/L, SS = 30mg/L and FC = 100 No/100mL) as specified by the SA reclaimed water guideline. As a result of meeting the Class B quality guidelines, TT4 becomes a feasible option and therefore gets a positive score. On the other hand, although TT3 meets the Class B criteria, it is still an infeasible option as turbidity levels for two-stage lime treatment is exceeded (See Table 7.12). Thus, TT4 is a feasible option when Class B criteria is selected while it is considered as an infeasible option if Class B$^+$ criteria has to be met.

As discussed in the Section 2.5.2, for a given reuse type and different reuse guidelines, it can be noted that the reuse criteria changes and accordingly the feasibility or acceptance of a TT compared to the guidelines changes. This is illustrated in this section by selecting SA reclaimed water guidelines and Victoria State guidelines for irrigation of golf course (with restricted access).

The SA Reclaimed water guideline specifies FC value of 100 No/100mL as against 1000 No/100mL of Victoria State guidelines while BOD and SS values specified by both guidelines are the same (i.e. BOD = 20 mg/L and SS = 30 mg/L). Since all of the user generated TTs are able to remove FC to a level lower than 100 No/100mL, they meet both the State guidelines. However in case of minimum removal efficiency, TT2 (FC = 105 No/100mL) meets the FC criteria (150 No/100mL) of Victoria State guideline where as it fails to meet the FC criteria (100 No/100mL) of SA reclaimed water guidelines. Thus reuse guidelines influence the feasibility of a TT option.

7.3.3 MOSTWATAR Generated Options for New WWTP

This section describes the MOSTWATAR generated options for Victor Harbor. As a first step in TT generation, it is necessary to determine the optimum GA parameters before generating TTs. With these optimum parameters different TT options were generated and then compared. In this section, the sensitivity analysis carried out for GAs is first described and then the options generated and the comparative studies are presented.

7.3.3.1 Sensitivity Analysis for GA Parameters

The sensitivity analysis was carried out to determine the optimal values of different GA parameters listed in Table 7.13. The purpose of this section is to present the sensitivity analysis of the GA parameters carried out in order to study their effect on the optimum solution and also the computation time. The following GA parameters were used to generate TT options for Victor Harbor.

Table 7.13 Range of GA Parameters Tested for Victor Harbor

GA Parameters	Values/Types Tested
Population size	50, 100, 200
Tournament size	2, 3
Probability of selection, P_s	0.5, 0.6, 0.7
Probability of crossover, P_c	0.7, 0.8, 0.9
Probability of mutation, P_m	0.01, 0.02, 0.2, 0.4, 0.8,
Maximum number of generations	50, 100, 200
Type of fitness evaluation	APM, MPM, DPM, ADPM
Type of initial population generation	S, R1, R2, R3 **

** S- refers to seeding of initial population with known treatment trains

R1- refers to the random generation of TTs by selecting unit processes based on recommended treatment and checking the rules for feasibility

R2- refers to the random generation of TTs by selecting from ALL the unit processes present in the database and checking the rules for feasibility

R3- refers to the random generation of TTs by selecting from ALL the unit processes present in the database without checking rules (refer to Section 5.4.3.2 for details on different initial population generation methods)

The range of parameters listed in the Table above is based on Goldberg (1989) and Simpson and Goldberg (1994). Several test runs were carried out for Victor Harbor WWTP for the different values of GA parameters shown in Table 7.13. A range of population sizes of 50, 100 and 200 were tested and it was found that solutions converged faster with a population size of 50 and the 5 best solutions were not very different from one another. On the other hand, for a population size of 200, the convergence rate was very slow. Therefore a population size of 100 was selected.

Initially tournament sizes of 2, 3 and 4 were tested and it was seen that higher tournament sizes resulted in premature convergence. This can be attributed to an increase in the selection pressure. Therefore to reduce the selection pressure a probability of selection 'Ps' was used along with a tournament size of 2 as discussed by Simpson and Goldberg (1994). In this study a P_s value of 0.6 was used which means that there is a 60 % chance of selecting the fitter string as a parent.

It was evident that higher mutation rate was necessary to get over the initial block and allow for better exploration of the search space. Mutation rates as high as 0.2 (i.e. 20% of the population undergoing mutation) was found to give better solutions. Similarly a probability of crossover 'P_c' value of 0.6 and higher was found to produce good mixing in the population thus increasing the chances of finding a good solution. Probability of crossover 'P_c' values ranging from 0.5 to 0.9 was tested for this study. However a default value 0.8 was considered for single point crossover after initial test runs.

On the other hand, the probability of mutation (P_m) is usually chosen in the range of 0.01 to 0.05. Based on the guidelines suggested by Goldberg & Koza (1990), the default value for P_m was taken as 0.02. But there was no improvement of solutions over generations indicating that there was not sufficient mixing of the population until a P_m value as high as 0.2 was considered. Furthermore, for the R3 method of generation, where the initial population had no feasible solutions, P_m values as high as 0.8 had to be used to get improvements in the fitness score over the generations.

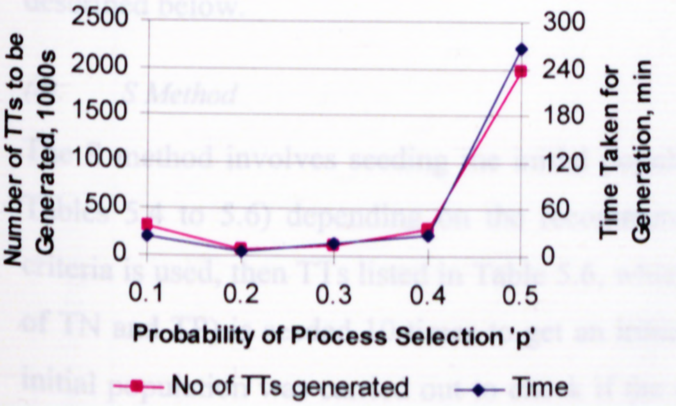
After several test runs it was also found that the solutions were converging between the 40^{th} and 50^{th} generations. Thus a maximum of 100 generations was found to be sufficient to arrive at the 5 best solutions. The optimum parameters from these test runs are listed in Table 7.14. All subsequent testing was carried out using these parameters and are discussed in the following sections.

Table 7.14 GA Parameters Used

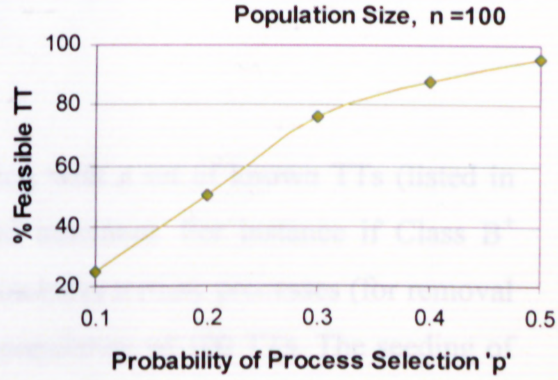
GA Parameters	Value
Population size	100
Tournament size	2
Probability of selection, P_s	0.6
Probability of crossover, P_c	0.8
Probability of mutation, P_m^*	0.2
Maximum number of generations	100

(* on an average 20 % of the population undergo mutation)

An important parameter necessary for setting up the initial population is the probability of process selection 'p'. It was necessary to determine the optimum value for 'p' as this strongly influences the computation time. The 'p' value was varied from 0.1 to 0.5. The number of TTs to be generated (to get an initial population of 100 TTs meeting the rules) and the time taken are plotted against 'p' in Figure 7.7(a).



(a)



(b)

Figure 7.7 Effect of Probability of Process Selection on Generation and Feasibility

As shown in the Figure 7.7 (a), the shortest time of generation occurs with p = 0.2. As the 'p' value increases above 0.4, larger number of processes will be included in a TT string and they are less likely to satisfy the rules. Furthermore, it was found that the percentage of feasible TTs (i.e. TTs meeting the rules and criteria) increased with increase in the 'p' value as shown in Figure 7.7(b). However, since the idea was to generate solutions, which meet the criteria and then let the GA develop better solutions, a 'p' value of 0.2 was selected throughout this case study as the computation time involved for initial generation was a minimum (2 to 6 minutes depending on the method of random generation used i.e. R1 or R2).

In the following sections a comparison of TTs generated has been carried out in terms of the generation technique, different fitness evaluation methods and type of processes selected. The reports generated from MOSTWATAR for each of these comparative studies are presented in the following sections. The purpose of this comparative study was to establish the most suitable generation technique and fitness evaluation method in order to arrive at the best five TTs.

7.3.3.2 Comparison of Different Generation Techniques

As listed in Table 7.13, TTs can be generated in the initial population by any of the following four methods: S, R1, R2 or R3 (Section 5.4.3.2). Each of these methods is described below.

(a). S Method

The S method involves seeding the initial population with a set of known TTs (listed in Tables 5.4 to 5.6) depending on the recommended treatment. For instance if Class B^+ criteria is used, then TTs listed in Table 5.6, which includes tertiary processes (for removal of TN and TP) is seeded 10 times to get an initial population of 100 TTs. The seeding of initial population was carried out to check if the computation time could be reduced. This is further explained in Section 7.3.3.3.

(b). R3 Method

R3 method involves complete random generation of TTs from the total search space (see Figure 5.6) to obtain initial population. It was observed that with the R3 generation technique, no solutions meeting rules were produced even after 500 generations for crossover and mutation rates of 0.8 and 0.2 respectively as shown in Table 7.14. Therefore in order to achieve better mixing of the population, the mutation rate was increased in the R3 technique. However, in spite of increasing the mutation rate to as high as 0.8, no feasible solution was found. It is interesting to note that all the best solutions displayed after 500 generations for the Class B^+ criteria contained the continuous flow BNR process. But there was no improvement of solutions after the 43rd generation as shown in Table 7.15.

Of the best five TTs at the end of 500 generations, all of them met the reuse criteria but failed to meet the acceptable configuration rules. The 1st, 3rd and 5th options (generated at the 22nd and 23rd generations) do not have screens and sludge dewatering processes such as sludge drying beds or filter presses while the 2nd and 3rd TT options do not have sludge dewatering processes. Thus, none of these TTs met the acceptable configuration rules, suggesting that the R3 technique is not effective in finding feasible solutions. Therefore subsequent comparative studies were all carried out using only the S, R1, and R2 techniques.

Table 7.15 List of Best Five TTs Selected after 500 generations Using R3

Printed on 28/02/2002

Community Data

Name of the Community	Victor Harbor (Case R3)
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	M.Stevens

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
22	Primary Clarifier w lime+Anaerobic Lagoon+Continuous Flow BNR+Chlorination+Post Chlorination+Land Filling of Sludge	-0.168
42	Bar Screen+Primary Clarifier w lime+Anaerobic Lagoon+Continuous Flow BNR+Chlorination+Post Chlorination+Land Filling of Sludge	-0.168
43	Bar Screen+Primary Clarifier w lime+Anaerobic Lagoon+Continuous Flow BNR+Chlorination+Land Filling of Sludge	-0.172
23	Primary Clarifier w lime+Anaerobic Lagoon+Continuous Flow BNR+Chlorination+Land Filling of Sludge	-0.172
23	Primary Clarifier w lime+Anaerobic Lagoon+Continuous Flow BNR+Chlorination+UV Disinfection+Post Chlorination+Land Filling of Sludge	-0.175

(c). R1 and R2 Method

The R1 method involves random generation of TTs from the selected unit processes based on recommended treatment while the R2 method involves random generation of TTs using all the unit processes in the database. In both these methods, the initial population of TTs includes only TTs meeting acceptable configuration rules listed in Table 4.2 (a to c). A typical comparison of the number of TTs generated initially with R1 and R2 techniques is as shown in Figure 7.8. The word 'typical' is used to describe the comparison, as the actual number of TTs to be generated to meet the rules depends on many factors such as the type of reuse and the recommended guidelines.

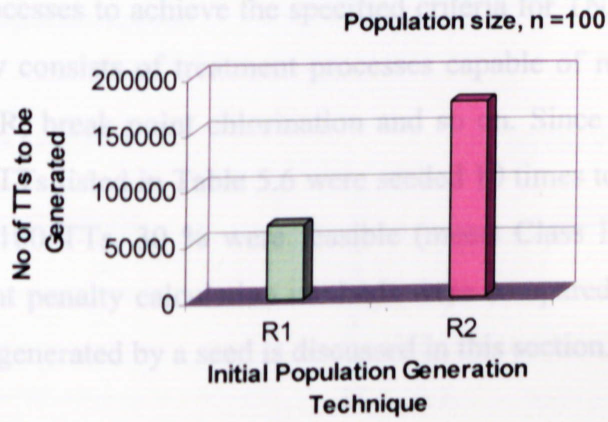


Figure 7.8 A Typical Comparison of the R1 and R2 Techniques

As shown in this Figure for the current case study a total of 175,000 TTs had to be generated to get an initial population of 100 TTs that meet rules using the R2 technique as against 65,000 TTs for the R1 technique for the Class B $^+$ guideline. This is because the length of the string in case of R2 is longer (= 40) as all unit processes are considered for the generation of TTs.

In the current case study, the TT options were generated for both Class B and Class B$^+$ criteria to demonstrate how the selection of a set of guidelines affects the selection of unit processes in TT options. For these guidelines, TT options were generated using the S and R2 techniques. On the other hand the R1 technique was not used for the generation of TT options to meet the Class B$^+$ criteria, as the secondary treatment processes in the current database are not capable of reducing TN and TP levels to as low as 5 and 0.5 mg/L respectively.

In the following sections, new WWTP options generated by MOSTWATAR using the S and R2 method for both Class B and Class B$^+$ criteria are presented. While in Section 7.4, the upgrade options generated for Victor Harbor are discussed.

7.3.3.3 New WWTP Options Generated by MOSTWATAR Using Seed

In this section wastewater treatment options generated using seed by the MOSTWATAR is presented. The initial population was seeded using the TTs listed in Table 5.6. This table was selected, as the recommended treatment ID (RID) for Class B$^+$ criteria is RID 3 (i.e. it requires tertiary processes to achieve the specified criteria for TN and TP). The TTs listed in Table 5.6 mainly consists of treatment processes capable of reducing TN, TP such as lime treatment, BNR, break point chlorination and so on. Since the population size was selected as 100, 10 TTs listed in Table 5.6 were seeded 10 times to get a population of 100 TTs. Out of these 100 TTs, 30 % were feasible (meets Class B$^+$ criteria) in the initial population. Different penalty calculation methods were compared and the best TT option out of the solutions generated by a seed is discussed in this section.

7.3.3.3 (i). Comparison of Different Penalty Calculation Techniques

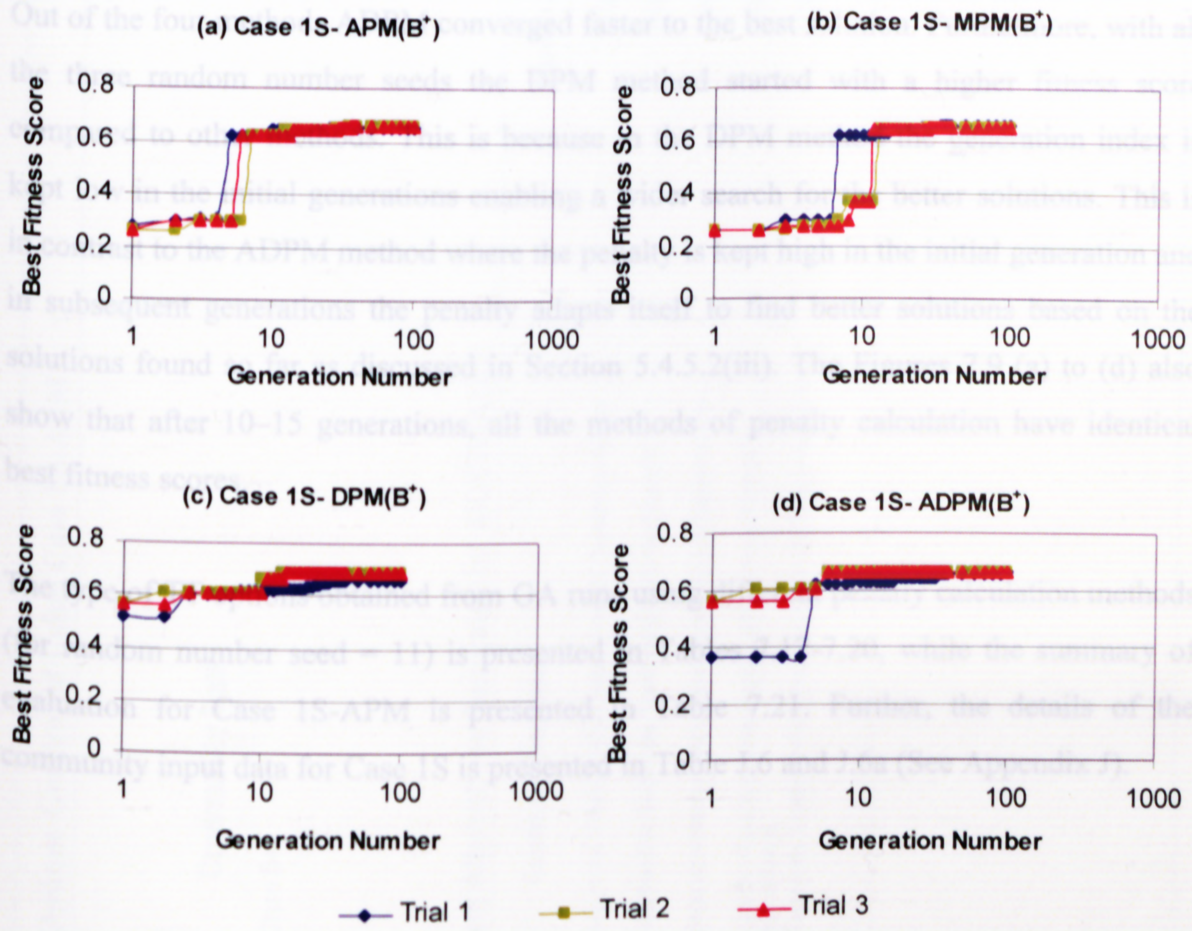
GA runs were carried out for the four penalty calculation methods namely APM, MPM, DPM and ADPM using the GA parameters given in Table 7.16.

Table 7.16 GA Parameters Used for Seeding

GA Parameters	Case 1S
Population size	100
Tournament size	2
Probability of selection, P_s	0.6
Probability of crossover, P_c	0.8
Probability of mutation, P_m	0.2
Maximum number of generations	100
Type of initial population generation	S

Further to ensure consistency of the results generated, three different random number seed namely 11, 9, & 9999 were tested. The variation in best fitness score with the generation number using different random seed is plotted in Figure 7.9 (a, b, c & d). In this text, Case

1S-APM refers to the additive penalty method, Case 1S-MPM for multiplicative penalty method and so on.



(Note: Generation number is plotted on a logarithmic scale and Trial 1, 2 & 3 refers to GA runs with random number seed of 11, 99 & 9999 respectively)

Figure 7.9 Variation of Best Fitness with Generation Number for Case 1S

The best fitness score for all the four penalty methods for the 0th generation was 0.2578 as the initial population consisted of same set of seed. The Figures 7.9 (a, b, c & d) show that the rise of fitness score trend is the same for all the different random number seeds thus indicating that the algorithm developed can consistently provide the same output for a given input data. On the other hand, it was observed that there was difference in the way the fitness score changed in the first 10 generations for the various penalty calculation methods. In order to highlight this change, the generation number was plotted on a logarithmic scale.

Out of the four methods ADPM converged faster to the best solution. Furthermore, with all the three random number seeds the DPM method started with a higher fitness score compared to other methods. This is because in the DPM method the generation index is kept low in the initial generations enabling a wider search for the better solutions. This is in contrast to the ADPM method where the penalty is kept high in the initial generation and in subsequent generations the penalty adapts itself to find better solutions based on the solutions found so far as discussed in Section 5.4.5.2(iii). The Figures 7.9 (a) to (d) also show that after 10–15 generations, all the methods of penalty calculation have identical best fitness scores.

The type of TT options obtained from GA runs using different penalty calculation methods (for random number seed = 11) is presented in Tables 7.17-7.20, while the summary of evaluation for Case 1S-APM is presented in Table 7.21. Further, the details of the community input data for Case 1S is presented in Table J.6 and J.6a (See Appendix J).

Table 7.17 TT Options Generated Using Case 1S-APM

Printed on 18/03/2002

Community Data

Name of the Community	Victor Harbor (Case1S-APM, Class B+)
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	M.Stevens

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
34	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.655
34	Bar Screen+Grit Chamber+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.653
22	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Gravity Thickener+Sludge Drying Beds+Land Spreading of Sludge	0.644
34	Bar Screen+Grit Chamber+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Gravity Thickener+Sludge Drying Beds+Land Spreading of Sludge	0.641
18	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge	0.631

Table 7.18 TT Options Generated Using Case 1S-MPM

Printed on 18/03/2002

Community Data

Name of the Community	Victor Harbor (Case 1S-MPM, Class B+)
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	M.Stevens

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
34	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.655
24	Bar Screen+Grit Chamber+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.653
27	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Gravity Thickener+Sludge Drying Beds+Land Spreading of Sludge	0.644
34	Bar Screen+Grit Chamber+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Gravity Thickener+Sludge Drying Beds+Land Spreading of Sludge	0.641
30	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge	0.631

Table 7.19 TT Options Generated Using Case 1S-DPM

Printed on 19/03/2002

Community Data

Name of the Community	Victor Harbor (Case 1S-DPM, Class B+).
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	M.Stevens

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
35	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.655
36	Bar Screen+Grit Chamber+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.653
28	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge	0.631
26	Bar Screen+Grit Chamber+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge	0.628
23	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Gravity Thickener+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge	0.624

Table 7.20 TT Options Generated Using Case 1S-ADPM

Printed on 19/03/2002

Community Data

Name of the Community	Victor Harbor (Case 1S-ADPM, Class B+).
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	M.Stevens

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
26	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.655
22	Bar Screen+Grit Chamber+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.653
19	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Gravity Thickener+Sludge Drying Beds+Land Spreading of Sludge	0.644
26	Bar Screen+Grit Chamber+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Gravity Thickener+Sludge Drying Beds+Land Spreading of Sludge	0.641
26	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge	0.631

Table 7.21 Summary of TT Options Generated by MOSTWATAR Using Case 1S-APM

Printed on18/03/2002

Page1

Community Name:Victor Harbor (Case1S-APM, Class B+)

Design Population:17000
Design Average Flow,m3/d:3400
Design Peak Flow,m3/d:10200

Summary of Evaluation of Wastewater Treatment Alternatives generated by MOSTWATAR

Items	R.Criteria	Option:1(34)*	Option:2(34)*	Option:3(22)*	Option:4(34)*	Option:5(18)*
BOD,mg/L	20	2.3	2.2	2.3	2.2	2.3
SS,mg/L	30	1.8	1.7	1.8	1.7	1.8
TN,mg/L	5.0	4.4	4.4	4.4	4.4	4.4
TP,mg/L	0.5	0.1	0.1	0.1	0.1	0.1
FC,No/100mL	100	0.0	0.0	0.0	0.0	0.0
Turbidity,NTU	-	0.0	0.0	0.0	0.0	0.0
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.83	0.85	0.81	0.83	0.81
Varying flow rate		0.63	0.67	0.63	0.67	0.67
Varying influent quality		0.83	0.85	0.85	0.87	0.85
Ease of O & M		0.58	0.59	0.63	0.63	0.63
Ease of construction		0.63	0.63	0.59	0.60	0.63
Reliability		0.79	0.81	0.81	0.83	0.81
Odour		0.50	0.48	0.44	0.43	0.44
Ground water impact		0.63	0.67	0.67	0.70	0.67
Chemical requirement		0.71	0.74	0.74	0.77	0.74
Power requirement		0.46	0.48	0.44	0.47	0.44
Total land required, ha		1.66	1.67	1.73	1.75	1.74
Total sludge produced,kg/d		1613	1670	1535	1590	1613
Total capital cost,**		$9,775	$10,002	$10,352	$10,586	$10,741
Total land cost,**		$267	$267	$267	$267	$267
PV O & M cost,**		$5,696	$5,817	$5,928	$6,051	$6,276
Total project cost,**		**$15,737**	**$16,087**	**$16,547**	**$16,905**	**$17,285**
Annualised project cost***		**$1,474**	**$1,507**	**$1,550**	**$1,584**	**$1,619**
Life cycle cost****		**$1.19**	**$1.21**	**$1.25**	**$1.28**	**$1.30**
Fitness score		**0.655**	**0.653**	**0.644**	**0.641**	**0.631**

NOTE:Sort Key= Max Fitness Score;Fitness score is scaled from 0 to 1, negative score indicates an infeasible option.
* Number within brackets indicate the generation number in which the option was generated. **1000s $, ***1000s $/yr,****$/m3.

As shown in Tables 7.17-7.20, all the four methods selected the same TT option (i.e. bar screen + primary clarifier w lime + ASP w Ni & clarifier + two stage lime treatment + dual media filter +UV Disinfection + sludge drying beds + land spreading of sludge), with a fitness score of 0.655 as the best solution. Furthermore APM, MPM and ADPM methods selected the same 5 TTs as the best 5 TTs as shown in the result sheets (See Tables 7.17, 7.18 & 7.20). While the DPM method selected two inferior TTs (i.e. 4th and 5th TTs listed in Table 7.19) consisting of grit chamber and gravity thickener respectively in addition to the unit processes of the best TT option. All the best 5 TT options have similar effluent quality except those selected by DPM method in which the effluent BOD and SS was slightly better due to selection of grit chamber. As seen from Table 7.21, the total project cost for the TT options selected by Case 1S-APM ranged from $15.73 to $17.28 million. The detail output for the best TT option generated by Case1S-APM (B+) is presented in Tables J.7 and 7a in Appendix J.

The ADPM method performed better than the other three methods as it selected the same TT option at the 26th generation number as against 34th and 35th generations in the other methods. In the ADPM method, the fitness of the population increased steeply until the 10th generation and then a better solution was found at 19th generation. While the best TT option with a total project cost of $15.74 million was found at 26th generation (see Table 7.21). Similarly the MPM method also selected the same TT option as the best at the 34th generation as against the 26th generation in the ADPM method.

The DPM method was the slowest of all the four methods to achieve convergence. The best TT option for the DPM method was found at the 35th generation. However the improvement of solutions continued until 36th generation. The best fitness score increased from 0.2578 in the 0th generation (i.e. initial population) to 0.5147 in the 1st generation. It was observed that DPM method was selecting processes namely continuous flow BNR, ASP w Ni and two stage lime treatment in almost all the best five options until the 10th generation. After the 10th generation, BNR was not selected in any of the best five options. None of the other methods selected BNR, as it is a relatively expensive process. The summary of TT option evaluation for Case 1S-MPM, DPM and ADPM is presented in Tables J.8 to J.10 in Appendix J respectively.

Figures 7.10 (a & b) show how the percentage feasible solution in the population changes with respect to the generation number. To start with, only 30 % of the population were found to be feasible (i.e. meeting the rules and reuse criteria for Class B$^+$). It was noted that for all of the different penalty calculation methods except the DPM method, the percentage feasible TTs drops from 30 to (12 to 17) % in the 1st generation while in DPM method it increases to 33 % in the 1st generation. In the DPM method the percentage feasibility rises steadily from 33 % to 93 % at the 35th generation at which it finds the best solution. After the 35th generation, the feasibility fluctuates between 86 to 95 %. On the other hand in the APM method, the percentage feasibility steadily increases from 17 % in the 1st generation to 92 % in the 26th generation where the best solution was found. In the ADPM method the maximum percentage feasibility is reached at the 26th generation while in the MPM it is reached at the 31st generation.

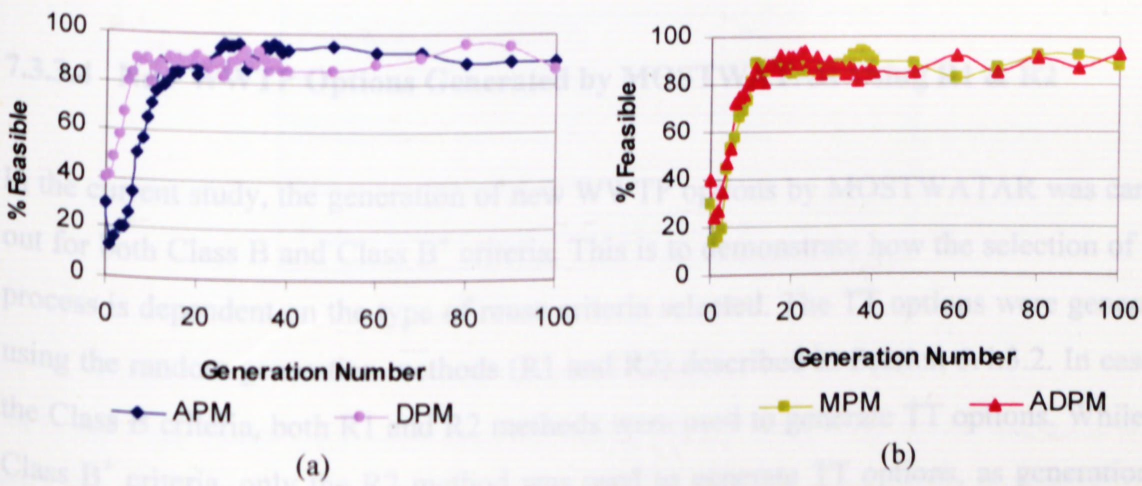


Figure 7.10 Variation of Feasibility for Different Penalty Methods

The decrease in the percentage feasibility in the first generation of the APM, ADPM and MPM methods can be attributed to crossover and mutation, which causes disruption to the TT strings. In the subsequent generations it was found that the GA adjusted itself to find better solutions and the percentage feasibility increased. Whereas in the DPM method, feasibility was found to increase steadily from the 0th generation without any decrease in the percentage feasibility in the 1st generation. This is due to the fact that the penalty term (i.e. generation index, t/t_{max}) is kept high in the 0th generation (assumed as 1) and then in the 1st generation it is assumed as (1/100 = 0.01) and in the 2nd generation (2/100 = 0.02) and so on as explained in Section 5.4.5.2 (ii). As a result, there is a better chance of exploration of the search space and finding feasible solutions. This was evident as the DPM method was displaying TT options with the BNR process as one of the best options up to the 8th generation. On the other hand, the other methods did not consider the BNR process in any of the best five TT options in the first generation.

7.3.3.3 (ii). Comparison of Best TT options for the Various Penalty Calculation Methods

The result sheets obtained from the GA runs using S and the various penalty calculation methods indicate that all the four methods of penalty calculations resulted in the same best TT option as shown in Tables 7.17 to 7.20. Therefore the best TT option of the four methods has the same total project cost of $15.74 million and includes the following processes: Bar screen + primary clarifier w lime + ASP w Ni w clarifier + two stage lime treatment + dual media filter + UV disinfection for wastewater treatment while for sludge treatment, sludge drying beds and land spreading of sludge was selected.

7.3.3.4 New WWTP Options Generated by MOSTWATAR Using R1 & R2

In the current study, the generation of new WWTP options by MOSTWATAR was carried out for both Class B and Class B^{+} criteria. This is to demonstrate how the selection of unit process is dependent on the type of reuse criteria selected. The TT options were generated using the random generation methods (R1 and R2) described in Section 5.4.3.2. In case of the Class B criteria, both R1 and R2 methods were used to generate TT options. While for Class B^{+} criteria, only the R2 method was used to generate TT options, as generation of TTs using unit processes based on the recommended treatment (R1) and the generation using all the unit processes in the database (R2) will be essentially the same. This is because tertiary treatment processes will be necessary to meet Class B^{+} criteria and therefore all unit processes present in the database need to be considered.

In this section firstly, the TT options generated for Class B^{+} criteria are presented followed by TT options generated for Class B criteria. In the next section a comparison of the TT options generated by MOSTWATAR and the user is presented.

7.3.3.4 (i). TT Options Generated for Class B^+ Criteria

The Table 7.22 shows the values of the different GA parameters used in the R2 method to generate TT options. In order to differentiate TT options generated by the R2 method for Class B and Class B^+ criteria, the symbol (B^+) is used as shown in Table below. The runs are called Case R2-APM (B^+) for the additive penalty method, Case R2- MPM (B^+) for the multiplicative penalty method and so on. For all the four cases listed below, about 73,000 to 75,000 TTs had to be generated to get 100 (i.e. n = 100) TTs in the initial population, which met the rules. To generate this initial population of TTs, an average of 5 to 6 minutes of computation time was required.

Table 7.22 GA Parameters Used for R2 Method

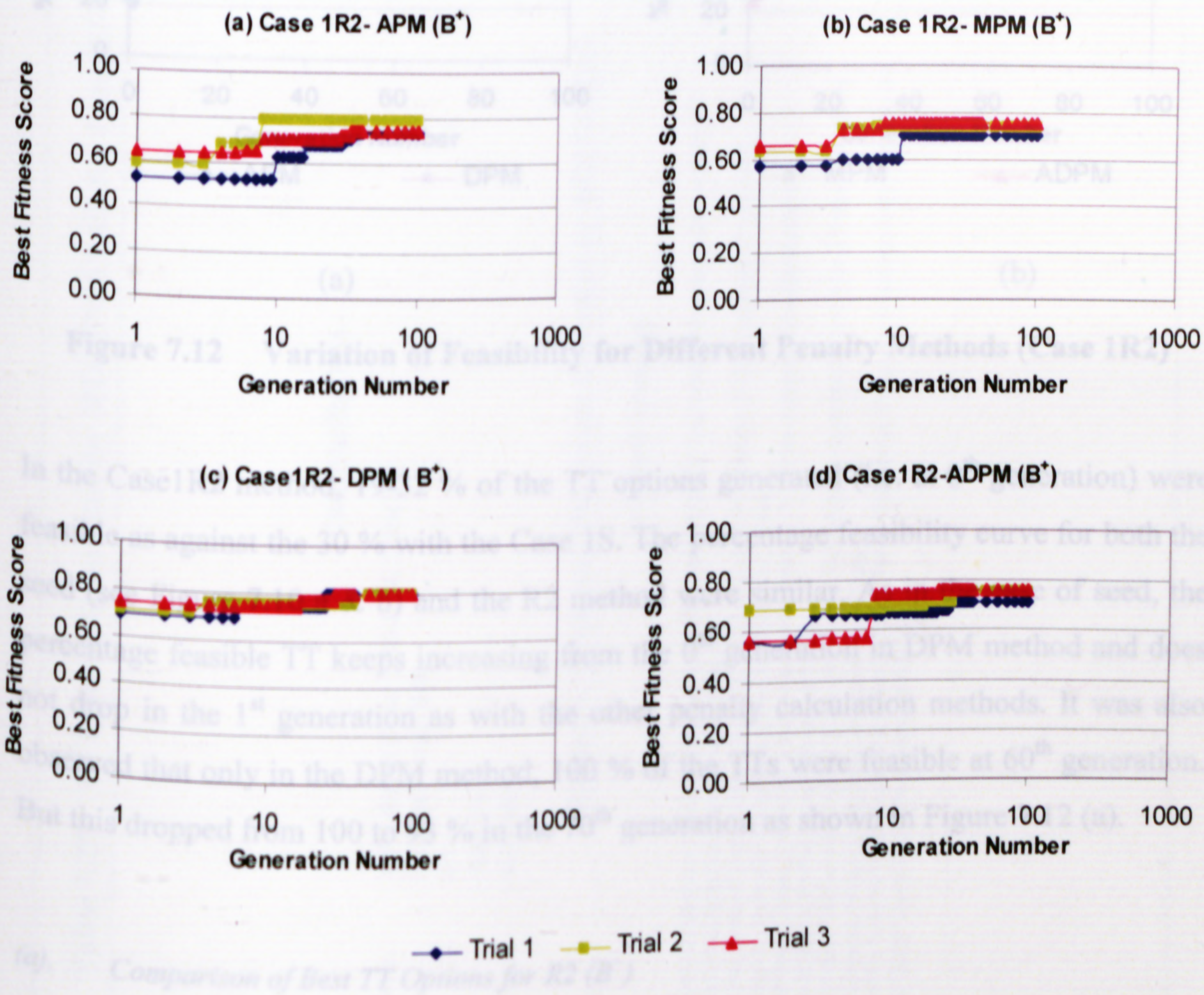
GA Parameters	Case R2
Population size	100
Tournament size	2
Probability of selection, P_s	0.6
Probability of crossover, P_c	0.8
Probability of mutation, P_m	0.2
Maximum number of generations	100
Type of initial population Generation	R2

(a) Comparison of Different Penalty Calculation Methods

As in the Case 1S (B^+), GA runs were carried out for R2 using four penalty methods along with three different random number seeds. The variation of the best fitness score with the generation number for Case 1R2 (B^+) is shown in Figures 7.11 (a, b, c & d). In all the trials, the percentage feasible solutions (i.e. TTs meeting rules and reuse criteria) in the initial population varied from 19 % to 32 %. Further, the best fitness score for the initial population varied from 0.5620 to 0.7440. The rise of fitness score in the different penalty methods for the first 10 generations was similar to those of Case 1S (B^+). In order to highlight this change, the generation number was plotted on a logarithmic scale.

Of the four penalty calculation methods, the DPM method found the best solution followed by ADPM, MPM and APM. Furthermore, with all the three random number seeds the DPM method started with a higher fitness score compared to the other methods.

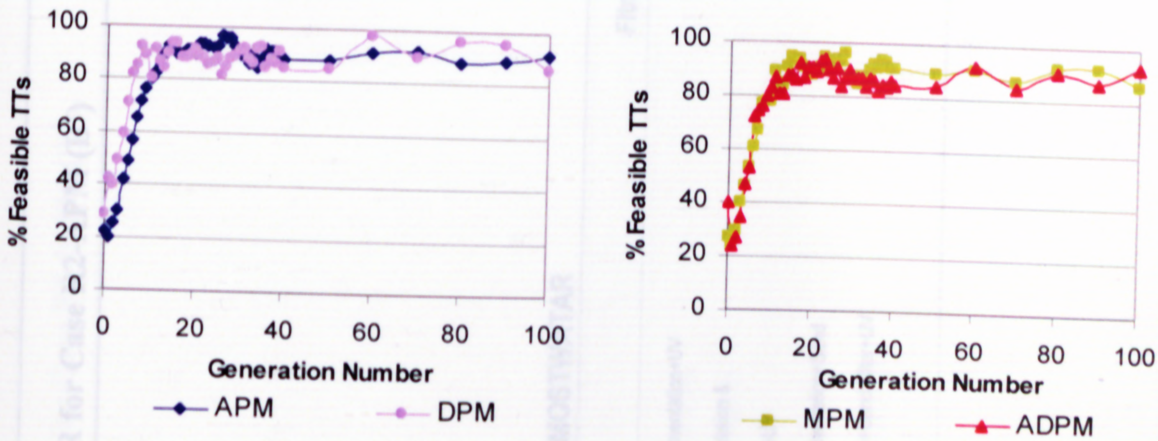
This is because in the DPM method the penalty is based on the generation index and thus it will be kept low in the initial generations enabling wider search for the better solutions. This is in contrast to the ADPM method where the penalty is kept high in the initial generation and in the subsequent generations the penalty adapts itself to find better solutions based on the solutions found so far as discussed in Section 5.4.5.2(iii). The MPM method converged faster to the best solution than other methods. Figures 7.11 (a) to (d) show that after 20 generations, all the methods of penalty calculation have similar best fitness scores.



(Note: The best fitness score for the 0[th] generation varied from 0.5620 to 0.7440 and the generation number is plotted on a logarithmic scale. Trial 1,2, & 3 refers to GA runs with random seed of 11, 99 & 9999 respectively)

Figure 7.11 Variation of Best Fitness Score with Generation Number for Case 1R2 (B^+)

The percentage of feasible TTs in every generation for the four penalty methods using different random number seed was similar. This variation in percentage feasibility for the four different penalty methods using a random number seed of 11 is plotted in Figure 7.12 (a & b).



(a) (b)

Figure 7.12 Variation of Feasibility for Different Penalty Methods (Case 1R2)

In the Case1R2 method, 19-32 % of the TT options generated (i.e. at 0^{th} generation) were feasible as against the 30 % with the Case 1S. The percentage feasibility curve for both the seed (see Figure 7.10 a & b) and the R2 method were similar. As in the case of seed, the percentage feasible TT keeps increasing from the 0^{th} generation in DPM method and does not drop in the 1^{st} generation as with the other penalty calculation methods. It was also observed that only in the DPM method, 100 % of the TTs were feasible at 60^{th} generation. But this dropped from 100 to 93 % in the 70^{th} generation as shown in Figure 7.12 (a).

(a). Comparison of Best TT Options for R2 (B^+)

The best 5 TT options obtained from GA runs using different penalty calculation methods namely APM, MPM, DPM and ADPM methods (for random number seed = 11) are shown in Tables 7.23 to 7.26.

Table 7.23 TT Options Generated by MOSTWATAR for Case R2-APM (B^+)

Printed on 19/03/2002

Community Data

Name of the Community	Victor Harbor (Case 1 R2- APM, Class B+)
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	M.Stevens

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
33	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+FWS Wetland (BOD)+Coagulation, Flocculation & Sedimentation+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.745
33	Bar Screen+Fine Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+FWS Wetland (BOD)+Coagulation, Flocculation & Sedimentation+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.729
32	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Coagulation, Flocculation & Sedimentation+Sand Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.720
32	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+FWS Wetland (BOD)+Coagulation, Flocculation & Sedimentation+Sand Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.707
38	Bar Screen+Fine Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Coagulation, Flocculation & Sedimentation+Sand Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.704

Table 7.24 TT options Generated by MOSTWATAR for Case R2-MPM (B^+)

Printed on 19/03/2002

Community Data

Name of the Community	Victor Harbor (Case 1R2- MPM, Class B+).
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	M.Stevens

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
9	Bar Screen+Primary Clarifier+Continuous Flow BNR+Single Stage Lime Treatment+Sand Filter+UV Disinfection+Sludge Drying Beds+Land Filling of Sludge	0.758
10	Bar Screen+Primary Clarifier+Continuous Flow BNR+Single Stage Lime Treatment+Coagulation & Flocculation+Sand Filter+UV Disinfection+Sludge Drying Beds+Land Filling of Sludge	0.729
10	Bar Screen+Primary Clarifier+Anaerobic Lagoon+Continuous Flow BNR+Coagulation, Flocculation & Sedimentation+Chlorination+Sludge Drying Beds+Land Filling of Sludge	0.724
11	Bar Screen+Fine Screen+Primary Clarifier+Anaerobic Lagoon+Continuous Flow BNR+Coagulation, Flocculation & Sedimentation+Chlorination+Sludge Drying Beds+Land Filling of Sludge	0.711
22	Bar Screen+Fine Screen+Primary Clarifier+Continuous Flow BNR+Single Stage Lime Treatment+Coagulation & Flocculation+Sand Filter+UV Disinfection+Sludge Drying Beds+Land Filling of Sludge	0.710

Table 7.25 TT Options Generated by MOSTWATAR for Case R2-DPM (B^+)

Printed on 19/03/2002

Community Data

Name of the Community	Victor Harbor (Case1R2-DPM.,Class B+)
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	M.Stevens

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
29	Bar Screen+Primary Clarifier w lime+Continuous Flow BNR+Sand Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.801
29	Bar Screen+Primary Clarifier w lime+Continuous Flow BNR+Sand Filter+UV Disinfection+Post Chlorination+Sludge Drying Beds+Land Spreading of Sludge	0.776
20	Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Continuous Flow BNR+Sand Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.725
21	Bar Screen+Primary Clarifier w lime+Continuous Flow BNR+Two Stage Lime Treatment+UV Disinfection+Post Chlorination+Sludge Drying Beds+Land Spreading of Sludge	0.707
22	Bar Screen+Primary Clarifier w lime+Continuous Flow BNR+Two Stage Lime Treatment+Sand Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge	0.694

Table 7.26 TT Options Generated by MOSTWATAR for Case R2-ADPM (B^+)

Printed on 19/03/2002

Community Data

Name of the Community	Victor Harbor (Case 1R2-ADPM, Class B+)
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	M.Stevens

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
23	Bar Screen+Primary Clarifier+Anaerobic Lagoon+Sedimentation Pond+Continuous Flow BNR+Dual Media Filter+Belt Filter Press+Land Filling of Sludge	0.761
31	Bar Screen+Grit Chamber+Primary Clarifier+Anaerobic Lagoon+Sedimentation Pond+Continuous Flow BNR+Dual Media Filter+Belt Filter Press+Land Filling of Sludge	0.757
26	Bar Screen+Primary Clarifier+Anaerobic Lagoon+Sedimentation Pond+Continuous Flow BNR+Dual Media Filter+UV Disinfection+Belt Filter Press+Land Filling of Sludge	0.751
8	Bar Screen+Grit Chamber+Primary Clarifier+Anaerobic Lagoon+Sedimentation Pond+Continuous Flow BNR+Dual Media Filter+UV Disinfection+Belt Filter Press+Land Filling of Sludge	0.747
14	Bar Screen+Primary Clarifier+Anaerobic Lagoon+Sedimentation Pond+FWS Wetland (BOD & Ni)+Continuous Flow BNR+Dual Media Filter+Belt Filter Press+Land Filling of Sludge	0.576

The TT options in Case 1R2-APM (B^+) (as shown in Table 7.23) included mainly combinations of ASP w Ni, FWS wetland (BOD); coagulation, flocculation & sedimentation and UV disinfection. The primary clarifier with lime was selected in all the TT options, as reduction in TP was necessary.

Further only the 3rd, 4th and 5th options contain sand filter. In the 1st and 2nd TT options, media or membrane filters did not precede UV disinfection, as the influent turbidity was 0.4 to 5 NTU, which is within the maximum allowable influent quality specified for UV systems (see Table 4.4). However the designers may have reservations about using UV systems without media filtration because if there is any process upset prior to the UV systems, the influent turbidity levels may be much higher and may affect the disinfection process. In terms of sludge treatment and disposal all the options selected sludge drying beds and land spreading of sludge, which is the cheapest, compared to other options such as belt filter press, and land filling of sludge. The total project cost for the Case R2-APM (B^+) ranged from $9.54 million to $12.3 million as shown in Table J.11 in Appendix J.

In Case R2-MPM (B^+), the best 5 TT options included combinations of primary clarifier, BNR, single stage lime treatment, sand filter, chlorination and UV disinfection. For sludge treatment and disposal, sludge drying beds and land filling of sludge was selected (as against the land spreading in APM method). The total project cost of these options ranged from $11.24 to $ 13.72 million. The list of TTs obtained from the model for MPM is presented in Table 7.24 while the summary of the evaluation is presented in Table J.12. in Appendix J.

It can be seen from Table 7.24, that the MPM method selected a wide range of suitable unit processes forming quite different TT options unlike the APM method. This indicates that MPM method is better in exploring the search space. In case of DPM method (Case 1R2-DPM (B^+)) the best TT solutions had combinations of primary clarifier w lime, BNR, two stage lime treatment, sand filter and UV disinfection. Furthermore, in these solutions, sludge-drying beds and land spreading of sludge were selected for sludge treatment and disposal option. The total project cost of the TT options ranged from $8.10 to $13.83 million as shown in Table 7.27.

Table 7.27 Summary of TT options Generated by MOSTWATAR for Case R2-DPM (B^+)

Printed on19/03/2002

Community Name:Victor Harbor (Case1R2-DPM.,Class B+)

Design Population:17000
Design Average Flow,m3/d:3400
Design Peak Flow,m3/d:10200

Summary of Evaluation of Wastewater Treatment Alternatives generated by MOSTWATAR

Items	R.Criteria	Option:1(29)*	Option:2(29)*	Option:3(20)*	Option:4(21)*	Option:5(22)*
BOD,mg/L	20	4.9	4.9	0.5	2.7	1.6
SS,mg/L	30	3.6	3.6	0.7	3.3	1.0
TN,mg/L	5.0	4.1	4.0	0.6	4.3	3.1
TP,mg/L	0.5	0.3	0.3	0.3	0.0	0.0
FC,No/100mL	100	4.5	0.0	1.4	0.0	1.1
Turbidity,NTU	-	1.5	1.5	0.6	1.2	0.3
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.81	0.75	0.79	0.75	0.83
Varying flow rate		0.62	0.58	0.63	0.58	0.67
Varying influent quality		0.86	0.88	0.79	0.92	0.88
Ease of O & M		0.67	0.63	0.67	0.58	0.63
Ease of construction		0.67	0.63	0.63	0.63	0.67
Reliability		0.76	0.79	0.75	0.83	0.79
Odour		0.38	0.42	0.42	0.46	0.46
Ground water impact		0.71	0.75	0.63	0.75	0.75
Chemical requirement		0.81	0.75	0.83	0.67	0.71
Power requirement		0.43	0.42	0.50	0.42	0.42
Total land required, ha		1.53	1.59	1.87	1.64	1.72
Total sludge produced,kg/d		872	872	1082	1567	1574
Total capital cost,**		$5,041	$5,273	$7,508	$7,641	$8,981
Total land cost,**		$265	$266	$269	$266	$267
PV O & M cost,**		$2,794	$3,797	$4,282	$4,931	$4,587
Total project cost,**		**$8,100**	**$9,336**	**$12,059**	**$12,838**	**$13,835**
Annualised project cost***		**$759**	**$875**	**$1,130**	**$1,203**	**$1,296**
Life cycle cost****		**$0.61**	**$0.70**	**$0.91**	**$0.97**	**$1.04**
Fitness score		**0.801**	**0.776**	**0.725**	**0.707**	**0.694**

NOTE:Sort Key= Max Fitness Score;Fitness score is scaled from 0 to 1, negative score indicates an infeasible option.
* Number within brackets indicate the generation number in which the option was generated, **1000s $, ***1000s $/yr,****$/m3.

The TT options selected by the ADPM method included primary clarifier, BNR, dual media filter and UV disinfection. Interestingly, the 1st, 2nd and 5th TT options selected by ADPM did not include any disinfection process. In spite of this the effluent FC in these options were within the limits (i.e. 100 No/100mL). Furthermore, in all the TTs, anaerobic lagoon and sedimentation (functioning as polishing) ponds were included. Also FWS wetland (BOD & Ni) was selected in the 5th best TT option as displayed in Table 7.26. While for the sludge treatment and disposal, belt filter press and land filling of sludge was selected. The TT options selected by the ADPM method had better effluent quality than all other TT options selected by the other methods. However, these options were the most expensive as the total project cost ranged from $ 10.9 to $ 20.37 million as shown in Table J.13 in Appendix J.

The comparison of total project cost and the fitness score of the best TT options from different penalty calculation methods are presented in Figure 7.13. This figure shows that the fitness score for TT selected by the MPM method had higher total project cost compared to best TT selected by the APM method. This is because most of the criterion scores (such as upgrade, adaptability to varying influent quality) were much higher for the best TT selected by MPM as shown in Table J.12. Summaries of the TT evaluation for the APM, MPM and ADPM are presented in Tables J.11 to J.13 in Appendix J. While the details of the best TT option selected by DPM method is presented in Table 7.28 & 7.28 a.

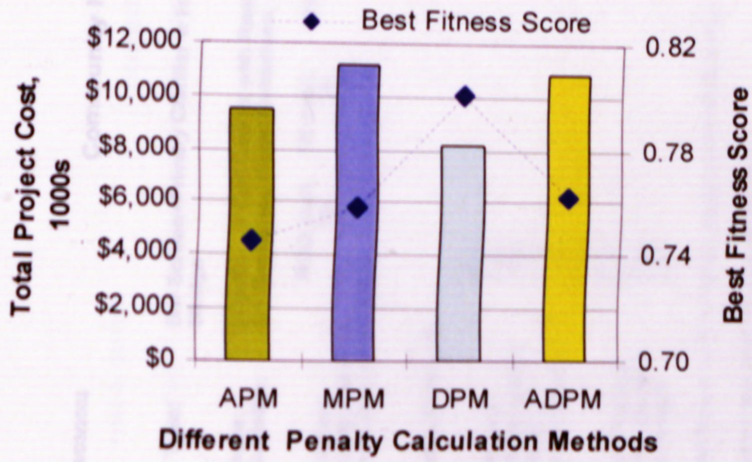


Figure 7.13 Comparison of Best TTs from Different Penalty Methods (Case 1R2-B^{+})

Table 7. 28 Details of the Best TT Option Generated by MOSTWATAR for Case 1R2-DPM (B^+)

Printed on 19/03/2002

Community Name:Victor Harbor (Case1R2-DPM.,Class B+)

TT OPTION-1

Treatment Train: Bar Screen+Primary Clarifier w lime+Continuous Flow BNR+Sand Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge

Desired Reuse: Irrigation of Golf Course with Restricted Access
Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	30	5	0.5	100	-
Effluent Quality Achieved:	4.9	3.6	4.1	0.3	4.5	1.5

Meets Criteria (Yes/No): YES

Effectiveness Measures

Upgrade:	0.81
Varying flow rate:	0.62
Varying influent quality:	0.86
Ease of O & M:	0.67
Ease of construction:	0.67
Reliability:	0.76
Odour:	0.38
Ground water impact:	0.71
Chemical requirement:	0.81
Power requirement:	0.43

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	1.53
Sludge produced,kg/day:	872

Table 7. 28 a Construction Cost Details for the Best TT Option Generated by Case 1R2-DPM (B^+)

Printed on 19/03/2002

Community Name:Victor Harbor (Case1R2-DPM.,Class B+)

Summary of Construction Cost Estimate for TT Option-1

Item	**Construction Cost 1000s $**
Bar Screen	$106
Primary Clarifier w lime	$491
Continuous Flow BNR	$830
Sand Filter	$884
UV Disinfection	$142
Sludge Drying Beds	$147
Land Spreading of Sludge	$120
Miscellaneous Cost	$160
Total UP Construction Cost	**$3,153**
Additional Cost*	$816
Total Construction Cost for WWTP	**$3,969**
Engineering and Contingency Cost	$1,072
Total Capital Cost	**$5,041**
Total Land Cost	$265
PV O & M Cost	$2,794
Total Project Cost	**$8,100**
Annualised Project Cost* **	**$759**
Life Cycle Cost******	**$0.61**

*Miscellaneous cost includes: Cost for raw sewage pumping, rising main and sludge pumping station
**Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
*** 1000s $/yr,**** Life cycle cost is expressed as $/m3 of reclaimed water

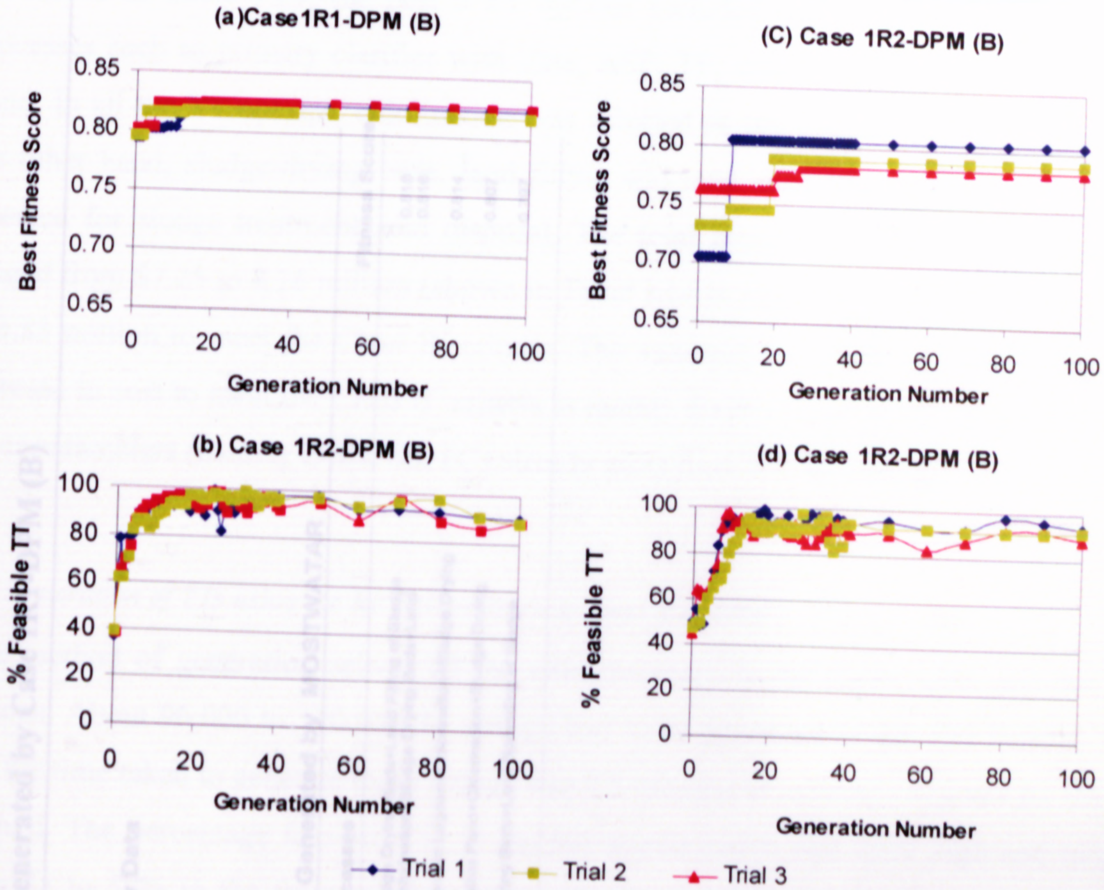
7.3.3.4 (ii). TT Options Generated for Class B Criteria

As discussed earlier, TT options were generated to meet the Class B criteria to demonstrate how the reuse criteria affects the process selection in MOSTWATAR. In this case the random generation of TTs was tested for both R1 and R2 methods using different random number seeds as in the Case 1S(B^+) and 1R2(B^+). For both these generation techniques, the penalty was calculated using the DPM method as this method performed better than the other penalty methods for Class B^+ criteria.

(a). Generation of TTs using the R1 method to meet Class B criteria

In order to generate an initial population of 100 TTs (meeting the rules), it was found that about 59,000 to 60,400 TT strings had to be generated for R1 technique. The initial population generation required 5 to 6 min of computer time of which 32 to 37 % were feasible (meeting rules and criteria) while the total run time was between 21 and 22 minutes for a maximum generation of 100. As in the previous cases, three runs with different random number seeds were carried out. The change in the best fitness score and the percentage feasibility was plotted against the generation number as shown in Figure 7.14 (a & b).

The recommended treatment based on SA reclaimed water guidelines for Class B irrigation is full secondary with disinfection. Hence in the R1 method, the TTs were generated using primary, secondary, disinfection and sludge treatment processes. In Case R1-DPM (B) the best fitness of the initial population ranged from 0.7942 to 0.8161 for the three trials while the percent feasible in the initial population ranged from 37 to 39 % as shown in Figure 7.14 (a & b).



(Note: Trial 1, 2 and 3 refers to GA runs with random number seed of 11, 99 & 9999 respectively)

Figure 7. 14 Variation of Best Fitness Score and Percentage Feasibility for Case 1R1 & 1R2(B) Using DPM.

The best 5 TTs selected after 100 generations from Trial 1 are displayed for Case 1R1(B) in Table 7.29 while the summary of the TT evaluation and the details of the best TT option selected and is presented in Tables J.14, J.15 & J.15a in Appendix J respectively.

Table 7. 29 List of Best 5 TTs Generated by Case 1R1-DPM (B)

Printed on 25/03/2002

Community Data

Name of the Community	Victor Harbor (Case 1R1-DPM.,Class B)
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	N.dinesh

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
13	Bar Screen+Primary Clarifier w lime+Anaerobic Lagoon+Facultative Pond+Chlorination+Sludge Drying Beds+Land Filling of Sludge	0.818
13	Bar Screen+Grit Chamber+Primary Clarifier w lime+Anaerobic Lagoon+Facultative Pond+Chlorination+Sludge Drying Beds+Land Filling of Sludge	0.816
20	Bar Screen+Fine Screen+Grit Chamber+Primary Clarifier+TF,Plastic Media,w Clarifier+Anaerobic Lagoon+Chlorination+Sludge Drying Beds+Land Spreading of Sludge	0.814
14	Bar Screen+Fine Screen+Grit Chamber+Primary Clarifier w lime+Anaerobic Lagoon+Facultative Pond+Chlorination+Sludge Drying Beds+Land Filling of Sludge	0.807
3	Bar Screen+Primary Clarifier w lime+Conventional ASP, w Clarifier+Chlorination+Sludge Drying Beds+Land Spreading of Sludge	0.797

As shown in Table 7.29, the best 5 TT options included mainly primary & secondary processes such as primary clarifier with lime, ASP, TF, anaerobic lagoon and facultative pond. In all the TT options, chlorination was selected as the best disinfection option. On the other hand, sludge-drying beds, land filling and land spreading of sludge have been selected for sludge treatment, and disposal. The total project cost for these TT options ranged from \$7.25 to 8.16 million (shown in Table J.14 in Appendix J) as against \$ 8.10 to \$13.83 million to meet the Class B^+ criteria. The summary in Table J.13 shows that this increase in cost to meet the Class B^+ criteria is mainly for the removal of TN and TP as all other parameters (namely BOD, SS, FC) already meet the Class B^+ criteria.

(b). Generation of TTs using the R2 method to meet Class B criteria

This method of generation selects all the unit processes in the database to generate TT options. About 96,000 to 120,900 TT strings had to be generated to get 100 feasible TTs and the time taken to generate these strings was 8.5 minutes as against 5 minutes for the R1 method. The percentage feasible TTs in the initial population was quite high and ranged from 45 to 58% in the three trials as shown in Figure 7.14 (d). The best 5 TT options generated in Trial 1 are presented in Table 7.30.

The TT options generated by Case 1R2-DPM(B) method included processes such as primary clarifier w lime, TF rock media, ASP w Ni, BNR and chlorination. None of these best 5 TTs generated by Case 1R2-DPM (B) consisted of land-based systems such as anaerobic lagoon, facultative pond and wetlands as in case of Case 1R1-DPM (B). This is because the processes such as BNR have better criterion scores than the land-based systems. While sludge drying beds and land filling of sludge have been selected for sludge treatment and disposal. The total project cost ranged from \$8.02 to \$12.10 million (see Table J.16) as against \$7.25 to \$8.16 million for the R1 method (Table J.14). The details of the best TT option selected by Case 1R2-DPM (B) is presented in Tables J.17 and J.17a.

Table 7. 30 List of Best 5 TTs Generated by Case 1R2-DPM (B)

Printed on 26/03/2002

Community Data

Name of the Community	Victor Harbor (Case 1R2-DPM.,Class B)
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	N.Dinesh

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
8	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Filling of Sludge	0.805
13	Bar Screen+Grit Chamber+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Filling of Sludge	0.802
13	Bar Screen+Fine Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Filling of Sludge	0.788
22	Bar Screen+Fine Screen+Grit Chamber+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Filling of Sludge	0.784
10	Bar Screen+Primary Clarifier w lime+TF,Plastic Media,w Clarifier+Continuous Flow BNR+Coagulation & Flocculation+Dual Media Filter+UV Disinfection+Belt Filter Press+Land Filling of Sludge	0.732

(c). Comparison of Best TT options of R1 and R2 technique for Class B criteria

The variation of best fitness score for both R1 and R2 methods using DPM method (for Trial 1) are shown in Figure 7.15. This Figure illustrates how the search space can affect the best fitness score. As shown in this Figure, the fitness score for the 0th generation for the R1 method is quite high (0.7942). This is due to the fact that the random generation is started in a restricted search space where the recommended treatment processes are available. Whereas for the R2 method, (in which the processes are selected randomly from all the unit processes present in the database), the fitness score of solutions was found to be low (0.7054) in the initial generations and this increases over generations to reach maximum best fitness score of 0.805.

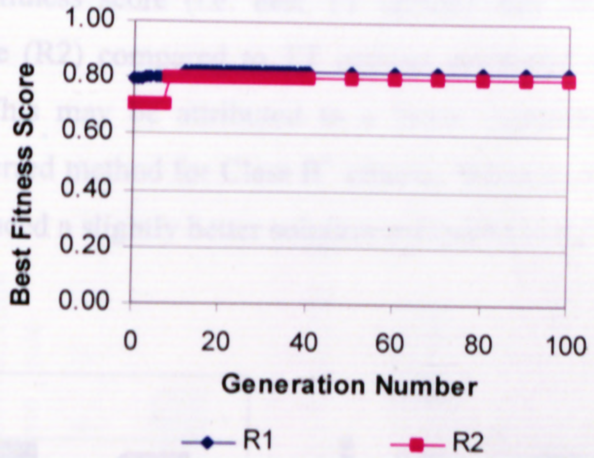


Figure 7.15 Comparison of Best Fitness Score for R1 & R2 (B)

On the other hand the percentage feasible solutions for the R2 method in the 0th generation was 55 % while it was only 37 % in R1 method as shown in Figure 7.14 (b and d). This is because in the R1 search space there are a total of only 29 unit processes, out of which a limited set of TT combinations are feasible (i.e. which can meet the reuse criteria and the rules). However the percentage of feasible solutions increases over generations by crossover and mutation as shown in Figure 7.14 (b & d). Whereas in the R2 method, the percentage of feasible solutions is higher to begin with as the search space includes all 40 unit processes.

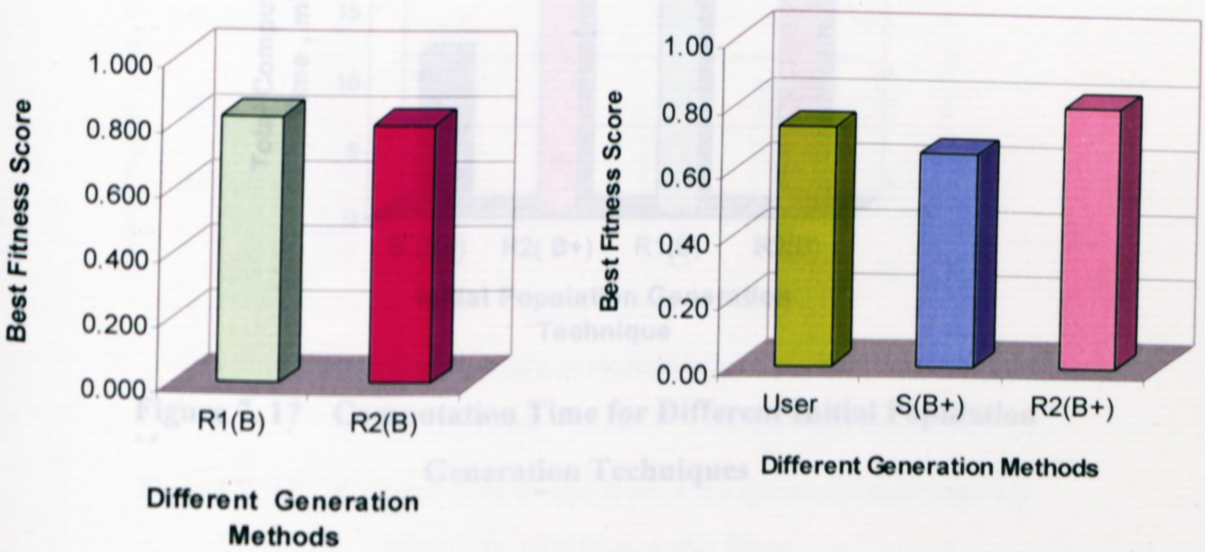
Overall, the R1 method generated the best TT solution to meet Class B criteria i.e. bar screen + primary clarifier w lime + anaerobic lagoon + facultative pond + chlorination + sludge drying beds + land filling of sludge.

7.3.3.5 Comparative Studies Between the User, Seed and Random Generated Options

In this section a comparison between different generation techniques in terms of computation time, fitness score and type of processes included are discussed. Further the comparison between user generated and MOSTWATAR options is also presented.

7.3.3.5(i) Best Fitness Versus Initial Population Generation Techniques

Figure 7.16 (a & b) illustrates the best fitness found overall in the S, R1 and R2 techniques for both Class B & B^+ criteria. As discussed earlier, the DPM technique produced better solutions compared to other penalty calculation methods for S and R2 methods. It can be seen that the best fitness score (i.e. best TT option) was obtained using the random generation technique (R2) compared to TT options generated by the user and seed for Class B^+ criteria. This may be attributed to a better exploration of search space and therefore is the preferred method for Class B^+ criteria. Whereas in case of Class B criteria, the R1 method produced a slightly better solution compared to R2 method.



(a) Class B (b) Class B^+

Figure 7.16 Comparison of Best TTs Generated Using S, R1 and R2

7.3.3.5 (ii). Comparison of Types of Processes in TT options for S and R2 (B^+)

In the case of Class B^+ criteria, TT options generated by Seed method consisted mainly of ASP w Ni for BOD & TN removal, primary clarifier with lime and two-stage lime treatment for TP removal. While the TT options generated by the R2 method consisted of BNR, primary clarifier with lime and /or two-stage lime treatment for removal of BOD, TN and TP. Furthermore, the APM & ADPM method selected FWS wetlands along with ASP w Ni and two-stage lime treatment.

7.3.3.5 (iii). Evaluation of Computation Time for S and R2

Figure 7.17 shows the computation time required to generate and optimise a population size of 100 TTs (over a maximum of 100 generations) for different generation techniques and reuse criteria. This study was carried out using a Pentium III system with a processor speed of 966 MHz. The computation time for generation and optimisation of TTs using Seed method is the least, as a set of TTs based on the recommended guideline is used to seed the initial population.

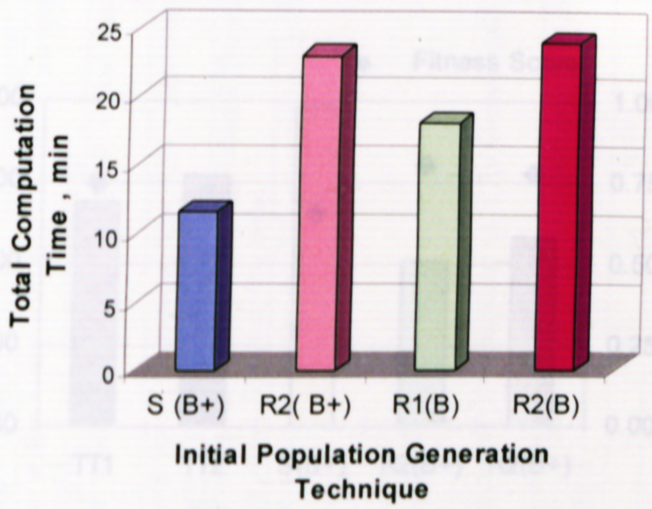


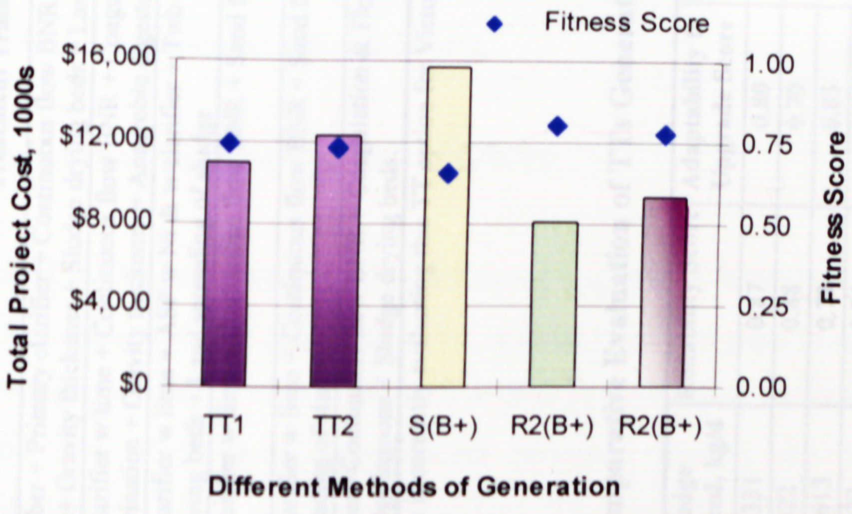
Figure 7. 17 Computation Time for Different Initial Population Generation Techniques

For the current case study, the total computation time using Seed method was an average of 10 minutes. Whereas for R2 (B^+) and R2 (B) the computation time was found to be 21 and 24 minutes respectively. While the time taken for R1 (B) method was much less and was 1.5 to 1.8 times the time required by the Seed method. This is because in the R1 (B) method the total number of processes in the case of Class B criteria is 29 as against 40 unit processes for the R2 (B) and R2 (B^+).

7.3.3.6 Comparison of the User & MOSTWATAR Generated New WWTP Options for B⁺ Criteria

In order to compare MOSTWATAR options with the user-generated options, the best TT options generated by using S and R2 (B^+) methods are compared with those generated by the user. The types of processes included in each of the TTs are presented in Table 7.31 below. As shown in this Table the best TT option was generated by the R2 (DPM) method whereas the Seed method generated a TT option with the lowest fitness score. It can be noted that the R2 method generated a TT, that required less land, and lower life cycle cost compared to the other generation methods as shown in Table 7.32.

The total project cost of the TT options and the fitness score is illustrated in Figure 7.18. This Figure shows that the best TT generated by R2 (DPM) method had the lowest total project cost while the TT generated by the Seed method had the highest total project cost.



(Note: TT1 and TT2 are generated by the user)

Figure 7. 18 Comparison of the Best TT Options Generated by MOSTWATAR and the User

The above Figure shows that the best solution was generated by R2 (DPM) method while the Seed (B+) generated the worst solution. This indicates that the restrictive search space in the initial population actually hinders the optimisation process and therefore may not be suitable for generation and optimisation.

Table 7.31 Summary of the Best TT Options Generated by the User and MOSTWATAR

Method of Generation	Treatment Trains	Fitness Score
User	Bar screen + Grit Chamber + Primary clarifier + Continuous flow BNR + Coagulation, flocculation & Sedimentation + Sand filter + UV disinfection + Gravity thickener + Sludge drying beds + Land spreading of sludge	0.742
User	Bar screen + Primary Clarifier w lime + Continuous flow BNR + Coagulation & flocculation + Dual media filter + UV disinfection + Post chlorination + Gravity thickener + Anaerobic digester + Sludge drying beds + Land spreading of sludge	0.731
Seed (B^+)*	Bar screen + Primary Clarifier w lime + ASP w Ni & w clarifier + Two stage lime treatment + Dual media filter + UV disinfection + Sludge drying beds + Land spreading of sludge	0.655
R2(B^+, DPM1)*	Bar screen + Primary Clarifier w lime + Continuous flow BNR + Sand filter + UV disinfection + Sludge drying beds + Land spreading of sludge	0.801
R2(B^+, DPM2)*	Bar screen + Primary Clarifier w lime + Continuous flow BNR + Sand filter + UV disinfection +Post chlorination + Sludge drying beds + Land spreading of sludge	0.776
SA Water**	Bar screen + Grit chamber +Continuous flow BNR + Coagulation & Flocculation + Dual media filter + UV disinfection + Gravity thickener + Sludge lagoons + Sludge drying beds.	---

*Generated by MOSTWATAR, ** SA Water is currently evaluating this TT option for Victor Harbor. Since the current database does not include sludge lagoons the fitness score is not calculated.

Table 7.32 Comparative Evaluation of TTs Generated by the User and MOSTWATAR

Method of Generation	Total Land Required, ha	Sludge Produced, kg/d	Reliability Score	Adaptability to Upgrade Score	Life Cycle Cost, \$/m3	Final Effluent Quality		
						BOD, mg/L	SS, mg/L	FC, No/100mL
User (1)	1.68	2,331	0.87	0.80	0.83	3.1	1.5	4.5
User (2)	1.87	622	0.88	0.70	0.93	5.3	4.0	0
Seed (B^+)	1.66	1,613	0.79	0.83	1.19	2.3	1.8	0
R2(B^+,DPM1)	1.53	872	0.76	0.81	0.61	4.9	3.6	4.5
R2(B^+,DPM2)	1.59	872	0.79	0.75	0.70	4.9	3.6	0

As discussed earlier in this chapter, SA Water is currently evaluating TT options .The current preferred TT option by SA Water is shown in Table 7.31. The best 2 TT options generated by R2 (DPM method) consists of similar processes (except sludge lagoons which are not included in the current database) as those being currently evaluated by SA Water. This shows that MOSTWATAR can be used effectively for generating new WWTP.

7.4 Evaluation of Upgrade Options for Victor Harbor

This section presents a validation study carried out to evaluate upgrade treatment options for Victor Harbor WWTP using the MOSTWATAR model. This section is divided in to three main sub sections. In Section 7.4.1 the input data used for both the user and MOSTWATAR generated options is presented. The user generated TT options and the assessment of these alternatives by the MOSTWATAR model is presented in Section 7.4.2. While in Section 7.4.3 the alternatives generated and optimised by the genetic algorithm are presented. A comparison of options generated by the user and MOSTWATAR is presented in Section 7.4.4.

7.4.1 Input Data Used for Upgrade of WWTP

As discussed in Chapter 4 (See Section 4.5.4) the upgrade of WWTP in the current study refers to the addition of unit processes to the existing treatment plant to meet reuse criteria. The following assumptions were made with respect to the existing treatment processes.

- The two of the existing treatment processes namely the Imhoff tank and chlorination would be made redundant. The Imhoff tank is obsolete and was therefore considered to be redundant while the existing chlorination unit was made redundant in order to consider alternative disinfection schemes like UV, a maturation pond and post chlorination.
- All other processes (namely bar screen, TF rock media w clarifier, anaerobic digester, sludge drying beds and land filling of sludge) are in good working condition (see Figure 7.2 for the existing treatment scheme).
- As there is a high demand for irrigation water for golf courses in Victor Harbor, the treatment plant is to be upgraded to meet Class A quality (requirements of SA

reclaimed water guidelines). This also presents a contrast to the quality requirements considered for the design of new WWTP.

In the following paragraphs the site-specific data used for evaluating upgrade options for Victor Harbor WWTP is described. The design population and treatment capacity of the upgrade treatment facility are given in Table 7.33. Since the existing treatment plant capacity is reported as 8,000 EP (Engineering and water supply department, 1992) the upgrade facility was also designed for 8,000 EP as against 17,000 EP for the new WWTP presented in the previous sections. Influent wastewater characteristics are the same as those for the new WWTP and are presented in the Table below.

Since it has been recommended to reduce nitrogen levels and odour to overcome excessive growth of grass and discomfort to golfers, the TN and TP values in reclaimed water were set to 5 and 0.5 mg/L respectively. Therefore, in addition to the BOD, turbidity and faecal coliforms criteria values set by SA reclaimed water guidelines, it is envisaged to limit the TN and TP values to 5 and 0.5 mg/L respectively. This criteria is henceforth referred to as Class A^+ and the proposed upgrade treatment facility will be designed to treat wastewater to Class A^+ quality.

Table 7.33 Design Data Used for Evaluating Upgrade Options

Description	**Stage 1**	**Class A+***
Design Year	2009	-
Equivalent Population (EP)	8000	-
Per capita wastewater generation, lpcd	200	-
Average annual flow, m^3/d	1,600	-
Average dry weather flow, m^3/d	1,360	-
Peak wet weather flow, m^3/d	4,800	-
BOD, mg/L	250	20
SS, mg/L	300	-
TN, mg/L	65.0	5**
TP, mg/L	12.0	0.5**
Turbidity, NTU	50 #	2
FC, no/100mL	10^6	10

(# Influent turbidity is not monitored in this plant nor is reported in the literature for any other plants in South Australia. Hence a value of 50 NTU was used, * SA reclaimed water guidelines, 1999, **Designated values from ECA 2001)

In order to compare TTs generated by the user and MOSTWATAR, the following criterion values listed in Table 7.34 was used for scaling the objective function. The maximum and minimum values for upgrade options were set much lower than for the new plants. This is because in case of upgrade options the cost, land and sludge produced is evaluated for only new or additional processes.

Table 7.34 Maximum and Minimum Values Used for Scaling

Type of criterion	Maximum Value	Minimum Value
Total Project Cost, 1000s $	30,000	0.02
Land Required, ha	40	0.1
Sludge Produced, kg/d	3500	0*

(*value of '0' is assumed as the minimum value as for TTs in which land based treatment systems are present the sludge is not removed every day but is instead desludged once every 3 to 5 years)

The user-input data used to evaluate upgrade options for Victor Harbor plant is presented in Table 7.35. These values were input to the model using user-interfaces discussed in the previous Chapter. Further, the default values for the relative weights shown in Table 7.3c were used while the GA parameter values are discussed in Section 7.4.3.

Table 7.35 Input Data Used for Evaluating Upgrade Options for Victor Harbor

Module	Name of the Variable	Input Values
Community Data	*Type of WWTP plant* New Upgrade of existing Plant	 - Yes
	Wastewater Flow Initial project year	 2001
	Initial project population	-
	Design period, yrs	25
	Estimated design population	8,000
	Per capita wastewater generation, lpcd	200
	Peaking Factors Relative to Average Flow: Peak monthly	 1.4
	Peak daily	2.5
	Peak hourly	3.0
	Unit Cost Data Site electrical *	 9 %
	Site development*	6 %
	Control &instrumentation*	6 %
	Plant piping*	10 %
	Site excavation*	8 %
Reuse Criteria	Type of reuse(s) desired:	Irrigation of golf course with unrestricted access
	Type of guideline selected:	SA Reclaimed Water Guidelines (Class A^+)
	Guideline Values BOD, mg/L	 10
	SS, mg/L	-
	FC, No/100mL	10
	TN, mg/L	5**
	TP, mg/L	0.5**
	Turbidity, NTU	2
Form TT	*Specify TT* User MOSTWATAR Both the above options	 Both

(* Percentages of total unit process construction cost,** Source: SCH report, 2000)

7.4.2 User Generated Upgrade Options

As described in the Section 6.4.3.2, firstly the user needs to input the community data along with the existing unit processes as shown in Table 7.36. In this case study, based on the assumptions made in the previous Section, the following unit processes were selected as existing treatment processes.

> *Bar screen, TF Rock media w clarifier, Anaerobic digester, Sludge drying beds and Land filling of sludge.*

To demonstrate the methodology for the selection and evaluation of upgrade options, 5 treatment trains listed in Table 7.37 were generated by the author.

7.4.2.1 Output for the User Generated Options

As in the case of new treatment options, the output of the MOSTWATAR has been divided in to 4 main sections namely community data, list of TT alternatives, details of TT alternatives and summary as described in Section 6.4.8.1. The results obtained for the user-generated upgrade options are outlined in the Tables 7.36 - 7.39.

Out of the 5 options generated, only 3 TT options namely TT2, TT3 and TT4 (as shown in Table 7.39) are feasible. The details of the best TT alternative namely TT2 is presented in Table 7.38 while the construction cost details for this TT is presented in Table 7.38a. As seen from this Table (7.38a), the BNR process is major component of upgrade as it forms 32 % of the total unit process construction cost. The output sheets for the remaining TT alternatives are presented in Tables J.18 to J.21a in Appendix J.

The summary sheet obtained from MOSTWATAR output for average removal efficiency is presented in Table 7.39. This summary sheet presents the effluent quality achieved by each upgrade option generated by the user. Further, the final effluent quality is compared against the reuse criteria selected by the user. As in the case of new WWTP options, the qualitative criteria scores, land required and sludge produced by each of the TTs are also presented in this sheet. However in this case the total construction cost, land required and sludge produced is reported for only new processes added. In Table 7.39, the TTs are sorted by their fitness score.

Table 7. 36 Community Input Data for Upgrade of Treatment Plant at Victor Harbor

Printed on20/03/2002

Community Data

Name of the Community	Victor Harbor (Upgrade Options- MOSTWATAR)
Planning Authority	SA Water Corporation
State	SA Country Australia
Entered By	Dinesh

Design Information

Design Population	8000
Per Capita Wastewater Generation,lpcd	200
Average Annual Flow, m3/d	1600(1.60)*
Dry Weather flow, m3/d	1360(1.36)
Peak Monthly Flow, m3/d	1920(1.92)
Peak Daily Flow, m3/d	3840(3.84)
Peak Wet Weather Flow, m3/d	4800(4.80)

* Note: The figures inside the brackets indicate flow in million litres per day,ML/d

Type of Wastewater Treatment Plant: Upgrade of an Existing Plant

Existing Treatment Processes:
Bar Screen+TF,Rock Media, w Clarifier+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge

	BOD,mg/L	SS,mg/L	NH3-N,mg/L	ON,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Influent Wastewater Characteristics:	250	300	48	17	65	12	1000000	50

Peak Daily Organic Loading

BOD, kg/d	1120
SS, kg/d	1344
TN, kg/d	291
TP, kg/d	54

Desired Reuse Application(s) Irrigation of Golf Course with Unrestricted Access
Selected Reuse Guideline SA Reclaimed Water Guidelines, April 1999

Relative Weights Assigned for Different Selection Criteria:

Adaptability to Upgrade:	8	Odour Generation Potential:	6	Reliability:	9
Adaptability to Varying Flow Rate:	4	Land Requirement:	5	Chemical Requirement:	5
Adaptability to Varying Influent Quality:	7	Sludge Production:	8	Ease of O & M:	5
Ease of Construction:	3	Power Requirement:	2	Impact on Ground Water:	3
Total Project Cost:	2*	(*This indicates that Total Project Cost is 2 times more important than the sum of all other criteria)			

Table 7. 37 List of Upgrade Options Generated by the User

Printed on 27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

Upgrade Options Generated by: Dinesh

TTIDNo	TTName	Treatment Processes*	Fitness Score
1	TT1	Bar Screen + Primary Clarifier + TF,Rock Media, w Clarifier + ASP w Ni & w Clarifier + Single Stage Lime Treatment + Sand Filter + UV Disinfection + Anareobic Digestor + Sludge Drying Beds + Land Filling of Sludge	-42.744
2	TT2	Bar Screen + Grit Chamber + Primary Clarifier + TF,Rock Media, w Clarifier + Continuous Flow BNR + Coagulation, Flocculation & Sedimentation + Sand Filter + UV Disinfection + Anareobic Digestor + Sludge Drying Beds + Land Filling of Sludge	0.815
3	TT3	Bar Screen + Primary Clarifier w lime + TF,Rock Media, w Clarifier + SBR + Break Point Chlorination + Coagulation & Flocculation + Sand Filter + UV Disinfection + Anareobic Digestor + Sludge Drying Beds + Land Filling of Sludge	0.725
4	TT4	Bar Screen + Primary Clarifier + TF,Rock Media, w Clarifier + Continuous Flow BNR + Coagulation, Flocculation & Sedimentation + Microfiltration + UV Disinfection + Anareobic Digestor + Sludge Drying Beds + Land Filling of Sludge	0.715
5	TT5	Bar Screen + Primary Clarifier w lime + TF,Rock Media, w Clarifier + FWS Wetland (BOD & Ni) + Maturation Pond + Post Chlorination + Anareobic Digestor + Sludge Drying Beds + Land Filling of Sludge	-132.090

*Note: Existing Treatment Processes are as Follows:

Bar Screen , TF,Rock Media, w Clarifier , Anareobic Digestor , Sludge Drying Beds , Land Filling of Sludge

Table 7. 38 Details of the Upgrade Option Generated by the User

Printed on 27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

TT OPTION-2:TT2

Treatment Train: Bar Screen+Grit Chamber+Primary Clarifier+TF,Rock Media, w Clarifier+Continuous Flow BNR+Coagulation, Flocculation & Sedimentation+Sand Filter+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge

Desired Reuse(s): Irrigation of Golf Course with Unrestricted Access
Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	-	5	0.5	10	-
Effluent Quality Achieved:	0.8	0.4	2.9	0.2	3.8	0.6

Meets Criteria (Yes/No): YES

Effectiveness Measures

Upgrade:	0.85
Varying flow rate:	0.79
Varying influent quality:	0.91
Ease of O & M:	0.79
Ease of construction:	0.67
Reliability:	0.82
Odour:	0.33
Ground water impact:	0.82
Chemical requirement:	0.88
Power requirement:	0.45

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	0.67
Sludge produced, kg/day:	1401

Table 7. 38a Construction Cost Details for the Upgrade Option Generated by the User

Printed on 27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

Summary of Construction Cost Estimate for TT Option-2:TT2

Item	**Construction Cost 1000s $**
Bar Screen*	--
Grit Chamber	***$91***
Primary Clarifier	***$238***
TF,Rock Media, w Clarifier*	--
Continuous Flow BNR	***$549***
Coagulation, Flocculation & Sedimentation	***$272***
Sand Filter	***$420***
UV Disinfection	***$86***
Anareobic Digestor*	--
Sludge Drying Beds*	--
Land Filling of Sludge*	--
Miscellaneous Cost**	$33
Additional Unit Process Construction Cost	**$1,691**
Additional Cost***	$507
Total Construction Cost for Upgrade of WWTP	**$2,199**
Engineering and Contingency Cost	$594
Total Capital Cost	**$2,792**
Total Land Cost	$257
PV O & M Cost	**$1,472**
Total Project Cost	**$4,521**
Annualised Project Cost @*	**$423**
Life Cycle Cost @**	**$0.73**

*Indicates an existing unit process and the cost of these processes are not included in the Total Project Cost
**Miscellaneous cost includes: Cost for minor modifications to existing plants
***Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
@* $/yr,@** Life cycle cost is expressed as $/m3 of reclaimed water

Table 7. 39 Summary of the Upgrade Options Generated by the User

Printed on27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

Design Population:8000
Design Average Flow,m3/d:1600
Design Peak Flow,m3/d:4800

Summary of Evaluation of Upgrade Options Generated by the User

Items	R.Criteria	TT2	TT3	TT4	TT1	TT5
BOD,mg/L	20	0.8	1.8	0.5	0.4	2.5
SS,mg/L	-	0.4	0.8	0.5	0.5	0.9
TN,mg/L	5.0	2.9	1.6	1.1	3.7	7.2
TP,mg/L	0.5	0.2	0.4	0.3	1.0	1.9
FC,No/100mL	10	3.8	1.5	9.2	3.5	0.1
Turbidity,NTU	2	0.6	1.5	1.6	3.3	0.9
Meets criteria (Yes/No)		YES	YES	YES	NO	NO
Upgrade		0.85	0.91	0.83	0.90	0.85
Varying flow rate		0.79	0.70	0.73	0.73	0.70
Varying influent quality		0.91	0.88	0.90	0.83	0.93
Ease of O & M		0.79	0.70	0.77	0.77	0.74
Ease of construction		0.67	0.76	0.67	0.67	0.74
Reliability		0.82	0.76	0.67	0.67	0.74
Odour		0.33	0.42	0.37	0.40	0.26
Ground water impact		0.82	0.82	0.80	0.70	0.56
Chemical requirement		0.88	0.70	0.87	0.87	0.81
Power requirement		0.45	0.45	0.40	0.53	0.52
Total land required, ha		0.67	0.40	1.94	0.40	15.47
Total sludge produced,kg/d		1401	361	1359	585	319
Total capital cost*		$2,792	$5,446	$6,694	$3,148	$3,641
Total land cost*		$257	$254	$269	$254	$405
PV O & M cost*		$1,472	$3,171	$1,980	$2,404	$2,763
Total project cost*		**$4,521**	**$8,871**	**$8,944**	**$5,806**	**$6,809**
Annualised project cost**		**$423**	**$831**	**$838**	**$544**	**$638**
Life cycle cost***		**$0.73**	**$1.42**	**$1.43**	**$0.93**	**$1.09**
Fitness score		**0.815**	**0.725**	**0.715**	**-42.744**	**-132.090**

NOTE: Alternatives Sorted by :Max Fitness Score.Fitness score scaled from 0 to 1, a negative score indicates an infeasible treatment train, *1000s $,**1000s $/yr,***$/m3

7.4.3 Upgrade Options Generated by MOSTWATAR

This section describes the upgrade options generated by MOSTWATAR. Since Class A^+ quality was required, the R2 method was used to generate TTs as tertiary unit processes would be required to achieve Class A^+ quality. As in the case of Class B^+, both the R1 and R2 methods are the same as the recommended treatment for Class A includes tertiary unit processes in the database. Seed TTs described in Section 5.4.3.2 were not used for the following reasons.

- The Seed method was included in this research to establish if the computation time for the initial generation could be reduced. Although Seed TTs, reduce time for the initial population by 2.5 times, the solutions selected were inferior for a new WWTP as discussed in Section 7.3.3.3.
- Furthermore, the existing treatment train actually acts like a seed as the generation of the initial population is carried out using the existing unit processes. Since the existing unit processes were used in the generation of initial population, the time taken to generate 100 TTs meeting rules was just 1 to 1.5 minutes as against 5 to 7 minutes for new WWTP options. Hence in this case study only the R2 method of generation was tested.

The initial test runs indicated that a smaller population size (n = 50) with a higher mutation rate (P_m = 0.7) yielded better solutions for upgrade options as against a population size of 100 and mutation rate of 0.2 for new TTs. The GA parameters used for the generation of upgrade options for Victor Harbor are listed in Table 7.40.

Table 7.40 GA Parameters Used for Generating Upgrade Options

GA Parameters	Values/Types used
Population size	50
Tournament size	2
Probability of selection, P_s	0.6
Probability of crossover, P_c	0.8
Probability of mutation, P_m*	0.7
Maximum number of generations	100
Type of penalty calculation method	APM, MPM, DPM, ADPM
Type of initial population generation	R2

* on an average 70% of the strings will mutate in a population

As discussed earlier in Section 5.4.3.3, the initial population for upgrade options was generated using the existing unit processes. In addition to the rules set out in Table 4.5.2, a check was made in every generation to ensure that the TT strings included the existing unit processes. It was observed that of the initial population of 50 TT strings, about 18 to 22 % were feasible (i.e. meeting rules and criteria) and about 2250 to 2400 TT strings had to be generated to get 50 TT strings that meet rules. This took just 25 to 30 seconds of the total computation time.

As in case of new WWTP options, four penalty calculation methods were tested for the generation and optimisation of upgrade options. The variation of best fitness score and the percentage feasibility for the trial using random number seed of 9999 is presented in Figure 7.19.

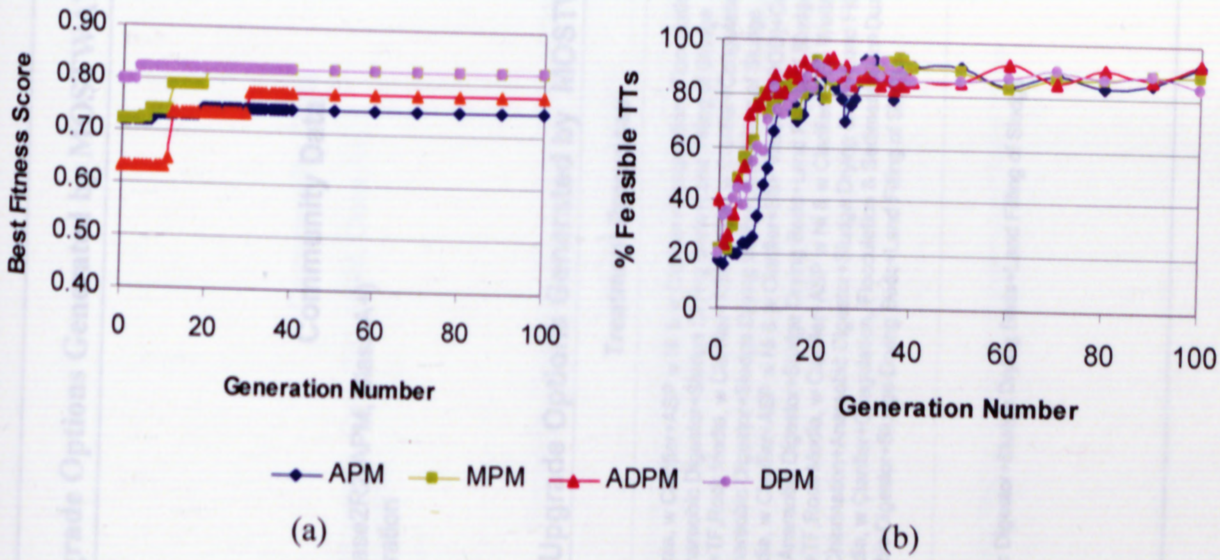


Figure 7. 19 Variation of Best Fitness Score and Percentage Feasibility for Different Penalty Methods (Case 2R2-A^{+})

The Figure 7.19 (a) shows that the best fitness score ranged from 0.6250 to 0.7940 in the initial population, while only 18 to 22 % were feasible (i.e. those meeting rules and criteria) as shown in Figure 7.19 (b). This Figure shows that the DPM method performed better than other penalty calculation methods as it selected the best upgrade option as shown in Figure 7.20. This is similar to the previous case of new TT options. The best TTs obtained for Trial 1 with random number seed of 9999 is presented in Tables 7.41 to 7.44. Each of these cases is represented as Case 2R2-APM (A^{+}) to represent the additive penalty method, Case 2R2-MPM (A^{+}) for the multiplicative penalty method and so on.

Table 7. 41 Upgrade Options Generated by MOSTWATAR for Case 2R2-APM (A^+)

Printed on 26/03/2002

Community Data

Name of the Community	Victor Harbor (Case2R2-APM, Class A+)`
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	Dinesh

Upgrade Options Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
19	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+ASP w Ni & w Clarifier+Coagulation, Flocculation & Sedimentation+Dual Media Filter+Chlorination+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.745
7	Bar Screen+Fine Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+ASP w Ni & w Clarifier+Coagulation, Flocculation & Sedimentation+Dual Media Filter+Chlorination+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.731
12	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+ASP w Ni & w Clarifier+SSF Wetland (BOD)+Coagulation, Flocculation & Sedimentation+Dual Media Filter+Chlorination+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.720
19	Bar Screen+Fine Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+ASP w Ni & w Clarifier+SSF Wetland (BOD)+Coagulation, Flocculation & Sedimentation+Dual Media Filter+Chlorination+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.705
14	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Coagulation, Flocculation & Sedimentation+Dual Media Filter+Reverse Osmosis+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.584

*Note: Existing Treatment Processes:

Bar Screen+TF,Rock Media, w Clarifier+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge

Table 7. 42 Upgrade Options Generated by MOSTWATAR for Case 2R2-MPM (A^+)

Printed on 26/03/2002

Community Data

Name of the Community	Victor Habor (Upgrade, Case 2R2-MPM, Class A+)
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	N.Dinesh

Upgrade Options Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
20	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Continuous Flow BNR+Break Point Chlorination+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.822
30	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Continuous Flow BNR+Dual Media Filter+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.817
20	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Continuous Flow BNR+Break Point Chlorination+Dual Media Filter+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.790
7	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+FWS Wetland (BOD & Ni)+Continuous Flow BNR+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.739
9	Bar Screen+Grit Chamber+Primary Clarifier w lime+TF,Rock Media, w Clarifier+FWS Wetland (BOD & Ni)+Continuous Flow BNR+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.737

*Note: Existing Treatment Processes:
Bar Screen+TF,Rock Media, w Clarifier+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge

Table 7. 43 Upgrade Options Generated by MOSTWATAR for Case 2R2-DPM (A^+)

Printed on 26/03/2002

Community Data

Name of the Community	Victor Harbor(Case2R2-DPM, Class A+).
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	Dinesh

Upgrade Options Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
4	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Continuous Flow BNR+Break Point Chlorination+UV Disinfection+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.822
12	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Continuous Flow BNR+Dual Media Filter+UV Disinfection+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.817
21	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+ASP w Ni & w Clarifier+Single Stage Lime Treatment+UV Disinfection+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.795
10	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Continuous Flow BNR+Break Point Chlorination+Dual Media Filter+UV Disinfection+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.790
11	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+FWS Wetland (BOD)+Continuous Flow BNR+Coagulation, Flocculation & Sedimentation+Dual Media Filter+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.781

*Note: Existing Treatment Processes:
Bar Screen+TF,Rock Media, w Clarifier+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge

Table 7. 44 Upgrade Options Generated by MOSTWATAR for Case 2R2-ADPM (A^+)

Printed on 26/03/2002

Community Data

Name of the Community	Victor Harbor (Case 2R2- ADPM, Class A+)
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	Dinesh

Upgrade Options Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
30	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+SSF Wetland (BOD)+Continuous Flow BNR+Break Point Chlorination+Chlorination+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.775
31	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+SSF Wetland (BOD)+Continuous Flow BNR+Single Stage Lime Treatment+Chlorination+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.765
30	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+SSF Wetland (BOD)+Continuous Flow BNR+Single Stage Lime Treatment+Break Point Chlorination+Chlorination+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.738
32	Bar Screen+Grit Chamber+Primary Clarifier w lime+TF,Rock Media, w Clarifier+SSF Wetland (BOD)+Continuous Flow BNR+Single Stage Lime Treatment+Break Point Chlorination+Chlorination+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.735
33	Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+FWS Wetland (BOD & Ni)+Continuous Flow BNR+Break Point Chlorination+Dual Media Filter+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge	0.687

*Note: Existing Treatment Processes:
Bar Screen+TF,Rock Media, w Clarifier+Anaerobic Digestor+Sludge Drying Beds+Land Filling of Sludge

7.4.3.1 Comparison of Upgrade Options Generated by Different Penalty Methods

As can be seen from the Tables (7.41 to 7.44), DPM and MPM methods selected the best TT option with a fitness score of 0.822. This upgrade option consists of primary clarifier w lime, BNR, break point chlorination and UV disinfection. The summary of upgrade evaluation is presented in Tables J.22 to 25 for Case 2R2 APM, MPM and ADPM respectively. The comparison of total project cost and best fitness score of the best upgrade options generated by different penalty calculation methods is shown in Figure 7.20.

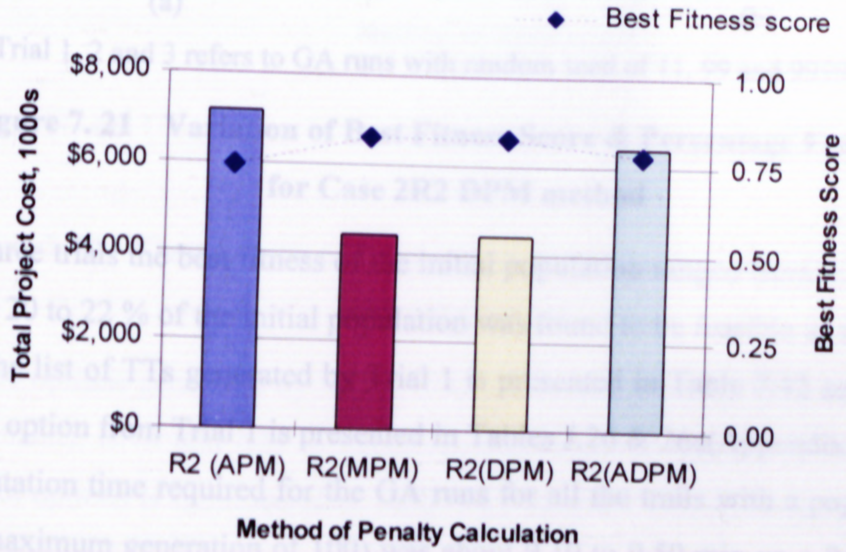
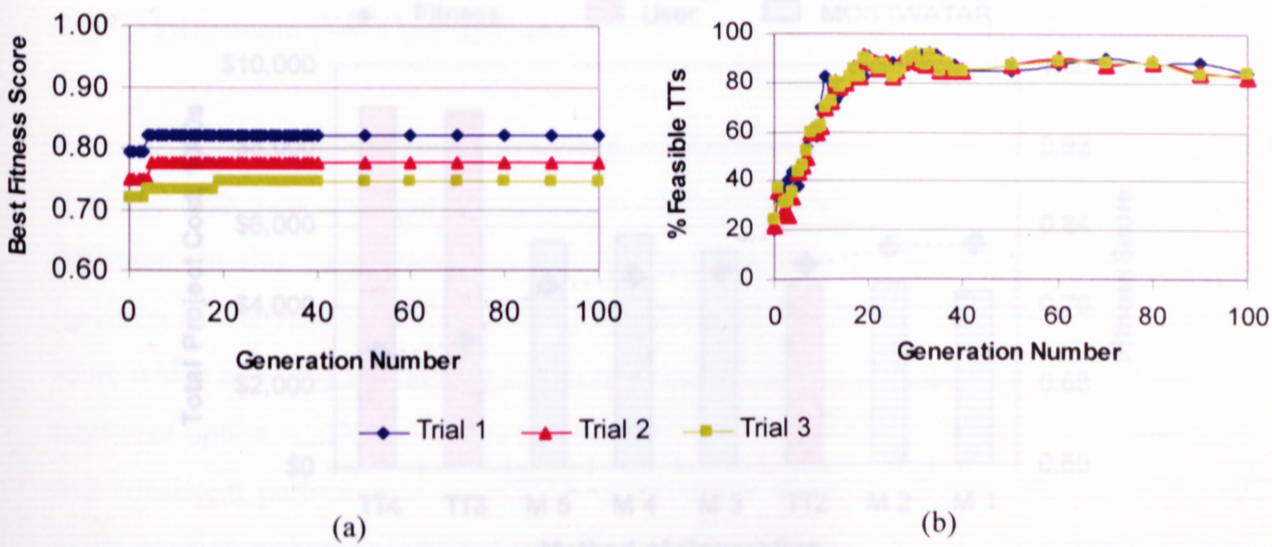


Figure 7. 20 Comparison of Penalty Methods for Upgrade Options Generated using R2 Technique

Although both the MPM and DPM methods generated the best TT option, the TT options were generated at 20th and 30th generation in MPM method as against 4th, 12th and 21st generations for the DPM method as shown in Table 7.42 and 7.43. Hence, subsequent trials were carried out using the DPM method.

7.4.3.2 Generation of Upgrade Options using the DPM method

As in case of new TT options, the upgrade options were generated using DPM method with three different random number seeds. The variation of best fitness score and percent feasible TTs for these three trials is shown in Figure 7.21.



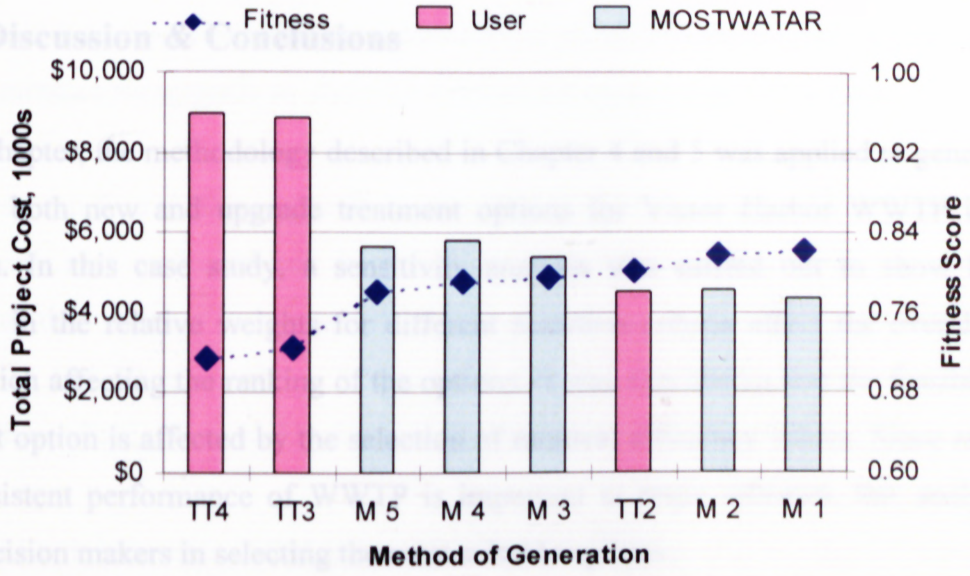
(Note: Trial 1, 2 and 3 refers to GA runs with random seed of 11, 99 and 9999 respectively)

Figure 7. 21 Variation of Best Fitness Score & Percentage Feasibility for Case 2R2 DPM method

In all the three trials the best fitness of the initial population ranged from 0.7196 to 0.7948. While only 20 to 22 % of the initial population was found to be feasible as shown in Figure 7.21 (b). The list of TTs generated by Trial 1 is presented in Table 7.42 and the details of the best TT option from Trial 1 is presented in Tables J.26 & 26a(Appendix J). Further, the total computation time required for the GA runs for all the trails with a population size of 50 (and a maximum generation of 100) was about 9.10 to 9.50 min on a Pentium III (966 MHz system). In the next section, a comparison is made between the upgrade options generated by MOSTWATAR and the user.

7.4.4 Comparison of the User and MOSTWATAR Generated Upgrade Options

The total project cost and the fitness score of the upgrade options generated by the user and those by MOSTWATAR are shown in Figure 7.22. The options generated by MOSTWATAR are represented as M1, M2 to M5. As seen from this Figure, the best upgrade option was generated by MOSTWATAR. The total project cost for the upgrade options generated by MOSTWATAR ranged from \$4.40 to \$5.66 million while it ranged from \$4.52 to \$8.94 million for the feasible options generated by the user.



(Note: TT1 and TT5 generated by the user are not feasible and hence not shown in this Figure)

Figure 7. 22 Comparison of Upgrade Options Generated by the User and MOSTWATAR

The upgrade options generated by MOSTWATAR selected a wide range of unit processes such as wetlands, BNR and ASP w nitrification as shown in Table 7.44. The comparative evaluation of options is summarised in Table 7.45. In this Table, the best options generated by the user and MOSTWATAR are shown in blue and red colours respectively.

Table 7. 45 Comparative Evaluation of Upgrade Options

Method of Generation	Total Land Required, ha	Reliability Score	Adaptability to Upgrade Score	Final Effluent Quality						Life Cycle Cost, $/m^3$
				BOD, mg/L	SS, mg/L	TN, mg/L	TP, mg/L	FC, No/100 mL	Turbidity, NTU	
TT2*	**0.67**	**0.82**	**0.85**	**0.8**	**0.4**	**2.9**	**0.2**	**3.8**	**0.6**	**0.73**
TT3*	0.40	0.76	0.91	1.8	0.8	1.6	0.4	1.5	1.5	1.42
TT4*	1.94	0.67	0.83	0.5	0.5	1.1	0.3	9.2	1.6	1.43
M-1	0.59	0.74	0.85	2.3	3.3	1.9	0.4	6.1	3.9	0.70
M-2	**0.66**	**0.78**	**0.81**	**1.5**	**1.1**	**3.7**	**0.2**	**0.2**	**0.1**	**0.73**
M-3	0.30	0.70	0.89	0.5	1.3	4.4	0.4	8.4	3.9	0.87
M-4	0.68	0.77	0.83	1.5	1.1	1.5	0.2	0.1	0.1	0.93
M-5	7.17	0.83	0.83	0.1	0.1	2.1	0	9.2	0	0.91

(Note: * Generated by the user, M-1 to M-5 generated by MOSTWATAR)

7.5 Discussion & Conclusions

In this Chapter, the methodology described in Chapter 4 and 5 was applied to generate and optimise both new and upgrade treatment options for Victor Harbor WWTP in South Australia. In this case study, a sensitivity analysis was carried out to show how the variation in the relative weights for different selection criteria affect the overall fitness score which affecting the ranking of the options. It was also shown that the feasibility of a treatment option is affected by the selection of removal efficiency values. Since reliability and consistent performance of WWTP is important in reuse schemes, this analysis can assist decision makers in selecting the most suitable options.

Rules set up in the database were effective in eliminating infeasible TT options in the initial population while in the subsequent generations they were effective in differentiating feasible & infeasible options. It was observed that some TT options with UV disinfection immediately after BNR or ASP were found acceptable by the model although designers seldom approve this because of possible high influent turbidity. However, with the current database of removal efficiency, it was possible to reduce the turbidity levels of the influent to less than 5 NTU. This indicates that in practice, the actual removal efficiency can be lower than what is reported in the literature.

In order to demonstrate how the random generation of TTs is affected by the recommended treatment by the guideline, TT options for both class B and B^+ criteria were evaluated in this case study. The percentage of feasible TTs in the initial population varied from 30% in case of using a seed to 19 - 32 % while using random generation (R2) for class B^+ criteria. On the other hand, in case of Class B criteria, percentage feasibility in the initial population varied from 32 to 37% in case of R1 as against 45 to 50 % in case of R2 methods as TTs are generated using the entire search space.

Four different TT generation methods were studied. The complete random generation of TTs did not produce any feasible solution while the generation of TTs using a known set of TTs (based on recommended treatment) produced solutions inferior to those selected by random generation methods. On the other hand the random generation of TTs using the R1 and R2 method required about 18 to 25 % of the total computation time to generate 100

TTs that met the rules. The total computation time using random generation method varied from 9.5 minutes for upgrade to about 23 minutes for optimising new options.

In this research four different penalty calculation methods namely APM, MPM, DPM & ADPM were also evaluated and it was found that dynamic penalty method performed better than the others. For a population size of one hundred, convergence occurred in between 25 and 50 generations. It was also observed that a higher mutation rate was required than what is discussed by Simpson and Goldberg, 1994.

The type of unit processes included in any TT option is dependent on the reuse criteria and the type of initial population generation used. This is evident from the type of unit processes selected from R1 and R2 methods for Class B criteria. For the same Class B criteria, R1 method selected land based treatment systems with chlorination while R2 method selected TTs that included sand filters and UV disinfection.

Most of the optimisation techniques that have been applied in the past are for very limited search space comprising of less than 30 unit processes. Furthermore these investigations carried out by researchers such as Rossman (1980) and Camara (1985) did not consider the screening rules as implemented in this model. Hence a comparison of computation time or optimisation techniques could not be made.

In this case study, it was shown that the least total project cost to construct and operate a new WWTP in Victor Harbor to treat wastewater to Class B^+ quality, was $ 8.1 million. The cost estimated by MOSTWATAR was found to be in the range of what is being estimated by SA Water consultants (ECA, 2001). On the other hand, to upgrade the existing plant to meet Class A^+ quality set by the SA reclaimed water guidelines; the least project cost was $4.37 million. Furthermore, it is to be noted that with upgrade of the existing plant, the additional population influx during summer seasons was not taken in to account as the upgrade facility was designed for 8,000 EP as against 17,000 EP for new WWTP.

Thus the following conclusions can be drawn from this case study.

- The complete random generation of unit process without any process constraints using the R3 method has shown that the solutions generated were not feasible even after 500 generations. This shows that the TTs generated by completely random method will not be feasible.
- Although the computation time taken for generation and optimisation for a seed was the least, the solutions generated using Seed was inferior.
- The random generation of TTs based on the recommended treatment produced better TT options for both Class B^+ and B criteria. Further the type of processes selected is dependent on the type of reuse criteria and the weight assigned for cost.
- The computation time required for the generation and optimisation of treatment options is about 9.5 to 23 minutes depending on the type of generation option selected on a 966 MHz Pentium III system. This can save lot of resources and man-hours put in for evaluation of options.
- Of the four penalty calculation methods, that DPM selected better options for both new and upgrade options.
- The genetic algorithm developed can generate good treatment options for both new plants and plant upgrades.
- The consistent results obtained from different random number seeds for the same input data has indicated that the TT options generated for a case can be reproduced. However the generalisation of this research to other locations in Australia was not validated as it was beyond the scope of this research.
- In this case study it was shown how the user and MOSTWATAR could generate alternative TTs for a feasibility analysis. It was also shown how the TTs generated by the model were superior in this case to those selected by the users.

The results presented in this chapter have demonstrated that MOSTWATAR can not only generate and optimise treatment options but also assist the user in the generation of suitable TT options for given reuse(s) and criteria. This case study has shown that by using the MOSTWATAR model, the decision makers can identify best 5 treatment options, which can be evaluated further in pilot plant studies before implementation.

Chapter 8 Conclusions and Recommendations

8.1 Thesis Summary

Reuse of reclaimed wastewater is becoming an integral part of sustainable water resources management in most countries including Australia. In order to meet stringent regulations and to overcome increasing water demand & environmental pollution, many new wastewater treatment plants are being designed with reclamation and reuse facilities as an integral feature. This has also resulted in existing plants being upgraded to meet reclaimed water quality criteria for various reuse applications.

The planning of any reuse scheme involves assessment of reuse opportunities, alternate treatment technologies and identification of financial and regulatory requirements. In this study, the primary focus was on the assessment of alternative technologies for reuse as this is very critical to ensure the delivery of reclaimed water at minimum health risks & cost to consumers.

There are a number of alternate technologies available to meet any reuse criteria. The increasing number of technologies has made the selection process difficult for facility planners and decision makers. Present methodologies and models to select appropriate reclamation technologies are inadequate. The only model developed for this purpose, called WAWTTAR has a number of limitations. In particular (a) it is intended primarily for developing countries, (b) it requires the user to specify the treatment trains to be considered and (c) it does not allow the user to evaluate upgrade options.

Thus there is a need for decision support systems to be developed to assist planners and wastewater managers in technical feasibility investigation (i.e. preliminary screening of alternatives) based on techno-economic and environmental aspects for Australian conditions. In the present study, a decision support system namely MOSTWATAR was developed to evaluate and select the best alternatives from a wide range of reclamation technologies applicable to municipal wastewater reclamation and reuse schemes in Australia.

MOSTWATAR model has a database of (1) performance, cost and qualitative scale for comparing unit processes and (2) reuse guidelines applicable to different states of Australia. The knowledge base consists of rules for (1) screening unacceptable treatment trains and (2) design of unit processes and allowable influent quality. This model has a user-friendly interface developed as a "point and click" type application.

In this study, the framework for feasibility investigation involved linking cost, performance and indices to a single objective of maximising the fitness function. This research also examined the application of genetic algorithms (GA) for the first time to optimise the selection of wastewater treatment processes. The objective of the GA module was to generate & optimise feasible treatment alternatives for both new and the upgrade of treatment plants for given reuse application(s) and site-specific conditions.

In order to generate TT alternatives in the initial population, the random generation of TTs using all or selected processes from the database (based on recommended treatment) was tested. In addition to this, the initial population was seeded with alternatives based on treatment levels recommended by the guidelines. Four different methods of penalty calculations were included for a comparative study. The methodology developed was then applied to a case study namely Victor Harbor in South Australia to evaluate both new and the upgrade treatment options.

8.2 Research Outcome

The outcome of this research is significant as wastewater reclamation and reuse has been focus of scientific and socio–economic attention in recent years in Australia. The most significant contribution of this research is the development of a decision support system, which can be used to select optimum TT alternatives rationally and objectively. This research has also demonstrated that GAs can be used successfully for the generation and optimisation of TT alternatives. Notable contributions of this research are listed below:

1. A user friendly decision support system named MOSTWATAR to guide planners through the decision-making steps for investigation of feasible treatment alternatives for given reuse(s) and reuse criteria.
2. A methodology for techno-economic evaluation of TTs.
3. A database and knowledge base of unit processes applicable to Australian conditions.
4. Pioneering of the application of GAs in wastewater treatment optimisation.
5. An algorithm to generate suitable new and upgrade treatment options for given conditions. Furthermore, different penalty calculation methods have been compared.

Each of these contributions is described in more detail below:

8.2.1 Development of a Decision Support System

MOSTWATAR has a user-friendly interface with which the user can enter site-specific details such as the design population and wastewater characteristics and select the reuse type and criteria. The user can even specify site-specific reuse criteria values. The user can form as many options as required and select the relative weights for various selection criteria. Based on these inputs, the model evaluates the TTs and computes the fitness score. The model also ranks the TT alternatives formed by the user and provides a possible reason for the infeasibility of any TT formed by the user. The major advantage of MOSTWATAR lies in the fact that it can be used to compare a large number of treatment alternatives.

On the other hand, the user can also specify that MOSTWATAR generate the options. Upon such a selection the model generates and optimises TTs. An important feature of this model is that it designs TT alternatives based on the input provided by the user. MOSTWATAR identifies the best five treatment trains. This model can be used for evaluation of both new and upgrade options.

8.2.2 Methodology for Evaluation of TTs

A methodology has been developed for techno–economic evaluation of TTs. A consistent methodology has been applied to develop cost equations, performance and qualitative criteria scores for the selected unit processes. Based on this, a fitness function has been developed to evaluate TTs. The contribution of this research to the methodology for the selection of appropriate wastewater reclamation and reuse technologies is significant, as few models have been developed so far to assist decision-makers in this area.

8.2.3 Database and Knowledge base

A database consisting of performance and qualitative scores for 40 unit processes were developed. A knowledge base consisting of design and cost of the unit processes was developed with the help of literature and information provided by the manufacturers and the South Australian water authority (SA Water). In addition, reuse guidelines applicable in different states and territories of Australia was also reviewed and collated in the database. The reuse applications were categorized into over 30 different types to compare different guidelines.

Another important feature of knowledge base is development of rules to form acceptable treatment alternatives. This also included rules based on site-specific factors and maximum allowable influent quality.

8.2.4 Genetic Algorithm to Generate and Optimise Alternatives

An algorithm has been developed to generate and optimise TT alternatives based on given local conditions. Several generation methods were tested to reduce the computation time for generation and evaluation of TTs. A review of the important findings of this study suggests that the GA module can successfully identify efficient TTs for both new and upgrade options for given conditions.

8.2.5 Limitations

The limitations of this model are listed below:

1. This model does not provide detailed design analysis of all the aspects of the implementation of a reuse scheme such as planning, site selection, impact analysis or the selection of suitable reuse alternatives.
2. It is not a design model but an effective tool for preliminary/comparative evaluation.
3. Currently the database has 40 unit processes. However in practice the number of unit processes available under each category is much higher.
4. This model does not include reclaimed water storage and distribution costs.
5. The cost database is based on South Australian conditions and cost indices for other states of Australia need to be incorporated.

8.3 Conclusions

In this section, general conclusions drawn from this research and specific conclusions from the case study are presented.

8.3.1 General Conclusions

The decision support system for the optimum selection of treatment processes has been successful developed. The model has been developed in a modular fashion so that the database and knowledge base can be easily updated. This model can be used for feasibility investigation of treatment alternatives by planners for various reuse applications in South Australia. The following conclusions can be drawn from this research:

- This research has proven that decision support system can assist the planners in the feasibility investigation of treatment alternatives. Since this model can generate and optimise TTs within 25 minutes, the planners can have best 5 alternatives to choose from rather than selecting just those that may have been selected with a bias.

- MOSTWATAR has a user-friendly interface and presents the input forms in an intuitive way. With the current rules and the knowledge base, MOSTWATAR can recommend best 5 TT alternatives suitable for a variety of reuse applications. Further MOSTWATAR also identifies infeasible TT alternatives.
- GAs have been successfully applied for the near-optimal selection of wastewater treatment alternatives for both new and upgrade of existing treatment plants for a given reuse.
- Another unique feature of MOSTWATAR is that it can also be successfully used for evaluation of upgrade options. This feature is going to be very useful to planning authorities as most of the existing plants in South Australia are being upgraded to meet the stringent EPA requirements.
- In order to minimize the preferences or biases of the users, it is necessary to carry out sensitivity analysis.
- In this research, four different penalty calculation methods were evaluated. These were: additive, multiplicative, dynamic and adaptive penalty methods. Of these methods the dynamic penalty was found to provide the best results for both new and upgrade options.
- The knowledge base and database has been developed with inputs from a wide variety of sources including information from reuse experts, manufacturer's and various literature and design manuals. It was found that often the information with regard to design, cost and performance, from these sources was either incomplete or contradictory and several assumptions had to be made.
- The complete random generation of unit process using R3 method has shown that the solutions generated were not feasible even after 500 generations. This shows that the TTs generated at completely random order will not be feasible and is therefore, not suitable for the generation of alternatives. It was found that in case of random generation, the percentage of infeasible solutions was high. About 75,000 to 80,000 TT strings had to be generated to find 100 feasible solutions that meet Class B quality using the R2 method.
- Convergence occurred between 30 and 50 generations for a population size of hundred. Unlike other GA applications where the mutation rate was usually less than 0.02, this study used a higher mutation rate to ensure proper mixing of population.

- The total computation time using random generation method varied from 9.5 minutes for upgrade to about 23 minutes for optimising new options.

8.3.2 Conclusions from Case Study- Victor Harbor

Conclusions from the Victor Harbor case study are as follows:

(a) New WWTP options for Victor Harbor

- The best GA parameters were concluded to be population size = 100, number of generations = 75, probability of crossover = 0.8, probability of mutation = 0.2, and tournament selection with two members.
- Although the computation time taken for generation and optimisation using seeded initial population was the least, the solutions generated using this method were inferior.
- The dynamic penalty method outperformed other three penalty calculation methods.
- The random generation of TTs based on the recommended treatment produced better TT options for both Class B^+ and B criteria. Furthermore, the type of processes selected is dependent on the type of reuse criteria and the weights given to cost.
- The computation time required for the generation and optimisation of treatment options was about 9.5 to 23 minutes on a 966 MHz Pentium III system depending on the type of generation option selected. This can save lot of resources and person-hours required for the evaluation of options using 'rule of thumb' techniques.
- The consistent results obtained from different random number seeds for the same input data has indicated that the TT options generated for a case can be reproduced.
- The minimum total project cost to meet Class B^+ quality was \$ 8.1 million while it was \$ 7.25 million to meet Class B quality.
- In this case study it was shown that the TTs generated by the model were superior to those selected by the users. Further, the TT alternatives generated by this model was similar to what is being considered by SA Water.

(b) Upgrade Options for Victor Harbor

- The best GA parameters were concluded to be population size =50, number of generations = 100, probability of crossover = 0.8, probability of mutation = 0.7, and tournament selection with two members. A higher mutation rate had to be used compared to new TT options.
- As in case of new TT options, the dynamic penalty method outperformed other three penalty calculation methods.
- The minimum total project cost to meet Class A^+ quality was $ 4.40 million
- The total computation time was 9 minutes on average on a 966 MHz Pentium III system.

8.4 Recommendations for Further Research

The framework for DSS for optimum selection of treatment process for reuse has been developed. This model can be further developed to include total water resources management in a region.

8.4.1 Model Extensions

The following aspects of the model can be improved, which was beyond the scope of this research.

(i). Currently the user can add new processes by entering their performance and costs in the database. This has the disadvantage, as the user needs to be familiar with Paradox database and the Delphi™ program. However a suitable management interface to add new processes could be developed to overcome this limitation.

(ii). It would be preferable to have an editable or updateable cost database by which the user can have more control on the costing process. Currently the user can only input the local costs such as discount rate, cost of land and so on.

(iii). As the design affects the cost and hence the selection of TTs, it will be useful if the user can actually edit the design assumptions made. Currently the design assumptions are displayed as "read only" data.

(iv). The cost data should be developed for 500 EP and above as many country treatment plants in South Australia are in this range and are currently being considered for upgrade to meet local reuse requirements.

(v). The performance can vary widely depending on many factors including the influent wastewater characteristics and local climatic conditions. It can be noted that performances of entire treatment plants is monitored and documented while those of individual unit processes are not studied. Therefore, performance data of unit processes was based on literature, as very little data is available for individual unit processes. Hence the performance of unit processes under local conditions should be incorporated in the model. Further this model did not consider the effect of pH on the removal efficiencies. It would be worthwhile to include the effect of pH on individual unit process performance.

(vi). As treatment evaluation is just one step in facility planning, it will be very useful to incorporate the steps outlined in Table 2.10 to ensure wastewater reclamation and reuse is considered in totality.

(vii). TT evaluation can also be based on budgetary evaluation. The user can enter the maximum total project cost and the model can evaluate TT options in this range. However one has to be cautious about such an approach as it can greatly restrict the search space for GAs.

(viii). Cost of reclamation is included in the total project cost in this model. But the majority of the reuse schemes include storage and distribution cost. This could be included in the model to provide the total cost of the project. Since this cost is common to all the treatment alternatives considered, it will not affect the evaluation and selection process.

(ix). As discussed in Chapter 5 (See Section 5.3) the primary aim of this research was to investigate if GAs could be applied to generate and optimise TTs. In order to do this, it was necessary to convert the complex multi-objective problem into a single objective problem. Since this research has shown that GAs can be effectively used for TT optimisation, multi-objective optimisation using GAs should be further investigated.

(x). Several parameters such as heavy metals and pesticides which pose potential health and environmental risks are not included in the model as their removal efficiency by each unit processes is not monitored. With an increase in public concern about the long-term effect of use of reclaimed wastewater, it is necessary to include these parameters in relation to the unit processes in the database.

(xi). Development of a total water management model using the MOSTWATAR model for evaluation of wastewater treatment and reuse schemes could be investigated.

(xii). Since the cost database was developed for South Australian conditions, it would be worthwhile to investigate the use of cost indices to update costs to other states of Australia. Since the guidelines are all currently in place, only cost needs to be updated.

(xiii). Further research is needed to quantify the criteria such as reliability & odour generation potential and that of socio-cultural indicators like institutional acceptance and willingness to pay for reclaimed water.

(xiv). To take the sludge evaluation a step further it will be necessary to include qualitative tests such as the water content and the amount of C, N, P in sludge produced.

(xv). The application of MOSTWATAR for selection of upgrade options has been demonstrated in this model. However this research was based on simplifying assumptions. While in practice, the upgrade of an existing plant can be a result of many reasons including increase in population and or need to replace one ore more of the existing unit processes. It is worthwhile to investigate further development of upgrade module as it is of primary importance to many councils and planning authorities.

In conclusion, the framework for MOSTWATAR has been developed which can now with some further development be employed by the councils and planners to evaluate TT options for any given conditions. Several interactions with local planning authority have lead to improvement of the preliminary model. The application of this model to further case studies and feedback from practitioners and reuse experts will lead to further development of the software. This work has also shown that application of genetic algorithms for the optimum selection of WWT options is possible although further research needs to be done to incorporate the multi-objective nature of the problem.

This research has provided a focused and effective approach to one of the important steps in facility planning of reuse schemes i.e. a treatment alternative feasibility study. With its user-friendly interfaces and editable database, it is envisaged that this useful tool can go a long way in saving time and money in the planning of wastewater reclamation and reuse schemes in South Australia. Following consultation, a number of practising engineers have regarded MOSTWATAR as a valuable preliminary design and evaluation tool. It is envisaged that this model will help planners in making objective and rational assessment of wastewater treatment alternatives for both new wastewater treatment plants and their upgrades.

Appendix A – Glossary of Terms

Acronym	Full term
ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
ADPM	Adaptive penalty method
AHP	Analytic hierarchy process
APM	Additive penalty method
ASP	Activated sludge process
BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CAPDET	Computer Assisted Procedures for the Design and Evaluation of Treatment systems
CATID	Category identification number
CBS	Computer based system
CIDNo	Community identification number
CPI	Consumer price index
CRC	Co-operative research centre
CRF	Capital recovery factor
DAF	Dissolved air flotation
DBP	Disinfection by- products
DM	Decision maker
DPM	Dynamic penalty method
DS	Dissolved solids
DSS	Decision support system
DWM	Decentralized waste management
EP	Equivalent population
F/M	Food to microbes ratio
FC	Faecal coliforms

FWS	Free water surface wetlands
GA	Genetic algorithm
GAC	Granular activated carbon
HLR	Hydraulic loading rate, $m^3/m^2.d$
ID	Identification number
lpcd	Litres per capita per day
MCRT	Mean cell residence time
MF	Microfiltration
ML/d	Million litres per day
ML/yr	Million litres per year
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
Mm^3/yr	Million cubic meters per year
MOSTWATAR	**M**odel for **O**ptimum **S**election of **T**echnologies for **WA**stewater **T**reatment **A**nd **R**euse
MPM	Multiplicative penalty method
N	Nitrogen
NH_3-N	Ammonia nitrogen
NRC	National Research Council at USA
NSW	New South Wales, Australia
NT	Northern Territory, Australia
NTU	Nephelometric Turbidity Unit
NWQM	National Water Quality Management
O & M	Operations and Maintenance
OLR	Organic loading rate, kg/m^3
ON	Organic nitrogen
P	Phosphorous
PTID	Process type identification number
QLD	Queensland, Australia
RID	Reuse identification number
RO	Reverse Osmosis
SA Water	The South Australian Water Corporation
SA	South Australia

SANEX®	Sanitation Expert
SBR	Sequential batch reactors
SF	Sand filter
SLR	Solids loading rate
SOR	Surface overflow rate, $m^3/m^2.d$
SS	Suspended solids
SSF	Sub surface flow wetlands
TC	Total coliforms
TDS	Total dissolved solids
TF	Trickling filter
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
TT	Treatment train
TTID	Treatment train identification number
UF	Ultra filtration
UIDNo	Unit process identification number
UP	Unit process
USEPA	United States Environmental Protection Agency
UV	Ultraviolet disinfection
UWRAA	Urban Water Research Association of Australia
VIC	Victoria, Australia
WA	Western Australia
WAWTTAR®	Water And Wastewater Treatment Technologies & Reuse
WEF	Water Environment Federation, USA
WHO	World Health Organization
WWR	Wastewater reclamation
WWRR	Wastewater reclamation and reuse
WWT	Wastewater treatment
WWTP	Wastewater treatment plants

Appendix B – Nomenclature

Abbreviation	**Explanation**
Base year	2001, the year in which the cost database was developed
EffBOD	Effluent BOD, mg/L
EffFC	Effluent FC, mg/L
EffSS	Effluent SS, mg/L
EffTN	Effluent TN, mg/L
EffTP	Effluent TP, mg/L
f_{TTI}	Fitness score for i^{th} TT
Gen	Generation number
InfBOD	Influent BOD, mg/L
InfFC	Influent FC, mg/L
InfSS	Influent SS, mg/L
InfTN	Influent TN, mg/L
InfTP	Influent TP, mg/L
K_d	Decay coefficient
Max P'_{ik}	Maximum criterion score
MaxGen	Maximum number of generations
Min P'_{ik}	Minimum criterion score
n	Population size
O_{TTI}	Objective score for i^{th} TT
p	Probability of unit process selection
P'_{ik}	Criteria score for i^{th} TT for k^{th} criteria
P'_{ikj}	Criteria score for the j^{th} unit process in the i^{th} TT
P_c	Probability of crossover
P_{fd}	Daily peak factor
P_{fh}	Hourly peak factor

P_{fm}	Monthly peak factor
P_{ik}	Normalized criterion score
Pm	Peak monthly factor
P_m	Probability of mutation
P_s	Probability of selection pressure
PsBOD	Penalty score for exceeding BOD criteria
PsEV	Penalty score for exceeding EV criteria
PsFC	Penalty score for exceeding FC criteria
PsHeggs	Penalty score for exceeding helminth eggs criteria
PsL	Penalty score for exceeding land available
PsMaxInfQ	Penalty score for exceeding maximum allowable influent quality
PsNMDGW	Penalty score for selecting land based treatment systems when depth of ground water table is less than or equal to 2 m.
PsNMR	Penalty score for not meeting rules to form acceptable process configuration
PsRC	Penalty score for exceeding reuse criteria
PsSLBT	Penalty score for selecting land based treatment when the user specifies it as unacceptable
PsSS	Penalty score for exceeding SS criteria
PsTN	Penalty score for exceeding TN criteria
PsTP	Penalty score for exceeding TP criteria
PsTurb	Penalty score for exceeding turbidity criteria
Q_{av}	Average flow
Q_{avdwf}	Average dry weather flow
Q_{pd}	Peak daily flow
Q_{ph}	Peak hourly flow
Q_{pm}	Peak monthly flow
r	Rate of inflation (%)
R1	Random generation of TTs based on recommended treatment
R2	Random generation of TTs based on ALL the unit processes in the database
R3	Random generation of TTs based on ALL the unit processes in the database without rules being checked.

S_{eff}	Effluent parameter
S_{inf}	Influent parameter
t	Generation number
ts	Tournament size
y	Length of a TT string
δ	Penalty constant
$	Australian dollars, 2001(unless otherwise specified)
η	Process efficiency in percentage
ρ	Constant penalty weight assigned for exceeding constraints
ρ'	Generation index (t/t_{max})
α_{TTI}	Penalty function for i^{th} TT

Appendix C – Data Collection

C.1 Data Collection for Knowledge Base Development

Data about design, cost and performance of unit processes was collected from a number of manufactures and distributors of wastewater treatment equipment. A standard questionnaire was sent to over 30 leading manufactures/companies in Australia and companies listed in Table C.1, responded. A copy of the questionnaire distributed to these companies is presented in Section C.2.

Table C. 1 List of Manufacturers Responded

Company Name	Process/Equipment/chemicals
AMEC, Australia	IDEA
Aeroflo Pty Ltd	IDEA
EPCO	Clarifiers, Chlorinators
Factor UTB	SBR
Hydro Australasia	Grit Chamber, Clarifiers
Nalco Chemicals	Chemicals
Outokumpo	Clarifiers
PICA	Granular Activated Carbon
Syskill Pty Ltd	Dissolved air flotation
Tema Engineers	Sand filters, fine screen, belt filter presses
USF	MF, RO
UVTA	UV disinfection, media filters

C.2 Questionnaire

A Typical Questionnaire sent out to Manufacturers

Name of the company:

Contact person:

Address:

Phone number:

E-mail:

(Please copy this questionnaire and complete one per process)

1. Name of the process:

2. Process description: (please attach any additional information you would like to include about your process)

3. Type of process (please tick one)

    : Primary

    : Secondary

    : Tertiary

    : Others (specify)

4. Capacities available in ML/day:

   (Is it custom built or is it available off shelf?) YES/NO

5. Typical power requirement (kW):

6. Economic Life span (yrs):

7. Performance characteristics*

Constituent	Average % removal
CBOD	
Total N	
Total P	
SS	
Turbidity	
Faecal Coliforms	
Other (please specify)	

* Please indicate the source of above information: (please tick one)

Pilot plant tests:

Data from full-scale treatment plants:

Other (please specify):

8. Temperature range for optimum performance:

9. By-Products:

   I) Typical quantity of sludge produced (kg/d):

   II) Moisture content of sludge:

10. Approximate Capital and Operation & Maintenance costs:

(for capacities ranging from 1,000 m^3/d to 10,000 m^3/d)

Please write additional comments (if any):

Appendix D – Performance Data

D.1 Performance Data of Unit Processes

The Table below presents data on the minimum, average and maximum removal efficiencies of various unit processes considered in this model.

Table D. 1a Performance Data

UIDNo / Process Name	Parameter	% Removal Efficiency Minimum	Average	Maximum	Source
1100, Bar Screen	BOD	0	2.5	5	1
	EV	0	0	0	
	FC	0	0	0	1
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	5	7.5	10	1
	TN	0	0	0	1
	TP	0	0	0	1
	Turbidity	0	0	0	
1101, Fine Screen	BOD	20	30	35	1
	EV	0	0	0	
	FC	0	0	0	
	Grit	10	20	30	2
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	20	27.5	35	1
	TN	0	0	0	
	TP	0	0	0	
	Turbidity	0	0	0	
1200, Grit Chamber	BOD	2	4	6	6
	EV	0	0	0	
	FC	0	0	0	
	Grit	90	95	100	6
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	0	5	10	6
	TN	0	0	0	4
	TP	0	0	0	4
	Turbidity	0	0	0	4

Table D. 1b Performance Data (Contd.)

UIDNo / Process Name	Parameter	% Removal Efficiency Minimum	Average	Maximum	Source
1500, Primary Clarifier	BOD	30	35	40	4
	FC	0	0	0	
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	0	0	0	1
	ON	20	30	40	1
	SS	50	57.5	65	4
	TN	10	15	20	2
	TP	10	15	20	4
	Turbidity	0	0	0	
1600, Primary Clarifier with lime	BOD	40	55	70	1
	EV	0	0	0	
	FC	30	40	60	2
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	0	0	0	1
	ON	50	75	90	1
	SS	50	65	80	1
	TN	20	30	40	2
	TP	70	80	90	1
	Turbidity	50	70	80	2
2100 High Rate Trickling Filter, Rock Media w clarifier	BOD	65	72.5	80	4
	EV	0	0	0	
	FC	10	15	25	2
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	8	12	15	1
	ON	60	70	80	1
	SS	60	72.5	85	4
	TN	10	15	30	2
	TP	8	10	12	4
	Turbidity	25	35	50	2
2101 High Rate Trickling Filter, Plastic Media w Clarifier	BOD	65	75	85	4
	EV	0	0	0	
	FC	10	20	25	2
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	8	12	15	7
	ON	60	70	80	7
	SS	65	75	85	4
	TN	15	32.5	50	4
	TP	8	10	12	4
	Turbidity	25	30	50	2

Table D. 1c Performance Data (Contd.)

UIDNo / Process Name	Parameter	% Removal Efficiency Minimum	Average	Maximum	Source
2200 Conventional ASP w Clarifier	BOD	80	82.5	85	1
	EV	0	0	0	
	FC	60	70	95	2
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	8	12	15	1
	ON	60	72.5	85	1
	SS	80	85	90	1
	TN	10	20	30	2
	TP	10	17.5	25	1
	Turbidity	50	60	75	2
2201 Activated Sludge Process w Nitrification & clarifier	BOD	80	90	95	1
	EV	0	0	0	
	FC	60	70	95	2
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	85	90	95	1
	ON	75	80	85	1
	SS	70	80	90	1
	TN	0	0	0	
	TP	10	12.5	15	1
	Turbidity	50	60	75	2
2300 Sequential Batch Reactor	BOD	85	90	95	6
	EV	0	0	0	
	FC	60	70	95	6
	Grit	95	100	100	6
	Heggs	0	0	0	
	NH_3-N	90	92.5	95	1
	ON	70	82.5	95	1
	SS	80	90	95	6
	TN	10	20	30	6
	TP	60	75	90	6
	Turbidity	25	40	50	6
2400 Anaerobic Lagoon	BOD	60	77.5	90	1
	EV	0	0	0	
	FC	70	85	99	2
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	70	75	80	2
	TN	10	15	30	2
	TP	10	20	30	2
	Turbidity	50	70	75	2

Table D. 1d Performance Data (Contd.)

UIDNo / Process Name	Parameter	% Removal Efficiency			Source
		Minimum	Average	Maximum	
2401 Facultative Pond	BOD	70	80	90	1
	EV	0	0	0	2
	FC	70	85	99	2
	Grit	95	100	100	2
	Heggs	0	0	0	2
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	70	75	80	2
	TN	20	40	60	2
	TP	10	20	30	2
	Turbidity	50	70	75	2
2402 Aerobic Lagoon	BOD	40	60	80	1
	EV	0	0	0	2
	FC	70	85	99	2
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	70	80	90	2
	TN	20	40	60	2
	TP	10	20	30	2
	Turbidity	50	60	75	2
2403 Aerated Lagoon	BOD	60	80	90	3
	EV	0	0	0	2
	FC	60	85	95	2
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	70	80	90	3
	TN	20	40	60	2
	TP	20	30	40	2
	Turbidity	50	60	75	2
2500 Secondary Circular Clarifier	BOD	10	35	60	2
	EV	0	0	0	
	FC	0	0	0	
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	65	80	95	2
	TN	0	0	0	
	TP	0	0	0	
	Turbidity	0	0	0	

Table D. 1e Performance Data (Contd.)

UIDNo / Process Name	Parameter	% Removal Efficiency			Source
		Minimum	Average	Maximum	
2501 Sedimentation Pond**	BOD	70	80	90	1
	EV	0	0	0	2
	FC	70	85	99	2
	Grit	95	100	100	2
	Heggs	0	0	0	2
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	70	75	80	2
	TN	20	40	60	2
	TP	10	20	30	2
	Turbidity	50	70	75	2
3100 SSF Wetland	BOD	70	80	90	2
	EV	90	99	99.99	2
	FC	90	99	99.99	2
	Grit	100	100	100	2
	Heggs	100	100	100	2
	NH_3-N	85	90	95	7
	ON	60	75	90	7
	SS	70	80	90	2
	TN	20	30	50	2
	TP	5	10	15	2
	Turbidity	50	70	75	2
3101 FWS Wetland (BOD & Ni)	BOD	80	90	95	2
	EV	99	99.9	99.9	2
	FC	99	99.9	99.9	2
	Grit	100	100	100	2
	Heggs	100	100	100	2
	NH_3-N	85	90	95	7
	ON	60	75	90	7
	SS	85	95	99	2
	TN	75	85	90	2
	TP	0	10	80	2
	Turbidity	50	70	75	2
3102 FWS Wetland (BOD)	BOD	70	80	90	2
	EV	90	99	99.9	2
	FC	90	99.9	99.9	2
	Grit	100	100	100	2
	Heggs	100	100	100	2
	NH_3-N	85	90	95	7
	ON	60	75	90	7
	SS	70	80	90	2
	TN	20	30	50	2
	TP	5	10	15	2
	Turbidity	50	70	75	2

Table D. 1f Performance Data (Contd.)

UIDNo / Process Name	Parameter	% Removal Efficiency Minimum	Average	Maximum	Source
4100 Continuous Flow BNR	BOD	90	92.5	95	1
	EV	0	0	0	
	FC	60	70	95	2
	Grit	85	100	100	2
	Heggs	0	0	0	
	NH_3-N	90	92.5	95	1
	ON	70	82.5	95	1
	SS	80	87.5	95	1
	TN				
	TP	70	80	90	1
	Turbidity	50	60	70	2
4200 Single Stage Lime Treatment	BOD	80	85	90	1
	EV	0	0	0	
	FC	30	45	60	2
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	0	0	0	1
	ON	60	75	90	1
	SS	70	75	80	1
	TN	20	30	40	2
	TP	75	80	85	1
	Turbidity	50	65	80	2
4201 Two Stage Lime Treatment	BOD	50	67.5	85	1
	EV	0	0	0	
	FC	50	75	80	2
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	0	0	0	1
	ON	70	80	90	1
	SS	50	72.5	90	1
	TN	20	30	40	2
	TP	85	90	95	1
	Turbidity	60	80	90	2
4300 Break Point Chlorination	BOD	0	0	0	
	EV	0	0	0	
	FC	0	0	0	
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	80	95	90	1
	ON	0	0	0	
	SS	0	0	0	1
	TN				
	TP	0	0	0	1
	Turbidity	0	0	0	

Table D. 1g Performance Data (Contd.)

UIDNo / Process Name	Parameter	% Removal Efficiency Minimum	Average	Maximum	Source
4400 Coagulation & Flocculation with Alum***	BOD	0	0	0	
	EV	0	0	0	
	FC	0	0	0	
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	0	0	0	
	TN	0	0	0	
	TP	0	0	0	
	Turbidity	0	0	0	
4401 Coagulation, Flocculation and Sedimentation	BOD	40	55	70	1
	EV	0	0	0	
	FC	30	40	60	2
	Grit	95	100	100	2
	Heggs	0	0	0	
	NH_3-N	0	0	0	1
	ON	50	70	90	1
	SS	50	65	80	1
	TN	20	30	40	2
	TP	70	80	90	1
	Turbidity	60	80	99	3
4500 Sand Filter	BOD	20	40	60	1
	EV	0	0	0	
	FC	60	75	90	2
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	0	0	0	1
	ON	50	60	70	1
	SS	60	70	80	6
	TN	0	0	0	2
	TP	20	35	50	1
	Turbidity	60	75	98	6
4501 Dual Media Filter	BOD	25	35	50	2
	EV	0	0	0	
	FC	85	99	100	2
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	60	67	90	2
	TP	50	65	80	2
	Turbidity	97	98	99	2

Table D. 1h Performance Data (Contd.)

UIDNo / Process Name	Parameter	% Removal Efficiency			Source
		Minimum	Average	Maximum	
4700 MicroFiltration	BOD	90	95	100	1
	EV	0	0	0	
	FC	95	99.95	100	1
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	60	75	90	1
	ON	90	95	100	1
	SS	90	95	100	1
	TN	0	0	0	2
	TP	90	95	100	1
	Turbidity	90	95	100	2
4800 Granular Activated Carbon	BOD	50	67.5	85	1
	EV	0	0	0	
	FC	20	40	60	2
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	0	0	0	1
	ON	30	40	50	1
	SS	50	65	80	1
	TN	0	0	0	
	TP	10	20	30	1
	Turbidity	20	40	60	2
4900 Reverse Osmosis	BOD	90	95	100	1
	EV	0	0	0	
	FC	95	99.95	100	1
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	60	75	90	1
	ON	90	95	100	1
	SS	90	95	100	1
	TN	0	0	0	2
	TP	90	95	100	1
	Turbidity	90	95	100	2
5100 Maturation Pond	BOD	10	17.5	25	5
	EV	0	0	0	
	FC	60	80	85	5,4
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	0	0	0	
	TN	0	0	0	
	TP	0	0	0	
	Turbidity	50	70	75	7

Table D. 1i Performance Data (Contd.)

UIDNo / Process Name	Parameter	% Removal Efficiency Minimum	Average	Maximum	Source
5200 Chlorination	BOD	0	0	0	
	EV	0	0	0	
	FC	95	99.95	100	4
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	0	0	0	
	TN	0	0	0	
	TP	0	0	0	
	Turbidity	0	0	0	
5300 UV Disinfection	BOD	0	0	0	
	EV	0	0	0	
	FC	95	99.99	100	6
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	0	0	0	
	TN	0	0	0	
	TP	0	0	0	
	Turbidity	0	0	0	
5400 Post Chlorination	BOD	0	0	0	
	EV	0	0	0	
	FC	95	99.9	100	7
	Grit	0	0	0	
	Heggs	0	0	0	
	NH_3-N	0	0	0	
	ON	0	0	0	
	SS	0	0	0	
	TN	0	0	0	
	TP	0	0	0	
	Turbidity	0	0	0	

Source:
1- Qasim (1998), 2 - Finney & Gearheart (1998), 3 - Martin & Martin (1992)
4- Metcalf & Eddy (1991), 5- Mara (1998,pp 149), 6-Manufacturer, 7- Assumed values
** No data available hence performance assumed to be same as that of Facultative pond
*** Used as Pretreatment to Sand filtration

Appendix E– Qualitative Criteria Scores

E.1 Criteria Scores for Unit Processes

Table E. 1a Qualitative Scores for Various Unit Processes

UIDNo	Process Name	Adaptability to Upgrade	Adaptability to Varying Flow Rate	Adaptability to Varying Influent Condition	Ease of O&M	Ease of Construction	Reliability	Chemical Requirement	Odour Generation	Groundwater Impact	Power Requirement	Source
1100	Bar Screen	3	3	3	3	2	1	0	2	0	1	1
1101	Fine Screen	2	2	3	2	1	2	0	1	0	3	1
1200	Grit Chamber	3	3	3	2	2	3	0	2	0	1	5
1500	Primary Clarifier	3	3	3	2	2	3	0	2	0	1	1
1600	Primary Clarifier w lime	3	2	3	1	2	2	3	1	0	2	1,6
2100	TF,Rock Media, w Clarifier	3	2	2	2	2	1	0	2	3	2	1
2101	TF,Plastic Media,w Clarifier	2	2	3	2	2	2	0	2	3	0	2
2200	Conventional ASP, w Clarifier	3	2	3	2	1	2	0	3	1	2	1
2201	ASP w Ni & w Clarifier	2	2	1	2	1	2	0	1	3	0	2,3
2300	SBR	3	2	3	2	3	2	0	2	0	2	1
2400	Anaerobic Lagoon	3	2	2	2	2	1	0	2	3	1	1
2401	Facultative Pond (Oxidation Pond)	3	2	3	2	2	2	0	2	3	1	2,3
2402	Aerobic Lagoon	1	2	3	1	2	2	1	2	3	1	1
2403	Aerated lagoon (Aerated Ponds)	2	2	3	1	2	1	0	3	3	3	1
2500	Secondary Circular Clarifier	2	3	3	2	2	2	0	1	0	2	4,6
2501	Sedimentation Pond	3	2	3	2	2	2	0	2	3	1	6
3100	SSF Wetland (BOD)	3	3	3	2	2	3	0	3	3	1	4,6
3101	FWS Wetland (BOD & Ni)	3	3	3	2	3	3	0	3	3	1	4,6
3102	FWS Wetland (BOD)	3	3	3	2	3	3	0	3	3	1	4,6

Note: 0- Nil, 1- Low, 2- Medium, 3- High

(Source: 1– Martin & Martin, 1991; 2 – Qasim, 1999; 3 – Mara, 1992; 4 – Finney and Gearheart, 1998; 5 – Manufacturer; 6 – Assumed)

Table E. 1b Qualitative Scores for Different Criteria (Contd.)

UIDNo	Process Name	Adaptability to Upgrade	Adaptability to Varying Flow Rate	Adaptability to Varying Influent Condition	Ease of O&M	Ease of Construction	Reliability	Chemical Requirement	Odour Generation	Groundwater Impact	Power Requirement	Source
4100	Continuous Flow BNR	1	2	3	2	1	3	0	2	0	2	2,3,1
4200	Single Stage Lime Treatment	3	2	3	2	2	2	3	0	0	1	6
4201	Two Stage Lime Treatment	3	3	3	1	2	3	3	0	0	2	2,6
4300	Break Point Chlorination	3	3	3	1	3	2	3	1	0	1	6
4400	Coagulation and Flocculation	2	1	2	2	2	3	3	0	0	1	6
4401	Coagulation,Flocculation and Sedimentation	2	3	3	3	2	3	3	1	0	2	2,6
4500	Sand Filter	3	3	2	2	2	2	1	1	0	2	2
4501	Dual Media Filter	2	2	3	1	1	3	1	1	0	3	
4700	Microfiltration	3	2	2	1	2	3	1	0	0	3	5
4800	Granular Activated Carbon	1	1	1	1	1	3	0	2	0	3	2,1
4900	Reverse Osmosis	3	2	1	1	2	3	1	0	0	3	5
5100	Maturation Pond	2	2	2	2	2	2	0	2	3	1	6
5200	Chlorination	1	1	3	1	1	3	3	1	0	2	1,2
5300	UV Disinfection	2	1	2	1	1	2	0	1	0	3	
5400	Post Chlorination	1	1	3	1	1	3	2	1	0	2	1,2
6100	Sludge Thickener	2	2	3	3	1	3	0	3	0	2	6
6200	Anareobic Digestor	2	3	3	3	2	3	0	3	0	2	1
6300	Belt Filter Press	2	2	2	3	3	3	1	3	0	3	6
6301	Sludge Drying Beds	3	1	3	3	3	3	0	3	3	1	1
6400	Land Spreading of Sludge	2	1	2	2	3	3	0	3	3	1	1
6401	Land Filling of Sludge	3	2	3	3	3	3	0	3	0	1	6
5100	Maturation Pond	2	2	2	2	2	2	0	2	3	1	6
5200	Chlorination	1	1	3	1	1	3	3	1	0	2	1,2
5300	UV Disinfection	2	1	2	1	1	2	0	1	0	3	
5400	Post Chlorination	1	1	3	1	1	3	2	1	0	2	1,2
6100	Gravity Thickener	2	2	3	3	1	3	0	3	0	2	6
6200	Anareobic Digestor	2	3	3	3	2	3	0	3	0	2	1
6300	Belt Filter Press	2	2	2	3	3	3	1	3	0	3	6
6301	Sludge Drying Beds	3	1	3	3	3	3	0	3	3	1	1
6400	Land Spreading of Sludge	2	1	2	2	3	3	0	3	3	1	1
6401	Land Filling of Sludge	3	2	3	3	3	3	0	3	0	1	6

Note: 0- Nil, 1- Low, 2- Medium, 3- High

(Source: 1– Martin & Martin, 1991; 2– Qasim, 1999; 3 – Mara, 1992; 4 – Finney and Gearheart, 1998; 5 – Manufacturer; 6 – Assumed)

Appendix F – Cost Data Sheets

F.1 Basic Assumptions for Cost Estimation

The unit cost assumed for the estimation of cost and the basic assumptions are presented in this Section.

Table F. 1 Unit Cost Assumed

Description	Assumptions
Earthwork (cut & fill)	\$ 15/m^3 up to 3,000 m^3
	\$ 10/m^3 > 3000 to 6000 m^3
	\$ 8/m^3 > 6,000 to 15,000 m^3
	\$ 6/m^3 > 15,000 to 20,000 m^3
	\$ 5/m^3 > 20,000 to 25,000 m^3
	\$ 4/m^3 > 25,000 to 100,000 m^3
	\$ 2.50/m^3 > 100,000 m^3
Liner + Underlay	\$10.00/m^2
Inlet + Outlet + Overflow structure	50% of earthwork cost
Drain pipe[1]	\$17.00/m
Gravel media	\$25/m^3
Electric power	\$0.10/kW.hr
Labour[2]	\$45/hr
Hydrated lime[2] ($Ca(OH)_2$)	\$165/ tonne
Alum	\$140/ tonne
Ferric chloride	\$120/ tonne
Land costs[4]: Urban area	\$20,000/ha
Rural area	\$10,000/ha

(Source: Bentley, 2001)

Note: [1] Supply and laying, [2] including fringe benefits, [3] 1 kg of CaO = 1.33 kg of $Ca(OH)_2$.
[4] In addition to land cost, land acquisition fee of \$ 250,000 is added.

The following assumptions apply to all unit processes:

1. Construction and O & M costs are in 2001 A$. Construction cost for unit processes does not include land costs (see Note 4 for land cost calculations). O & M cost includes operation and maintenance, power, labour and consumables. For processes where no data were available, O & M cost were assumed to be between 5 to 10 % of construction cost.

2. Cost of mechanical items/equipment is based on budget price for supply and delivery. Installation costs are estimated as % of equipment cost and data from SA Water.

3. For some processes (indicated in the cost data sheets) construction and O & M cost were taken from the cost equations developed in USA (Qasim, 1999, Martin and Marin, 1991; Finney and Gearheart, 1998). There are two methods widely used for converting US $ to A$.

   First method is to convert US $ to A$ using that years exchange rate and then convert to current year A$ costs using the Australian Consumer Price Index (CPI). The second method is to convert US $ to current year US $ by using the US CPI and then convert US $ to A$ using the current exchange rate. These two methods produce widely varied costs and the method to be employed mainly depends upon the percentage of local and overseas component (Pinkerton, 2001).

   For the purpose of this study, it was assumed that most of the components are available locally and hence the first method was employed to convert US $ to A$. For example to convert 1992 US $ to 2001 A$, first the 1992 US $ was converted to 1992 A$ and then converted to 2001 A$ using a CPI of 1.24. The exchange rate in 1992 was A$1 = US $0.65 (Hewitson, 1999; p 269).

4. Calculation of land cost:

   Land cost for a TT = {Total land area X appropriate land cost (i.e. urban or rural)} + land acquisition fee of $250,000.

5. In case of land based treatment systems, the surface area of the liner is assumed to be 15 % more than the surface area of lagoons and wetlands.

6. The following factors are used for calculation of design flows: (Lewis, 2001).
   - $Average\ Annual\ Flow,\ m^3/d = Design\ population \times 0.2\ m^3 per\ capita\ per\ day$
   - $Annual\ Dry\ Weather\ Flow = Annual\ Average\ Flow \times 0.85$
   - $Peak\ Wet\ Weather\ Flow = Annual\ Average\ Flow \times 3$ **
   - $Peak\ Daily\ Flow = Annual\ Average\ Flow \times 2.4$
   - $Peak\ Monthly\ Flow = Annual\ Average\ Flow \times 1.2$

**Peak wet weather flow is also referred to as design peak flow

F.2 Cost Data Sheets

The design criteria and assumptions used to develop cost equations for the individual unit processes are presented in Table F.2 to F.43.

Table F.2 Cost Data Sheet for Bar Screen

A	B	C	D	E	F	G	H
UIDNo/ Process Name	Population	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Design Peak Flow, lps	Land Requirement, ha	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
1100, Bar Screen	5000	1000	2550	30	0.0005	$49	$4.9
	10000	2000	5100	59	0.0010	$70	$6.4
	25000	5000	12750	148	0.0025	$112	$10.0
	50000	10000	25500	295	0.0050	$160	$14.9

Assumptions:

20 mm opening between bars, Av quantity of screening produced in m^3/d = $20m^3$ per 1 million m^3 of wastewater treated (Qasim, pp196).

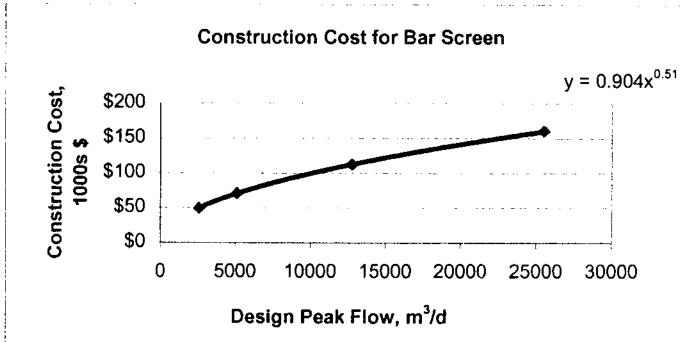
Weight of screenings (assuming 80% moisture) = 960 kg/m^3.(Qasim,1999; pp195), Sludge produced, kg/m^3 = 0.0192 (i.e $(20/10^6)*960$)

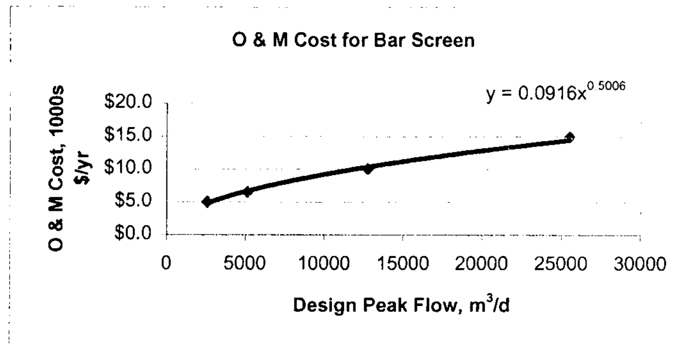
Economic Life = 20 yrs

Land area = 0.00045 ha per $1000m^3/d$ includes inlet structure and channel (Finney and Gearheart,1998)

Construction cost: Concrete structure, screening equipment, screenings handling equipement

O & M cost: overhauling, operation and maintenance





Reference: Qasim(1999,pp195-196),Bentley(2001)

Table F.3 Cost Data Sheet for Fine Screen

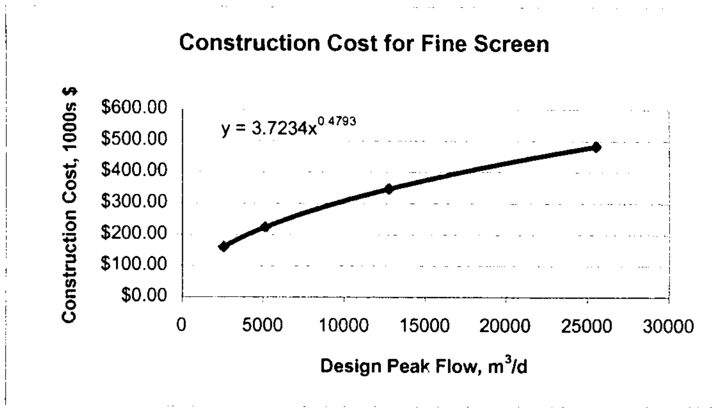
A	B	C	D	E	F	G	H
UIDNo/ Process Name	**Population**	**Design Average Flow, m3/d**	**Design Peak Flow, m3/d**	**Design Peak Flow, lps**	**Land Requirement, ha**	**Construction Cost, 1000s $**	**O & M Cost, 1000s $/yr**
1101, Fine Screen (Rotary drum)	5000	1000	2550	30	0.0008	$160.00	$16.0
	10000	2000	5100	59	0.0010	$222.70	$22.3
	25000	5000	12750	148	0.0015	$345.80	$34.6
	50000	10000	25500	295	0.0020	$482.30	$48.2

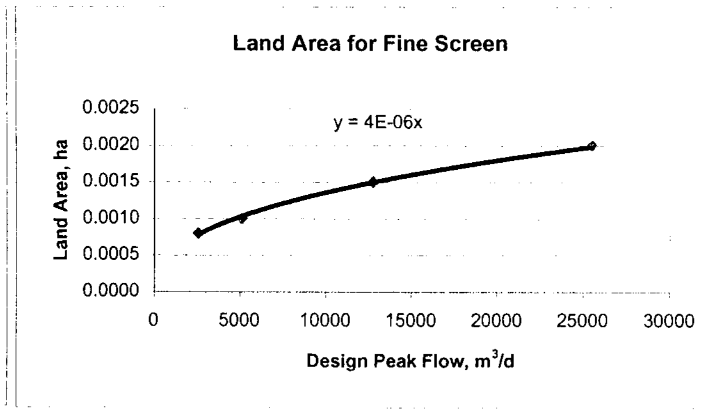
Assumptions:

Maximum inflow = Design peak flow, rotary drum screen, Hydraulic loading = 32 $m^3/m^2.d$, treated, Economic Life = 20 yrs

Construction Cost :Concrete structure, screening equipment, screenings handling equipement

O & M Cost: labour, power, repair and maintenance, Assumed as 10 % of construction cost





Reference: Qasim(1999,pp195-196),Bentley(2001)

Table F.4 Cost Data Sheet for Grit Chamber

A	B	C	D	E	F	G	H	I	J
UIDNo/ Process Name	Population	Design Average Flow, m^3/d	Design Average Dry Weather Flow, m^3/d	Design Peak Flow, m^3/d	Design Peak Flow, lps	Diameter*, m	Land Required, ha	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
1200 Grit Chamber	5000	1000	850	2550	30	1.1	0.0083	$64	$6.4
	10000	2000	1700	5100	59	1.5	0.0091	$90	$9.0
	25000	5000	4250	12750	148	2.4	0.0108	$130	$13.0
	50000	10000	8500	25500	295	3.4	0.0129	$180	$18.0

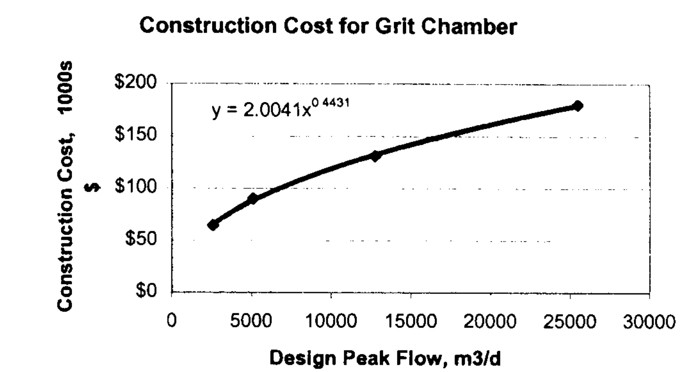
Assumptions

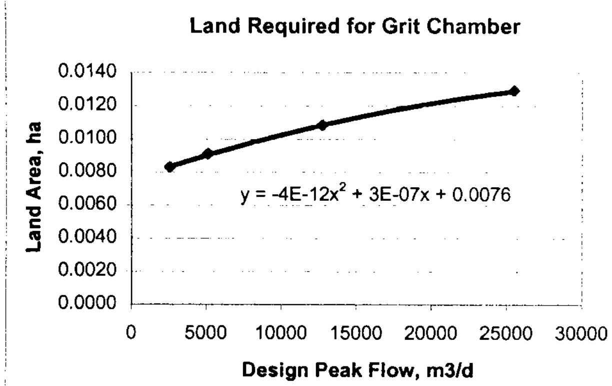
4m perimeter around the grit removal and handling equipment to allow for access and expansion, Average grit removal = 0.0205 $m^3/1000m^3$ of wastewater treated, Density of grit = 1600 kg/m3, Economic Life = 20 yrs

Construction cost: Concrete structure,mechanical, electrical and metal work for grit removal & grit handling

O & M cost: Operation and maintenance cost for grit handling, power and labour. Assumed as 10 % of Construction cost

Col.F = Col.E*1000/(24*60*60)
Col.G =0.0242*(Col.E)^0.486 *
Col.H =((Col.G+ 8)^2*)/10000
Col.J = Col.I *0.10
*empirical formula provided by manufacturer





Reference: Bentley(2001), HydroAustralasia(1999), WEF(1998,Vol.2, pp 9-35)

Table F.5 Cost Data Sheet For Primary Clarifier

A	B	C	D	E	F	G	H	I
UIDNo/Process Name	Population	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Surface Area, m^2	Diameter, m	Land Requirement, ha	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
1500 Primary Clarifier	5000	1000	2550	30	6	0.0402	$198	$19.8
	10000	2000	5100	60	9	0.0561	$269	$26.9
	25000	5000	12750	150	14	0.0953	$432	$43.2
	50000	10000	25500	300	20	0.1518	$647	$64.7

Assumptions used :

Surface overflow rate = 3.5m/hr @ design average flow, Water Depth = 3.5m, Economic Life = 30 yrs

Free board= 0.5 m, Maximum diameter <= 40m, HRT = 1.5 hrs @ design peak flow, Sludge pumping head of 15 m,

Land requirement =2* plant capacity

Construction cost: Concrete structure, mechanical, electrical and metal work and sludge pumping

O & M cost: Sludge and scum removal

Calculations

Average quantity of sludge produced, kg /day = InfSS*Percentage removal SS* Qav/1000

Col.C=Col.B*0.2

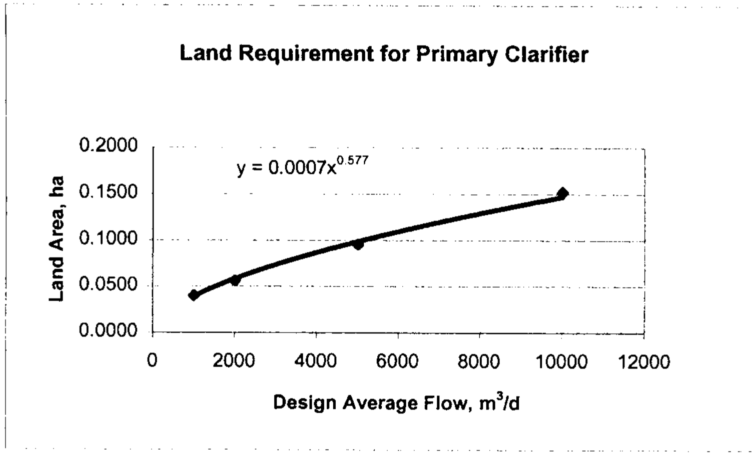
Col.D=Col.B*0.17*3

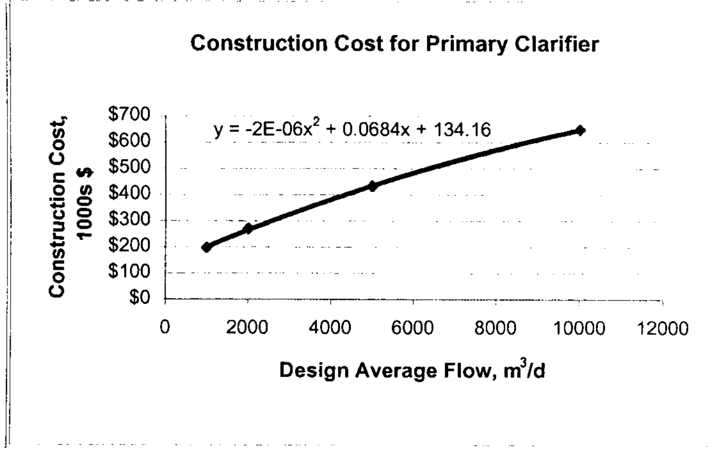
Col.E = Col.D/85

Col.F=SQRT((4*Col.E)/3.14)

Col.G=$(((\text{Col.F}+8)^2)*10^{-4})*2$

Col.I =Col.H*0.10





Reference: Bentley(2001), HydroAustralasia(1999)

Table F.6 Cost Data Sheet for Primary Sedimentation w Lime

A	B	C	D	E	F	G	H	I	J	K
UIDNo/ Process Name	Population	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Surface Area, m^2	Land Area, ha	Construction Cost for Clarifier, 1000s $	Average Lime Dosage, kg/d	Construction Cost for Lime Storage & Feed, 1000s $	Total Construction Cost, 1000s $	O & M Cost, 1000s $/yr
1600 Primary Sedimentation w Lime	5000	1000	2550	30	0.0602	$198	33.3	$60	$258	$23
	10000	2000	5100	60	0.0761	$269	66.5	$70	$339	$31
	25000	5000	12750	150	0.1153	$432	166.3	$90	$522	$52
	50000	10000	25500	300	0.1718	$647	332.5	$110	$757	$81

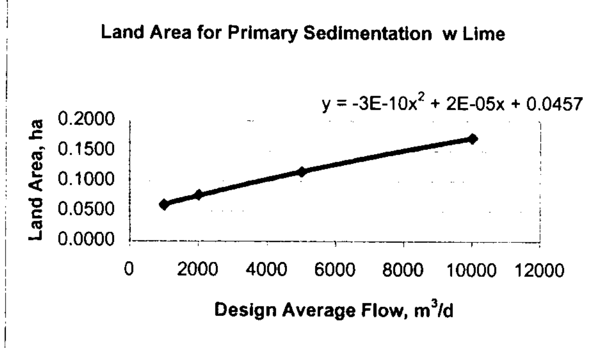
Assumptions:

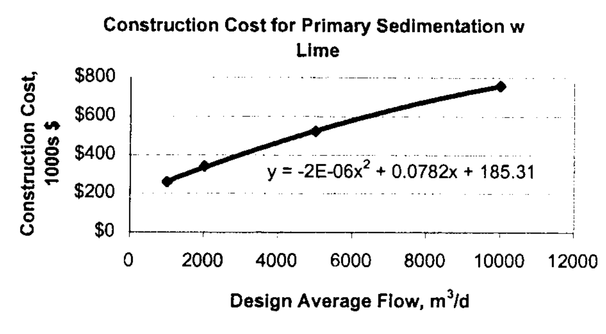
Maximum surface overflow rate = 5m/hr @ design peak flow, Lime dosage= 25 mg/L,Water Depth = 3.5m, Lime storage area 100 m^2 Economic Life = 20 yrs
Free board= 0.5 m, Maximum diameter <=40m, HRT = 1.5 hrs @ design peak flow, Sludge pumping head of 15 m,
Land required = Surface area for (clarifier +lime storage)*2 (i.e 2 times plant capacity for major unit processes)
Average quantity of sludge produced, kg /day = (InfSS*Percentage removal SS* Qav/1000)+0.58*Lime dosage(kg/d))**
Construction cost:Concrete structure, Mechanical, electrical and metal work,Lime storage and rapid mix ,flocculation
O & M Cost:Sludge pumping and operation of scrapers

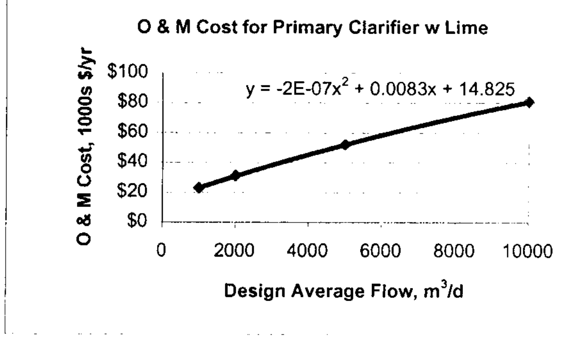
Calculations:

Col.E = Col.D/85
Col.F=((Clarifier area)+ ((64*2)/10000)
Col.H=(Col.C*25*1.33)*10^3 #
# 1 kg of CaO=1.33kg of $Ca(OH)_2$

Col.I = lumpsum
Col.J = Col.(G+I)
Col.K =((Col.H*365/1000)*165)/1000+0.08*Col.J







Reference:** Martin & Martin (1991), Bentley(2001)

Table F.7 Cost Data Sheet for High Rate Trickling Filter, Rock Media, w Clarifier

A	B	C	D	E	F
UIDNO/ Process Name	Design Average Flow, m^3/d	Surface Area, m^2	Land Required Based on HLR, ha	Construction Cost, 1000s	O & M Cost, 1000s $/yr
2100 TF, Rock Media	1000	50	0.1068	$289	$12.2
	2000	100	0.1567	$446	$18.7
	5000	250	0.2841	$894	$37.1
	10000	500	0.4728	$1,561	$64.6

Assumptions:

Depth of media = 1.5 m, OLR = 0.50 kg/m3, HLR= 20 m3/m2.d @ 4:1 recycle ratio

Land required (based on HLR),ha =2*(land area for TF + land area required for secondary clarifier)

Sludge produced, kg/ m^3 =0.072, Economic Life = 30 yrs

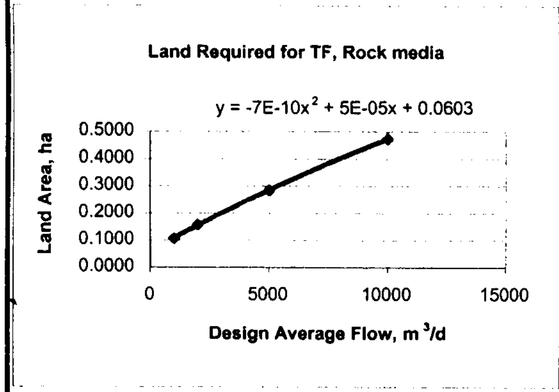
Construction Cost: circular filter units with rotating distributor arms, plastic media, underdrains and **includes secondary clarifier**

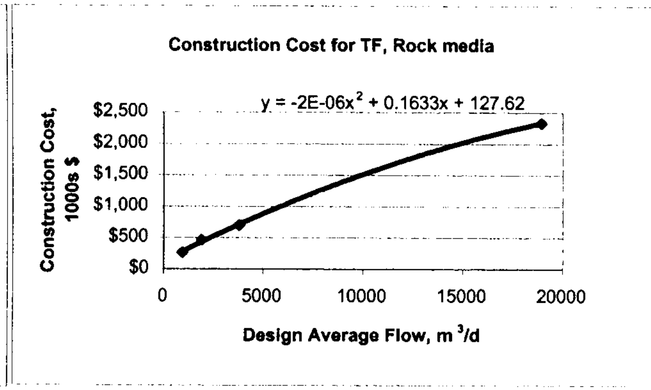
Calculations: (Col.C to Col.F based on HLR)

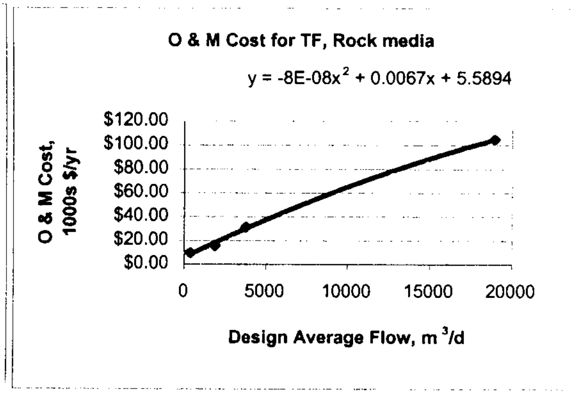
Col.C =(Col.B/ 20)

Col.D =2*(((SQRT(Col.C*4/3.14)+8)^2)/10000 + Land area for secondary clarifier)

Col.E= Construction cost based on US $(1992) converted to A$ (2001) using CPI and Exchange rate (See Section F.1, Note 3)







Reference: Finney & Gearheart (1998), Pinkerton (2001)

Table F. 8 Cost Data Sheet For High Rate Trickling Filter, Plastic Media w clarifier

A	B	C	D	E	F
UIDNo/ Process Name	Design Average Flow, m^3/d	Surface Area, m^2	Land Required, ha	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
2101 TF, Plastic Media	1000	35	0.0990	$296.48	$17.69
	2000	71	0.1435	$395.68	$24.82
	5000	177	0.2564	$681.28	$45.13
	10000	353	0.4226	$1,117.28	$75.38

Assumptions:

Depth of media = 1.8 m, OLR = 0.72 kg/m^3, HLR= 28.3 m^3/m^2.d @ 3:1 recycle ratio, Economic Life = 30 yrs

Construction Cost: circular filter units with rotating distributor arms, plastic media, underdrains and**ncludes secondary clarifier**

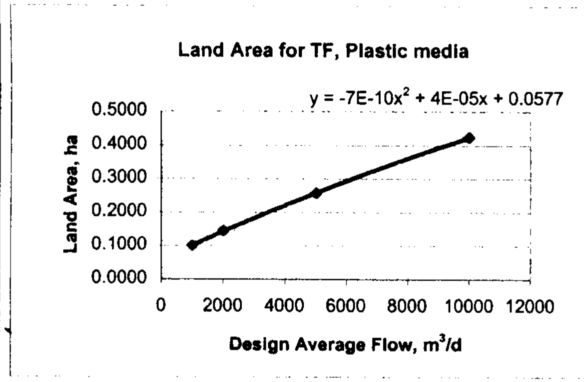
Land required,ha = 2*(land area for TF + land area required for secondary clarifier), Sludge produced = 0.03 kg/$m^3$of wastewater

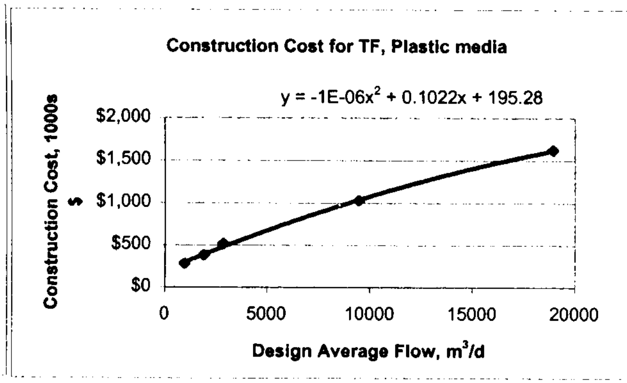
Calculations: (Col.C to Col.F based on HLR)

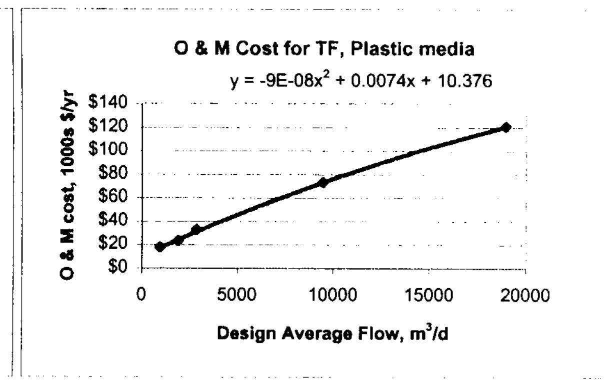
Col.C =(Col.B/ 28.3)

Col.D =2*((SQRT(Col.C*4/3.14)+8)^2)/10000 + Land area for secondary clarifier)

Col.E= Construction cost based on US $(1992; Finney & GearHeart,1998) converted to A$ (2001) using CPI and Exchange rate (See Section F.1, Note 3)



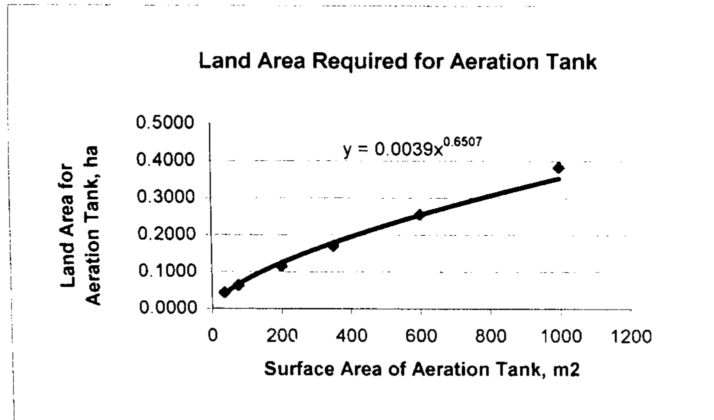




Reference: Qasim (1999), Finney & Gearheart (1998)

Table F.9 Cost Data Sheet for Conventional Activated Sludge Process w Clarifier

A	B	C	D	E
UIDNo/ Process Name	Surface Area of Aeration Tank, m^2	Land Area for Aeration Tank, ha	Construction Cost of Aeration Tank + Equipment, 1000s $	O & M Cost of Aeration Tank+Equipment, 1000s $/yr
2200 ASP , w clarifier & mechanical aerator**	35	0.0431	$438	$43.84
	75	0.0632	$492	$49.23
	200	0.1148	$673	$67.30
	350	0.1695	$874	$87.35
	600	0.2541	$1,188	$118.82
	1000	0.3818	$1,674	$167.42



Assumptions:

Aeration Tank: Aeration by surface aerators: $Theta_C$ = 10 days, Kinetic coefficient, Y= 0.5 per day, Free board = 0.8 m, Aeration requirement based on 1.5 * average organic loading, Transfer efficiency of Oxygen = 1.5 kg of O_2/kW.hr, Conversion factor to change BOD5 to BODL, f = 0.68, Side water depth= 3.5m, BOD removal efficiency = 90 %, MLVSS(X) = 3000 mg/L, Decay Coefficient , K_d= 0.06, Economic Life = 25 yrs

Construction Cost: concrete structure, surface aerators, metal work, sludge pumping

O & M Cost: 10 % of construction cost

Calculations:

Volume of Aeration tank =($Theta_C$*Qpk*Y*(Inf BOD-EffBOD))/(X*(1+K_d*$Theta_C$)

Surface Area =Volume of Aeration tank/depth

Sludge wasted every day, P_x kg/d= Y*Qav*(InfBOD-EffBOD)/(1000*(1+K_d*$Theta_C$)

Oxygen required, kg/d = (Qav*(Peak InfBOD-Peak EffBOD)/(1000*f))-(1.42*P_x)

Col.B = Assumed range of surface area of aeration tank based on the equations given above

Col.C =((SQRT(Col.B*4/(3.14))+ 8)^2)/10000)*2

Col.E = Col.D*0.10

**** Cost and land area shown in this data sheet is for aeration tank only.**

NOTE: Total Construction Cost of ASP w clarifier = Construction cost of (aeration tank + secondary clarifier)

Details of the secondary clarifier is given in pp 366.

Reference: Metcalf & Eddy (1991, pp 550), Bentley(2001)

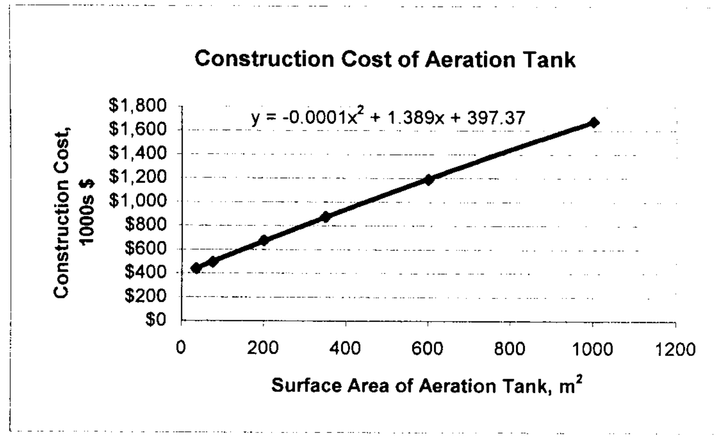
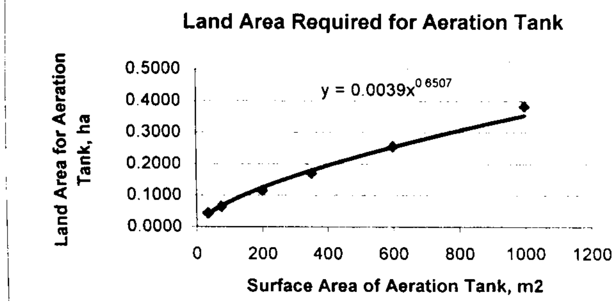


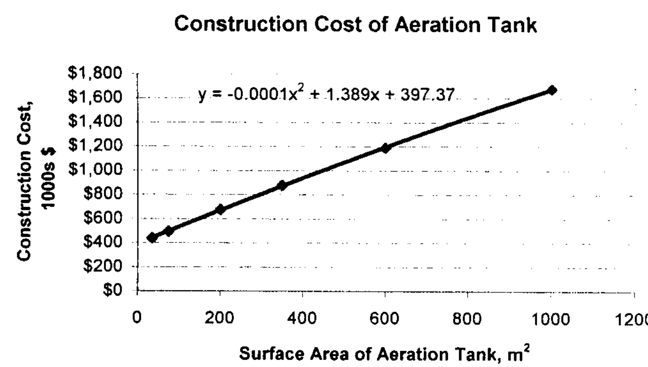
Table F. 10 Cost Data Sheet For Activated Sludge Process w Nitrification

A	B	C	D	E
UIDNo/ Process Name	Surface Area of Aeration Tank, m^2	Land Area for Aeration Tank, m^2	Construction Cost of Aeration Tank + Equipment, 1000s $	O & M Cost of Aeration tank, 1000s $/yr
2201 ASP, w Ni + clarifier + mechanical aerators	35	0.0431	$438	$43.84
	75	0.0632	$492	$49.23
	200	0.1148	$673	$67.30
	350	0.1695	$874	$87.35
	600	0.2541	$1,188	$118.82
	1000	0.3818	$1,582	$158.19



Assumptions:
This is similar to ASP w clarifier process except for the calculation of surface area of aeration tank which is based on Nitrification as well.
Aeration Tank: Aeration by surface aerators: Design peak flow = 3*Qavdwf, Kinetic coefficient, Y= 0.2 per day, Decay Coefficient , K_d= 0.05, MLVSS(X) = 2000 mg/L, Specific growth rate μ_m = 0.5/day,HRT based on both Nitrification and BOD removal, KO_2= 1.3, Safety factor, Sf = 2.5, DO= 2mg/L, Aeration requirement based on 1.5 * average organic loading rate, Transfer efficiency of Oxygen = 1.5 kg of O_2/kW.hr, Conversion factor to change BOD5 to BODL, f = 0.68, Side water depth= 3.5m, BOD removal efficiency = 90 %, TN removal efficiency =12.5 %, Economic Life = 25 yrs
Construction Cost: concrete structure, surface aerators, metal work, sludge pumping
O & M Cost: 10 % of construction cost
Calculations:

$\mu m' = \mu m(DO/1.3+DO)$, /day
$K' = \mu m'/Y$, days
$Theta_{min} = 1/(Y+K')-Kd)$, days
$Theta_{Dsn}=Theta_{min}*Sf$
$\mu=(1/Theta_{Dsn})+Kd)*(1/Y)$
$Theta_{BOD}= (InfBOD-EffBOD)/(\mu*MLVSS)$
$Theta_{Ni}=(InfTN-EffTN)/(\mu*MLVSS*0.08)$
if $Theta_{Ni}>Theta_{BOD}$ then $Theta=Theta_{Ni}$ else $Theta=Theta_{BOD}$
Volume of Aeration tank(Ni), m^3 =(Theta*Qav)
Surface Area =Volume of Aeration tank(Ni)/depth
Sludge wasted every day, P_x kg/d= Y*Qav*(InfBOD-EffBOD)/(1000*(1+K_d*Theta)
Oxygen required, kg/d = (Qav*(1.5*Peak InfBOD+4.57*Peak Influent TN)*Sf/1000
Col.B = Assumed range of surface area of aeration tank based on the equations given above
Col.C =((SQRT(Col.B*4/(3.14))+8)^2)/10000)*2
Col.E = Col.D*0.10



NOTE: Total Construction Cost of ASPw Ni w clarifier = Construction cost of (aeration tank+ secondary clarifier)
Details of the secondary clarifier construction cost is given in Table F.16
References: Metcalf & Eddy (1991, pp 550,701), Qasim (1999, pp 392)

Table F.11 Cost Data Sheet for Sequential Batch Reactor

A	B	C	D	E	F	G
UIDNo/ Process Name	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Surface Area, m^2	Land Required, ha	Construction Cost, 1000s $	O & M Cost , 1000s $/yr
2300 SBR	1000	2550	167	0.1019	$1,450	$145
	2000	5100	333	0.1637	$2,500	$250
	5000	12750	833	0.3294	$5,650	$565
	10000	25500	1667	0.5849	$10,900	$1,090

Assumptions

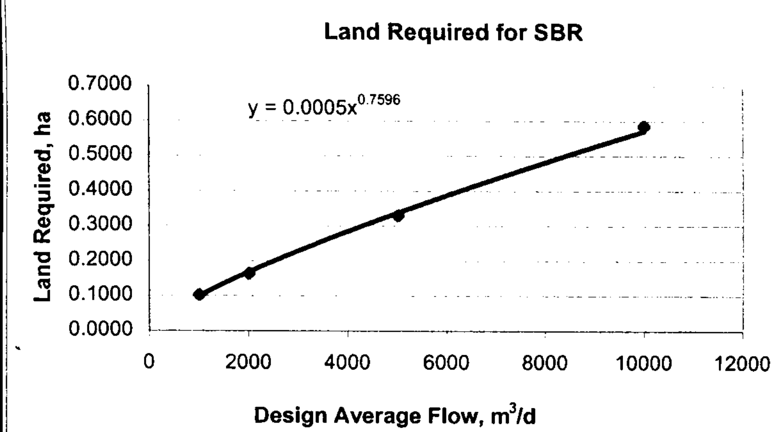
Sludge Produced, kg/d =(InfSS*%removal*Qav)/1000, Economic Life = 40 yrs

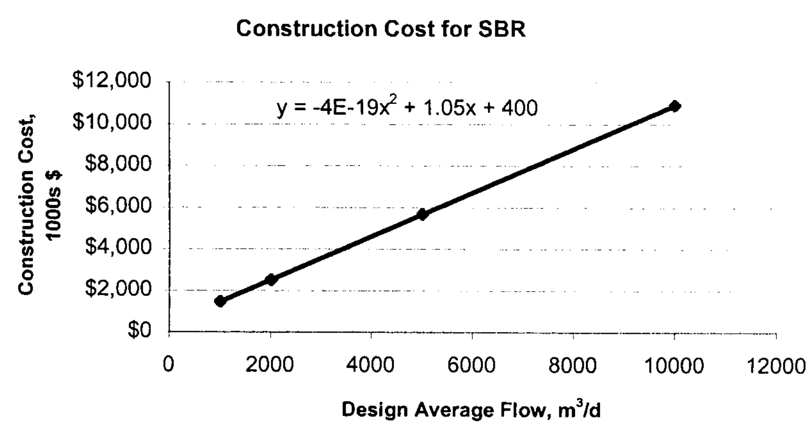
Design and construction cost provided by manufacturer

O & M Cost: 10 % of construction cost

Calculations

Col.E =(SQRT(Col.D*4/(3.14))+8)^2)/10000)*2





Reference: Factor UTB (2001)

Table F.12 Cost Data Sheet For Anaerobic Lagoon

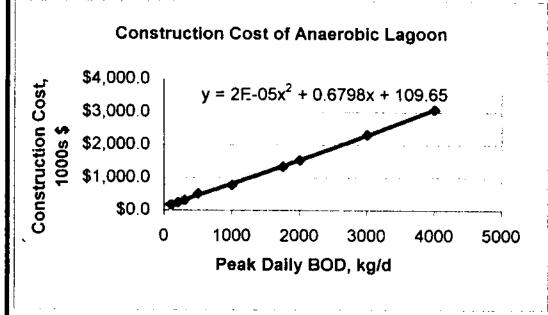
A	B	C	D	E	F	G	H	I	J	K	L
UIDNo/ Process Name	Peak Daily BOD, kg/d	Surface Area of Pond, ha	Volume of Anaerobic Lagoon, m^3	Surface Area of Liner, m^2	Land Area required, ha	Volume of Earthwork, m^3	Cost of Earthworks, 1000s $	Cost of Liner+Underlay, 1000s $	Cost of Inlet,Outlet+ Overflow, pipes & structure, 1000s $	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
2400 Anaerobic Lagoon /pond	100	0.3	850	3423	0.51	11310	$90.48	$34.23	$45	$169.9	$13.21
	200	0.6	1701	6845	1.01	22619	$113.10	$68.45	$57	$238.1	$19.29
	300	0.9	2551	10268	1.52	33929	$135.71	$102.68	$68	$306.3	$25.38
	500	1.5	4252	17113	2.53	56548	$226.19	$171.13	$113	$510.4	$42.30
	1000	3.0	8503	34226	5.06	113095	$282.74	$342.26	$141	$766.4	$66.79
	1750	5.2	14881	59896	8.85	197917	$494.79	$598.96	$247	$1,341.1	$116.88
	2000	6.0	17007	68452	10.12	226190	$565.48	$684.52	$283	$1,532.7	$133.57
	3000	8.9	25510	102679	15.18	339286	$848.21	$1,026.79	$424	$2,299.1	$200.36
	4000	11.9	34014	136905	20.24	452381	$1,130.95	$1,369.05	$565	$3,065.5	$267.14

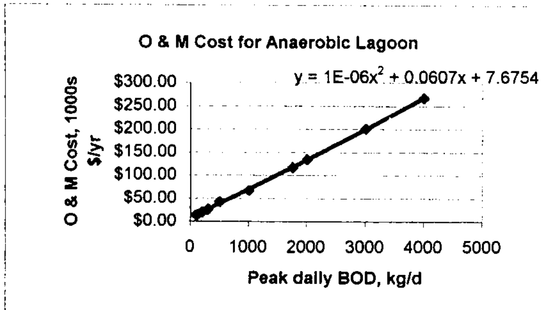
Assumptions

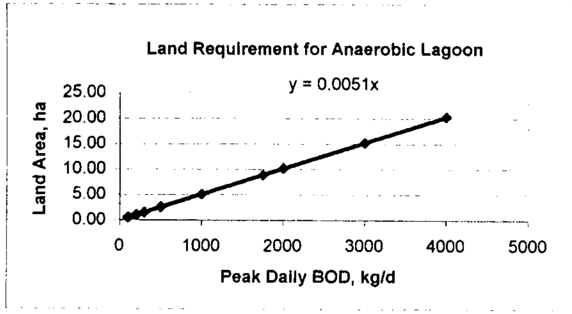
BOD Loading Rate = 336 kg/ha.d, Water Depth =3.5 m, Free board =0.3m, L:W =1:3, additional 4 m perimeter for total land area,Sludge removal frequency = 5 yrs, Economic Life = 40 yrs,O & M cost includes weeding, general maintenance of the pond and its surrounding and cost of sludge removal($40/- per tonne averaged/year)

Calculations

Col.C =Col.B /336
Col.D =(Col.C/3.5)*10000
Col.E = Col.D *1.15
Col.F=1.7*Col.D/10000
Col.G =Col.D*3.8
Col.H=Col.G*Earthwork cost
Col.I =Col.E*Liner Cost/1000
Col.J =Col.H*0.5
Col.K =Col.(H+I+J)







Reference: Bentley(2001),M&E(1991, pp 645)

Table F.13 Cost Data Sheet For Facultative Pond

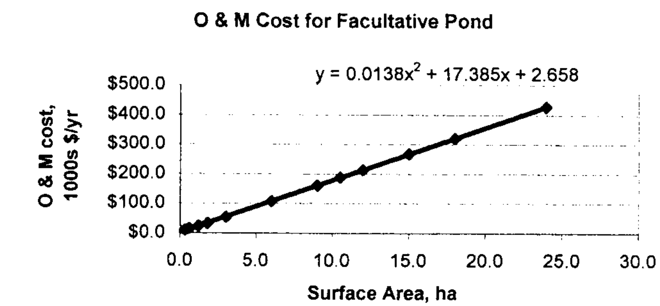
A	B	C	D	E	F	G	H	I	J	K
UIDNo/ Process Name	Peak Daily BOD, kg/d	Surface Area, ha	Land Area required, ha	Surface Area of Liner, m^2	Volume of Earthwork, 1000s m^3	Cost of Earthwork 1000s $	Cost of Liner+Underlay, 1000s $	Cost of Inlet,Outlet+ Overflow structure, 1000s $	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
2401 Facultative Pond	50	0.3	0.51	3443	5	$54	$34	$27	$115	$8.7
	100	0.6	1.02	6886	11	$86	$69	$43	$198	$15.2
	200	1.2	2.04	13772	22	$108	$138	$54	$299	$23.6
	300	1.8	3.05	20659	32	$129	$207	$65	$401	$32.0
	500	3.0	5.09	34431	54	$216	$344	$108	$668	$53.3
	1000	6.0	10.18	68862	108	$431	$689	$216	$1,335	$106.6
	1500	9.0	15.27	103293	162	$647	$1,033	$323	$2,003	$159.9
	1750	10.5	17.81	120509	189	$754	$1,205	$377	$2,337	$186.6
	2000	12.0	20.36	137725	216	$862	$1,377	$431	$2,671	$213.2
	2500	15.0	25.45	172156	269	$1,078	$1,722	$539	$3,338	$266.5
	3000	18.0	30.54	206587	323	$1,293	$2,066	$647	$4,006	$319.8
	4000	24.0	40.72	275449	431	$1,725	$2,754	$862	$5,341	$426.5

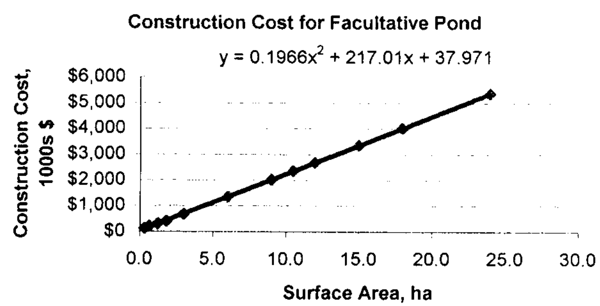
Assumptions

BOD Loading Rate, kg/ha.d =350(1.107-0.002*T)$^{T-25}$, Water Depth =1.5 m, Free board =0.3m, L: W : 1:3, 4m perimeter area for access, Economic Life = 40 yrs
Sludge is removed once in 5 years and the cost of removal is considered in the O & M cost, $40/- per tonne of sludge,BOD loading rate assumed as 167kg/ha.d @ Min Temperature=15 Deg C, O & M cost includes weeding, general maintenance and cost of sludge removal

Calculations

Col.C =Col.B /167
Col.D =Col.C *1.7(see Note: 7)
Col.E =Col.C*10000*1.15
Col.F=Col.C *1.8*10000
Col.H =Col.F*Earthwork cost
Col.H=Col.E*Liner cost/1000
Col.I =Col.G*0.5
Col.J =Col.(G+H+I)





Reference: Bentley (2001), Crites & Tchobanoglous (1998,pp 533), Mara (1998, pp 147)

Table F.14 Cost Data Sheet For Aerobic Lagoon

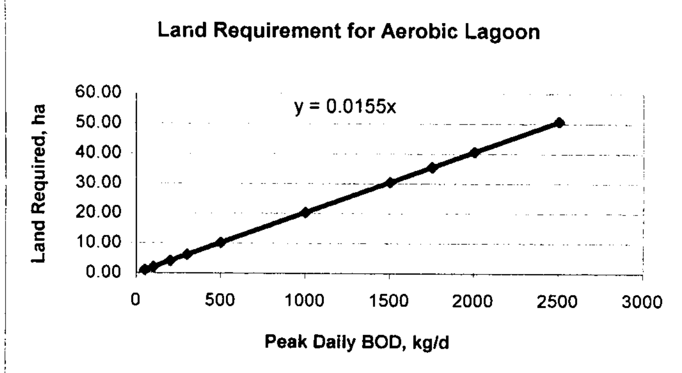
A	B	C	D	E	F	G	H	I	J	K
UIDNo/ Process Name	Peak Daily BOD, kg/d	Surface Area, ha	Surface area of Liner, m^2	Land Area required, ha	Volume of Earthwork, 1000s m^3	Cost of Earthworks, 1000s $	Cost of Liner+Underlay, 1000s $	Cost of Inlet,Outlet+Overflow, pipe & structure, 1000s$	Construction Cost, 1000s $	O & M Cost, 1000's $/yr
2402 Aerobic Lagoon	50	0.6	6845	1.01	11	$86	$68	$43	$197	$14
	100	1.2	13690	2.02	21	$107	$137	$54	$298	$22
	200	2.4	27381	4.05	43	$171	$274	$86	$531	$40
	300	3.6	41071	6.07	64	$257	$411	$129	$796	$60
	500	6.0	68452	10.12	107	$268	$685	$134	$1,086	$83
	1000	11.9	136905	20.24	214	$536	$1,369	$268	$2,173	$165
	1500	17.9	205357	30.36	321	$804	$2,054	$402	$3,259	$248
	1750	20.8	239583	35.42	375	$938	$2,396	$469	$3,802	$289
	2000	23.8	273810	40.48	429	$1,071	$2,738	$536	$4,345	$330
	2500	29.8	342262	50.60	536	$1,339	$3,423	$670	$5,432	$413
	3000	35.7	410714	60.71	643	$1,607	$4,107	$804	$6,518	$496
	4000	47.6	547619	80.95	857	$2,143	$5,476	$1,071	$8,690	$661

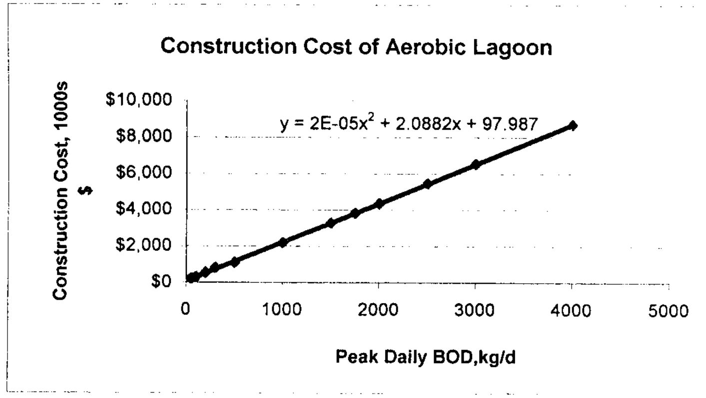
Assumptions

BOD Loading Rate =84 kg/ha.d, Water Depth =1.5 m, Free board =0.3m,Detention time = 25 days, Economic Life = 40 yrs
Sludge is removed once in 5 years and the cost of removal is considered in the O & M cost, $40/- per tonne of sludge
O & M cost includes weeding, general maintenance of the pond and its surrounding and cost of sludge removal

Calculations

Col.C =Col.B /84
Col.D =Col.C*1.15*10000
Col.E=Col.C *1.7(See Note:7)
Col.F =Col.C*10000*(1.5+0.3)
Col.G=Col.F*Earthwork cost
Col.H =Col.D*10/1000
Col.I =Col.G*0.5
Col.J =Col.(G+H+I)





Reference: Bentley(2001), Crites & Tchobanoglous (1998,pp 533)

Table F.15 Cost Data Sheet For Aerated Lagoon

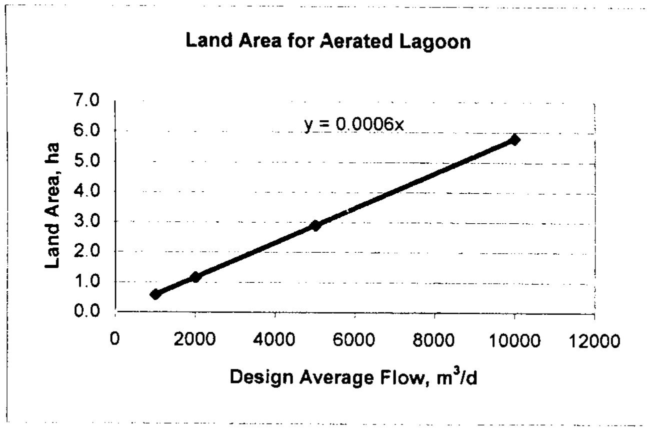
A	B	C	D	E	F	G	H	I	J	K	L	M
UID No./ Process Name	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Surface Area, m^2	Land Area Required, ha	Surface Area of Liner, m^2	Volume of Earthwork, 1000s m^3	Surface Mixers, kW#	Cost of Earthworks, 1000s $	Cost of Liner+Underlay, 1000s $	Cost of Inlet,Outlet +Overflow structure+ Surface mixers, 1000s $	Construction Cost, 1000s $	O&M Cost, 1000s $/yr
2403 Aerated Lagoon	1000	2550	3400	0.6	3910	13	38	$106	$39	$78.04	$223	$22.32
	2000	5100	6800	1.2	7820	27	77	$106	$78	$98.04	$282	$28.23
	5000	12750	17000	2.9	19550	66	191	$265	$196	$207.60	$668	$66.83
	10000	25500	34000	5.8	39100	133	383	$332	$391	$265.75	$988	$98.83

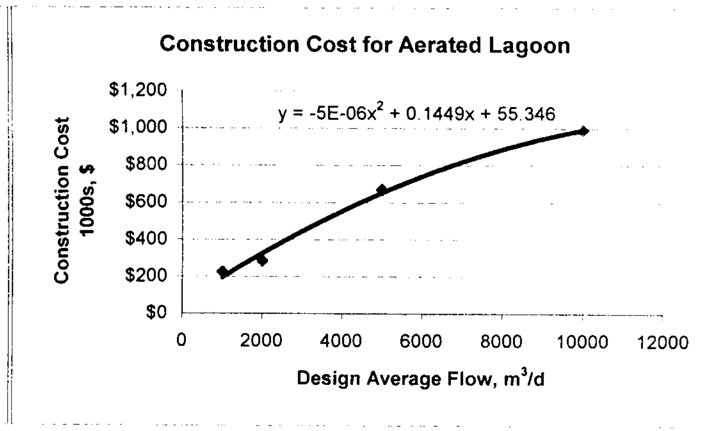
Assumptions

MCRT(Theta) = 4 days, Water Depth =3.0 m, Free board =0.9m,Decay Coefficient, K_d/day = 0.07,Yield Co-efficient,Y=0.65,MLVSS= Y*(InfBOD-EffBOD)/(1+kd*theta),
Surface aerator rating, kg of O_2/kW.hr = 2.0, Transfer rate of O_2 in kg /kW.d=31.68, Power required for mixing = 15 kW/1000m^3,
Correction factor for surface aerators, Cf = 0.66, Economic Life = 30 yrs, Sludge Produced, kg/d =(MLVSS*Qav)/1000
#Energy requirement for mixing greater than energy requirement for oxygen supply (Metcalf & Eddy,1979, pp531)

Calculations

Col.D =Col.C*4/3
Col.E =Col.B*1.7/10000 (See Note : 7)
Col.F=Col.B *1.15
Col.G =Col.D*(3+0.9)
Col.H=15*(Col.C)/1000
Col.I=Col.G*Earthwork cost
Col.J =Col.F* Lining Cost/1000
Col.K =Col.I*0.5+ cost of surface mixer
Col.L =Col.(I+J+K)
Col.M =Col.L*0.10





References: Metcalf & Eddy (1979, pp 528), Bentley(2001)

Table F.16 Cost Data Sheet For Secondary Circular Clarifier

A	B	C	D	E	F	G
UIDNo/ Process Name	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Surface Area, m^2	Land Required, ha	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
2500 Secondary Clarifier	1000	2550	59	0.0557	$270	$26.96
	2000	5100	119	0.0824	$341	$34.07
	5000	12750	297	0.1505	$531	$53.12
	10000	25500	593	0.2518	$823	$82.29

Assumptions

Design peak flow= 3* Qavdwf, SOR @ design peak flow = 43 m^3/m^2.d, Sludge loading rate @ Qavdwf +100 % recycle = 90 kg/m^2.d, Recycle ratio of 1:1, Side water depth = 3.5m, Free board = 0.5 m, Economic Life = 20 yrs

Construction Cost: concrete structure, mechanical and electrical equipment, metal work and sludge, recycle pumping

O & M Cost: 10% of construction cost

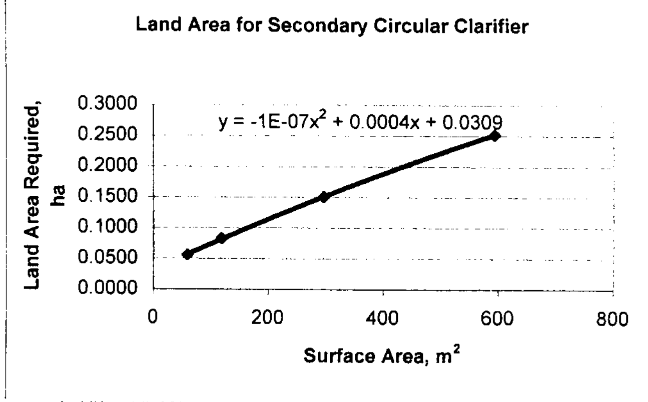
Calculations:

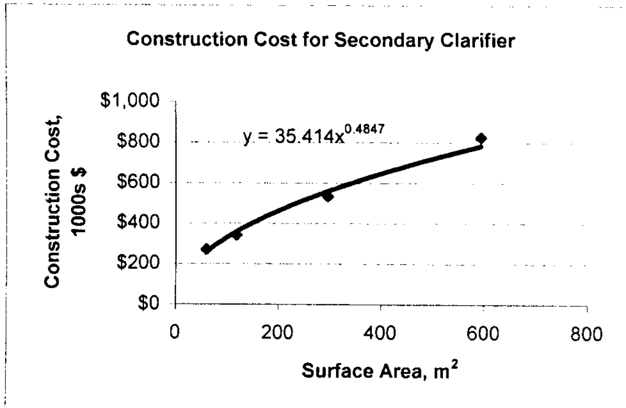
Col.C= Col.B*0.85*3

Col.D=Col.C/43

Col.E=2*(((SQRT(D4*4/(3.14))+8)^2)/10000)

Col.G =Col.F*0.1





Reference: Bentley (2001),Richards (1998, pp 1365)

Table F.17 Cost Data Sheet for Sedimentation Pond

A	B	C	D	E	F	G	H	I	J	K
UIDNo/ Process Name	Design Peak Flow, m^3/d	Surface Area, ha	Surface area of Liner, m^2	Land Area required, ha	Volume of Earthwork, 1000s m^3	Cost of Earthworks, 1000s $	Cost of Liner+Underlay, 1000s $	Cost of Inlet,Outlet+ Overflow structure, 1000s $	Construction Cost, 1000s $	O & M Cost, 1000's $/yr
2501 Sedimentation Pond	2550	0.34	3910	0.58	8.8	$71	$39	$35	$145	$17
	5100	0.68	7820	1.16	17.7	$106	$78	$53	$237	$24
	12750	1.70	19550	2.89	44.2	$177	$196	$88	$461	$60
	25500	3.40	39100	5.78	88.4	$354	$391	$177	$921	$101

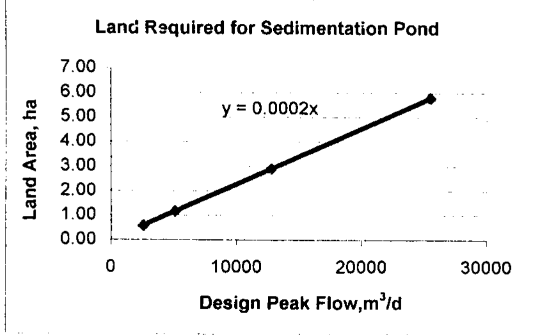
Assumptions

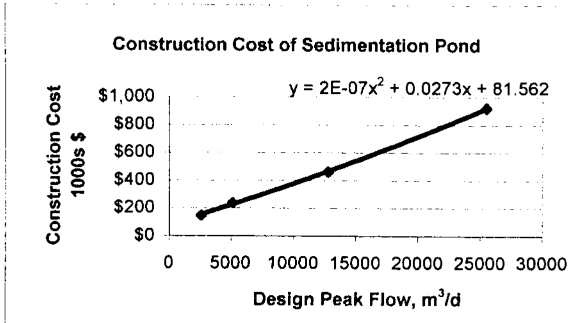
Water Depth =1.5 m, Free board =0.3m,Detention time =2 days, Density of accumulated solids =1.06, deposited solids to compact to an average of 15 %, Sludge removal frequency =2 yrs, Economic Life = 40 yrs

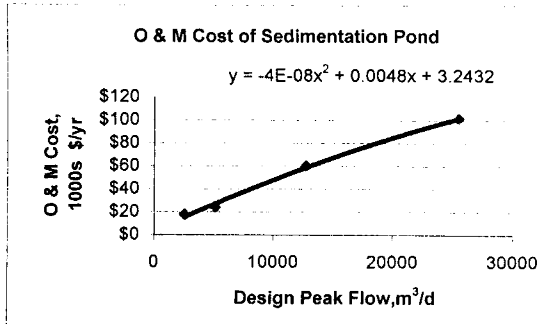
O & M cost includes weeding, general maintenance of the pond and its surrounding and cost of sludge removal($40/- per tonne of sludge)

Calculations

Col.C =Col.B *2/(1.5*10000)
Col.D =Col.C*1.15*10000
Col.E=Col.C *1.3
Col.F =Col.C*10000*(1.5+0.3+0.8)** **Maximum sludge depth assumed =0.8m
Col.G=Col.F*Earthwork cost
Col.H =Col.D*Liner cost/1000
Col.I =Col.G*0.5
Col.J =Col.(G+H+I)







Reference: Bentley(2001); Metcalf & Eddy (1979, pp 533)

Table F.18 Cost Data Sheet For Subsurface(SSF) Wetland (BOD)

A	B	C	D	E	F	G	H	I	J	K
UIDNo/ Process Name	Surface Area, m^2	Surface Area of Liner, m^2	Land Area Required, ha	Volume of Earthwork, 1000s m^3	Cost of Earthworks, 1000s $	Cost of Gravel Media +Liner, 1000s $	Cost of Inlet,Outlet structures, 1000s $	Cost for vegetation planting & establishment+ miscellaneous, 1000s $	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
3100 SSF Wetland (BOD)	2500	2875	0.43	2	$23	$66	$11	$17	$117	$5.9
	5000	5750	0.85	3	$45	$133	$23	$34	$234	$11.7
	10000	11500	1.70	6	$60	$265	$30	$62	$417	$20.9
	20000	23000	3.40	12	$96	$530	$48	$119	$793	$39.7
	40000	46000	6.80	24	$120	$1,060	$60	$224	$1,464	$73.2
	60000	69000	10.20	36	$144	$1,590	$72	$329	$2,135	$106.7
	70000	80500	11.90	42	$168	$1,855	$84	$384	$2,491	$124.5
	100000	115000	17.00	60	$240	$2,650	$120	$548	$3,558	$177.9
	200000	230000	34.00	120	$300	$5,300	$150	$1,060	$6,810	$340.5
	500000	575000	85.00	300	$750	$13,250	$375	$2,650	$17,025	$851.3

Assumptions

Subsurface wetland with Geotextile liner, Total Depth of wetland = 0.6m, K_r=1.104/d, Temperature Coefficient for Nitrification,$Theta_r$=1.06, Reference Temperature, Tr = 20 Deg C, Winter water temperature,T_w= (Minimum Temperature-2) Deg C, $K_t = K_r * Theta_r^{(Tw-Tr)}$, Porosity,n = 0.65, Factor of Safety, FS = 1.2, Economic Life = 35 yrs

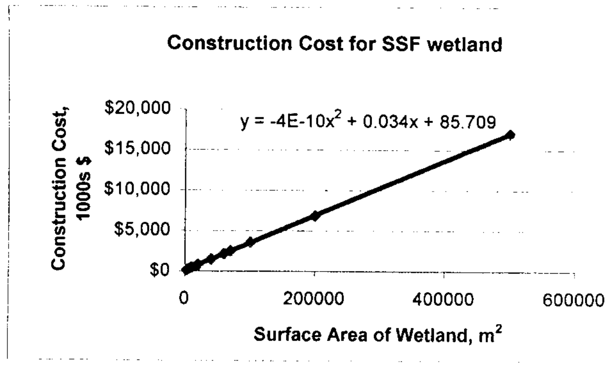
Construction Cost: cost of earthwork, liner, gravel media, inlet & outlet structures,vegetation planting & establishment, miscellaneous like pipe anchors; **O & M Cost**: 5% of construction cost

Calculations

Surface Area, m^2= ((Qav*ln(InfBOD/EffBOD))/(K_t*y*n))*FS

where Qav = Average flow in m^3/d,
EffBOD = Effluent BOD mg/L,
InfBOD = Influent BOD mg/L.

Col.C =Col.B *1.15
Col.D =Col.C*1.7/10000
Col.E=Col.B *(0.6)/1000
Col.F =Col.E*Earthwork cost
Col.G=(Col.C*Liner cost/1000)+(Col.E*Media cost)
Col.H =Col.F*0.5
Col.I ==((Col.B*5)/1000+(Col.F*0.2))
Col.J =Col.(F+G+H+I)
Col.K =Col.J *0.05



Reference: Bentley(2001);Mitchell *et al*., (1998, pp 271), Crites & Tchobanoglous (1998, pp 630)

Table F.19 Cost Data Sheet For Free Water Surface Wetland (BOD+Ni)

A	B	C	D	E	F	G	H	I	J	K
UIDNo/ Process Name	Surface Area, m^2	Surface Area of Liner, m^2	Land Area Required, ha	Volume of Earthwork, 1000s m^3	Cost of Earthworks, 1000s $	Cost of liner+ underlay, 1000s $	Cost of Inlet,Outlet +Overflow structure, 1000s $	Cost for vegetation planting & establishment+ miscellaneous, 1000s $	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
3101 FWS Wetland (BOD+Ni)	2500	2875	0.43	2	$26	$29	$13	$18	$86	$8.6
	5000	5750	0.85	4	$35	$58	$18	$32	$142	$14.2
	10000	11500	1.70	7	$56	$115	$28	$61	$260	$26.0
	20000	23000	3.40	14	$112	$230	$56	$122	$520	$52.0
	60000	69000	10.20	42	$168	$690	$84	$334	$1,276	$127.6
	70000	80500	11.90	49	$196	$805	$98	$389	$1,488	$148.8
	100000	115000	17.00	70	$280	$1,150	$140	$556	$2,126	$212.6
	200000	230000	34.00	140	$350	$2,300	$175	$1,070	$3,895	$389.5
	400000	460000	68.00	280	$700	$4,600	$350	$2,140	$7,790	$779.0

Assumptions

Free water surface wetlands with geotextile liner, Depth of wetland = 0.4m, Free board = 0.3m, K_r=0.2187/d, Temperature Coefficient for Nitrification,$Theta_r$=1.048, Winter water temperature,Tw= (Minimum Temperature-2)Deg C, Porosity, n = 0.65, Factor of Safety FS = 1.2, Reference Temperature T_r = 20 Deg C, $K_t = K_r{*}Theta_r^{(Tw-Tr)}$,

Construction Cost: earthwork, liner,inlet and outlet structures, vegetation planting (cattails, bulrush, reeds, arrowhead), miscellaneous-pipe anchors

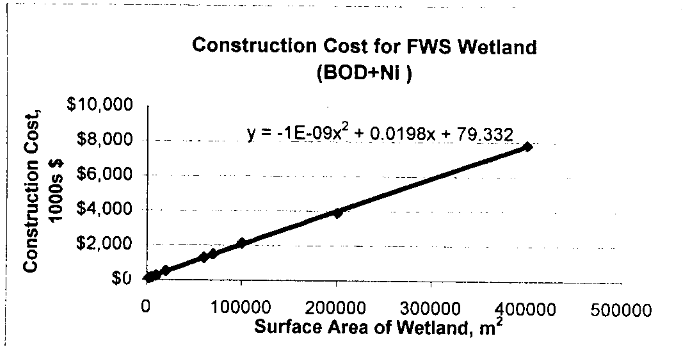
O & M Cost includes vegetation harvesting, Economic Life = 40 yrs

Calculations

Surface Area, m^2= ((Qav*ln(InfTN/EffTN))/(K_t*y*n))*FS

where Qav = Average flow in m^3/d,
InfTN= Influent TN mg/L,
EffTN=Effluent TN mg/L,

Col.C =Col.B *1.15
Col.D =Col.C*1.7/10000
Col.E=Col.B *(0.4+0.3)
Col.F =Col.E*Earthwork cost
Col.G=Col.C*Liner cost/1000
Col.H =Col.F*0.5
Col.I=5*Col.B/1000+(0.2*Col.F)
Col.J =Col.(F+G+H+I)
Col.K =Col.J *0.10



Reference: Bentley(2001);Mitchell *et al*., (1998, pp272-273), Crites & Tchobanolgous (1998,pp597)

Table F.20 Cost Data Sheet for Free Water Surface Wetland (BOD)

A	B	C	D	E	F	G	H	I	J	K
UIDNo/ Process Name	Surface Area, m^2	Surface Area of Liner, m^2	Land Area Required, ha	Volume of Earthwork, 1000s m^3	Cost of Earthworks, 1000s $	Cost of liner+ underlay, 1000s $	Cost of Inlet,Outlet structure+recirculation pumps & piping, 1000s $	Cost of vegetation planting +establishment+ miscellaneous, 1000s $	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
3102 FWS Wetland(BOD)	2500	2875	0.43	2	$26	$29	$13	$18	$86	$8.6
	5000	5750	0.65	4	$35	$58	$18	$32	$142	$14.2
	10000	11500	1.30	7	$56	$115	$28	$61	$260	$26.0
	20000	23000	2.60	14	$112	$230	$56	$122	$520	$52.0
	60000	69000	7.80	42	$168	$690	$84	$334	$1,276	$127.6
	70000	80500	9.10	49	$196	$805	$98	$389	$1,488	$148.8
	100000	115000	13.00	70	$280	$1,150	$140	$556	$2,126	$212.6
	200000	230000	26.00	140	$350	$2,300	$175	$1,070	$3,895	$389.5
	400000	460000	52.00	280	$700	$4,600	$350	$2,140	$7,790	$779.0

Assumptions

Wetland with geotextile liner, Depth of wetland = 0.4m, Free board = 0.3m, K_r = 0.678/d, Winter water temperature,T_w = (Minimum Temperature-2) Deg C, Porosity, n = 0.65, Factor of Safety,FS = 1.2, Reference Temperature T_r = 20 Deg C, $K_t = K_r*\text{Thetar}^{(Tw-Tr)}$, Economic Life = 40 yrs

Construction Cost and O & M Cost: Same as FWS wetland (BOD+Ni). The difference is in the calculation of surface area of the wetland which is based on influent and effluent BOD as given in the equation below.

Calculations

Surface Area, m2= ((Qav*ln(InfBOD/EffBOD))/(Kt*y*n))*FS

where Qav = Average flow in m3/d,

InfBOD =Influent BOD in mg/L

EffBOD=Effluent BOD in mg/L,

Col.C =Col.B *1.15

Col.D =Col.C*1.7/10000

Col.E=Col.B *(0.6+0.5)

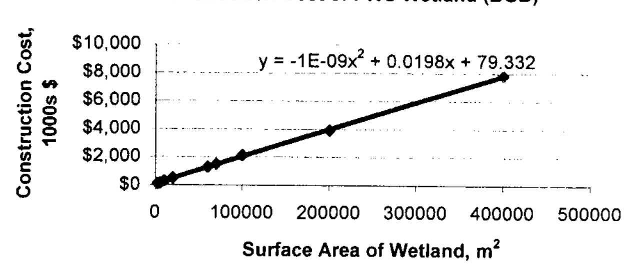
Col.F =Col.E*Earthwork cost/1000

Col.G=Col.C*Liner cost/1000

Col.H =Col.F*0.5

Col.J =Col.(F+G+H+I)

Col.K =Col.J *0.10



Reference: Bentley(2001); Mitchell *et al*., (1998, pp 272-273)

Table F. 21 Cost Data Sheet for Continuous Flow Biological Nutrient Removal (BNR)

A	B	C	D	E	F	G	H	I
UIDNo/ Process Name	Design Average Dry Weather Flow, m^3/d	Total Volume of Reactor, ML	Volume of Reactor, m^3	Depth, m	BNR Reactor Area, m^2	Clarifier Surface Area, m^2	Total Surface Area, m^2	Land Area, ha
4100 BNR	5300	2.88	2880	4	720	794	1514	0.3609
	9450	2.71	2710	4	678	1441	2118	0.4758
	27200	31.8	31800	4.5	7067	5000	12067	2.2187

Assumptions

BNR plants are complex systems and require detail design. However for the purpose of planning level estimate, design and cost reported in UWRAA report on BNR plants (Report No.94; Hartley,1995) and Hartley(1998) has been used. The Land requirement was calculated using data from UWRAA report while the construction cost equation was adapted from Hartley(1998).

Construction cost: Cost of BNR reactor + secondary clarifier

Cost of BNR reactor is a function of effluent nitrogen and phosphorus and plant capacity. The BNR construction cost estimation involves the following steps.

1. Estimate the Cost of BNR reactor as a function of plant capacity

$Y = (5.2242x^{0.5882})$

where Y= Cost as a function of effluent nitrogen and phosphorus

X= plant capacity in 1000s

2. Substitute Y value obtained from the step above in to the following equation to get construction cost

Construction cost, 1000s \$2001 = $(Y/(N^{0.59}*P^{0.29})*1000)*1.12$

where N = effluent 50 percentile Nitrogen concentration, mg/L;

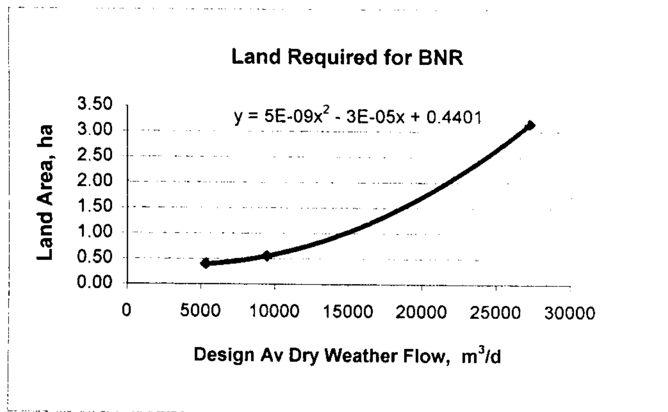
P = effluent 50 percentile Phosphorus concentration, mg/L.

Effluent quality range N : 3-10 mg/L and P: 0.2-3 mg/L

For the purpose of this study, average effluent concentration is assumed as 50 percentile concentration

To convert \$1997 to \$ 2001, the above construction cost is multiplied by CPI 1.12

3. Construction cost of secondary clarifier (See UIDNo 2500)



O & M Cost

10 % of construction cost

Economic Life = 25 yrs

References: Hartley(1995 &1998)

Table F. 22 Cost Data Sheet for Single Stage Lime Treatment

A	B	C	D	E	F	G	H	I	J	K	L
UIDNo/ Process Name	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Rapid Mix Detention Tank Volume, m^3	Flocculation Tank Volume, m^3	Surface Area of Flocculation Tank, m^2	Surface Area of Clarifier, m^2	Lime Dosage, tonne/yr	Land Required, ha	Cost of Lime, 1000s $/yr	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
4200 Single Stage Lime Treatment	1000	2550	0.03	35.42	14.2	67.1	242.0	0.0491	$38.72	$256.6	$61.8
	2000	5100	0.06	70.83	28.3	134.2	484.0	0.0653	$77.44	$341.3	$108.2
	5000	12750	0.15	177.08	70.8	335.5	1210.0	0.1141	$193.60	$513.5	$239.8
	10000	25500	0.30	354.17	141.7	671.1	2420.0	0.1953	$387.19	$712.0	$451.3

Assumptions

Lime dosage(CaO) = 200 mg/L, Rapid mix detention time = 1 sec, Flocculation detention time = 20 min,Depth of flocculation tank = 2.5m, Clarifier HLR @ design peak flow = 38 m^3/m^2.d,

Sludge produced, kg/d = (InfSS * %SS removed * Qav/1000)+(0.58*lime dosage(kg/d))

Land required = 2*land for (rapid mix tank + 30 days storage area for lime+ flocculation tank+clarifier+buffer distance)

Construction cost: cost of rapid mix tank,lime storage, flocculation tank, clarifier; **O & M Cost**: cost for chemical, power, labour and repair & maintenance.

Calculations

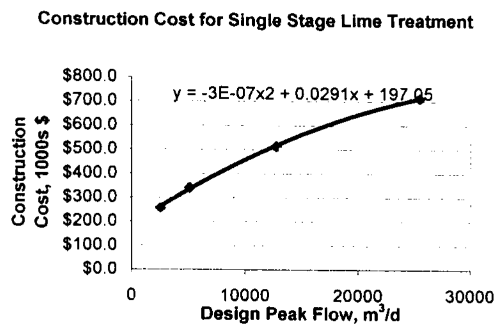
Col.C=Col.B*3*0.85 — Col.H=200*10^-3*1.3*Col.C*365/(1000), (Assumed CaO= 1.3 $Ca(OH)_2$)

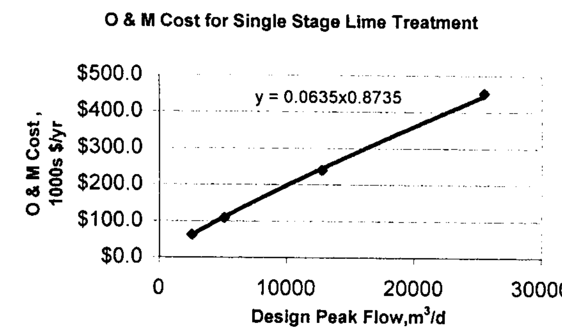
Col.D=Col.C*1/86400 — Col.I =Col.H*1000*0.5/250

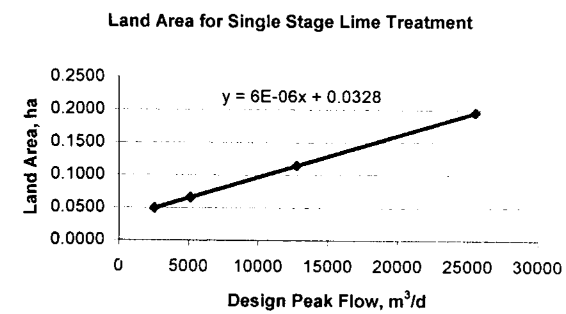
Col.E =Col.C*20/1440 — Col.I=2*((Col(F+G)+64+100)/10000))

Col.F=Col.E/2.5 — Col.J=Col.H*160/1000

Col.G=Col.C/38 — Col.L= Col.J+ (0.09*Col.K)





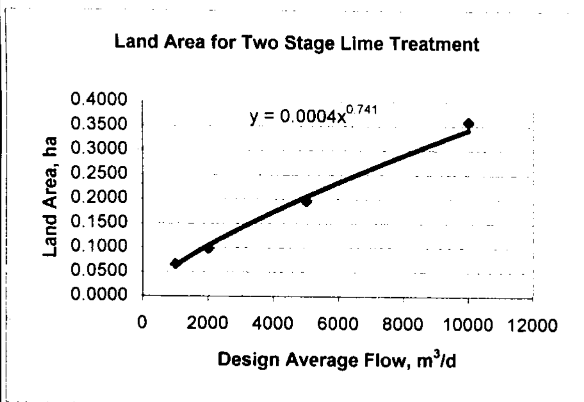


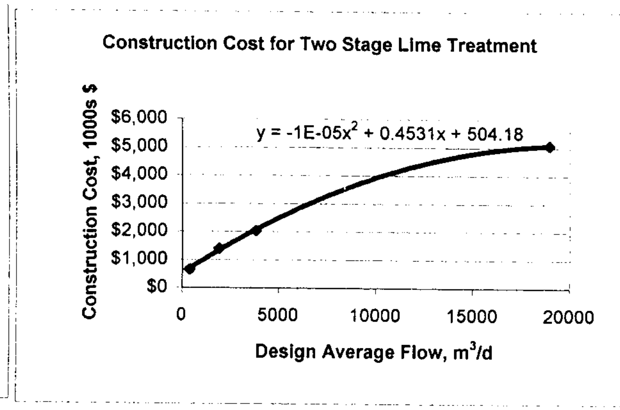
References: Bentley(2001)

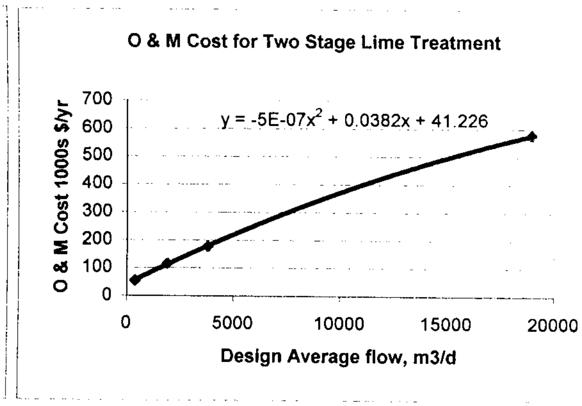
Table F.23 Cost Data Sheet for Two Stage Lime Treatment

A	B	C	D	E	F
UIDNo/ Process Name	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Land Required, ha	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
4201 Two Stage Lime Treatment	1000	2550	0.0653	$947.3	$51.6
	2000	5100	0.0978	$1,370.4	$110.6
	5000	12750	0.1953	$2,519.7	$169.6
	10000	25500	0.3579	$4,035.2	$553.0

Assumptions
Design flow =3*Qav, Lime dosage(CaO)= 400 mg/L, Rapid mix detention time= 1 sec, Flocculation detention time = 20 min, Depth of flocculation tank = 2.5m, recarbonation: Feed tank detention time = 10 min, CO_2 feed rate= 1.5 mg/L for every mg/L of Calcium precipitate , Clarifier HLR @ design peak flow = 47 m3/m2.d, Side water depth = 3.0 m, Sludge produced, kg/d= (InfSS * %SS removed * Qav/1000)+(0.58*lime dosage(kg/m3)*Qav)
Land area required = land for (rapid mix tank + 30 days storage area for lime+ flocculation tank+clarifier+CO_2 feed tank + second stage clarifier + buffer distance), Economic Life = 20 yrs
Construction cost: cost of rapid mix tank, lime storage, flocculation tank, clarifier, CO_2 feed tank and equipment for recarbonation
O & M Cost: cost for chemical, power, labour and repair & maintenance.







Reference: Finney and Gearheart(1998)

Table F.24 Cost Data Sheet for Break Point Chlorination

A	B	C	D	E	F	G
UIDNo/ Process Name	Design Average Flow, m^3/d	Design Average Dry Weather Flow, m^3/d	Chlorine Contact Tank Volume, m^3	Land Required, ha	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
4300 Break Point Chlorination	1000	850	18	0.0170	$151	$49.4
	2000	1700	35	0.0176	$213	$88.8
	5000	4250	89	0.0194	$337	$200.3
	10000	8500	177	0.0223	$477	$381.3

Assumptions

Design flow = Qavdwf, Average chlorine demand = 20 mg/L @ 1.2 Qavdwf, plant capacity = 30 mg/L @ 3 Qavdwf, NaOH added @ 1.2 kg per kg of Cl_2 to neutralise the HCl formed due to addition of chlorine, Depth of contact tank= 3m ,Chlorine contact time= 30 min, Economic Life = 20 yrs

Land required = land for (chlorine tank + 30 days storage area for chlorine & NaOH +feed system +buffer distance)

Construction cost: Chlorine & NaOH storage tank and feed system, contact tank, dosing and control

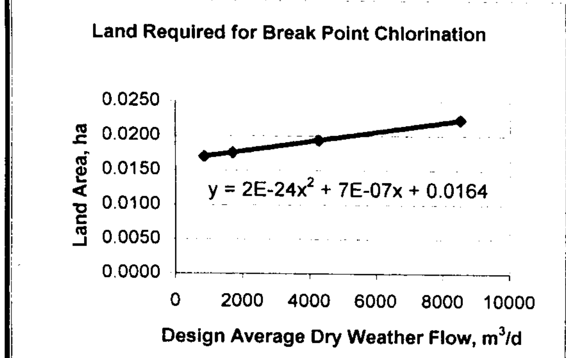
O & M Cost: Chemical, power, labour and repair & maintenance.

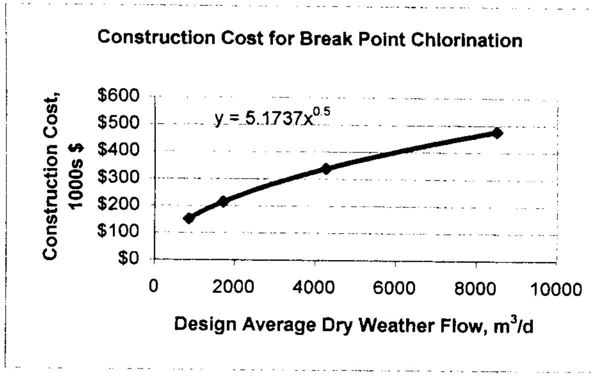
Calculations

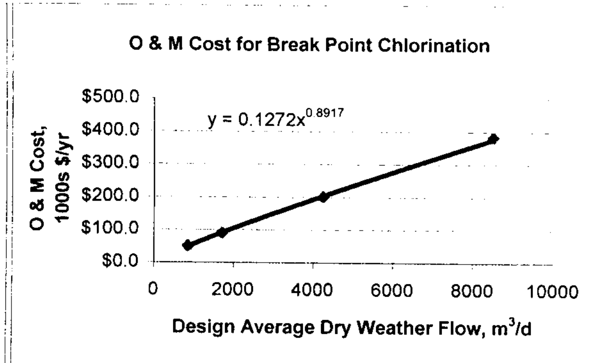
Col.C=Col.B*0.85

Col.D=Col.C*30/1440

Col.E =((Col.D/3) +64+64)/10000)







References: Bentley (2001)

Table F.25 Cost Data Sheet for Coagulation and Flocculation w Alum

A	B	C	D	E	F	H	I	J	K	L
UIDNo/ Process Name	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Rapid Mix Detention Tank Volume, m^3	Flocculation Tank Volume, m^3	Surface Area of Flocculation Tank, m^2	Alum Dosage, tonne/yr	Land Required, ha	Cost of Alum, 1000s $/yr	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
4400 Coagulation & Flocculation	1000	2550	0.03	35.42	14.2	23.3	0.0356	$3.26	$63.4	$6.4
	2000	5100	0.06	70.83	28.3	46.5	0.0385	$6.52	$72.7	$10.2
	3400	8670	0.10	120.42	48.2	79.1	0.0424	$11.08	$81.9	$15.2
	10000	25500	0.30	354.17	141.7	232.7	0.0611	$32.58	$108.3	$38.0

Assumptions

Alum dosage = 25 mg/L, Rapid mix detention time = 1 sec, Flocculation detention time = 20 min, Depth of flocculation tank = 2.5m, Land required = 2* land for (rapid mix tank + 30 days storage area + flocculation tank+buffer distance),Economic Life = 20 yrs

Construction cost: cost of rapid mix tank,lime storage, flocculation tank

O & M cost: Cost for chemical, power, labour and repair & maintenance.

Calculations

Col.C=Col.B*3

Col.D=Col.C*1/86400

Col.E =Col.C*20/1440

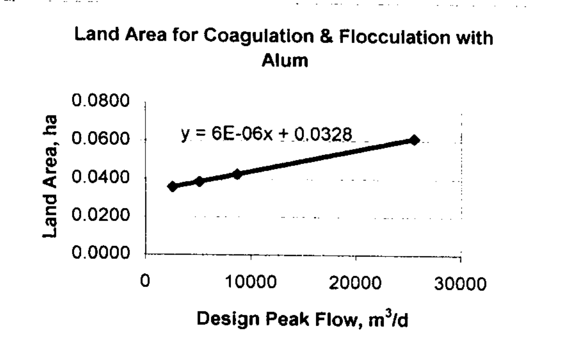
Col.F=Col.E/2.5

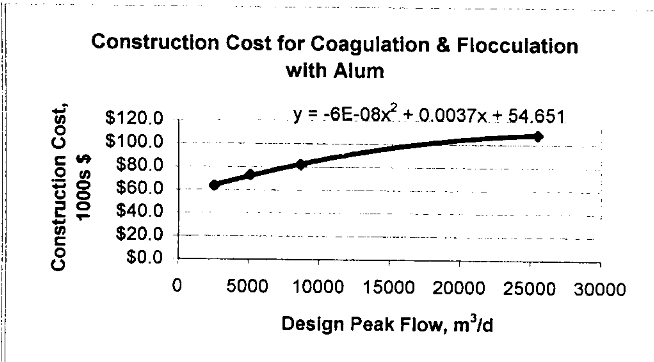
Col.G=Col.C/38

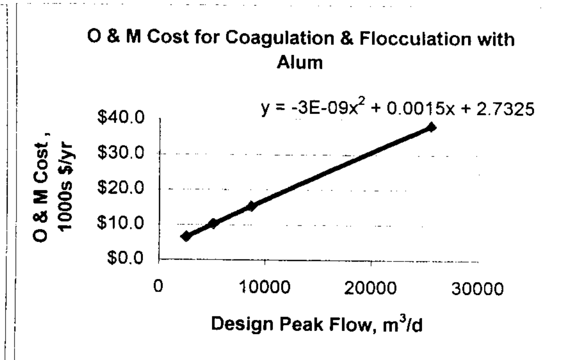
Col.H=25*Col.C*365/(10^6)

Col.J=Col.H*140/1000

Col.L= Col.J+ (0.09*Col.K)







References: Bentley(2001)

Table F.26 Cost Data Sheet For Coagulation, Flocculation & Sedimentation w Alum

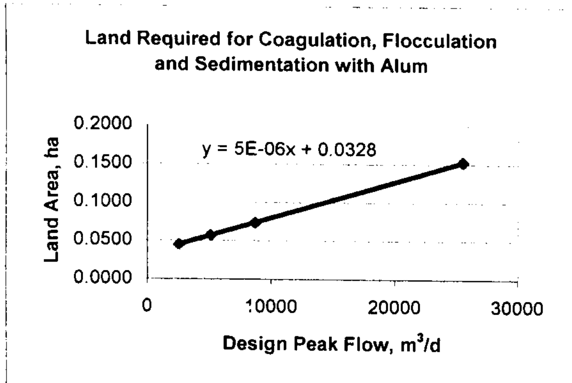
A	B	C	D	E	F	G	H	I	J	K	L
UIDNo/ Process Name	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Rapid Mix Detention Tank Volume, m^3	Flocculation Tank Volume, m^3	Surface Area of Flocculation Tank, m^2	Surface Area of Clarifier, m^2	Alum Dosage, tonne/yr	Land Required, ha	Cost of Alum, 1000s $/yr	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
4401 Coagulation, Flocculation and Sedimentation	1000	2550	0.03	35.42	14.2	45.5	69.8	0.0447	$9.77	$167.7	$24.9
	2000	5100	0.06	70.83	28.3	91.1	139.6	0.0567	$19.55	$272.5	$44.1
	3400	8670	0.10	120.42	48.2	154.8	237.3	0.0734	$33.23	$395.1	$68.8
	10000	25500	0.30	354.17	141.7	455.4	698.1	0.1522	$97.73	$840.7	$173.4

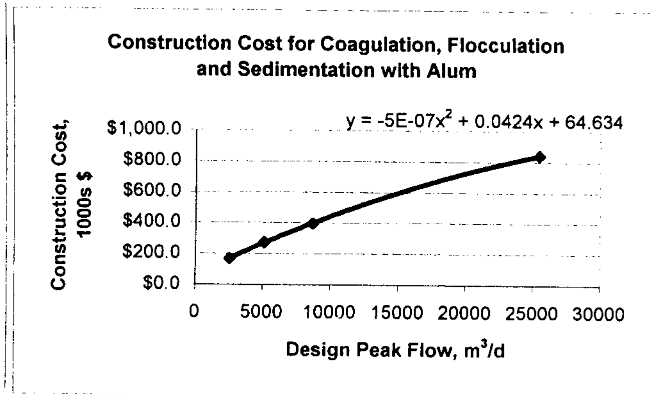
Assumptions

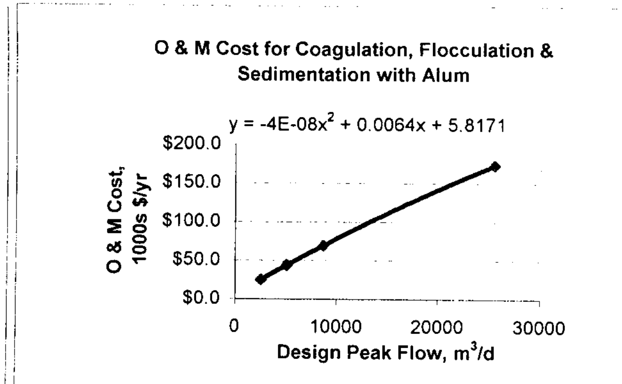
Alum dosage = 75 mg/L, Rapid mix detention time= 1 sec, Flocculation detention time = 20 min,Depth of flocculation tank = 2.5m, SOR @ peak flow= 56 $m^3/m^2.d$
Land required = land for (rapid mix tank + 30 days storage area + flocculation tank+clarifier+ buffer distance), Economic Life = 20 yrs
Construction cost: cost of rapid mix tank,lime storage, flocculation tank, clarifier
O & M cost: Cost for chemical, power, labour and repair & maintenance.

Calculations

Col.D=Col.C*1/86400
Col.E =Col.C*20/1440
Col.F=Col.E/2.5
Col.G=Col.C/38
Col.H=50*Col.C*365/(10^6)
Col.J=Col.H*140/1000
Col.L= Col.J+ (0.09*Col.K)







References: Bentley (2001)

Table F.27 Cost Data Sheet for Sand Filter

A	B	C	D	E	F	H	I
UIDNo/ Process Name	**Design Average Flow, m³/d**	**Design Peak Flow, m³/d**	**Total Diameter, m**	**No of units ****	**Land Required, ha**	**Total Construction Cost, 1000s $**	**O & M Cost, 1000s $/yr**
4500 Sand Filter	1000	2550	5	2	0.0343	$265.00	$26.50
	1667	4250	9	3	0.0545	$410.00	$41.00
	5000	12750	26	11	0.2245	$1,250.00	$125.00
	10000	25500	51	21	0.6962	$2,350.00	$235.00

Assumptions:

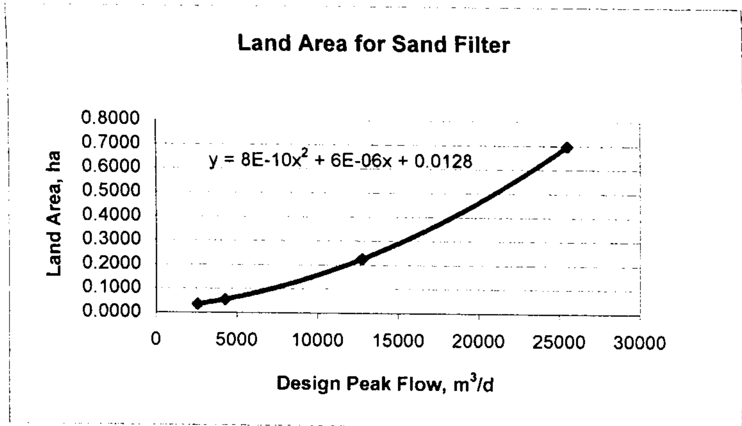
Maufacturer's design and cost data, **1.25 MLD = 2.5 m dia unit, Economic Life = 20 yrs

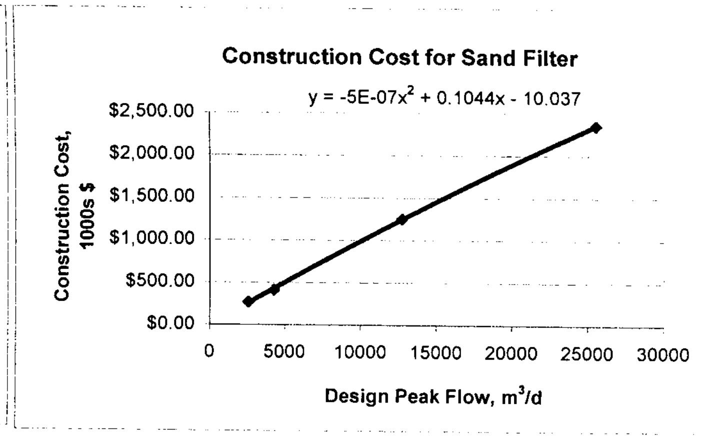
Maximum influent SS < 30 mg/L,if influent SS > 30 mg/L then coagulation using alum dosage of 30 mg/L recommended

Land required= 2*(diameter+8)^2, Av Sludge produced, kg/d= (Average flow *Inf SS* Removal effciency)/1000

Construction cost: equipment, civil, mechanical, piping

O & M cost: 10 % of construction cost



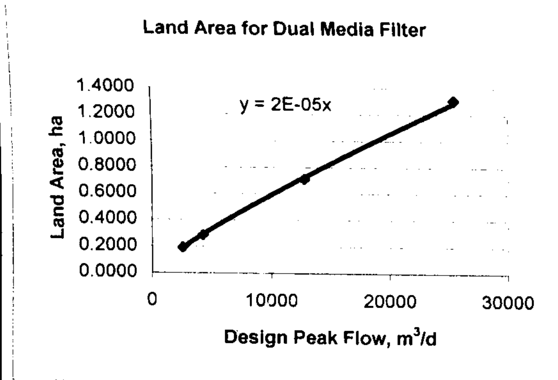


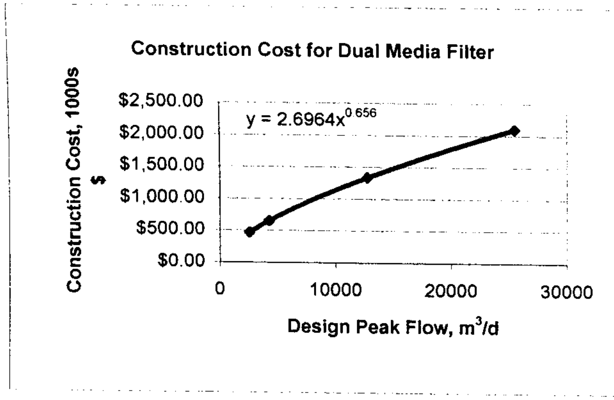
Reference: Bentley (2001), Tema Engineers (2001)

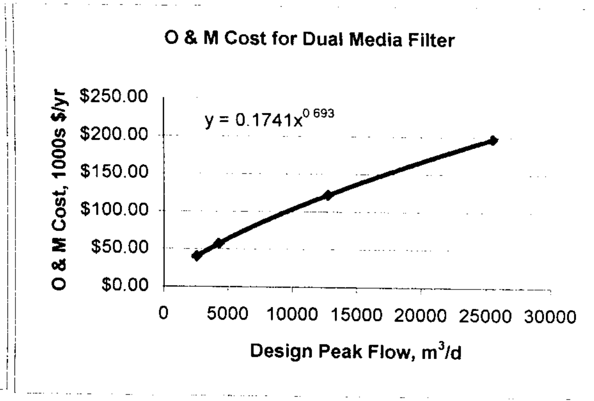
Table F.28 Cost Data Sheet For Dual Media Filter

A	B	C	D	E	F	G
UIDNo/ Process Name	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Surface Area of Filter, m^2	Land Required, ha	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
4501 Dual Media Filter	1000	2550	417	0.1927	$462.88	$39.94
	1667	4250	694	0.2849	$647.16	$56.91
	5000	12750	2083	0.7084	$1,330.44	$121.85
	10000	25500	4167	1.3075	$2,096.38	$196.98

Assumptions:
HLR @ average flow = 9.8 m/hr, backwash rate of 36.7m/hr, Economic Life = 25 yrs
Maximum influent SS < 30 mg/L,if influent SS > 30 mg/L then coagulation using alum dosage of 30 mg/L recommended
Land required assumed as 30 % more than surface area ,Sludge produced, kg/d= (Average flow *Inf SS* Removal efficiency)/1000
Construction cost: backwash storage, feed, backwash pumps, piping, filter building, pipe gallery, filter equipment.
O & M cost: As per Qasim (1999, pp 1044)







Reference: Qasim(1999, pp 1044), Bentley(2001)

Table F.29 Cost Data Sheet For Microfiltration

A	B	C	D	E	F	G	H
UIDNo/ Process Name	Design Peak Flow, m^3/d	Process Capacity, L/s	Land Required, ha	Main Equipment Cost, 1000s $	Ancillary works inclusive of relift pumping station, 1000s $	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
4700 Microfiltration (MF)	2000	23	0.0010	$700	$900	$1,600	$48
	5000	58	0.0012	$1,350	$1,300	$2,650	$106
	10000	116	0.0016	$2,500	$2,020	$4,520	$158
	20000	231	0.0024	$3,700	$3,400	$7,100	$284
	30000	347	0.0030	$4,500	$4,000	$8,500	$425

Assumptions

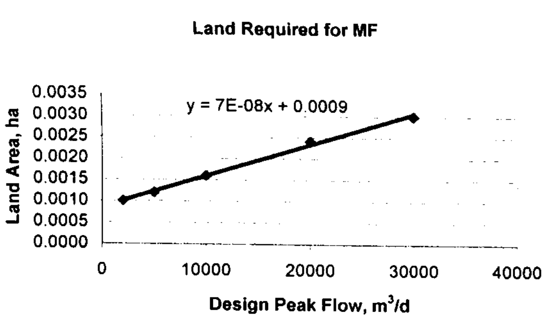
Process capacity based on design peak flow, Economic Life = 20 yrs

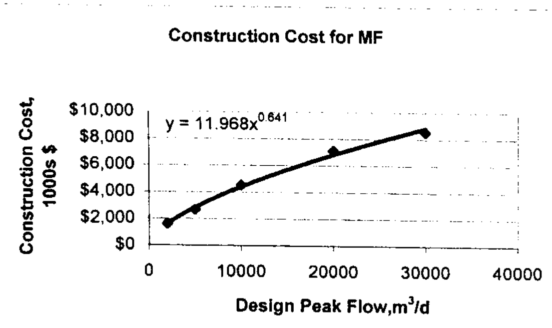
Construction Cost : Equipment cost, building, inlet & outlet mains, storage tank, backwash disposal lagoons, relift pumping station, instrumenation & telemetry, cleaning equipment

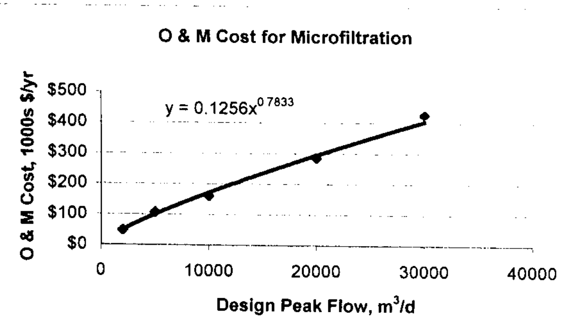
O & M Cost: Operating hours/day=24, operating days/week=7,Cleaning every 2 weeks, 2 service visits per year, Membrane life= 5yrs,

Calculations

Col.G = Col.(E+F)







References: Bentley(2001), USF(1999)

Table F.30 Cost Data Sheet For Granular Activated Carbon (GAC)

A	B	C	D	E	F	G	H	I
UIDNo/ Process Name	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Process Capacity, L/s	Volume of Carbon Required, m^3	Volume of Filter Column Required, m^3	Land Required, ha	Cost of Filter Column+ Backwash Facility, 1000s $	O & M Cost, 1000s $/yr
4800	980	2500	29	35	58	0.0280	$898	$209
Granular	1176	3000	35	42	69	0.0298	$1,011	$237
Activated	5882	15000	174	209	348	0.0607	$2,891	$722
Carbon	11765	30000	347	417	694	0.0908	$4,545	$1,166

Assumptions

Process capacity based on design peak flow, Hydraulic Loading Rate = 10 m/hr, contact time= 20 min, Depth of carbon = 3m,Free board (top + bottom) = 2m , Total depth of column = 5 m, Backwash cycle: 3 min of air scour at 30 Nm3/m2/hr,10 min water at 10 m3/m2/hr, air at 30Nm3/m2/hr , 15 min to rinse the bed and allow for 30 % bed expansion, 10 min reset the filter, Econcmic Life = 25 yrs

Construction cost: Filter column, inlet & outlet mains, storage tank, backwash system and pumping station

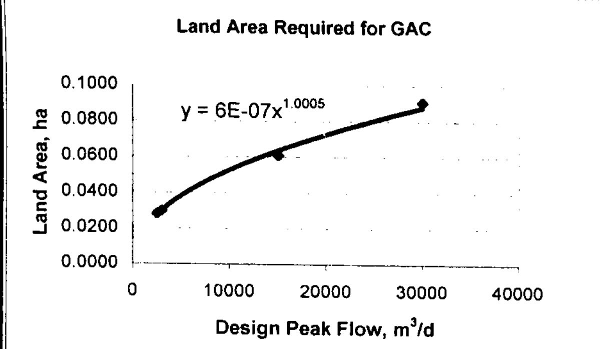
O & M Cost: O & M cost as per Finney& Gearheart(1998)

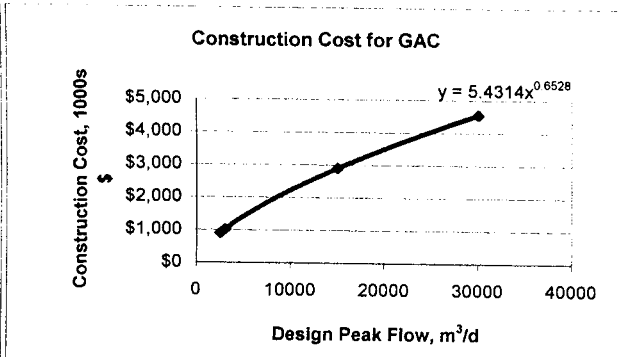
Calculations

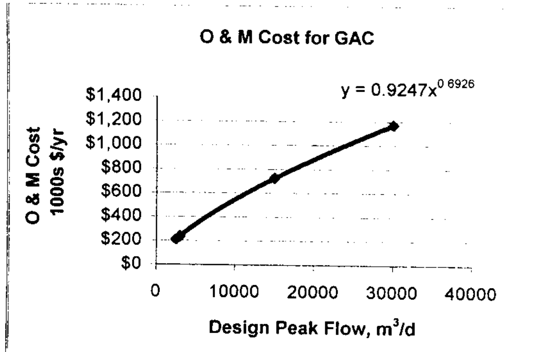
Col.E =Col.C*20/(24*60)

Col.F =(Col.D/3)*(3+2)

Col.G=((SQRT((Col.F/5)*4)/3.14)+8)^2/10000)*2







References: Finney & Gearheart (1998)

Table F.31 Cost Data Sheet For Reverse Osmosis

A	B	C	D	E	F	G	H	I	J	K
UIDNo/ Process Name	Design Peak Flow, m^3/d	Process Capacity, L/s	Land Required, ha	Pretreatment Cost, 1000s $	Main Equipment Cost, 1000s $	Tanks & Chemical Bulk Storage, 1000s $	Miscellaneous Equipment, 1000s $	Installation & Engineering, 1000s $	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
4900 Reverse Osmosis	2550	30	0.0010	$430	$365	$43	$1,160	$150	$2,148	$233
	5100	59	0.0012	$844	$717	$84	$2,279	$295	$4,220	$465
	25500	295	0.0020	$4,752	$4,040	$475	$12,832	$1,663	$23,762	$4,654
	40000	463	0.0040	$8,231	$6,800	$439	$21,817	$2,914	$40,201	$15,239

Assumptions

Design Peak Flow = 3 x Qavdwf, Free Chlorine residual of 0.5-1.0 mg/L,Economic Life = 20 yrs

Construction Cost

pretreatment (CMF),Housing, tanks, piping, membranes, pressure pumps, cleaning equipment

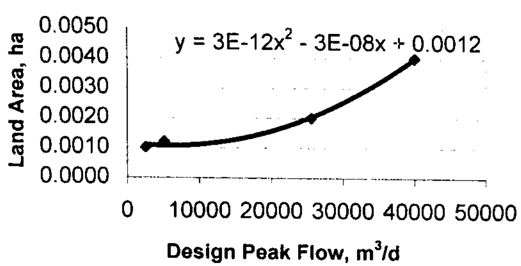
O & M Cost

Electricity cost $/kW.hr =0.10, Labour Cost, $/hr =45,Operating hours/day=24, operating days/week=7,
RO membrane type :Brackish, RO membrane life = 3yrs, Recovery = 85%, Antiscalent cost $/kg = 12, MF module life = 3 yr
Cleaning chemical cost, $4.80 / L, O & M Cost of 25 cents / m^3 for up to 60 lps and 50 cents /m^3 for 300 lps

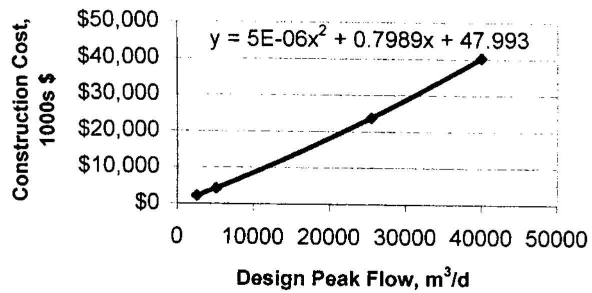
Calculations

Col.J = Col.(E+F+G+H+I)

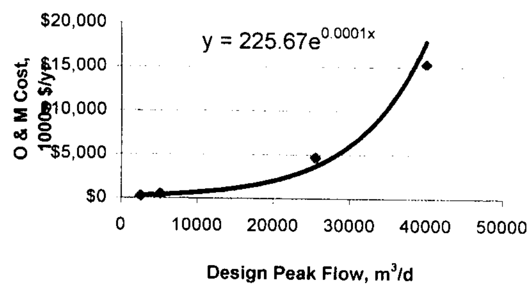
Land Requirement for RO



Construction Cost for RO



O & M Cost for RO



References: Bentley(2001), USF(1999)

Table F.32 Cost Data Sheet For Maturation Pond

A	B	C	D	E	F	G	H	I	J
UIDNo/ Process Name	Surface Area, m^2	Surface Area of Liner, m^2	Land Area Required, ha	Volume of Earthwork, 1000s m^3	Cost of Earthworks, 1000s $	Cost of Liner+Underlay , 1000s $	Cost of Inlet,Outlet Structure + Piping, 1000s $	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
5100 Maturation Pond	2000	2300	0.34	4	$36	$23	$18	$77	$5.4
	5000	5750	0.85	9	$72	$58	$36	$166	$11.6
	10000	11500	1.70	18	$108	$115	$54	$277	$19.4
	20000	23000	3.40	36	$144	$230	$72	$446	$31.2
	40000	46000	6.80	72	$288	$460	$144	$892	$62.4
	100000	115000	17.00	180	$450	$1,150	$225	$1,825	$127.8
	250000	287500	42.50	450	$1,125	$2,875	$563	$4,563	$319.4

Assumptions

Depth of pond = 1.5m, Free board = 0.3m, First Order FC removal rate constant, K_t/day =2.6(1.19)$^{T-20}$, T= Minimum temperature Deg C, Economic Life = 40 yrs

Retention time, Theta = 3 days (minimum), Evaporation rate, e mm/d =40 (i.e. 600 mm/yr)

Construction Cost: Cost of liner, excavation, inlet & outlet structure, piping

Calculations: Theta = (InfFC-EffFC)/EffFC*Kt

where InfFC and EffFC are Influent & Effluent FC in No/100mL respectively

Surface area,m^2 =(2*Q_{av}*theta)/(2*depth+0.001*e*Theta)

where Q_{av}= Average flow in m^3/d,

Col.C =Col.B *1.15

Col.D =Col.C*1.7/10000

Col.E=Col.B *(1.5+0.3)/1000

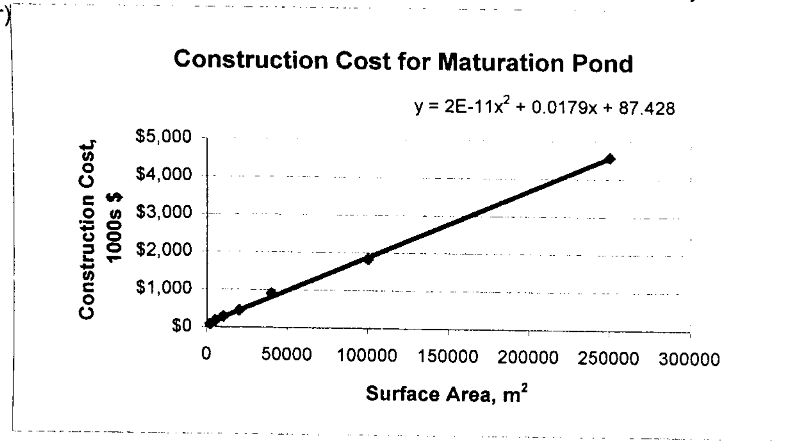
Col.F =Col.E*Earthwork cost

Col.G=Col.C*Liner cost/1000

Col.H =Col.F*0.5

Col.I=Col.(F+G+H)

Col.J =Col.I *0.07

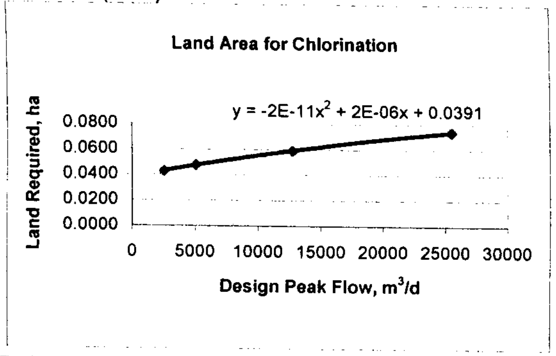


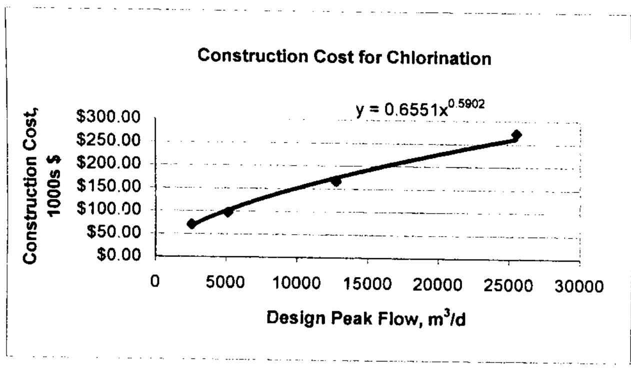
Reference: Bentley(2001); Mara(1998, pp 149)

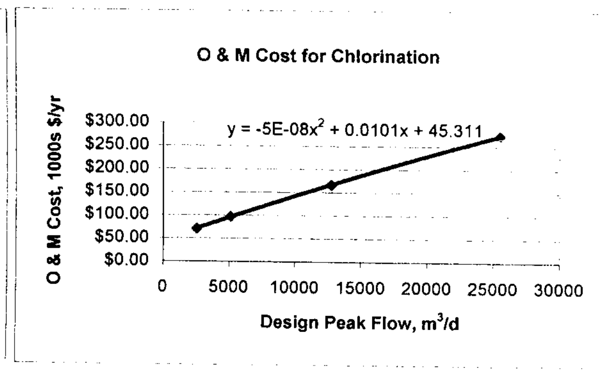
Table F.33 Cost Data Sheet for Chlorination

A	B	C	D	E	F	G	H	I	J
UIDNo/ Process Name	Design Average Dry Weather Flow, m^3/d	Peak Flow, m^3/d	Contact Tank Volume, m^3	Chlorine Plant Capacity, kg/d	Land Required, ha	Construction Cost Chlorine Feed & Storage, 1000s $	Construction Cost of Contact Tank, 1000s $	Total Construction Cost, 1000s $	O & M Cost, 1000s $ /yr
5200 Chlorination	850	2550	17.7	25.5	0.0427	$38.00	$19.17	$57.17	$70.24
	1700	5100	35.4	51.0	0.0477	$43.54	$35.77	$79.31	$96.50
	4250	12750	88.5	127.5	0.0589	$58.21	$81.59	$139.80	$166.34
	8500	25500	177.1	255.0	0.0739	$84.67	$152.24	$236.92	$272.99

Assumptions:
Average chlorine demand = 5mg/L @ 1.3 Qavdwf , plant capacity = 10 mg/L @ 3 Qavdwf, Detention time = 30 min at Qavdwf, depth of contact tank = 2.5 m + free board = 0.3 m,
Construction Cost: Chlorinators, cylinder handling, feed equipment, dosing chamber, metal, piping and storage building
O & M Cost: Maintenance material including chlorine, power, labor, Economic Life = 20 yrs
Land Area =2*(Land for (contact tank + 4 m perimeter around the tank+ 100 sqm for storage & feed equipment))
Calculations:
Col.C= 3*Col.B
Col.D =Col.C*30/(24*60)
Col.E=10*10^(-3)* Col.D
Col.F=((length of the contact tank+8)^2)+100)/10000)*2
Col.I =Col.(H+G)







References: Bentley (2001), Qasim *et al*.,(1992)

Table F.34 Cost Data Sheet For UV Disinfection

A	B	C	D	E	F
UIDNo/ Process Name	Design Peak Flow, m^3/d	Design Peak Flow, lps	Land Requirement, ha	Construction Cost, 1000s $	O & M cost , 1000s $/yr
5300 UV Disinfection	2550	29.5	0.0070	$63	$3.2
	5100	59.0	0.0120	$83	$6.3
	6221	72.0	0.0130	$98	$7.7
	8640	100.0	0.0160	$117	$10.7
	10196	118.0	0.0200	$138	$12.7
	12750	148.0	0.0240	$177	$15.9
	25500	296.0	0.0500	$315	$31.7

Assumptions

Construction Cost includes: cost of UV system + disinfection channel +base slab + building cost+ flow meter+miscellaneous

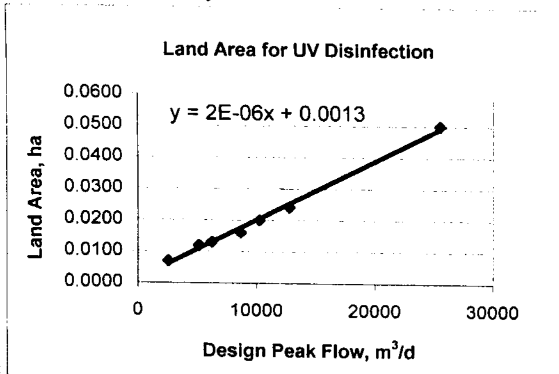
O & M Cost includes: cost of lamp replacement + maintenance + power required

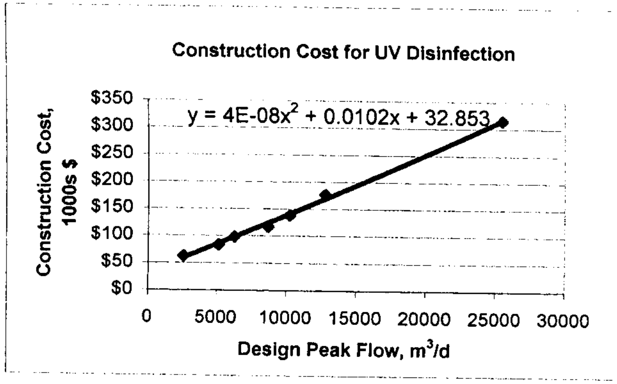
Lamp replacement after every 8700 hrs (about 2 years) of continuos use, lamp cost @ $ 150 each

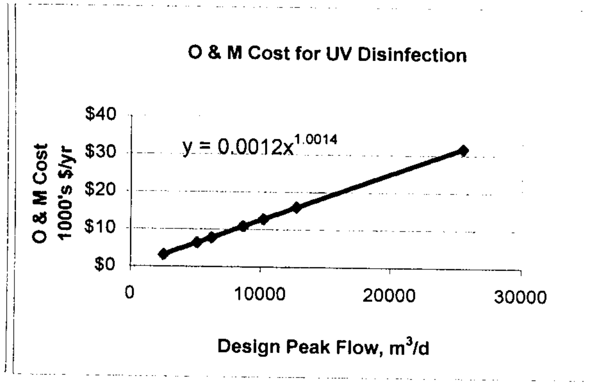
No of operators required = 1 occasionally and cleaning interval once in 2-3 months

O & M cost = approximately $ 3.40 per ML disinfected

Economic Life =20 yrs





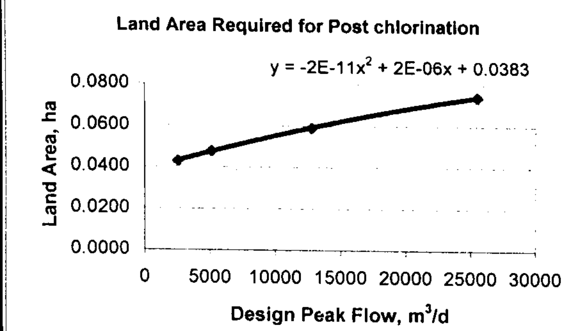


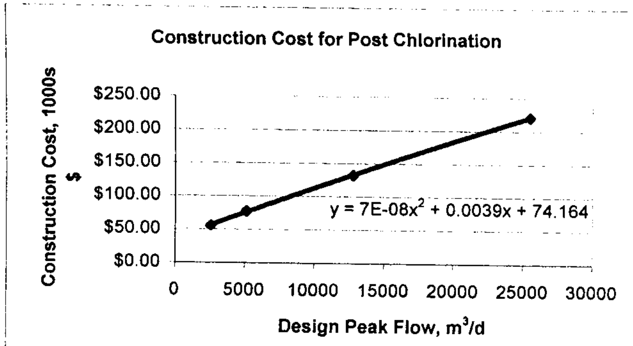
Reference: UVTA(2001)

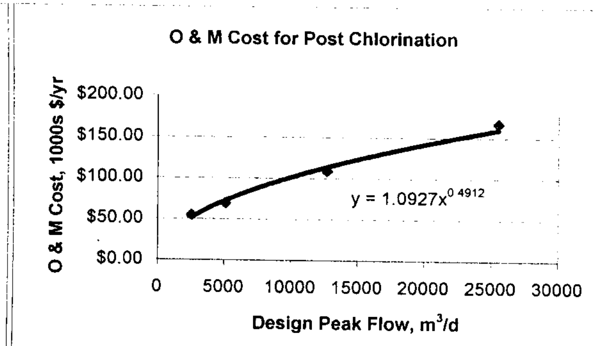
Table F.35 Cost Data Sheet For Post Chlorination

A	B	C	D	E	F	G	H	I	J
UIDNo/ Process Name	Design Average Dry Weather Flow, m^3/d	Peak Flow, m^3/d	Contact Tank Volume, m^3	Chlorine Plant Capacity, kg/d	Land Required, ha	Construction Cost Chlorine Feed & Storage, 1000s $	Construction Cost of Contact Tank, 1000s $	Total Construction Cost, 1000s $	O & M Cost, 1000s $ /yr
5400 Post Chlorination	850	2550	17.7	12.8	0.0427	$36.00	$19.17	$55.17	$53.91
	1700	5100	35.4	25.5	0.0477	$41.40	$35.77	$77.16	$69.04
	4250	12750	88.5	63.8	0.0589	$50.43	$81.59	$132.02	$108.62
	8500	25500	177.1	127.5	0.0739	$68.38	$152.24	$220.62	$166.83

Assumptions:
Average chlorine demand = 2 mg/L @ 1.3 Qavdwf , Plant capacity = 5 mg/L @ 3 Qavdwf, Detention time = 30 min at Qavdwf, Depth of contact tank = 2.5 m + free board = 0.3 m
Land Area =2*(Land for contact tank + 4 m perimeter around the tank+ 100 sqm for storage & feed equipment)), Economic Life =20 yrs
Construction Cost: Chlorinators, cylinder handling, feed equipment, dosing chamber, metal, piping and storage building
O & M Cost: 10 % of construction cost
Calculations:
Col.C= 3*Col.B
Col.D=Col.C*30/(24*60)
Col.E=5*10^(-3)* Col.D
Col.F =2*((((SQRT(Col.D/2.5))+8)^2+100)/10000)
Col.I=Col.(G+H)







References: Bentley(2001)

Table F.36 Cost Data Sheet For Gravity Sludge Thickener

A	B	C	D	E	F	G	H	I
UIDNo/ Process Name	Sludge Generated at Peak Flow, kg/d	Sludge Flow to Thickener, m^3/d	Surface Area of Thickener, m^2	Weight of Thickened Sludge, kg/d	Volume of Thickened Sludge, m^3/d	Land Requirement, ha	Construction Cost, 1000s $	O & M Cost, 1000s $ /yr
6100 Gravity Sludge Thickener	500	24.27	11	21	0.3	0.0276	$247	$18
	1000	48.54	21	41	0.7	0.0347	$260	$19
	2000	97.09	43	83	1.3	0.0474	$271	$21
	5000	242.72	106	206	3.3	0.0772	$451	$29

Assumptions:

SLR = 47 kg/m^2.d, Sp.gravity=1.03, Solids in thickened sludge = 6%,

Average solids production in WWTP = 0.25 kg/m^3 (WEF, 1998; Vol.3, pp 17-20)

Sludge produced @ peak condition = 12 % more than Average sludge produced (5-20 % typical as per Qasim(1999,pp661))

Solids capture efficiency = 85 %, Economic Life = 20 yrs

Construction Cost : Circular concrete tanks, mechanical, electrical and pumps

O & M Cost: Pumping head = 15 m, Operation = 8hrs per day, Sludge feed at 2%, Sludge withdrawal pump operates 2hrs /day,Supernatant withdrawal pump operates 4 hrs/

Calculations

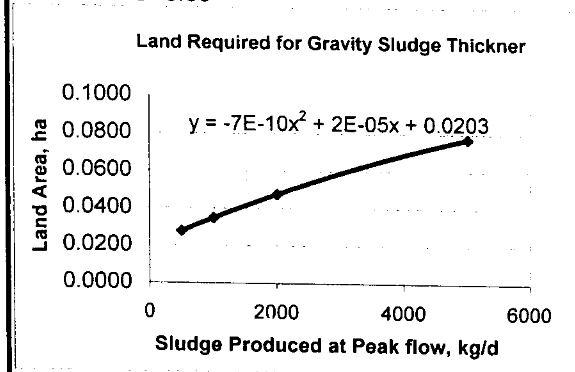
Col.C =Col.B /(0.02*1.03*1000)

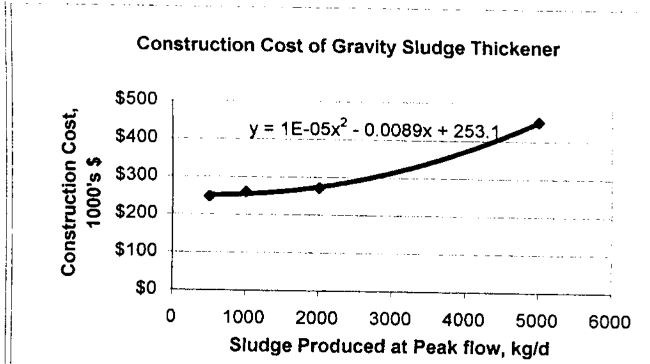
Col D =Col.B/47

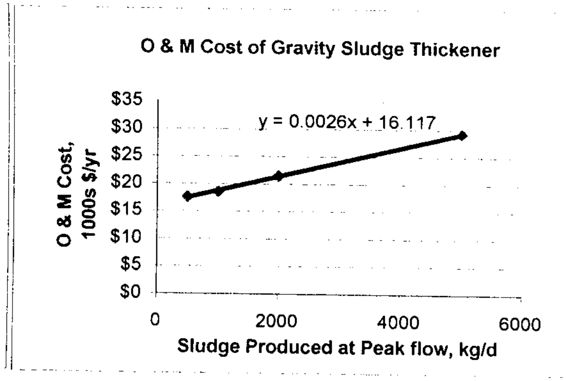
Col.E =Col.C *0.85

Col.F =Col.E/(0.06*1.03*1000)

Col.G =2*((Diameter of thickener + 8)^2/10000)







References: Qasim(1999, pp 661,pp673), WEF(1998,Vol.3, pp17-20)

Table F.37 Cost Data Sheet For High Rate Anaerobic Digestor

A	B	C	D	E	F	G	H	I
UIDNo/ Process Name	Design Population	Digestor Tank Volume, m^3	Average Influent Sludge, m^3/d	Volume of Digested Sludge, m^3/d	Weight of Digested Sludge, kg/d	Land Requirement, ha	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
6200 High Rate Anaerobic Digestor	5000	150	10	7.5	386	0.03723	$288	$29
	10000	300	20	15.0	773	0.05108	$408	$41
	25000	750	50	37.5	1931	0.08503	$680	$68
	50000	1500	100	75.0	3863	0.13360	$1,041	$104

Assumptions:

SRT= 15 days, Depth = 6m, Digested solids = 5%, Sp.gravity = 1.03,Volume based on per capita allowance: 0.03 m^3/person,Pumping head = 15m, Volume of digested sludge = 75 % of influent raw sludge, Economic Life = 50 yrs

Construction Cost: Digestor, sludge & supernatant withdrawal pumps, piping, miscellaneous

O & M cost assumed as 10 % of construction cost

Calculations

Col.C = Col.B* 0.03

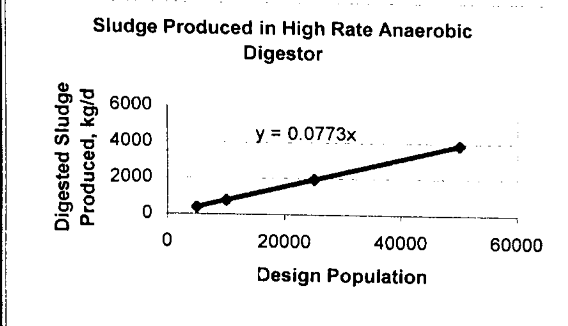
Col.D = Col.C /15

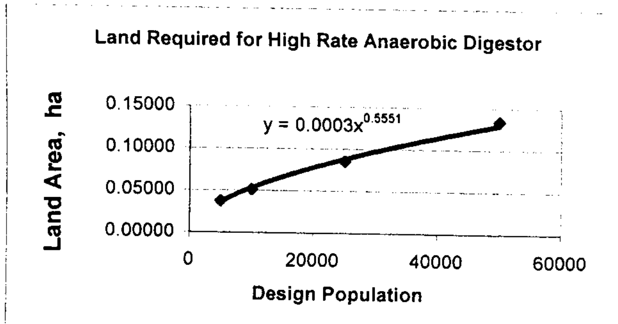
Col.E = 0.75 * Col.D

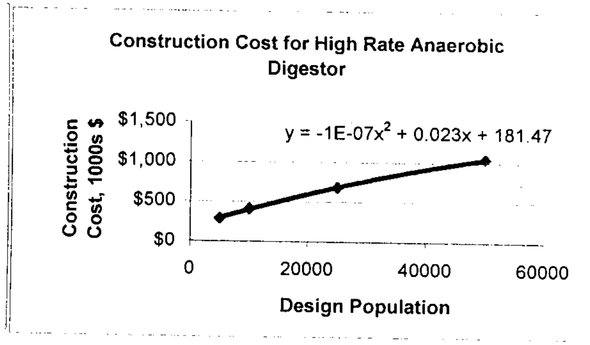
Col.F = Col.E* 0.05*1000*1.03

Col.G = (((SQRT(Col.L*4/3.14)+8)^2)/10000)*2

Col.I = Col.H*0.10





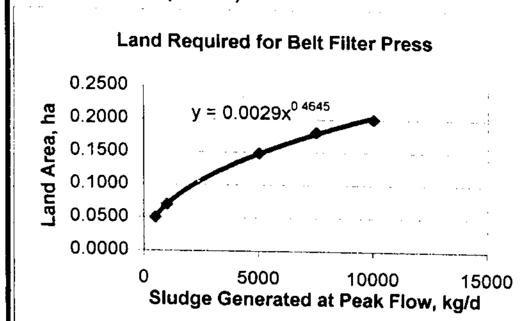


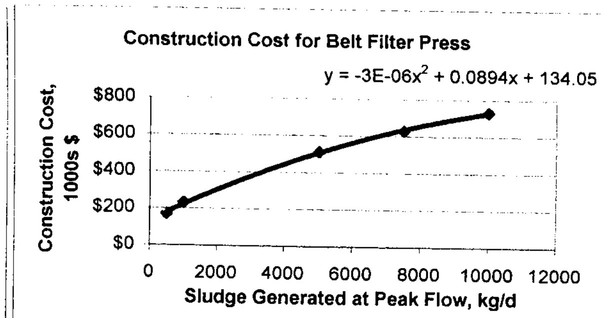
References: Qasim (1999,pp700,705), Bentley (2001)

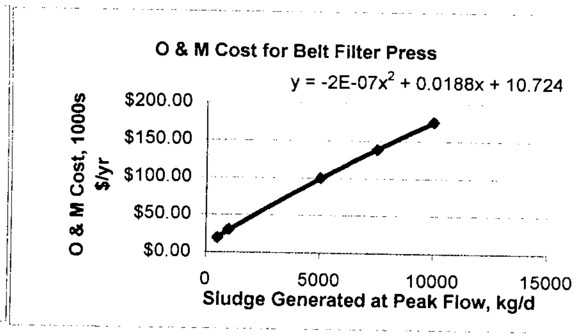
Table F.38 Cost Data Sheet For Belt Filter Press

A	B	C	D	E	F	G	H	I
UIDNo/ Process Name	Sludge Generated at Peak Flow, kg/d	Polymer Dosage, kg/d	Capacity, kg/d	Belt Width, m	Land Required, ha	Construction Cost, 1000s $	Cost of Polymer, 1000s $/yr	O & M Cost, 1000s $/yr
5300 Belt Filter Press	500	2	502	0.25	0.0500	$168	$5.84	$19.28
	1000	4	1004	0.50	0.0700	$231	$11.68	$30.16
	5000	20	5020	2.51	0.1480	$510	$58.40	$99.16
	7500	30	7530	3.77	0.1800	$628	$87.60	$137.84
	10000	40	10040	5.02	0.2000	$731	$116.80	$175.25
	15000	60	15060	7.53	0.2040	$1,018	$175.20	$256.64
	20000	80	20080	10.04	0.2100	$1,200	$233.60	$329.60

Assumptions:
Design SLR = 250 kg/m of belt width.hr, Maximum width of belt = 3m, Sludge solids at 5 %, polymer for conditioning = 0.5% of dry solids, Sp.gravity of sludge cake = 1.06, SS capture = 95 %, operation of 8hrs /day, Belt replaced every 5 years, Economic Life = 15 yrs
Construction cost: Belt filter equipment, polymer dosing unit, storage tank, electrical and miscellaneous equipment
O & M Cost: Cost of polymer, pumps, mixer, belt drives, power, labour
Calculations:
Col.B = assumed range of sludge solids
Col.C=Col.B*0.005*0.8
Col.D = Col.B+Col.C
Col.E = Col.D/(250*8)
Col.H= Col.C*8*365/1000
Col.I = Col.H +0.08*ColG







Reference: Qasim (1999, pp 742), Tema Engineers(2001)

Table F.39 Cost Data Sheet For Sludge Drying Beds

A	B	C	D	E	F	G	H	I	J	K
UIDNo/ Process Name	Design Population	Drying Bed Area, ha	Land Requirement, ha	Drain Pipe Length, m	Volume of Earthwork, 1000s m^3	Cost of Earthwork, 1000s $	Cost of Inlet structure + Drain pipe, 1000s $	Cost of lining, underlay, sand and gravel bed, 1000s $	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
6301 Sludge Drying Beds	5000	0.10500	0.18	65	1	$16	$9	$19	$44	$4
	10000	0.21000	0.36	92	2	$32	$17	$38	$87	$9
	25000	0.52500	0.89	145	5	$53	$29	$95	$177	$18
	50000	1.05000	1.79	205	11	$84	$45	$191	$320	$32

Assumptions:

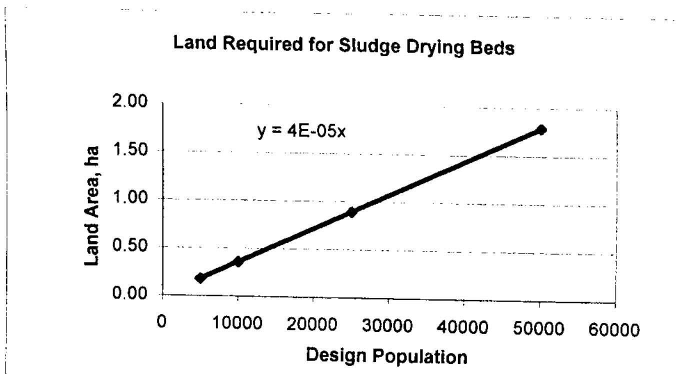
Sludge drying bed area = 0.21 m^2 per capita, Drying period = 15 days, Mositure content= 65 % , Coarse sand requirement = 0.20 m, Graded gravel bed (size 10mm-35mm) = 0.25 m , Length : Width = 1:3, Sludge depth= 0.25m, Total depth= 1m (i.e (0.2+0.25+0.25)+ 0.3m free board), Economic Life = 20 yrs

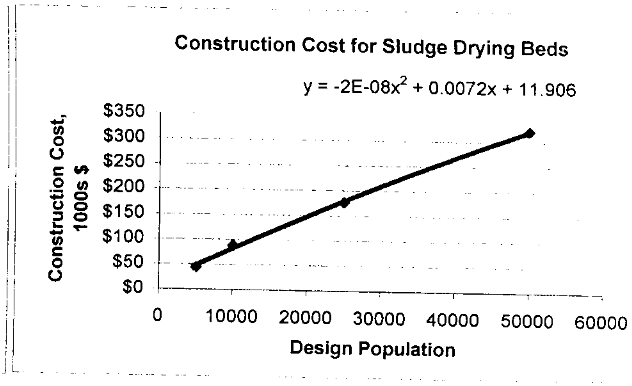
Construction cost: Sludge pumps, drain pipes, excavation cost, inlet structure, lining cost, sand & gravel bed

O & M cost: Maintenance of pipes, pumps, inlet structure

Calculations

Col.C =Col.B*0.21/10000
Col.D =Col.B*1.7
Col.E =SQRT(Col.C*10000/4)*4
Col.F =Col.C*1.0*10000
Col.G =Col.F*Earthwork cost
Col.H =0.5*Col.G+(17*Col.E/1000)
Col.I =((Liner cost*Col.C*10000*1.15)+(coarse sand cost*Col.C*10000*0.2)+(graded gravel cost*Col.C*10000*0.25))/1000
Col.J =Col.(G+H+I)
Col.K = Col.J * 0.1





References: Bentley(2001); Qasim(1999, pp728-733)

Table F.40 Cost Data Sheet For Land Spreading

A	B	C	D	E	F	H
UIDNo/ Process Name	Sludge Produced , kg/d	Sludge Produced , tonnes/yr	Sludge Volume, m3/yr	Land Requirement , ha	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
6400 Land Spreading	250	91	344	79	$115	$33
	500	183	689	158	$117	$34
	1000	365	1377	316	$121	$36
	3000	1095	4132	949	$136	$44
	8000	2920	11019	2531	$175	$62
	15000	5475	20660	4745	$229	$88

Assumptions:

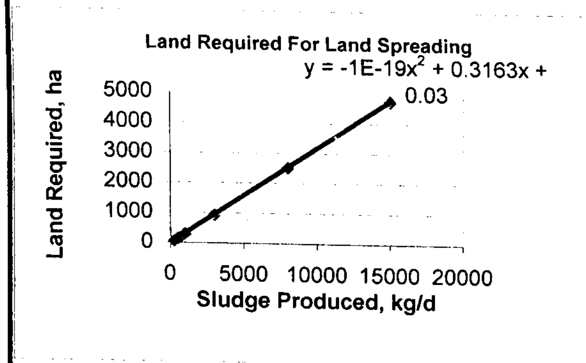
Since no data was available from the local WWTP's, cost equations developed by Qasim (1999) has been considered.

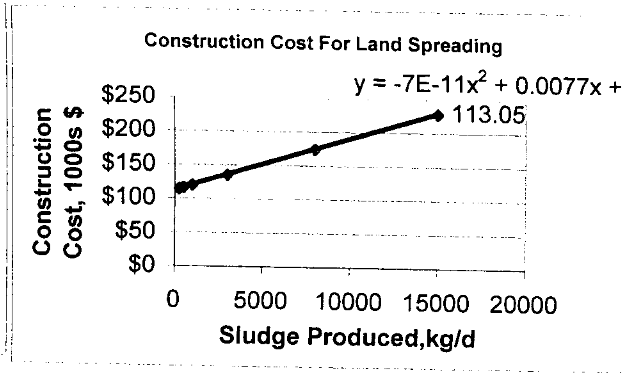
Dewatered sludge at 20% solids, sludge application rate = 30 tons/ha-yr, density of sludge =1060 kg/m3 and 25% solids,Economic Life = 20 yrs

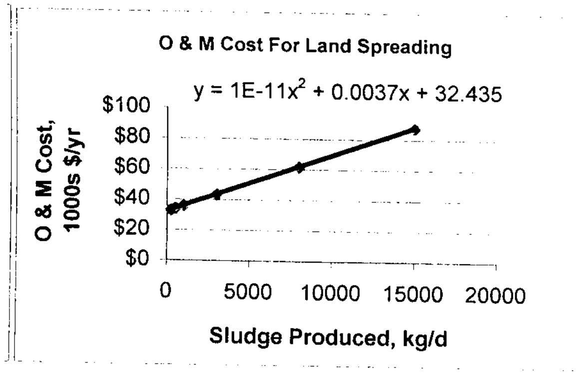
Land requirement = land based on sludge application rate+ 300 sqm access for trucks+loading tank+miscellaneous+buffer distance

Construction Cost: Includes transportation and sludge application vehicles, sludge loading and unloading equipment and concrete pad and storage facility.

O & M Cost: Preventive maintenance, labour and material.







Reference: Qasim(1999,pp784,770)

Table F.41 Cost Data Sheet For Land Filling

A	B	C	D	E	F	G	H
UIDNo/ Process Name	Sludge Produced , kg/d	Sludge Produced , tonnes/yr	Sludge Volume, m3/yr	Land Requirement, ha	Construction Cost, 1000s $	Land Filling Cost, 1000s $/yr	O & M Cost, 1000s $/yr
6401 Land Filling	500	183	689	3.8	$162	$44	$44
	1000	365	1377	7.5	$173	$88	$88
	3000	1095	4132	22.4	$200	$263	$263
	8000	2920	11019	59.7	$241	$701	$701
	15000	5475	20660	111.9	$279	$1,315	$1,315

Assumptions:

Wide trench filling, dewatered sludge at 25% solids, sludge application rate = 12000 m^3/ha, density of sludge =1060 kg/m3 ,Land fill tipping fee = $ 20/ tonne, Economic Life = 50 yrs, sludge transport contract cost= $20/ tonne for haulage distance <10 km, land requirement = land based on sludge application rate+ 300 sqm access for trucks+loading tank+miscellaneous+buffer distance

Construction Cost: loading tanks, hoppers, pumping sludge. Cost of establishment of landfill site is included in the tipping fee

O & M Cost: Haulage cost($20/ tonne), landfill tipping fee($20/tonne) and landfilling cost on contract basis

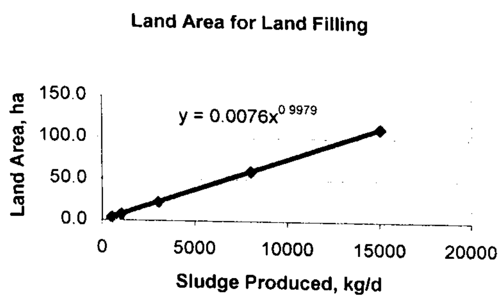
Calculation: Average sludge produced at rate of 0.25 kg/m3 (WEF, 1998, pp 17-20)

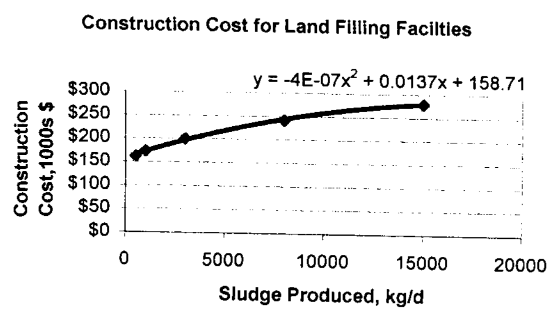
Col.C =(Col.B*365)/1000

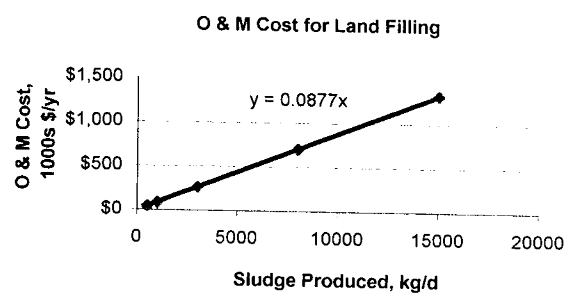
Col.D=((Col.C)*(1/0.25)*(1/1060))

Col.E=((Col.D/12000)*1.3)*50#+(0.03), # for economic life of 50 years

Col.H=(40*Col.C/1000)/1000+Col.G







Reference: Qasim (1999, pp 784), Bentley (2001), WEF (1998, Vol.3, pp 17-20)

Table F.42 Cost Data Sheet for Inlet Structure

A	B	C	D	E	F	G
UIDNo/ Process Name	Population	Average Flow, Qav m³/d	Design Peak Flow, m³/d	Design Peak Flow, lps	Constructio n Cost, 1000s $	O & M Cost, 1000s $/yr
7100, Inlet structrure	5000	1000	2550	30	$20	$1.4
	10000	2000	5100	59	$33	$1.6
	25000	5000	12750	148	$66	$2.0
	50000	10000	25500	295	$112	$2.4

Assumptions:

Construction cost: includes concrete structure, flow measurement and metal work

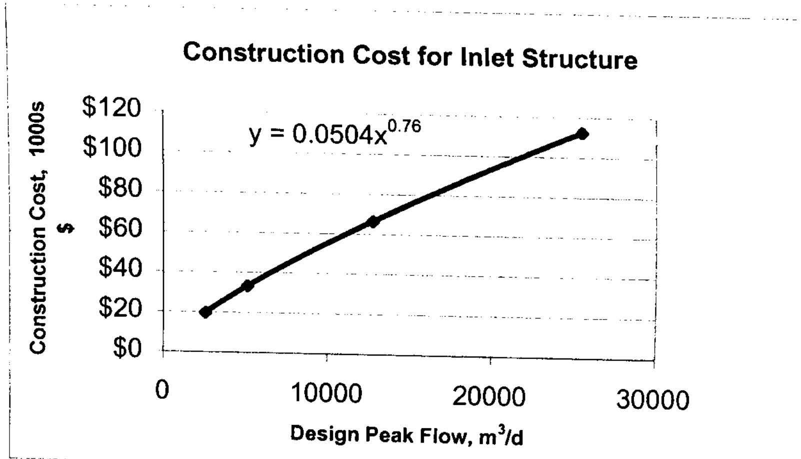
O & M cost includes repair & maintenance work

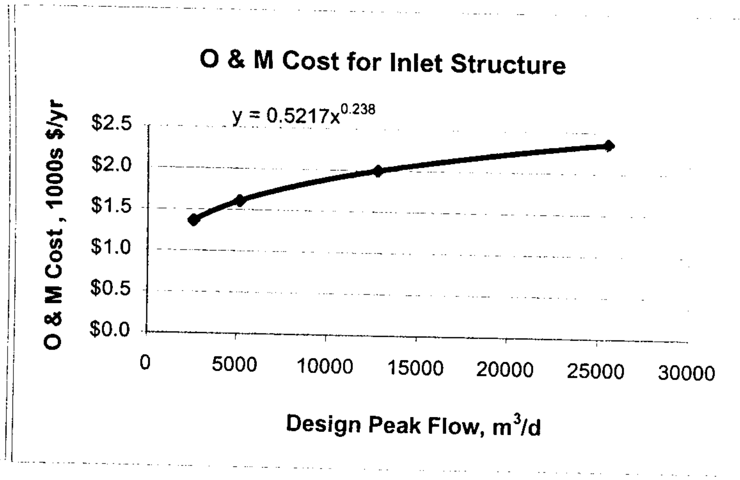
Calculations

Col.C= Col.B*200/1000

Col.D=Col.C*3

Col.E=Col.D/ 86400





Reference: Bentley(2001)

Table F.43 Cost Data Sheet for Raw Sewage Pumping Station

A	B	C	D	E	F	G
UIDNo/ Process Name	Population	Design Average Flow, m^3/d	Design Peak Flow, m^3/d	Design Peak Flow, lps	Construction Cost, 1000s $	O & M Cost, 1000s $/yr
7101 Raw Sewage Pumping Station(submersible)	5000	1000	2550	30	$82	$9
	10000	2000	5100	59	$94	$13
	25000	5000	12750	148	$129	$23
	50000	10000	25500	295	$182	$35

Assumptions

10m total head, submersible type , one standby pump, land required for pumping station considered under land for miscellaneous processes

Construction cost: Concrete structure, metal works, pumping equipment & piping, controls

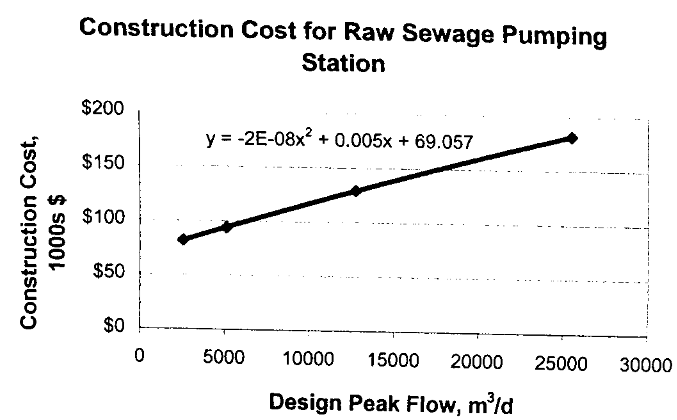
O & M cost: operation,labour, electrical power, repair and maintenance

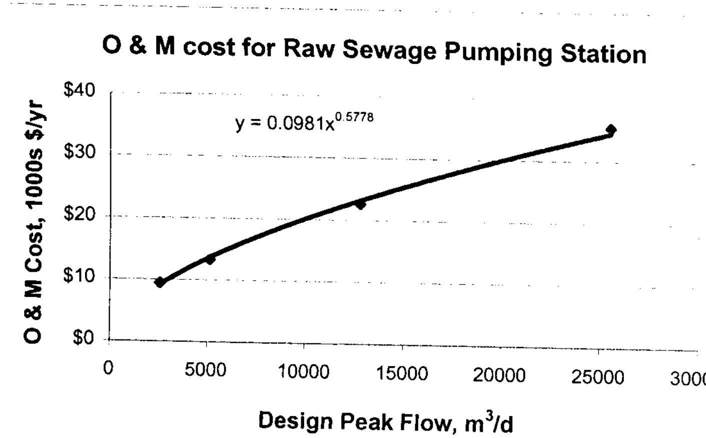
Calculations

Col.C= Col.B*200/1000

Col.D=Col.C*3

Col.E=Col.D/ 86400





Reference: Bentley(2001)

Appendix G – Reuse Types and Guidelines

G.1 Reuse Types Included in the Database

Table G. 1a List of Reuse Types Included in MOSTWATAR

Reuse ID	Name of the Reuse Type
1	Boiler feed water
2	Cooling Water
3	Dust Suppression at Sites with Restricted Access
4	Dust Suppression at Sites with Unrestricted Access
5	Environmental Reuse- Wildlife Habitat, Stream Augmentation
6	Fire Fighting
7	Freeway Landscaping
8	Groundwater Recharge (By Injection to Potable Aquifer)
9	Groundwater Recharge (By Spreading into Potable Aquifer)
10	Human Food Chain Aquaculture
11	Irrigation of Cemeteries
12	Irrigation of Non Processed Food Crops ("In Direct" Contact)
13	Irrigation of Non Processed Food Crops ("Not in Direct" Contact)
14	Irrigation of Non Processed Food Crops (Subsurface Irrigation)
15	Irrigation of Parks and Playgrounds with Restricted Access
16	Irrigation of Parks and Playgrounds with Unrestricted Access
17	Irrigation of Pasture and Fodder for Dairy Animals
18	Irrigation of Pasture and Fodder for Grazing Animals
19	Irrigation of Processed Food Crops ("In Direct" Contact)
20	Irrigation of Processed Food Crops ("Not in Direct" Contact)
21	Irrigation of School Yards
22	Irrigation of Turf
23	Non Restricted Recreational Impoundment's (Primary Contact)
24	Non-Human Food Chain Aquaculture
25	Ornamental Nursery / Horticulture
26	Ornamental Ponds with Public Access

Table G. 1b List of Reuse Types Included in MOSTWATAR (Contd.,)

Reuse ID	Name of the Reuse Type
27	Ornamental Ponds With Restricted Access
28	Residential Non Potable Uses
29	Irrigation of Golf Course with Restricted Access
30	Restricted Recreational Impoundment's (Secondary Contact)
31	Silviculture /Non Food Crop Irrigation
32	Irrigation of Golf Course with Unrestricted Access
33	Washdown and Live stock water
34	Others*

(* The users can specify any other end use and criteria values by selecting "Other" type in the model)

G.2 Reuse Guidelines Incorporated in MOSTWATAR

The reuse guidelines against for each reuse type (listed in Table G.1) is presented in Tables G.2a to G.2f.

Table G.2a Reuse Guidelines Included in MOSTWATAR

SL.No.	Type of Reuse	Name of the Reuse Guideline	pH	BOD, mg/L	SS, mg/L	Turbidity, NTU	Chlorine Residual, mg/L	Faecal Coliforms, No/ 100 mL	E.Coli, No/100mL	Enteric Viruses, No/50L	Helminth Eggs, No/50L	Recommended Treatment ID
1	Boiler Feed Water [a]	NWQM Guidelines, April 1996						1000				2
		SA Reclaimed Water Guidelines, April 1999 [1]										2
		QLD: Interim Guidelines for reuse, April1996						1000				2
		Victoria State Guidelines, March 1996	6.5-8.0	10	15	2	1	10				3
		Tasmanian State Guidelines, 1999 draft						1000				2
2	Cooling Water [b]	NWQM Guidelines, April 1996 [1]										-1
		SA Reclaimed Water Guidelines, April 1999 [1]										2
		QLD: Interim Guidelines for reuse, April1996 [1]						1000				2
		Tasmanian State Guidelines, 1999 draft						10000				2
		USEPA, 1992	6.0-9.0	30	30		1	200				2
3	Dust Suppression in Construction, Mine sites with Restricted Access [c]	NWQM Guidelines, April 1996						1000				2
		SA Reclaimed Water Guidelines, April 1999		20	30				100			2
		QLD: Interim Guidelines for reuse, April1996						150				2
		Victoria State Guidelines, March 1996	6.5-8.0	20	30			1000				2
		ACT WW Reuse for irrigation, July1999	6.5-8.0				1	1000				2
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992		30	30		1	200				2
4	Fire Fighting	NWQM Guidelines, April 1996	6.5-8.0			2	1	10				3
		SA Reclaimed Water Guidelines, April 1999 [2]		20	30				100			2
		Victoria State Guidelines, March 1996	6.5-8.0	10	15	2	1	10				3
		Tasmanian State Guidelines, 1999 draft						10				3
		USEPA, 1992	6.0-9.0	10		2	1	0				3
5	Restricted Recreational Impoundment's (Secondary Contact Recreation) [d]	NWQM Guidelines, April 1996	6.5-8.0					1000				2
		SA Reclaimed Water Guidelines, April 1999 [2]		20	30				100			2
		QLD: Interim Guidelines for reuse, April1996						150				2
		USEPA, 1992	6.0-9.0	10		2	1	0				3
6	Freeway Landscaping	NWQM Guidelines, April 1996						1000				2
		SA Reclaimed Water Guidelines, April 1999		20	30				100			2
		QLD: Interim Guidelines for reuse, April1996						150				2
		Victoria State Guidelines, March 1996	6.5-8.0	20	30			1000				2
		ACT WW Reuse for irrigation, July1999	6.5-8.0				1	1000				2
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992	6.0-9.0	30	30		1	200				2
		WHO	6.0-9.0	60	75			200		1		2

Table G.2b Reuse Guidelines Included in MOSTWATAR

SL.No.	Type of Reuse	Name of the Reuse Guideline	pH	BOD, mg/L	SS, mg/L	Turbidity, NTU	Chlorine Residual, mg/L	Faecal Coliforms, No/ 100 mL	E.Coli, No/100mL	Enteric Viruses, No/50L	Helminth Eggs, No/50L	Recommended Treatment ID
7	Ground Water Recharge (by injection to potable aquifer)	NWQM Guidelines, April 1996						1000				3
		QLD: Interim Guidelines for reuse, April1996						150				3
		Tasmanian State Guidelines, 1999 draft						10				3
		USEPA, 1992 [3]	6.5-8.5			2	1	0				3
8	Irrigation of Turf	NWQM Guidelines, April 1996 [4]										1
		SA Reclaimed Water Guidelines, April 1999							10000			1
		QLD: Interim Guidelines for reuse, April1996						1000				2
		Victoria State Guidelines, March 1996	6.5-8.0	20	30			1000				2
		ACT WW Reuse for irrigation, July1999 [4]	6.5-8.5					10000				1
		Tasmanian State Guidelines, 1999 draft						10000				1
		USEPA, 1992	6.0-9.0	30	30		1	200				2
9	Irrigation of Cemeteries	NWQM Guidelines, April 1996										2
		SA Reclaimed Water Guidelines, April 1999		20	30				100			2
		QLD: Interim Guidelines for reuse, April1996						150				2
		Victoria State Guidelines, March 1996	6.5-8.0	10	15	2	1	10				3
		ACT WW Reuse for irrigation, July1999	6.5-8.0		2		1	10				2
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992	6.0-9.0	10		2	1	0				3
10	Irrigation of Parks and Playgrounds with Unrestricted Access	NWQM Guidelines, April 1996 [5]	6.5-8.0			2	1	10				3
		SA Reclaimed Water Guidelines, April 1999		20		2			10			3
		NSW State Guidelines				2		1				3
		QLD: Interim Guidelines for reuse, April1996				2		10				3
		Victoria State Guidelines, March 1996	6.5-8.0	10		2	1	10		1	2	3
		ACT WW Reuse for irrigation, July1999	6.5-8.0			2	1	10				3
		Tasmanian State Guidelines, 1999 draft						10				3
		USEPA, 1992	6.0-9.0	10		2	1	0				3
11	Irrigation of Parks and Playgrounds with Restricted Access	NWQM Guidelines, April 1996						1000				2
		SA Reclaimed Water Guidelines, April 1999 [2]		20	30				100			2
		QLD: Interim Guidelines for reuse, April1996						150				2
		Victoria State Guidelines, March 1996	6.5-8.0	20	30			1000				2
		ACT WW Reuse for irrigation, July1999	6.5-8.0				1	1000				3
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992	6.0-9.0	30	30		1	200				2

Table G.2c Reuse Guidelines Included in MOSTWATAR

SL.No.	Type of Reuse	Name of the Reuse Guideline	pH	BOD, mg/L	SS, mg/L	Turbidity, NTU	Chlorine Residual, mg/L	Faecal Coliforms, No/ 100 mL	E.Coli, No/100mL	Enteric Viruses, No/50L	Helminth Eggs, No/50L	Recommended Treatment ID
12	Irrigation of Pasture and Fodder for Grazing Animals	NWQM Guidelines, April 1996 [5]						1000				1
		SA Reclaimed Water Guidelines, April 1999 [2]		20	30				1000			1
		QLD: Interim Guidelines for reuse, April1996 [6]						1000				2
		Victoria State Guidelines, March 1996	6.5-8.0	20	30			1000				2
		ACT WW Reuse for irrigation, July1999	6.5-8.0					1000				2
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992	6.0-9.0	30	30		1	200				2
		WHO	9	60	75			1000		1		2
13	Irrigation of Pasture and Fodder for Dairy Animals	NWQM Guidelines, April 1996	6.5-8.0					200				2
		SA Reclaimed Water Guidelines, April 1999		20	30				100			2
		QLD: Interim Guidelines for reuse, April1996						10				3
		Victoria State Guidelines, March 1996	6.5-8.0	10	15	2	1	10				3
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992	6.0-9.0	30	30		1	200				2
14	Irrigation of School Yards	NWQM Guidelines, April 1996 [5]	6.5-8.0			2	1	10				3
		SA Reclaimed Water Guidelines, April 1999		20		2			10			3
		QLD: Interim Guidelines for reuse, April1996				2		10				3
		Victoria State Guidelines, March 1996	6.5-8.0	10	15	2	1	10				3
		ACT WW Reuse for irrigation, July1999	6.5-8.0			2	1	10				3
		Tasmanian State Guidelines, 1999 draft						10				3
		USEPA, 1992	6.0-9.0	10		2	1	0				3
		WHO	9	60	75			1000		1		2
15	Ornamental Ponds With Restricted Access	NWQM Guidelines, April 1996						10000				1
		SA Reclaimed Water Guidelines, April 1999		20	30				1000			1
		Victoria State Guidelines, March 1996 [5]	6.5-8.0	20	30			1000				2
		ACT WW Reuse for irrigation, July1999						1000				1
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992		30	30		1	200				2
16	Irrigation of Non Processed Food Crops ("Not in Direct" Contact) *	NWQM Guidelines, April 1996						1000				2
		SA Reclaimed Water Guidelines, April 1999		20	30				100			2
		QLD: Interim Guidelines for reuse, April1996						150				2
		Victoria State Guidelines, March 1996	6.5-8.0	10	15	2	1	10				3
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992	6.0-9.0	10		2	1	0				3

Table G.2d Reuse Guidelines Included in MOSTWATAR

SL.No.	Type of Reuse	Name of the Reuse Guideline	pH	BOD, mg/L	SS, mg/L	Turbidity, NTU	Chlorine Residual, mg/L	Faecal Coliforms, No/ 100 mL	E.Coli, No/100mL	Enteric Viruses, No/50L	Helminth Eggs, No/50L	Recommended Treatment ID
17	Non-Human Food Chain Aquaculture	NWQM Guidelines, April 1996 [7]						10000				2
		SA Reclaimed Water Guidelines, April 1999						10000				1
		QLD: Interim Guidelines for reuse, April1996 [7]						1000				2
		Victoria State Guidelines, March 1996 5	6.5-8.0	10	15	2	1	10				3
		ACT WW Reuse for irrigation, July1999 [7]						10000				2
		Tasmanian State Guidelines, 1999 draft						10000				2
18	Human Food Chain Aquaculture	NWQM Guidelines, April 1996 [5]	6.5-8.0			2	1	10				3
		QLD: Interim Guidelines for reuse, April1996						10				3
		Victoria State Guidelines, March 1996	6.5-8.0	10		2	1	1		1	2	3
		ACT WW Reuse for irrigation, July1999 [5]	6.5-8.0			2	1	10				3
19	Non Restricted Recreational Impoundment's (Primary Contact) [f]	NWQM Guidelines, April 1996	6.5-8.0					150				3
		SA Reclaimed Water Guidelines, April 1999		20		2			10			3
		NSW State Guidelines				2		1				3
		QLD: Interim Guidelines for reuse, April1996						10				3
		USEPA, 1992	6.0-9.0	10		2	1	0				3
20	Ornamental Ponds with Public Access	NWQM Guidelines, April 1996	6.5-8.0			2	1	10				3
		SA Reclaimed Water Guidelines, April 1999		20	30				100			2
		NSW State Guidelines				2		1				3
		QLD: Interim Guidelines for reuse, April1996						1000				2
		Victoria State Guidelines, March 1996	6.5-8.0	10	15	2	1	10				3
		ACT WW Reuse for irrigation, July1999	6.5-8.0			2	1	10				3
		Tasmanian State Guidelines, 1999 draft						10				3
21	Ornamental Nursery / Horticulture	NWQM Guidelines, April 1996 [5]						1000				1
		SA Reclaimed Water Guidelines, April 1999		20	30				1000			0
		QLD: Interim Guidelines for reuse, April1996						1000				2
		Victoria State Guidelines, March 1996	6.5-8.0	20	30			1000				2
		ACT WW Reuse for irrigation, July1999	6.5-8.5				1	1000				1
		Tasmanian State Guidelines, 1999 draft						10000				2
		USEPA, 1992	6.0-9.0	30	30		1	200				2
22	Irrigation of Processed Food Crops ("In Direct" Contact) [f]	NWQM Guidelines, April 1996 [5]	6.5-8.0					1000				2
		SA Reclaimed Water Guidelines, April 1999		20	30				1000			0
		QLD: Interim Guidelines for reuse, April1996						1000				2
		Victoria State Guidelines, March 1996	6.5-8.0	10	15	2		1000				3
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992	6.0-9.0	30	30		1	200				2

Table G.2e Reuse Guidelines Included in MOSTWATAR

SL.No.	Type of Reuse	Name of the Reuse Guideline	pH	BOD, mg/L	SS, mg/L	Turbidity, NTU	Chlorine Residual, mg/L	Faecal Coliforms, No/ 100 mL	E.Coli, No/100mL	Enteric Viruses, No/50L	Helminth Eggs, No/50L	Recommended Treatment ID
23	Residential Non Potable Uses	NWQM Guidelines, April 1996[9]	6.5-8.0			2	1	10				3
		SA Reclaimed Water Guidelines, April 1999		20		2			10			3
		QLD: Interim Guidelines for reuse, April1996				2		10				3
		Victoria State Guidelines, March 1996[9]	6.5-8.0	10		2	1	1		1	2	3
		ACT WW Reuse for irrigation, July1999	6.5-8.0			2	1	10				3
		Tasmanian State Guidelines, 1999 draft						10				3
		USEPA, 1992	6.0-9.0	10		2	1	0				3
24	Irrigation of Non Processed Food Crops ("In Direct" contact)	NWQM Guidelines, April 1996	6.5-8.0			2	1	10				3
		SA Reclaimed Water Guidelines, April 1999		20		2			10			3
		QLD: Interim Guidelines for reuse, April1996				2		10				3
		Victoria State Guidelines, March 1996	6.5-8.0	10		2	1	1				3
		ACT WW Reuse for irrigation, July1999	6.5-8.0			2	1	10				3
		USEPA, 1992	6.0-9.0	10		2	1	0				3
25	Irrigation of Golf Course with Restricted Access	NWQM Guidelines, April 1996						1000				2
		SA Reclaimed Water Guidelines, April 1999		20	30				100			2
		QLD: Interim Guidelines for reuse, April1996						150				3
		Victoria State Guidelines, March 1996	6.5-8.0	20	30			1000				2
		ACT WW Reuse for irrigation, July1999	6.5-8.0				1	1000				2
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992	6.0-9.0	30	30		1	200				2
26	Silviculture /Non Food Crop Irrigation	NWQM Guidelines, April 1996[4]										1
		SA Reclaimed Water Guidelines, April 1999							10000			0
		QLD: Interim Guidelines for reuse, April1996						1000				2
		Victoria State Guidelines, March 1996	6.5-8.0	20	30			1000				2
		ACT WW Reuse for irrigation, July1999	6.5-8.0					10000				1
		Tasmanian State Guidelines, 1999 draft						10000				2
		USEPA, 1992	6.0-9.0	30	30		1	200				2
27	Irrigation of Golf Course with Unrestricted Access	NWQM Guidelines, April 1996[5]	6.5-8.0			2	1	10				3
		SA Reclaimed Water Guidelines, April 1999		20		2			10			3
		QLD: Interim Guidelines for reuse, April1996				2		10				3
		Victoria State Guidelines, March 1996	6.5-8.0	10	15	2	1	10				3
		ACT WW Reuse for irrigation, July1999	6.5-8.0			2	1	10				3
		Tasmanian State Guidelines, 1999 draft						10				3
		USEPA, 1992	6.0-9.0	10		2	1	0				3

Table G.2f Reuse Guidelines Included in MOSTWATAR

SL.No.	Type of Reuse	Name of the Reuse Guideline	pH	BOD, mg/L	SS, mg/L	Turbidity, NTU	Chlorine Residual, mg/L	Faecal Coliforms, No/ 100 mL	E.Coli, No/100mL	Enteric Viruses, No/50L	Helminth Eggs, No/50L	Recommended Treatment ID
28	Irrigation of Non Processed Food Crop (Subsurface Irrigation)	NWQM Guidelines, April 1996 [5]						1000				2
		SA Reclaimed Water Guidelines, April 1999		20	30				1000			0
		QLD: Interim Guidelines for reuse, April1996						150				3
		Victoria State Guidelines, March 1996	6.5-8.0	10	15	2	1	10				3
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992	6.0-9.0	10		2	1	0				3
29	Irrigation of Processed Food Crops ("Not in Direct" contact)	NWQM Guidelines, April 1996 [5]						1000				2
		SA Reclaimed Water Guidelines, April 1999							10000			0
		QLD: Interim Guidelines for reuse, April1996						1000				2
		Victoria State Guidelines, March 1996	6.5-8.0	20	30			1000				2
		ACT WW Reuse for irrigation, July1999 [8]	6.5-8.0					1000				2
		Tasmanian State Guidelines, 1999 draft						1000				2
		USEPA, 1992	6.0-9.0	30	30		1	200				2
30	Washdown and Live Stockwater	SA Reclaimed Water Guidelines, April 1999 [2]		20	30				100			2
31	Environmental reuse- Wildlife habitat, Stream Augmentation	NWQM Guidelines, April 1996 [1]										2
		SA Reclaimed Water Guidelines, April 1999		20	30				100			2
		QLD: Interim Guidelines for reuse, April1996						150				2
		Tasmanian State Guidelines, 1999 draft						10				3
		USEPA, 1992 [1]		30	30			200				2
33	Groundwater Recharge (By Spreading into Potable Aquifer)	NWQM Guidelines, April 1996 [1]						1000				3
		QLD: Interim Guidelines for reuse, April1996						1000				3
		Tasmanian State Guidelines, 1999 draft						10				3
		USEPA,1992 [3]										3
34	Dust Suppression in Construction, Mine Sites with Unrestricted Access	NWQM Guidelines, April 1996 [5]	6.5-8.0			2	1	10				3
		SA Reclaimed Water Guidelines, April 1999		20		2			10			3
		QLD: Interim Guidelines for reuse, April1996				2		10				3
		Victoria State Guidelines, March 1996	6.5-8.0	10		2		1		1	2	3
		ACT WW Reuse for irrigation, July1999	6.5-8.0			2	1	10				3
		Tasmanian State Guidelines, 1999 draft						10				3

Note:

1 Water quality requirement based on specific industrial use and water quality guidelines for Fresh and Marine Water.

2 Specific removal of viruses.

3 Meets Class D water quality.

4 Restricted public access, withholding period of 4 hours or until dry.

5 Nutrients, toxicants, salinity controls.

6 Withholding period of 5 days. If no withholding days are provided, then filtration required and maximum 10 FC/100 mL to be met.

7 TDS < 1000 mg/L.

8 Crops must be cooked at greater 70 Deg. C for 2 min.

9 Plumbing controls required.

a Open system

b Closed system

c Irrigation during no public access

d Wading, boating, fishing (secondary contact recreation)

e Class C-Subsurface irrigation

f Swimming, diving, skiing (primary contact recreation)

g Spray irrigation

Table G. 2 Representation of Recommended Treatment ID

Recommended Treatment ID	Recommended Treatment
-1	Site Specific
0	Primary + Lagooning + Disinfection
1	Secondary
2	Secondary + Disinfection
3	Tertiary + Disinfection

Appendix H – System Requirements

Table H.1 System Requirements for MOSTWATAR model

System Specifications	Minimum Requirements	Recommended
Operating system	Microsoft Windows 95, 98, 2000 or NT 4.0	Microsoft Windows 2000 or NT 4.0
Processor	400 MHz, Pentium II	1 GHz, Pentium III
Memory	128 MB	256 MB
Hard disk space	30 MB	30 MB
Graphic resolution	800 x 600 with 256 colours	1024 x 768
Database Engine	BDE Version 7.1	-

Appendix I – Default Values

I.1 Default Values Used in the Model

The default values displayed to the user are listed in the following Tables.

Table I. 1a Default Values Displayed in MOSTWATAR

Module	Name of the Variable	Range Specified	Default Value
Community Data	*Nature of Site*		
	Land available for WWTP construction, ha	-	10
	Depth of water table below ground level, m	-	3
	Type of soil	Coarse Sand to Gravel, Medium to Coarse Sand, Fine Sand to Loamy Soil, Loam to Silty Soil, Silty Soil to Clay	Fine sand to loamy
	Average monthly precipitation, mm/month	-	50
	Average monthly evaporation rate, mm/month	-	40
	Average daily minimum temperature, C	-	10
	Average daily maximum temperature, C	-	30
	Type of WWT plant		
	New		New
	Upgrade of Existing Plant		-
	Wastewater Flow		
	Initial project year	-	2001
	Initial project population	-	4500
	Design period, yrs	10-25	25
	Estimated design population	-	5000
	Per capita wastewater generation, lpcd	200-300	200
	Peaking Factors Relative to Average Flow:		
	Peak monthly	1.2-1.4	1.2
	Peak daily	2.4-2.8	2.4

Table I. 1b Default Values Used in MOSTWATAR (contd.)

Module	Name of the Variable	Range Specified	Default Value
Community Data	Peak hourly	2.5-4.0	3.0
	Wastewater Characteristics *Peaking Factors Relative to Average Organic Loading:* Peak monthly	1.2-1.4	1.4
	Peak daily	2.6-3.0	2.8
	Community Cost Data Cost of land, $ per ha - Metropolitan region Country region	- -	$20,000 $10,000
	Sludge landfill tipping fee, $/ tonne	-	$ 20
	Discount rate, % per yr	6-9	8
	Exchange rate (A $ to US$)	-	0.5089
	Site work, %	5-8	5
	Site electrical, %	6-9	8
	Plant piping, %	7-10	10
	Site development cost, %	6-9	7
	Controls and instrumentation, %	5-8	5
	Engineering cost, %	12-20	12
	Contingencies, %	15-20	15
	Operating cost, %	-	3
	Maintenance cost, %	-	4
	Taxes and insurance, %	-	2
	Cost Calculation Method for Ranking TTs Total Project Cost Annualized Project Cost Life Cycle Cost		Yes
Reuse Criteria	*Types of reuse desired*		Irrigation of golf course with restricted access
	Name of the guideline selected		SA Reclaimed Water Guidelines

Table I. 1c Default Values Used in MOSTWATAR (Contd.)

Module	Name of the Variable	Range Specified	Default Value
Reuse Criteria	*Guideline Values* BOD, mg/L	-	20
	SS, mg/L	-	30
	FC, No/100mL	-	100
	TN, mg/L	-	-
	TP, mg/L	-	-
Form TT	*Specify TT* User MOSTWATAR Both the above	-	Both
Selection Criteria	*Relative Weights* Adaptability to upgrade	0-10	8
	Adaptability to varying flow rate	0-10	3
	Adaptability to varying influent quality	0-10	4
	Chemical requirement	0-10	2
	Ease of construction	0-10	3
	Ease of O & M	0-10	2
	Impact on ground water	0-10	5
	Land requirement	0-10	9
	Odour generation potential	0-10	6
	Power requirement	0-10	7
	Reliability	0-10	9
	Sludge generation	0-10	8
	Total project cost	0-10	2
Optimise TT	*GA Parameters* Population size, n	50-200	100
	Tournament size, ts	2-4	2
	Probability of crossover, P_c	0.1-1	0.8
	Probability of mutation, P_m	0.01-1	0.2
	Selection pressure, P_s	0.5-1.0	0.6
	Maximum number of generations	1000	100

Appendix J – Case Study Results

J.1 Result Sheets for Victor Harbor WWTP

The report obtained from MOSTWATAR for both new and upgrade treatment options for the Victor Harbor WWTP are presented in this Section.

Table J. 1 Details of TT option – TT2

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

TT OPTION-2:TT2

Treatment Train: Bar Screen+Primary Clarifier w lime+Continuous Flow BNR+Coagulation & Flocculation+Dual Media Filter+UV Disinfection+Post Chlorination+Gravity Thickener+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge

Desired Reuse(s):
Irrigation of Turf
Irrigation of Pasture and Fodder for Grazing Animals
Irrigation of Golf Course with Restricted Access
Silviculture /Non Food Crop Irrigation
Irrigation of Processed Food Crops ("Not in Direct" Contact)

Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	30	5	0.5	100	-
Effluent Quality Achieved:	5.3	4.0	4.6	0.2	0.0	0.1

Meets Criteria (Yes/No): YES

Effectiveness Measures

Upgrade:	0.70
Varying flow rate:	0.58
Varying influent quality:	0.91
Ease of O & M:	0.67
Ease of construction:	0.58
Reliability:	0.88
Odour:	0.39
Ground water impact:	0.82
Chemical requirement:	0.73
Power requirement:	0.39

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	1.87
Sludge produced,kg/day:	622

Table J. 1a Construction Cost Details of TT option – TT2

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

Summary of Construction Cost Estimate for TT Option-2:TT2

Item	**Construction Cost 1000s $**
Bar Screen	$106
Primary Clarifier w lime	$491
Continuous Flow BNR	$830
Coagulation & Flocculation	$94
Dual Media Filter	$775
UV Disinfection	$142
Post Chlorination	$131
Gravity Thickener	$295
Anareobic Digestor	$544
Sludge Drying Beds	$147
Land Spreading of Sludge	$118
Miscellaneous Cost*	$527
Total Unit Process Construction Cost	**$4,200**
Additional Cost**	$1,260
Total Construction Cost for WWTP	**$5,460**
Engineering and Contingency Cost	$1,474
Total Capital Cost	**$6,934**
Total Land Cost	$269
PV O & M Cost	$5,077
Total Project Cost	**$12,279**
Annualised Project Cost* **	**$1,150**
Life Cycle Cost******	**$0.93**

*Miscellaneous cost includes: Cost for raw sewage pumping, rising main and sludge pumping station
**Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
1000s $/yr , * Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 2 Details of TT option – TT3

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

TT OPTION-3:TT3

Treatment Train: Bar Screen+Primary Clarifier+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Sand Filter+UV Disinfection+Gravity Thickener+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge

Desired Reuse(s): Irrigation of Turf
Irrigation of Pasture and Fodder for Grazing Animals
Irrigation of Golf Course with Restricted Access
Silviculture /Non Food Crop Irrigation
Irrigation of Processed Food Crops ("Not in Direct" Contact)

Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	30	5	0.5	100	-
Effluent Quality Achieved:	3.1	1.9	4.6	0.6	1.9	1.0
Meets Criteria (Yes/No): NO						

Effectiveness Measures

Upgrade:	0.87
Varying flow rate:	0.77
Varying influent quality:	0.87
Ease of O & M:	0.77
Ease of construction:	0.63
Reliability:	0.83
Odour:	0.37
Ground water impact:	0.80
Chemical requirement:	0.87
Power requirement:	0.50

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	1.74
Sludge produced,kg/day:	1009

Table J. 2a Construction Cost Details of TT option – TT3

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

List of Unit Processes for which Maximum Influent Quality is Exceeded

Unit Process Name	Parameter	Units	Influent Value	Maximum Allowable Influent Quality
Two Stage Lime Treatment	Turb	NTU	20.00	10

Summary of Construction Cost Estimate for TT Option-3:TT3

Item	Construction Cost 1000s $
Bar Screen	$106
Primary Clarifier	$344
ASP w Ni & w Clarifier	$1,488
Two Stage Lime Treatment	$2,211
Sand Filter	$983
UV Disinfection	$142
Gravity Thickener	$315
Anaerobic Digestor	$544
Sludge Drying Beds	$147
Land Filling of Sludge	$172
Miscellaneous Cost*	$804
Total Unit Process Construction Cost	**$7,256**
Additional Cost**	$2,177
Total Construction Cost for WWTP	**$9,433**
Engineering and Contingency Cost	$2,547
Total Capital Cost	**$11,980**
Total Land Cost	$267
PV O & M Cost	$6,741
Total Project Cost	**$18,989**
Annualised Project Cost* **	**$1,779**
Life Cycle Cost******	**$1.43**

*Miscellaneous cost includes: Cost for raw sewage pumping, rising main and sludge pumping station
**Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
1000s $/yr , * Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 3 Details of TT option – TT4

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

TT OPTION-4:TT4

Treatment Train: Bar Screen+Aerated lagoon+Sedimentation Pond+FWS Wetland (BOD & Ni)+Maturation Pond+Post Chlorination

Desired Reuse(s):
Irrigation of Turf
Irrigation of Pasture and Fodder for Grazing Animals
Irrigation of Golf Course with Restricted Access
Silviculture /Non Food Crop Irrigation
Irrigation of Processed Food Crops ("Not in Direct" Contact)

Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	30	5	0.5	100	-
Effluent Quality Achieved:	0.8	0.5	5.8	6.0	0.0	0.5
Meets Criteria (Yes/No): NO						

Effectiveness Measures

Upgrade:	0.78
Varying flow rate:	0.72
Varying influent quality:	0.94
Ease of O & M:	0.61
Ease of construction:	0.67
Reliability:	0.67
Odour:	0.28
Ground water impact:	0.33
Chemical requirement:	0.89
Power requirement:	0.50

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	36.97
Sludge produced,kg/day:	0

Table J.3a Construction Cost Details of TT option – TT4

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

Summary of Construction Cost Estimate for TT Option-4:TT4

Item	**Construction Cost 1000s $**
Bar Screen	$106
Aerated lagoon	$490
Sedimentation Pond	$333
FWS Wetland (BOD & Ni)	$3,218
Maturation Pond	$209
Post Chlorination	$131
Miscellaneous Cost*	$609
Total Unit Process Construction Cost	**$5,096**
Additional Cost**	$1,529
Total Construction Cost for WWTP	**$6,625**
Engineering and Contingency Cost	$1,789
Total Capital Cost	**$8,413**
Total Land Cost	$620
PV O & M Cost	$5,906
Total Project Cost	**$14,938**
Annualised Project Cost* **	**$1,399**
Life Cycle Cost******	**$1.13**

*Miscellaneous cost includes: Cost for raw sewage pumping, rising main and sludge pumping station
**Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
1000s $/yr , * Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 4 Details of TT option – TT5

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

TT OPTION-5:TT5

Treatment Train: Bar Screen+SBR+Break Point Chlorination+Coagulation, Flocculation & Sedimentation+Sand Filter+UV Disinfection+Gravity Thickener+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge

Desired Reuse(s): Irrigation of Turf
Irrigation of Pasture and Fodder for Grazing Animals
Irrigation of Golf Course with Restricted Access
Silviculture /Non Food Crop Irrigation
Irrigation of Processed Food Crops ("Not in Direct" Contact)

Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	30	5	0.5	100	-
Effluent Quality Achieved:	6.6	2.9	2.0	0.4	1.8	1.5

Meets Criteria (Yes/No): YES

Effectiveness Measures

Upgrade:	0.83
Varying flow rate:	0.73
Varying influent quality:	0.90
Ease of O & M:	0.77
Ease of construction:	0.73
Reliability:	0.80
Odour:	0.33
Ground water impact:	0.80
Chemical requirement:	0.77
Power requirement:	0.43

Note: Scaled from 0 to 1, a higher sccre indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	1.50
Sludge produced,kg/day:	1707

Table J. 4a Construction Cost Details of TT option – TT5

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

Summary of Construction Cost Estimate for TT Option-5:TT5

Item	**Construction Cost 1000s $**
Bar Screen	$106
SBR	$3,970
Break Point Chlorination	$319
Coagulation, Flocculation & Sedimentation	$495
Sand Filter	$983
UV Disinfection	$142
Gravity Thickener	$384
Anareobic Digestor	$544
Sludge Drying Beds	$147
Land Spreading of Sludge	$126
Miscellaneous Cost*	$882
Total Unit Process Construction Cost	**$8,098**
Additional Cost**	$2,430
Total Construction Cost for WWTP	**$10,528**
Engineering and Contingency Cost	$2,843
Total Capital Cost	**$13,370**
Total Land Cost	$265
PV O & M Cost	$7,663
Total Project Cost	**$21,298**
Annualised Project Cost* **	**$1,995**
Life Cycle Cost******	**$1.61**

*Miscellaneous cost includes: Cost for raw sewage pumping, rising main and sludge pumping station
**Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
1000s $/yr , * Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 5 Details of TT option – TT6

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

TT OPTION-6:TT6

Treatment Train: Bar Screen+Grit Chamber+Primary Clarifier+Continuous Flow BNR+Single Stage Lime Treatment+Dual Media Filter+UV Disinfection+Gravity Thickener+Anareobic Digestor+Sludge Drying Beds+Land Spreading of Sludge

Desired Reuse(s): Irrigation of Turf
Irrigation of Pasture and Fodder for Grazing Animals
Irrigation of Golf Course with Restricted Access
Silviculture /Non Food Crop Irrigation
Irrigation of Processed Food Crops ("Not in Direct" Contact)

Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	30	5	0.5	100	-
Effluent Quality Achieved:	1.1	1.2	4.2	0.1	0.2	0.4

Meets Criteria (Yes/No): YES

Effectiveness Measures

Upgrade:	0.79
Varying flow rate:	0.70
Varying influent quality:	0.94
Ease of O & M:	0.73
Ease of construction:	0.61
Reliability:	0.88
Odour:	0.33
Ground water impact:	0.82
Chemical requirement:	0.88
Power requirement:	0.45

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	1.79
Sludge produced,kg/day:	827

Table J. 5a Construction Cost Details of TT option – TT6

Printed on 18/03/2002

Community Name:Victor Harbor (User Generated, Class B+)

Summary of Construction Cost Estimate for TT Option-6:TT6

Item	**Construction Cost 1000s $**
Bar Screen	$106
Grit Chamber	$128
Primary Clarifier	$344
Continuous Flow BNR	$830
Single Stage Lime Treatment	$489
Dual Media Filter	$775
UV Disinfection	$142
Gravity Thickener	$304
Anareobic Digestor	$544
Sludge Drying Beds	$147
Land Spreading of Sludge	$119
Miscellaneous Cost*	$553
Total Unit Process Construction Cost	**$4,481**
Additional Cost**	$1,344
Total Construction Cost for WWTP	**$5,825**
Engineering and Contingency Cost	$1,573
Total Capital Cost	**$7,398**
Total Land Cost	$268
PV O & M Cost	$5,845
Total Project Cost	**$13,510**
Annualised Project Cost* **	**$1,266**
Life Cycle Cost******	**$1.02**

*Miscellaneous cost includes: Cost for raw sewage pumping, rising main and sludge pumping station
**Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
1000s $/yr , * Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 6 Community Input Data for Generation of TTs Using Seed

Printed on 18/03/2002

Community Data

Name of the Community	Victor Harbor (Case 1S-APM, Class B+)
Planning Authority	SA Water Corporation
State	SA, Country Australia
Entered By	M.Stevens

Design Information

Design Population	17000
Per Capita Wastewater Generation,lpcd	200
Average Annual Flow, m3/d	3400(3.40)*
Dry Weather Flow, m3/d	2890(2.89)
Peak Monthly Flow, m3/d	4080(4.08)
Peak Daily Flow, m3/d	8160(8.16)
Peak Wet Weather Flow, m3/d	10200(10.20)

* Note: The figures inside the brackets indicate flow in million litres per day, ML/d

Type of Wastewater Treatment Plant: New Plant

	BOD,mg/L	SS,mg/L	NH3-N,mg/L	ON,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Influent Wastewater Characteristics:	250	300	48	17	65	12	1000000	50

Peak Daily Organic Loading

BOD, kg/d	2380
SS, kg/d	2856
TN, kg/d	619
TP, kg/d	114

Desired Reuse Application(s) Irrigation of Golf Course with Restricted Access

Selected Reuse Guideline SA Reclaimed Water Guidelines, April 1999

Relative Weights Assigned for Different Selection Criteria:

Adaptability to Upgrade:	8	Odour Generation Potential:	6	Reliability:	9
Adaptability to Varying Flow Rate:	4	Land Requirement:	5	Chemical Requirement:	5
Adaptability to Varying Influent Quality:	7	Sludge Production:	8	Ease of O & M:	5
Ease of Construction:	3	Power Requirement:	2	Impact on Ground Water:	3
Total Project Cost:	2*	(*This indicates that Total Project Cost	is 2	times more important than the sum of all other criteria)	

Table J. 6a GA Input Data for TT Generation and Optimisation

Printed on 18/03/2002

Community Data

Name of the Community	Victor Harbor (Case 1S-APM, Class B+)
Planning Authority	SA Water Corporation
Sate	SA, Country Australia
Entered by	M.Stevens

GA Parameters Used

Population Size:	100
Tournament Size:	2
Probability of Selection, Ps:	0.6
Probability of Crossover, Pc:	0.8
Probability of Mutation, Pm:	0.2
Maximum Number of Generation:	100
Method of Fitness Evaluation:	Additive Penalty Method (APM)
Type of Population Generation:	Seeding Initial Population with Feasible Alternatives

Table J. 7 Details of TT option –1 (Case 1S-APM(B^+)

Printed on 18/03/2002

Community Name:Victor Harbor (Case 1S-APM, Class B+)

TT OPTION-1

Treatment Train: Bar Screen+Primary Clarifier w lime+ASP w Ni & w Clarifier+Two Stage Lime Treatment+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Spreading of Sludge

Desired Reuse: Irrigation of Golf Course with Restricted Access
Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	30	5	0.5	100	-
Effluent Quality Achieved:	2.3	1.8	4.4	0.1	0	0.0
Meets Criteria (Yes/No): YES						

Effectiveness Measures

Upgrade:	0.83
Varying flow rate:	0.63
Varying influent quality:	0.83
Ease of O & M:	0.58
Ease of construction:	0.63
Reliability:	0.79
Odour:	0.50
Ground water impact:	0.63
Chemical requirement:	0.71
Power requirement:	0.46

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	1.66
Sludge produced,kg/day:	1613

Table J. 7a Construction Cost Details of TT option – 1 (Case 1S-APM (B^+))

Printed on 18/03/2002

Community Name:Victor Harbor (Case 1S-APM, Class B+)

Summary of Construction Cost Estimate for TT Option-1

Item	**Construction Cost 1000s $**
Bar Screen	$106
Primary Clarifier w lime	$491
ASP w Ni & w Clarifier	$1,386
Two Stage Lime Treatment	$2,211
Dual Media Filter	$775
UV Disinfection	$142
Sludge Drying Beds	$147
Land Spreading of Sludge	$125
Miscellaneous Cost	$160
Total UP Construction Cost	**$6,082**
Additional Cost*	$1,615
Total Construction Cost for WWTP	**$7,697**
Engineering and Contingency Cost	$2,078
Total Capital Cost	**$9,775**
Total Land Cost	$267
PV O & M Cost	$5,696
Total Project Cost	**$15,737**
Annualised Project Cost* **	**$1,474**
Life Cycle Cost******	**$1.19**

*Miscellaneous cost includes: Cost for raw sewage pumping, rising main and sludge pumping station
**Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
*** 1000s $/yr,**** Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 8 Summary of TT Options Generated by MOSTWATAR for Case 1S-MPM (B^+)

Printed on18/03/2002

Community Name:Victor Harbor (Case 1S-MPM, Class B+)

Design Population:17000
Design Average Flow,m3/d:3400
Design Peak Flow,m3/d:10200

Summary of Evaluation of Wastewater Treatment Alternatives generated by MOSTWATAR

Items	R.Criteria	Option:1(34)*	Option:2(24)*	Option:3(27)*	Option:4(34)*	Option:5(30)*
BOD,mg/L	20	2.3	2.2	2.3	2.2	2.3
SS,mg/L	30	1.8	1.7	1.8	1.7	1.8
TN,mg/L	5.0	4.4	4.4	4.4	4.4	4.4
TP,mg/L	0.5	0.1	0.1	0.1	0.1	0.1
FC,No/100mL	100	0.0	0.0	0.0	0.0	0.0
Turbidity,NTU	-	0.0	0.0	0.0	0.0	0.0
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.83	0.85	0.81	0.83	0.81
Varying flow rate		0.63	0.67	0.63	0.67	0.67
Varying influent quality		0.83	0.85	0.85	0.87	0.85
Ease of O & M		0.58	0.59	0.63	0.63	0.63
Ease of construction		0.63	0.63	0.59	0.60	0.63
Reliability		0.79	0.81	0.81	0.83	0.81
Odour		0.50	0.48	0.44	0.43	0.44
Ground water impact		0.63	0.67	0.67	0.70	0.67
Chemical requirement		0.71	0.74	0.74	0.77	0.74
Power requirement		0.46	0.48	0.44	0.47	0.44
Total land required, ha		1.66	1.67	1.73	1.75	1.74
Total sludge produced,kg/d		1613	1670	1535	1590	1613
Total capital cost,**		$9,775	$10,002	$10,352	$10,586	$10,741
Total land cost,**		$267	$267	$267	$267	$267
PV O & M cost,**		$5,696	$5,817	$5,928	$6,051	$6,276
Total project cost,**		**$15,737**	**$16,087**	**$16,547**	**$16,905**	**$17,285**
Annualised project cost***		**$1,474**	**$1,507**	**$1,550**	**$1,584**	**$1,619**
Life cycle cost****		**$1.19**	**$1.21**	**$1.25**	**$1.28**	**$1.30**
Fitness score		**0.655**	**0.653**	**0.644**	**0.641**	**0.631**

NOTE:Sort Key= Max Fitness Score;Fitness score is scaled from 0 to 1, negative score indicates an infeasible option.
* Number within brackets indicate the generation number in which the option was generated, **1000s $, ***1000s $/yr,****$/m3.

Table J. 9 Summary of TT Options Generated by MOSTWATAR for Case 1S-DPM (B^+)

Printed on19/03/2002

Community Name:Victor Harbor (Case 1S-DPM, Class B+).

Design Population:17000
Design Average Flow,m3/d:3400
Design Peak Flow,m3/d:10200

Summary of Evaluation of Wastewater Treatment Alternatives generated by MOSTWATAR

Items	R.Criteria	Option:1(35)*	Option:2(36)*	Option:3(28)*	Option:4(26)*	Option:5(23)*
BOD,mg/L	20	2.3	2.2	2.3	2.2	2.3
SS,mg/L	30	1.8	1.7	1.8	1.7	1.8
TN,mg/L	5.0	4.4	4.4	4.4	4.4	4.4
TP,mg/L	0.5	0.1	0.1	0.1	0.1	0.1
FC,No/100mL	100	0.0	0.0	0.0	0.0	0.0
Turbidity,NTU	-	0.0	0.0	0.0	0.0	0.0
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.83	0.85	0.81	0.83	0.80
Varying flow rate		0.63	0.67	0.67	0.70	0.67
Varying influent quality		0.83	0.85	0.85	0.87	0.87
Ease of O & M		0.58	0.59	0.63	0.63	0.67
Ease of construction		0.63	0.63	0.63	0.63	0.60
Reliability		0.79	0.81	0.81	0.83	0.83
Odour		0.50	0.48	0.44	0.43	0.40
Ground water impact		0.63	0.67	0.67	0.70	0.70
Chemical requirement		0.71	0.74	0.74	0.77	0.77
Power requirement		0.46	0.48	0.44	0.47	0.43
Total land required, ha		1.66	1.67	1.74	1.75	1.81
Total sludge produced,kg/d		1613	1670	1613	1670	1152
Total capital cost,**		$9,775	$10,002	$10,741	$10,969	$11,313
Total land cost,**		$267	$267	$267	$268	$268
PV O & M cost,**		$5,696	$5,817	$6,276	$6,398	$6,493
Total project cost,**		**$15,737**	**$16,087**	**$17,285**	**$17,634**	**$18,075**
Annualised project cost***		**$1,474**	**$1,507**	**$1,619**	**$1,652**	**$1,693**
Life cycle cost****		**$1.19**	**$1.21**	**$1.30**	**$1.33**	**$1.36**
Fitness score		**0.655**	**0.653**	**0.631**	**0.628**	**0.624**

NOTE:Sort Key= Max Fitness Score;Fitness score is scaled from 0 to 1, negative score indicates an infeasible option.
* Number within brackets indicate the generation number in which the option was generated, **1000s $, ***1000s $/yr,****$/m3.

Table J. 10 Summary of TT Options Generated by MOSTWATAR for Case 1S-ADPM (B+)

Printed on19/03/2002

Community Name:Victor Harbor (Case 1S-ADPM, Class B+).

Design Population:17000
Design Average Flow,m3/d:3400
Design Peak Flow,m3/d:10200

Summary of Evaluation of Wastewater Treatment Alternatives generated by MOSTWATAR

Items	R.Criteria	Option:1(26)*	Option:2(22)*	Option:3(19)*	Option:4(26)*	Option:5(26)*
BOD,mg/L	20	2.3	2.2	2.3	2.2	2.3
SS,mg/L	30	1.8	1.7	1.8	1.7	1.8
TN,mg/L	5.0	4.4	4.4	4.4	4.4	4.4
TP,mg/L	0.5	0.1	0.1	0.1	0.1	0.1
FC,No/100mL	100	0.0	0.0	0.0	0.0	0.0
Turbidity,NTU	-	0.0	0.0	0.0	0.0	0.0
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.83	0.85	0.81	0.83	0.81
Varying flow rate		0.63	0.67	0.63	0.67	0.67
Varying influent quality		0.83	0.85	0.85	0.87	0.85
Ease of O & M		0.58	0.59	0.63	0.63	0.63
Ease of construction		0.63	0.63	0.59	0.60	0.63
Reliability		0.79	0.81	0.81	0.83	0.81
Odour		0.50	0.48	0.44	0.43	0.44
Ground water impact		0.63	0.67	0.67	0.70	0.67
Chemical requirement		0.71	0.74	0.74	0.77	0.74
Power requirement		0.46	0.48	0.44	0.47	0.44
Total land required, ha		1.66	1.67	1.73	1.75	1.74
Total sludge produced,kg/d		1613	1670	1535	1590	1613
Total capital cost,**		$9,775	$10,002	$10,352	$10,586	$10,741
Total land cost,**		$267	$267	$267	$267	$267
PV O & M cost,***		$5,696	$5,817	$5,928	$6,051	$6,276
Total project cost,**		**$15,737**	**$16,087**	**$16,547**	**$16,905**	**$17,285**
Annualised project cost***		**$1,474**	**$1,507**	**$1,550**	**$1,584**	**$1,619**
Life cycle cost*****		**$1.19**	**$1.21**	**$1.25**	**$1.28**	**$1.30**
Fitness score		**0.655**	**0.653**	**0.644**	**0.641**	**0.631**

NOTE:Sort Key= Max Fitness Score;Fitness score is scaled from 0 to 1, negative score indicates an infeasible option.
* Number within brackets indicate the generation number in which the option was generated, **1000s $, ***1000s $/yr,****$/m3.

Table J. 11 Summary of TT Options Generated by MOSTWATAR for Case 1R2-APM (B+)

Printed on19/03/2002

Community Name:Victor Harbor (Case 1 R2- APM, Class B+)

Design Population:17000
Design Average Flow,m3/d:3400
Design Peak Flow,m3/d:10200

Summary of Evaluation of Wastewater Treatment Alternatives generated by MOSTWATAR

Items	R.Criteria	Option:1(33)*	Option:2(33)*	Option:3(32)*	Option:4(32)*	Option:5(38)*
BOD,mg/L	20	1.0	0.7	3.0	0.6	2.1
SS,mg/L	30	1.4	1.0	2.0	0.4	1.5
TN,mg/L	5.0	4.1	4.1	3.8	2.9	3.8
TP,mg/L	0.5	0.4	0.4	0.3	0.2	0.3
FC,No/100mL	100	0.1	0.1	2.7	0.0	2.7
Turbidity,NTU	-	0.4	0.4	0.3	0.1	0.3
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.83	0.81	0.83	0.85	0.81
Varying flow rate		0.67	0.67	0.67	0.70	0.67
Varying influent quality		0.83	0.85	0.79	0.81	0.81
Ease of O & M		0.71	0.70	0.71	0.70	0.70
Ease of construction		0.71	0.67	0.67	0.70	0.63
Reliability		0.79	0.78	0.75	0.78	0.74
Odour		0.38	0.41	0.46	0.41	0.48
Ground water impact		0.50	0.56	0.63	0.56	0.67
Chemical requirement		0.75	0.78	0.71	0.74	0.74
Power requirement		0.54	0.48	0.50	0.52	0.44
Total land required, ha		15.08	15.12	1.50	15.23	1.54
Total sludge produced,kg/d		2465	2537	2478	2467	2547
Total capital cost,**		$5,513	$6,099	$6,944	$7,085	$7,531
Total land cost,**		$401	$401	$265	$402	$265
PV O & M cost,***		$3,629	$3,938	$4,203	$4,287	$4,512
Total project cost,**		**$9,542**	**$10,439**	**$11,412**	**$11,774**	**$12,308**
Annualised project cost***		**$894**	**$978**	**$1,069**	**$1,103**	**$1,153**
Life cycle cost****		**$0.72**	**$0.79**	**$0.86**	**$0.89**	**$0.93**
Fitness score		**0.745**	**0.729**	**0.720**	**0.707**	**0.704**

NOTE:Sort Key= Max Fitness Score;Fitness score is scaled from 0 to 1, negative score indicates an infeasible option.
* Number within brackets indicate the generation number in which the option was generated, **1000s $, ***1000s $/yr,****$/m3.

Table J. 12 Summary of TT Options Generated by MOSTWATAR for Case 1R2-MPM (B+)

Printed on19/03/2002

Community Name:Victor Harbor (Case 1R2- MPM, Class B+).

Design Population:17000
Design Average Flow,m3/d:3400
Design Peak Flow,m3/d:10200

Summary of Evaluation of Wastewater Treatment Alternatives generated by MOSTWATAR

Items	R.Criteria	Option:1(9)*	Option:2(10)*	Option:3(10)*	Option:4(11)*	Option:5(22)*
BOD,mg/L	20	1.1	1.1	1.2	0.8	0.7
SS,mg/L	30	1.1	1.1	1.3	0.9	0.8
TN,mg/L	5.0	3.7	3.7	4.5	4.5	3.7
TP,mg/L	0.5	0.3	0.3	0.3	0.3	0.3
FC,No/100mL	100	4.1	4.1	13.5	13.5	4.1
Turbidity,NTU	-	5.0	5.0	1.2	1.2	5.0
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.88	0.85	0.79	0.78	0.83
Varying flow rate		0.71	0.67	0.71	0.70	0.67
Varying influent quality		0.92	0.89	0.96	0.96	0.90
Ease of O & M		0.75	0.74	0.79	0.78	0.73
Ease of construction		0.67	0.67	0.67	0.63	0.63
Reliability		0.79	0.81	0.83	0.81	0.80
Odour		0.42	0.48	0.29	0.33	0.50
Ground water impact		0.88	0.89	0.75	0.78	0.90
Chemical requirement		0.83	0.74	0.75	0.78	0.77
Power requirement		0.50	0.52	0.54	0.48	0.47
Total land required, ha		1.47	1.57	1.63	1.62	1.61
Total sludge produced,kg/d		1093	1093	2372	2460	1171
Total capital cost,**		$5,744	$6,625	$5,259	$5,604	$7,212
Total land cost,**		$265	$266	$266	$266	$266
PV O & M cost,**		$5,235	$5,857	$6,297	$6,546	$6,237
Total project cost,**		**$11,244**	**$12,748**	**$11,823**	**$12,417**	**$13,715**
Annualised project cost***		**$1,053**	**$1,194**	**$1,108**	**$1,163**	**$1,285**
Life cycle cost****		**$0.85**	**$0.96**	**$0.89**	**$0.94**	**$1.04**
Fitness score		**0.758**	**0.729**	**0.724**	**0.711**	**0.710**

NOTE:Sort Key= Max Fitness Score;Fitness score is scaled from 0 to 1, negative score indicates an infeasible option.
* Number within brackets indicate the generation number in which the option was generated, **1000s $, ***1000s $/yr,****$/m3.

Table J. 13 Summary of TT Options Generated by MOSTWATAR for Case 1R2-ADPM (B+)

Printed on19/03/2002

Page1

Community Name:Victor Harbor (Case 1R2-ADPM, Class B+)

Design Population:17000
Design Average Flow,m3/d:3400
Design Peak Flow,m3/d:10200

Summary of Evaluation of Wastewater Treatment Alternatives generated by MOSTWATAR

Items	R.Criteria	Option:1(23)*	Option:2(31)*	Option:3(26)*	Option:4(8)*	Option:5(14)*
BOD,mg/L	20	0.3	0.3	0.3	0.3	0.0
SS,mg/L	30	0.3	0.3	0.3	0.3	0.0
TN,mg/L	5.0	3.8	3.8	3.8	3.8	0.9
TP,mg/L	0.5	0.5	0.5	0.5	0.5	0.4
FC,No/100mL	100	67.5	67.5	0.0	0.0	0.1
Turbidity,NTU	-	0.0	0.0	0.0	0.0	0.0
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.83	0.85	0.81	0.83	0.85
Varying flow rate		0.75	0.78	0.70	0.73	0.78
Varying influent quality		0.92	0.93	0.89	0.90	0.93
Ease of O & M		0.75	0.74	0.70	0.70	0.74
Ease of construction		0.67	0.67	0.63	0.63	0.70
Reliability		0.79	0.81	0.78	0.80	0.81
Odour		0.25	0.26	0.30	0.30	0.22
Ground water impact		0.75	0.78	0.78	0.80	0.67
Chemical requirement		0.92	0.93	0.93	0.93	0.93
Power requirement		0.46	0.48	0.41	0.43	0.48
Total land required, ha		2.97	2.98	2.99	3.00	34.21
Total sludge produced,kg/d		742	809	742	809	740
Total capital cost,**		$6,196	$6,408	$6,449	$6,661	$11,917
Total land cost,**		$280	$280	$280	$280	$592
PV O & M cost,***		$4,424	$4,606	$4,536	$4,718	$7,857
Total project cost,**		**$10,900**	**$11,293**	**$11,265**	**$11,659**	**$20,366**
Annualised project cost***		**$1,021**	**$1,058**	**$1,055**	**$1,092**	**$1,908**
Life cycle cost****		**$0.82**	**$0.85**	**$0.85**	**$0.88**	**$1.54**
Fitness score		**0.761**	**0.757**	**0.751**	**0.747**	**0.576**

NOTE:Sort Key= Max Fitness Score;Fitness score is scaled from 0 to 1, negative score indicates an infeasible option.
* Number within brackets indicate the generation number in which the option was generated, **1000s $, ***1000s $/yr,****$/m3.

Table J. 14 Summary of TT Options Generated by MOSTWATAR for Case 1R1-DPM (B)

Printed on 25/03/2002

Community Data

Name of the Community	Victor Harbor (Case 1R1-DPM.,Class B)
Planning Authority	SA Water Corporation
State	SA
Country	Australia
Entered By	N.dinesh

Wastewater Treatment Alternatives Generated by MOSTWATAR

Gen No	Treatment Processes	Fitness Score
13	Bar Screen+Primary Clarifier w lime+Anaerobic Lagoon+Facultative Pond+Chlorination+Sludge Drying Beds+Land Filling of Sludge	0.818
13	Bar Screen+Grit Chamber+Primary Clarifier w lime+Anaerobic Lagoon+Facultative Pond+Chlorination+Sludge Drying Beds+Land Filling of Sludge	0.816
20	Bar Screen+Fine Screen+Grit Chamber+Primary Clarifier+TF,Plastic Media,w Clarifier+Anaerobic Lagoon+Chlorination+Sludge Drying Beds+Land Spreading of Sludge	0.814
14	Bar Screen+Fine Screen+Grit Chamber+Primary Clarifier w lime+Anaerobic Lagoon+Facultative Pond+Chlorination+Sludge Drying Beds+Land Filling of Sludge	0.807
3	Bar Screen+Primary Clarifier w lime+Conventional ASP, w Clarifier+Chlorination+Sludge Drying Beds+Land Spreading of Sludge	0.797

Table J. 15 Details of TT Option-1 Generated by MOSTWATAR for Case 1R1-DPM (B)

Printed on 25/03/2002

Community Name:Victor Harbor (Case 1R1-DPM.,Class B)

TT OPTION-1

Treatment Train: Bar Screen+Primary Clarifier w lime+Anaerobic Lagoon+Facultative Pond+Chlorination+Sludge Drying Beds+Land Filling of Sludge

Desired Reuse: Irrigation of Golf Course with Restricted Access
Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	30	-	-	100	-
Effluent Quality Achieved:	4.9	6.1	31.3	1.5	6.7	1.4
Meets Criteria (Yes/No): YES						

Effectiveness Measures

Upgrade:	0.90
Varying flow rate:	0.62
Varying influent quality:	0.95
Ease of O & M:	0.71
Ease of construction:	0.71
Reliability:	0.71
Odour:	0.24
Ground water impact:	0.57
Chemical requirement:	0.71
Power requirement:	0.57

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	3.54
Sludge produced,kg/day:	604

Table J. 15a Construction Cost of TT Option-1 Generated by MOSTWATAR for Case 1R1-DPM (B)

Printed on 25/03/2002

Community Name:Victor Harbor (Case 1R1-DPM.,Class B)

Summary of Construction Cost Estimate for TT Option-1

Item	**Construction Cost 1000s $**
Bar Screen	$106
Primary Clarifier w lime	$491
Anaerobic Lagoon	$418
Facultative Pond	$311
Chlorination	$167
Sludge Drying Beds	$147
Land Filling of Sludge	$167
Miscellaneous Cost	$160
Total UP Construction Cost	**$2,148**
Additional Cost*	$542
Total Construction Cost for WWTP	**$2,690**
Engineering and Contingency Cost	$726
Total Capital Cost	**$3,416**
Total Land Cost	$285
PV O & M Cost	$3,544
Total Project Cost	**$7,246**
Annualised Project Cost* **	**$679**
Life Cycle Cost*** **	**$0.55**

*Miscellaneous cost includes: Cost for raw sewage pumping, rising main and sludge pumping station
**Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
*** 1000s $/yr,**** Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 16 Summary of TT Options Generated by MOSTWATAR for Case 1R2-DPM (B)

Printed on 25/03/2002

Community Name:Victor Harbor (Case 1R1-DPM.,Class B)

TT OPTION-1

Treatment Train: Bar Screen+Primary Clarifier w lime+Anaerobic Lagoon+Facultative Pond+Chlorination+Sludge Drying Beds+Land Filling of Sludge

Desired Reuse: Irrigation of Golf Course with Restricted Access
Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	30	-	-	100	-
Effluent Quality Achieved:	4.9	6.1	31.3	1.5	6.7	1.4
Meets Criteria (Yes/No): YES						

Effectiveness Measures

Upgrade:	0.90
Varying flow rate:	0.62
Varying influent quality:	0.95
Ease of O & M:	0.71
Ease of construction:	0.71
Reliability:	0.71
Odour:	0.24
Ground water impact:	0.57
Chemical requirement:	0.71
Power requirement:	0.57

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	3.54
Sludge produced,kg/day:	604

Table J. 17 Details of TT Option-1 Generated by MOSTWATAR for Case 1R2-DPM (B)

Printed on 26/03/2002

Community Name:Victor Harbor (Case 1R2-DPM.,Class B)

TT OPTION-1

Treatment Train: Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Dual Media Filter+UV Disinfection+Sludge Drying Beds+Land Filling of Sludge

Desired Reuse: Irrigation of Golf Course with Restricted Access
Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	30	-	-	100	-
Effluent Quality Achieved:	19.6	8.8	31.2	0.8	0.5	0.2

Meets Criteria (Yes/No): YES

Effectiveness Measures

Upgrade:	0.90
Varying flow rate:	0.62
Varying influent quality:	0.90
Ease of O & M:	0.67
Ease of construction:	0.67
Reliability:	0.71
Odour:	0.38
Ground water impact:	0.71
Chemical requirement:	0.81
Power requirement:	0.38

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	1.39
Sludge produced,kg/day:	849

Table J. 17a Construction Cost Details of TT Option-1 Generated by MOSTWATAR for Case 1R2-DPM (B)

Printed on 26/03/2002

Community Name:Victor Harbor (Case 1R2-DPM.,Class B)

Summary of Construction Cost Estimate for TT Option-1

Item	**Construction Cost 1000s $**
Bar Screen	$106
Primary Clarifier w lime	$491
TF,Rock Media, w Clarifier	$660
Dual Media Filter	$775
UV Disinfection	$142
Sludge Drying Beds	$147
Land Filling of Sludge	$170
Miscellaneous Cost	$160
Total UP Construction Cost	**$2,900**
Additional Cost*	$747
Total Construction Cost for WWTP	**$3,647**
Engineering and Contingency Cost	$985
Total Capital Cost	**$4,632**
Total Land Cost	$264
PV O & M Cost	$3,130
Total Project Cost	**$8,025**
Annualised Project Cost*	**$752**
Life Cycle Cost**	**$0.61**

*Miscellaneous cost includes: Cost for raw sewage pumping, rising main and sludge pumping station
**Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
*** 1000s $/yr,**** Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 18 Details of User Generated Upgrade Option (TT3) .for Victor Harbor WWTP

Printed on 27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

TT OPTION-3:TT3

Treatment Train: Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+SBR+Break Point Chlorination+Coagulation & Flocculation+Sand Filter+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge

Desired Reuse(s): Irrigation of Golf Course with Unrestricted Access
Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	-	5	0.5	10	-
Effluent Quality Achieved:	1.8	0.8	1.6	0.4	1.5	1.5

Meets Criteria (Yes/No): YES

Effectiveness Measures

Upgrade:	0.91
Varying flow rate:	0.70
Varying influent quality:	0.88
Ease of O & M:	0.70
Ease of construction:	0.76
Reliability:	0.73
Odour:	0.42
Ground water impact:	0.82
Chemical requirement:	0.70
Power requirement:	0.45

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	0.40
Sludge produced, kg/day:	361

Table J. 18a Construction Cost Details of Upgrade Option(TT3) Generated by User

Printed on 27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

Summary of Construction Cost Estimate for TT Option-3:TT3

Item	**Construction Cost 1000s $**
Bar Screen*	--
Primary Clarifier w lime	***$350***
TF,Rock Media, w Clarifier*	--
SBR	***$2,080***
Break Point Chlorination	***$219***
Coagulation & Flocculation	***$79***
Sand Filter	***$420***
UV Disinfection	***$86***
Anareobic Digestor*	--
Sludge Drying Beds*	--
Land Filling of Sludge*	--
Miscellaneous Cost**	$65
Additional Unit Process Construction Cost	**$3,299**
Additional Cost***	$990
Total Construction Cost for Upgrade of WWTP	**$4,288**
Engineering and Contingency Cost	$1,158
Total Capital Cost	**$5,446**
Total Land Cost	$254
PV O & M Cost	**$3,171**
Total Project Cost	**$8,871**
Annualised Project Cost @*	**$831**
Life Cycle Cost @**	**$1.42**

*Indicates an existing unit process and the cost of these processes are not included in the Total Project Cost
**Miscellaneous cost includes: Cost for minor modifications to existing plants
***Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
@* $/yr,@** Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 19 Details of the Upgrade Option (TT4) Generated by the User

Printed on 27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

TT OPTION-4:TT4

Treatment Train: Bar Screen+Primary Clarifier+TF,Rock Media, w Clarifier+Continuous Flow BNR+Coagulation, Flocculation & Sedimentation+Microfiltration+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge

Desired Reuse(s): Irrigation of Golf Course with Unrestricted Access
Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	-	5	0.5	10	-
Effluent Quality Achieved:	0.5	0.5	1.1	0.3	9.2	1.6
Meets Criteria (Yes/No): YES						

Effectiveness Measures

Upgrade:	0.83
Varying flow rate:	0.73
Varying influent quality:	0.90
Ease of O & M:	0.77
Ease of construction:	0.67
Reliability:	0.83
Odour:	0.37
Ground water impact:	0.80
Chemical requirement:	0.87
Power requirement:	0.40

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	1.94
Sludge produced, kg/day:	1359

Table J. 19a Construction Cost Details of the User Generated Upgrade Option (TT4) for Victor Harbor WWTP

Printed on 27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

Summary of Construction Cost Estimate for TT Option-4:TT4

Item	**Construction Cost 1000s $**
Bar Screen*	--
Primary Clarifier	***$238***
TF,Rock Media, w Clarifier*	--
Continuous Flow BNR	***$549***
Coagulation, Flocculation & Sedimentation	***$272***
Microfiltration	***$2,829***
UV Disinfection	***$86***
Anareobic Digestor*	--
Sludge Drying Beds*	--
Land Filling of Sludge*	--
Miscellaneous Cost**	$80
Additional Unit Process Construction Cost	**$4,055**
Additional Cost***	$1,216
Total Construction Cost for Upgrade of WWTP	**$5,271**
Engineering and Contingency Cost	$1,423
Total Capital Cost	**$6,694**
Total Land Cost	$269
PV O & M Cost	**$1,980**
Total Project Cost	**$8,944**
Annualised Project Cost @*	**$838**
Life Cycle Cost @**	**$1.43**

*Indicates an existing unit process and the cost of these processes are not included in the Total Project Cost
**Miscellaneous cost includes: Cost for minor modifications to existing plants
***Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
@* $/yr,@** Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 20 Details of the User Generated Upgrade Options (TT5) for Victor Harbor WWTP

Printed on 27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

TT OPTION-5:TT5

Treatment Train: Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+FWS Wetland (BOD & Ni)+Maturation Pond+Post Chlorination+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge

Desired Reuse(s): Irrigation of Golf Course with Unrestricted Access
Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	-	5	0.5	10	-
Effluent Quality Achieved:	2.5	0.9	7.2	1.9	0.1	0.9

Meets Criteria (Yes/No): NO

Effectiveness Measures

Upgrade:	0.85
Varying flow rate:	0.70
Varying influent quality:	0.93
Ease of O & M:	0.74
Ease of construction:	0.74
Reliability:	0.78
Odour:	0.26
Ground water impact:	0.56
Chemical requirement:	0.81
Power requirement:	0.52

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	15.47
Sludge produced, kg/day:	319

Table J. 20a Construction Cost Details of the User Generated Upgrade Option (TT5)

Printed on 27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

Summary of Construction Cost Estimate for TT Option-5:TT5

Item	Construction Cost 1000s $
Bar Screen*	--
Primary Clarifier w lime	***$350***
TF,Rock Media, w Clarifier*	--
FWS Wetland (BOD & Ni)	***$1,563***
Maturation Pond	***$145***
Post Chlorination	***$105***
Anareobic Digestor*	--
Sludge Drying Beds*	--
Land Filling of Sludge*	--
Miscellaneous Cost**	$43
Additional Unit Process Construction Cost	**$2,205**
Additional Cost***	$662
Total Construction Cost for Upgrade of WWTP	**$2,867**
Engineering and Contingency Cost	$774
Total Capital Cost	**$3,641**
Total Land Cost	$405
PV O & M Cost	**$2,763**
Total Project Cost	**$6,809**
Annualised Project Cost @*	**$638**
Life Cycle Cost @**	**$1.09**

*Indicates an existing unit process and the cost of these processes are not included in the Total Project Cost
**Miscellaneous cost includes: Cost for minor modifications to existing plants
***Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
@* $/yr,@** Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 21 Details of the User Generated Upgrade Options (TT1) for Victor Harbor WWTP

Printed on 27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

TT OPTION-1:TT1

Treatment Train: Bar Screen+Primary Clarifier+TF,Rock Media, w Clarifier+ASP w Ni & w Clarifier+Single Stage Lime Treatment+Sand Filter+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge

Desired Reuse(s): Irrigation of Golf Course with Unrestricted Access
Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	-	5	0.5	10	-
Effluent Quality Achieved:	0.4	0.5	3.7	1.0	3.5	3.3

Meets Criteria (Yes/No): NO

Effectiveness Measures

Upgrade:	0.90
Varying flow rate:	0.73
Varying influent quality:	0.83
Ease of O & M:	0.77
Ease of construction:	0.67
Reliability:	0.73
Odour:	0.40
Ground water impact:	0.70
Chemical requirement:	0.87
Power requirement:	0.53

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	0.40
Sludge produced, kg/day:	585

Table J. 21a Construction Cost Details of the User Generated Upgrade Option (TT1) .

Printed on 27/03/2002

Community Name:Victor Harbor (Upgrade-User Generated Options.)

Summary of Construction Cost Estimate for TT Option-1:TT1

Item	**Construction Cost 1000s $**
Bar Screen*	--
Primary Clarifier	***$238***
TF,Rock Media, w Clarifier*	--
ASP w Ni & w Clarifier	***$768***
Single Stage Lime Treatment	***$356***
Sand Filter	***$420***
UV Disinfection	***$86***
Anareobic Digestor*	--
Sludge Drying Beds*	--
Land Filling of Sludge*	--
Miscellaneous Cost**	$37
Additional Unit Process Construction Cost	**$1,907**
Additional Cost***	$572
Total Construction Cost for Upgrade of WWTP	**$2,479**
Engineering and Contingency Cost	$669
Total Capital Cost	**$3,148**
Total Land Cost	$254
PV O & M Cost	**$2,404**
Total Project Cost	**$5,806**
Annualised Project Cost @*	**$544**
Life Cycle Cost @**	**$0.93**

*Indicates an existing unit process and the cost of these processes are not included in the Total Project Cost
**Miscellaneous cost includes: Cost for minor modifications to existing plants
***Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
@* $/yr,@** Life cycle cost is expressed as $/m3 of reclaimed water

Table J. 22 Summary of MOSTWATAR Generated Upgrade Options for Case 2R2-APM (A+)

Printed on26/03/2002

Community Name:Victor Harbor (Case2R2-APM, Class A+)`

Design Population:8000
Design Average Flow,m3/d:1600
Design Peak Flow,m3/d:4800

Summary of Evaluation of Upgrade Options generated by MOSTWATAR

Items	R.Criteria	Option:1(19)*	Option:2(7)*	Option:3(12)*	Option:4(19)*	Option:5(14)*
BOD,mg/L	20	0.9	0.6	0.2	0.2	0.4
SS,mg/L	-	0.6	0.4	0.2	0.1	0.2
TN,mg/L	5	3.3	3.3	1.7	1.7	4.7
TP,mg/L	0.5	0.1	0.1	0.1	0.1	0.0
FC,No/100mL	10	4.6	4.6	0.9	0.9	0.0
Turbidity,NTU	2	0.0	0.0	0.0	0.0	0.0
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.80	0.79	0.82	0.81	0.87
Varying flow rate		0.70	0.70	0.73	0.72	0.70
Varying influent quality		0.90	0.91	0.91	0.92	0.87
Ease of O & M		0.73	0.73	0.73	0.72	0.70
Ease of construction		0.63	0.61	0.64	0.61	0.67
Reliability		0.80	0.79	0.82	0.81	0.80
Odour		0.40	0.42	0.36	0.39	0.43
Ground water impact		0.70	0.73	0.64	0.67	0.80
Chemical requirement		0.67	0.70	0.70	0.72	0.73
Power requirement		0.47	0.42	0.48	0.44	0.33
Total land required, ha		0.49	0.51	2.77	2.79	0.26
Total sludge produced,kg/d		1416	1458	1414	1457	1289
Total capital cost,**		$3,755	$4,163	$4,611	$5,019	$9,310
Total land cost,**		$255	$255	$278	$278	$253
PV O & M cost,**		$3,125	$3,339	$3,382	$3,596	$5,095
Total project cost,**		**$7,135**	**$7,757**	**$8,271**	**$8,893**	**$14,658**
Annualised project cost***		**$668**	**$727**	**$775**	**$833**	**$1,373**
Life cycle cost****		**$1.14**	**$1.24**	**$1.33**	**$1.43**	**$2.35**
Fitness score		**0.745**	**0.731**	**0.720**	**0.705**	**0.584**

NOTE:Sort Key= Max Fitness Score. Fitness score is scaled from 0 to 1, negative score indicates a infeasible option and a positive score indicates a feasible option.
* Number within the bracket indicate the generation number in which the option was generated. **1000s $, ***1000s $/yr,****$/m3,

Table J. 23 Summary of MOSTWATAR Generated Upgrade Options for Case 2R2-MPM (A+)

Printed on26/03/2002

Community Name:Victor Habor (Upgrade, Case 2R2-MPM, Class A+)

Design Population:8000
Design Average Flow,m3/d:1600
Design Peak Flow,m3/d:4800

Summary of Evaluation of Upgrade Options generated by MOSTWATAR

Items	R.Criteria	Option:1(20)*	Option:2(30)*	Option:3(20)*	Option:4(7)*	Option:5(9)*
BOD,mg/L	20	2.3	1.5	1.5	0.2	0.2
SS,mg/L	-	3.3	1.1	1.1	0.2	0.2
TN,mg/L	5	1.9	3.7	1.5	1.2	1.2
TP,mg/L	0.5	0.4	0.2	0.2	0.4	0.4
FC,No/100mL	10	6.1	0.2	0.1	0.0	0.0
Turbidity,NTU	2	3.9	0.1	0.1	1.2	1.2
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.85	0.81	0.83	0.85	0.87
Varying flow rate		0.70	0.67	0.70	0.70	0.73
Varying influent quality		0.93	0.93	0.93	0.93	0.93
Ease of O & M		0.70	0.70	0.67	0.74	0.73
Ease of construction		0.70	0.63	0.67	0.70	0.70
Reliability		0.74	0.78	0.77	0.78	0.80
Odour		0.33	0.33	0.37	0.26	0.27
Ground water impact		0.78	0.78	0.80	0.67	0.70
Chemical requirement		0.78	0.85	0.77	0.89	0.90
Power requirement		0.44	0.37	0.40	0.44	0.47
Total land required, ha		0.59	0.66	0.68	15.27	15.28
Total sludge produced,kg/d		463	467	467	463	502
Total capital cost,**		$2,289	$2,741	$3,130	$4,679	$4,841
Total land cost,**		$256	$257	$257	$403	$403
PV O & M cost,**		$1,830	$1,575	$2,421	$2,653	$2,738
Total project cost,**		**$4,375**	**$4,573**	**$5,807**	**$7,734**	**$7,982**
Annualised project cost***		**$410**	**$428**	**$544**	**$725**	**$748**
Life cycle cost****		**$0.70**	**$0.73**	**$0.93**	**$1.24**	**$1.28**
Fitness score		**0.822**	**0.817**	**0.790**	**0.739**	**0.737**

NOTE:Sort Key= Max Fitness Score. Fitness score is scaled from 0 to 1, negative score indicates a infeasible option and a positive score indicates a feasible option.
* Number within the bracket indicate the generation number in which the option was generated, **1000s $, ***1000s $/yr,****$/m3,

Table J. 24 Summary of the MOSTWATAR Generated Upgrade Options for Case 2R2-ADPM (A+)

Printed on26/03/2002

Community Name:Victor Harbor (Case 2R2- ADPM, Class A+)

Design Population:8000
Design Average Flow,m3/d:1600
Design Peak Flow,m3/d:4800

Summary of Evaluation of Upgrade Options generated by MOSTWATAR

Items	R.Criteria	Option:1(30)*	Option:2(31)*	Option:3(30)*	Option:4(32)*	Option:5(33)*
BOD,mg/L	20	0.6	0.1	0.1	0.1	0.1
SS,mg/L	-	1.0	0.3	0.3	0.2	0.1
TN,mg/L	5	0.9	1.7	0.7	0.7	0.4
TP,mg/L	0.5	0.4	0.1	0.1	0.1	0.1
FC,No/100mL	10	6.1	8.4	3.4	3.4	0.6
Turbidity,NTU	2	1.2	1.2	1.2	1.2	0.0
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.83	0.83	0.85	0.86	0.87
Varying flow rate		0.73	0.70	0.73	0.75	0.77
Varying influent quality		0.97	0.97	0.97	0.97	0.97
Ease of O & M		0.70	0.73	0.70	0.69	0.70
Ease of construction		0.70	0.67	0.70	0.69	0.73
Reliability		0.80	0.80	0.79	0.81	0.80
Odour		0.30	0.33	0.36	0.36	0.30
Ground water impact		0.70	0.70	0.73	0.75	0.70
Chemical requirement		0.70	0.70	0.64	0.67	0.77
Power requirement		0.50	0.50	0.52	0.53	0.47
Total land required, ha		2.91	2.90	2.92	2.93	15.37
Total sludge produced,kg/d		463	650	650	688	464
Total capital cost,**		$3,182	$3,427	$3,816	$3,978	$5,755
Total land cost,**		$279	$279	$279	$279	$404
PV O & M cost,**		$2,949	$3,070	$3,915	$4,000	$4,036
Total project cost,**		**$6,410**	**$6,775**	**$8,010**	**$8,257**	**$10,194**
Annualised project cost***		**$601**	**$635**	**$750**	**$774**	**$955**
Life cycle cost****		**$1.03**	**$1.09**	**$1.28**	**$1.32**	**$1.64**
Fitness score		**0.775**	**0.765**	**0.738**	**0.735**	**0.687**

NOTE:Sort Key= Max Fitness Score. Fitness score is scaled from 0 to 1, negative score indicates a infeasible option and a positive score indicates a feasible option.
* Number within the bracket indicate the generation number in which the option was generated, **1000s $, ***1000s $/yr,****$/m3,

Table J. 25 Summary of the MOSTWATAR Generated Upgrade Options for Case 2R2-DPM (A+)

Printed on26/03/2002

Community Name:Victor Harbor(Case2R2-DPM, Class A+).

Design Population:8000
Design Average Flow,m3/d:1600
Design Peak Flow,m3/d:4800

Summary of Evaluation of Upgrade Options generated by MOSTWATAR

Items	R.Criteria	Option:1(4)*	Option:2(12)*	Option:3(21)*	Option:4(10)*	Option:5(11)*
BOD,mg/L	20	2.3	1.5	0.5	1.5	0.1
SS,mg/L	-	3.3	1.1	1.3	1.1	0.1
TN,mg/L	5	1.9	3.7	4.4	1.5	2.1
TP,mg/L	0.5	0.4	0.2	0.4	0.2	0.0
FC,No/100mL	10	6.1	0.2	8.4	0.1	9.2
Turbidity,NTU	2	3.9	0.1	3.9	0.1	0.0
Meets criteria (Yes/No)		YES	YES	YES	YES	YES
Upgrade		0.85	0.81	0.89	0.83	0.83
Varying flow rate		0.70	0.67	0.67	0.70	0.77
Varying influent quality		0.93	0.93	0.85	0.93	0.97
Ease of O & M		0.70	0.70	0.74	0.67	0.77
Ease of construction		0.70	0.63	0.67	0.67	0.70
Reliability		0.74	0.78	0.70	0.77	0.83
Odour		0.33	0.33	0.41	0.37	0.30
Ground water impact		0.78	0.78	0.67	0.80	0.70
Chemical requirement		0.78	0.85	0.78	0.77	0.77
Power requirement		0.44	0.37	0.52	0.40	0.43
Total land required, ha		0.59	0.66	0.30	0.68	7.17
Total sludge produced,kg/d		463	467	646	467	1424
Total capital cost,**		$2,289	$2,741	$2,874	$3,130	$3,366
Total land cost,**		$256	$257	$253	$257	$322
PV O & M cost,**		$1,830	$1,575	$2,272	$2,421	$1,974
Total project cost,**		**$4,375**	**$4,573**	**$5,399**	**$5,807**	**$5,662**
Annualised project cost***		**$410**	**$428**	**$506**	**$544**	**$530**
Life cycle cost****		**$0.70**	**$0.73**	**$0.87**	**$0.93**	**$0.91**
Fitness score		**0.822**	**0.817**	**0.795**	**0.790**	**0.781**

NOTE:Sort Key= Max Fitness Score. Fitness score is scaled from 0 to 1, negative score indicates a infeasible option and a positive score indicates a feasible option.
* Number within the bracket indicate the generation number in which the option was generated, **1000s $, ***1000s $/yr,****$/m3.

Table J. 26 Details of the MOSTWATAR Generated Upgrade Option-1 for Case 2R2-DPM (A+)

Printed on 26/03/2002

Community Name:Victor Harbor(Case2R2-DPM, Class A+).

TT OPTION-1

Treatment Train: Bar Screen+Primary Clarifier w lime+TF,Rock Media, w Clarifier+Continuous Flow BNR+Break Point Chlorination+UV Disinfection+Anareobic Digestor+Sludge Drying Beds+Land Filling of Sludge

Desired Reuse: Irrigation of Golf Course with Unrestricted Access
Selected Guideline: SA Reclaimed Water Guidelines, April 1999

	BOD,mg/L	SS,mg/L	TN,mg/L	TP,mg/L	FC,No/100mL	Turbidity, NTU
Guideline Values:	20	-	5	0.5	10	-
Effluent Quality Achieved:	2.3	3.3	1.9	0.4	6.1	3.9

Meets Criteria (Yes/No): YES

Effectiveness Measures

Upgrade:	0.85
Varying flow rate:	0.70
Varying influent quality:	0.93
Ease of O & M:	0.70
Ease of construction:	0.70
Reliability:	0.74
Odour:	0.33
Ground water impact:	0.78
Chemical requirement:	0.78
Power requirement:	0.44

Note: Scaled from 0 to 1, a higher score indicates a better TT

Land Requirement and Sludge Produced

Total land required,ha :	0.59
Sludge produced,kg/day:	463

Table J. 26a Construction Cost Details of the MOSTWATAR Generated Option (Case 2R2-DPM, A+)

Printed on 26/03/2002

Community Name:Victor Harbor(Case2R2-DPM, Class A+).

Summary of Construction Cost Estimate for Upgrade Option-1

Item	**Construction Cost 1000s $**
Bar Screen*	--
Primary Clarifier w lime	*$350*
TF,Rock Media, w Clarifier*	--
Continuous Flow BNR	*$549*
Break Point Chlorination	*$219*
UV Disinfection	*$86*
Anareobic Digestor*	--
Sludge Drying Beds*	--
Land Filling of Sludge*	--
Miscellaneous Cost**	$237
Total UP Construction Cost	**$1,441**
Additional Cost***	$361
Total Construction Cost for WWTP	**$1,803**
Engineering and Contingency Cost	$487
Total Capital Cost	**$2,289**
Total Land Cost	$256
PV O & M Cost	**$1,830**
Total Project Cost	**$4,375**
Annualised Project Cost@*	**$410**
Life Cycle Cost@**	**$0.70**

*Indicates an existing unit process and the cost of these processes are not included in the Total project Cost
**Miscellaneous cost includes: Cost for minor modifications to existing plant
***Additional cost includes: Cost for site development + site works+ plant piping + controls and instrumentation + site electrical
@* $/yr,@** Life cycle cost is expressed as $/m3 of reclaimed water

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