The Use of Treated Effluent for Agricultural Irrigation in the Bottelary River Area: Effluent Quality, Farmers' Perception and Potential Extent

By

Li Rui

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Supervisor: Dr. Nebo Jovanovic

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DECLARATION

I, Li Rui, hereby declare that

"The *use of treated effluent for agricultural irrigation in the Bottelary River area: effluent quality, farmers' perception and potential extent*"

is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by means of complete references.

Full name: Li Rui   Date: May 2005

Signed:

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KEY WORDS

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Effluent;

Farmers' perception;

Irrigation;

Reuse;

SAPWAT;

Scottsdene;

Wastewater treatment works;

Water quality.

ABSTRACT

The Bottelary River area is located in a Mediterranean climate region, where the agricultural sector plays an important role. During the dry summer season, there is not enough precipitation to meet the agricultural irrigation requirements. Some farmers extract river water which is practically the final treated effluent from the Scottsdene Wastewater Treatment Works (WWTW) to irrigate crops. This research investigates the use of treated effluent for agricultural irrigation in this area, particularly focuses on the effluent quality, farmers' perception, and the potential extent.

The methods used in this research included the statistical analysis of the effluent quality and questionnaire analysis of the collected data. In addition, the research employed the SAPWAT model to calculate the irrigation requirements and the potential area that could be irrigated by treated effluent.

The research indicated that the effluent quality variables in general complied with the regulation of requirements for the purification of wastewater or effluent (known as 1984 general standard), which controlled the wastewater treatment works discharging final effluent to the watercourses. The only exception was faecal coliform concentration, which exceeded the general standard in certain periods. According to the South African water quality guideline on irrigation water use, the treated effluent should be used with caution, in order to minimize the potential risks, protect the public health, crops, soil and surface waters and groundwaters.

The research found that although the farmers' attitudes were various, their most important concerns were on the effluent quality. The farmers cared for the impact of this unconventional water sources to human beings' health, crops and soil. Thus, eliminating the concerns amongst the farmers and solving the problems met during the practice would contribute to the use of treated effluent in agricultural irrigation in this area.

The research indicated that during the normal dry summer season, treated effluent could act as an additional water resource to meet irrigation demand. During the normal wet winter season, the treated effluent was surplus compare to the irrigation requirements due to the ample precipitation. The treated effluent needs to be stored in dams to fulfill the summer peak demand.

In order to promote the use of treated effluent as an additional water resource in agricultural irrigation, improved technologies, comprehensive monitoring systems and an extended public participation need to be established.

ACRONYMS

CMA	Cape Metropolitan Area
COD	Chemical Oxygen Demand
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
ECe	Electrical conductivity of the saturated soil extract
ECw	Electrical conductivity of irrigation water
EPA	Environmental Protection Agency (US)
FAO	Food and Agricultural Organization of the United Nations
TSS	Total Suspended Solids
WHO	World Health Organization
WRC	Water Research Commission
WWTW	Wastewater Treatment Works

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1. Introduction

1.1 Introduction

Due to urbanization and population growth, the problem of water shortage is becoming more serious, especially in arid and semi-arid regions. In addition, the rapid increases in urbanization and population result in the generation of more wastewater. Wastewater contains a wide range of pathogens and sometimes heavy metals and organic compounds that are hazardous to human health and the environment. This degrades not only the surrounding area but also the water quality. In order to minimize these harmful effects, wastewater should only be discharged to watercourses after proper treatment.

It appears that there exists an increasing interest to use unconventional water sources to solve the water shortage problem (Boyden and Rababah, 1996; Al-Nakshabandi et al. 1997; Eriksson et al. 2002; Pollice et al. 2004). Wastewater reuse falls within this category. After proper treatment, wastewater can be used widely, such as in industrial processing, landscape and agricultural irrigation, groundwater recharge and even for the provision of potable water depending on the water quality (van Leeuwen, 1996; Oron et al. 1999; Hamoda et al. 2004). Wastewater reuse thus can meet part of the increasing demand for water.

Wastewater reuse in agricultural irrigation can provide nitrogen, phosphorus and other micronutrients to the crops. These nutrient elements in the treated effluent can increase crop yields, reduce the need for fertilizer and allow savings on fertilizer cost. Full use of the nutrients in wastewater is often the primary aim of using this water in the agricultural sector (Scott et al. 2000).

South Africa experiences water shortages due to the limited rainfall distribution that is uneven across the country. Irrigated agriculture in the Western Cape is the largest water user and it consumes about 55% of the total water supply (Western Cape Department of Agriculture Website www.elsenburg.com). Depending on the crops and the processing methods, water of a lower quality than fresh water can be used in agricultural irrigation

(Ninham Shand and Arcus Gibb, 2001). Thus, using treated effluent in irrigation is becoming more attractive and it is also a positive way to dispose of the treated wastewater effluent.

1.2 The Study Area

The total water supply within the Cape Metropolitan Area (CMA) is about 800Ml/d, and the water is used by different sectors. The biggest water user during the high demand season is irrigation (Ninham Shand and Arcus Gibb, 2001). There are twenty wastewater treatment works and three sea outfalls in the CMA. The total volume of wastewater treated by these works is 539Ml/day (State of the Environment Report, 2002). Only 9% of the treated wastewater is being reused (State of the Environment Report, 2002). This is mostly reused for summer irrigation (6%), and the remainder is used for industrial processing (0.6%-1.5%), and for aquifer recharge (1.7%-2.5%) (Ninham Shand and Arcus Gibb, 2001). If the treated effluent reuse can be extended to a wider area, portion of the fresh water supply will be freed for high value uses in domestic, commerce and industry.

In this research, the Bottelary River area was selected to conduct an investigation on effluent irrigation. The Bottelary River area is in many ways representative of the whole CMA. It is a relatively small catchment, where the main economic activity is agriculture. Agricultural irrigation offers the highest level of water consumption and provides the opportunity of disposing treated effluent on irrigated land (Khouri et al. 1994). The Scottsdene wastewater treatment works (WWTW) is located in this area. The relatively small Bottelary River catchment facilitated the collection of data on agriculture and treated effluent.

1.3 The Statement of Research Problem

Farming communities in water-scarce regions increasingly practice the use of treated effluent to augment the scarce potable or other water supplies. The use of treated effluent for agricultural irrigation provides an opportunity for the local farmers to sustain their livelihood especially during the dry summer season. The nitrogen and phosphorous contained in the treated effluent act as crop fertilizer and improve crop growth (Thomas et al. 1997; Hamoda, 2004). The use of treated effluent presents a potential risk to the users, as well as to the crops, soil, surface and groundwater. Thus the most important issue of using treated effluent for agricultural irrigation is the quality of the treated effluent. The suitability of treated effluent from the Scottsdene WWTW for agricultural irrigation, the potential risk to the above-mentioned factors needs to be investigated.

To get the information which can reflect the public attitudes towards effluent irrigation is important. In the study area, farmers are more sensitive than other communities in relation to effluent irrigation. The farmers' perception is an important factor that affects the adoption of effluent irrigation. Also, their individual concerns and expectations need to be considered when making the decision on whether to go for effluent irrigation or not.

Depending on the water quality and farmers' perception, the use of treated effluent for agricultural irrigation in the Bottelary River area could be extended. Therefore, research is required to assess the potential area that could be irrigated given the effluent volume.

1.4 The Objectives of Research

In order to investigate the potential use of treated effluent for agricultural purposes, the effluent quality is always the first issue that needs to be addressed. Comparing the water quality variables to regulatory guidelines gives a clear picture of the suitability of effluent for irrigation. This also determines the farmers' acceptance of the practice. The farmers' perception is the basic element for promoting the treated effluent in agricultural irrigation, to ensure the success of the practice. Should the effluent quality be suitable for irrigation and farmers' perception positive, there could be a possibility to extend the adoption of irrigation with treated effluent.

Due to the above-mentioned reasons, this research focuses on:

- assessing the quality of the effluent and its suitability for agricultural irrigation compared to the irrigation water quality guidelines.

- assessing the current use of treated effluent for agricultural irrigation in the Bottelary River area.

- investigating the farmers' perception of using treated effluent for agricultural irrigation.

- assessing the potential extent of using treated effluent in the Bottelary River area.

1.5 Chapter Outline

Chapter One – Introduction

Chapter one gives an overview of the research. The motivation and driving forces of the research, together with the research objectives are presented in chapter one.

Chapter Two – Literature review

Chapter two addresses the general concepts of wastewater and treated effluent at first. Then this chapter reviews the literature on, inter alia, crop tolerance to salinity, irrigation methods, guidelines on effluent irrigation, advantages and disadvantages of this practice based on international experiences on effluent irrigation.

Chapter Three – Research design and methodology

This chapter first describes the physical area being investigated in this research. The remainder of the chapter illustrates how the effluent quality, the farmers' perception and the potential extent were obtained and used to reach the aims of the research.

Chapter Four – Results: presentation and analysis

The analysis of the data obtained in this research is presented in chapter four. The research results provide a discussion on the water quality variables analysis, the analysis of the questionnaire completed by the farmers and the calculation of the potential areas that can be irrigated with treated effluent for typical crops grown in the Bottelary River catchment.

Chapter Five – Conclusion and recommendation

Chapter five provides conclusions and recommendations emanating from this research.

2. Literature Review

2.1 Introduction

Water is essential to human health, economic growth, and environmentally sustainable development. Urban population growth combined with rapid agricultural and industrial development has not only increased the total demand of fresh water, but also increased waste into the watercourses that may destroy the environment. This has made natural water scarcity problem even worse. It is because water resources have been exploited to their maximum capacity (Grobicki and Cohen, 1999; Bindra et al. 2003; Shomar et al. 2004), and more and more water will be needed to satisfy urban water demand in the coming decades (Beltran, 1999).

In order to conserve the limited water resources and protect the environment, wastewater reuse is becoming more attractive. It has become now an option to relieve the demand on fresh water and environmental pressure and it will play an important role in future water utilization patterns (Boyden and Rababah, 1996; Butler and MacCormick, 1996).

Wastewater reuse has several benefits. After proper treatment, wastewater can be used for different purposes, such as agricultural irrigation. It becomes a new source of water instead of traditional water sources to reduce the demand on fresh water supplies (Neal, 1996; Beltran, 1999; Al-Jayyousi, 2003). Nutrients such as nitrogen (N) and phosphorous (P) contained in wastewater and treated effluent, if used properly, can act as fertilizer for crop production (Magesan et al. 1998; Edraki et al. 2004).

In addition, the reuse of wastewater does not only protect the entire environment but also reduce the cost of discharging wastewater to the water body. In a situation where a high level treatment is required before discharging treated effluent into the watercourses for environmental protection purposes, using treated effluent on irrigated land reduces the volume of wastewater discharged directly into surface water and possibly limits the damage to the environment. Using treated effluent for agricultural irrigation can therefore be seen as a disposal option to save money on further tertiary treatment process (Khouri et al. 1994; Thomas et al. 1997; Bouwer, 2000).

2.2 Wastewater and Treated Effluent

2.2.1 Characteristics of wastewater

In this study, wastewater is liquid wastes collected from the sewage system and processed in wastewater treatment works. Wastewater consists 99% of water, whilst other components (pollutants and nutrients) only account for a small portion (WHO, 1989; FAO, 1992). Table 2.1 lists the main constituents in typical wastewater. In addition, there are some other water quality factors being used to evaluate wastewater, for example, the color, odor, turbidity, temperature and pH value. The amount and type of pollutants present in wastewater can be determined based on the factors mentioned above (FAO, 1992). After proper treatment, wastewater can be discharged into the watercourses. Otherwise, some of the constituents present in wastewater in large quantities can endanger public health and the environment.

Table 2.1 Major constituents of typical domestic wastewater (Adapted from FAO, 1992)

Constituent	Concentration (mg/l)		
	Strong	Medium	Weak
Total solids	1200	700	350
Dissolved solids	850	500	250
Suspended solids	350	200	100
Nitrogen (as N)	85	40	20
Phosphorus (as P)	20	10	6
Chloride	100	50	30
Alkalinity (as CaCO3)	200	100	50
Grease	150	100	50
BOD5 *	300	200	100

*: BOD_5 is the biochemical oxygen demand at 20°C over 5 days and is a measure of the biodegradable organic matter in the wastewater.

Wastewater is now widely considered as a growing, reliable, and extra water resource (van Oorschot and French, 1996; Abdel-Jawad et al. 1999; Bakir, 2001; Pollice et al. 2004). An increase in water usage results in the increased production of wastewater, Therefore, the production of wastewater is not only relatively constant during the year, but also mostly persistent between different years ("with a tendency to increase as time elapses") (Friedler, 2001, Morrison et al. 2001).

2.2.2 Wastewater treatment processes

Each receiving body of water has a limited capacity to absorb pollutants without declining the water quality. Wastewater treatment aims to remove as many as possible of the pollutants and disease-causing agents from the wastewater, to protect the environment and ensure public health. It also provides a suitable effluent for reuse (Hamoda, 2004).

The traditional treatment requirements for the raw wastewater are as follows: to remove the organic materials, to remove the suspended solids, to make the pathogens more stable and to remove the dissolved pollutants (van Leeuwen, 1996). Wastewater treatment is a multi-stage process. Haruvy (1997) and Lawrence et al. (2002) state three stages of the treatment process: primary treatment process can remove settleable solids and some adsorbed materials; secondary treatment removes more degradable organic material; further treatment, called tertiary treatment, is employed when specific wastewater constituents which cannot be removed by secondary treatment but must be removed to achieve a high quality of effluent. After these treatment processes, the final effluent can be discharged into the watercourses or being reused in the intended field.

The Scottsdene WWTW employs an activated sludge process to treat wastewater, which mainly comes from the domestic area (Cape Metropolitan Council, 1999). The raw wastewater flows into the works, through screens and grit removal channels. The wastewater mixed with biological organisms, namely the activated sludge, then goes to the aeration ponds. In the aeration ponds, mechanical aerators introduce air to the wastewater. Under gravitation, wastewater then flows into anoxic ponds, where some of the organisms utilize the oxygen bound in the nitrated molecule and release the nitrogen as nitrogen gas. The removal of the nitrogen ensures the optimum operation conditions for the organisms. The water is then diverted into sedimentation ponds. In these ponds, the activated sludge is settled. The relatively clean wastewater flows into the maturation ponds. Before being discharged to the receiving water body, the relatively clean wastewater is chlorinated in the chlorinated pond in order to kill harmful bacteria (van Driel, 2003). In order to maintain a certain sludge age for the optimal operation of the treatment works, some of the settled sludge is wasted and the rest recycled back to the aeration reactor. The wasted sludge is dried in sludge drying beds. The photographs in Appendix A illustrate the treatment processes used in the Scottsdene WWTW.

2.2.3 Treated effluent quality

The quality of treated effluent depends on the source of wastewater, the treatment processes in the wastewater treatment works and the potential end uses (Thomas et al. 1997; Morrison et al. 2001; Lawrence et al. 2002). In the case of effluent reuse, the effluent quality should achieve certain requirements, as the end users of the treated effluent may be different. From the agronomic, environmental and sanitary point of view, there are different water quality criteria to comply with (Friedler, 2001). It is important to match the level of effluent quality with the requirements of the final users (Lawrence et al. 2002).

The effluent quality is the key issue for irrigation and environmental security (van Leeuwen, 1996). "The water quality requirements for agricultural irrigation are not as rigorous as those for drinking water" (Lin et al. 2000). When using treated effluent for agricultural irrigation, the effluent quality should consider the health and agronomic aspects. The quality characteristics here include physical and chemical variables, bacteria, viruses (Lawrence et al. 2002).

2.3 Agricultural Irrigation with Treated Effluent

Sbeih (1996) states that at least sixty percent of the world water is used for agricultural purposes, especially in developing countries. "The quality of water required for each of the different sectors varies according to its intended use...demand for agriculture can be satisfied with lower quality water" (Papaiacovou, 2001).

Kapp (1979) demonstrated that treated effluent for agricultural irrigation is the widest usage of wastewater all over the world. Friedler (2001) points out that the treated effluent can be seen as an extra source of water available to the agricultural sector. Treated effluent being used in agricultural irrigation can not only recycle the water but also the nutrients (Boyden and Rababah, 1996; Morrison et al. 2001). Based on Table 2.1, 1 Ml of medium concentrated wastewater contains 40 kg of nitrogen and 10 kg of phosphorus. These nutrients are beneficial to crops. In studies carried out in Thailand and India, the crop yields increased greatly using treated effluent without other fertilizer compared to fresh water irrigation with inorganic fertilizer (Khouri et al. 1994). The practice helps many water-short areas to increase their agricultural productivity and profitability.

Considering the effluent irrigation, the effluent quality requirements depend on the crop to be irrigated, the soil conditions and irrigation methods adopted (FAO, 1992; Hussain and Al-Saati, 1999; Morrison et al. 2001). The effluent quality must comply with the guidelines of effluent irrigation in order to minimize the health risks to human beings, agricultural products and soils (Al-Nakshabandi et al. 1997; Morrison et al. 2001; Al-Lahham et al. 2003).

In order to deal with the land use, agriculture, irrigation, health and the environmental issues, agricultural irrigation with treated effluent also needs the cooperation between the government (the institutions and the organizations) and the public (Lawrence et al. 2002).

2.3.1 Salt tolerance of crops

Treated effluent contains various organic and inorganic constituents. Inorganic constituents, such as salts, may lead to the contamination and salinization of the soil. The common treatment process cannot decrease salinity level (Haruvy, 1997), so it is important to determine the suitability of treated effluent for irrigation according to the salt concentration (Shuval et al. 1986; Haruvy, 1997). If salts accumulate in the crop root zone to an extent that the crops are not able to extract sufficient water from the soil solution, yield losses will occur.

The crops have different response to salinity. Figure 2.1 illustrates the relationship between the relative crop yields (%) and the soil salinity (dS/m). The point at which the functions shift from 100% relative crop yields designates the threshold tolerance to salinity, viz, crops begin to experience yield-reducing effects. As the level of electrical conductivity in irrigation water (ECw) or saturated soil extract (ECe) exceeds the threshold, the crop yields will decrease linearly (See Figure 2.1). The more sensitive crops react first to salinity (Maas, 1986). Those crops that are more tolerant to saline water can still produce high yields under relatively high salinity conditions. In those areas where soil salinity cannot be maintained at acceptable levels, alternative crops can be selected to fit the soil condition and water quality. These crops will maintain economically feasible yields (FAO, 1992). Table 2.2 lists the salt tolerance parameters for some crops.

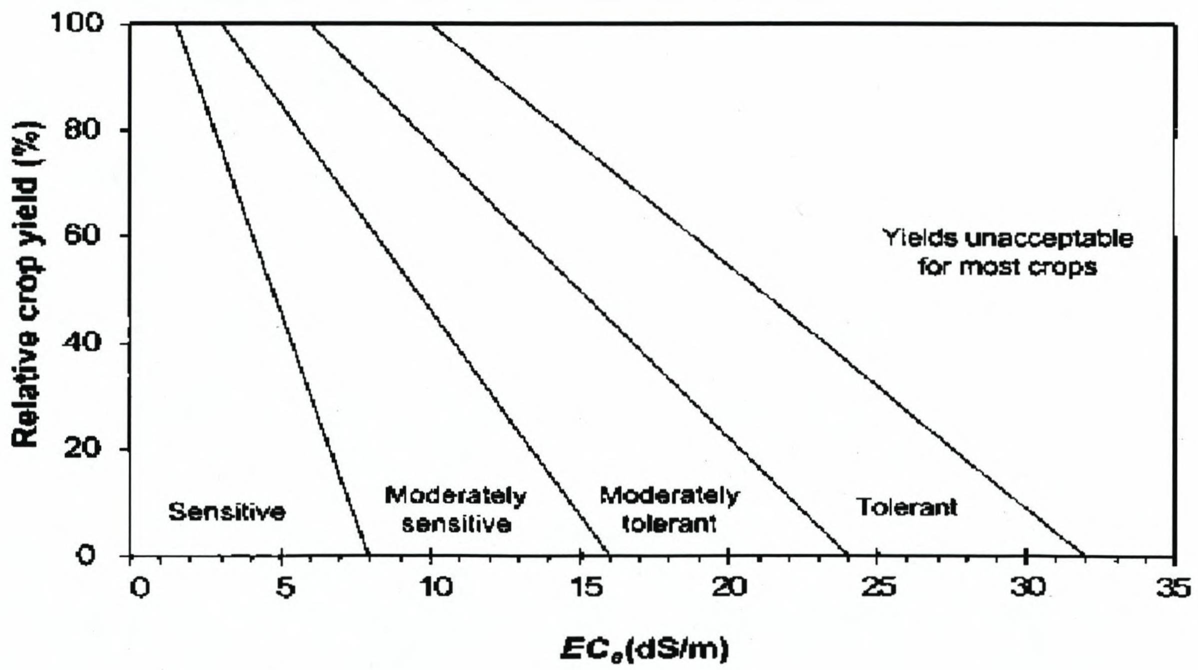

Figure 2.1: Classification of crop tolerance to salinity (Adapted from FAO, 2003)

Climate and irrigation frequency also influence crop response to salinity (Shuval et al.1986; Khouri et al. 1994). During dry, hot season, salts become concentrated in the soil solution, and they increase the salt stress. Therefore, salt problems are more severe than in cool, humid conditions. Increasing irrigation frequency and applying water exceeding crops demand (leaching) can minimize salinity stress.

Table 2.2: Salt tolerance of crops (adapted from "Salt Tolerance of Plants", Maas, 1986)

Crops names	Electrical conductivity of saturated soil extract		
	Threshold (dS/m)	Slope (% per dS/m)	Rating
Bean	1.0	19	S
Broccoli	2.8	9.2	MS
Cabbage	1.8	9.7	MS
Carrot	1.0	14	S
Cauliflower	-	-	MS
Celery	1.8	6.2	MS
Eggplant	-	-	MS
Lettuce	1.3	13	MS
Onion	1.2	16	S
Pepper	1.5	14	MS
Potato	1.7	12	MS
Pumpkin	-	-	MS
Radish	1.2	13	MS
Spinach	2.0	7.6	MS
Tomato	2.5	9.9	MS
Turnip	0.9	9.0	MS

S = sensitive   MS = moderately sensitive

2.3.2 Toxicity risks

Another consideration related to effluent irrigation is the toxicity impacts on the crops. "Toxicity normally results when certain ions are taken up by crops with the soil water and accumulate in the leaves to such an extent that the crop is damaged" (FAO, 1992). Chloride, boron and sodium are the usual toxic ions existing in irrigation water, and they may be contained in the wastewater and treated effluent (FAO, 1985, 1992). Chloride cannot be adsorbed in the soil, thus it will be easily taken up by crops and accumulate in the leaves. Excessive concentration of chloride in the crops can lead to leaf burn or dying of leaf tissue at the leaf tip (FAO, 1985). Relatively high concentration of sodium in the treated effluent will result in sodium toxicity. The major symptom of sodium toxicity is leaf burn, scorch and dead tissue around the outside edges of leaves (FAO, 1985). Boron is a basic element for crop growth. If boron concentration in irrigation water reaches a high level, harmful impact to the crops will occur (FAO, 1985; Maas, 1986; Khouri et al. 1994). Boron toxicity can affect all crops, it shows as a yellowing, spotting, or drying of leaf tissue at the tips and edges (FAO, 1985).

In addition to chloride, sodium, and boron, many trace elements are toxic to crops at low concentrations. Generally, most of the chemical components in municipal treated effluent are below the toxic level to human health (Khouri et al. 1994). Industrial wastewater discharging to the watercourse adds heavy metal and other organic pollutants. The heavy metals and the pollutants bear potential risks to the health of human beings (Khouri et al. 1994). Fortunately, most irrigation supplies and sewage effluents contain very low concentrations of these trace elements, they are generally not a problem (FAO, 1992). FAO recommended maximum concentration of various trace elements in irrigation water.

Excessive nutrients in treated effluent can also be damaging to the crops and the environment (Khouri et al. 1994; Magesan et al. 1998). For example, nitrogen will be required variously depending on different growth season. If treated effluent has high concentration of nitrogen applied to the crops and the level exceeds the nitrogen requirement, crops will be affected. If the total nitrogen concentration exceeds 5 mg/l in irrigation water, fruit crops are likely to be affected. Most other crops are affected when the concentration exceeds 30 mg/l (DWAF, Vol. 4, 1986). Excessive leaf growth will result in crops lodging and decrease in harvestable yield. Groundwater will be polluted by "percolating nitrogen in the form of nitrates" (Khouri et al. 1994).

2.3.3 Soil resources

The impact of effluent irrigation on soil is due to the presence of nutrients (nitrogen and phosphorus), high total dissolved solids and sometimes heavy metals, which can be added to the soil through irrigation and accumulation over time.

Wastewater contains salts that may pile up in the crop root zone. The use of saline treated effluent for a prolonged period on agricultural land may result in contamination of the soil. If the salt concentration reaches a certain level, which is high enough to have negative impact on soil physico-chemical properties and crop yields, soil degradation and crop yield losses will occur. Soil contamination due to irrigation with saline water manifests mainly through salinization and deterioration of soil structure in the presence of high sodium concentrations. In order to ensure sustainable production and limit damage to the soil, leaching of salts is essential. Climatic conditions, in particular rainfall amounts and distribution, need therefore to be considered. Wetter climatic conditions will ensure more salt leaching compared to drier climates. However, the leaching of these salts below the root zone may cause soil and groundwater pollution (Hussain et al. 2002).

Using treated effluent for agricultural irrigation will convey heavy metals and trace elements to the soil. This can lead to crop damage and affect soil flora and fauna (Hussain et al. 2002). Accumulation of toxic elements in crops may occur to such an extent that it may cause poisoning of grazing cattle and impact on human health. Some of the heavy metals accumulate in the soil while others may be reallocated by soil fauna. However the intended users' concern of heavy metal and trace elements impacting the practice of effluent irrigation is limited. Separation and water treatment techniques can be applied to reduce the concentrations of heavy metals and trace elements. In addition, in common treatment processes, most heavy metals and trace elements are separated into the sludge, as by-product of the water treatment process (Hussain et al. 2002).

The impact of effluent irrigation on soil also depends on the soil properties, viz, inter alia, the soil texture, permeability, pH, and chemical composition, which are important to decide the suitability of the area for effluent irrigation (FAO, 1992).

2.3.4 Irrigation methods

According to FAO (1992) and Environmental Protection Agency (EPA) (2004), the following factors are the main determinants of selecting irrigation methods for effluent irrigation:

1. Crops growing in effluent irrigated area,
2. The potential risks to farm workers and the environment,
3. Irrigation methods efficiency.

Flood irrigation with treated effluent will affect crops, but it also gives the opportunity of leaching more salts out of the soil profile. Furrow irrigation does not wet the entire soil area, and any damage due to irrigation with low quality water can be limited by growing crops on furrow ridges (FAO, 1992). However, these surface irrigation methods cause potential risks to the farm workers due to the exposure to treated effluent. Both flood and furrow irrigation methods will cause great water loss through seepage and evaporation. Neither are suitable for practicing effluent irrigation in water scarcity areas due to the high losses and low efficiency of the systems. If the treated effluent contains high quantities of suspended solids, these may settle out and restrict the flow in irrigation channels (FAO, 1985, 1992).

Sprinkler irrigation with treated effluent will create potential risks to the crops and farm workers due to the over-head irrigation method. The suspended solids and other compounds existing in the effluent may result in crop leaf burn, damage of the crops and the clogging of the sprinkler heads. If the effluent contains pathogens, sprinkler irrigation will transport them to the crops and residents to cause potential hazards. The sprinkler irrigation is relatively more efficient compared to surface irrigation methods in terms of water use since "greater uniformity of application can be achieved" (FAO, 1992).

Trickle irrigation with treated effluent can optimize water and nutrient use efficiency, therefore crop growth and yield can potentially achieve high level. This method has minimal potential health risks to human beings. Trickle irrigation has high level irrigation efficiency, due to "no canopy interception, wind drift or conveyance losses and minimal drainage losses" (FAO, 1992).

Drip irrigation is considered as a suitable method compared to the other methods for effluent irrigation in terms of water use efficiency. The volume of soil wetted by drip irrigation is localized and smaller than for others systems (Al-Nakshabandi et al. 1997). Drip irrigation can reduce risks to human health and crops (Thomas et al. 1997; Jagals and Steyn, 2002). However, this expensive irrigation system requires high quality of treated effluent to prevent the clogging of the irrigation equipment (FAO, 1992).

2.3.5 Guideline on effluent irrigation

There is no unified water quality standard for treated effluent irrigation (Lin et al. 2000). The microbiological pollutants levels recommended by the World Health Organization (WHO) have been widely adopted all over the world to evaluate the treated effluent for irrigation. The physical and chemical pollutants levels should comply with the local general water quality standards (Lin et al. 2000).

The main purpose of the effluent irrigation related guidelines is to protect the public health (Khouri et al. 1994). To achieve this goal, different countries adopt different ways to develop guidelines. Most of the developed countries set the guidelines based on a high technology, high-cost approaches, while developing countries use low technology, low-cost approaches to protect the public health (Jagals and Steyn, 2002).

With regard to the health aspect, the reuse criteria refer to microbiological content, mostly the faecal coliform concentration level in the treated effluent, to evaluate the suitability of treated effluent for agricultural irrigation (Oron et al. 1999). The concepts outlined in the guidelines balance the public health hazards and the beneficial use of unconventional resources. The guidelines are also intending to encourage people to use best management practices in the processes of implementing effluent reuse, but not to restrict this practice.

WHO health guidelines for the use of wastewater in agriculture and aquaculture (1989), were adopted by most countries as a standard for effluent reuse. They were based on the epidemiological study, emphasis being put on the potential risks to the human health. These guidelines specified the microbiological quality standard of intestinal nematodes and faecal coliform and the treatment level to fulfil the microbiological requirement. However, there was limited data related to the impact of effluent irrigation to the public (Gregory et al. 1996; Tsagarakis et al. 2004). The WHO health guidelines could easily be achieved by simple and inexpensive treatment method.

The current South African guidelines on permissible utilization and disposal of treated sewage effluent were issued by the Department of National Health and Population Development in 1978. SA guidelines focus more on the classification of wastewater treatment methods, along with the treated effluent irrigation regulations. These guidelines use microbiological indicators to evaluate the effluent quality, rather than the avoidance of health risks caused by chemical pollutants. The faecal coliform level in the guidelines is more stringent than the one in the WHO guidelines. They restrict the use of treated effluent for agricultural irrigation on a large scale (Jagals and Steyn, 2002; Pollice et al. 2004).

2.4 Major Concerns on Effluent Irrigation

Although the use of treated effluent for agricultural irrigation is practiced all over the world, concerns on health hazards, environment, economic feasibility and social-cultural aspects should also be considered (Butler and MacCormick, 1996; Dillon, 2000; Al-Lahham et al. 2003). In addition, education, information and training of farmers also play an important role in promoting the reuse of treated effluent (Shomar et al. 2004). The most important constraint to the use of treated effluent is the concern of health risks to human beings (Khouri et al. 1994), which rises from the concern of the technical capacity of removing the pathogens, organics materials and trace elements from the wastewater (Butler and MacCormick, 1996; Hamoda et al. 2004). In order to guarantee the public health, treated effluent quality standard must be established and adhered to, especially the level of faecal coliform (Ho, 1996).

The environmental concern relevant to effluent irrigation is the contamination of surface water as well as groundwater. The treated effluent carries nitrogen and chemical pollutants. The excessive nitrogen that cannot be utilized by crops will contribute to the loading in freshwater, cause eutrophication of the freshwater source (Mason, 1996). Nitrogen and other pollutants accumulate in the soil to a high concentration over time and will negatively affect the water table via seepage (International Water Management Institute, 2003).

Effluent irrigation will not be economically attractive in areas where sufficient rainfall can meet agricultural irrigation demand. To evaluate the economic suitability of effluent irrigation, the total cost, total benefits and the risks to the environment need to be analyzed to achieve the maximum net benefits (Khouri et al. 1994; Oron et al. 1999). The existing practices undertaken in some arid and semi-arid countries indicate that the cost of reuse is similar to the total cost of fresh water supply and effluent discharge (Butler and MacCormick, 1996).

Public acceptance of the use of treated effluent in agriculture is a crucial factor to ensure the success of effluent irrigation. The fresh water availability, religious and cultural beliefs, and previous experience with the reuse of treated effluent influence the degree of public acceptance of effluent irrigation (Anderson, 1996). The public now is more aware of the priority of wastewater reuse to save water resources and to protect the environment, despite sometimes the wastewater reuse encounters the rejection from some communities (Pollice et al. 2004).

2.5 International Experiences of Effluent Irrigation

Most of the arid and semi-arid countries adopted treated effluent reuse schemes.

Amongst the different sectors, agriculture reuse of treated effluent for irrigation is the most popular practice. The agricultural sector is the largest water user, and effluent irrigation can not only provide sufficient water but also supply nutrients to increase the production. International case studies on effluent irrigation are discussed below.

The serious shortage of fresh water makes Israel practice treated effluent reuse nationwide. Presently, Israel is using nearly 70% of treated effluent in agricultural irrigation (Friedler, 2001). The water reused represents 20% of the total water supply for irrigation (Scott et al. 2000; EPA, 2004). The use of treated effluent for irrigation in Israel firstly reduces the demand pressure on fresh water. Secondly, it prevents the municipal wastewater from entering the watercourse and polluting the environment (Friedler, 2001). The economic benefit towards effluent irrigation is that the agricultural development is boosted by using this reliable, constant source of water (Friedler, 2001).

In Jordan, there are limited renewable water resources. Exploring unconventional water resources to meet the increasing demand of water is important (EPA, 2004). An experimental study carried out in Jordan has determined some environmental problems related to the treated effluent for eggplant irrigation. The physical and chemical analysis showed there was a low heavy metal content in the treated effluent, and the nitrogen concentration was high. Restriction on using treated effluent to irrigated crops and soil needed to be considered. The soil surface was found to contain faecal coliform, but the count decreased with the soil depth. A trend of increased salinity was found with distance from the emission point. Nutrient and heavy metal concentration in eggplant tissue was within the normal range. Eggplant yield was increased due to the available nutrients contained in the treated effluent. Although there was a clogging of the irrigation equipment, this would be controlled with acid and chloride (Al-Nakshabandi et al. 1997).

Saudi Arabia is an arid country. With rural and urban expansion, the bulk of wastewater has become available for reuse in different sectors. Experiments conducted in Saudi Arabia demonstrated that using treated effluent as a supplemental irrigation not only increased crop production, but also served as a crop nutrient to save fertilizer (Hussain and Al-Saati, 1999). Some problems were experienced when effluent water was used for irrigation. For example, irrigation with treated effluent containing high concentrations of salts may cause soil salinity. Blending with normal irrigation water to dilute the highly saline treated effluent can decrease the negative impact to the soil. Lack of information and proper education of the farmers resulted in over- or under-irrigation of crops, leading to soil property degradation (Hussain and Al-Saati, 1999).

2.6 Advantages and Disadvantages of Effluent Irrigation

Benefits of agricultural reuse of treated effluent appear when agricultural production is maintained while water resources and environmental quality are preserved (Haruvy, 1997). The benefits of treated effluent reuse can be mainly categorized into two aspects, viz, the environmental and economic benefits. Some of the advantages of the reuse of effluent for agriculture were found in the literature:

1. Preserve scarce fresh water resources (Haruvy, 1997; Friedler, 2001);
2. Maintain the environment quality (Haruvy, 1997; Papaiacovou, 2001);
3. Reduce the purification level and fertilization costs, because soil and crops serve as biofilters and wastewater contains nutrients (Haruvy, 1997; Papaiacovou, 2001);
4. Reuse of treated effluent on irrigated land sorts out the water scarcity problem as well as the problem of sewage disposal (Oron et al. 1999).

However, there are some disadvantages related to effluent irrigation to human beings, the crops and soil. The presence of pathogens in treated effluent can endanger the human health (Al-Nakshabandi et al. 1997; Tsagarakis et al. 2004). The salinity and toxicity problem may harm the crops and the soil, if appropriate management systems are not put in place. In addition, poor management will impact surface and groundwater as well as downstream users (Haruvy, 1997).

3. Research Design and Methodology

This chapter describes the methods used to collect and analyze the data for the research, including the effluent quality data from the Scottsdene WWTW, during the period from January 2001 to December 2004. The compilation and distribution of the questionnaire on current users of effluent and farmers' perception of effluent irrigation in the Bottelary River area is discussed. The SAPWAT model was used to calculate the irrigation water requirements. The irrigation requirements, along with the volume of available treated effluent, were used to estimate the potential area which can be irrigated with treated effluent.

3.1 Overview of the Kuils River Catchment

The study area is located in the Bottelary River catchment. Literature data specifically available on this area are limited. This area is a sub-catchment of the Kuils River catchment, so it was worth first having a clear understanding of the Kuils River catchment.

Location:

The Kuils River originates in the Durbanville Hills and flows southerly to meet the Eerste River at the False Bay estuary (Ninham Shand, 1994). The Kuils River catchment area is 270 km^2 (van Driel, 2003), including the urban area of Durbanville, Brackenfell, Kraaifontein, Bellville and Kuilsriver. The Kuils River itself used to be a seasonal river with continuous winter flow and no summer flow. But now the Kuils River has a perennial flow. It receives treated effluent from the wastewater treatment works at Scottsdene, Bellville, Zandvleit and Macassar (Ninham Shand, 1993).

Geology:

According to Ninham Shand (1979, 1994), the upper streams of the Kuils River and Bottelary River are located on the Malmesbury group, which includes the quartzites, phyllite, greywacke and shales of Pre-cambrian age. The rocks are thinly covered by recently deposited turf and loam. In the downstream of the confluence of these two rivers, loose sand and dune formations covering clay lenses characterize the geological features. Gravel, sandstone, conglomerates and silcrete can also be seen in this area (Ninham Shand, 1979, 1994; Petersen, 2002). These geological features result in a high surface runoff in the upper stream of these rivers and small subsurface flow. The sandy area downstream of the confluence results in little surface runoff (Ninham Shand, 1994).

Climate:

The Kuils River catchment is located in a Mediterranean climate region with hot dry summers and cool wet winters. The mean annual precipitation is approximately 600mm/annum, with 80% of rain falling in the winter season between March and September. The rainfall distribution is uneven. The annual rainfall varies from 500 mm in Cape Flats to 800 mm in the eastern hills (Tygerberg Hills) (City of Cape Town Website www.capetown.gov.za; Fisher, 2003). The climate pattern impacts the river flow. Generally, the Kuils River has high peak winter flows and low summer flows (Cape Metropolitan Council, 1999).

Water use:

Agricultural use of water is divided into livestock and irrigation (Ninham Shand, 1993). Along the Kuils River catchment, water is mainly used by the agricultural sector for the irrigation of the vine and citrus farm (Ninham Shand, 1993). There are also some industrial water users in the upper stream of the Kuils River (Fisher, 2003). In recent years, urbanization in this catchment has increased the water demand. Simultaneously, it has contributed to large quantities of wastewater and decreased the water quality (Ninham Shand, 1993).

Land use:

Due to the soil type, rainfall, climate and water availability and quality, the Kuils River catchment is suitable for vine farming and fruit trees growing. However, the increasing urbanization has already reduced the agricultural land area in the northern suburbs, for example in Durbanville, Bellville and Kraaifontein Municipality area (Ninham Shand, 1993; Fisher, 2003).

3.2 Bottelary River Area

Due to the time limitation of the research, it would have been difficult to do a comprehensive study on the Kuils River catchment, including several municipality jurisdictions, four WWTW and a variety of activities and land uses. The research then had to focus on a small area representative in many ways of the whole Kuils River catchment, in order to investigate the reuse of treated effluent for agricultural irrigation.

The following criteria were used to select the study area:

- Agriculture plays a dominant role in the area, the farming community is the interested and affected party in the practice of effluent irrigation.
- Wastewater treatment works are located in this area.
- Treated effluent is currently used in this area.

With regard to these aspects, a relatively small catchment area, namely the Bottelary River catchment, was selected for this study.

The Bottelary River is a tributary of the Kuils River. It is 14 km in length and the catchment covers an area of about 80 km^2 (van Driel, 2003). Agriculture, predominately vineyard and vegetable farming, are the major activities in this area (van Driel, 2003). High natural water flows are generally recorded in winter due to the ample precipitation that can generally satisfy the needs of irrigation. But in the summer season, there is not enough rainfall to meet agricultural water requirements. Due to the limited water resources in the area, it is important to have another water source for irrigation.

The Scottsdene WWTW is located in the Bottelary River catchment. The designed capacity of the Scottsdene WWTW is 7.5 Ml/day. The actual average treated capacity of the works is 7.0 Ml/day (Bvi Consulting Engineers, 2003). In summer, the effluent forms the entire water flow of the Bottelary River (van Driel, 2003). The treated effluent is therefore becoming an extra water resource for agricultural irrigation. Therefore, the conditions for the reuse of treated effluent needed to be investigated.

Figure 3.1 gives the catchment map of the Bottelary River area. It illustrates the location of the Scottsdene WWTW, the Bottelary River and its tributaries, and the conjunction of Kuils River and Bottelary River.

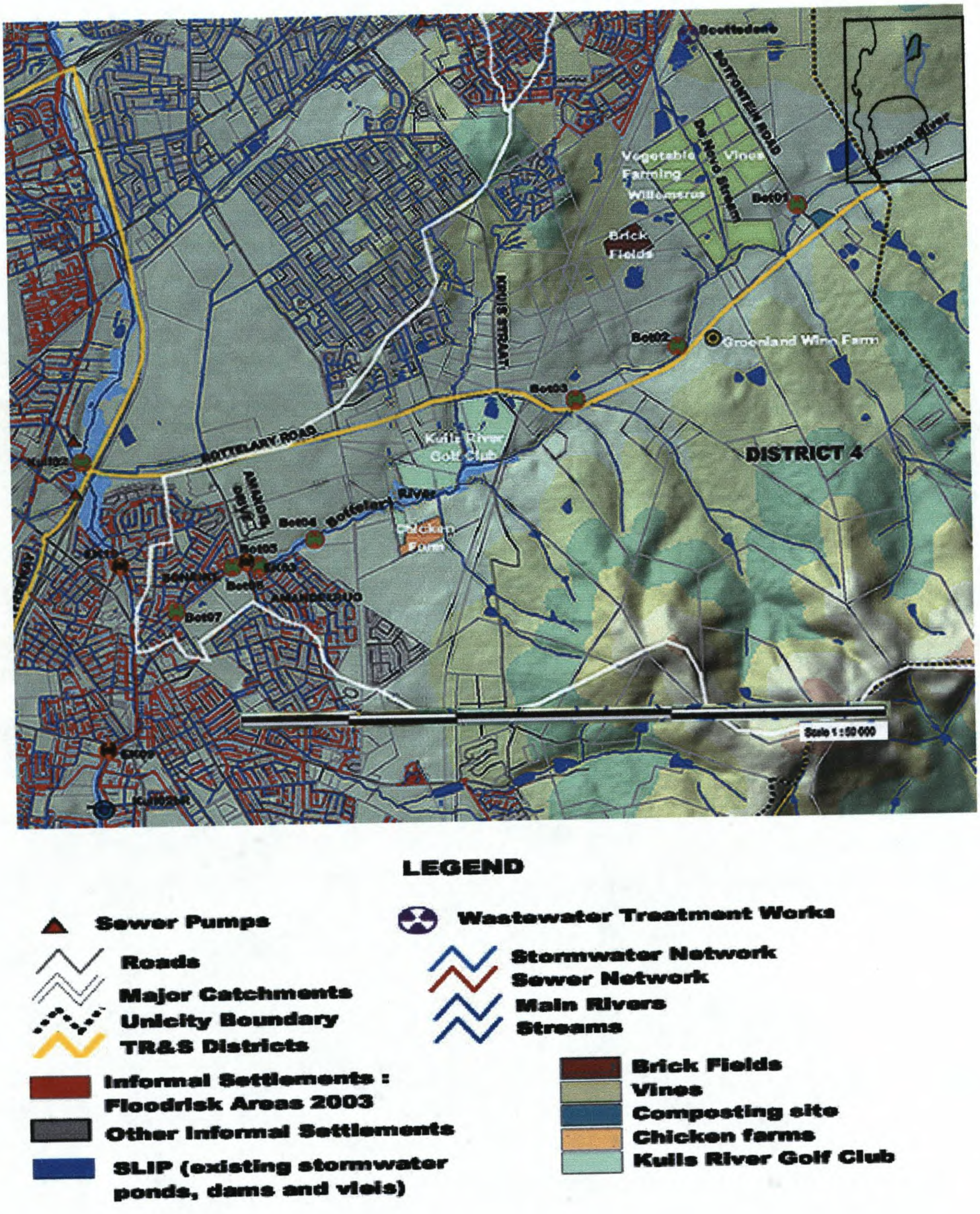

Figure 3.1 Study area (Source: City of Cape Town)

3.3 Research Design

The research aims at evaluating the quality of the treated effluent, investigating the current effluent water use, the farmers' perception, and estimating the potential extent of using treated effluent for agricultural irrigation in the Bottelary River area.

The water quality of the Scottsdene WWTW final treated effluent was the first consideration of this research. The effluent quality reflects the treatment efficiency of the wastewater treatment works. In this study, the effluent quality was used to determine the suitability of the treated effluent being used for irrigation purposes. The effluent quality variables will be described in details to reflect the possible impacts on agricultural irrigation.

The research used questionnaires to obtain current use and the farmers' perception of effluent irrigation. The farmers are general public and workers which are affected more than others through the crop growing, harvesting and even consuming processes. The questions were systematically grouped into different categories to facilitate the analyses of the responses to the questionnaires.

The potential extent of effluent irrigation was calculated based on the hypothesis that the effluent quality is suitable and the farmers' perception is positive. Under these conditions, the use of treated effluent for irrigation could be extended to a broad area. The potential area was calculated using data of effluent flow and irrigation requirements estimated with the SAPWAT computer model. Dividing the total seasonal irrigation requirements for certain crops with the total effluent volumes in this period, the potential irrigation area was calculated.

3.4 Data Collection and Analysis Methods

3.4.1 Data collection

The effluent quality data were obtained from the Scientific Services Department in the City of Cape Town, where effluent quality of the Scottsdene WWTW was monitored weekly. The Government Gazette (Regulation No. 991: Requirements for the purification of wastewater or effluent issued on 18 May 1984) was used to evaluate the effluent quality. This legislation has special and general standards for wastewater or effluent arising in the catchment area within which water is drained to any rivers specified. According to this division, the effluent quality of the Scottsdene WWTW is governed by general standards (in the following text, this regulation is stated as 1984 general standard). New proposed 2005 and 2010 standards need to be finalized to meet the new environmental protection requirements.

The South African water quality guidelines for agricultural irrigation use (stated as SA water quality guidelines in the following text) were used to evaluate the treated effluent quality for irrigation. Effluent quality variables were compared to the SA water quality guidelines in order to assess the possible impact on the crops and soil (SA water quality guidelines, Vol. 4, 1996).

In terms of the health guidelines related to effluent irrigation, the South African guide: permissible utilization and disposal of treated sewage effluent (1978) (stated as SA effluent reuse guide in the following text) was used to assess the potential risks posed to the farm workers and consumers, based on the microbiological concentration level.

The farmers' perception of effluent irrigation was collected through a personally administered questionnaire. This questionnaire elicited information relevant to the research (see Appendix C). A list of nine farms was compiled based on the cadastral map provided by the Oostenberg Municipality (Appendix D) and the location of the Scottsdene WWTW. The questionnaire was first distributed to these nine farms, most of whom are vineyard farms. In a second round, the questionnaire was distributed to seven additional vegetable farms in the same area, following the recommendation of Prof Raitt (Personal communication: Prof L Raitt, Department of Biodiversity and Conservation Biology, University of the Western Cape, Feb. 2005).

3.4.2 Data analysis

Effluent quality

Analysis of the effluent quality was performed on the Scottsdene WWTW weekly final effluent quality data recorded from January 2001 to December 2004. The water quality variables obtained here were total suspended solids (TSS), chemical oxygen demand (COD), ammonia nitrogen (NH3), nitrate nitrogen (NO3), ortho-phosphorous (Ortho-PO4), faecal coliform as well as flow rate. More than 200 values were collected for each variable. Each variable was evaluated by seasonal trend and its average, standard deviation and minimum and maximum peaks. Seasonal trend was calculated by averaging each sequential three-month data, while the average and standard deviation of the whole study period was considered. Correlation graphs were drawn and regression equations were determined between the water quality variables.

Due to the lack of weekly data of electrical conductivity (EC) and pH for the study period, the average annual data of these two variables were used in the evaluation (average from July 2002 to June 2003 and from July 2003 to June 2004). The maximum and minimum values of EC and pH during this period were also available.

Questionnaire data analysis

The questionnaire included 26 questions. To analyse the questionnaire data, the information was split into four categories:

<u>Social-economic factors:</u>

- What are respondents' gender, age and education level?
- How big is the farm size?

<u>Production factors:</u>

- What irrigation methods do the respondents use?
- What crops do they grow in summer and winter season?
- What kind of fertilizer do they use?
- Where do they get irrigation water?

<u>Behavior factors:</u>

- Do the respondents suffer from water shortage in this area?

- Are they willing to increase the irrigation area with different irrigation source water?
- How many of them are using/not using treated effluent?
- What do they think about the treated effluent?

Perception of effluent irrigation:

- What are reasons for applying/not applying effluent irrigation?
- In what conditions do the respondents prefer effluent irrigation?
- What are the concerns on practicing effluent irrigation?
- Where do they obtain the information on effluent irrigation?
- What are the advantages and disadvantages on effluent irrigation?

The first two categories gave the study area a broad description; the last two categories would capture the respondents' perception, in order to reach the goal of the research. The data collected through the questionnaire were analyzed by firstly checking the answers for each question and recording the common conceptions from the questionnaires. The perceptions, feelings and viewpoints of the respondents were captured. Frequency distribution was used for the important variables. Then by applying quantitative research methodology, with thematic interpretation, the differences between individual respondents were identified.

The use of SAPWAT model

SAPWAT is a computer-based model that was developed to estimate the crop irrigation requirements in a selected area, to make irrigation plans, and to manage water resources. Estimation of the irrigation water was essential to make a plan for irrigation schemes and water management, to upgrade the farming properties and for irrigation projects (Crosby, 1996). The SAPWAT model is based on South African climate and crops databases. This research used SAPWAT version 2.6.0 (developmental) to calculate the crop water requirements.

In this study, climate data were selected from the SAPWAT database (Klein Bottelary weather station). Crop type, geographical region and planting date can be selected in the program. After selecting crop canopy cover at full growth, frequency of wetting and wetting area, the monthly crop factors for a specific crop were calculated. The water requirements value was calculated by the SAPWAT model and it could be seen on the computer screen along with the crop evapotranspiration, rainfall and effective rainfall (see Figure 3.2 and Figure 3.3, set the example of potato). The monthly water requirements were calculated as the difference between crop evapotranspiration and effective rainfall, and taking into account the irrigation efficiency. In order to compare the irrigation requirements in years with different rainfall, favourable season, normal season and severe season can be selected in SAPWAT. The program then used the climatic database to calculate monthly rainfall in normal, favourable and severe seasons. Normal season represents the median rainfall, favourable season represents the top 20% rainfall occurrence, and severe season is the bottom 20% rainfall occurrence of all rainfall data stored in the database (Crosby et al. 2000; Crosby, www.sapwat.org.za).

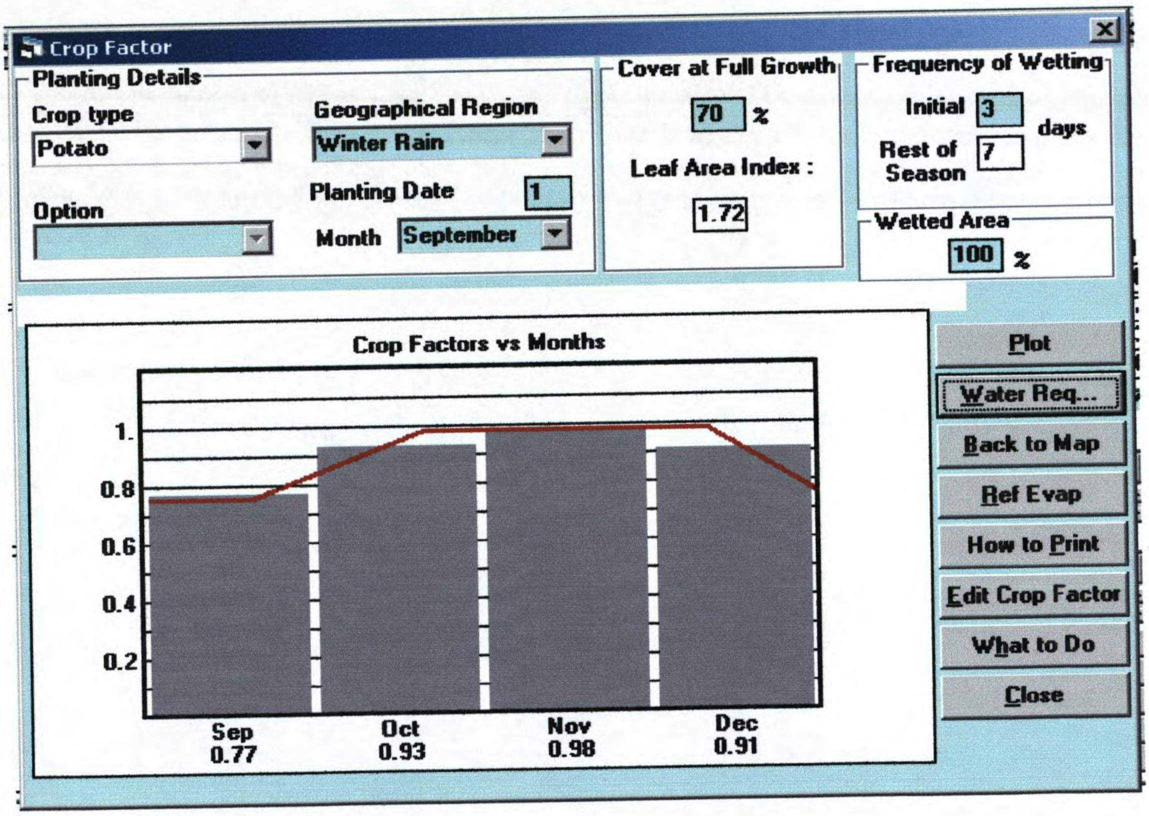

Figure 3.2 Crop factors of potato (printout screen of the SAPWAT model)

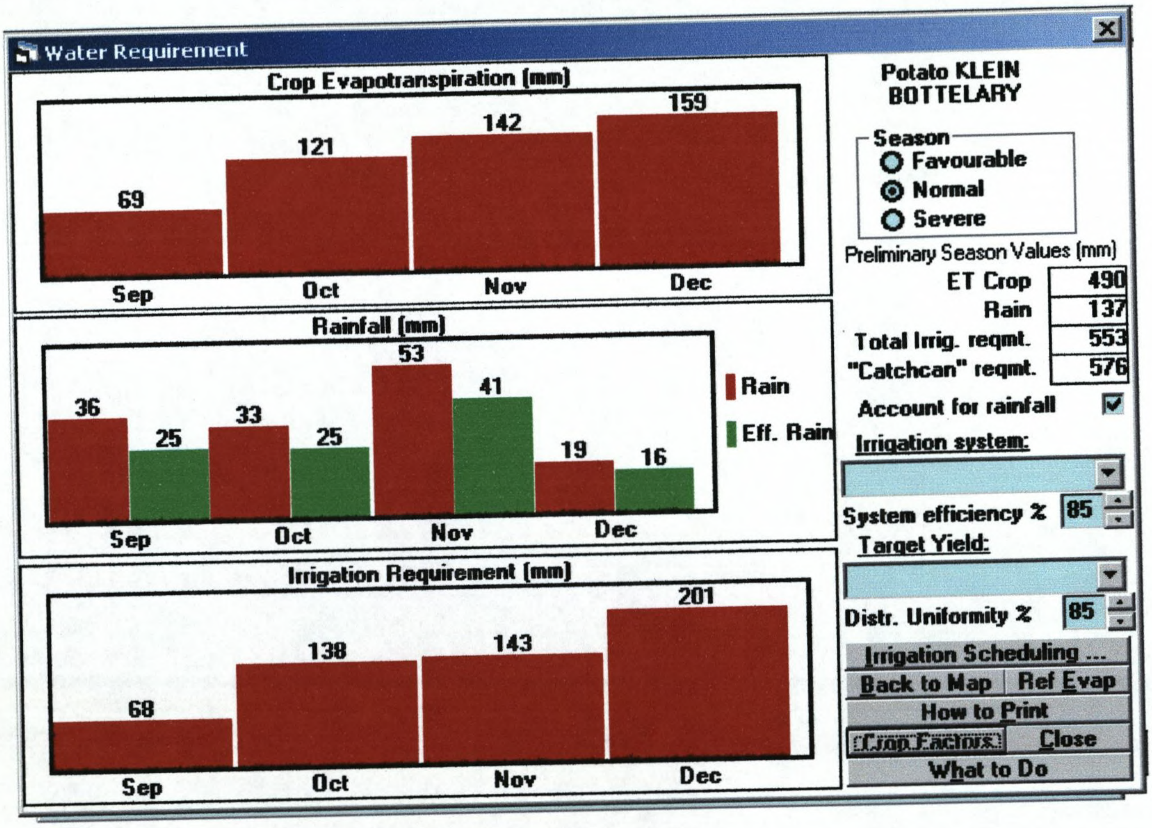

Figure 3.3 Water requirements for potato (printout screen of the SAPWAT model)

4. Results: Presentation and Analysis

This chapter presents the analysis of the treated effluent quality data which is obtained from the Scottsdene WWTW, and the data collected from the questionnaire survey. Further, the potential irrigation area is estimated based on the crop information data collected through the questionnaire, the effluent flow data and the calculation of crop water requirements using the SAPWAT model.

4.1 Effluent Quality Data Analysis

The main characteristics of the treated effluent from the Scottsdene WWTW are presented. The fitness of using treated effluent for agricultural irrigation is evaluated through the comparison of the data with the 1984 general standard and SA water quality guidelines and SA effluent reuse guide.

4.1.1 Analysis of the effluent quality variables

Table 4.1 summarizes the average, standard deviation, maximum and minimum values of effluent quality variables during the study period, as well as the 1984 general standard, proposed 2005 and 2010 general standard for each variable. The standard deviations of effluent flow, COD, NH_3, Ortho-PO_4 and faecal coliform are relatively high. The high standard deviations indicate that values fluctuated widely. TSS and NO_3 have relatively low standard deviations, which implies that these two variables were more stable than others during the sampling period.

Total suspended solids (TSS)

As shown in Table 4.1, the average value of TSS is 13.4 mg/l, the maximum value is 190 mg/l which appeared on 15 October 2003, and the minimum value is 1 mg/l. Comparing to the 1984 general standard, the average and minimum values are below the standard level. 193 out of 208 tests (93%) comply with the legislation. In terms of peak values, the possible reason can be either the poor water sampling or the breaking up of the sludge in the maturation pond (Personal communication: Roland Moollan, Scientific Services Dept., City of Cape Town, March 2005). The seasonal trend of TSS

Table 4.1 Effluent standards and short-term (Jan. 2001-Dec. 2004) statistics of effluent quality variables at the Scottsdene WWTW.

Variable	Flow Ml/d	TSS mg/l	COD mg/l	NH3 mgN/l	NO3 mgN/l	PO4 mgP/l	Faecal coliform Counts/ 100ml
1984 Standard	-	25	75	10.0	N.A.	N.A.	1000
2005 Standard	-	18	65	3.0	15	1.0	N.A.
2010 Standard	-	18	65	1.0	15	1.0	100
Average Value	7.8	13.4	51.2	7.8	2.0	7.2	33372
Standard Deviation	2.3	14.5	24.4	4.5	2.5	2.0	74491.8
Maximum Value	17.1	190.0	279.0	24.0	14.0	15.0	510000.0
Minimum Value	2.6	1.0	22.0	0.9	0.0	1.9	5.0

N.A.: Not Available

can be seen from Figure 4.1. In the summer season, TSS is generally higher than in winter season. This is probably due to the stormwater diluting the raw wastewater and reducing TSS levels. Using sand filtration in tertiary treatment process can efficiently lower the suspended solids value (Puig-Bargues et al. 2005).

The sprinkled irrigation water containing high level of suspended solids can reduce the crop yields due to the suspended solids deposited on the leaves, which reduces the photosynthetic activity. High level of TSS in irrigation water may cause salinization, soil surface crusting, and this will affect the infiltration rate and reduce seedling emergence. Based on the TSS value, potential clogging problems with drip irrigation emitters and related filtration equipment can be expected. The mitigation measures of high TSS in irrigation water include using dams to settle the suspended solids, changing of the irrigation system or improved equipment to minimize the clogging problem (DWAF, Vol. 4, 1996).

SA water quality guidelines have no numerical criteria for TSS concentration level in irrigation water which lead to the potential risks to the crops and the soil. However, a target water quality range of TSS concentration impacting the drip irrigation equipment is recommended. With no more than 50 mg/l TSS concentration in irrigation water, the drip irrigation system will not be impacted. The range between 50-100 mg/l will cause slight to moderate problems with clogging of the drip irrigation system. The ranges over 100 mg/l are expected to cause severe problems of clogging of drip systems. Based on the TSS data and the guidelines, the effluent is suitable for irrigation.

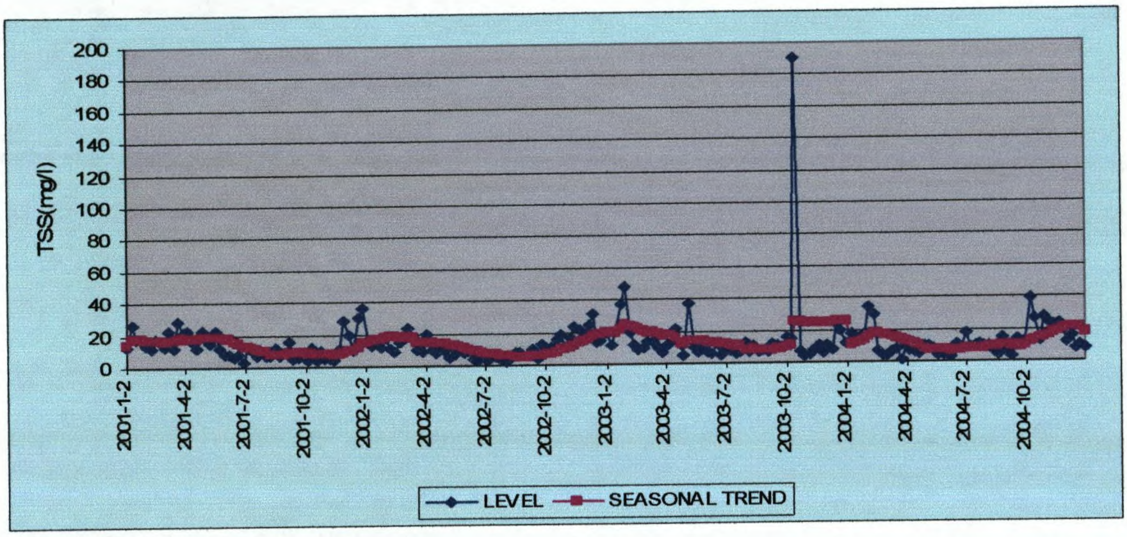

Figure 4.1 Total suspended solids (TSS) levels in effluent from the Scottsdene WWTW

Chemical oxygen demand (COD)

Figure 4.2 shows the weekly monitored chemical oxygen demand (COD) level in the treated effluent. The measurement of COD level is used to determine the treatment efficiency and effluent quality. It also indicates the suitability of water for non-potable uses. The average value is 51.2 mg/l, the maximum value is 279 mg/l and the minimum value is 22 mg/l. Compared to the 1984 general standard, the COD concentration level should not exceed 75 milligrams per liter after chlorination. 188 out of 208 tests (90%) comply with the legislation. The peak value, 279 mg/l, appeared on 15 Oct 2003, which is exactly the same day as the peak value of TSS (190 mg/l) on. This, together with high ammonia concentrations, can be as attributed to sewer surcharge occurring during this period, poor water sampling, or it could be due to the mechanical failure in the treatment process in the plant. The COD shows an oscillation pattern with peaks in summer (see Figure 4.2). This can be explained by the dilution effect of winter influx of urban stormwater flows into the sewerage system. SA water quality guidelines do not include COD standards for agricultural use.

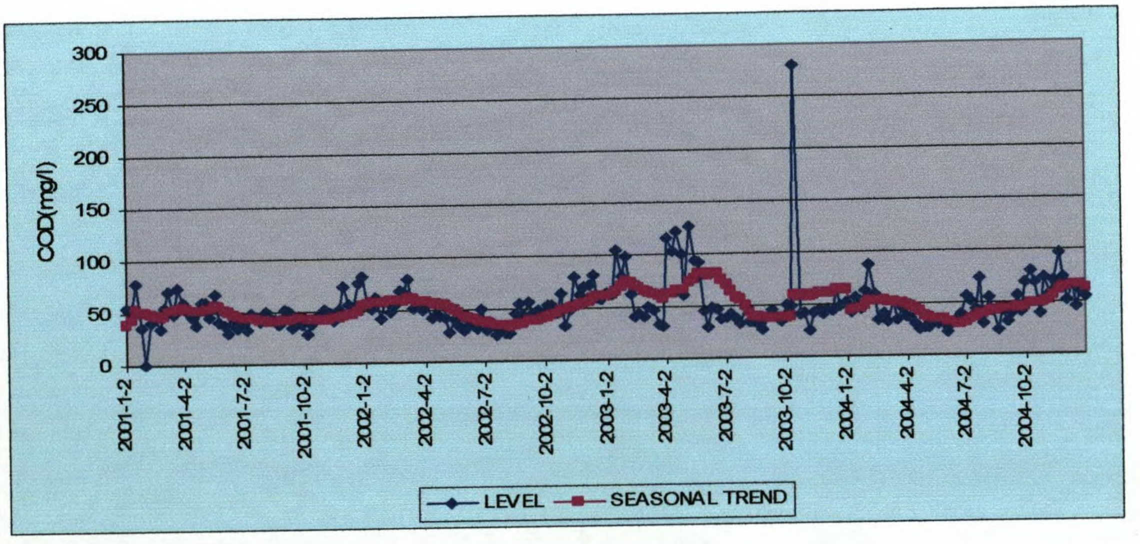

Figure 4.2 Chemical oxygen demand (COD) levels in effluent from the Scottsdene WWTW

Ammonia nitrogen (NH3)

As shown in Table 4.1, the average value of NH3 is 7.8 mgN/l, the maximum value is 24 mgN/l, and the minimum value is 0.9 mgN/l. According to the 1984 general standard, the NH3 cannot exceed 10 mgN/l. The average and minimum values are within the standard level at the Scottsdene WWTW. 169 out of 208 tests (81%) comply with the legislation. There seems no obvious seasonal trend for the ammonia concentration as a whole (see Figure 4.3).

SA water quality guidelines give target water quality ranges of NH3 concentration based on the effects on crop yields and quality, groundwater, and the impact on irrigation equipment. The NH3 concentration level is less than 5 mgN/l, this will not affect the sensitive crops. Depending on the frequency of irrigation water applied, decrease of crop yields and groundwater contamination may occur if the NH3 concentration levels are between 5-30 mgN/l. If the concentration level is more than 30 mgN/l, this will have serious impacts on the crop yields and quality as well as groundwater (DWAF, Vol. 4, 1996). Based on the analysis of NH_3 concentration, the effluent is suitable for irrigation.

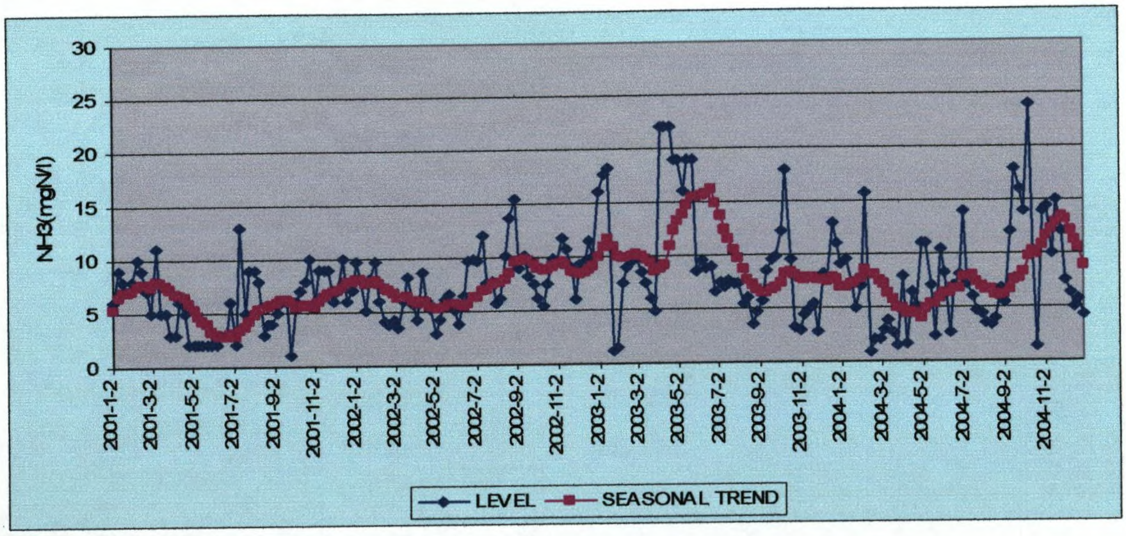

Figure 4.3 Ammonia nitrogen (NH_3) levels in effluent from the Scottsdene WWTW

Nitrate nitrogen (NO_3)

As shown in Table 4.1, the average value of NO_3 is 2.0 mgN/l, the maximum value is 14 mgN/l and the minimum value is 0 mgN/l. There is no requirement for NO_3 concentration in the 1984 general standard, but the 2005 and 2010 proposed general standards suggest the level should be within 15 mgN/l. All the values measured at the Scottsdene WWTW therefore comply with the proposed general standards. The results suggest that the NO_3 concentration in treated effluent show a weak seasonal trend (See Figure 4.4). The nitrate concentration level in treated effluent increases with the increasing of the influent. In the rainy winter season, the nitrate level is generally higher in the water body, possibly due to the contribution of stormwater flow into the sewage system.

SA water quality guidelines give target water quality ranges for NO_3 concentration in terms of the effects on crop yields and quality, groundwater, and the impact to irrigation equipment. Concentration level of NO_3 less than 5 mg/l can benefit the crop growth, because NO_3 serves as fertilizer to crops. If irrigation water contains high concentration of NO_3 (5-30 mg/l), this may stimulate the crop growth, but the excessive NO_3 cannot be taken by the crops and may leach below the root zone and increase groundwater pollution (Haruvy, 1997). If the NO_3 concentration level is over 30 mg/l, most crops will be affected and severe groundwater contamination will occur (DWAF, Vol. 4, 1996). This nutrient-enriched water from wastewater treatment works and fertilizer wash-off from the irrigated land ends up in fresh water bodies and contributes to the eutrophication problem downstream in the river (Boyden and Rababah, 1996; Raike et al. 2003). The mitigation measures include reduced nitrogen fertilizer, dilution of high concentration NO_3 water, and application of nitrogen-rich treated effluent when the crop nitrogen requirement is high etc (FAO, 1985; DWAF, Vol. 4, 1996). Based on the NO_3 concentration levels measured, the treated effluent is suitable for agricultural irrigation.

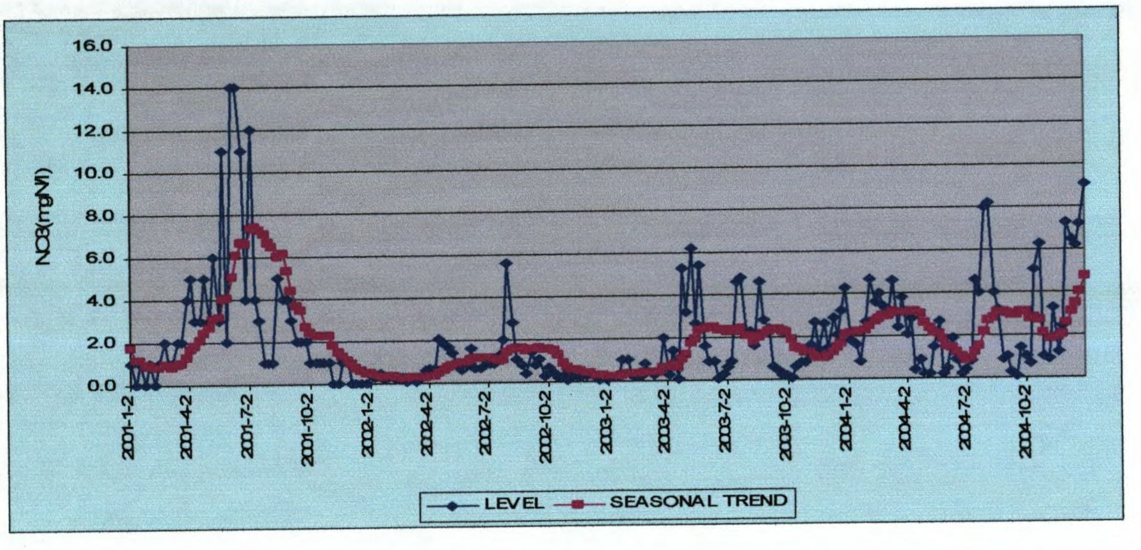

Figure 4.4 Nitrate nitrogen (NO_3) levels in effluent from the Scottsdene WWTW

Ortho-PO4

Figure 4.5 indicates the ortho-phosphate levels in the effluent. The average value of ortho-PO_4 is 7.2 mgP/l, the maximum value is 15 mgP/l, and the minimum value is 2.0 mgP/l. There is no legislation that regulates the concentration of ortho-PO_4 in treated effluent at present, but the proposed 2005 and 2010 general standards suggest that the concentration level should not exceed 1.0 mgP/l. None of the data meet the proposed 2005 and 2010 general standards. No seasonal trend is observed in Figure 4.5.

High levels of ortho-PO4 in the irrigation water, along with nitrate, can over-stimulate the growth of crops. The treated effluent with different concentration of ortho-PO4 should be used in different crop growing stages, so to maximize the merit and reduce the potential risks to the crops. At early stage, the irrigation water that contains high concentration of ortho-PO4 is favourable to crop growth. But continued irrigation with this high concentration ortho-PO4 water will cause vegetative growth late into the season, and this may result in yield loss (DWAF, Vol. 4, 1996). Based on the Ortho-PO4 data, the effluent would not satisfy the proposed 2005 and 2010 general standards.

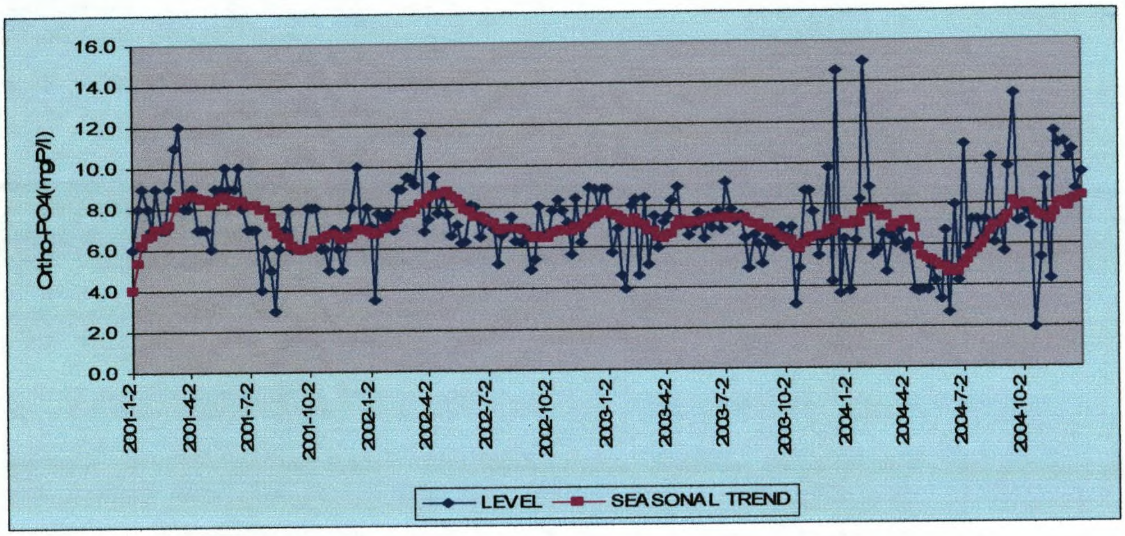

Figure 4.5 Ortho-phosphorus levels in effluent from the Scottsdene WWTW

Faecal coliform

Table 4.1 gives the analysis results for faecal coliform. Faecal coliform is the most common bacterial indicator that is being used to assess the microbial quality of irrigation water. It indicates the faecal pollutants of the water (DWAF, Vol. 4, 1996). The average value in the period studied is 33372 counts/100 ml, the maximum value is 510000 counts/100 ml, and the minimum value is 5 counts/100 ml. The 1984 general standard suggests faecal coliform level should not exceed 1000 counts/100 ml. Comparing the Scottsdene data to the standard, 112 out of 208 tests (54%) comply with the legislation. The average value and some values exceeded the DWAF 1984 general standard. Especially during the period from October 2003 to October 2004, extremely high faecal coliform levels were recorded on many occasions (see Figure 4.5). The reason that such high concentration levels occurred, was that the chlorine contact tank at the Scottsdene WWTW was not in operation (Personal communication: Alfred Mbewe, City of Cape Town, November 2004). There is no seasonal trend observed in Figure 4.6.

High concentration faecal coliform in irrigation water will negatively impact the crops and the soil, and might have a high health risk for workers and people at large. It will cause clogging of the irrigation system if secondary growth of these micro-organisms occurs under sufficient nutrients conditions. In order to reduce the concentration level of faecal coliform, wastewater treatment with chlorine is required. Other mitigation measures include not irrigating crops that are eaten raw, using irrigation system which wet small areas under the canopy, and disinfecting the irrigation system to prevent secondary re-growth of micro-organisms (DWAF, Vol. 4, 1996).

SA water quality guidelines give the target water quality concentration range for faecal coliform. Less than 1 count/100 ml of faecal coliform in irrigation water can be applied to any crops with any irrigation method. In the range between 1 and 1000 counts/100 ml, irrigation water can be applied to crops that are not eaten raw and fruits that are not wetted by irrigation water. If the range is over 1000 counts/100 ml, it is prohibited to use this water to irrigate crops that are eaten raw (Shatanawi and Fayyad, 1996), but water can be used to irrigate fodders, trees and parks (DWAF, Vol. 4, 1996). In terms of irrigation equipment, if the concentration level is below 10000 counts/1000 ml, no clogging of drip irrigation equipment is expected. If the level is between 10000-50000 counts/100 ml, clogging of equipment will likely occur. If the level is over 50000, the likelihood of clogging of equipment will increase (DWAF, Vol. 4, 1996).

pH

Values of pH from the Scottsdene WWTW were obtained for two periods, namely from July 2002 to June 2003 and from July 2003 to June 2004. During these periods, the average pH value was 7.4, the maximum value was 8.7 and the minimum value was 6.9. The 1984 general standard suggests that the optimal pH range is 5.5-9.5. All the measured values comply with the standard.

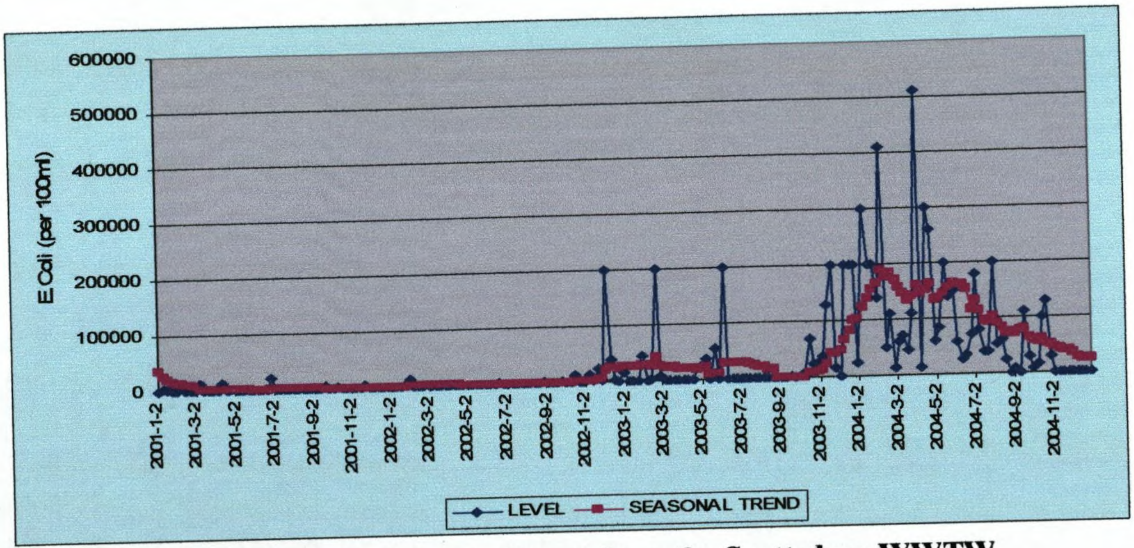

Figure 4.6 Faecal coliform in treated effluent from the Scottsdene WWTW

Most of the crop nutrients and potential toxic constituents highly depend on the level of pH in irrigation water. At higher pH, the nutrients and heavy metals are more difficult to be extracted than in lower pH condition. Irrigation water affects the soil pH slowly, so the effect of soil pH on crop production is indirect. Too low and too high pH of irrigation water in contact with crop leaves will damage the crops and influence the yield. Extreme high pH values in irrigation water will have an impact on corrosion and encrustation of irrigation equipment (DWAF, Vol. 4, 1996). The mitigation measures include applying irrigation methods which do not wet the leaves and the harvestable products, adjustment and maintenance of soil pH through the application of amendments.

SA water quality guidelines recommend that the target pH range is 6.5-8.4. Within this range, the crop leaves, crop production, soil suitability and irrigation equipment have no major problems (DWAF, Vol. 4, 1996). If pH values are below 6.5 or over 8.4, increasing problems will occur, as for example damage to crop leaves, reduced production, unavailability of some nutrients and corrosion and encrustation to the irrigation equipment (DWAF, Vol. 4, 1996). Based on the pH data, the treated effluent is suitable for agricultural irrigation.

Electrical conductivity (EC)

Values of EC from the Scottsdene WWTW were obtained for two periods, namely from July 2002 to June 2003 and July 2003 to June 2004. During these periods, the average EC value was 50 mS/m, the maximum value was 60.5 mS/m and the minimum value was 40.5 mS/m. The 1984 general standard has no requirement for the EC range.

Irrigation water containing salts induces salt accumulation in the soil. As a result of evaporation of salty irrigation water, salt accumulates in the soil and salinization occurs. Soil salinity can be controlled by irrigating additional water to leach excessive salt. The higher EC concentration in irrigation water, the higher leaching fraction is required, the more water needs to be used to meet the leaching requirement (DWAF, Vol. 4, 1996). When the salt concentration in the soil reaches a certain level (threshold level), the crops cannot extract water from the soil to meet the atmospheric evaporative demand, crop growth will be reduced and eventually it will result in yield losses. The mitigation measures include applying surplus water to leach the excessive salts, choosing more salt tolerant crops to grow and improving irrigation efficiency (DWAF, Vol. 4, 1996).

SA water quality guidelines indicate a target EC of 40 mS/m. Irrigation water with an EC value below the target value can support sensitive crops to achieve optimal yield. If the range is 40-90 mS/m, 5% yield losses can be expected for salt sensitive crops. For other ranges of EC in irrigation water, the guidelines give a summary of the potential effects. The soils' ability to sustain crop yields will determine the soil sustainability, thus the EC ranges of irrigation water effects on soil sustainability are comparable to the EC impacts on crop production (DWAF, Vol. 4, 1996). The Scottsdene effluent is therefore generally suitable for agricultural irrigation in terms of EC levels.

Flow

The designed capacity of the WWTW is 7.5 Ml/day. There was no information with respect to the peak design flow (van Driel, 2003). As can be seen from Table 4.1, the average treated capacity is 7.9 Ml/day, which indicates that the plant is over capacity.

The peak flow was 17.1 Ml/day (May 2003), and the lowest flow was 2.6 Ml/day (December 2002). The peak flow was assumed to be due to stormwater inflow in the winter season. Generally speaking, the inflow during summer is lower because of the lack of precipitation, but the seasonal trend was weak (Figure 4.7). The highest treated effluent flows were recorded in the winter season, when stormwater flows into the sewage system contributing to the high effluent levels.

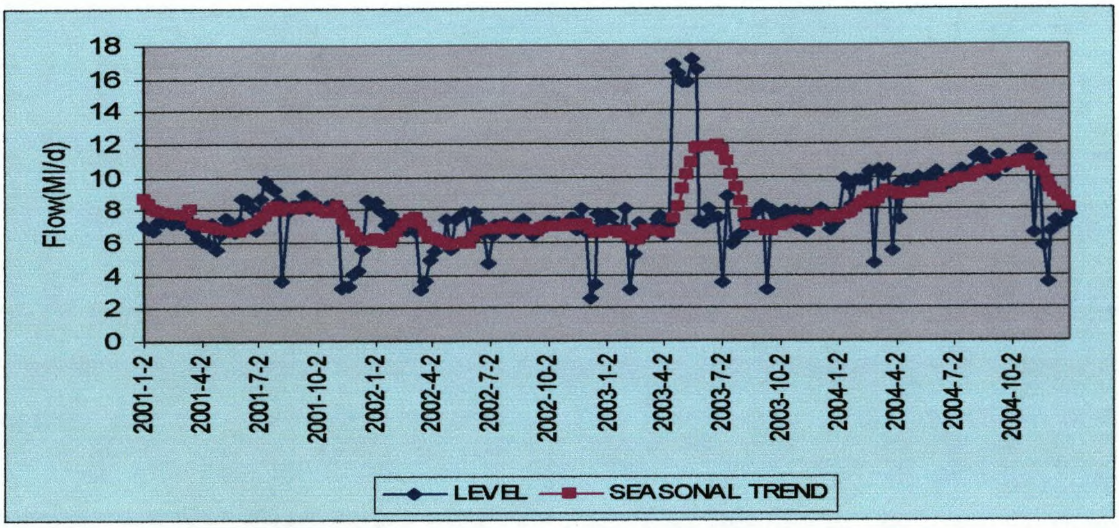

Figure 4.7 Flow measurements of effluent from the Scottsdene WWTW

Summary

By comparing the average values of each effluent quality variable to the 1984 general standard (Table 4.1), it was concluded that TSS, COD and NH3 concentration levels satisfied the standard. No standards for the NO3 and ortho-PO4 concentration in the final effluent are available at current stage. The faecal coliform concentration level did not meet the requirements of the 1984 general standard on several occasions.

All effluent quality variables did not show increasing nor decreasing trends during the study period. The fluctuations of these variables reflect the nature of the flow into the WWTW, the treatment processes, and the possibility of the WWTW being overloaded with respect to the designed capacity.

In terms of SA water quality guideline, the concentration level of the variables examined was generally within the target ranges. The water was generally suitable for agricultural irrigation with no obvious problems to the crops, soil, surface water and groundwater, as well as the irrigation equipment. If the concentration levels exceed the target ranges, negative impacts may occur on crops, soil and irrigation equipment when using this water to irrigate (DWAF, Vol. 4, 1996).

The impacts of effluent quality on the crops, soil and surface and groundwater are not known within the study area at this stage. Suspended solids, excess ammonia and salts contained in the effluent may lead to damage to crops, soil and pollution of water sources. The improvement in the treatment processes can lead to a higher quality of final effluent. In this case, the maintenance of the treatment works also need to be monitored regularly for the intended purposes as well as to comply with the 1984 standards as indicated as the plant license.

4.1.2 Health guideline on effluent irrigation

This research used SA effluent reuse guide to evaluate the suitability of the treated effluent for agricultural irrigation from the human health point of view.

SA effluent reuse guide focuses on monitoring the microbiological variables to minimize the health risks to the consumers. In this guide, fecal coliform concentration is treated as the only pathogen indicator. According to the effluent quality analysis, the average fecal coliform concentration level generally complied with the SA effluent reuse guide. Exception was the period between October 2003 and October 2004, when the breakdown of the chlorination plant occurred. The effluent containing such high level fecal coliform during this period could not be used to irrigate crops both eaten raw and not eaten raw.

Irrigation with treated effluent containing fecal coliform no more than 1000 counts/100 ml can be applied to crops which are not eaten raw, using any type of irrigation methods. For vineyard irrigation with this concentration of effluent, the flood irrigation method can be applied. Drip and micro irrigation methods are permissible if the products are not directly exposed to the spray. Fallen products during the irrigation procedure cannot be consumed by humans. Although coliform levels comply with the standard most of the time, measures still need to be taken in the future to ensure the health of consumers.

In terms of treatment techniques, SA effluent reuse guide permits effluent irrigation of crops that are eaten raw only after primary, secondary, tertiary and advanced treatment. Effluent quality also needs to be comparable to drinking water quality levels. For crops that are not eaten raw, the treatment requirement is primary, secondary and tertiary, and the fecal coliform level cannot exceed 1000 counts /100 ml. The treatment technology applied in Scottsdene WWTW can be categorized into PST (primary, secondary and tertiary treatment) classification. The Scottsdene WWTW is qualified to produce high quality final effluent, but on-going maintenance needs to be ensured.

4.1.3 Correlation of effluent quality variables

Correlation graphs have been plotted for each pair of water quality variables. A reasonable correlation was found amongst the variables shown in Figure 4.8. They are the most representative graphs and the following text gives the explanation of their correlation. Other correlation graphs are shown in Appendix B.

The correlation between TSS and COD is relatively strong (Figure 4.8a). It is concluded that the solids in the effluent have carbon associated with them, as COD reflects the organic matter present in the water body (DWAF, Vol. 6, 1996). Suspended solids in water adsorb inorganic and organic compounds and transport them in the effluent.

The ammonia nitrogen in effluent is weakly correlated with the COD concentration in effluent, as illustrated in Figure 4.8b. Basically, higher COD loading is accompanied by higher ammonia loads.

Weak correlations were observed between PO_4 and NH_3. As can be seen from the red box in Figure 4.8c, most of the PO_4 values are concentrate within 4 to10 mg/l while the NH_3 concentration ranges between 2 and 11 mg/l. Figure 4.8d illustrates the correlation between PO4 and NO3. The concentration level of PO4 ranges from 3 to 10 mg/l while most of the NO3 concentration is between 0.1 and 5.0 mg/l. With the NO3 concentration increasing, the PO4 concentration ranges between 5 and 10 mg/l.

Figure 4.8e shows the correlation between PO4 and COD. Most data for these two variables concentrated in the red box area. When PO4 ranges are between 5 and 10 mg/l, the concentration of COD is expected to be between 20 and 80 mg/l.

A negative correlation between NH3 and NO3 was observed (Figure 4.8f). With the NH3 concentration increasing, the concentration level of NO3 is expected to decrease. The extreme values of NH3 and NO3 are delineated with the red line.

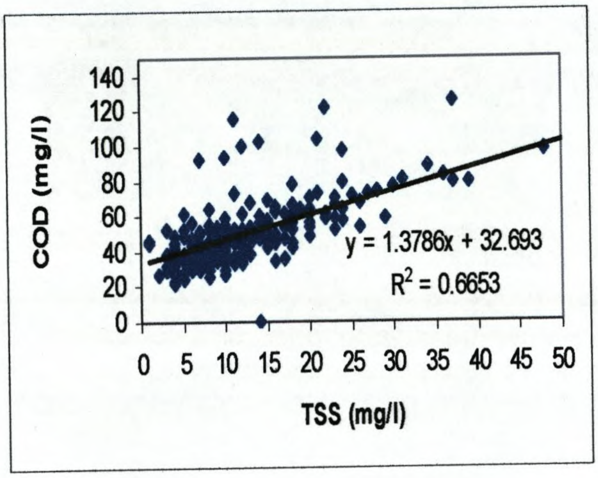

Figure 4.8 a

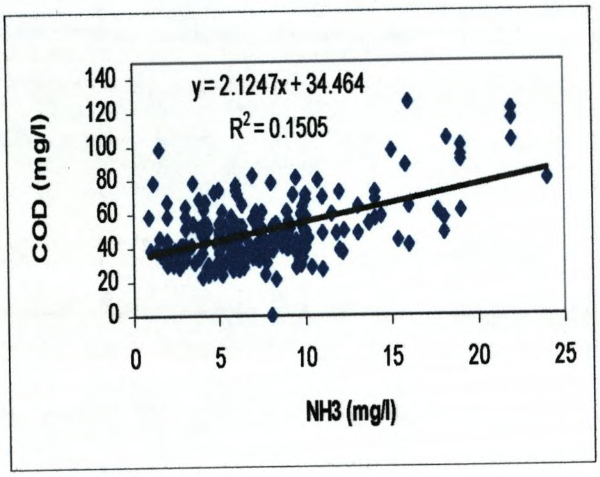

Figure 4.8 b

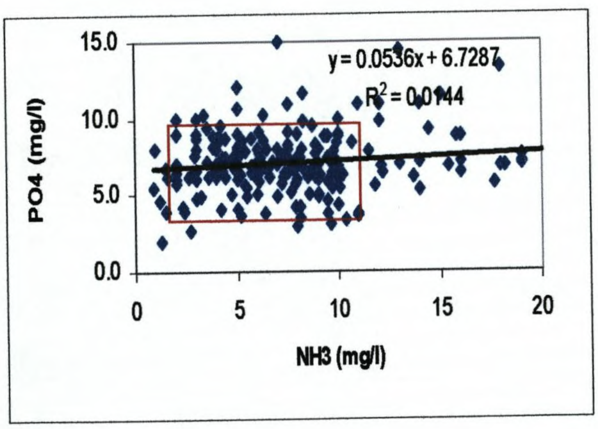

Figure 4.8 c

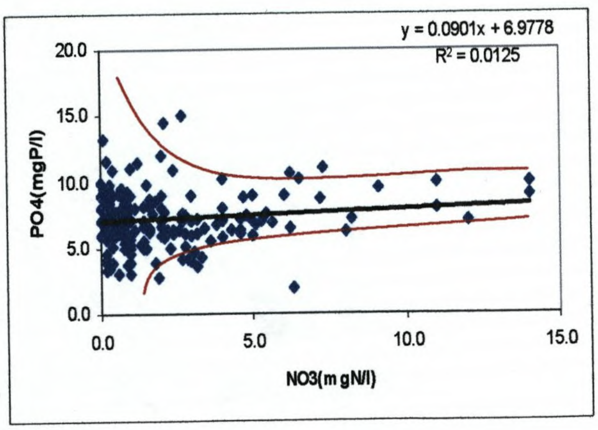

Figure 4.8 d

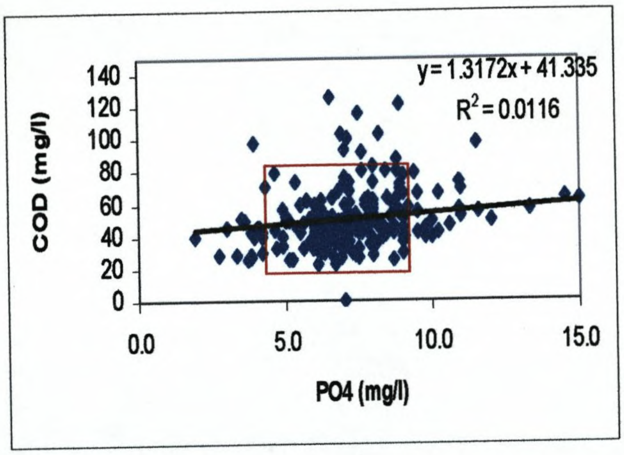

Figure 4.8 e

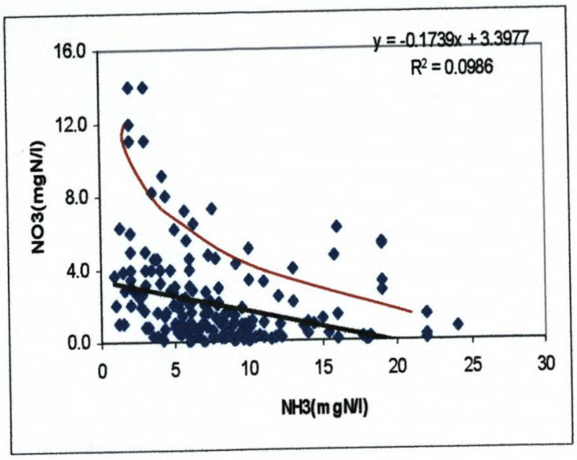

Figure 4.8 f

Figure 4.8 Most representative graphs showing the correlation of effluent quality variables

4.2 Analysis of the Questionnaire Results

Table 4.2 Questionnaire distribution and collection results

	First distribution		Second distribution		Total
Farm	Vineyard	Vegetable	Vineyard	Vegetable	
questionnaire distributed	7	2		7	16
Returned questionnaires	4	1		6	11
Percentage of respondents	57%	50%		86%	69%

The questionnaire distribution and collection results are listed in Table 4.2.

4.2.1 Current use

Social economic factors

This section of the questionnaire surveys social economic factors, such as age, education level, and farm size.

Age distribution of the respondents is shown in Figure 4.9. The majority of the farmers' age (64%) is between 41 and 60 years. The respondents are a group of mature population. The age of decision-makers is often the key factor for the adoption of new practices. By increasing age and experience, the potential to accept new and unusual practices decreases (Stevens and Duvel, 2004).

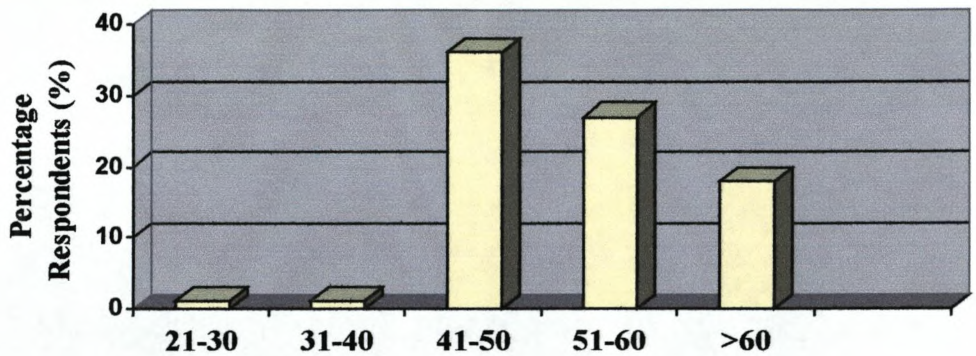

Figure 4.9 Distribution of respondents according to age (N = 11)

The education level of the respondents is shown in Figure 4.10. There are 45% of the respondents with education at standard 10 (grade 12) level. The rest (55%) of the respondents attained a tertiary education qualification, of which 33% of them have agricultural related diploma or degree. According to a study done by Stevens and Duvel (2004), there is no significant relationship between farmer's education level and the adoption of agricultural practices. With regard to this research, 4 out of 6 current effluent irrigation users have standard 10 education level. Four out of 5 respondents who have not yet practiced effluent irrigation, have obtained degrees. Due to the small sample size, it would be difficult to draw conclusions on the relationship between education level and the adoption of treated effluent for irrigation.

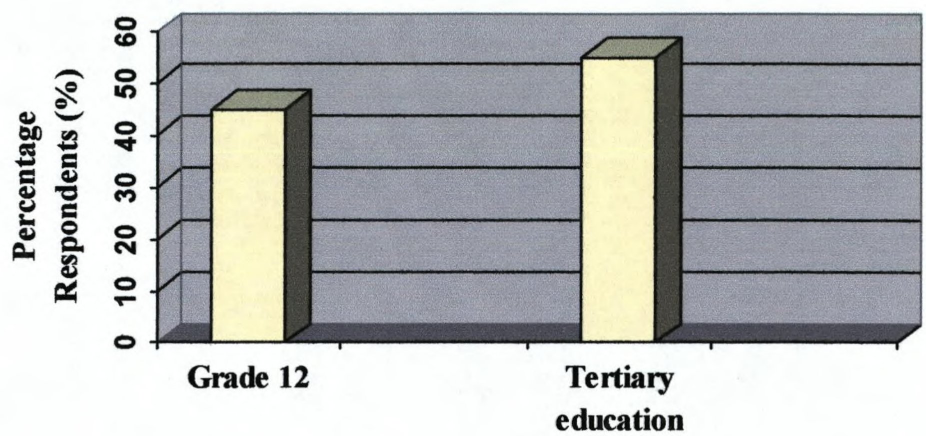

Figure 4.10 Education level of the respondents (N =11)

The farm size of the respondents is shown in Figure 4.11. The smallest farm size is 8 ha, and the largest farm size is 192 ha. 50% of the farm sizes are less than 50 ha, and 30% of the farm sizes are among 50-100 ha. Two farms of 172 ha and 192 ha, account for 20% of the total farm sizes. The assumption is that bigger farm sizes irrigate larger areas, so they will use more irrigation water to meet the demand, even adopting the treated effluent.

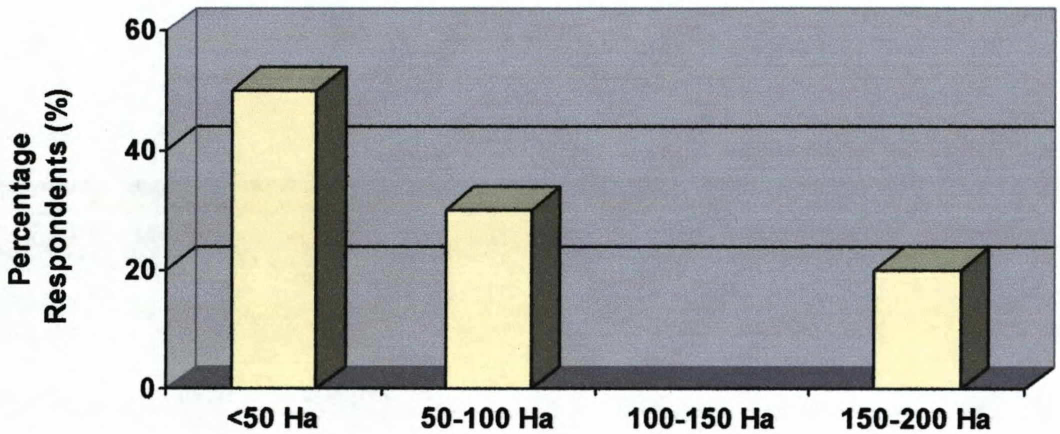

Figure 4.11 Size of the farms (N = 10)

Production factors

This sub-section surveys the type of crops and fertilizer, irrigation methods, source of irrigation water that are used by the respondents.

Irrigation methods

The irrigation methods adopted by the respondents are summarized in Figure 4.12. The choice of irrigation method mainly depends on the condition of the land, the water use efficiency, and the capital cost (Stevens and Duvel, 2004). Through the questionnaire survey, four types of irrigation methods are used in the Bottelary River area. 55% of the respondents use only one kind of irrigation method. The rest uses more than two types of irrigation methods.

Based on the questionnaire survey, the majority of the irrigation method is sprinkler irrigation system. From the effluent irrigation point of view, if the effluent has a poor quality, sprinkler irrigation can cause potential hazards to farm workers, crop leaves and the soil. The negative impact of effluent irrigation with drip system is the clogging of equipment (Shatanawi and Fayyad, 1996). According to Puig-Bargues et al. (2005), chlorination in the treatment process is an effective way to reduce clogging of the irrigation equipment due to the appearance of bacteria and algae in treated effluent. The applicability of the irrigation equipment needs to be investigated to accommodate irrigation with treated effluent.

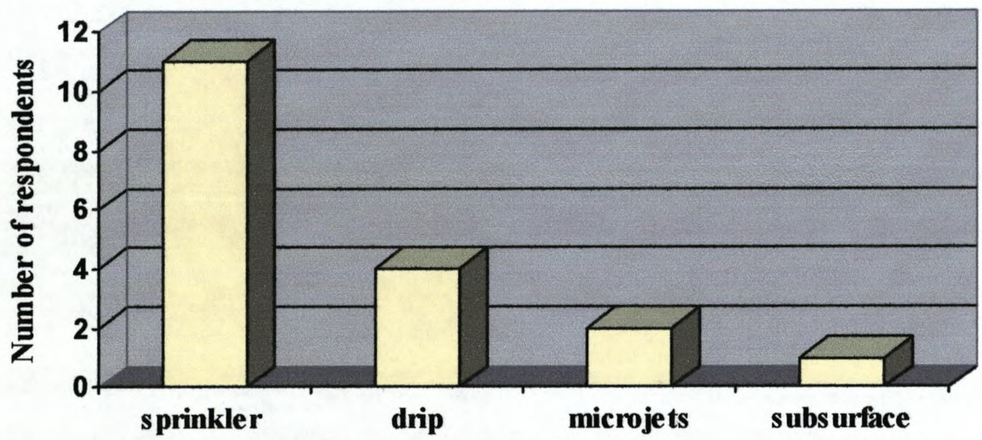

Figure 4.12 Irrigation methods used by the respondents (N= 11)

Type of crops

The major crops grown by the respondents in the Bottelary River area are listed in Table 4.2. Vineyard farms and vegetable farms are the major agricultural activities in the study area. Some other crops, which only account for a small portion of the area, are not included in Table 4.2. These crops include butternuts, leeks, tomatoes, eggplants, spinach, baby marrows and celery. According to the yield response curves (See Figure 2.1), the most popular crops, beans and carrots, are sensitive to salinity. The threshold values of EC of the saturated soil extract are 1.0 dS/m for beans and 1.2 dS/m for carrots. Cabbages and cauliflowers are also widely grown in the study area and they are moderately sensitive to salinity. The threshold value of EC of saturated soil extract is 1.8 dS/m for cabbages and there is no threshold value available for cauliflowers (Table

2.2) (Maas, 1996). Yield reduction can be expected beyond these saturated soil extract EC.

The average EC of the Scottsdene WWTW final effluent is 0.5 dS/m. This saline water gets more concentrated in the soil solution due to crop water uptake and it may affect crop yields, although no dramatic yield reduction can be expected, provided appropriate irrigation scheduling is practiced. Some of the salts are expected to be washed out of the root zone through rainfall, in particular during the rainy winter season. The EC requires slight to moderate restrictions on use of treated effluent for crops sensitive to salinity. This water can be used without restriction to crops tolerant to moderately tolerant to salinity (Shatanawi and Fayyad, 1996). In terms of microbiological pollution, if the faecal coliform value exceeded 1000 counts/100 ml, the treated effluent can only be applied to crops which are not eaten raw and vineyard products irrigated with drip or micro systems (Shatanawi and Fayyad, 1996). It should be noted that, due to the high investment and management costs in vineyards, high quality effluent needs to be guaranteed and specific management practices need to be ensured on vine farms, in order to avoid financial losses that could be detrimental to the business.

Behavioral factors

Awareness of water shortage

Figure 4.13 shows the percentages of respondents' points of view on the water shortage problems. 73% of the respondents agree that there is a water shortage problem in the area. All the vineyard farmers strongly support this point. The possible reason is that summer is the period of water consumption for vineyards, and there is not enough precipitation available. 27% of the respondents who have small size farms do not agree that there is a water shortage problem. This is partially because their demand for irrigation water is not that high as for those who have big size farms. It is assumed that those respondents who are aware of water shortage problems are more likely to use additional water resources to meet the demand of irrigation water. According to the results, 4 out of 7 respondents who are aware of water shortage problems are using treated effluent for irrigation, but none of them are vineyard farms.

Table 4.3 Crops grown by the respondents in the Bottelary River area

Crops		Farmers											
		1	2	3	4	5	6	7	8	9	10	11	Total
Summer crops	Cabbage	1		1		1		1				1	5
	Cauliflower			1				1		1	1	1	5
	Chilli					1					1		2
	Bean	1		1				1		1	1	1	6
	Greenpepper			1						1			2
	Lettuce	1				1				1			3
	Radish							1				1	2
Winter crops	Grapes		1		1		1		1				4
	Carrot	1		1		1					1	1	5
	Pumpkin	1									1		2
	Potato					1				1		1	3
	Beetroot					1				1			2

Willingness to increase irrigation area

Figure 4.14 shows the willingness of increasing the irrigation area irrigated with fresh water, treated effluent and other waters respectively. 6 out of 11 (55%) respondents are willing to increase the irrigation area with treated effluent. With regard to the extension of irrigated area using fresh water and other water sources, the respondents' interests

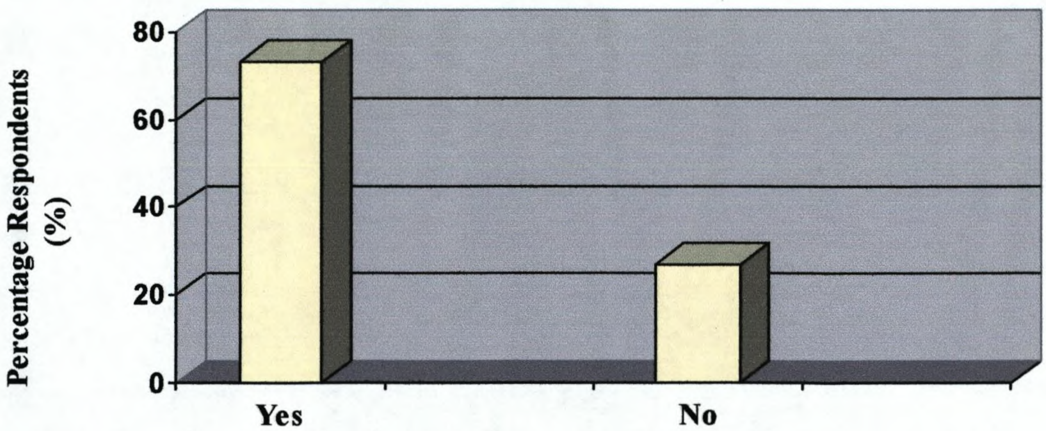

Figure 4.13 Awareness of water shortage problem (N = 11)

are 27% and 18%, respectively. The financial consideration can also affect the farmers' decisions. Compared to other water sources, the treated effluent has a relative cost advantage (Haruvy, 1997). It is the main reason that the majority of the farmers are willing to use the treated effluent to increase the irrigation area.

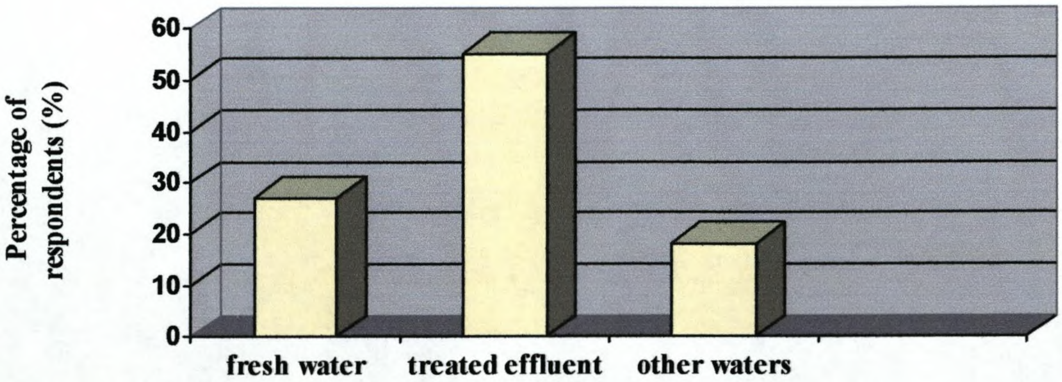

Figure 4.14 Willingness to increase the irrigation area with different water sources (N =11)

Status of treated effluent usage

Figure 4.15 shows that 6 out of 11 (55%) respondents are currently using treated effluent. The age distribution of these current users is among all age groups. In terms of crop type, 86% of the vegetable farmers are effluent users. No vineyard farmer currently uses treated effluent. The total farming area of the effluent users is 213 ha, but the exact area under treated effluent irrigation is not known, as the farmers use irrigation water from different sources and they do not irrigate the entire farming area.

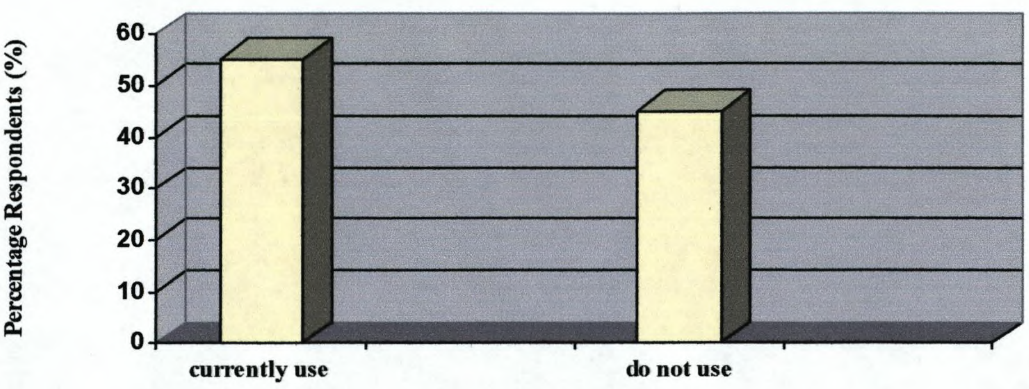

Figure 4.15 Status of treated effluent usage (N= 11)

4.2.2 Farmers' perception

Six out of eleven (55%) respondents are currently using treated effluent for irrigation, and the rest (45%) are not using it (Figure 4.15). The following text provides the analysis of the reasons for applying/not applying effluent irrigation, the concerns and the respondents' opinions on effluent irrigation.

Reasons for applying/not applying effluent irrigation

As shown in Table 4.4, there are two reasons why farmers do not apply effluent irrigation. All five respondents pointed out that the absence of equipment, such as the lack of pumping facility for conveying water to the farm land or no pipe connecting treated effluent to the users, are the reasons for not practicing effluent irrigation. One respondent stated that "considering the consumers' interest" was the second reason for him to still use fresh water irrigation. His concern was that consumers may not be willing to accept the agricultural products which are irrigated with the treated effluent.

Most of the current effluent users regard the easy access to the treated effluent as the reason for practicing effluent irrigation. The farm location and infrastructure therefore play an important role in adopting effluent water for irrigation. The farms close to the Scottsdene WWTW or close to the river can easily extract and use treated effluent at present stage. In addition, some farmers mentioned that using treated effluent can not only conserve the fresh water but it can also lower farmers' cost, as the treated effluent is cheaper than the fresh water.

Table 4.4 Reasons for applying/not applying effluent irrigation

	Reasons	Number of respondents
Not practiced (N=5)	Accessibility of effluent	5
	Customers' interest	1
Already practiced (N=6)	Easy access	5
	Conserve fresh water	2
	Fresh water expensive	1

Concerns on effluent irrigation

Table 4.5 shows respondents' concerns on effluent irrigation. Most respondents who have not adopted effluent irrigation worried that the poor quality effluent may harm the soil and reduce crop yields as well as negatively impact on human health. Others considered that the poor quality effluent may cause hazards to the environment, and problems with consumers' acceptance of effluent irrigated products. For the current effluent users, 4 out of 6 respondents showed no concern of effluent irrigation. Two respondents agreed with the concern that effluent irrigation has health hazards to human beings. The impact on the irrigated soil is another concern for current effluent users. All the respondents who currently do not use the treated effluent are willing to accept it, but with caution. In any case, the guarantee of treated effluent quality is the priority for respondents to adopt treated effluent for agricultural irrigation.

Table 4.5 Concerns on effluent irrigation

Concerns on effluent irrigation	Not practiced (N=5)	Already practiced (N=6)
	Number of respondents	Number of respondents
No concerns		4
Environmental risks	1	
Effluent quality will influence the soil	4	1
Effluent quality will influence crops yields	3	
Has negative effect to the profit	1	
Health hazards to human beings	2	2
Perception problems with the consumers	1	

4.3 Potential Area Irrigated with Treated Effluent

This study firstly investigated the treated effluent quality of the Scottsdene WWTW. Despite temporary problems, such as high concentration of faecal coliform in certain periods and the relatively high level of ammonia nitrogen, the total quality of treated effluent met the 1984 general standard. According to the SA water quality guidelines, the treated effluent should be used with caution to minimize the potential hazards to the crops, soil, groundwater and consumers.

Secondly, the questionnaire captured the farmers' perception of using treated effluent. The feedback from the farmers was generally positive. The farmers who have not applied effluent irrigation would consider this practice if the quality of treated effluent could be ensured, and the concerns on the impacts on crops, soil as well as human health could be resolved.

Based on the promising feedback from these first two stages of the research, it was concluded that the area irrigated with treated effluent could potentially be increased to a larger scale. This section estimates the potential area that can be irrigated with treated effluent in regard to different cropping systems and seasons. Potential vine areas are estimated as about 50% of the respondents are wine farmers. Although none of them apply effluent irrigation at present, they showed the willingness to practice it.

In order to determine the potential area that can be irrigated with effluent, the SAPWAT model was firstly used to calculate crop water requirements. The calculation of irrigation requirements was done using weather data from the Klein Bottelary weather station included in the SAPWAT database. The Klein Bottelary weather station is located in the study area and the data collected by this weather station reflect the weather conditions of the Bottelary River catchment.

The next step of the procedure included the selection of the crops. Based on the questionnaire survey, the crops grown in the catchment depend on the season. For example, the main crops planted in summer are bean, cauliflower, tomato. Carrot, cabbage and potato are mainly planted in winter. A generic cropping system including winter and summer vegetables was therefore selected in SAPWAT. The planting dates of crops were taken from the responses to the questionnaire and typed in the SAPWAT model as input data. The planting date used in SAPWAT was 1st October for summer-planted vegetables and 1st March for winter-planted vegetables. The geographic region was selected as "winter rain" in the crop factors screen of the SAPWAT model. The cover at full growth and wetting frequency of the crops was determined based on one's experience, knowledge and general practice in the area. The cover at full growth was selected to be 90%, and the wetting frequency was seven days throughout the season. The wetted area was 100%. Based on the above mentioned inputs, the SAPWAT model calculated the crop water requirements.

For summer-planted vegetables, the default growth season was from October to February. The irrigation requirements are 52 mm in October, 92 mm in November, 220 mm in December, 211 mm in January and 109 mm in February. The total seasonal water requirements are the sum of the five months' water requirements, namely 684 mm. The average effluent flow in these five months is 267 Ml, 183 Ml, 202 Ml, 279 Ml and 190 Ml respectively, and the total effluent flow is 1120 Ml (the sum of the five months' average effluent flow). Dividing the total irrigation requirements by the total available effluent flow in this period, the total potential area which could be irrigated with treated effluent for summer planted vegetables in a normal season was calculated as:

Potential area (ha) = Total average effluent flow (Ml) / Total irrigation requirements (mm) = 1120 Ml / 684 mm = 164 ha

The total effluent available is therefore sufficient to cultivate 164 ha of summer-planted vegetables. This is less than the total area available for planting. This indicates that the volume of effluent available may not be enough to satisfy crop water requirements, should the current effluent users want to irrigate the whole area of their farms.

For winter-planted vegetables, the growth season is from March to August. The irrigation requirements are 69mm in March, 62mm in April, 23mm in May. The total irrigation requirement during the growth season is the sum of the irrigation requirements in the three months, namely 154 mm. During June, July and August, no irrigation requirements were calculated as rainfall is expected to fully satisfy crop water requirements. The average treated effluent flow from March to August is 217 Ml, 252

Ml, 291 Ml, 168 Ml, 254 Ml and 248 Ml respectively. The total average effluent flow during the winter growth season is the sum of the average effluent flow in March, April and May, namely 760 Ml.

Theoretically, during periods of no irrigation requirements, the surplus treated effluent could be stored in a dam to meet the summer peak demand. According to van Driel's (2003) rough estimation, the total storage capacity in the Bottelary River area is about 1000 Ml. The total annual treated effluent volume is 2847 Ml (average effluent flow of 7.8 Ml/day multiplied by 365 days). Therefore, only 35% of the annual treated effluent volume can be stored. In the absence of major storage facilities in the area, the effluent was assumed to be discharged in the river during months of no irrigation requirements. In the case of winter-planted vegetables, the effluent flow in June, July and August was therefore excluded from the balance for the vegetables growth season. Dividing the total irrigation requirements by the total average effluent flow in March, April and May, the potential area that could be irrigated with treated effluent for winter-planted vegetables in a normal season was calculated as follows:

Potential area (ha) = Total average effluent flow (Ml) / Total irrigation requirements (mm) = 760 Ml / 154 mm = 494 ha

Table 4.6 lists the irrigation requirements, effluent flow, and the potential areas that can be irrigated with treated effluent for summer-planted and winter-planted vegetables. In summer, vegetable evapotranspiration is high (for example, in December, the evapotranspiration value of generic summer-planted vegetables is 173 mm) and rainfall cannot meet the irrigation requirements (in December the rainfall and effective rainfall are 19 mm and 16 mm respectively). Therefore, the demand for irrigation water is relatively high in summer. The treated effluent could fill in the difference between the evapotranspiration of vegetables and effective rainfall.

During winter time, the vegetable evapotranspiration rate is low (for example, in June, the evapotranspiration of generic winter-planted vegetable is 49 mm) and the precipitation is high (in June, the rainfall and effective rainfall are 146 mm and 89 mm respectively). The irrigation requirements in winter are much less than those in summer, mainly because rainfall meets large portion of the demand for water. As can be seen in Table 4.6, there are no irrigation requirements in June, July, and August, regardless whether the season is favorable, normal or severe. Therefore, the potential area that can be irrigated with the effluent is larger in winter than in summer.

Tables 4.6 (vegetables) and 4.7 (vineyard) list also the irrigation requirements, effluent flow and potential areas that can be irrigated with treated effluent in favourable season and severe season. The calculation is the same as that for the normal season (the potential area to be irrigated is equal to the average monthly effluent flow divided by irrigation requirements). The differences in irrigation requirements and potential areas are due to different rainfall calculated by the model for favorable, normal and severe season.

The vineyards do not need much water during winter, due to low evaporation demand. There are no irrigation requirements for vineyards in May, June, July and August in favourable, normal or severe seasons (Table 4.7). In summer, the vineyards need more irrigation to meet the water requirements due to the high rate of crop evapotranspiration. Rainfall cannot satisfy these requirements in summer (These can be seen from Figures 4.16 and 4.17, which represent screen printouts of the SAPWAT model). Thus, treated effluent can serve as an additional water source to meet the water demand.

Table 4.6 Summer-planted vegetables (Oct.-Feb.) and winter-planted vegetables (Mar.-Aug.) irrigation requirements, effluent flow and potential areas that can be irrigated with treated effluent

Month		Irrigation requirements (mm)			Effluent flow (Ml) (Average 2001-2004)
		Favorable Season	Normal season	Severe season	
Jan.		198	211	214	279
Feb.		72	109	123	190
March		57	69	68	217
April		32	62	72	252
May		-	23	21	291
June		-	-	-	168
July		-	-	-	254
Aug.		-	-	-	248
Sep.		-	-	-	243
Oct.		-	52	65	267
Nov.		70	92	88	183
Dec.		184	220	232	201
Total					2793
Total irrigation requirements (mm)	Summer vegetables	524	684	722	
	Winter Vegetables	89	154	161	
Total flow (Ml)	Summer Vegetables	853	1120	1120	
	Winter Vegetables	469	760	760	
Potential area (ha)	Summer Vegetables	163	164	155	
	Winter Vegetables	527	494	472	

Table 4.7: Wine vineyard (May-April) irrigation requirements, effluent flow and potential areas that can be irrigated with treated effluent

Month	Irrigation requirements (mm)				Effluent flow (Ml) (Average 2001-2004)
	Favourable season (Sprinkler, wetted area 100%)	Normal season		Severe season (Sprinkler, wetted area 100%)	
		Sprinkler (wetted area: 100%)	Drip (wetted area: 20%)		
May	-	-	-	-	291
June	-	-	-	-	168
July	-	-	-	-	254
Aug.	-	-	-	-	248
Sept.	-	34	3	44	243
Oct.	5	86	48	101	267
Nov.	64	85	49	80	183
Dec.	113	143	92	155	202
Jan.	152	163	108	166	279
Feb.	96	133	87	149	190
Mar.	94	108	64	104	217
April	10	37	2	45	252
Total	534	789	453	844	2794
Total flow(Ml)	1590	1833	1833	1833	
Potential area (ha)	298	232	405	217	

According to the questionnaire results, all the vineyard farmers use sprinkler and drip irrigation systems. In order to illustrate the difference in irrigation requirements in a normal season using these two irrigation systems, Figure 4.16 and Figure 4.17 are used. The irrigation requirements with a drip irrigation system are lower compared to a sprinkler system because the efficiency of the drip system is higher, and the wetted area smaller.

It should be noted that water losses accounted for in the SAPWAT model are related only to the efficiency of the irrigation system, and do not include losses due to evaporation and seepage in storage facilities, conveyance losses etc. These additional losses would further decrease the efficiency of the system resulting in smaller areas that could potentially be irrigated.

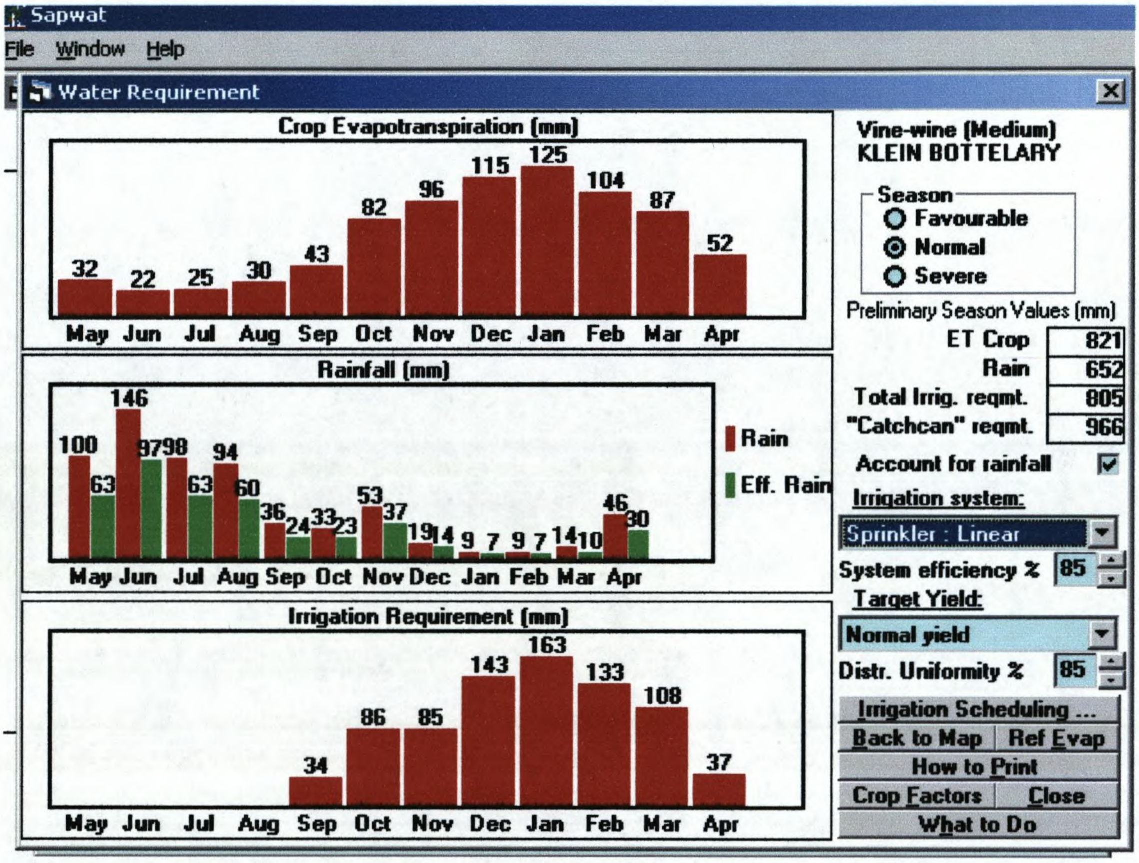

Figure 4.16 Evapotranspiration, rainfall and irrigation requirements for vineyard-wine in a normal season with a sprinkler irrigation system (printout screen of the SAPWAT model).

It should also be noted that irrigation of vineyards with low quality water requires specific management practices, specialized knowledge and skills, as well as maintenance of the irrigation systems, in particular due to possible clogging of equipment (e.g. drippers). Fresh water is therefore the preferred option for farmers, due to the high economic risk associated with high investments and profits from vineyards. Irrigation requirements vary seasonally. They are also different between years due to variability in annual rainfall, distribution of rainfall and different intensity of rainfall events (Friedler, 2001). In the Mediterranean climate of the area, the main irrigation requirements are in the dry summer season, namely December to March, whilst treated effluent is produced throughout the whole year. It is necessary to store the treated effluent during periods of low irrigation requirements in order to meet the demand during the high water consumption season On the other hand, storage reservoirs could also act as maturation ponds and buffer the effluent quality to help produce an effluent suitable for irrigation (Khouri et al. 1994; Friedler, 2001).

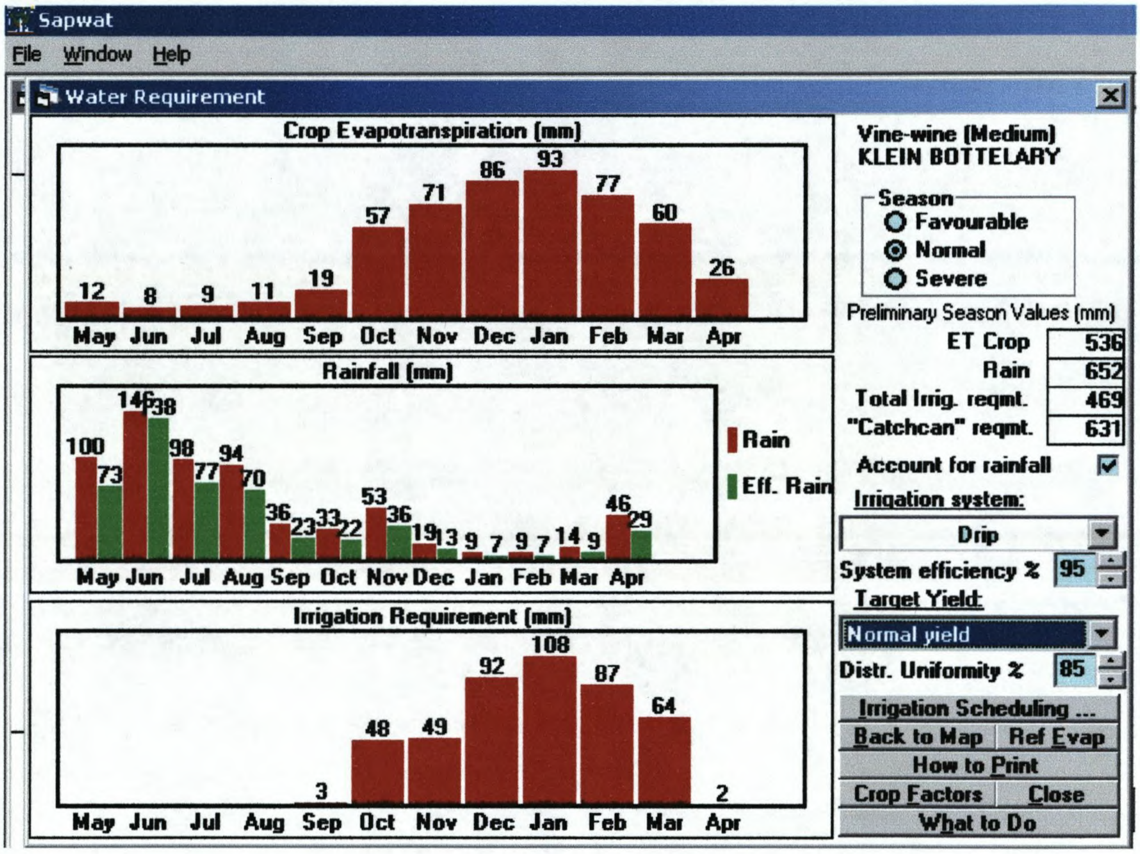

Figure 4.17 Evapotranspiration, rainfall and irrigation requirements for vineyard-wine in a normal season with a drip irrigation system (printout screen of the SAPWAT model).

Effluent could be stored during periods of no irrigation requirements or when the effluent flow is higher than the irrigation requirement. This stored effluent could then be used during the months of peak irrigation requirements. In Table 4.8, the balance of winter effluent flow and summer effluent demand was determined for generic vegetables irrigated in a normal season with a sprinkler irrigation system. Assuming full storage of effluent during periods of low demand, it was calculated that the potential area that could be irrigated is 224.5 ha. In the months when the effluent volume is higher than the irrigation requirements, the excess effluent volume can be stored. The following formula was used to calculate the volume of effluent that can be stored:

Storage (Ml) = Effluent volume (Ml) – Irrigation requirements for the area (mm x ha / 100).

In Table 4.8, the storage capacity in March, April, May and October are positive, and they are 62.1 Ml, 112.8 Ml, 239.4 Ml and 150.3 Ml respectively. A total storage capacity of 564.5 Ml would then be required. The storage facility would be fully filled with water in October (Table 4.8), before the start of the summer season.

Table 4.8 Balance of winter effluent flow and summer effluent demand for generic vegetables irrigated in a normal season with a sprinkler irrigation system

Month	Effluent flow (EF) (Ml)	Irrigation requirements (mm)	Effluent requirement (ER) (Ml)	Cumulative difference between ER and EF (Ml)	Area (ha)
Jan.	279	211	473.695	194.695	224.5
Feb.	190	109	244.705	249.4	
Mar.	217	69	154.905	187.305	
Apr.	252	62	139.19	74.495	
May	291	23	51.635	-164.87	
Oct.	267	52	116.74	-315.13	
Nov.	183	92	206.54	-291.59	
Dec.	202	220	493.9	0.31	

5. Conclusion and Recommendation

This research investigated the use of treated effluent for agricultural irrigation from the points of view of effluent quality, farmers' perception as well as the potential extent of this practice in the Bottelary River area, where the agricultural sector plays a dominant role in the economy.

The research identified that the effluent quality was generally within the standard level in terms of the current 1984 general standard. In some periods, the concentration of some of the variables exceeded the standard. In particular, the concentration of faecal coliform exceeded the standard from October 2003 to October 2004 because the chlorination pond was out of commission due to repairs at the Scottsdene WWTW. The faecal coliform concentration did improve since November 2004. According to the data from November 2004 to April 2005 from the Scottsdene WWTW, the tests complied 20 out of 21 times with the 1984 general standard. The average value of faecal coliform concentration was 884 counts/100 ml during this period. The proposed 2005 and 2010 standards account for NO3 and ortho-PO4 concentration level, and this should be considered in the management of the effluent. The plant license does not stipulate compliance with special standards. However, for specific needs like for example irrigation, it may be advantageous to comply with special standards.

According to the SA water quality guidelines, the effluent from the Scottsdene could be used for irrigation, but with caution. The target water quality ranges could be used as recommendation for concentrations of water quality variables in irrigation water. If these variables' concentration in treated effluent exceeded the target range, the risks of surface water and groundwater pollution through discharge and seepage would increase. The high concentration of specific ions would damage the crop leaves if sprinklers are used and finally result in yield losses. In the long run, this may affect the soil physical and chemical properties. Irrigation equipment could also be impacted by the poor quality effluent, through clogging of emitters and corrosion of pipes.

In terms of the SA effluent reuse guide, the Scottsdene WWTW generally produced good quality of final treated effluent, although there were some technical problems influencing the effluent quality. The treated effluent could be used for irrigation of crops that are not eaten raw, if the faecal coliform concentration level is less than 1000 counts/100 ml.

As shown in this research, treated effluent is currently being used for agricultural irrigation in the Bottelary River area. Farmers who are close to the river and treated effluent sources pump the effluent to irrigate crops. Accessibility of water was indicated as one of the main limiting factors by farmers. Most of the farmers were aware of water shortage problems in the study area. Farmers that are not using effluent displayed a willingness to practice effluent irrigation. The focus was on the effluent quality and the health impact to the humans, crops and soil. The existing users were satisfied with effluent irrigation. Few of them were concerned about the poor quality effluent impacting the soil and human health.

It should also be noted that, due to the high investment and management costs in vineyards, high quality effluent needs to be guaranteed and specific management practices need to be ensured on vine farms, in order to avoid financial losses that could be detrimental to the business.

The research results suggested that, during the dry summer season, the treated effluent could act as an additional water resource to serve a large area. During the wet winter season, the irrigation requirements were low. If the treated effluent could be stored in dams during winter, it could then satisfy the summer peak demand from large areas.

Based on the discussion above, the following recommendations can be made:

1. Most of the farmers need a constant supply of treated effluent of good quality. This can minimize the potential risks to the surface and groundwater, to the crops and soil when using effluent irrigation. The improvement in the treatment processes can lead to

a higher quality of final effluent. In this case, the maintenance of the treatment works also needs to be monitored regularly in order to ensure good effluent quality for the intended purpose, as well as to comply with the 1984 general standard.

2. The Bottelary River area is a good example for similar studies in adjacent regions which have similar conditions of water scarcity, social economic factors, and treated effluent production. The findings and conclusions of this study can be applied in these regions.

3. The infrastructure for distributing the treated effluent is lacking and this represents an obstacle for implementing the effluent irrigation. The infrastructure should be considered seriously in the plan and design procedure. The building of storage dams is also needed in order to balance the effluent demand and supply. Water quality in storage facilities needs to be controlled in order to prevent eutrophication and contamination of surface and groundwaters.

The design of effluent irrigation in a broader area can be planned. Farmers' involvement is important in this process. Education, information and training of farmers are essential for the operation of effluent irrigation. These may include management of effluent water and specific on-farm practices. They also play an important role in promoting future reuse practices.

Western Cape is experiencing water scarcity problems. The use of treated effluent for agricultural irrigation can release the pressure on fresh water resources. In short, the results of the data analysis reveal that the use of the treated effluent for agricultural irrigation has a promising future. However, it should be highlighted that further research is required to determine the effects of irrigation with treated effluent on crops, soil, surface waters and groundwaters. This could be done by:

1. Establishing field trials aimed at optimizing agricultural practices (e.g. fertilization, tillage, weed control etc.) in order to achieve optimal crop yields under irrigation with

treated effluent.

2. Monitoring soil physical and chemical properties in order to identify potential short- and long-term impacts of irrigation with treated effluent.

3. Establishing a monitoring programme for surface and groundwaters that may be impacted by effluent irrigation in the short- and long-term.

Research considering the health impact, agricultural productivity, economic feasibility and other socio-cultural aspects should also be carried out.

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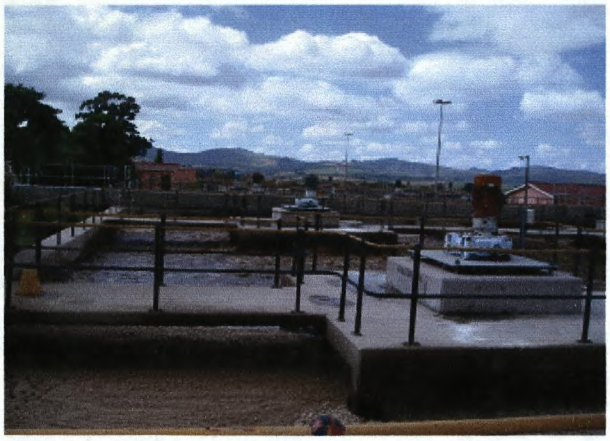
Appendix A:

Wastewater treatment processes in the Scottsdene wastewater treatment works

I. Input (Raw wastewater flows into the Scottsdene WWTW)

II. Separator (Screening and grit removal of the raw wastewater)



III. Aerobic pond (mechanical aerators introduce air to the wastewater)

IV. Anoxic pond (Removal of nitrogen by microorganisms to optimize the operation conditions)

V. Sedimentation pond (Activated sludge is separated from the wastewater)

VI. Maturation pond (further purification of the relatively clean wastewater takes place)

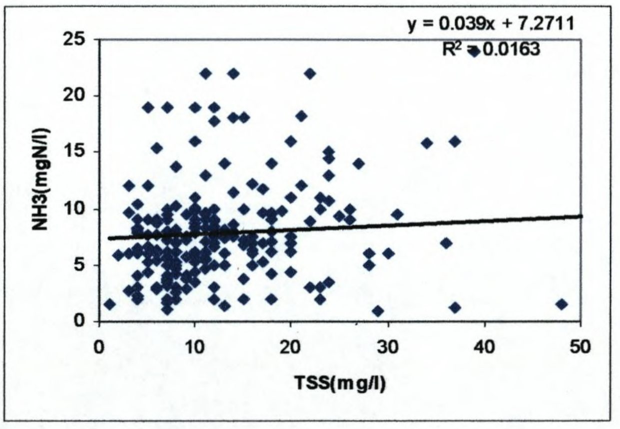
VII. Chlorination pond (Killing off the harmful bacteria)

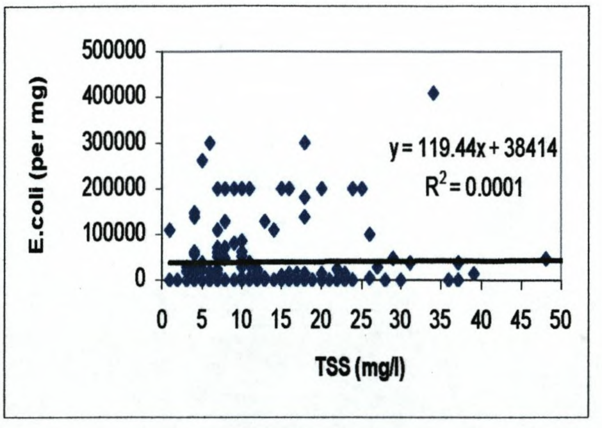
VIII. Outlet just outside WWTW (Final effluent discharges into the river)

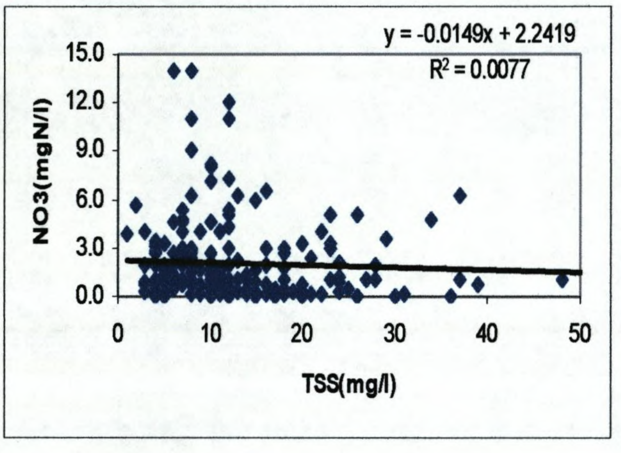
IX. Dry bed (Sewage sludge allows to be dried before removal)

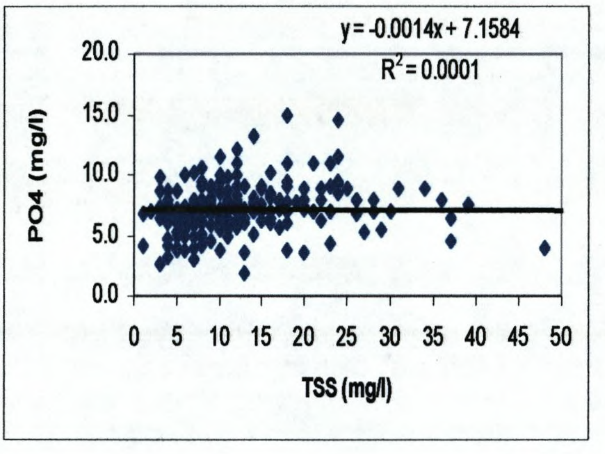
Appendix B:

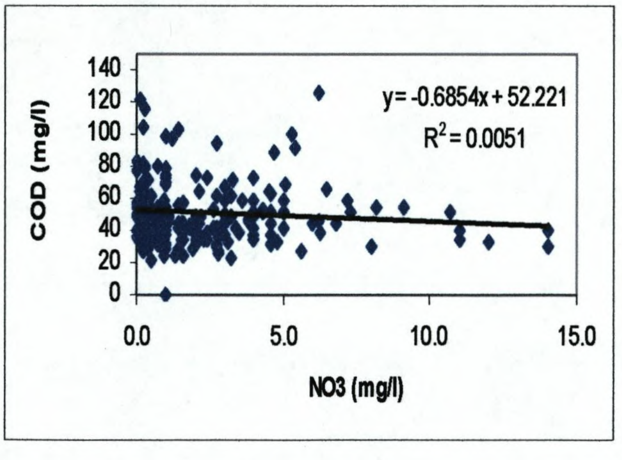
Correlation graphs of effluent quality variables

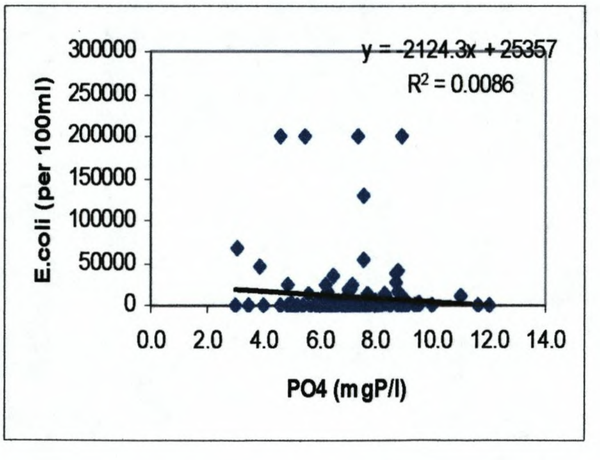


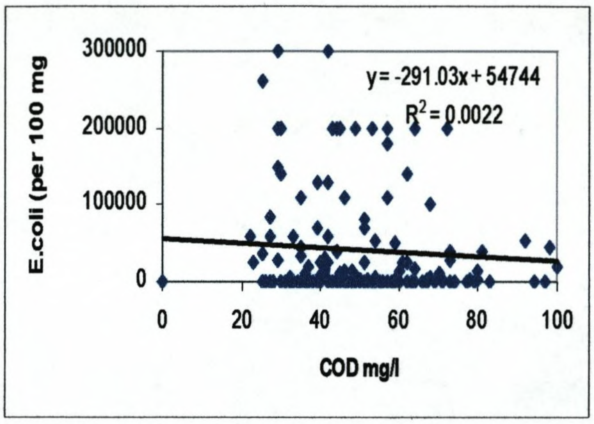


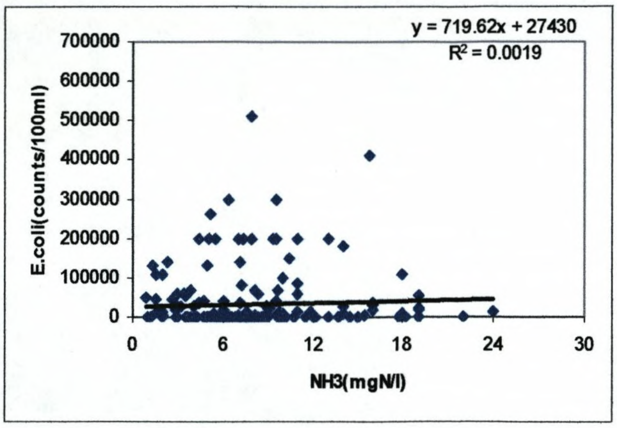


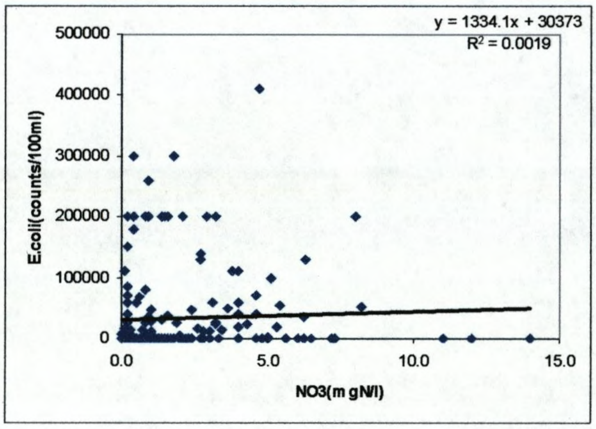


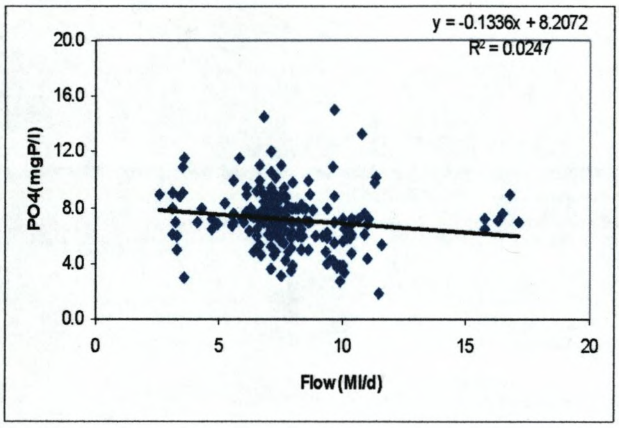


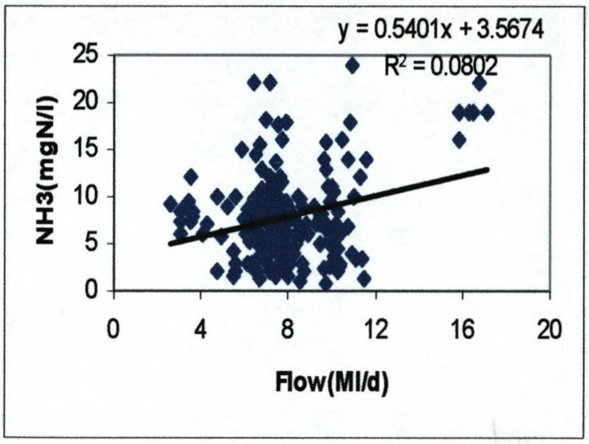


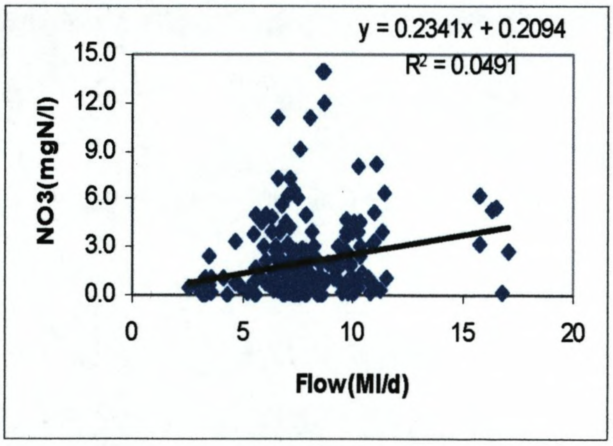

E.coli (per 100 mg
y= -291.03x + 54744
R2 = 0.0022
300000
200000
100000
0
0
20
40
60
80
100
COD mg/l

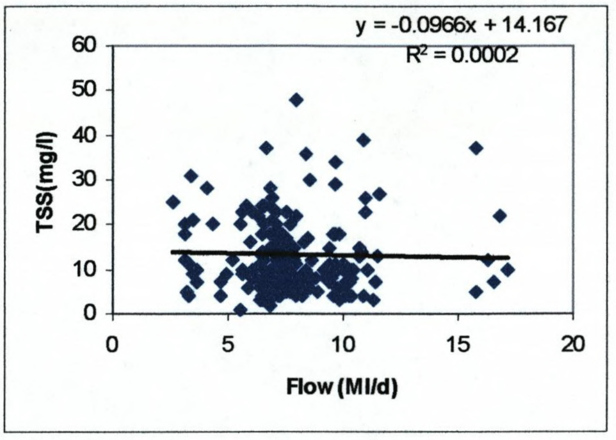

y = 719.62x + 27430
R2 = 0.0019
E.coli(counts/100ml)
700000
600000
500000
400000
300000
200000
100000
0
0
6
12
18
24
30
NH3(mgN/l)

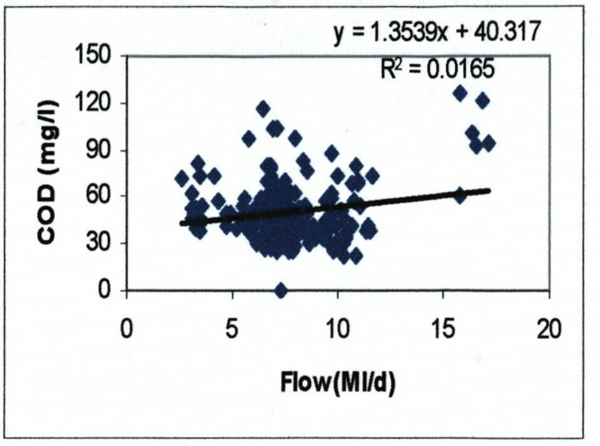

y = 1334.1x + 30373
R2 = 0.0019
E.coli(counts/100ml)
500000
400000
300000
200000
100000
0
0.0
5.0
10.0
15.0
NO3(m gN/l)

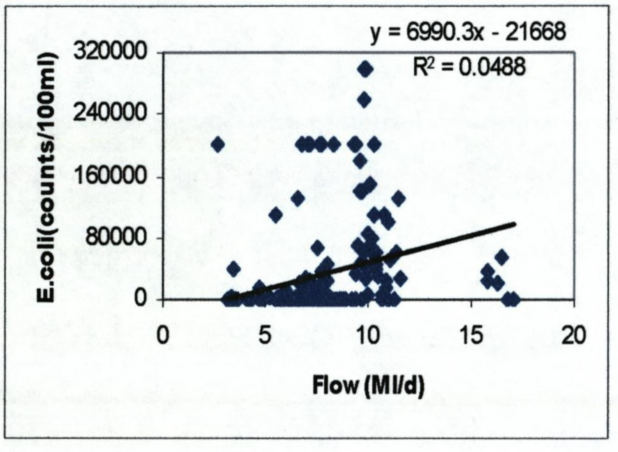

y = -0.1336x + 8.2072
R2 = 0.0247
PO4(mgP/l)
20.0
16.0
12.0
8.0
4.0
0.0
0
5
10
15
20
Flow(Ml/d)


y = 0.5401x + 3.5674
R2 = 0.0802
NH3(mgN/l)
25
20
15
10
5
0
0
4
8
12
16
20
Flow(Ml/d)


y = 0.2341x + 0.2094
R2 = 0.0491
NO3(mgN/l)
15.0
12.0
9.0
6.0
3.0
0.0
0
5
10
15
20
Flow(Ml/d)


y = -0.0966x + 14.167
R^2 = 0.0002
TSS(mg/l)
Flow (Ml/d)


y = 1.3539x + 40.317
R^2 = 0.0165
COD (mg/l)
Flow(Ml/d)


y = 6990.3x - 21668
R^2 = 0.0488
E.coli(counts/100ml)
Flow (Ml/d)

Appendix C:

Questionnaire on irrigation with treated effluent (wastewater)

Instructions:

For multiple choices, circle your answers.

For Yes/No question, Tick (√) in the box.

<u>Social economic factors</u>

1. Gender

A. Female

B. Male

2. Age

A. Under 20 B. 20-30 C. 31-40

D. 41-50 E. 51-60 F. Over 60

3. Education

A. No Schooling

B. Highest standard attained: (specify) ______________________

4. What is the total area of your farm? ________________

5. What is the percentage of your land irrigated with:

A. Fresh water________________

B. Treated effluent (treated wastewater)________________

C. Other waters(Specify) ________________

6. Will you extend the area irrigated with fresh water?

Yes ☐ No ☐

7. Will you extend the area irrigated with treated effluent?

Yes ☐ No ☐

8. Will you extend the area irrigated with other water sources?

Yes ☐ No ☐

9. What type of crops do you grow?

Season	Crop	Planting date	Harvest date	Irrigated			Dry land
				Fresh water	Waste-water	Other waters	
Summer							
Winter							

10. What irrigation method do you use? (Select all that apply)

A. Sprinkler

B. Pivot

C. Drip

D. Microjets

E. Furrows

F. Basins

G. Subsurface (underground pipes)

H. Others (specify)

11. What type of fertilizer do you use? (Select all that apply)

A. Chemical fertilizer

B. Organic fertilizer

C. Sewage sludge from wastewater treatment works

D. Others (specify) ____

12. Where do you get your irrigation water from? (Select all that apply)

A. Private farm dam

B. Communal farm dam

C. Irrigation board

D. River water

E. Wastewater

F. Ground water (borehole)

G. Other (specify) ____

13. Do you think there is a water shortage problem in your area?

Yes ☐ No ☐

14. What do you think about the treated effluent from the wastewater treatment work? (Select all that apply)

A. It has no use

B. It can be used for some purposes, depending on its quality

C. It can be used for irrigation at any time

D. It should be used for irrigation with caution

E. It is harmful

F. Have no idea

G. Others (specify) ____

<u>**Treated effluent**</u>

15. Do you use treated effluent in growing your crops?

Yes ☐ No ☐

If No, proceed to questions 16 - 20

If Yes, proceed to questions 21 - 26

16. Have you ever considered using treated effluent for growing crops?

Yes ☐ No ☐

17. What made you decide not to use treated effluent for growing crops? (Select all that apply)

A. Never heard of it

B. The effluent is too far from my farm

C. It has negative impact to the health

D. Customers won't buy the products irrigated by treated effluent

E. In my culture, it is not allowed

F. Land is not available

G. Any other reason? ____

18. Would you prefer using treated effluent to fresh water? (Select all that apply)

A. If treated wastewater can be made available

B. If the quality of the water can ensure good crops

C. If consumers accept the products irrigated with treated effluent

D. After getting more information on how to use this kind of water properly

E. If treated wastewater can save more money than fresh water for irrigation

F. Only during drought season

G. If I cannot afford fertilizer costs

H. Never

I. Other (specify) ____

19. What would your concerns be on treated effluent irrigation? (Select all that apply)

A. Effluent quality will influence the soil

B. Effluent quality will influence the crop yields

C. Negative effect to the profit

D. Environmental risks

E. Health hazards to human beings

F. None

G. Others (specify) ____

20. How do you feel about farmers using treated effluent to grow crops?

____

____

____

____

Your answer can stop here, many thanks for your participation.

If the answer for Question 15 is Yes, please answer the following questions

21. Why do you use treated effluent to irrigate the crops? (Select all that apply)

A. It is easy to get the treated effluent

B. It conserves fresh water resources

C. Fresh water is expensive

D. More nutrients contained in this water can be used as fertilizer

E. Others (specify)____

22. How do you know treated effluent can be used for agricultural irrigation? (Select all that apply)

A. Information from media (TV, newspaper, broadcast, internet etc.)

B. Friends and other family members mentioned about it

C. From Government representatives

D. From private consultants

E. From scientists

F. Others (specify) ______________________________________

23. What are your concerns on treated effluent irrigation? (Select all that apply)

A. Effluent quality will influence the soil

B. Effluent quality will influence the crop yields

C. Negative effect to the profit

D. Environmental risks

E. Health hazards to human beings

F. None

G. Others (specify) ______________________________________

24. From your point of view, what are the advantages of effluent irrigation? (Select all that apply)

A. It saves fresh water

B. It saves fertilizer

C. It can be used anytime (it is reliable)

D. I don't know

E. Others (specify) ____

25. From your point of view, what are the disadvantages of effluent irrigation? (Select all that apply)

A. It does harm the crops and lowers the profits

B. It does harm human health

C. It has negative effects to the environment

D. None

E. Others (specify) ____

26. How do you feel about farmers using treated effluent to grow crops?

____

____

____

____

Many thanks for your participation

Appendix D:

Cadastral map of the Bottelary River Area (the yellow line indicates the main stream of the Bottelary River, the plots triangles indicate the sampling farm)