Water Reclamation for Direct Re-Use in Urban and Industrial Applications in South Africa and its Projected Impact Upon Water Demand

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by
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WATER RECLAMATION FOR DIRECT RE-USE IN URBAN AND INDUSTRIAL APPLICATIONS IN SOUTH AFRICA, AND ITS PROJECTED IMPACT UPON WATER DEMAND

A STUDY FOR THE WATER RESEARCH COMMISSION

BY

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EXECUTIVE SUMMARY

Water reclamation, or the direct use of treated sewage effluent to replace a proportion of the fresh water demand, is regarded as a non-conventional approach to water management. However, water reclamation is becoming increasingly common internationally, especially in countries which have water shortages similar to that in South Africa.

In the past, investigations have centred upon treatment of sewage effluent to potable standard for re-use in the main water distribution system, as has been implemented in Windhoek, Namibia, since the 1960s. This report however focuses upon the use of water reclamation to meet non-potable requirements, since only a fraction of actual water consumption requires water of a potable standard. As well as conserving freshwater resources, this may also result in a considerable saving over time in terms of treatment costs, since the level of treatment is matched to the water quality requirement for a particular application.

This study investigated the possibilities of intensifying water reclamation in a number of South African applications. After assessing its significance within the national water balance, various potential applications of reclaimed water, with examples of where these have been implemented both internationally and locally were investigated. Water quality issues are addressed by discussing guidelines for the water quality necessary to reclaim water for various applications, and investigating the typical quality to which sewage effluent is treated in South Africa. The most promising applications of water reclamation in the South African context have been assessed through detailed case studies, which appear in the appendices to this report. These applications are as follows :

- Firstly, urban re-use in coastal cities, where treated sewage effluent is currently released directly to sea. [Case studies: Cape Town and Durban]
- Secondly, direct industrial re-use of treated sewage. [Case study : the paper industry]
- Thirdly, new industrial developments which can and should be planned to use reclaimed water. [Case study : Capricorn Park in Cape Town]

Finally, the social, institutional and other constraints presently preventing the wider usage of reclaimed water were investigated, informed by both international and local experience. Recommendations are made to overcome these constraints, together with broader policy issues that need to be addressed.

Current water demand and sewage production in South Africa, based on the data available, showed that there is great potential for the re-use of treated sewage effluent (TSE).

Total water demand (1996)	20 045 x 10^6 m^3/a
Demand in urban/domestic sectors	2 171 x 10^6 m^3/a
Demand in industry/mining outside urban areas	1 598 x 10^6 m^3/a
TSE production from urban and domestic (estimated)	**1 086 x 10^6 m^3/a**

From these estimates, it can be seen that reuse of TSE in various applications has significant potential to affect the demand in certain sectors. Treated sewage effluent represents some 5% of the total water demand for South Africa. However, for the industrial and urban sectors, the report shows how the potential impact on demand for raw water could be much greater than 5%, were the usage of reclaimed water to be intensified.

Various applications, as well as the current levels of usage of reclaimed water internationally and, to a lesser extent, locally, were explored. Potential applications for reclaimed water include:

- Agriculture / irrigation
- Construction (dust control, soil settling and compaction, aggregate washing, concrete making)
- Domestic - non-potable (fire fighting, car washing, toilet flushing, garden watering), industrial (cooling towers, boiler feed, quenching)
- Groundwater recharge (recharge of aquifers)
- Return to rivers
- Potable water (drinking water, either supplied directly or blended with raw water)

A number of international examples of applications for using reclaimed water were found. From these reports, which represent but a few of the international initiatives for using reclaimed water, it can be identified that the applications for projects which make use of reclaimed water are broad, especially in a country with limited water resources like South Africa. These examples may assist in identifying where the potential lies for intensifying water reclamation in South Africa. Countries which have put in place policy initiatives for intensifying the use of reclaimed water include Israel, the USA, Japan and most recently, Australia. Israel currently leads the field, re-using 84% of the total treated sewage effluent (TSE) produced in the country. South Africa, on the other hand, is estimated in this report to re-use less than 3% of the TSE which is available.

The appropriateness of a reclaimed water supply for reuse depends on three factors: the quality to which the water is treated; the consistency of treatment quality (i.e. can the reclaimed water user be guaranteed of a regular quality of water?); and the cost implications of reuse. A number of countries have set standards for acceptable qualities of reclaimed water in various reuse applications. Although the acceptability for reuse depends on the physical, chemical and microbiological quality of the water, the main concern regarding reuse of water in all applications is generally the microbiological quality of the water. Factors which affect the quality of reclaimed water include source water quality, wastewater treatment processes and treatment effectiveness, treatment reliability, and distribution system design and operation.

The investigation into the standards applied for treatment of reclaimed water showed that standards for treatment vary from country to country, and depend on the proposed water reuse. Certain standards specify the required treatment technologies to be used in wastewater treatment.

- In **irrigation**, which is one of the most widespread uses for reclaimed water, required qualities depend on how irrigation is to be carried out (drip, subsurface or spray irrigation), and whether crops are to be consumed raw or cooked. Irrigation guidelines should, but do not always, take into account also the protection of farm workers and their families. Irrigation standards are generally set for coliform concentrations, and, in some cases, for parasites and viruses.
- For direct and indirect **potable**, and **domestic non-potable** use, standards are more stringent. Here both coliforms and viruses and parasites need to be closely monitored. A number of additional physical and chemical water quality specifications also need to be met to ensure protection of users.
- No standards for reuse in **industrial** applications are generally set as the water quality required by industrial users will vary depending on the application for which the water is required.

In a situation of water stress, the increasing demand for water caused by urbanisation and industrialisation must ultimately be matched by increasing intensity of land-based treatment and recycle, or in other words, by water reclamation. This may make available for use a total amount of water which is many times the supply of raw water available, depending on the extent of losses from the water system, and the number of times water is recycled through the system. There are many factors causing losses in the water loop, through leakage, evaporation, or use of water for irrigation, for instance. Between 35% and 65% of the total urban and industrial water consumption is typically produced as treated sewage effluent in South African cities and towns. It is possible to aim towards a "zero effluent" scenario whereby all of this remaining water is reclaimed, and kept within the human water management loop. Water reclamation strategies can significantly delay the need for fresh water resources to be developed in order to meet increasing demand.

The case studies in this report investigate the major potential applications of reclaimed water in South Africa, which could be implemented within a short time span. Coastal cities are already beginning to look seriously at intensifying water reclamation efforts, driven by the re-valuation of water brought about by the introduction of the National Water Act of 1998. The **Cape Metropolitan Area**, which currently discharges almost all its treated sewage effluent to sea, is developing a detailed policy for reclaiming water, primarily for industrial and irrigation use. Re-charge of the Cape Flats Aquifer with treated sewage effluent is also being re-investigated. The policy is to be presented to the Cape Metropolitan Council for debate during 1999. **Durban Metro Water Services**, on the other hand, has pro-actively pursued a public-private partnership arrangement which will allow for the reclamation of up to 30 Ml/day from the Southern wastewater treatment works. The reclaimed water will be sold to industrial clients, from a tertiary treatment plant which will be operated by a private water company

Re-use of treated sewage effluent (TSE) in industrial applications is an area which requires active promotion. Innovative schemes such as that adopted by Durban Metro Water Services will undoubtedly raise the profile of this type of application. The driving force will be the difference in cost between the reclaimed water and potable water, and the availability of the reclaimed water. Cost incentives such as tax rebates are needed to make these projects feasible and attractive. Small, localised schemes will have the highest chances of success. As the Durban example shows, retro-fitting dual reticulation in existing developments may be economically feasible in many cases, depending on the incentives which are provided. The **paper industry** in South Africa is the major industrial user of treated sewage effluent, in a number of plants around the country. Valuable experience has been gained and the paper industry will provide a positive role model for other potential industrial users.

Since South Africa is in a rapid development phase, **new industrial developments** should be specially targeted to ensure that re-use of TSE is implemented. The case study of Capricorn Park, which is planning to use reclaimed water for irrigation only, rather than to supply to its industrial customers, illustrates some of the constraints and resistances to the re-use of TSE which currently exist.
In order to ensure that developers are required to consider facilities for providing reclaimed water, a feasibility study on the re-use of TSE should be a prerequisite for approvals for subdivision, for all major new developments.

Existing institutional, economic, technical and social constraints to water reclamation in South Africa are reported. The following recommendations to overcome these are :

- To encourage local authorities to implement projects for reclaimed water usage, the Department of Water Affairs and Forestry should consider imposing targets for reuse to individual local authorities, within the framework of water demand management.
- To make the use of reclaimed water attractive to customers on a cost basis. Cost incentives for reuse should be formally implemented within tariff structures.
- To ensure a constant, reliable supply of treated sewage effluent of consistent quality from wastewater treatment works whose effluent is re-used, especially in agricultural applications where water quality is a major issue. Tertiary treatment needs to be considered for reuse in industrial applications.
- To address issues of possible public concern, where projects involving the reuse of TSE are implemented. Education programmes need to be set up which may be in the form of newspaper reports, pamphlets, flyers and public meetings. The nature of such communication will depend on the proposed use for the TSE.
- To address the need for national policy and strategy in water reclamation, through the development of guidelines.

For large industries and power plants situated far from urban centres, it is apparent however that the high cost of long-distance distribution pipelines will continue to constrain the possibility of usage of reclaimed water. Given the size of South Africa, and the sparse population in certain areas, it is inevitable that some large water users in industry and mining may never be served by reclaimed water. It is important therefore to focus upon specific regions and local authorities where the development pattern lends itself to intensifying water reclamation.

In the initial phase of promoting water reclamation, coastal towns and cities should be targeted. However, this study argues that the water management system in inland areas should also be re-examined, carrying out thorough salt and nutrient balances for specific areas. There are potentially large savings in avoiding treatment costs in treating water to potable standard for industrial use, as well as for irrigation. Both in terms of cost and in terms of conserving freshwater resources, water reclamation must become a vital part of South Africa’s water management strategy for the future.

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1. Introduction

South Africa is a country with limited water resources and a rapidly growing population. With increasing industrial and urban development, the demand on the country's water resources is nearing the point where conventional supplies will soon be exceeded. This has already happened in many catchments around the country. In 1995 there were more than 12 million people in South Africa who did not have adequate access to drinking water [DWAF (1997a)]. Since water is a basic requirement for all development, the supply of water has been identified as a primary objective of the Reconstruction and Development Programme. The RDP aims, however, to meet more than the basic needs of the people - it aims towards social restructuring to create a more efficient and equitable society. Affordable ways must therefore be found to ensure that the water needs of the whole population and of economic development are met.

Planning for the water needs of the country in the future is a complex task, and non-conventional areas must now be addressed to supplement the two major areas of water resource management and water demand management. Water reclamation, or the direct use of treated sewage effluent to replace a proportion of the fresh water demand, is such a non-conventional approach. Internationally, especially in countries which have water shortages similar to that in South Africa, water reclamation is becoming increasingly common. In South Africa, as this study will show, most of the sewage effluent produced is treated and then released into rivers or oceans. Less than 3% of the available treated sewage effluent is directly reused. Increasing the usage of reclaimed water in certain applications is therefore a viable way of reducing the demand for fresh water, which needs to be promoted and incorporated into policy decision-making.

In the past, investigations have centred upon treatment of sewage effluent to potable standard for re-use in the main water distribution system, as has been implemented in Windhoek, Namibia, since the 1960s. This report however focuses upon the use of water reclamation to meet non-potable requirements, since only a fraction of actual water consumption requires water of a potable standard.

In this document, "water reclamation" is used as the generic term for the various practices and applications of re-using or recycling treated sewage effluent, industrial effluent, or wastewaters, although the words are used interchangeably. The term water reclamation is preferred for a number of reasons : it is increasingly the accepted term used in the international literature; it carries a positive environmental connotation; and it avoids the negative social connotations that the terms "wastewater re-use" or "re-use of treated sewage effluent" carry for many people.

This study investigates the possibilities of intensifying water reclamation in a number of South African applications. After assessing its significance within the national water balance, we present various potential applications of reclaimed water, with examples of where these have been implemented both internationally and locally. Water quality issues are then addressed by discussing guidelines for the water quality necessary to reclaim water for various applications, and investigating the typical quality to which sewage effluent is treated in South Africa. The most promising applications of water reclamation in the South African context have been assessed through detailed case studies, which appear in the appendices to this report. These applications are as follows :

- Firstly, urban re-use in coastal cities is an obvious candidate, where treated sewage effluent is currently released directly to sea. [Case studies: Cape Town and Durban]
- Secondly, direct industrial re-use of treated sewage effluent, which cuts down on treatment costs, may be viable anywhere in the country. [Case study : the paper industry]
- Thirdly, new industrial developments which can and should be planned to use reclaimed water. [Case study : Capricorn Park in Cape Town]

Finally, the social, institutional and other constraints presently blocking the wider usage of reclaimed water are summarised, informed by both international and local experience. Some ways forward in terms of removing these constraints are recommended, together with broader policy issues that need to be addressed in order to intensify water reclamation in South Africa.

2. Definitions, Acronyms and Units

Acronyms

ASR	Aquifer Storage and Recovery
CMC	Cape Metropolitan Council
CSIR	Council for Scientific and Industrial Research
DMWS	Durban Metro Water Services
DWAF	Department of Water Affairs and Forestry
RMB	Rand Merchant Bank
TSE	Treated Sewage Effluent

Definitions

Grey water:	Wastewater from washing applications such as bathrooms, washing machines and sinks, which may be suitable for irrigation of gardens.
Water balance:	The calculation of the inputs and outputs into the water supply and treatment loop.
Water cycle:	The cyclical process of evaporation or transpiration, followed by condensation, precipitation (as rain or frost), and percolation into the ground or surface runoff into surface water bodies.
Water reclamation :	The direct re-use of treated sewage effluent to replace a proportion of the fresh water demand.
Water supply and treatment loop:	Water is extracted from rivers, dams and lakes, and then used either directly for agricultural or industrial purposes, or treated to the standards required for potable or other uses. Used water then returns either to rivers or to the sea. This loop is shown in Figure 2.1 overleaf. Also shown in this figure is the path for the direct reuse of TSE.

Units

The standard units used throughout this document are:

Cubic metres per annum (m^3/a),
Million cubic metres per annum ($x10^6$ m^3/a)
Megalitres per day (Ml/day)

To convert from:	To:	Multiply by:
Gigalitres	Megalitres	0.001
Gigalitres	m^3	10^6
Litres	m^3	0.001
Megalitres	Gigalitres	1000
Megalitres	m^3	1000
Megalitres	10^6 m^3	0.001
Ml/day	10^6 m^3/a	0.365
m^3	acre foot	$1.235x10^{-3}$
10^6 m^3/a	Gigalitres/yr	1
US gallon	m^3	$4.546x10^3$

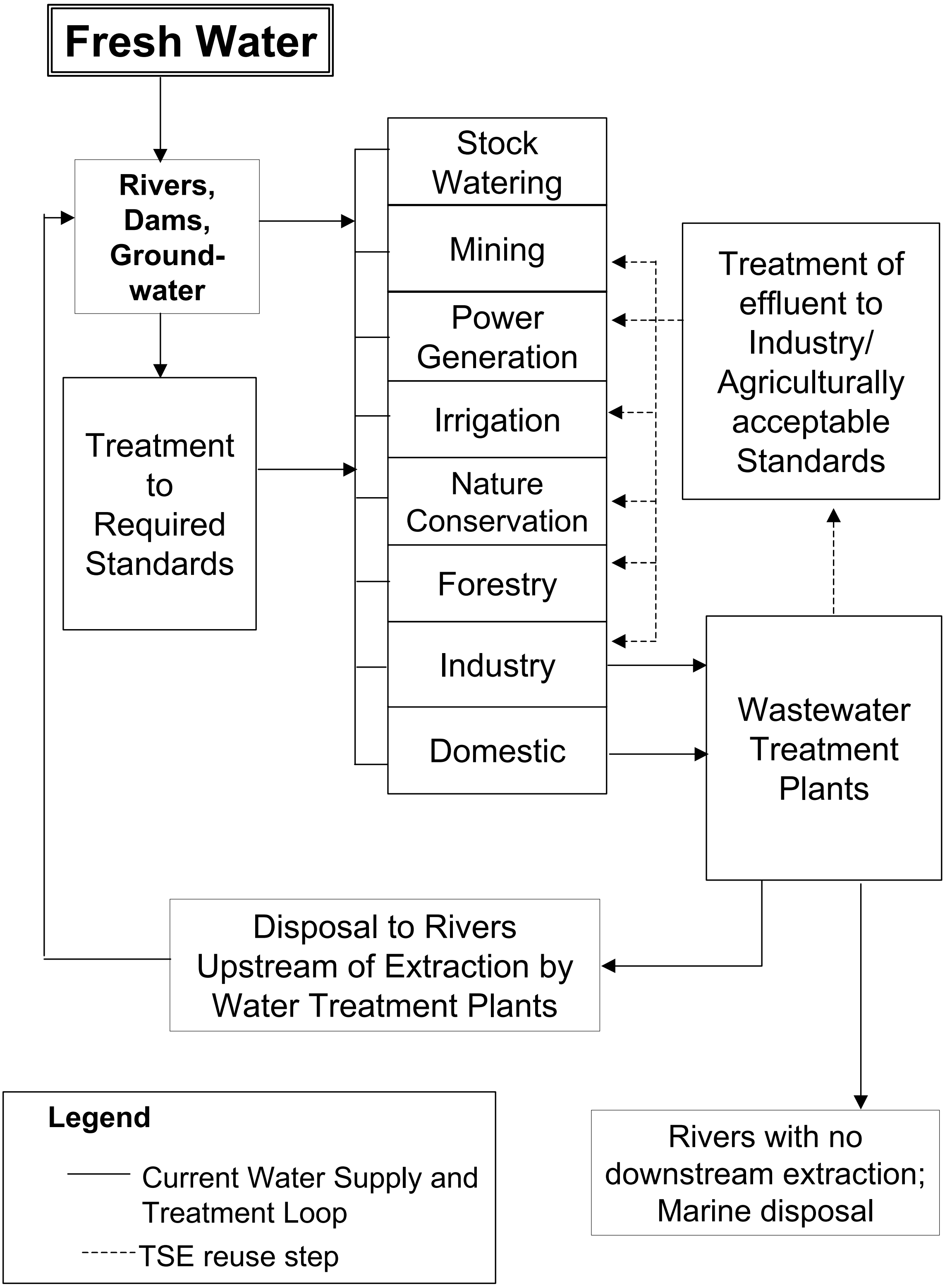


Figure 2.1 – Simplified Water Supply and Treatment Loop

3. Current Water Demand and Sewage Production in South Africa

3.1 Information Sources

The most comprehensive information regarding water demand for South Africa is currently found in a study, entitled 'Overview of Water Resources Availability and Utilisation in South Africa' [DWAF (1997b)]. This provides an estimated breakdown of water usage in four sectors (Agriculture and Forestry, Domestic and General Urban, Mining and Industry and Environmental) for the country as a whole, and for seven catchment areas. The document also provides a prediction of the water demand in the year 2030, based on the current growth in demand.

Information used in the estimation of sewage production in South Africa was gathered from personal communication with individuals within various local and government authorities. These are referenced accordingly throughout the text. There is currently no study available on sewage production, and in the case of many municipalities this information is not easy to access, as there is no central database containing details of all sewage treatment plants.

3.2 Current Water Demand in South Africa

An estimate of the 1996 demand for water was as follows:

Table 3.1 – Sectoral Water Demand in South Africa [DWAF (1997b)]

Activity	**Total water consumption (10^6 m^3/a)**	**Percentage of total**
Agriculture and Forestry[1]	12344	61.6%
Domestic and general urban	2171	10.8%
Mining and large industry[2] outside urban areas	1598	8.0%
Environmental water requirements	3932	19.6%
Total	**20045**	**100%**

Total water usage for South Africa, including Lesotho and Swaziland, is thus estimated to be 20 045 x 10^6 m^3/a for 1996. Agricultural and forestry usage currently represents the highest proportion, over 60% of the total water demand. Environmental water requirements are the in-stream flow requirements of rivers, lakes and estuaries for environmental purposes.

The total requirement for domestic, urban and industrial usage is expected to double in the next 30 years, growing at a rate of 3% per annum. The rate of growth in demand will be influenced by growth in population, industrial growth and the extent to which water is supplied to people and areas who currently have no supply.

The amount of water used by each sector varies from region to region. DWAF divides the country into seven drainage areas (DWAF (1997b)]. Table 3.2 below presents a breakdown of usage in each of these drainage areas.

[1] Of this value, approximately 54% is used in irrigation, with the balance going to forestry.
[2] This includes big users such as Sasol, Eskom and Sappi. Smaller and general industries are included under urban water use.

Table 3.2 – Breakdown of Water Requirements for the Regions indicated on the Map (10^6 m^3/a)

Region	Urban and Domestic	Mining and Industrial	Irrigation and afforestation	Environ-mental	Total
Northern	704	433	1861	375	3373
Eastern Inland	150	44	1826	300	2320
Eastern Coastal	508	589	2217	2290	5604
Southern Coastal	137	41	1350	240	1768
South Western	351	105	1570	370	2396
Karoo	65	10	2173	307	2555
Central	256	376	1347	50	2029
TOTAL	**2171**	**1598**	**12344**	**3932**	**20045**

Usage in the Northern region is dominated by irrigation requirements. Significant mining and industrial use occurs in the upper Crocodile and upper Olifants basins. Formal domestic use of water is concentrated in the urban areas, while a large number of people in the rural areas do not have adequate access to water. In-stream flow requirements for environmental purposes are relatively low due to the natural variability and intermittent nature of the flow of rivers in the area. The enormous concentration of industrial and mining demand for water on the Reef is split between the Central and Northern regions, as Gauteng itself is located on a watershed.

The Eastern Inland region has high irrigation requirements for production of sugar cane, citrus and subtropical fruit. Once again, several hundred thousand people in rural areas have no formal domestic supplies of water available. The Sabie River is one environmentally important river in the region, as are the flood plains along the Phongola River.

The Eastern Coastal region, extending from below East London to the Mozambique border, and including a large part of the KwaZulu Natal region, demonstrates the highest demand for irrigation/afforestation and environmental usage. The former is attributable to cultivation of sugar cane and subtropical fruit, and forests grown for paper-making. The area also has considerably higher environmental requirements than other regions, particularly in the Mzimbubu Basin. The Mkuze Swamp and Lake St Lucia are of specific environmental importance in the area.

The irrigation requirements of the Southern Coastal region are for fodder (lucerne), annual crops and citrus production. Domestic and industrial consumption is primarily concentrated around Port Elizabeth. Areas of specific environmental importance are the Tsitsikama forest and coastal area and the Knysna, Swartvlei and Wilderness lakes and lagoons. Several other important river mouths lie in the area, including those of the Fish, Sundays and Outeniqua rivers.

The South Western region, which includes the Western Cape discussed further in this report, requires water for irrigation of fruit, vineyards and citrus production. The greatest future increase in water requirements is foreseen for the urban areas due to population growth, migration and general industrial and socio-economic development. Once again, several estuaries, river mouths and wetlands of environmental importance exist in the region, including the lower Palmiet River, Langebaan Lagoon and the lower Berg River.

The Karoo region, being particularly arid, also has a high demand for irrigation water. The region's urban usage is very low, with Bloemfontein being the only major urban centre. An important environmental use is the maintenance of salinity balances and the saltwater marshes at the mouth and estuary of the Orange River.

The Central Region comprises the total Vaal River basin with its tributaries. The largest use in this area is irrigation, followed by mining and industrial use, with a similar proportion also going to urban and domestic use. Little growth is foreseen in irrigation use. The main mining, industrial, urban and domestic uses are the larger cities, the gold mining areas, the Sasol petrochemical industries and cooling water for thermal power generation. Population growth, migration, improved standards of services and industrial and economic growth will lead to high growth rates in demand for the urban, domestic and industrial sectors.

3.3 Estimation of the Current Production of Treated Sewage Effluent

Due to the fact that no centralised information is available regarding the production of treated sewage effluent (TSE) suitable for reuse in South Africa, it was necessary to calculate an estimate thereof based on production of TSE from areas where figures are available.

The following assumptions were made in performing this calculation:

(i) The major source of TSE which is suitable for reuse is effluent to water treatment works from the "Urban and Domestic" sector of water users. This includes industry which is located within urban areas, but excludes large industrial water users outside of urban areas, and mines. These usually discharge directly to rivers and other water bodies, after on-site treatment. Effluent from domestic use is more suitable for reuse than industrial effluent or mine drainage, as these complex effluents are more difficult and expensive to treat to suitable reuse standards. It may soon become necessary to consider the potential reuse of acid mine drainage in particular, but this falls outside the scope of the present study.

(ii) The production of effluent in the urban and domestic sector is proportional to the water demand by the sector. The proportionality factor will be a function of factors such as the geographical area, the integrity of the reticulation system, the economic bracket of the consumers, the use of septic tanks in some houses, and the amount of water which will be used for gardening purposes.

In order to calculate the relationship between domestic and urban use and the amount of wastewater produced for the country as a whole, water consumption and sewage production was examined for Langebaan, Cape Town, Durban and Hermanus. These areas represent both primarily domestic demand (Langebaan, Hermanus) and mixed domestic/industrial demand (Cape Town, Durban). The resulting figures are presented in Table 3.3.

Table 3.3 – Water Consumption and Sewage Production

Area	Water demand ($x10^6$ m^3/a)	Sewage Return Flows ($x10^6$ m^3/a)	Ratio of Return to Demand
Langebaan (1996)	0.4468	0.17195	0.38
Cape Town Metropole	292	180	0.65
Durban Metropole (1997/1998)	276.0	167.9	0.61
Hermanus (1997/1998)	2.57	0.91	0.35

The proportion of return to demand thus lies somewhere between 0.35 and 0.65. It is suggested that, in the case of small towns like Langebaan and Hermanus, a number of septic tanks and soakaways exist, reducing return to sewage. The direct reuse of grey water in watering of gardens will also reduce the ratio of return to demand. The above table suggests that industrial return is higher than domestic return, although this would be highly dependent on the type of industry in the area.

In order to estimate the total sewage production in South Africa, a ratio of return to demand of 0.5 was taken, being the average of the return ratio from a large city and a small town. From Table 3.1, the total annual domestic and urban water demand represents 2 171 x 10^6 m^3/a. Hence TSE production in South Africa may be estimated at 1 086 x 10^6 m^3/a, or 2 975 Ml/day. Using a higher return ratio would clearly result in a higher figure for available TSE; for the purposes of this study, however, the conservative figure will be used.

It is acknowledged that this value provides only a rough estimate. Factors which will affect the amount of water returned to sewer for the country as a whole include use of septic tanks, leakage of both water pipes and sewerage lines, infiltration into sewage lines, regional and seasonal variations in the amount of water used and the nature of industrial clients, to name but a few. In the absence of any more accurate information, however, this provides a ball-park figure from which to start this study.

3.4 Fate of Treated Sewage Effluent in South Africa

Whilst approximately 3% of treated sewage effluent is reused (see section 3.5 below), the majority of treated sewage effluent in South Africa is discharged either into inland water bodies (rivers, lakes, dams) or into the sea. In the Gauteng area, about 60 % of the water extracted by Rand Water is returned to the Vaal and Crocodile rivers as treated effluent [DWAF (1997b)]. In the coastal areas, a high proportion of the treated wastewater ends up in the oceans, either through direct ocean discharge or through discharge to rivers with no downstream extraction.

In inland water systems a large amount of treated wastewater is returned to river systems. Two different configurations of such return systems can be visualized. In the first, water is returned to the body from which it was withdrawn. The second configuration removes water from one river, but the treated sewage effluent is returned into another river. The implications of these different configurations on flows and the salt loadings on the receiving water is discussed further in Appendix E.

For comparison DWAF (1997b) provides a rough estimate of the major point source flows of TSE from the largest producing areas in the country for 1996. This indicates that of the major point discharges, approximately 321×10^6 m^3/a is discharged to the oceans, while 715 $\times 10^6$ m^3/a is returned into inland rivers and dams. The estimated total flow from point sources of 1 036 $\times 10^6$ m^3/a provided by DWAF (1997b) is observed to be close to the estimate made of TSE production in section 3.3 above, although the DWAF estimate excludes returns from small effluent treatment works. Again, this would indicate that the chosen figure of 1 086 $\times 10^6$ m^3/a is on the conservative side.

3.5 Summary

In summary, we have the following figures for water demand :

(i) Water demand (1996)	20 045 x 10^6 m^3/a
(ii) Demand in urban/domestic sectors	2 171 x 10^6 m^3/a
(iii) Demand in industry/mining outside urban areas	1 598 x 10^6 m^3/a
(iv) TSE production from urban and domestic (estimated)	**1 086 x 10^6 m^3/a**

From these figures, therefore, it can be seen that reuse of TSE in various applications has significant potential to affect the demand in certain sectors. Treated sewage effluent represents some 5% of the total water demand for South Africa. However, for the industrial and urban sectors, the potential impact on demand for raw water could be much greater than 5%, were the usage of reclaimed water to be intensified. This issue is taken up and explored in more detail in chapter 7. We will first examine in chapter 4 the various applications, as well as the current levels of usage of reclaimed water internationally and, to a lesser extent, locally. This will assist in identifying where the potential lies for intensifying water reclamation in South Africa.

4. Potential Applications and Current Usage of Reclaimed Water

The substitution of reclaimed water for fresh water in certain applications is practised widely internationally, and to a limited degree in South Africa. The potential uses for reclaimed water include:

- **Agriculture/ irrigation**
- **Construction applications** – dust control, soil settling and compaction, aggregate washing, concrete making
- **Domestic** (non-potable) – fire fighting, car washing, toilet flushing, garden watering
- **Industrial –** cooling towers and other cooling applications, boiler feed, quenching
- **Groundwater Recharge**
- **Return to Rivers**
- **Potable water** – drinking water, either supplied directly (pipe-to-pipe) or mixed in with water in reservoirs or aquifers

Each of these possible applications is examined in its context.

4.1 Agricultural/Irrigation

Agricultural usage of fresh water represents some 54% of the total fresh water usage in South Africa. Urban irrigation, whilst not as significant a user as agriculture, still also represents a considerable use of water.

The use of reclaimed water in the irrigation of crops and other areas is widespread both internationally and nationally. Some examples include the following. In Tunisia, 6600 ha of agricultural land is equipped for irrigation via treated sewage effluent. Due to a number of factors, only 2430 ha is actually irrigated, using a pumped volume of 12.83×10^6 m^3/a of a possible 95 $\times 10^6$ m^3/a of the total wastewater treated in the country. This accounts for 15% of the treated volume of wastewater produced. Constraints which do not allow for full utilization of the equipped area are :

(i) irrigation is only practiced for 6 months per year,

(ii) no wastewater can be stored and hence the irrigation rate is limited to that of the pumps withdrawing treatment plant effluents and

(iii) most of the area which is equipped is still not irrigated at all, as farmers are not yet taking advantage of the scheme [Bahri and Brissaud (1996)].

Israel, having a very arid climate, has focused upon using reclaimed water for agriculture for a number of years. In 1994, 232 $\times 10^6$ m^3/a of wastewater was treated, with 194 $\times 10^6$ m^3/a being reused [Shelef and Azov (1996)]. This represents a national reuse ratio for TSE of 84%, which is the highest in the world. It must be remembered, however, that Israel is smaller than the Kruger National Park, with relatively high population concentrations in its towns and cities. This level of reuse is therefore unrealistic for South Africa as a whole, but provides a potential target on a local or regional basis.

In South Africa, a number of small schemes are currently in place where wastewater is used for irrigation purposes, mostly in urban applications. From the regional case studies undertaken of Durban and Cape Town (presented in Appendices A and B), these applications include golf courses (King David, Mowbray, Rondebosch, Milnerton, Steenberg, Parow, Durbanville, Cato Ridge in Durban and the Langebaan Country Club), the Milnerton Racecourse, the Milnerton Beachfront, Bellville South sports facilities, the Sanlam grounds in Bellville, Kraaifontein Sportsground, Peninsula Technicon, the University of the Western Cape, and various small agricultural applications. Effluent from SAPPI's Ngodwana Mill is used in the irrigation of surrounding farms, although this practice will probably soon be stopped (see Appendix C2). In general, however, there are no large-scale schemes in South African utilising treated sewage effluent for agricultural irrigation, such as exist elsewhere. This is a particular application deserving further attention, which falls outside the scope of the present study.

4.2 Domestic (non-potable)

Domestic uses of reclaimed non-potable water include fire fighting, car washing, toilet flushing and garden watering. To supply non-potable water to buildings in urban areas, two sets of piping are required, one for potable and the other for reclaimed water. Laying of dual reticulation can either be done for a new development, or retrospectively.

The most innovative project where reclaimed water is to be supplied to a new development for non-potable purposes is at the Rouse Hill development in Australia. Situated north of Sydney, the development will eventually house 300 000 people. An Environmental Impact Statement for the area conducted prior to development of the township indicated that, unless specific measures were implemented to deal with the sewage discharges from the area, severe degradation of a nearby river would occur. A dual water supply for non-domestic potable reuse was proposed as one measure to reduce the volume of treated effluent released into the environment. It was estimated that the dual water supply could reduce discharge by ~40%. For the purposes of supplying reclaimed water, two different piping systems were laid down: one for potable and one for non-potable water. Prices for reclaimed water are 20 c/kl (Australian) and 65 c/kl for the potable water. It is noted that the former prices are subsidised – they do not reflect the actual cost of the water [Law (1996)].

The Tokyo Metropolitan Government in Japan has long been involved in projects regarding the use of treated wastewater in, among others, domestic applications. Over $1x10^6$ m^3/year of reclaimed water is used in the flushing of toilets alone - the water used in flush toilets is reported to represent 15% of the total domestic water consumption [Nakazato and Kawamura (1997)]. New office blocks and apartment buildings in certain sections of Tokyo are routinely fitted with two sets of pipes, one for potable water and one for reclaimed water.

In South Africa, dual reticulation on a large scale to supply non-potable water has not been practised to date. There are however some small household systems available which recycle greywater for use in flushing toilets.

4.3 Industrial Usage

4.3.1 Power generation

Make-up water for recirculating cooling systems generally represents the single largest water demand in electric power generation industries [Wijesinghe et al (1996)]. In the United States in 1980, the power generation industry’s usage of water represented 64% of the total industrial demand. In power plants which use steam, cooling water is used to condense the steam after its useful heat has been expended to produce electricity. The condensate is returned to the power plant heater to produce additional steam which is once again used to produce electricity. The cooling water system can be either once-through or recirculating. In the latter case, water is cooled in a tower, pond or spray canal and reused.

Use of treated secondary effluent (TSE) for industrial cooling occurs at a number of facilities world wide. Of the problems associated with the use of TSE are the relatively high concentrations of nitrogen, phosphorous and ammonia over those found in potable water or most river waters. The first two substances are significant due to the promotion of microbiological growth. Phosphorous or phosphate may cause scaling due to the deposition of phosphate at high temperatures. Ammonia concentrations of higher than 1 mg/l promote corrosion cracking [Wijesinghe et al (1996), Parkinson and Basta (1991)]. Sewage effluent treated by an activated sludge process however will contain low ammonia concentrations, while nutrient removal may be effected by tertiary treatment. Hence potential problems and costs are related to the quality of the treated effluent which is locally available.

The Palo Verde nuclear plant near Phoenix, Arizona is using $124.1x10^6$ m^3/a of reclaimed water for cooling. Secondary sewage effluent is first run through trickling filters, reducing ammonia content to less than 5 mg/l by biological nitrification. A cold lime-soda ash process softens and removes calcium, phosphates, magnesium and silica and then gravity filtration removes suspended solids. A dispersant is added by the operators to reduce scaling, as is antifoam, and sodium hypochlorite for biological control [Parkinson and Basta (1991)].

The oil refinery in Richmond, California, run by the Chevron Corporation was re-designed in order to use reclaimed water for about half its cooling tower needs. The water reclaimed was estimated to amount to some $8.96x10^6$ m^3/a [Parkinson and Basta (1991)].

Australian efforts at water reclamation are also focusing strongly upon power generation and cooling. In May 1998, Sydney Water signed what is currently the largest industrial re-use agreement in Australia, selling up to 14 Ml/day to the Sithe Energies co-generation plant to be built to the South of the city. [Hayward 1998]

In South Africa, Eskom does not make use of treated effluent for any of their cooling applications; raw water is extracted directly from rivers. Total water consumption by all Eskom power stations amounted to some 586 Ml/day, or 214 $x10^6$ m^3/a, in 1995. Eskom's use of raw water rather than reclaimed water is primarily due to the fact that insufficient TSE is available in the areas where their power plants are located. The majority of the plants are located close to small towns which may produce only 1 Ml/day of TSE; a large power station may require up to 120 Ml/day of cooling water.

However, power stations, which are located in larger urban areas and run by municipalities, are in an ideal position to use reclaimed water, and several municipal power stations in South Africa are doing so. The Kelvin power station, which is run by the Johannesburg municipality, has used TSE from the Northern Suburbs of Johannesburg for its operations for a number of years, utilising some $3x10^6$ m^3/a of treated sewage effluent. The Athlone power station in Cape Town utilises $1.2x10^6$ m^3/a of treated sewage effluent from the nearby Athlone sewage treatment works, and has done so for several decades. Bromine is added for disinfection, and ammonium sulphate is used to raise the pH of the TSE to 7.5. No significant problems, whether technical, social, or of a health and safety nature, have been experienced with this usage of reclaimed water to date.

4.3.2 Industrial Cooling and Other Industrial Applications

St Petersburg, Florida, is one US city which has been implementing extensive programs to stimulate the use of reclaimed water. Because it proved to be too expensive to treat wastewater to potable standards, the city decided to use reclaimed water only for irrigation and industrial-cooling purposes. Existing treatment plants and storage facilities were upgraded, and a new distribution system completely separate from the potable-water system was laid out.

In St Petersburg four treatment plants exist, which treat and chlorinate sewage water, with all pathogens being completely removed. Approximately 45.5 Ml/day, or 16.6 $x10^6$ m^3/a, of reclaimed water is routed through the separate distribution system to 7 340 customers who use the water for irrigation and cooling. Although the city hires inspectors to ensure that cross-connections between the two systems do not occur, the reclaimed water is of high enough quality that occasional mistakes have not resulted in any adverse health effects to consumers. Although the water reclamation project had to overcome “initial public skepticism . . a public-education campaign resulted in both acceptance and pride in the innovative program on the part of city residents.”

The reclaimed-water treatment and distribution system has the capacity to reach 11 000 industrial customers with potential demand of 90.9 Ml/day; the city feels that it can reach this level of service in another 5 years, using wastewater from other sources. Total water demand in the city (potable and nonpotable) is approximately 190.9 Ml/day, or 69.7 $x10^6$ m^3/a, so reclaimed water for nonpotable uses could eventually account for almost half of all St. Petersburg water deliveries. By substituting reclaimed water for potable water in irrigation and cooling, the city has eliminated the need for expansion of its potable water-supply system until the year 2030. St. Petersburg is "…the first major municipality in the United States to achieve zero waste-water discharge to surrounding surface waters" [Internet 2].

Harlingen, Texas has a wastewater treatment plant which produces reclaimed water for use primarily in a textile and clothing manufacturing concern. The manufacturer required relatively high quality process water, and to meet this need reverse osmosis membranes are used in the treatment plant. They produce 5.7 Ml/day (2 $x10^6$ m^3/a) of reclaimed water, which is supplied to the textile plant. The ability of the treatment plant to produce this water, with the subsequent development of the factory and two nearby support plants, resulted in the creation of about 3 000 new jobs in the area [Filteau (1995)].

In Japan, 8.1 $x10^6$ m^3/a of treated wastewater is used in cooling applications in industry, while another 15 $x10^6$ m^3/a is used in various other industrial applications (Maeda et al, 1996).

Australian applications include a steelworks in Port Kembla which uses up to 20 Ml/day for quenching at their coke ovens and the Eraring power station near Newcastle where up to 4 Ml/day of water from a sewage plant receives advanced treatment using microfiltration and reverse osmosis before being fed into their demineralisation plant to provide boiler feed water [Anderson (1996)].

Sydney Water's trading arm, AWT, is starting a programme for the encouragement of non-potable schemes for industrial use. Here water pricing is still an inhibitor to uptake. Additionally, there has been difficulty in getting the various government agencies involved to agree on what is permissible, and health standards are emerging on a case by case basis. Under existing industrial agreements, 27 Ml/day of Sydney's wastewater is being re-used. Sydney Water aims to achieve 58 Ml/day of reuse by the year 2001. [Hayward 1998]

The chief South African example of reclaimed water being substituted for potable water usage in industrial applications is found in the paper industry. This industrial case study is discussed in detail in Appendix C. In paper-making, both Mondi and SAPPI make use of TSE in a number of their mills, using a total of approximately 26.2 Ml/day or 9.6 $x10^6$ m^3/a. In Port Elizabeth a number of small industries, such as leather tanneries, also make use of TSE from the pipeline which was laid to supply the SAPPI plant.

In order to increase the uptake of TSE from their Southern Sewage Works, over and above that supplied to the Mondi plant, Durban Metro Water Service has established an innovative scheme whereby a public/private sector partnership is being established, to supply TSE to industrial customers (see Appendix A). This proposed scheme has the potential to reuse a total of up to 30 Ml/day or $10.95x10^6$ m^3/a of TSE.

4.4 Groundwater Recharge

Groundwater recharge or the replenishment of aquifers, is a practice widely used in the management of water resources. Three motivations are identified for this practice [Murray and Tredoux (1998)]:
- Conservation of water for future use
- Improvement of water quality
- Averting saline water intrusion

Aquifer storage and recovery (ASR) wells are particularly useful in semi-arid areas with a marked rainy season, as they may be used for recharge when surplus water is available, and pumped water when the water is needed. Typical recovery efficiencies in aquifer storage and recovery systems are found to be up to 70%, although it is suggested that most schemes can be developed to 100%, with the exception of transmissive, highly saline aquifers. For comparison, efficiency of surface water storage facilities such as impoundments can be significantly less than 50% [Murray and Tredoux (1998)]. The water used for recharge may either be fresh water from rivers and lakes, or, of particular interest in this report, reclaimed water.

Factors which need to be assessed when considering artificial recharge include the hydraulic characteristics of the aquifer, the quality of the recharge water, potential for clogging of the recharge basins, trenches or boreholes, groundwater recovery, management requirements and economic factors.

The nature of the soils overlying the aquifer, and the desired recharge volumes, will determine the mechanisms by which groundwater recharge can be achieved. Where permeable soils such as sandy loams and loamy or fine sands exist above the aquifer, treated water is commonly pumped into infiltration basins from which it is allowed to permeate through the soil into the aquifer. This technique is known as direct recharge. The advantage of this method is that the water often undergoes treatment (what is known as "Soil Aquifer Treatment" or SAT) as it permeates through the unsaturated zone of the soil. This reduces pretreatment requirements [Murray and Tredoux (1998)]. Clogging by algae is a potential problem, which may be overcome by making the infiltration basins shallow. This avoids compaction of the clogging layer, and promotes rapid turnover of water to minimize algal growth [Bouwer (1991)].

The second possible option for aquifer recharge is well or direct recharge. This is practiced where permeable surface soils are not available, overlying soils have restricting layers, or aquifers are confined. Here water is charged directly into the aquifer through seepage trenches or boreholes. Extraction of water is usually downstream of the recharge point, although in certain cases the same borehole is used for recharge and extraction. Where aquifers are directly recharged with treated sewage, advanced wastewater treatment is required to bring water to the equivalent of drinking water standards. This is done for two reasons. Firstly, limited treatment actually occurs in the aquifer itself. Secondly, one of the main problems with direct injection is clogging around the well. This is averted by the removal of suspended solids, assimilable organic carbon, nutrients such as nitrogen and phosphorus, and microorganisms prior to recharge.

An example of groundwater recharge of wastewater is seen in El Paso, Texas. Water is treated in an advanced wastewater treatment process and then pumped into the aquifer. The water is withdrawn downstream from the entry point to the aquifer, and is treated again to drinking water standards [Bouwer (1992)]. In Phoenix, Arizona, an experimental system has been set up for infiltration of secondary effluent into an aquifer. The soils in this region are calcareous and phosphates from the water precipitate as calcium phosphate in the vadose zone and aquifer. This is deemed not to be a problem, however, as the accumulation rate is so slow that soil porosity, hydraulic conductivity and infiltration rates would not be significantly reduced for decades or even centuries [Bouwer (1991)].

Dillon et al (1998) present a number of cases of successful implementation of ASR in Australia, mostly within urban areas or country towns in the Adelaide region. These include Mt Gambier (established in the late 1800s) where 2800 Ml/a of stormwater is allowed to infiltrate into 300 drainage wells, Angas Bremer, where 1000 Ml/a of river water enters an aquifer through 30 drainage wells, and The Paddocks, where 75 Ml/a of stormwater enters an aquifer through wetlands and an injection well. The authors suggest further that with aquifer storage and recovery it would be possible that half of the municipal demand for the city of Adelaide could be met by water recycling.

In South Africa, a number of small cases exist where farmers augment borehole supplies through small earth dams. The major example of aquifer storage and recharge is in Atlantis in the Western Cape, where the town's potable water is supplied primarily from the aquifer, and extensive recharge occurs. Two large infiltration basins, covering an area of approximately 500 000 m^2 exist some 500 m up-gradient of the extraction point, recharging to the order of 2 x 10^6 m^3/a with treated domestic effluent. Stormwater runoff from the town is also used for recharge of domestic supplies. In addition, effluent of greater salinity from industrial wastewater treatment is used to recharge an area close to the coast. This creates a mound of water which maintains a balance between the sea and the potable aquifer. The resulting effective hydraulic dam creates additional storage, while non-potable water escapes into the ocean. Stormwater from first flush rainstorms is diverted to the non-potable infiltration areas [Murray et al (1998), Murray and Tredoux (1998)].

4.5 Return to rivers

Return of treated water to rivers forms an important part of the water resource management system in the inland areas of South Africa. In South African coastal areas, discharge of treated sewage effluent is primarily into the ocean, and hence the direct reuse of such water is of undisputed benefit. However, inland water resource management is dependent upon manipulation of the flows in rivers, and in certain areas treated sewage effluent is the major component of the flow. In this situation, it may be argued that return to rivers is the best option for reuse of the treated sewage effluent. This argument is examined in more detail below, as well as in Appendix E.

Return flows typically occur as point discharges of treated effluent into a water course, or as diffuse seepage from irrigated areas close to a river. About 60% of the water abstracted by Rand Water later returns as TSE to the Vaal and Crocodile rivers. The Vaal River is carefully managed not to exceed selected water quality (salinity) thresholds, while spillage to the Orange River is allowed only during flood events [DWAF (1997b)].

Return of TSE to rivers has become a significant factor in maintaining the water balance in South Africa. There are two possible reservations against increasing the direct reuse of TSE, and hence decreasing the quantity returned to rivers :

- Return of TSE is widely believed to be important in terms of maintaining flows in rivers, especially where downstream extraction occurs.
- In certain cases, return of TSE is also valuable in diluting water in rivers with poor water quality due to surface runoff.

On the other hand, there are strong arguments for the consideration of reusing TSE directly. Return of TSE to rivers may lead to the deterioration of water quality in rivers receiving large quantities of effluent, mainly due to salinity build-up which results from the concentration of salts through most uses of water. Secondly, the increase in the nutrient loading may cause eutrophication to occur. Finally, there may also be severe ecological implications in cases where the return flow of TSE is much greater than the natural base flow in the river, and where the returned TSE creates a perennial river from an episodic or seasonal stream.

An additional consideration is that the cost implications of returning TSE to rivers without direct reuse are considerable. The water essentially undergoes double treatment. Sewage is treated to acceptable water quality standards prior to discharge into the river. Subsequently, extracted river water is treated to potable standard, prior to distribution. Direct reuse of TSE shortcircuits the second step, taking the water out of the potable water loop. Return of TSE to rivers as opposed to reclaiming the water for direct reuse is examined further, in detail, in Appendix E. Although in certain cases the *status quo* may in fact be the best option for reuse of the treated sewage effluent, this is an aspect of water management in South Africa which would benefit from more detailed and localised research.

4.6 Potable Supplies

Treated sewage effluent which is used as potable water may be either supplied directly (pipe-to-pipe) or mixed with water in reservoirs or aquifers.

One of the longest standing and best known projects for using reclaimed water for potable water supply is that at Windhoek, Namibia. The project was started in 1968, and has undergone a number of modifications over the years. It has, however, consistently produced water of acceptable quality with regard to chemical, bacteriological, virological and epidemiological monitoring. Windhoek is currently extending its water reclamation system from 4.8 to 21 Ml/day or 7.6 $x10^6$ m^3/a [Haarhoff et al (1996)]. It is concurrently introducing stricter water demand management, and is investigating the laying of dual reticulation to supply TSE, rather than potable water, for urban irrigation applications.

Denver carried out a pilot plant study to produce potable water from sewage. The process included lime clarification, recarbonation, granular medium filtration, ultraviolet irradiation, granular activated carbon adsorption, reverse osmosis, air stripping, ozonation and chloramination [Bouwer (1992)]. Although this study proved to be highly successful in terms of producing a constant supply of high quality water, it has not been expanded into full scale operation.

The city of Cape Town has carried out a pilot study at the Faure treatment works, in which tertiary treated effluent was blended with fresh water for potable purposes, in a ratio of 1:4. This project is discussed further in Appendix B. At present this is not considered to be a feasible option for taking to full scale operation, on grounds of cost.

4.7 City-Wide and Nation-Wide Reports of the Use of Reclaimed Water

A number of countries and/or individual cities have programmes and policies for water reclamation. Japan is one such country having a wastewater reuse programme, which is useful in demonstrating the wide range of applications which should be considered under such programmes. Although the total volumes given are not large, the programme is under active development. Their wastewater treatment plants generate $1.09x10^{10}$ m^3/a, of which $85x10^6$ m^3/a was reused in 1994. The annual usage of treated wastewater in Japan in 1994 is presented in Table 4.1 below [Maeda et al (1996)]:

Table 4.1 – Reclaimed Water Usage in Japan (1994)

Application	**1000 m^3/a**
Toilet flushing	2 095
Train washing	6 189
Industrial water	15 089
Cooling water	8 139
Dilution water for night soil	6 409
Agriculture	12 702
Environmental	28 293
Landscape irrigation	165
Snow melting	6 434

Other examples of volumes of reclaimed water used in various areas with large-scale water applications are presented in Table 4.2.

Table 4.2 – Reclaimed Water Usage in Various Places Around the World

Place	**Year**	**Wastewater Produced ($x10^6$ m^3/a)**	**Reclaimed Water Used ($x10^6$ m^3/a)**	**Application**
California	1970[^]	Not reported	216	Primarily irrigation
	1987[^]	Not reported	329	Primarily irrigation
	1993[^]	Not reported	407	Primarily irrigation
Florida (St Petersburg)	1995	16.5	16.5	Industrial
Australia	1994 2020	1519 2300	18 64	Industrial and irrigation
Israel	1990/1 1994[•]	260 232	188 194	Agriculture
Japan[μ]	1994[z]	10 900	85	Various (see above)
Tokyo city[μ]	1995*	1 767	134	Various

^ Mills and Asano (1996)

Projections based on current trends: Thomas et al (1997); however, implementation of the water reform schemes being advocated in Australia are expected to result in much more water reclamation taking place

z Maeda et al (1996)

• Shelef and Azov (1996)

μ It is noted that the amount of water reused in 1995 for Tokyo is greater than that reused in the whole country for the previous year. The Tokyo figure includes 102 $x10^6$ m^3/a that is re-used in the wastewater treatment plants themselves for general cleaning, equipment cleaning and gas scrubbing. This application is not included in the list of national uses of reclaimed water.

* Nakazato and Kawamura (1997)

□ Tselentis and Alexopoulou (1996)

Although the international figures available are rather scanty, it is still helpful to gain a sense of perspective in situating South Africa in comparison with the countries where some data is available. From Table 4.2, we see that the proportion of water reclaimed as a percentage of total wastewater produced ranges from less than 1% for Japan as a whole, to 84% for Israel, and 100% for a small city, namely St Petersburg. Table 4.3 below shows the data which we have been able to gather during this study, for current water reclamation applications in South Africa.

Table 4.3 – Reclaimed Water Usage in South Africa

Application	**m^3/a**
Aquifer storage and recharge (Atlantis)	2×10^6
Industrial water (paper industry)	9.6×10^6
Industrial water (other)	data not available
Cooling in municipal power stations	4.2×10^6
Irrigation in urban areas	data not available

No overall figures exist for wastewater reuse over the whole of South Africa. Based on more detailed regional data we have gathered, we estimate that current reclamation of water nationwide is probably less than 30×10^6 m^3/a (excluding return to rivers). This represents less than 3% of the total wastewater flow generated in the country, which we have estimated in chapter 3 to be 1086×10^6 m^3/a. When the innovative scheme initiated by Durban Metro Water Services (described in Appendix A) is implemented, the total water reclaimed in South Africa will rise by 11×10^6 m^3/a. Clearly, the potential to reclaim more water in South Africa is enormous, and such a development needs to be driven by political will at both national and local level. There is plenty of scope to raise our proportion of water reclaimed from the paltry level of 3% where it currently stands. From these reports, which represent but a few of the international initiatives for using reclaimed water, it can be identified that the applications for projects which make use of reclaimed water are broad, especially in a country with limited water resources like South Africa.

5. International Standards for Treatment of Wastewater for Reuse

The appropriateness of a reclaimed water supply for reuse will depend on three factors: the quality to which the water is treated; the consistency of treatment quality (i.e. can the reclaimed water user be guaranteed of a regular quality of water?); and the cost implications of reuse. This chapter discusses the acceptable reclaimed water qualities which may be used in various applications.

A number of countries have set standards for acceptable qualities of reclaimed water in various reuse applications. Although the acceptability for reuse depends on the physical, chemical and microbiological quality of the water, the main concern regarding reuse of water in all applications is generally the microbiological quality of the water. Factors which affect the quality of reclaimed water include source water quality, wastewater treatment processes and treatment effectiveness, treatment reliability, and distribution system design and operation [Crook and Surampally (1996)].

Prior to discussing specific standards used in individual countries, the following general comments are made regarding required water qualities for reuse:

- The highest standards of treatment required will be for potable water. Water is usually treated to standards better than for surface water, to minimize any potential health risks associated with reclaimed water usage.
- Where water is to be used for agricultural purposes, treatment standards become more stringent as human contact and the potential for ingestion increase. The toughest agricultural standards are for unrestricted irrigation such as the spray irrigation of lettuce and other crops which are to be consumed raw (see below for more details) [Bouwer (1992)]. It is noted that for agricultural crops, agronomic requirements must be taken into account, including salinity, sodium absorption ratio, nitrogen, and toxic and trace elements.
- Treatment of water which is to be used for indirect potable water supply augmentation (such as discharge to rivers and aquifers) needs to account for the health risks associated with both pathogenic microorganisms and chemical constituents in the pollution of these water bodies.
- Most standards only make provisions for coliforms in terms of bacteriological quality. Limits are often not set for parasites and viruses. Viruses in wastewater are discussed further below
- TSE from plants treating almost exclusively domestic effluent is preferable to that from plants treating industrial effluents, especially in agriculture/irrigation, urban reuse and groundwater recharge. Processes for the treatment of industrial effluents, which may contain toxic constituents, to standards which are suitable for domestic, irrigation, urban use and groundwater recharge are more expensive and less reliable than those used for the treatment of domestic effluents. This is due to the complexity and variability of many industrial effluent discharges.
- Industrial applications for reclaimed water may have specific water quality requirements which are independent of the imposed standards discussed below, depending on the use of the water. An example which was presented earlier is the use of reclaimed water in cooling towers, where the levels of nitrogen, phosphorous and ammonia are significant in promotion of microbiological growth and/or scaling. Ammonia may promote corrosion cracking [Wijesinghe et al (1996), Parkinson and Basta (1991)]. Treated wastewater which is supplied to industry must, therefore, take into account the specific requirements of that industry, regardless of the recommended standards imposed. Furthermore, worker safety must be ensured. The precautions and water qualities required for ensuring worker safety for different degrees of exposure in agricultural applications (see below) must be adhered to in industry.

A number of guidelines from around the world for different applications are presented below, including WHO guidelines, the US EPA guidelines as well as the criteria adopted for Florida and California, and standards applying in Australia and France for the use of reclaimed water.

5.1 World Health Organisation (WHO)

The World Health Organisation guidelines were developed to establish the basic criteria for health protection of the groups at risk in reuse applications. These are shown in Table 5.1.

Table 5.1 – World Health Organisation Recommended microbiological quality guidelines for wastewater use in agriculture [Hespanhol and Prost (1994)]

Type of Use	Exposed group	Intestinal nematodes[a] (no of eggs per litre)	Faecal Coliforms (no per 100 ml)	Wastewater treatment required to achieve microbial quality
Irrigation of crops likely to be eaten uncooked, sports fields, public parks[b]	Workers, consumers, public	≤ 1	≤ 1000	Series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[c]	Workers	≤ 1	Not applicable	Retention in stabilization ponds for 8 – 10 days or equivalent helminth and faecal coliform removal
Localized irrigation of crops in the above if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by the irrigation technology, but no less than primary sedimentation

[a] *Ascaris*, *Trichuris* and hookworms

[b] A more stringent guideline (≤ 200 faecal coliforms /100 ml) is recommended for public lawns, such as hotel lawns, with which the public may have direct contact. .

[c] In the case of fruit trees, irrigation should cease 2 weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

The guideline of 1 nematode egg per litre for irrigation of crops which are to be consumed raw was added for the protection of both consumers and workers. A study in Mexico, however, indicates that this guideline protects crop consumers, but not necessarily fieldworkers and their families. Children are especially at risk. This is especially the case when recontamination of the treated wastewater with small quantities of raw wastewater may occur, and when wild vegetables are harvested and consumed [Blumenthal et al (1996)]. Blumenthal et al recommend that, where contamination of treated wastewater with untreated water cannot be ruled out, it may be more appropriate to modify the guideline to ≤ 0.5 egg per litre to stop transmission of nematode infections. Furthermore, these authors recommend adding a faecal coliform guideline of $\leq 10^4$ FC per 100ml to protect against the transmission of bacterial and viral infections to farmworkers.

5.2 American Standards

In the US, there are no federal regulations governing water reclamation and reuse. Regulations are thus set down by the individual states. California was one of the first states to use reclaimed water, with their first standards for water reclamation and reuse for agricultural purposes being adopted in 1918. No states in the US have comprehensive criteria addressing potable reuse, but California and Florida are developing guidelines covering indirect potable reuse such as river and groundwater recharge.

5.2.1 California and Florida's Water Quality Criteria

California's reclamation criteria specify water quality standards, treatment process requirements, operational requirements and treatment reliability requirements. The treatment and quality criteria are given in Table 5.2 below. This table includes proposed revisions to the current criteria.

Table 5.2 – California and Florida Treatment and Quality Criteria for Nonpotable uses of reclaimed water [Crook and Surampalli (1996)]

State	**Type of Use**	**Water Quality Limits**	**Treatment Required**
California	Irrigation of fodder, fiber and seed crops, orchards and vineyards[a], and processed food crops	No limit imposed	Secondary treatment
Florida	Restricted public access areas such as forests, pasture land, areas used to grow fodder, fiber and seed crops, or similar areas	200 faecal coliforms/100 ml 20 mg/l TSS 20 mg/l BOD	Secondary treatment and disinfection
California	Irrigation of pasture for milking animals, landscape areas[b], industrial or commercial cooling water where no mist is created, nonstructural fire fighting, industrial boiler feed, soil compaction, dust control, cleaning of roads, sidewalks and outdoor areas	23/100 ml total coliforms	Secondary treatment and disinfection
California	Surface irrigation of food crops, restricted landscape impoundments	2.2/100 ml total coliforms	Secondary and disinfection
California	Irrigation of food crops[c], and landscape areas[d], nonrestricted recreational impoundments, toilet and urinal flushing, industrial process water, decorative fountains, commercial laundries, snow-making, structural fire fighting, industrial or commercial cooling where mist is created	2.2/100 ml total coliforms	Secondary treatment, coagulation, clarification[e], filtration and disinfection
Florida	Public access areas[g], irrigation of food crops[h], toilet flushing[i], recreational impoundments[j], decorative purposes, fire fighting, dust control	pH 6-9, $BOD_5 \leq 10$ mg/l, Turbidity ≤ 2TU, FC 0/100 ml, Cl_2 residual 1 mg/l, clear, odourless, non-toxic to ingestion	

Notes:

[a] No contact between reclaimed water and edible portion of crop

[b] Cemeteries, freeway landscaping, restricted access golf courses, other controlled access irrigation areas

[c] Contact between reclaimed water and edible portion of crop, includes edible root crops

[d] Parks, playgrounds, schoolyards, residential landscaping, unrestricted access golf courses and other restricted access irrigation areas

[e] Coagulation is not required if the turbidity prior to filtration does not exceed 5 NTU, except for nonrestricted recreational impoundments and cooling uses where mist is created

[f] The turbidity of filtered effluent cannot exceed an average of 2 NTU during any 24 hour period

[g] Residential lawns, gold courses, cemeteries, parks, landscaped areas, highway medians

[h] Only allowed if crops are peeled, skinned, cooked or thermally processed before consumption

[i] Only allowed where residents do not have access to plumbing system. Not allowed in single-family residences

[j] For full body contact impoundments, reclaimed water must meet drinking water bacteriological standards if it constitutes > 50% of the inflow to the impoundment

Coliform samples must be collected at least daily and compliance is based on a running seven-day median number. Turbidity and chlorine residual must be monitored continuously. Proposed future regulations require that reclaimed water be used for nonrestricted impoundments must be monitored for enteric viruses *Giardia* and *Cryptosporidium* during the first two years of operation if the treatment chain does not include a sedimentation unit process between the coagulation and filtration processes [Crook and Surampalli (1996)].

5.2.2 US EPA Guidelines

In 1992 the US EPA published guidelines which are intended to provide guidance to states that have not developed their own criteria or guidelines for the use of reclaimed water. These guidelines address water reclamation and reuse for nonpotable urban, industrial and agricultural applications as well as indirect potable reuse by groundwater recharge and augmentation of surface water sources of supply. They address all important aspects of water reuse and include recommended treatment processes, reclaimed water quality limits, monitoring frequencies, setback distances and other controls for various water reuse applications. A summary of the EPA guidelines are presented in Table 5.3.

Table 5.3 – US EPA Guidelines for Water Reuse

Type of Use	**Reclaimed Water Quality**	**Treatment**
Urban uses, irrigation of food crops eaten raw, recreational impoundments	PH = 6-9 ≤ 10 mg/l BOD ≤ 2 NTU[a] No detectable faecal coliforms/ 100 ml[b] ≤ 1 mg/l Cl_2 residual[c]	Secondary, filtration and disinfection
Irrigation of restricted access areas and processed food crops, aesthetic impoundments, construction uses, industrial cooling[d], environmental reuse	PH = 6-9 ≤ 30 mg/l BOD ≤ 30 mg/l SS ≤ 200 faecal coliforms/100 ml[e] ≤ 1 mg/l Cl_2 residual[c]	Secondary and disinfection
Groundwater recharge of nonpotable aquifers by spreading	Site specific and use dependent	Site specific and use dependent – minimum primary
Groundwater recharge of nonpotable aquifers by injection	Site specific and use dependent	Site specific and use dependent – minimum secondary
Groundwater recharge of potable aquifers by spreading	Site specific Meet drinking water standards after percolation through the vadose zone	Site specific and use dependent – minimum secondary and disinfection
Groundwater recharge of potable aquifers by injection, augmentation of surface supplies	Includes the following: PH = 6.5-8.5 ≤ 2 NTU[a] No detectable faecal coliforms/100 ml[b] ≤ 1 mg/l Cl_2 residual[c] Meet drinking water standards	Includes the following: secondary, filtration, disinfection, advanced wastewater treatment

[a] 24 hour average value. Should not exceed 5 NTU any time. Should be met prior to disinfection
[b] Based on a 7-day median value. Should not exceed 14 faecal coli/100 ml in any sample
[c] After a minimum contact time of 30 minutes
[d] Recirculating cooling towers
[e] Based on a 7 day median value. Should not exceed 800 faecal coli/100 ml in any sample

The EPA guidelines include limits for faecal coliform organisms but exclude parasite or virus limits. While viruses are a concern in reclaimed water, virus limits are not recommended in the guidelines for a number of reasons. Firstly, it is suggested that a significant body of information exists indicating that viruses are inactivated or removed to low or immeasurable levels via appropriate wastewater treatment. Secondly, the identification and enumeration of viruses in wastewater are hampered by relatively low virus recovery rates. Thirdly, there are a limited number of facilities in the US, and in South Africa, having the personnel and equipment necessary to perform the analyses. Any laboratory analyses that are undertaken can take up to four weeks to complete. Finally, there is no consensus among public health experts in the States regarding the health significance of low levels of viruses in reclaimed water – there have not been any documented cases of viral disease resulting from the reuse of wastewater in the US [Crook and Surampalli (1996)].

Hespanhol and Prost (1994) suggest that intestinal nematodes present the highest risk of wastewater related disease transmission due to their long survival periods in the soil, their long persistence in the environment, a low infective dose, practically no host immunity and the limited possibility of concurrent infection in the home.

5.3 Standards for New South Wales, Australia – Non-Potable Domestic Water Usage

The New South Wales Recycled Water Coordination Committee has laid down guidelines relating to the use of reclaimed water for non-potable domestic usage. These standards are used as guidelines for the Rouse Hill housing project, which was discussed in section 4.6, in which a dual reticulation water supply is being fitted to all houses in the new development. The guidelines specify both the microbiological and physical quality of water that can be safely used as a non-potable domestic supply, and recommend an acceptable treatment train, permissible uses for the reclaimed water, storage considerations and system management, control and monitoring. The water quality requirements of this standard are presented in Table 5.4 [Law (1996)].

Table 5.4 – New South Wales guidelines for Non-Potable domestic supply

Parameter	Requirement
Microbiological Quality:	
- Faecal Coliforms	<1 in 100 ml
- Total Coliforms	<10 in 100 ml (in 95% of samples)
- Virus	< 2 in 50 *l*
- Parasites	< 1 in 50 *l*
Physical Quality:	
- Turbidity	< 2 NTU geometric mean < 5 NTU in 95% of samples
- pH	6.5 to 8.0 allowable range 7.0 to 7.5 desirable range
- Colour	< 15 TCU

As would be expected, these requirements are more stringent than those for irrigation purposes discussed previously. The coliform count in particular needs to be low to ensure limited risk of infection. It is noted that virus and parasite limits are particularly stringent, due to the potential for direct contact with the water (e.g. during car washing). In irrigation applications it was identified that limited knowledge is available as to the potential hazard of parasites and viruses, and that viruses are expected to be inactivated or removed to low or immeasurable levels via appropriate wastewater treatment.

5.4 Standards used in France

Reuse of treated wastewater for irrigation is not automatically permitted, and each application for permits requires approval by the Ministry of Health. The following requirements of the application need to be met prior to the Ministry considering an application for approval [Bontoux and Courtois (1996)]:

- The protection of underground water resources must be a priority in all projects
- As in other standards, required water qualities depend on the use of the water – the French recommendations follow the WHO guidelines discussed above for bacterial quality, but add criteria for usage limitations for crops, techniques of irrigation and distances from residences etc. One example is that spray irrigation is not encouraged and may be used only in certain cases. In the case of golf courses, spray irrigation may be used if irrigation is to be outside of opening hours and if the water jets do not spray too far. Spraying must be performed far enough from residence to avoid risk, taking local climate into account – the minimum required distance is 100 m but may be greater in certain cases.
- The piping network for treated wastewaters must comply with specific regulations.
- The chemical quality of the treated waters to be used must be defined, both to identify for mineral and organic micro contamination and the fertilizing capacity of the waters

- The control of the rules of hygiene for each treatment and irrigation facility must be explicit in the spreading permit
- Operation and control personnel must be systematically trained.

5.5 Summary

Standards for treatment vary from country to country, and depend on the proposed water reuse. Certain standards specify the required treatment technologies to be used in wastewater treatment.

In irrigation, which is one of the most widespread uses for reclaimed water, required qualities depend on how irrigation is to be carried out (drip, subsurface or spray irrigation), and whether crops are to be consumed raw or cooked. Irrigation guidelines should, but do not always, take into account protection of workers and their families. Irrigation standards are generally set for coliform concentrations, and, in some cases, for parasites and viruses.

For direct and indirect potable, and non-potable domestic use, standards are more stringent. Here both coliforms and viruses and parasites need to be closely monitored. A number of additional physical and chemical water quality specifications also need to be met to ensure protection of users.

No standards for reuse in industrial applications are generally set. The water quality required by industrial users will vary depending on the application for which the water is required.

6. Treatment of Sewage Effluent in South Africa

6.1 Acceptable Discharge Standards

The Department of Water Affairs and Forestry [Government Gazette 18 May 1984, No 9225, Regulation 991] has defined two standards for discharges to rivers. A special standard has been defined for discharges to rivers in certain scheduled pristine catchments, while discharges to all other rivers must meet the General Standard prescribed by DWAF. The General and Special standards are presented in Table 6.1 below.

Table 6.1 – Special and General Standards for Discharge to River Systems

Factor	Special Standard	General Standard
Colour, odour and taste	Wastewater shall not contain any substance in a concentration capable of producing any colour, odour or taste	Wastewater shall not contain any substance in a concentration capable of producing any colour, odour or taste
PH	Between 5.5 and 7.5	Between 5.5 and 9.5
Dissolved oxygen	At least 75% saturation	At least 75% saturation
Typical (faecal) coliforms	No faecal coliforms / 100 ml	No faecal coliforms/ 100 ml
Temperature	Maximum 25C	Maximum 35–C
COD	≤ 30 mg/l after applying chloride correction	≤ 75 mg/l after applying chloride correction
Oxygen absorbed	≤ 5 mg/l oxygen absorbed from acid N/80 potassium permangenate in 4 hours at 27–C	≤ 10 mg/l oxygen absorbed from acid N/80 potassium permanganate in 4 hours at 27–C
Conductivity	Not to be increased by more than 1.5% above that of the intake water Not to exceed 250 milli-Siemens per metre, determined at 25–C	Not to be increased by more than 75 milli-Siemens per metre (determined at 25–C)above that of the intake water Not to exceed 250 milli-Siemens per metre, determined at 25–C
Suspended solids	≤ 10 mg/l	≤ 25 mg/l
Sodium content	Not to be increased by more than 50 mg/l above that of the intake water	Not to be increased by more than 90 mg/l above that of the intake water
Soap, oil or grease	None	≤ 2.5 mg/l
Other constituents	Maximum concentration in mg/l	Maximum concentration in mg/l
Residual chlorine	Nil	0.1
Free and saline ammonia (as N)	1.0	10.0
Nitrates (as N)	1.5	-
Arsenic (as As)	0.1	0.5
Boron (as B)	0.5	1.0
Hexavalent chromium (as Cr)	-	0.05
Total chromium (as Cr)	0.05	0.5
Copper (as Cu)	0.02	1.0
Phenolic compounds	0.01	0.1
Lead (as Pb)	0.1	0.1
Soluble orthophosphate (as P)	1.0	-
Iron (as Fe)	0.3	-
Cyanide (as CN)	0.5	0.5
Sulphide (as S)	0.05	1.0
Fluoride (as F)	1.0	1.0
Zinc (as Zn)	0.3	5.0
Manganese (as Mn)	0.1	0.4
Cadmium (as Cd)	0.05	0.05
Mercury (as Hg)	0.02	0.02
Selenium (as Se)	0.05	0.05
		The sum of the concentrations of cadmium, chromium, copper, mercury and lead shall not exceed 1 mg/l
The water shall not contain other constituents in concentrations which are poisonous or injurious to humans, animals, fish other than trout, or other forms of aquatic life, or which are deleterious to agricultural use		

These special and general standards provide the target levels for treatment of wastewater, for discharge to surface water.

Sewage treatment plants make use of a wide variety of different wastewater treatment processes. Generally, however, wastewater for discharge into inland water bodies is treated by secondary treatment (often by activated sludge treatment) and then either sent to maturation ponds prior to discharge, or disinfected using, for example, chlorination. In the case of discharge to ocean outfall, the water is usually only primary treated to remove grit and large solids prior to being pumped out to sea.

6.2 The Suitability of Treated Wastewater in South Africa for Reuse

The above standards are the goal for all treatment works which discharge to rivers or other inland water bodies. Many plants report compliance with all of the requirements of the relevant standards, although the Department of Health has allowed certain treatment works relaxation on various parameters, most notably faecal coliform content, based on individual applications.

Relaxations on faecal coliform counts are for either of two reasons. Firstly, it is recognised that faecal coliforms exist naturally in river systems from animals and birds. Secondly, the attainment of the requirement of 0 FC/100 ml leads to an increased residual of chlorine in the water which is considered undesirable. For these two reasons, the Department of Health has allowed treatment plants effluent values of 126 FC/100 ml or sometimes even higher. Umgeni Water sets a working limit of 500 faecal coliforms per 100 ml which does not meet a number of the limits for reuse as discussed above. The Langebaan wastewater treatment works routinely achieves the General Standard, with occasional problems with ammonium levels being higher than those required in the standard.

Much of the wastewater which is currently consigned to ocean outfall is unsuitable for any reuse, as it has not undergone any form of treatment except for degritting and large solids removal.

In summary, therefore:

(i) Treated sewage effluent which meets the general standard in all instances is potentially suitable for all reuse applications described in chapter 4, including in many cases non-potable domestic use. Non-potable domestic use will depend on the pH, virus and parasite content of the water.

(ii) TSE from treatment plants which have been permitted raised faecal coliform levels may possibly be used in some irrigation applications, depending on the level of faecal coliforms in the water and on the type of irrigation application, as discussed in chapter 5.

(iii) Untreated water which is currently consigned to ocean outfalls will require at least secondary treatment prior to being suitable for any type of reuse.

7. The case for intensifying Water Reclamation in South Africa

7.1 Conservation of raw water inputs

When examining creatively the hydrological cycle, and the human water management loop, there are many points at which intervention could make more water available for use, without building new dams. Examples of such interventions which are being supported by the Water Research Commission include rainfall enhancement technology, and the eradication of alien species from catchments. Water demand management, water conservation and water saving devices also fall into this category of intervention.

This study proposes to show, however, that increasing demand for water caused by urbanisation and industrialisation must also ultimately be matched by increasing intensity of land-based treatment and recycle, or in other words, water reclamation. This may make available for use a total amount of water which is many times the supply of raw water available, depending on the extent of losses from the water system, and the number of times water is recycled through the system.

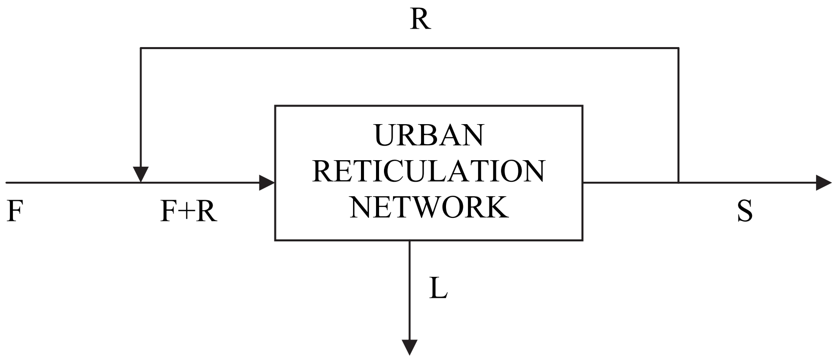
There are many factors causing losses in the water loop, through leakage, evaporation, or use of water for irrigation, for instance. Only a fraction of the total urban and industrial water demand is typically produced as treated sewage effluent in South African cities and towns (between 35% and 65%, as discussed in chapter 3). However, it is possible to aim towards a "zero effluent" scenario whereby all of this remaining water is kept within the human water management loop. The city of St Petersburg in the USA has already achieved this objective, and provides a useful case study of what is possible for other municipalities (see section 4.3.2). This means reclaiming and reusing <u>all</u> treated sewage effluent produced. Looking at it another way, this intensifies the recycle, since water will continue to recycle until it is lost from the loop by leakage or irrigation. Such a scenario utilises the minimum of freshwater resources : essentially, raw water is only required to make up for the water losses from the loop.

7.2 The "zero effluent" scenario

Examining in more detail the arithmetic of the "zero effluent" scenario will illustrate just how much more water is made available for urban and industrial use through full water reclamation. A simple flow diagram, shown in Figure 7.1, represents the various flows of water as : fresh water (F), reclaimed water (R), losses from the system (L) and the discharge to sea (S). The marine discharge situation is taken as the base case for these calculations, since situations where the effluent is discharged to rivers are more complex and are examined further in Appendix E.

The entire human water management system, i.e. the urban reticulation network, is a black box within this flow diagram, which takes water in, and then discharges it to the environment in various ways. All the losses from the system of various kinds are lumped together as the parameter L, including leakages, evaporation, and the use of water for irrigation, which effectively removes that water from the reticulation network. The residual discharge S is water which is treated and discharged into the environment from wastewater treatment plants. The zero effluent scenario under discussion is one in which the discharge $S = 0$. Thus all the water which would otherwise discharged from the reticulation network is reclaimed and put back into the system in various ways, through the flow shown as R.

Figure 7.1 - Flow balance around the urban reticulation network



where F = Fresh water
R = Reclaimed water (re-used sewage and industrial effluent)
L = Losses from the system (leakage, irrigation, and evaporation)
S = Discharge of effluent to surface water (sea)

The inflows to such a system must be equal to the outflows, hence a water balance over the entire system gives :

$$F = S + L \qquad (1)$$

A water balance over the "black box" itself, which takes into account the flow of reclaimed water, gives:

$$F + R = S + R + L \qquad (2)$$

which is equivalent to the water balance shown in (1) above. However, this formulation is useful because it shows the total flow of water that is available to satisfy water demand in the system.

7.2.1 Scenario with 50% return ratio

Assuming that the losses from the system are 50% of total water usage, which is the average return ratio in South Africa (as discussed in section 3.3), we have :

$$L = 0.5\ (F + R) \qquad (3)$$

Substituting for L in equation (2) above , we have :

$$F + R = S + 1.5\,R + 0.5\,F$$

$$0.5\,F - S = 0.5\,R$$

Hence,

$$R = F - 2\,S \qquad (4)$$

Under a zero effluent scenario, where the discharge S = 0, this gives :

$$R = F \qquad (5)$$

Hence the total flow of water available to satisfy total demand in the system (as in the left hand side of equation (2) above) is doubled. In algebraic terms :

$$F + R = 2\,F$$

Put another way, a full water reclamation scheme which utilised all the available treated sewage effluent would double the total inflow of water to the system, because the available inflow of reclaimed water would equal the existing inflow of fresh water to the system.

7.2.2 Scenario with 65% return ratio

Now, for major cities such as Cape Town or Durban, a higher return ratio of some 65% is currently achieved. This means that losses from the system are 35%, or in algebraic terms:

$$L = 0.35 \ (F + R)$$

Substituting into equation (2) and re-arranging, this gives us :

$$R = 1.86\,F - 2.86\,S$$

Under a zero effluent scenario, where S = 0, we have :

$$F + R = 2.86\,F$$

This means that the total available inflow into the system is 2.86 times the inflow of fresh water. Hence if full water reclamation were practised, water demand could rise to nearly treble its current level, before new water resources would need to be tapped.

7.2.3 Scenario for 90% return ratio

Taking the argument to its fullest extent involves assuming a situation where losses from the reticulation system are very tightly controlled, and comparatively little water is used for purposes like irrigation which take it out of the loop. Such a situation might arise in a localised area such as an industrial development or a high-density residential development. Under this scenario, working through the implications, using a return ratio of 90%, and assuming losses of 10% from the system.

Firstly, $$L = 0.1 \ (F + R)$$

This gives : $$R = 9\,F - 10\,S$$

In a zero effluent scenario, where S = 0, this means that the total available inflow into the system (F+R) is ten times the inflow of fresh water into the system.

Such an intensification of water use would obviously have to be matched by an intensification of treatment, to avoid the build-up of nutrients and salts in the system. However, with cutting-edge treatment methods such as membrane technology, this scenario is quite imaginable as the water management target in the twenty-first century. The implications of this are dramatic: on a localised basis, water demand could increase up to ten-fold without requiring new freshwater resources to be utilised.

7.3 Opportunities for intensifying water reclamation

At 1996 figures, this report showed (in section 3.2) that the water demand in the urban and industrial sectors in South Africa is 2171 x 10^6 m^3/a, while the production of treated sewage effluent can be estimated as 1086 x 10^6 m^3/a (section 3.4). However, current direct reuse is estimated to be less than 30 x 10^6 m^3/a (section 4.8). Water reclamation in South Africa is therefore currently less than 3% of the available treated sewage effluent, excluding the aspect of returning treated sewage effluent to rivers.

How is it possible to move from this dismal situation to a more forward-looking approach to wastewater re-use? Clearly, much work needs to be done on a policy level. It will also be necessary to create publicity for water reclamation and to carry out local education campaigns, possibly under the umbrella of water conservation and water demand management.

There are many different areas and approaches which are possible when one considers the wide range of applications of reclaimed water discussed in chapter 4. For instance, this study has not considered the aspect of water reclamation for irrigation, which is a large topic worthy of serious consideration in its own right, as it has contributed enormously to the water reclamation effort in countries such as Israel. However, a number of case studies have been carried out to investigate the possibilities for water reclamation in the urban and industrial sectors, which offer tremendous opportunity for change.

The sectors which currently appear to offer the greatest opportunities in terms of intensifying water reclamation efforts are:

- coastal cities and towns
- direct industrial re-use by large users
- new industrial developments

These are discussed in more detail below, as well as in the appendices to this report.

7.4 Water reclamation in coastal cities and towns

Urban re-use in coastal cities is an obvious candidate for intensifying water reclamation in many local authorities in South Africa, where treated sewage effluent is currently released directly to sea. This coastal focus avoids the long-drawn-out debates which will be inevitable in the case of many inland cities and towns, where return to rivers is practised, and will be vigorously defended. This report therefore concentrates on the lessons which can be drawn from two coastal case studies carried out, in Cape Town and Durban.

7.4.1 The case study of Durban

In a coastal city such as Durban, for instance, which is the only city for which detailed reuse figures are available, the daily production of treated sewage effluent is 460 Ml/day. Reuse of treated sewage effluent (TSE) at present amounts to some 9 Ml/day, or 2% of the total available. Details of water supply and wastewater production are given in Appendix A.

With an innovative scheme to expand water reclamation, described in Appendix A, the level of reuse will rise up to 30 Ml/day. This will be achieved by a public-private partnership, between Durban Metro Water Services and a private company who will undertake to treat the TSE further and sell it to an industrial customer base. This scheme still only represents some 7% of the available TSE, although it represents 27% of the TSE from the particular treatment works where the reclamation scheme is located. The balance of the TSE cannot be used under the treatment regime envisaged, because its quality may be affected by industrial effluent in the inflow to the works. However, this successful water reclamation scheme may well provide a model whereby local authorities and water providers elsewhere in the country could work together with the private sector to achieve higher levels of water reclamation.

7.4.2 The case study of the Cape Metropolitan Area

Currently, the re-use of treated sewage effluent in the Cape Metropolitan Area (CMA) appears to be limited to irrigation applications, mostly of golf courses and other sports facilities. Although detailed figures are available on water supply and wastewater production (see Appendix B), no figures on the re-use of TSE could be found.

In the past, several studies were carried out to assess the potential of water reclamation in various applications. Details are presented in Appendix B. A summary of the conclusions shows that in all cases, it was recommended not to pursue this option. However, the Cape Metropolitan Council is currently considering a policy on water reclamation, and all these options will be re-evaluated.

(i) **Agricultural irrigation** is a significant user of water in the Western Cape area as a whole, in which potential for substitution of TSE for fresh water would be possible. Cost implications were considered to be limiting in 1991. This situation is highly dependent upon the tariff structure imposed. Potentially, this could represent the reclamation of a significant portion of the TSE produced in the area.

(ii) Another potential application of reclaimed water from the CMA is the **recharge of the Cape Flats aquifer**. While in 1992 this option was rejected as being of no benefit, it is now being reconsidered.

(iii) Direct reuse in **potable** applications would require dilution in a ratio of 4:1 fresh water to TSE. A pilot plant was run at the Faure water treatment works to evaluate this option. At 1991 costs, it was considered to be too expensive, and not significant enough in terms of usage volume to be worth pursuing.

(iv) Implementation of **domestic non-potable systems** would require dual reticulation systems, which would be expensive to retrofit in existing developed areas. Legislation or substantial cost-savings would be required to encourage developers to implement such systems in new developments.

(v) **Industrial usage** of reclaimed water : currently only one small paper mill in the area uses TSE. The potential exists for the replacement of approximately 32% of the industrial water requirements of the Cape Metropolitan Area. This level of reclamation would re-use 9.3% of the TSE produced. The remainder of the industrial users require high grade water. The potential for selling TSE to industrial customers will soon be investigated in detail, under the terms of the new policy for water reclamation which is being put in place.

This case study shows the enormous potential that exists to intensify water reclamation in a variety of applications. Hence, while water reclamation was limited in the past in the Cape Metropolitan Area and was practised only in an opportunistic way, largely in irrigation applications, the outlook for the future is very different. The new Water Act and the emphasis on water demand management in local authorities is prompting local authority officials to explore new approaches. The policy on water reclamation which is being developed for the Cape Metropolitan Council promises to be highly comprehensive, and to offer strategic guidelines which may well inspire other coastal cities and towns to follow suit.

7.5 Water reclamation by direct industrial re-use

Direct industrial re-use of treated sewage effluent, by industries not requiring high-grade water, may be viable anywhere in the country. This application of TSE cuts down on treatment costs, since the water is not first treated to potable standards before being used. There are many industrial applications where lower-grade water is perfectly acceptable, as has been outlined in detail in section 4.3 above.

This is an area which has been pioneered in South Africa by the paper industry, where TSE has been used in certain paper mills for many years. As a successful case study therefore, this industry provides many useful lessons. Details of the case study are provided in Appendix C.

7.5.1 The case study of the paper industry

Two major paper-making companies in South Africa were approached for information on their usage of reclaimed water, namely Mondi and SAPPI (see Appendix C for details).

(i) **Mondi**. Only two of five paper-making machines currently operating at the Mondi Durban Paper Mill can use TSE. Mondi can at present withdraw up to 12 Ml/day of treated sewage effluent from the Southern wastewater treatment plant, run by the Durban Metro Water Service (see Appendix A). At present, usage of reclaimed water is constrained by the total volume of treated sewage effluent made available from the Southern WWTW. If the public/private partnership project to supply large volumes of tertiary treated water goes ahead (as described in Appendix A), and sufficient reclaimed water is made available, all five of Mondi's paper-making machines could in future run on reclaimed water, thus significantly reducing its freshwater demand.

Other Mondi operations include the Richard's Bay Kraft Mill, and board mills in both Springs and Piet Retief. Whilst TSE is not used in any of these operations, active programmes are in place to develop procedures for in-house reuse of water and reductions in both water and energy consumption. Mondi is currently implementing a five year programme to reduce the amount of water required per ton of paper produced. The current water requirement is 25 kl/ton of paper, while the aim is to acheive 10 kl/ton of paper by reusing process water in some applications.

(ii) **SAPPI**. Several Sappi paper mills re-use treated sewage effluent. The largest of these is the Enstra Mill near Springs, which requires a total of 53 Ml/day of water for its operations. Of this total, 16 Ml/day is TSE purchased from the Springs Municipality and treated further at the mill (details of tertiary treatment necessary are given in Appendix C). The TSE is used in the less demanding operations in pulp and paper-making, while potable water is used in higher grade applications. The practice of using TSE at Enstra was instituted over 50 years ago.

The Cape Kraft plant in Cape Town is a SAPPI plant, receiving about 1 Ml/day of TSE from the Milnerton Municipality. No on-site treatment is carried out on this reclaimed water prior to it entering the process. The Adamas Fine Paper plant in Port Elizabeth uses between 2.4 and 2.5 Ml/day of TSE from the Port Elizabeth municipality. 95% of the water requirements of the Adamas plant are met using treated sewage effluent, which is treated further on site.

Other Sappi plants in remote areas use surface water from rivers or lakes (which in the case of the Stanger mill on the North Coast of Natal is replenished by the discharge of treated sewage effluent from the nearby town of Stanger), or groundwater. These sources of water are also treated further on site prior to use.

No insoluble problems have been encountered with the long-term usage of TSE by paper mills in South Africa. Much can be learned from the details of tertiary treatment and the troubleshooting of problems which do occur, as detailed in Appendix C. These lessons may be applied in persuading other large-scale industrial users of water, where re-use of TSE has not been practised historically, that with tertiary treatment there may be few problems and considerable cost advantages to such re-use.

7.6 Water reclamation in new industrial developments

The final area which this study has considered in detail is intensifying water reclamation by providing dual reticulation in new developments. While there are strong social and economic barriers to laying dual reticulation in new housing developments in South Africa, new industrial developments can and should be planned to use reclaimed water.

At present, the major barrier preventing more wide-spread use of reclaimed water in new industrial developments is that of the cost to the developer of laying dual reticulation, where the benefit of savings in the use of TSE over potable water accrues to the industrial user. This is amply illustrated in the case study of the new industrial development at Capricorn Park, near Muizenburg in Cape Town. This case study is described in detail in Appendix D.

7.6.1 The case study of Capricorn Park in Cape Town

This new industrial development is currently under construction (1998), with infrastructure being laid. The developer will install a pump station at a cost of R180 000, together with a R 220 000 pipeline (250 mm diameter). TSE is to be supplied free of charge at present, while the cost of potable water is to the order of R 2.37/kl. Assuming irrigation volumes of 600 Ml/a for Phase 1, the cost of irrigation using potable water would be over R 1 422 000 in the first year. It is clear, therefore, that irrigation with TSE over potable water will quickly pay for itself, within the first year of operation.

Hence reclaimed water will be used for irrigation only at Capricorn Park, although individual industrial users may lay the reticulation themselves and draw TSE from the irrigation line if they so wish. Despite considerable interest in re-using TSE from individual investors, the developer would not install dual reticulation to allow industrial re-use of TSE from the Cape Flats wastewater treatment works, on the grounds of cost. A larger diameter pipeline would be required in order to transport a larger flowrate of TSE. In addition, the cost of laying dual reticulation would increase infrastructure costs considerably, while there was no guarantee that individual industrial users locating at Capricorn would in fact opt to re-use TSE. There was therefore no incentive for the developer to install the larger pipeline and to lay dual reticulation, as the cost savings on any industrial re-use of the TSE would accrue to the industrial user rather than to the developer.

The Capricorn Park project represents a case where a reuse option is to be implemented in practice, by a new industrial development, representing a considerable cost saving on using potable water for irrigation. Industrial activities at the site may also save on the cost of process water, should they choose to make use of the reclaimed water. However, dual reticulation is not being provided for industrial users of TSE by the developer. Should the users choose this option, they will be liable for the cost of installing the dual reticulation themselves.

Certainly, the incentive to industrial users to consider re-use of TSE would be far greater, if the dual reticulation system existed and the reclaimed water was ready to hand, at a much lower tariff than potable water. Under this scenario, the level of re-use of TSE would probably be much higher than in the situation obtaining at Capricorn. A case can therefore be made for the necessity of providing incentives to developers to lay dual reticulation, providing TSE to industrial users in new developments.

7.7 Intensifying land-based treatment and water reclamation

This chapter has argued the case for water reclamation, and the need for the intensification of land-based treatment which this implies. The role of land-based treatment, seen from this perspective, is essentially to remove the substances and compounds which accumulate in the water during use. Water's role as a carrier of substances is perhaps the least important of its functions, many of which are essential to support life itself, but this role is currently still the major one in its urban context, in terms of volume. However, it is a low-value role, which is no longer appropriate.

Redefining the value of water in the new Water Act will help to create a shift in perception, and will increase the value of water (as well as the price of water, which is not necessarily synonymous with value). This important legislative development, together with the practical consequences in terms of increasing tariffs, will undoubtedly change the ways in which water is used in South Africa. Hand-in-hand with this should go efforts to increase the extent of water reclamation taking place. Such efforts will push up the threshold of sustainable water use, to support much-needed economic and social development in South Africa. The next chapter examines in more detail why more water reclamation is not already taking place, and the hurdles and obstacles which must be overcome in order to intensify water reclamation efforts.

8. Institutional, Economic and Technical Constraints to Water Reclamation

This chapter deals with the constraints which are limiting the reclamation of water in South Africa. A useful paper has been published (Mills and Asano (1996)) which summarises problems with water reclamation in the United States, where reclamation projects are being pursued more vigorously. As in the US, the major constraints in South Africa appear to be both institutional and economic.

There are also a number of technical constraints which are dealt with below. Technical constraints are important to highlight, as their solution usually involves an increase in cost for a particular project. However, it is important to recognise that all the technical constraints raised can be overcome by technical means. In themselves, technical constraints do not pose a substantial barrier to the use of reclaimed water. Similarly, social constraints certainly exist, but they are not insuperable. Information and education are necessary for people to appreciate the value of using reclaimed water for certain applications.

8.1 Problems Encountered by Reclamation Projects in the US

Mills and Asano (1996) identify a number of problems which have been encountered by water reclamation projects in the US in the past. These are largely institutional and economic constraints, including :

Permit approvals – these should be received prior to commencing planning, as delays can be costly. One project in the US had a delay of 18 months waiting for permits, due to concerns that agricultural irrigation with reclaimed water would contaminate groundwater.

Reclaimed water market – securing a market for users has been found to be the single most critical factor to the success of a reclamation project. A number of projects have put forward proposals for funding without assurance that particular users intend to purchase the reclaimed water, even if they have expressed interest during planning phases. Particular problems are issues of water quality, water price, costs of conversion to reclaimed water (retrofitting costs), reliability of supply and liability.

Reliable data – is required to ensure that the water treatment plant is able to supply the flows required by the users. A number of projects have run into problems in that they have underestimated the demands which would be made for reclaimed water. Agricultural usage is one example of where seasonal changes in demands are experienced. It is also necessary to account for variabilities in the amount of reclaimed water which is produced. It is recommended that final project planning should be based on actual data where possible, and not just textbook projections.

Institutional issues – In the US a number of different agencies are responsible for potable water distribution and reclaimed water distribution. Although they intend to cooperate, they often have their own interests to protect, and for political or economic reasons cooperation is often not achieved.

8.2 Institutional Constraints in South Africa

8.2.1 Access to Information

Access to adequate data for South Africa was found to be one of the biggest problems in assimilating information for this project. While data on water demand and water supply is relatively easy to find and reliable, data on treated sewage effluent is very difficult to access in many cases. A lack of information can seriously hinder the process of instituting facilities or projects for the reuse of treated sewage effluent.

The following specific constraints were encountered:

(i) In most instances information and responses from public institutions (at both local and national level) were difficult to obtain. Two reasons were established for this:

- Due to the size of certain institutions, it was difficult to identify the persons responsible for certain tasks. Furthermore, people within certain institutions were unaware of what others within the same institution were doing.
- Numerous institutions, especially those undergoing internal change, are in a state of disarray. This leads to information being 'lost' or not easily accessible due to physical office relocations and, once again, to ill-defined roles of persons within the institutions.

(ii) Information which does exist was often found to be incomplete and not easily collatable; in many instances, information still exists only in hand-written records which were difficult to access and analyse in the time period available for this project.

(iii) Numerical information which was obtained from different sources for the same area was often contradictory.

A number of national institutions were consulted during the course of the work. These include the Department of Water Affairs and Forestry, the Landbou Unie, the Department of Land and Agriculture and the CSIR Departments of Water, Environment and Forestry. None of these institutions were able to provide accurate information with regard to the production of sewage effluent. Recent information on water demand is also difficult to access, with the latest figures available on a national level being 1996. In discussions with the Department of Water Affairs and Forestry it was indicated that a project is currently underway to establish a national water balance. This will include detailed assessments of the situation in the different provinces, and the development of a water balance model. The project was, however, in its infancy at the time of writing this report (May 1998).

An in-depth national assessment of the potential for reclaimed water to meet a proportion of South Africa's water demand will therefore face the need to gather detailed regional and local data country-wide, often having to spend time in a particular area and revisit officials in order to extract the necessary information. This may prove to be a costly and time-consuming exercise, whose main benefit may be to attract attention to the issue at local level, and to disseminate information. Alternatively, individual projects to reclaim water may best be realised on a regional or local basis, where the detailed data on sources of supply and potential customers for reclaimed water can be more accurately assessed.

8.2.2 The Durban Metro Project : constraints on a public sector body and the benefits of a public-private sector partnership

Such a local project is the initiative taken by Durban Metro Water Services (DMWS) in reclaiming water from their Southern wastewater treatment works. The institutional constraints encountered by DMWS are detailed in Appendix A. It was shown that, while it was not economically feasible for DMWS, being in the public sector, to supply tertiary treated water directly to customers. It is however possible for a private company to buy treated sewage effluent from DMWS, treat it further and supply it at a competitive rate to industrial users in the area (and make a profit!).

The institutional constraints on DMWS are as follows :

1. Since DMWS is a section of the City Council, the borrowing and repayment structures of loans for the project would need to be in accordance with the council procedures. This means that more favourable interest rates on loans could not be sought out by DMWS, and repayment structures were less favourable than those which are open to outside companies.
2. A tax rebate on capital expenditure for the project would be available for private companies; DMWS being a non-taxpayer cannot take advantage of this opportunity.
3. Private industries who specialise in wastewater treatment systems have developed or have access to the latest technologies for treating maximum volumes of water at minimal cost. These technologies may not necessarily be available to DMWS.

Tenders are currently being prepared for a private company to enter a public-private sector partnership with DMWS to supply TSE to users in the area. This represents a significant instance where innovative thinking has overcome institutional and economic constraints encountered by the local government body.

8.2.3 Constraints regarding policy initiatives on reclaimed water at local government level

At present local governments in South Africa are suffering from capacity shortages and transformation fatigue. There is, in general, little policy debate around the use of reclaimed water, as the issue of water supply is still dominating thinking in this sector. However, the Cape Metropolitan Council has recognised that it has a responsibility in this area. In November 1997, a proposed policy document considered by the Council stated that : "it is therefore to be expected that the CMC will encourage and actively promote the reuse of effluent. In the longer term, it may be anticipated that the CMC will develop a very proactive policy towards the promotion of the use of treated effluent in lieu of fresh water." This proposal led to a recommendation by the Executive Committee that a detailed policy be formulated and submitted for consideration. This work is currently in progress.

Two major constraints emerged from this policy process. The first concerns the role of the Cape Metropolitan Council versus that of the Metropolitan Local Councils or MLCs (the substructures). The MLCs are responsible for the operation of waste water treatment works (WWTWs) and hence the fate of treated effluent from the WWTWs is currently their direct responsibility. This means that the Cape Metropolitan Council is one step removed from the process of reclaiming water and must therefore work with the MLCs to implement this policy.

Secondly, the situation is highly dependent upon the implementation of the 1998 Water Act, in terms of which the treated effluent will fall under the control of the Department of Water Affairs and Forestry, and no longer under the local authority. Uncertainties relating to the permitting system and the level of tariffs to be set by DWAF, and the inevitable delays involved where 3 layers of government must work together to agree a *modus operandi,* may contribute towards a situation in which the reclamation of water is stymied, at least in the short to medium term, by contractual and institutional constraints.

8.2.4 Constraints within the existing water resource management system

This report has identified that return of treated sewage effluent to rivers is regarded in inland areas as an important aspect of water management. Hence the concept of reusing treated sewage effluent directly is not viewed as part of water conservation or water demand management. In order to take water reclamation seriously, there would need to be a re-orientation on the part of the Department of Water Affairs and of the major Water Boards who operate in inland areas.

Such a re-orientation would need to be based upon an investigation of the treatment and distribution costs of the present system, as compared to a system of direct re-use. Detailed salt balances and nutrient balances would need to be carried out, together with the system analysis and water balances normally used in water resource management. Initial theoretical salt balances for different situations involving return flows to rivers have been carried out in Appendix E.

During the course of this study, the following were but a few cases where the importance of TSE was expressed for maintaining river flows and dam levels :

(i) **The Hartebeespoort Dam**, north west of Johannesburg. The Jukskei river is one of several rivers flowing into the dam, and is responsible for 50% of the inflow. The Jukskei would naturally have been a seasonal river, but due to both the discharge of this TSE into the river, and development within the catchment, it currently flows all year round. The Northern sewage works, which is one of the larger works serving Johannesburg, discharges 400 Ml/day of TSE into the Jukskei River. A concern exists that, by reuse of this TSE directly in industrial or agricultural applications, the flow in the Jukskei, and consequently levels in the Dam, will drop.

(ii) A similar situation exists with the **Klip River**. A number of sewage works from Johannesburg's Southern suburbs and the East Rand discharge either directly or indirectly into this river. The Klip ultimately joins the Vaal River. Once again, removing sewage flows into this river will result in lowering of flows within the rivers [Hinch (1998)]. Rand Water returns approximately 60% of the water extracted from the Vaal River system back into the river.

(iii) **Eskom** initially made use of the local domestic TSE from its sites (including hostels on the sites) in a number of their power stations. In times of drought, however, the DWAF insisted that treated sewage was public water and should therefore be returned to public water courses. The practice of reclaiming the water was therefore stopped. Treated domestic sewage effluent is only reused when Eskom's own sewage treatment plants are unable to treat water to the general standards for discharge to river systems. On one or two sites, however, permits have been obtained for the use of TSE from the sewage works for irrigation.

(iv) **Durban Metro Water Services** (DMWS) reports pressure from a number of institutions for the continued release of TSE into rivers [Olivier (1998)]. These institutions include representatives from the CSIR, Earthlife Africa and the Natal Parks Board.

On the other hand, however, there are strong environmental arguments for decreasing the quantities of treated sewage effluent to certain rivers, particularly where this flow is affecting the riparian ecology negatively. In certain cases there are also capacity constraints. The following examples illustrate these points :

(i) **Durban Metro Water Services** (DMWS) discharges much of its treated sewage effluent into rivers which end in closed lagoons, where problems with eutrophication are encountered.

(ii) The **Kuils River** is the receiving stream for TSE from 3 sewage plants in the Western Cape, representing a flow of approximately 16.632×10^6 m^3/a. This represents the majority of the flow within the river. In the Kuils River situation, concerns exist regarding flooding from the river during winter, when both TSE and stormwater runoff enter the river. Other receiving bodies for some of the water currently entering this river are being explored.

Ultimately the debate which this study has opened up, with regard to return to rivers versus direct re-use, revolves around two quite distinct points :

- Firstly, issues surrounding **ownership of water.** Treated sewage effluent which is to be returned to rivers and dams is regarded as "public" water and hence certain institutions feel that all TSE (except that pumped to ocean discharges) should be returned to public watercourses. It is felt that where TSE is re-used directly, a charge should be levied to the user.

- Secondly, **environmental uses** including maintaining flows in rivers and levels in dams and lakes. In section 3.2 it was identified that environmental requirements represent almost 20% of the current water demand in South Africa. The discharge of TSE into rivers and, ultimately, dams also represents significant 'environmental' usage of water. However, this assertion has frequently been made in a context where in-stream flow requirements have not yet been calculated. There are also strong concerns about the environmental damage caused by returning TSE to rivers, as discussed above. Environmental reservations regarding the need for return of TSE to rivers and dams are dealt with in more detail in Appendix E.

The implementation of the 1998 Water Act will doubtless cast more light on both of these points. In the short term, however, there is certainly strong institutional resistance to the concept of direct water reclamation in inland areas.

8.3 Economic Constraints

8.3.1 The cost of laying dual reticulation systems

The Capricorn experience has shown that at present, developers are generally not interested in investigating the use of reclaimed water in new developments, be they industrial, commercial or residential. From a developer's viewpoint, a dual water supply system water system implies increased capital costs; while the benefits of using reclaimed water only affect the end users. A developer wishes to hand over an area as quickly as possible, with the minimum cost implications [Mitchell, 1998]. This is the perception of a local authority official who deals with developers and is involved with the process of encouraging people to reuse treated sewage effluent in Cape Town.

A specific example of the use of reclaimed water for non-potable purposes, and the constraints and resistances encountered, is presented in Appendix D for the Capricorn Park development. In this case, the developer was to remain responsible for the maintenance of the landscaped areas, and being adjacent to the Cape Flats WWTW, it was therefore a relatively easy option to consider reclaimed water for irrigation. However, even for this application the developer was hesitant to commit resources to designing the infrastructure, until the Council had provided a commitment as to reliability of supply and keeping the tariff very low. Providing reticulation for use of reclaimed water by individual industries within the Park was not considered feasible. It will be interesting to see in future how many individual investors at Capricorn in fact take up the option of installing their own reticulation for reclaimed water, and connecting to the irrigation main. As the water tariff for potable water rises, such an option will become increasingly attractive.

For new developments, once the information hurdle is overcome (i.e. once the developer is informed of the possibilities surrounding the use of reclaimed water), the cost factor of providing dual reticulation becomes the dominant constraint.

The problem is that the laying of dual reticulation involves increased capital costs in developing an area, while the benefits of using reclaimed water lie in the savings on operational expenditure, in the difference in tariff between using potable and reclaimed water. In new developments, the capital expenditure is incurred by the developer, while the benefits in ongoing savings are realised by the occupants of the development. Hence there is presently no incentive for the developer to become involved with the issue of reclaimed water.

8.3.2 The cost of long-distance distribution pipelines

Eskom, the primary power generating company and one of the most significant industrial users of water in South Africa, does not make any significant use of reclaimed water. Eskom's primary reason for not using treated sewage effluent for cooling applications is the limited availability in the vicinity of its power stations. Most of the large power stations are located near smaller towns. Conlyn (1998) indicates that some large power stations require to the order of 120 Ml/day of water; the amount of TSE available from settlements adjacent to the power stations is only up to 1 Ml/day. The cost of transport of reclaimed water from further afield was found to be prohibitively high, factoring in the amortisation cost of pipelin construction with the present cost structure of tariffs.

The argument that insufficient sources of TSE exist within a practical distance from industrial plants was encountered in several other cases. These include a number of the SAPPI paper mills which are discussed in Appendix C2. The high cost of long-distance distribution pipelines is therefore a major constraint presently limiting the volume of reclaimed water used in industrial applications. To make water reclamation economically feasible in these situations would require both a favourable tariff structure as well as subsidies on pipeline construction.

8.4 Technical Constraints

8.4.1 Health Issues in Irrigation with Reclaimed Water

Both internationally and in South Africa, concerns exist surrounding irrigation with treated sewage effluent containing industrial effluent, due to the possible heavy metal content. The potentially toxic pathogenic organisms in sewage are also of concern.

Health risks in irrigating with reclaimed water arise as a result of three factors. The first is direct contact with irrigation waters, by workers in the field. Secondly, when irrigation schemes are located near to residential areas, the mist formed by sprays is potentially dangerous to surrounding communities. Finally, eating vegetables if the water is applied through sprinkler irrigation systems directly onto plants and then ingested by humans and animals has potential to cause problems.

These factors and concerns are addressed in detail in the various international and national standards for the use of reclaimed water which are discussed in Chapter 5. Where the consistency of quality of the reclaimed water is assured, the application of reasonable standards can then be taken as protection against the associated health risks.

8.4.2 Concern for Contamination of Soils and Surface or Groundwaters

In agriculture (as in all activities), polluted runoff or return flow to surface streams or drainage to the underground water resources from fields irrigated with water containing environmentally dangerous substances is of concern. Such runoff may result in temporary or permanent degradation of the receiving water body's water quality. Pollution may be limited by using low application rates of contaminated water, which will restrict downward water movement past the root zone [WRC (1996)].

Furthermore, if the pH of the effluent is markedly high or low, it may change the natural pH of the soil, to the detriment of crops that are grown under irrigation.

A final concern which has been expressed regarding the use of TSE for irrigation is the high sodium and potassium contents in sewage outflow and the potential effect on soil structure. The WRC policy proposal on agricultural irrigation [WRC(1996)] notes that sodium may in some cases destroy the soil structure within a few irrigations, to such an extent that the water infiltration rate of the soil could become virtually zero. Furthermore, phosphates in the water may react with calcium to form calcium phosphate. The significance of this effect will, however, depend on the levels of the contaminants in the water, and on the type of soils through which irrigation is taking place. In a pilot Soil Aquifer Treatment (SAT) project in Phoenix, Arizona, it was observed that the accumulation rate of calcium phosphate in the soil was so slow that soil porosity, hydraulic conductivity and infiltration rates would not be noticeably reduced for decades or even centuries [Bouwer (1991)]. Since irrigation application rates are so much lower than during soil aquifer treatment, the effect of precipitation of solids may be insignificant in most scenarios.

8.4.3 Potential for Blockages of Irrigation Systems

High concentrations of algae in reclaimed water, which could grow as a result of high nutrient loadings, have the potential to cause clogging problems in drip- and micro-jet irrigation systems. Impact sprayers are not, however, commonly affected [van den Honert (1997)].

8.4.4 Reservations from Potential Industrial Users

The main reservations surrounding industrial usage of reclaimed water are regarding the quality of the water supplied and the availability of water.

As has been discussed previously, reclaimed water may contain high loadings of nutrients. These were identified to have the potential to promote microbiological growth, which may cause fouling of cooling systems. Phosphate may cause scaling due to deposition at high temperatures. Furthermore, ammonia has the potential to promote corrosion cracking [Wijesinghe et al (1996), Parkinson and Basta (1991)]. Although the problems associated with phosphate and algal growth are identified in the South African situation, it is recognised that these are not insurmountable. The Kelvin power station, which is run by the Johannesburg municipality, has used TSE from the Northern Suburbs of Johannesburg for its operations for a number of years. Whilst problems have been encountered, on the whole operation has been smooth.

In the paper mills discussed in Appendix C, other problems and reservations encountered include :

- colour problems with the water,
- chlorides which may cause corrosion,
- phosphate and nitrate levels which may result in microbial growth,
- larval infestations, and
- worker health concerns.

The tertiary treatment of the TSE must be designed in such a way as to deal with potential water quality problems. Furthermore, usage of TSE in industry needs to be coupled with training and information surrounding the TSE to all workers who may need to deal with the water system.

8.4.5 Water Quality Consistency and Reliability of Supply

The quality of water from certain treatment works may be highly variable. TSE quality may be influenced by, for instance, the time of day that a particular industry discharges its effluent into the sewage system.

Furthermore, quantities of water which are available will be a function of the amount of water entering the treatment plant. This will again be a function of the time of day and the season. Diurnal fluctuations are generally regular and predictable. However, seasonal fluctuations are more difficult to predict because, as with other parts of the water cycle, they are subject to the vagaries of climate. For instance, groundwater infiltration into wastewater lines will be markedly raised during the rainy season which is unusually wet.

Potential customers for TSE often look for guarantees of both quality and quantity of the supply of reclaimed water, which may not always be possible. Quality issues must be tackled by consideration of the tertiary treatment system which may be required. One manner of circumventing quantity of supply issues is to introduce make-up tanks into the supply system, where longer-term shortfalls of reclaimed water are made up by potable water supplies. Diurnal fluctuations can be dealt with by the installation of buffer tanks large enough to provide 12 hours supply of reclaimed water.

A further concern relating to water quality surrounds the possibility of salinity buildup in the water system. In a closed-loop system where there are evaporation losses, levels of salts in the water will gradually increase with recycling. Where there is a maximum salt level which can be tolerated for the process application, the concentrations of the ions in question can be kept below this level by means of a purge stream, with additional make-up water being added on a continuous basis. For processes which require high-grade water, membrane technology may be used to remove salts, as is carried out on a large scale by Sasol in Secunda.

8.5 Social Constraints

The major social constraint is that many people have an aversion to the notion of the handling and reuse of treated sewage effluent in certain applications, such as irrigation. There may also be objections to certain practices on the basis of religion, for instance in the Islamic faith. Hence the public participation process with regard to reclamation projects is very important, and issues of public concern must be properly and sensitively addressed within such a process. Education programmes need to be set up in the form of newspaper reports, pamphlets, flyers and public meetings, in the form suitable for the particular application.

The education of workers and other personnel on projects using reclaimed water is also necessary. Where people may come into contact with treated sewage effluent, either through their work or through accidental contact such as exposure to irrigation spray, there must be an awareness of the level of risk involved. Workers must be thoroughly educated as to the use of a dual reticulation system, and that reclaimed water should not be used for drinking or washing. Precautions that can be taken include providing protective clothing and gloves for workers, and using irrigation systems only during times when there is the least probability of people in the vicinity, for instance at night, and below a certain wind speed.

8.6 Recommendations to address constraints and resistances

a. In order to ensure that developers are required to consider facilities for providing reclaimed water to new areas, the investigation of the feasibility of re-use of TSE should be a prerequisite for approvals for subdivision or rezoning of new developments. This needs to be addressed by the planning and engineering departments of local authorities, for all major new developments.

b. The use of reclaimed water needs to be made attractive on a cost basis. Cost incentives for reuse should be formally implemented within tariff structures. As found in overseas experience, the establishment of the market for reclaimed water is the key to successful water reclamation projects. The market is highly sensitive to price signals, and these should therefore be set with great care, with a long-term perspective.

c. A constant reliable supply of treated sewage effluent of consistent quality needs to be ensured by wastewater treatment works whose effluent is re-used, especially for agricultural purposes, where water quality is a major issue. Tertiary treatment needs to be considered for reuse in industrial applications.

d. Where projects involving the reuse of TSE are implemented, issues of public concern must be addressed. Education programmes need to be set up which may be in the form of newspaper reports, pamphlets, flyers and public meetings. The nature of such communication will depend on the proposed use for the TSE.

e. More innovative thinking and new institutional arrangements in the local authority tier of government will allow for overcoming institutional constraints, as has been demonstrated in the case of the Durban Metro public-private partnership.

f. To encourage local authorities to implement projects for reclaimed water usage, in the short term, the Department of Water Affairs and Forestry should consider imposing targets for reuse upon individual local authorities.

g. The move towards the establishment of Catchment Management Agencies, as set out in the National Water Act of 1998, should facilitate investigations of the potential of water reclamation on a local and regional basis. Catchment Management Agencies should be required, upon their establishment, to frame targets for water reclamation in their catchment area.

h. Guidelines should be developed for national policy and strategy in water reclamation, taking into account the national strategic framework for water conservation and demand management of the Department of Water Affairs and Forestry.

9. Conclusions

Increasing demand for water caused by the pressures of urbanisation and industrialisation, as well as the rising standards of living of many of South Africa's people, are increasing the stress on the country's existing water resources. Attempting to expand these resources means tapping into new and ever more fragile sources of water, with devastating environmental effects. In many catchments, freshwater resources are already over-exploited. Hence there are strong arguments for working within existing freshwater resources and utilising them more effectively. Water reclamation to meet non-potable requirements is an important area for South Africa to implement in this regard, since only a fraction of actual water consumption requires water of a potable standard.

This report has shown that the extent of water reclamation in South Africa is less than 5% of the available treated sewage effluent. When one considers that Israel reuses 84% of the treated sewage effluent produced, it is clear that in South Africa, water reclamation is still in its infancy. Israel's major application for reuse is in agricultural irrigation, and the small size of the country also assists in focusing and concentrating such initiative (the area of Israel is less than that of the Kruger National Park). However, this illustration serves to emphasise how much can be achieved in water reclamation with the requisite policies in place.

Water reclamation projects in the USA are increasing rapidly, and valuable lessons have been learned from problems encountered in the past. As discussed in detail in chapter 8, these were largely institutional and economic constraints, such as : establishing cooperation between different agencies and levels of government; permit approval delays; acquiring reliable data on which to base project planning; and securing the user market. Interestingly, social constraints have not appeared to play a major role in holding back water reclamation in the USA.

There is undoubtedly scope in South Africa for re-using treated sewage effluent in agricultural irrigation. This has not been the major focus of this report, and is an aspect which deserves further investigation. The major driving force in this application will be the cost and availability of water for irrigation, and hence there are likely to be applications close to urban areas. For irrigation of public open space and sports facilities within urban areas, there are already several examples within South Africa, and this usage will undoubtedly increase. The laying of reticulation for such projects will increase the availability of reclaimed water more generally. Adjacent industrial areas could be encouraged to take advantage of such opportunities as they arise.

Re-use of treated sewage effluent in industrial applications is an area which requires active promotion. Innovative schemes such as that adopted by Durban Metro Water Services will undoubtedly raise the profile of this type of application. The driving force will be the difference in cost between the reclaimed water and potable water, and the availability of the reclaimed water. Cost incentives such as tax rebates are needed to make these projects feasible and attractive. Small, localised schemes will have the highest chances of success. Since South Africa is in a rapid development phase, new industrial developments should be targeted to ensure that re-use of TSE is implemented. However, retro-fitting dual reticulation in existing developments may also still prove feasible in many cases, depending on the incentives which are provided.

For large industries and power plants situated far from urban centres, it is apparent however that the high cost of long-distance distribution pipelines will continue to constrain the possibility of usage of reclaimed water. Given the size of South Africa, and the sparse population in certain areas, it is inevitable that some large water users may never be served by reclaimed water. It is important therefore to focus upon specific regions and local authorities where the development pattern lends itself to intensifying water reclamation.

In the initial phase of promoting water reclamation, coastal towns and cities should be targeted. However, this study argues that the water management system in inland areas should also be re-examined, carrying out thorough salt and nutrient balances for specific areas. There are potentially large savings in avoiding treatment costs in treating water to potable standard for industrial use, as well as for irrigation. Both in terms of cost and in terms of conserving freshwater resources, water reclamation must become a vital part of South Africa's water management strategy for the future.

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APPENDIX A. Area Case Study 1 - The Durban Metro Project

The Durban Metro area was identified as a worthwhile area of study for a number of reasons. The first is that records of water usage and TSE production are easily accessible and well organised. Secondly, reuse of TSE already occurs in the area, and further innovative projects for the use of TSE are being planned. These are discussed here. Finally, all water supplied by Durban Metro Water Services is purchased from Umgeni Water, a private company who controls water management in the Umgeni River Valley. Hence the DMWS represents a contained "flow in-flow out" system.

A1 Bulk Water Supply to the Durban Metro Region - Umgeni Water

Umgeni Water is responsible for the bulk storage, treatment and distribution of potable water in the Umgeni River valley in KwaZulu-Natal. It serves an area of 24 000 km^2 and the main infrastructure consists of eleven dams, twelve waterworks, ten wastewater works, a number of pump stations and an extensive network of tunnels, aqueducts and pipelines.

Umgeni Water has 28 bulk customers (of which DMWS is one) and 13 842 individual customers, and, in the period February 1996 to February 1997 treated approximately 316 x 10^6 m^3 of water in 13 water treatment plants. Water sales went up by 5.6% from 296 x 10^6 m^3 for the previous year. Potable water supplied to customers was as follows [Umgeni Water (1997c)] :

Customer	**Approximate Annual Purchases for 1996-1997 (x 10^6 m^3)**
Local authorities	
City of Durban (Durban Metro)	241.7
City of Pietermaritzburg	38.5
Howick Municipality	1.3
Stanger Town Board	0.02
Hilton Town Board (Hilton TLC)	0.61
Mt Michael Health Committee (Hilton TLC)	0.17
Ashburton Health Committee	0.23
Camperdown Health Committee	0.14
Cato Ridge Health Committee (Durban Metro)	0.16
Wartburg Health Committee	0.15
Joint Services Boards	
Dolphin Coast	1.9
Metro Water (North Coast)	4.9
Metro Water (South Coast)	6.1
South Coast Water (JSB – South Coast)	4.7
NPA and KwaZulu	
Edenvale (PMB TLC)	10.4
Mpumalanga	4.3
Mpophomeni	0.9
Others	7
TOTAL	316

Charges levied to clients by Umgeni Water are calculated to include the cost of capital of new developments by the company.

A2 Water Supplied by Durban Metro Water Services (DMWS)

Durban Metro Water Services (DMWS) is the municipal body responsible for the water supply and sewage treatment in the Durban Metropolitan area. The area supplied by DMWS runs along approximately 80 km on the coast and up to 70 km inland. Approximately 3 million people, and 2680 industrial clients are currently supplied with water, with a projected 300 000 more connections being required in the next 15 years. The amount of water currently supplied is approximately 850 to 870 Ml/day, with the current growth in demand being to the order of 12% annually. DMWS is, however, instituting procedures for demand management and water conservation to reduce the growth in demand.

Umgeni Water treats water to potable standard prior to supplying it to DMWS. The only treatment of fresh water which DMWS performs is the addition of chlorine where necessary. All clients of DMWS described in the previous paragraph thus currently receive potable water.

DMWS offers three supply options to water users. These are:

(i) Full pressure water supply, which is connection directly in to the water mains, with unlimited supply of water at high pressure. This option requires waterborne sewage.
(ii) Semi pressure water supply, in which a tank is installed in or on the roof of the house. A pipe from the water mains supplies water to the tank, which then feeds the taps and toilets in the house. The water pipe to the tank is at high pressure, but all the other pipes and fittings are not pressurized. Although the water supply is unlimited, this option has the limitation that, due to the low pressure of the water, spray hoses cannot be used. This option also requires waterborne sewage.
(iii) Low tanks, in which a 200 litre ground level tank is supplied to the client. Water is purchased in advance for a month at a fixed fee. The tank is filled once a day, and does not require waterborne sewerage.

Options (ii) and (iii) currently have approximately 4000 connections each, but are rapidly expanding

The charges to the consumer depend on the amount of water used. For low tank users, a fixed charge of R9.30 per month is levied. The detailed costs to other users is detailed below.

Table A1 – Water tariffs levied by DMWS (as at 5/9/97)

	Tank	**Domestic**		**Non-Domestic**
		Semi Pressure	**Full Pressure**	**Full Pressure**
Connection fee	R190.00	R 380	R 1310 to R 3 860*	R 1310 to R 3 860*
Account deposit	-	R60	R 130	R 130
Charges per kl	-			
Less than 6 kl/month	-	R 1.17	R 1.17	R 2.13
More than 6kl/month, less than 30 kl/month	-	R 1.53	R 2.13	R 2.13
More than 30 kl/month	-	R 3.19	R 3.19	R 2.13
Charge for use >200 l/day	-	-	R 10.20 for 15 mm connection	Varies by connection size

*Depends on pipe diameter fitted for supply. For pipes above 75 mm, the full cost of fitting is levied.

As mentioned above, the tank system is the only one which does not require waterborne sewage. The remaining users discharge effluents primarily to the public sewerage system.

A3 Sewage Production and Treatment

The region controlled by DMWS is characterised by a high proportion of clients who are supplied with water-borne sewage. Of the water which is supplied, there is a 50% to 60% return to sewage. Thirty-one sewage plants currently service the Durban Metro area. Of these, 28 are operated by DMWS, with the remaining three (Durban Heights, Hazelmere and Amanzimtoti) being operated by Umgeni Water. A list of some of the larger sewage plants operated by DMWS, and their average daily flows, is presented in Table A2.

Table A2 – Sewage Plants in the Durban Metro Region

Name of Plant	Type	Design Capacity (Ml/day)	Average Flow (Ml/day)
Southern WWTW	Marine Outfall	250	192
Central	Marine Outfall	110	57
Northern	Activated Sludge	70	37
Kwa Mashu	Activated Sludge	50	30
	Biofilter	15	20
Umlazi	J Ponds	*	14.5
Tongaat Central	Act. Sludge/ Biofilter	6	4.8
Tongaat South	*	2.5	2.4
Genazzano	*	1.5	0.8
Umdhloti	Act. Sludge/Ext aeration	1.5	0.8
Umhlanga	Act. Sludge/Ext aeration	7.2	5.8
Verulam	Act. Sludge/Biofilter	12	4.5
Amanzimtoti	Activated Sludge	26	15-20
Kingsburgh	Activated Sludge	3.3	1.5
Kwamakutha	Ponds	3	1.6
Mfolweni	Biofilter	*	*
Cato Ridge	Ponds	0.5	*
Glenwood Rd	Biofilter	0.08	*
Richmond Park	Biofilter	0.06	*
New Germany	Activated Sludge	7	1.8
Umbilo	Act. Sludge/Biofilter	23.2	17.2
Umhlatuzana	Activated Sludge	14.8	8.7
Umlaas	Activated Sludge	0.6	0.6
Blundell Road	Activated Sludge	0.8	*
Currie Cres.	Activated Sludge	0.03	*
Approximate Total			**418.5**

* no data supplied

In total, approximately 460 Ml of sewage is treated daily in the Durban Metro area, which includes that from those plants for which no data is supplied in the above Table. The large number of small treatment works is a carryover from prior to the formation of the DMWS, where 14 different water supply authorities existed in the Natal region alone. Some of these authorities now form part of the DMWS. Since DMWS believe that large sewage treatment works are more cost efficient and reliable than smaller ones, they are considering consolidation of various regional treatment works under their operation.

Most of the DMWS-operated sewage treatment plants discharge to rivers which end in closed lagoons. No downstream extraction occurs from any of the rivers to which the DMWS treatment plants discharge, with the exception of the Umhlanga River from which downstream extraction for irrigation occurs. The Central and Southern Sewage works have sea discharges. These sea outfalls are over 4 km out to sea, in over 60 m of water. The outfall from the Southern Treatment Works has a capacity of 108-116 Ml/day under gravity flow or 215-217 Ml/day under pump discharge.

The water treated in the sewage plants almost always meets, or is better than, the General Standard, with the obvious exception of that pumped to the sea outfalls.

Apart from the Cato Ridge golf course which is irrigated with TSE, the DMWS currently has only one user of TSE, being the Mondi Paper Mill. This plant is discussed in more detail later in this document. Furthermore, the new Durban International Airport which is to be built at La Mercy north of the city centre has expressed an interest in using TSE for activities such as aeroplane washing.

A4 The Southern Sewage Works

The Southern Sewage Works is the largest works run by DMWS, currently treating approximately 111 to 112 Ml/day. It is located close to Durban International Airport, south of the city centre, and receives sewage effluent from the Durban harbour and the area south of the harbour, and from the suburbs of Westville, Chatsworth and Umlazi.

Two main lines enter the sewage works; the Umlazi line carries approximately 30 Ml/day of mainly domestic sewage, and the Jacobs line which carries the remainder of the plants input which is a mixture of 60% industrial effluent and 40% domestic effluent.

The treatment plant was initially designed to treat sewage via primary treatment, and the sewage water and sludge were pumped out to sea outfall. A typical quality analysis of the sea outfall water is:

Suspended solids	508 mg/l
COD	2790 mg/l
NH_3	28 ml/l
PO_4 as P	no data
Colour	no data

A further 31 Ml/day of industrial effluent which bypasses treatment is combined with the primary treated effluent prior to discharge to sea outfall. The total flow to sea is thus approximately 142 Ml/day (June 1997).

To meet the need of the Mondi Paper Mill for secondary treated effluent (see the discussion in section 0), a 9 Ml/day secondary treatment plant was built by DMWS. This served Mondi's requirement, and, more recently, a 48 Ml/day secondary treatment plant was built at the site. The reasons for building this plant are discussed below.

A5 Feasibility Study of the Reuse of TSE from the Southern Treatment Works

Projections by DMWS identified that the Southern Treatment Works would reach the capacity of its sea outfall of 108-116 Ml/day under gravity flow or 215-217 Ml/day under pump discharge within 10 years or less. Extension of the sea outfall was identified to be a costly and time-consuming exercise. A policy decision was made to encourage the reuse of TSE by industry, with the ultimate aim of a reduction in ultimate discharge.

The attached panoramic view (Photo 1) shows the Southern Treatment Works, and the various industries surrounding the Works. These are AECI (to the extreme left, behind the hill), SASOL Fibres, SAPREF, Mondi (which currently uses TSE) and Engen. The close proximity of all these industries to the Works makes the reuse of TSE by industries an attractive option, due to the relatively low transport costs to the sites. It is noted that a new airport is being built north of Durban, and that shown in this photo will eventually close. It is speculated that the airport site will either be used for a further big petrochemical refinery, or as a second harbour for containers, both of which would potentially be users of reclaimed water.

These industries, as well as some smaller ones in the area, were approached regarding the use of reclaimed water. Although initially not overly enthusiastic about the idea, they indicated that they would consider it provided that :

- The reclaimed water was of suitable quality.
- The reclaimed water was competitive on a cost basis against mains water.
- The switch to using reclaimed water could be done without fitting any further onsite treatment facilities over and above those which they already had in place.

The first step taken by DMWS was to build new secondary treatment plant at the Works. As discussed above, the Southern Works treatment plant was initially treating sewage by primary treatment for discharge to deep sea outfall. A secondary treatment plant was later built with a capacity of 9Ml/day to supply the Mondi paper mill (usage of TSE at this mill is discussed in detail in section 0). The new secondary treatment plant, which was built at a cost of R36 million, had a capacity of 48 Ml/day. This gave the Works the option either to treat water to a high standard for resale to industry, or to treat the water to general standard to discharge to the beach, resulting a lower strain on the capacity of sea outfalls. The 48 Ml/day plant currently supplies Mondi with between 7 and 9 Ml/day of TSE. The remainder of water treated in the plant, which meets the General Standard, is discharged into a canal which ultimately discharges into the sea over the beach. This canal can be seen on the photograph. It is noted that the secondary treatment plant does not always operate at full capacity, and is mostly used to treat the primarily domestic sewage from the Umlazi line.

A pilot tertiary treatment plant was then built by DMWS to determine the costs of supplying tertiary treated water. This plant demonstrated that it was not viable for DMWS to extend this project to full-scale production: the cost of reclaimed water was ultimately greater than that of potable water. It was, however, identified that the project may be feasible if undertaken by a private company. Three reasons were identified why this may be so:

(i) Due to the fact that DMWS is a section of the City Council, the borrowing and repayment structures of loans for the project would need to be in accordance with Council procedures. Hence interest rates and repayment structures are less favourable for DMWS than those which are open to outside companies.
(ii) For private companies a tax rebate on capital expenditure for the project would be available. DMWS, being a government institution, can not take advantage of this tax rebate opportunity.
(iii) Private industries who specialise in wastewater treatment systems have developed or have access to the latest technologies, which reduce the unit costs of treatment. Such technology is not readily available to DMWS.

After approval by both the DWAF and Umgeni Water, DMWS appointed Rand Merchant Bank (RMB) in April 1997 to carry out an economic assessment of a tertiary treatment and supply facility, to be privately operated. Their report, issued in July of that same year, showed that the building and operation of such a tertiary treatment plant was potentially economically feasible. The fact that the RMB had assessed the project drew the attention of potential clients for reclaimed water. Prior to RMB’s report, Mondi was the only company which showed active interest in the project.

In a two-stage bid process, a number of companies submitted proposals and four companies were chosen in the pre-qualification round. These were major multinational concerns, one from the UK and three from France. These four companies were then asked to identify clients for reclaimed water in the area, and to put forward detailed proposals for their plants. It is desired to sell the greatest volume possible. Tenders for the project are rated on both the volume which they can sell and the price for which the reclaimed water can be produced (see detailed terms of reference below). At the time of writing the tender award has not yet been made.

A5.1 Implications of the Private-Public Partnership

In response to the RMB report, companies were invited to tender for the building of a tertiary treatment plant to treat water from the Southern Treatment Works for supply to industry in the area. Certain restrictions were placed on the quality and quantity of water to be supplied, the clients which may be recruited and the amount which the company should charge for its water as follows:

(i) The concessionaire will pay 22 c/kl of TSE sold to DMWS as a “loss of sales” levy. This is to cover the cost of infrastructure which has already been laid down by DMWS.
(ii) An administration charge of approximately R 250 000 per year, which will escalate annually, is to be payable to DMWS to cover the costs of factors such as contract meetings, water quality testing etc.
(iii) The concessionaire will need to take over the operation of the 48 Ml/day secondary treatment plant, and pay back the book value of this plant to DMWS.
(iv) The concessionaire needs to treat a certain volume of TSE to tertiary level for the DMWS at a competitive price to be agreed.
(v) The concessionaire will lease land for their plant at the Southern Treatment Works site from DMWS.
(vi) The concessionaire will need to lay down new piping infrastructure to transport TSE to their clients.
(vii) The cost to users of the tertiary treated sewage effluent may not escalate at above the consumer price index.

Feasibility analyses indicated that a minimum of 15 Ml/day needs to be sold to make the operation economically viable. Furthermore, as discussed above, the Southern Treatment Works receives approximately 30 Ml/day of primarily domestic effluent in the Umlazi line, with the Jacobs line carrying approximately 60% industrial and 40% domestic effluent. If the concessionaire sells more than 30 Ml/day, therefore, it will be necessary to treat more industrial effluent to the required standards. Whilst feasible, this may imply a higher treatment cost and a less reliable quality of supply as has been discussed previously.

A5.2 Implications of the Tertiary Treated Sewage Supply Facility for DMWS

The positive gains to DMWS of this project, should it materialise, are twofold. Firstly, no extensions to their sea outfalls will be required, implying a large cost saving. Secondly, the DMWS will save financially on the costs of operating the secondary treatment plant at the Southern Treatment Works.

Whilst the project does imply a loss of profit for DMWS, it will not imply a net loss. The levy of 22 c/kl of water sold will cover the cost of capital already spent on laying out infrastructure for existing water supplies.

One of the issues which needs to be considered is that the price charged by Umgeni Water to the DMWS for potable water is calculated based on the capital which Umgeni has spent on dams and piping infrastructure. If DMWS purchases less water from Umgeni, the cost per unit of water to the user (ie DMWS) will increase. This will directly translate to a cost increase for DMWS's clients. The largest cost factor in the price of water supplied by DMWS is the purchase cost of water from Umgeni. At this stage, though, the reuse of 15-30 Ml/day represents an insignificant proportion of the total amount of water purchased from Umgeni (of 850-870 Ml/day), and may therefore not affect the price of water purchased. Any further significant increase in water reclamation efforts within this area may however have the effect of reducing water purchases from Umgeni Water, which may result in the price of raw water being driven above what it would otherwise be.

A6 Summary

The Durban Metro project represents probably the most innovative reuse of TSE in the country. Whilst the amounts of water to be reused will probably represent less than 5% of the total demand in the area, the project is of key significance in that:

(i) Water which is currently disposed of to sea is reutilized,
(ii) The project may grow in the future,
(iii) The project is significant in stimulating innovative options for TSE reuse.

The project is also significant in demonstrating how the implementation of a private-public partnership has been used to overcome the institutional constraints encountered by the DMWS. Social and institutional constraints are discussed further in chapter 7 of this document.

APPENDIX B. AREA CASE STUDY 2 - THE WESTERN CAPE

B1 Current Water Usage in the Greater Cape Town Metropolitan Area

The Waterworks Branch of the Cape Town City Council, referred to as the Cape Town Water Undertaking (CTWU), provides the bulk supply of potable water to twenty other local authorities throughout the Greater Cape Town Metropolitan Area. The CTWU is the predominant urban water user in the Western Cape Region. Some of the local authorities do, however, have their own water sources [Ninham Shand (1994)].

The CTWU supplied approximately 284.5 $x10^6$ m^3/a in the 1995/1996 period [Singles (1998)]. The approximate breakdown of users supplied within the Municipal Area is given in Table B1.

Table B1 – Annual Urban Water Use Proportions in the Cape Town Municipal Area [Singles (1998)]

Usage	**Volume ($x10^6$ m^3/a)**	**Percentage**
Domestic	58.27	53.09
Sports Bodies	2.82	2.57
Municipal	6.17	5.62
Commercial and public	6.51	5.93
Industrial	10.46	9.53
Spoornet	1.79	1.63
Shipping	2.25	0.20
Harbour	0.65	0.59
Eskom	0.03	
Not accounted for		10%
Total	88.92	

Further customers who purchase from CTWU include the following:

Table B2 – Consumers who Purchase Water from the Cape Town Water Undertaking

Consumer	**Consumption ($x10^6$ m^3/a)**	**Consumer**	**Consumption ($x10^6$ m^3/a)**
Bellville Municipality	16.28	Mfuleni	0.66
Brackenfell Municipality	3.53	Milnerton Municipality	12.4
Western Cape Regional Services Council	45.23	Paarl Municipality	12.54
Durbanville Municipality	4.65	Parow Municipality	11.24
Fish Hoek Municipality	1.52	Pinelands Municipality	2.13
Goodwood Municipality	6.50	Simon's Town Municipality	0.26
Gordon's Bay Municipality	1.21	Somerset West Municipality	2.87
Ikapa Town Council	12.20	Wellington Municipality	2.73
Kraaifontein Municipality	3.15	Wemmershoek	2.86
Kuils River Municipality	3.62	Krantzkop	0.88
Llongulethu West	15.40	Miscellaneous	1.24

The above clients give a total demand of 166.16 x 10^6 m^3/a.

The total demand to the CTWU is thus that within the municipal area (109.76 x 10^6 m^3/a), other clients (166.16 x 10^6 m^3/a) and that unaccounted for (8.53 x 10^6 m^3/a), giving a total of 284.45 x 10^6 m^3/a.

The current demand (1997-1998) is estimated to be approximately 800 to 900 Ml/day, translating to between 292 x 10^6 m^3/a and 328 x 10^6 m^3/a.

The demand for water in the Cape Metropolitan Area is forecast to increase by the year 2012 up to $340x10^6$ m^3/a. In addition, substantial growth is predicted in the irrigation of farms in the Western Cape, which will require an additional $100x10^6$ m^3/a to be supplied from the same sources as serve the Metropolitan Area [Ninham Shand (1992)].

B2 TSE Production in the Region

In the Cape Town Metropole, approximately 24 wastewater treatment plants exist, treating between $180x10^6$ and $189x10^6$ m^3/a of sewage, with an average daily flow of 517.7 Ml/day. Of the treatment works, three (Hout Bay, Greenpoint and Camps Bay) consist only of primary treatment, namely coarse and fine screening, with maceration of the fine screenings prior to return to the sewage stream. The discharge quality of all the other treatment works in the region is to the DWAF's general standard for sewage. A list of the treatment works and marine outfalls, along with their average daily and annual flows, is presented in Table B3. These values were extracted from Jeffares and Green (1997), where it was noted that certain values are estimates. The values presented in Table B3 must thus be taken as guidelines and not accurate totals.

Table B3 – Wastewater Treatment Works operated by the CMC

Works	Daily Flow (Ml/day)	Annual Flow ($x10^6$ m^3/a)	Fate of Effluent
Wesfleur (Atlantis)	9.9	3.597	Infiltration Ponds, discharge to stormwater system
Groot Springfontein (Dover)	0.05	0.018	Infiltration Ponds, effluent lost by evaporation/seepage
Melkbosstrand	1.30	0.473	Soute River
Potsdam (Milnerton)	23.90	8.731	Diep River
Athlone	113.60	41.458	Black River System
Llandudno	0.20	0.063	Sea
Wildevoelvlei	6.00	2.179	Wildevoel Vlei
Simon's Town	1.50	0.546	Sea
Cape Flats	152.60	55.704	Sea
Mitchell's Plain	28.00	10.223	Sea
Borcherds Quarry	29.30	10.711	Kalksteenfontein canal into Black River System
Parow North	1.00	0.354	Irrigation to golf course
Bellville	39.70	14.493	Kuils River
Kuilsriver	1.80	0.646	Kuils River
Kraaifontein	5.70	2.097	Mosselbank River into Diep River
Scottsdene	3.30	1.193	Kuils River
Zandvliet	14.10	15.019	Eerste River
Oudekraal	0.03	0.011	Sea
Miller's Point	0.02	0.007	Sea
Gordon's Bay	1.60	0.586	Irrigation (summer), sea (winter)
Macassar	26.30	9.686	Eerste River
Subtotal	*459.9*	*177.795*	
Marine Outfalls:			
Hout Bay	2.30	0.853	Sea
Greenpoint	26.50	9.664	Sea
Camps Bay	2.00	0.724	Sea
OVERALL TOTAL	490.7	189.036	

The above sewage plants mainly treat domestic effluent, with the exception of Athlone and Belville which have a high industrial effluent input. Of the water entering sewage treatment plants, it is estimated that approximately 25% is accounted for by groundwater infiltration of fresh water. This is both as a result of leaks in the system, and due to discharges of stormwater directly into the sewer system.

B3 Potential Uses for TSE

B3.1 Industrial

Industrial water usage in the Cape Town Metropole represented 15% of the total urban water use in the Western Cape in 1992, and by the year 2000 is expected to represent 10% of the Western Cape region's requirements. Table B4, extracted from Ninham Shand (1994), presents a breakdown of the main industrial water users in the Cape Town Metropolitan Area. The figures presented are from 1991.

Table B4 - Breakdown of Main Industrial Water Consumers in the Western Cape Metropolitan Area

Major Industries	**Usage ($x10^6$ m^3/a)**	**% of Total**
Textiles	9.88	19.4
Chemicals	7.64	15.0
Foods	5.56	10.9
Canning/freezing	4.86	9.5
Cement	3.82	7.5
Engineering	3.82	7.5
Glass	3.45	6.8
Refinery	2.37	4.7
Dairy	1.51	3.0
Fish canning	1.44	2.8
Paper	1.37	2.7
White meat	1.32	2.6
Power	1.29	2.5
Beer	0.98	1.9
Meat	0.65	1.3
Food oils	0.38	0.7
Leather	0.38	0.7
Wine/spirits	0.28	0.5
TOTAL	**51.00**	

Ninham Shand (1994) suggests that there is little scope for industrial re-use on any significant scale as the sectors with the largest usage require high grade water (i.e. textiles, chemicals, food and canning/freezing). Based on the literature reports presented previously in this current document, it is, however, suggested here that potential may exist for reuse applications in the following sectors:

Table B5 - Main Industrial Water Consumers in the Western Cape Metropolitan Area, who can potentially re-use TSE (extracted from Table B4)

Sector	**Water Usage ($x10^6$ m^3/a)**
Cement	3.82
Engineering	3.82
Glass	3.45
Refinery	2.37
Paper*	1.37
Power	1.29
Leather	0.38
TOTAL	**16.50**

* the SAPPI paper mill already makes use of TSE from the Milnerton treatment plant (section 0)

The combined total of 16.5 x 10^6 m^3/a (approximately 45.2 Ml/day) used by these industries represents approximately 32% of the total industrial water consumption in the Western Cape Metropole. Raising wastewater re-use to this figure would mean the reclamation of 9.3% of the total treated sewage effluent available. The feasibility of substituting reclaimed water for these industries is undergoing more detailed investigation, as the Cape Metropolitan Council has now recognised the need to intensify water reclamation efforts. Existing industries are being approached, and new industrial developments will also be monitored to identify new potential low-grade water users.

B3.2 Irrigation

(a) Agricultural Use

Agricultural usage is forecast to represent 36% of the water demand in the Western Cape by the year 2000. In the Cape Town urban area itself there is limited agricultural activity. The Western Cape region is, however, characterised by intensive agricultural activity and high irrigation requirements. As noted previously, the projected increase in irrigation requirements by 2012 in the Western Cape is projected to be $100x10^6$ m^3/a.

It is thus seen that the entire irrigation demand in the Western Cape may be met by that produced in the treatment works listed in Table B3. The fact that the General Standard is met by most sewage works (except those discharged to sea outfall) implies that the TSE meets almost all of the international quality requirements for irrigation presented in section 5. The only parameters which will need to be checked are the pH, TSS and BOD levels which may in certain cases not be met. Furthermore, the importance of parasites and viruses, for which no standards are set, should not be ignored.

The limitation to using TSE in irrigation lies thus not in availability or quality, but in the cost implications of setting up the infrastructure required to transport the water to the point at which it is required. Farms are generally located away from the urban sewage treatment works.

Ninham Shand Inc (1992) reports two irrigation schemes in the vicinity of Stellenbosch. Known as the Helderberg and Stellenbosch schemes, these have been allocated up to $20x10^6$ m^3/a of water for irrigation.

To deliver to these schemes from the False Bay coast, where the four large domestic sewage effluent treatment works are located, will require a pipeline 45km long and pumping against a head of about 350 m. Furthermore, irrigation is only required during the summer months – for 3 months in the case of vineyards, and 6 months if other crops are grown in the future.

A costing analysis for such a scheme was prepared by Ninham Shand in 1991, which takes into account both capital and operational costs. The results of this analysis are presented in Table B6 below.

Table B6 – 1991 Estimated Cost for $20x10^6 m^3/a$ Irrigation Exchange Scheme
(extracted from Ninham Shand (1992))

Peak Delivery Rate	**Delivery Period**	**Capital Cost**	**Unit Reference Value[(1)]**
Ml/day	**Months/yr**	**R million**	**c/kl**
165	3	117	83
125	4	100	74
83	6	74	61

[(1)]Discounted at 8%

The feasibility of using reclaimed water for irrigation in either of these schemes is therefore highly dependent upon the water tariff being paid for raw water for irrigation.

(b) Urban Irrigation Use

Current urban use of TSE for irrigation in the Cape Town Metropolitan Area do exist – examples presented previously are the King David, Mowbray, Rondebosch, Milnerton, Steenberg, Parow, and Durbanville Golf Courses. The Bellville South sports facilities, the Sanlam grounds in Bellville, Kraaifontein Sportsground, Peninsula Technicon, the University of the Western Cape, the Milnerton Beachfront, the Milnerton Race Course and a local school in the area also make use of TSE for irrigation. No data is currently available to enable an estimation of the volume of reclaimed water used in this way.

The Capricorn Park industrial development near Muizenberg in the Cape Town metropolitan area will use TSE from the Cape Flats Wastewater Treatment Works for irrigation of its grounds. A detailed discussion of this project, and the limitations surrounding reuse for other purposes at this site, is presented in Appendix D.

B3.3 Recharge of Groundwater – The Cape Flats Aquifer System

(a) Recharge methods

Recharge of groundwater is one option for the reuse of treated sewage effluent, as discussed in section 4.4. In Atlantis in the Western Cape, TSE from domestic sources is already used to recharge the Atlantis aquifer which supplies potable water for the area. The availability of sewage effluent in Cape Town is at its highest in winter when the demand for water is at the lowest, and vice versa. Given this fact, it has been suggested that the Cape Flats Aquifer be used for the storage of sewage effluent for use in the summer months, if the availability of effluent were a constraint.

Two possible recharge methods were identified in the initial feasibility study: direct recharge (injecting directly into aquifer through recharge boreholes) or indirect recharge via surface infiltration [Ninham Shand (1992)]. Based on the information obtained from the Atlantis recharge project, an effective long term infiltration rate of 25 mm per day should be assumed for recharge through ponds. This means that an area of 11 ha would be required for every 10^6 m^3/a of water to be recharged. It was initially assumed that percolation through the overlying unsaturated sand and storage in the aquifer would improve the quality of the effluent to such an extent that a relatively low cost treatment process after withdrawal would suffice, to meet potable water standards. However, Ninham Shand (1992) reports of discussions with the CSIR which indicated that this arrangement could not be relied upon to treat the water and that full reclamation treatment should be provided before recharge or after abstraction. In addition, bearing in mind the existing and expected urban development in the area, the study concluded that the area of land required is not available for recharge to any significant degree, and hence that indirect recharge was not a feasible option.

The other option to be investigated was direct injection. The recommended maximum recharge ratio is 2.5, and the natural recharge rate of the Cape Flats Aquifer is $18x10^6$ m^3/a. Therefore it would be possible to recharge a maximum of $45x10^6$ m^3/a. At a recharge rate of 10 l/s per borehole, with 300 boreholes spread over an area of at least 6 km^2, the total rate of injection would be 3 m^3/s. This would enable the maximum recharge to be met, but would be difficult to arrange [Ninham Shand (1992)].

The quoted report concluded that recharge with TSE of the Cape Flats Aquifer System was not to be recommended due to the extreme cost and practicality implications associated with this option. With changes in water pricing structures, however, which results in the reuse of TSE potentially becoming more financially feasible, this option is now once again under consideration [A.Clayton, Pers.Comm. (1998)].

B3.4 Direct Potable Reuse

Guidelines issued by the Department of Health indicate that for potable reuse, sewage effluent needs to be blended with fresh water in a maximum blending ratio of 1:4 for potable reuse.

The WRC and Cape Town City Council operated a pilot plant treating effluent from the Cape Flats Sewage Treatment Works for four and a half years, aimed at establishing the practicability and cost of reclaiming effluent for direct re-use in the potable water supply. The most suitable scheme was identified to be one in which water from the four main domestic sewage works in Cape Town be collected in one pipeline and transported to the Faure Water Treatment Works for blending with fresh water.

The pilot plant successfully treated 4 500 m^3/day. Feed water to the plant was a secondary effluent treated in the pilot plant by chemical flocculation, primary sedimentation, chlorination, sand filtration, ozonation, activated carbon treatment, final chlorination and stabilization.

A cost analysis of this study indicated the unit reference value of water from the scheme to be 152 c/kl based on a discount rate of 8% p.a, and 186 c/kl based on a discount rate of 17% p.a. The total reclaimed water cost was identified at the time to be about four times higher in cost than for ordinary drinking water [Pieterse and Kfir (1991)]. About 30% of the unit cost is represented by the cost of activated carbon needed for tertiary treatment. In 1992 this was still being imported. Local manufacture, ozonation before activated carbon treatment and on site carbon regeneration would significantly reduce costs [Ninham Shand (1992), Pieterse and Kfir (1991)].

Since the Faure Water Treatment Works is planned to have an ultimate capacity of 1000 Ml/day, the plant could absorb a flowrate of reclaimed water of 200 Ml/day, or some 73 x 10^6 m^3/a. It was concluded from the pilot plant trial that the option of reclaimed water use for potable applications is both expensive and will not represent a significantly high enough reuse to make it worth the financial sacrifice.

B3.5 Non-potable domestic use

Non-potable domestic use of TSE requires the fitting of dual reticulation systems. The cost of retrofitting, however, would probably be restrictively high. The implementation of dual water systems in new urban townships may be feasible. New legislative requirements and/or significant cost saving implications would probably be required in order to compel developers to include dual water systems into development plans [Mitchell (1998)].

B4 Summary of the Western Cape Study

(i) Industrial usage of reclaimed water : the potential exists for the replacement of approximately 32% of the industrial requirements of the Cape Town Metropole, or 5% of the region's total water requirements. The remainder of the industrial users require high grade water.

(ii) Agricultural irrigation is a significant user of water in the Western Cape Area as a whole, in which potential for substitution of reclaimed water for fresh water would be possible. Cost implications are currently limiting in this case.

(iii) Another potential application is the recharge of the Cape Flats aquifer with TSE. While in 1992 this option was rejected as being of no benefit, it is now being reconsidered.

(iv) Direct reuse in potable applications would require dilution in a ratio of 4:1 fresh water to TSE. At 1991 costs, this option was considered to be too expensive, and not significant enough in terms of usage volume to be worth pursuing.

(v) Implementation of domestic non-potable systems would require dual reticulation systems which would be expensive to retrofit in existing developed areas. Legislation or cost saving benefits would be required to encourage developers to implement such systems in new developments.

It is clear that with the new perspective on the value of water which is being put forward by the Water Bill, many of these options for using reclaimed water will once again come under serious consideration. The Cape Metropolitan Council is currently putting in place a policy for water reclamation, which should be completed early in 1999.

APPENDIX C. INDUSTRIAL CASE STUDY 1 – RECLAIMED WATER USE IN PAPER MILLS

C1 The Mondi Paper Mill

The Mondi Durban Paper Mill, located in close proximity to Durban Metro Water Services' Southern Treatment Works discussed in Appendix A, uses reclaimed water as part of its process water requirements. The plant was built in 1970, and one of the permitting requirements issued prior to construction was that the mill should use treated sewage effluent as one of the sources of its water.

C1.1 Water Usage at the Mill

Only two of five paper-making machines currently operating at Mondi can use TSE. The approximate water requirements of the plant are presented in Table C1. It is noted that the volumes of water presented in the table are estimates, and that actual consumption varies from day to day. Mondi can at present withdraw up to 12 Ml/day of treated sewage effluent from the Southern WWTW (see Appendix A).

Table C1 – Approximate Water Usage at the Mondi Plant

Usage	Ml/day
Reclaimed Water (2 machines)	7
Potable water:	
Human Consumption	3
Boiler	2
PCC[3] Plant	2
Potable process water	28
Total Potable Water	35
Total Water Usage	**42**

C1.2 TSE Usage at the Plant

The Mondi plant currently purchases sewage from DMWS which is of a quality which almost meets the General Standard discussed previously. Prior to use, the reclaimed water is further treated by Mondi to their required standards. The water quality before and after activated carbon treatment is presented in Table C2. Tertiary treatment produces a high-grade water, with significant reductions in turbidity, colour, iron, oil, soap and grease, COD and oxygen absorbed. These factors are of particular importance in paper making as discussed in section 0 below. A schematic of the Mondi tertiary treatment process is presented in
Figure C1 below.

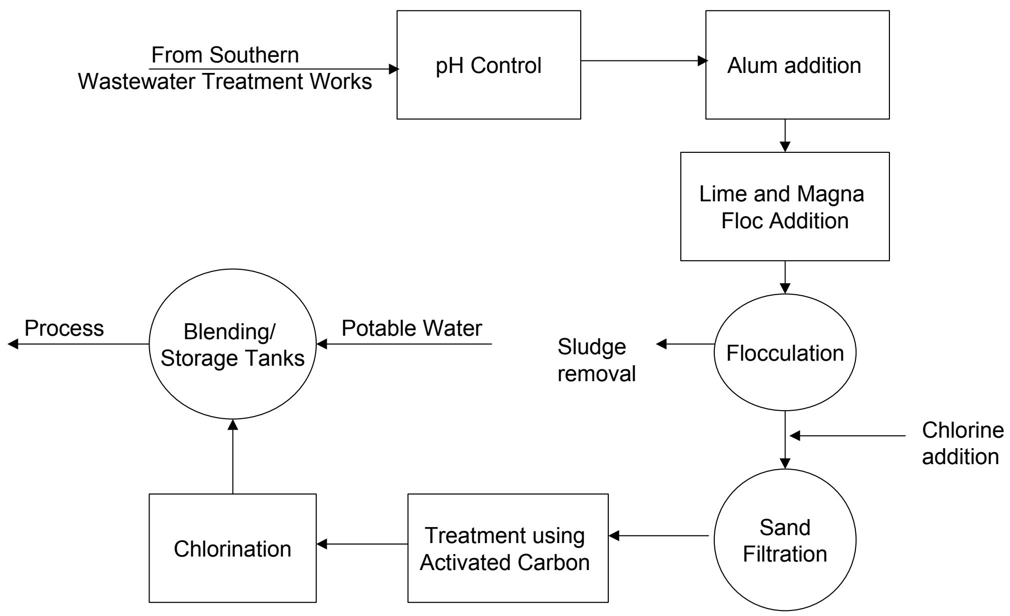
pH control is carried out where necessary using H_2SO_4 and NaOH to obtain the desired pH range of 6.5 to 7.5. 60% alum is then added for charge control. Approximately 0.274 kg/ton of water is used. Prior to flocculation, lime and a magnafloc flocculant is added. The flocculation unit is 25 m in diameter, 3.96 m in height and has a capacity of approximately 1 999 m^3. The solids are removed from the flocculation unit as a sludge, and chlorine is added at a level enough to remove all bacteria (to the order of 0.0033 kg/ton water), using a chlorine dioxide system. Sand filtration follows chlorine addition, with 5 sand filters on line at any one time. Then, in order to remove colour from the water, it is passed through activated carbon. Four carbon towers are on line at any one time, each tower containing 16 tons of Pittsburg granular F300 activated carbon, supplied by Chematron. The water is sent for final chlorination prior to being pumped to 1900 m^3 bulk storage tanks. Here it is mixed with potable water, for the sole purpose of making up quantity requirements. The blending or make-up water has nothing to do with the quality requirements for the process.

[3] Precipitated calcium carbonate, used as a filler in paper

Table C2 – Typical Water Quality Analysis for Sewage Supplied to Mondi by DMWS (12/11/97)

Parameter	**Incoming Sewage**	**After Activated Carbon treatment**
PH	6.6	6.6
Conductivity (μS/cm)	444	545
Turbidity (J.T.U)	3.5	0.2
Colour (H.U.)	30	5
Suspended solids (ppm)	4	
Dissolved solids (ppm)	270	382
Inorganic on dissolved solids (ppm)	178	276
Organic on dissolved solids (ppm)	92	106
M-Alkalinity as $CaCO_3$ (ppm)	51	39
Total Hardness as $CaCO_3$ (ppm)	82.9	107.8
Calcium as $CaCO_3$ (ppm)	51.4	87.9
Magnesium as $CaCO_3$ (ppm)	31.5	19.9
Iron as Fe (ppm)	0.13	0.08
Aluminium as Al (ppm)	0.07	0.06
Manganese as Mn (ppm)	0	0
Chlorine as Cl_2 (ppm)	0.2	0.5
Chlorine as Cl (ppm)	63.5	66.0
Sulphate as SO_4 (ppm)	16.5	73.2
Silica as SiO_2 (ppm)	12.4	10.2
Nitrate as N (ppm)	11.6	10.7
Nitrite as N (ppm)	0.05	Trace
Free and saline ammonia as N (ppm)	0.5	0.2
Phosphate as PO_4 (ppm)	7.8	Trace
Oil, soap and grease (ppm)	12.6	4.2
Detergent Monoxol (ppm)	0.15	0.09
COD (ppm)	19.0	6.0
Oxygen absorbed (ppm)	4.2	1.2

Figure C1 – Schematic of Tertiary Treatment Steps for TSE at Mondi



C1.3 Effluent from the Mill

The ultimate effluent from the paper mill is high in salts and suspended fibres. This water is placed in settling tanks to remove the solids, including residual fibres. A small amount of this water is returned to the paper-making process, while the majority is mixed with treated industrial effluent from the Southern Sewage Works and pumped out to deep sea outfall.

C1.4 Water Quality Parameters Significant in the Manufacture of Paper, and Problems Encountered at the Mondi Plant

Water quality parameters which are significant in paper-making, and the reasons for their significance, include the following:

Parameter	**Significance**
Conductivity	Corrosion
Colour	White paper
Residual Cl	Control of micro-organisms At >1 ppm interferes with dyes
Chloride	Corrosion Affects starch Needs to be less than 80 ppm for PCC
Iron	Colour, bleaching
Sulphate	Scale and deposits < 80 ppm required for PCC
Manganese and copper	Colour, bleaching
Oil, soap and grease	Foaming
Total organic carbon	< 5 ppm for fouling of resins
E.coli	Health
TAB[4]	Filimentous slime, S. natans

In the years of using wastewater at Mondi, four problems/concerns have been encountered:

(i) The colour of the water has presented problems, especially when industrial effluents have been present in the wastewater stream. To remove problems with colour, the TSE is passed over activated carbon.

(ii) Microbiological activity needs to be carefully controlled in that it may result in fouling of pipes and machinery.

(iii) TDS and COD need to be monitored, as they affect surface chemistry, which plays an important role in paper-making.

(iv) Although it has never posed problems at Mondi, worker safety needs to be ensured. For this reason *E.coli* in the TSE is monitored and the water is chlorinated as required

C1.5 The Future of Water Usage at Mondi Durban

(i) Mondi is currently implementing a five year programme to reduce the amount of water required per ton of paper produced. The current water requirement is 25 kl/ton of paper, while the aim is to acheive 10 kl/ton of paper by reusing process water in some applications. Mondi does, however, predict a growth in production from current levels (no numerical data of this growth was available), which will imply a net increase in water consumption for the plant.

(ii) At present, usage of reclaimed water is constrained by the total volume of treated sewage effluent made available from the Southern WWTW by Durban Metro Water Service. If the public/private partnership project to supply large volumes of tertiary treated water goes ahead (Appendix A), and sufficient reclaimed water is made available, all five of Mondi's paper-making machines could in future run on reclaimed water, thus significantly reducing its freshwater demand.

C1.6 Water Usage at Other Mondi Plants

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[4] Total Aerobic Bacteria

Other Mondi operations include the Richard's Bay Kraft Mill, and board mills in both Springs and Piet Retief. Whilst TSE is not used in any of these operations, active programmes are in place to develop procedures for in-house reuse of water and reductions in both water and energy consumption.

C2 SAPPI's Paper Mills

SAPPI also operates a number of paper mills around the country, most of which are significant users of water. Of these, several make use of treated sewage effluent in their operations. A brief overview of water and TSE use in SAPPI paper mills follows.

C2.1 Enstra Mill, Springs, Gauteng

The Enstra Mill requires a total of 53 Ml/day of water for its operations. Of this, 16 Ml/day is TSE purchased from the Springs Municipality. The TSE is supplied after secondary treatment, and is then put through flocculation, air flotation, pH control and disinfection with chlorine and activated bromine. The TSE is used in the less demanding operations in pulp and paper-making, while potable water is used in higher grade applications. The practice of using TSE at Enstra was instituted over 50 years ago.

Since the Springs Municipality treats a significant amount of industrial effluent, problems have been encountered at various times with the water quality at SAPPI, which have been attributed to heavy metals, dyes, blood from abattoirs and foaming agents in the wastewater.

C2.2 Stanger Mill, North Coast, Natal

A schematic diagram of the water supply configuration to the Stanger Mill is presented in Figure C2. The town of Stanger uses approximately 11 Ml/day of fresh water, supplied by Umgeni Water. Water which enters the Stanger sewage treatment plant is treated to the General Standard and is then discharged to the Mbozambo Lake, located close to the SAPPI plant.

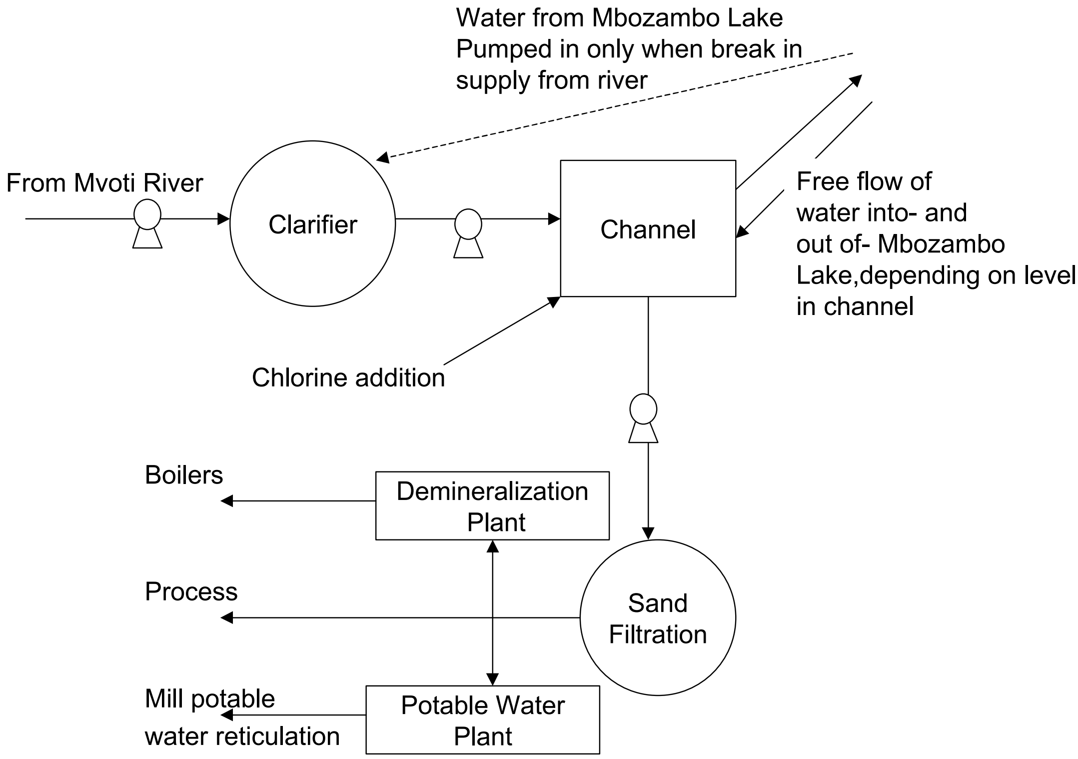
The Mill extracts the majority of its water requirement of 22 Ml/day from the Mvoti River. This water is sent to a clarifier to remove suspended solids. Polyaluminium sulphates and polyamine are added as flocculents to assist in settling. Also connected to the clarifier is a line to the Mbozambo Lake which can supply 7.5 Ml/day – approximately one third of the plant requirements. This line is used when either the river runs dry, or there is a failure of the main pump bringing fresh water from the river. The flow of TSE from the town of Stanger is insufficient to supply the mill with its total water requirements.

Water from the clarifier is pumped into a channel which is open to the lake. Thus free-flow of TSE, and subsequent blending, can occur, depending on the levels within the lake and the channel. In the channel chlorine is added to give a residual of 0.3-0.5 ppm. Water is then pumped out of the channel, into sand filters and is taken to the mill. Water for the boilers is sent to a demineralization plant, while a potable water plant treats water from the sand filters for the mill's potable water supply. The required water quality for process within the mill is less than 5 NTU and a pH of 7 to 7.5.

Effluent from the mill contains dissolved oxidized lignins, chlorinated organics and suspended fibres. This effluent is treated in an onsite treatment plant. The mill has been given a special permit to discharge water which does not meet the general standard into the Mvoti River.

Problems encountered with the use of TSE at various times during the plants operation include organics in the water, fouling of demineralization plant resins and high chlorine levels which may result in corrosion.

Figure C2 – Water Supply Configuration at the SAPPI Stanger Plant



C2.3 SAPPI Cape Kraft, Milnerton, Cape Town

This SAPPI plant receives TSE from the Milnerton Municipality. No on-site treatment is carried out on this water prior to it entering the process. Water demand at the plant is as follows:

Table C3 - Water Demand at SAPPI Cape Kraft Plant

Water	**kl/day**	**m^3/a**
Potable usage in gardens	7 – 35	2555 – 12775
Other potable usage (eg high pressure hoses)	350 – 800	127750 – 292000
TSE	850 – 1050	310 250 – 383 250

Water demand is seen to vary depending on the level of activity at the plant. Where there is a break in supply of TSE to the plant, potable water is substituted for TSE.

Use of TSE in processes at the plant has been carried out since approximately 1981. The only problems which have been reported regarding the reuse application are the potential for sulphate reducing bacteria in the water to be deposited on pipes. These bacteria have the potential to result in the formation of sulphur which may result in corrosion problems.

Effluent from the plant is sent to the Milnerton Municipality for treatment. A charge is levied to the plant on effluent produced, depending on the flow, COD and metals content of the effluent.

C2.4 Adamas Fine Paper Plant, Port Elizabeth

95% of the water requirements of the Adamas plant are met using treated sewage effluent from the Port Elizabeth municipality. The plant uses between 2.4 and 2.5 Ml/day of water which is treated to the General Standard by the municipality. SAPPI passes the reclaimed water through an air flotation unit, adds $Al(SO_4)$ for phosphate removal and decolourization, filters and chlorinates the water. Treated sewage effluent has been used instead of potable water at Adamas since 1993.

Problems encountered at the Adamas plant have been as follows : a once-off larval infestation, seasonal fluctuations in phosphate and nitrate levels in incoming air, and the potential for corrosion of pipes due to high chloride levels in the water.

C2.5 Tugela Mill, North Coast, Natal

This mill uses about 60 Ml/day of raw water, being extracted from local rivers. It is identified, however, that no significant sources of TSE are available in the area. The town of Mandini does not produce sufficient TSE to warrant the capital costs associated with substitution of a small amount of process water with TSE. The plant is, however, in the preliminary stages of developing an activated sludge treatment system for the treatment of their own process water for the purposes of on-site reuse. When this system is in place, the demand for raw water will be significantly reduced.

C2.6 Ngodwana Mill, Mpumalanga

The Ngodwana Mill uses groundwater for all its operations. They have, however, recently built a pilot plant to assess the feasibility of on-site reuse of process water. The effluent from the paper mill is currently being used in irrigation applications nearby. The reuse option was motivated by the potential for contamination of the nearby Elands River, and a full-scale treatment plant for recycle and reuse is planned to go into operation at the end of 1999.

APPENDIX D. INDUSTRY CASE STUDY 2 – THE CAPRICORN DEVELOPMENT

D1 Description of Capricorn Park

The Capricorn Park development is located near Muizenberg, Cape Town, close to the False Bay coastline. The Park consists of an area of land of 160 hectares, which has been divided into a number of properties to be sold off for office and industrial development, and will be developed in four phases. Communal, landscaped areas in the Park will consist of landscaped areas to be planted with indigenous fynbos, and an artificial lake.

Phase 1 of the Park, which comprises an area of 22.7 ha which is to be divided into over 140 sites, is currently under construction.

D2 Water Requirements within the Park

The three significant uses of water in the Park will be irrigation of gardens, domestic consumption and industrial consumption. During planning for supplies of potable water to the site, the following figures were used:

Industrial areas	1.92 l/sec/ha
Commercial areas	0.83 l/sec/ha

This equates to a peak flow water demand for all four phases of the development of some 7.1 Ml/day.

The irrigation requirements were estimated in the Environmental Impact Assessment carried out on the site to be 2.6 to 3.1 Ml/day for Phase 1 of the Park, for about eight months of the year. However, irrigation volumes actually used in practice will be highly dependent on rainfall.

D3 Potential for Effluent Reuse at Capricorn

In the initial identification of the site, it was recognised that the flat topography of the site would necessitate a system to allow for the drainage of stormwater through and away from the site. Further study of the soils and hydrology of the region showed a highly pervious upper layer and high water table. A decision was made to excavate a lake into the water table, both to provide a point of discharge for the stormwater system, and for aesthetic purposes. Furthermore, it was identified that the aquifer into which the lake would be excavated consisted of fresh water, and hence the potential for irrigation using water from the lake was suggested.

A hydrological study carried out as part of the EIA for the site identified that, taking into account rainfall and inflow into the area, the lake/aquifer system would supply insufficient water for irrigation. Four other possible sources of irrigation water were identified, and later rejected :

(i) Potable water, rejected due to the cost of supply
(ii) Sandvlei, which was saline
(iii) Zeekoevlei, which showed poor water quality and high costs to transport the water
(iv) The Zeekoe Canal, from which the quality was also poor

Due to the close proximity of Capricorn to the Cape Flats Wastewater Treatment Works, the use of treated sewage effluent for irrigation was then investigated. The water from the maturation ponds at the WWTW was identified in the EIA to represent "….a virtually unlimited, relatively inexpensive source of water….". The water does, however, contain excessively high concentrations of faecal bacteria, nitrate and phosphate. Water currently entering the maturation ponds is resident there for about 20 days before being discharged into the Zeekoe Canal and then into False Bay. It was identified that levels of faecal bacteria will depend on the length of retention time in the ponds.

The City Council, which runs the Cape Flats WWTW, supported the idea, and agreed to supply the water to the Park free of charge. The developer would, however, be responsible for abstraction and conveyance of the water from the plant. It is noted that in accordance with the requirements of the new Water Act, Capricorn may have to start paying for reclaimed water. Council have made an undertaking that in this event, the cost of reclaimed water charged to Capricorn will be "nominal".

Subsequent to the decision to supply TSE for irrigation at Capricorn, it was suggested by several parties, including prospective investors, that the supply of TSE for industrial usage should also be considered. The developer felt, however, that the cost of providing dual reticulation and individual connections for industrial purposes to each property in the Park in advance, without knowing the actual demand for TSE, would be prohibitively expensive. Further concerns raised by the developer included the lifetime of the Cape Flats WWTW, the quality of the reclaimed water and the reliability of supply. These latter issues were however satisfactorily dealt with in consultation with the City Council.

The issue over the cost of dual reticulation still remained as the major obstacle to industrial re-use of TSE from the Cape Flats WWTW. A compromise was eventually reached, and the current situation is the following:

(i) The developer has installed a pump station and pipeline sufficient to transport TSE from the Cape Flats WWTW to meet the irrigation needs of all four phases of the development, even though only Phase 1 is currently being developed.

(ii) Should there be demand from individual industries at Capricorn for the use of reclaimed water, this will either be extracted from the irrigation main running through the Park or, if necessary, a separate pipeline will be taken from the point at which the TSE line enters the Park boundary. If industrial demand for TSE is sufficiently high in Phase 1, thus using the irrigation capacity allotted to future phases, it will be necessary to install further reticulation for irrigation and industrial demand of those future phases.

Water will be pumped straight from the maturation ponds through a filter into the irrigation system at Capricorn, without undergoing any other treatment. Suspended solids which need to be removed include algae, which must be prevented from contaminating groundwater.

D4 Problems and Considerations which were Identified with TSE Use at Capricorn Park

Four considerations were identified in the Environmental Impact Assessment, surrounding the use of TSE for irrigation. These are:

- Plant species to be irrigated need to have salt tolerances in the moderate to tolerant range.
- The high bacteria content and the seasonally high densities of noxious algal species such as *Cyanobacteria* in the reclaimed water means that the irrigation spray is potentially harmful to human health if inhaled. The health risks could be reduced by irrigating at night, when wind speeds and human occupancy of the complex would be lowest. Since the algae are self-buoyant, the risk of inhaling *Cyanobacteria* can be further reduced by incorporating a device to skim the excess algae from the surface of the influent water, or by using filtration as discussed above.
- *Cyanobacteria* and other algae have potential to cause clogging problems in drip- and micro-jet irrigation systems. Impact sprayers should be unaffected.

During the EIA it was identified that the runoff of the reclaimed water into the artificial lake on the property may pose problems, due to the high nutrient levels which may cause eutrophication of the lake and, possibly, of the underlying aquifer. Two measures are to be introduced to ensure that TSE does not enter the lake. The first is that irrigation will be carefully planned, with jets facing away from the lake, no irrigation of the verge close to the lake and limiting surface runoff of irrigation water. Secondly, it was decided not to use TSE for irrigation of an island in the centre of the lake.

D5 Cost Implications associated with Reclaimed Water Usage

The developer will install a pump station at a cost of R180 000, together with a R 220 000 pipeline (a 250 mm ∅ pipe) to transport reclaimed water from the sewage treatment works to the site border. It is noted again that this should be sufficient for water supply for irrigation for all four phases of the Capricorn development.

Irrigation reticulation within Phase 1 is to cost a further R 400 000, excluding irrigation jets, timers, hoses etc. Should potable water have been used for irrigation, the potable reticulation system could have been used. The cost of reticulation for the potable system would, however, have increased if potable water was used for irrigation, as a greater volume of water would have been required.

TSE is to be supplied free of charge at present, while the cost of potable water is to the order of R 2.37/kl. Assuming irrigation volumes of 600 Ml/a for Phase 1, the cost of irrigation using potable water would be over R 1 422 000 in the first year. It is clear, therefore, that irrigation with TSE over potable water will quickly pay for itself, within the first year of operation.

A similar implication exists for industrial users: whilst they will be responsible for the initial cost of reticulation and connection to the TSE mains, the saving in potable water costs has significant long-term implications.

D6 Discussions with Surrounding Communities and Local Authorities

During planning of this project the idea of using reclaimed water for irrigation was put to members of the local community during community involvement meetings, and no resistance was encountered. Active support for the project was obtained from the City Council, and from operators at the sewage treatment works.

The developers also approached the Local Authority in the area to suggest extending the pipeline for irrigation activities in the area such as the re-establishment of dune vegetation and irrigation of public open space. No responses have, however, been received from the Local Authorities on this matter to date.

D7 Summary

The Capricorn Park project represents a case where a reuse option is to be implemented in practice, by a new industrial development, representing a considerable cost saving on using potable water for irrigation. Industrial activities at the site may also save on the cost of process water, should they choose to make use of the reclaimed water. However, dual reticulation is not being provided for industrial users of TSE by the developer. Should the users choose this option, they will be liable for the cost of installing the dual reticulation themselves.

The reuse scheme represents a reclamation of water which would otherwise end up in the ocean. The saving will be further enhanced should extensive use be made by industrial activities.

APPENDIX E. WATER AND SALT BALANCES IN INLAND RIVERS

E1 Returned TSE and its Role in Maintaining Flows in Rivers

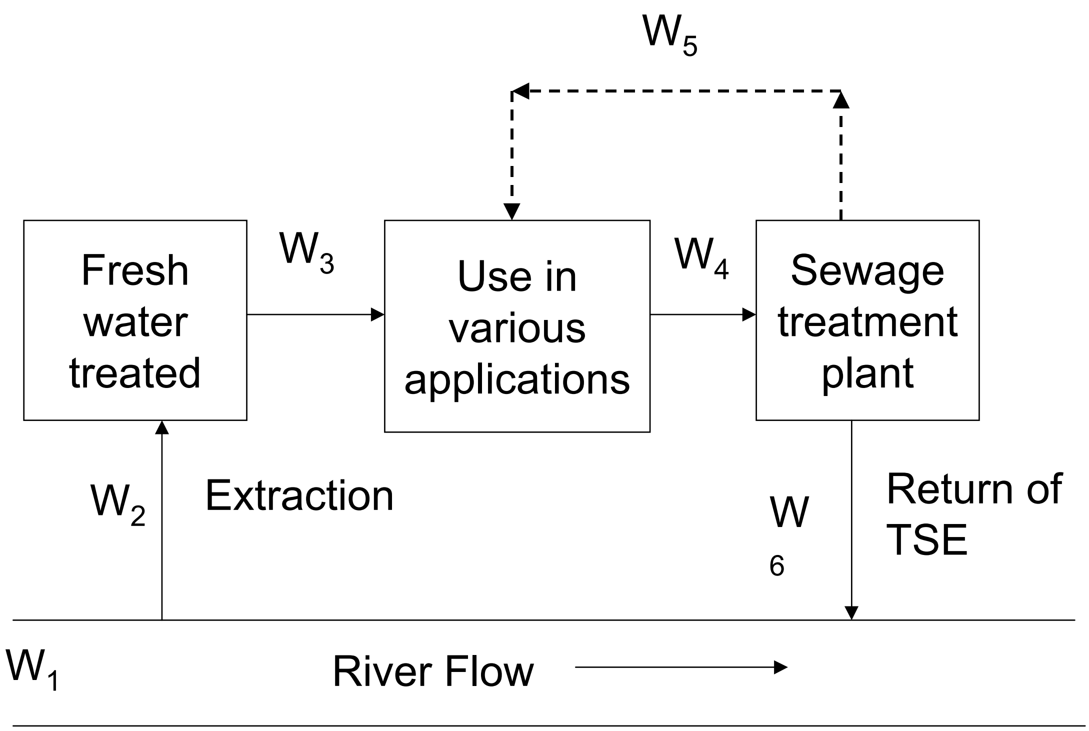
A reservation commonly encountered with regard to reuse of TSE is that the water is required to maintain the flows in a number of rivers in South Africa.

Given the existing perceptions of the negative impacts of reusing treated sewage effluent, and hence withdrawing it from the environment, it is necessary to attempt a broad analysis of the consequences of reclaiming water on the water balance in a given area.

(i) Effect of Reuse on Flow where TSE is Returned to the Same River

Consider the simple system shown in Figure E1. Here water is removed from a river (or dam), used, a proportion of the water not lost during use or transport is sent to a sewage treatment plant and the effluent returned to the same river.

Figure E1 – Withdrawal and return to the same river



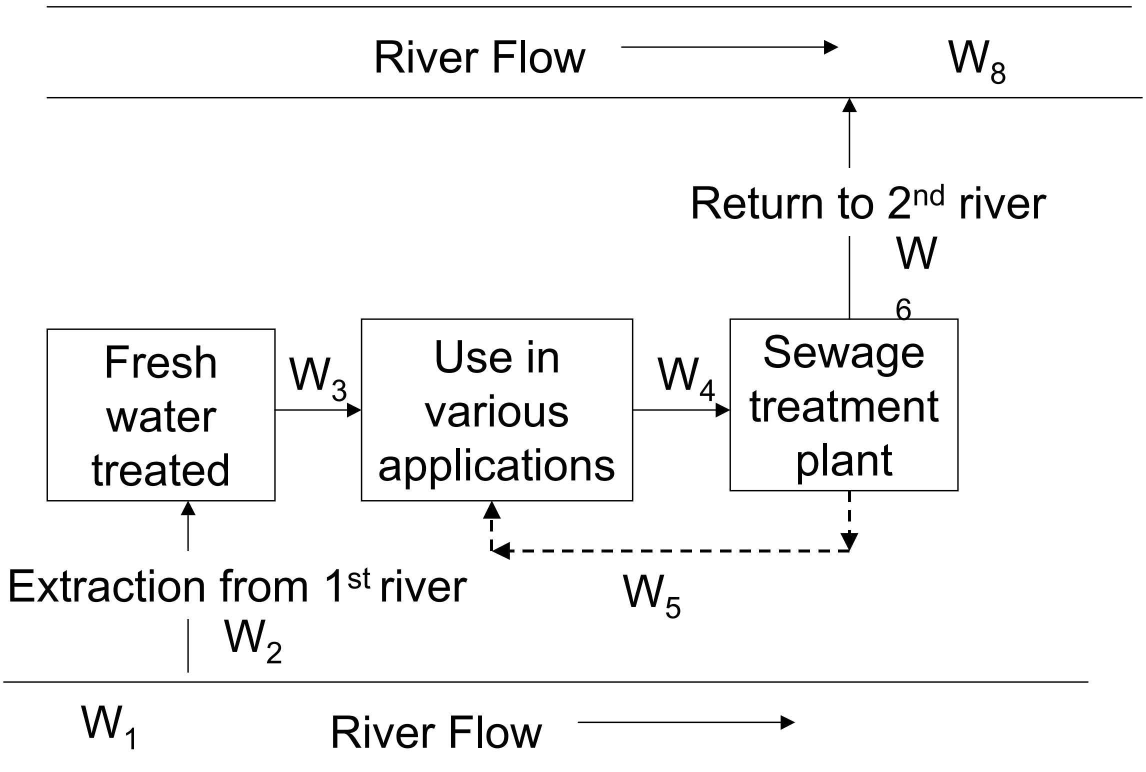
In this diagram, the flow in the river is reduced by extraction of stream W_2. A certain fraction of this water is consumed during use and the remainder is returned as stream W_6. Whilst reusing some of the TSE will result in a lowering of the return to river (ie less flow in W_6), it will also mean a lower extraction from the river in W_2. Providing the amount of water reused is equivalent to the amount of fresh water which would be withdrawn from the river to meet demand, the reuse of TSE will imply no overall change in the flow in the river, and will not affect any downstream withdrawal.

Thus, in the simplest case, reuse has no effect on the flow in the river. One indirect beneficial result of water reuse may, however, exist in this case. In practice, a large amount of water is lost in all of the steps presented in Figure E1. The introduction of a reuse step may imply the laying out of new infrastructure to treat, transport and store the reclaimed water, with lower losses in all steps. Thus in a reuse scenario, the total water abstracted, W_2 is reduced by the amount of TSE recycled plus the reduction in water losses during the cycle. W_6 is reduced only by the amount of TSE reused. Hence the net overall abstraction from the river decreases, resulting in a net increase in flow in the river due to TSE reuse, over a non-reuse scenario.

(ii) Effect of Reuse on Flow where TSE is Returned to a Different River

While the current Water Act requires discharge of water back into the river from which the water was abstracted, numerous exceptions to this requirement have been approved, with water being returned to rivers other than those than from which withdrawal has taken place. This situation includes the numerous inter-basin transfer schemes which are found in South Africa. Figure E2 is a schematic representation of this scenario.

Figure E2 – Return to a water body other than that from which water has been extracted



In this case reuse results in different consequences to those explored in section (i). A reuse scheme W_5 implies a reduction in return of treated sewage effluent to river 2, which is shown above as W_6. The reuse results in a reduction in demand for fresh water, W_2 and hence an increase in flow in river 1. The possible implications associated with a reduction in flow in river 2 need to be evaluated for each individual case, especially when downstream extraction from the discharge point occurs in river 2.

Once again, new infrastructure laid out for the purposes of reuse systems may imply lower losses through the system, and hence the reduction in W_6 may be less than the reduction in W_1.

E2 The Role of Returned TSE in Determining Water Quality

The importance of returned TSE flows with respect to the water quality and the salt balance within a river is a complex issue. Two opposing points of view may be taken on this issue:

- In instances where the sewage effluent which is returned is of higher quality than the water flowing in the river, the return flow is considered to be necessary in order to dilute the water in the river. In the Jukskei River – Hartebeespoort Dam system mentioned above, nutrients and bacteriological problems in this system are caused largely by polluted stormwater runoff from developed areas, as opposed to the TSE entering the system [Hinch (1998)]. The TSE serves to dilute the stormwater before it enters the dam.

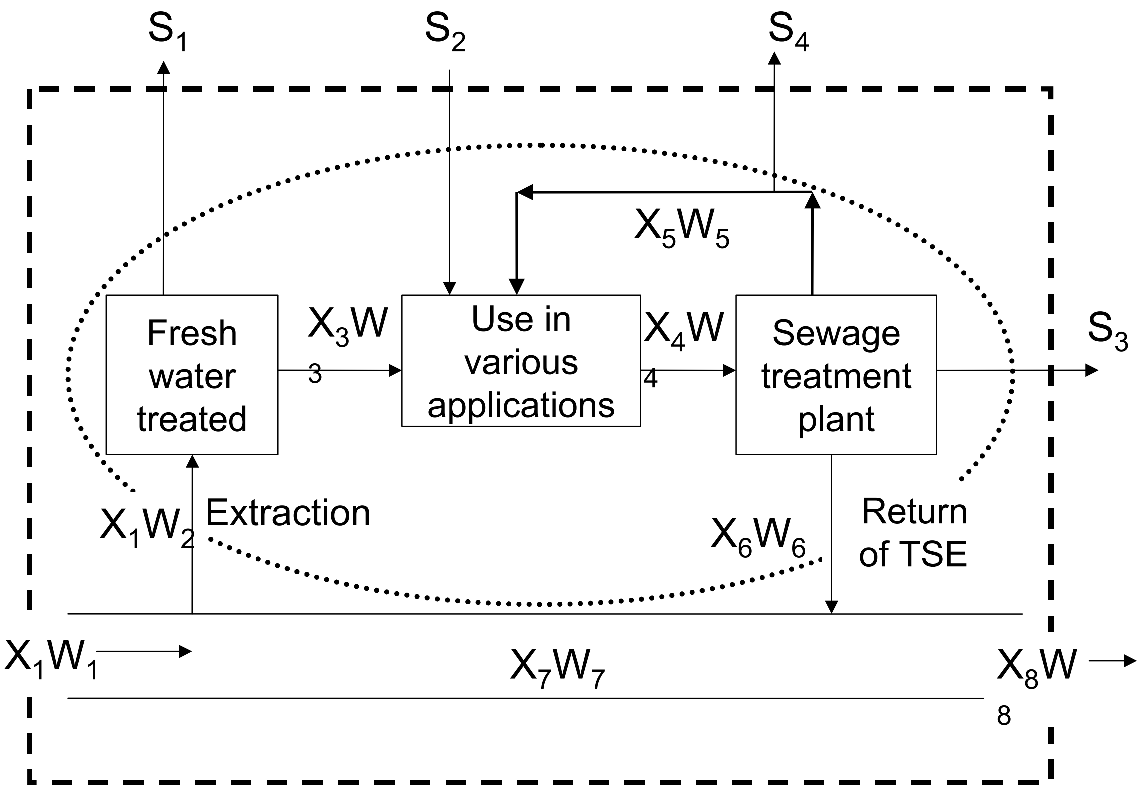
- On the other hand, in some cases high salt loadings in the TSE are diluted by pumping into a better quality river. DWAF (1996) reports that water qualities have deteriorated in rivers receiving large quantities of effluent, mainly due to salinity build-up which results from the addition of salts through most uses of water. Water quality in these rivers must be carefully managed through the control of effluent standards and by means of blending.

Each of these arguments will be analysed in turn, by means of a mass balance on the salt.

(i) Effect on Salt Loading and Concentration when Return is to the Same River

Consider Figure E3 below.

Figure E3 – Simple withdrawal – return scenario showing salt loadings



In this figure, W represents the flow in a stream (in, say, litres/hour), while X represents the salt concentration in the stream (grams/litre). XW thus represents the mass flowrate of salt in g/hr. The S terms represent a salt addition or removal to the water in g/hr as follows:

(i) S_1 is the removal of salts during treatment of fresh water.

(ii) S_2 is the addition of salt which results from normal use of the water, eg. domestic use.

(iii) S_3 is the removal of salt during sewage treatment, to get it to meet the quality requirements of the receiving water body.

(iv) S_4 is salt removed from the TSE in a further treatment step, to meet the water quality requirements of the user. Certain users may require TSE treated to the equivalent of potable water, while for others the quality of the TSE as is may be sufficient.

The total quantity of salt which is to be returned to the river in W_6 in a reuse scenario will depend on the value of S_4. From previous discussions, reuse of TSE implies a reduction in W_2 and hence an increase in W_7.

Consider the total salt balance over the whole system, indicated by the dashed square in Figure E3:

$X_8W_8 = X_1W_1 – (S_1 + S_4) + S_2 – S_3$

Consider the effect of a reuse scenario on the right hand side of the above equation. Assuming initially that losses remain the same:

(i) X_1W_1 will not change
(ii) S_2, the salt loading during use, and S_3, the salt removed to treat the effluent to acceptable standards, will be unaffected versus the non-reuse scenario.
(iii) S_1 will drop by a value ΔS_1, since less fresh water is being treated
(iv) S_4 lies between zero and the value by which S_1 has changed, ΔS_1, depending on the quality requirements of the TSE user.

Where S_4 is less than ΔS_1 (ie the quality of reclaimed water used is lower than potable) a reduction in X_8W_8 is demonstrated, while treatment of reclaimed water to potable standards, and $S_4 = \Delta S_1$ will imply no change in X_8W_8.

Since it was demonstrated above that a reuse scenario (with no change in system water losses) implies no change in the flow in the river, *the reuse scenario in this case results in no change or a lowering in salt loadings in the river downstream of the discharge point.*

To check this calculation, a balance is done over the dashed oval as indicated in Figure E3. Here:

$X_6W_6 = X_1W_2 – (S_1 + S_4) + S_2 – S_3$

Thus the reuse of TSE over a non-reuse scenario implies:

(i) A reduction in W_2 and hence in X_1W_2,
(ii) A reduction in S_1, ΔS_1, which is the equivalent of the reduction in X_1W_2,
(iii) No change in S_2 and S_3 as discussed above,
(iv) A reduction in W_6
(v) S_4 lies between 0 and ΔS_1, depending on quality requirements in reuse applications

Thus X_6W_6 either remains the same (where $S_4 = 0$, $\Delta X_1W_2 = \Delta S_1$ and thus X_6W_6 is unaffected) or decreases by a value of up to ΔX_1W_2 (in the case where S_4=S_1). Hence $\Delta X_1W_2 \leq \Delta X_6W_6 \leq 0$.

Now,

$X_8W_8 = X_1W_1 – X_1W_2 +X_6W_6$.

In the reuse scenario over a non-reuse scenario, X_1W_1 remains unchanged, X_1W_2 drops and X_6W_6 either remains the same or drops to any value up to or the equivalent of the change in X_1W_2. Thus X_8W_8 either remains the same (where $\Delta X_1W_2 = \Delta X_6W_6$) or drops (when $\Delta X_1W_2 < \Delta X_6W_6$) up to a value of ΔX_1W_2 when $\Delta X_6W_6 = 0$.

These results thus confirm the mass balance over the whole river.

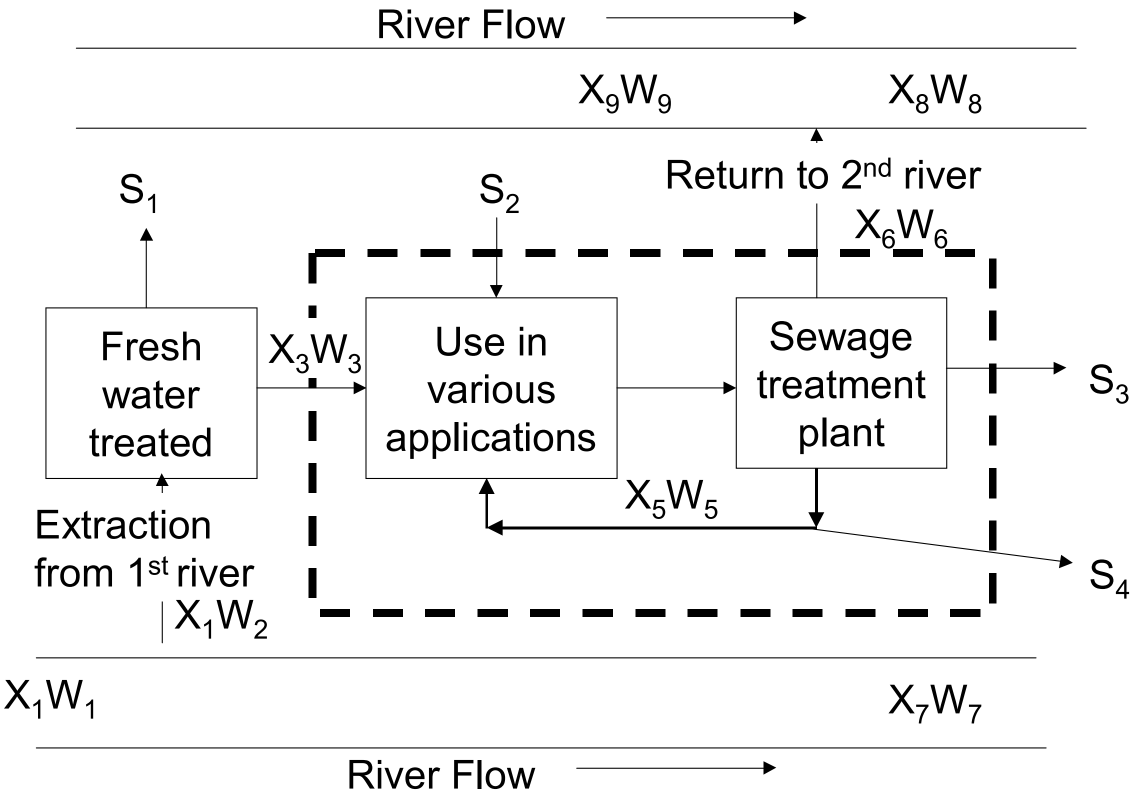
(i) X_1W_1, S_2 and S_3 do not change
(ii) The terms X_1W_2 and S_1 are reduced
(iii) The term X_6W_6 does not change

Hence the total salt flow X_8W_8 increases. It is necessary, however, to consider the total water flow to see how the concentration of salt in the final stream, X_8, changes. In the previous section it was established that the reuse of TSE in this scenario does not change the total water flow (W_2) in the river over a non-use scenario. Since the total salt flow has increased while the water flow has not, therefore, X_8 has increased. This applies to rivers equally regardless of whether the TSE was being added to dilute the water in the river, or whether the river was diluting the TSE.

(ii) Effect on Salt Loading and Concentration when Return is to a Different River

The situation where return is to another river is slightly more complicated. Consider Figure E4.

Figure E4 –Salt Balance where return is to a river other than that from which withdrawal has occurred



Since no discharge to river 1 is occurring, $X_1 = X_7$ and hence salt concentrations in the river remain unchanged. The flow is, however, higher in a non-reuse situation as discussed previously, and hence the total salt loading, X_7W_7 is higher.

The salt balance for river 2 is:

$$X_8W_8 = X_9W_9 + X_6W_6$$

When a reuse step for TSE is introduced,

(i) W_6 is reduced
(ii) X_9W_9 remains unchanged

Consider a balance over the dashed square in the Figure.

$X_6W_6 = X_3W_3 + S_2 - S_3 - S_4$

Assume in the above equation that S_2 and S_3 remain unchanged in a reuse scenario. X_3W_3 will drop as the requirement for fresh water drops. The value of S_4 ranges between 0 and the drop in X_3W_3. Thus, regardless of the value of S_4, X_6W_6 drops. The total salt load in river 2, X_8W_8, thus also drops in a reuse scenario.