GUIDELINES AND GOOD PRACTICES FOR WATER TREATMENT RESIDUES HANDLING, DISPOSAL AND REUSE IN SOUTH AFRICA

Report
to the Water Research Commission

by

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Umgeni Water

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Note to the reader

This report is presented in 2 parts:

- **Part 1** – details the legislative framework and current practices and prospective management strategies for water treatment residues handling, disposal and reuse
- **Part 2** – Guidelines and good practices for water treatment residues handling, disposal and reuse in South Africa

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EXECUTIVE SUMMARY

BACKGROUND

Water treatment residues (WTR) refer to the sludge that is formed during the production of potable. Water treatment residues comprise typically 3-10% of the conventional drinking water plant throughput, with approximately 90-95% of the waste stream produced at the clarification stage of the water treatment process. Traditionally in South Africa, WTR was disposed to a water source and later WTR was disposed to landfill. Due to an increase in the number and size of water treatment works coupled with the deterioration of source water quality, the continuous production of WTR has increased to a point where current management strategy have become unsustainable. Some of the current challenges in the management of WTR include (but not limited) the following:

- Promulgation of stringent regulations governing the disposal of WTR
- The increasing cost of disposal of WTR to landfill sites.
- The stringent environmental compliance for WTR treatment, disposal and reuse.

As such, a shift in the way water service institutions manage, ie plan, design, and operate facilities for appropriate handling of WTR. The residue from potable water treatment processes was historically viewed as a 'waste' to be disposed to landfill, however, this is slowly becoming the least desirable method of WTR management. As such, the current project aims to document best practice principles and approaches considering both current and innovative solutions for WRT management. The output from this project is a guideline document, which provides a strategic framework which will assist with making a decision on the best WTR strategy.

OBJECTIVES

The objectives of the project were to:

- Develop a sustainable and reliable method of managing water treatment residues within South Africa.
- Establish a reference document describing current practices in water treatment residue management and treatment objectives.
- Establish challenges and problems based on WTR management and assess whether the current practices complied with various legislation.
- Recommend future WTR management strategies including areas for further research and skill requirements based on best practices, as well as aspects of monitoring and quality assurance that should be implemented and adopted by water utilities.

METHODOLOGY

The first step in achieving these objectives was a comprehensive literature study looking at national and international WTR management strategies, legislation practices and determining the project scope. After obtaining as much information as possible from blue drop reports, communications with water treatment personnel, journal articles and text books, it was agreed that the project would focus on conventional water treatment works with capacities greater than 2 ML/ day. This project focused on WTR management for water treatment works that excluded any advanced treatment processes e.g., reverse osmosis, membranes and any materials that required regeneration, such as activated carbon or resins.

Site visits to participating water treatment plants were conducted to determine the status quo of WTR management in South Africa. Due to logistic and cost constraints water boards and metros were targeted for the site visits and data gathering. Raw water and WTR samples were obtained from 28 water treatment plants. All the WTR samples collected were prepared and analysed for classification in accordance with the National Environmental Management Waste Act No. 59 of 2008 (NEMWA). The main focus on WTR classification was to (i) investigate how raw water and treatment chemicals contribute to the composition of WTR, and (ii) determine the national trend of prevailing WTR chemicals of concern, as per current legislation.

MAJOR FINDINGS

The absence of legislation specifically governing the management of WTR was found to be one of the biggest challenges faced by the water sector nationally. The disposal of all solid waste is currently regulated by a group of general standards/criteria that may not be appropriate for WTR disposal. From the national perspective, there were still a significant number of water treatment facilities that have no sustainable WTR management strategies and are consequently not complying with environmental disposal standards. Only the larger, more financially sound water boards are complying but are struggling to do so cost-effectively.

WTR sampling and analysis exercises indicated that raw water was the major contributor to the presence of hazardous chemicals of concern (COC) in the WTR. It was also observed that many of the COCs as per current legislation were below detection limits. Furthermore, the COCs with concentrations above the threshold limit were those found naturally occurring in most soils. SANS 10234 classifications indicated that 60% of the WTR was rated as type 3 which can be disposed of at a class C landfill where hazardous material is disposed. The classification of the WTR as type 3 was due to the presence of manganese and lead rendering the WTR eco-toxic and carcinogenic respectively.

The study found that investment in WTR management was inadequate from both a financial and human resources perspective. This was also evident in the design philosophy of new waterworks where little or no prior consideration was given to sustainable, cost-effective and environmentally friendly WTR management. While studies done locally and internationally indicated that land application of WTR was not detrimental to the receiving environment over the short term (5 years), however there were no studies that covered the long-term effects. Case studies show that the cost of current WTR management strategies was prohibitively high with WTR treatment and disposal being the main cost drivers. Dewatering equipment and transportation were the most expensive components of WTR management costs. A few of the larger water utilities have highlighted WTR management as a risk and have the financial capacity to engage in research to find sustainable WTR management options. About 53% of waterworks in the sample set were not complying with legislation and some of these waterworks were operated by water utilities that have the capacity and resources to investigate alternative methods of WTR reuse and disposal.

Emanating from this study was an integrated WTR management strategy that incorporates reduction, re-uses and recycling options before disposal considerations. The proposed management strategy discourages a ‘one size fits all’ approach but suggests each waterworks management to generate their own WTR strategic plan depending on its own unique environment and drivers. The criteria used in the selection of a suitable management strategy will differ from user to user. Environmental factors, cultural, social, operational and financial aspects are included and site-specific conditions must be considered in any final selection. A decision-making framework was developed to assist waterworks to formulate a holistic sustainable WTR management strategy. The use of a decision-making tool will help in making such appropriate choices. This guideline was developed as a user-friendly document for regulatory authorities, managers, practitioners and operators responsible for WTR management and those responsible for formulating management strategies. International case studies indicated that strategic partnerships between local water service providers (WSPs), water service authorities (WSAs) and the private sector should be developed. This will ensure that the users and suppliers are aware of each other’s goals and concerns.

CONCLUSIONS

- A set of guidelines were developed to assist waterworks managers to initiate a WTR management strategy appropriate for their own circumstances. Critical WTR strategic drivers impacting on the economic and environmental sustainability were identified and rated.
- The response to the survey and other instruments used to establish current practices in water treatment residue management and treatment objectives was poor. However, four water utilities that generated over 70% of the estimated annual national WTR participated in the survey.
- The water sector is faced with many challenges with respect to WTR management in South Africa. These include but are not limited to relatively high WTR conditioning and disposal costs, shortage of land for disposal, low calorific value and suitability of the WTR for commercial use. The blanket

classification of WTR as hazardous with other solid wastes also contributes to the fact that approximately half of the waterworks surveyed were non-compliant to legislation in respect of WTR management.

- An integrated WTR management strategy is proposed where a hierarchal approach viz. reduce, recycle, reuse should be considered before disposal. From a bench marking exercise of participating water utilities it was proposed that water treatments plants should put in place monitoring programmes to document WTR production, conditioning and disposal costs.

RECOMMENDATIONS

Classification criteria for land application

For land application practices, current legislations should also consider the inherent metal concentrations in the receiving environment and then compare them with the concentrations from the residue. That way the contribution of the WTR on soil physical and chemical characteristics and environmental impact will be clearly comparable instead of relying solely on the classification criteria. It is suggested that some case studies are undertaken with respect to land applications and disposal to surface water. An in-depth study of the long-term impact of WTR disposal on the receiving environment will benefit both the sector and the departments promulgating WTR legislation.

Legislation

Dialogue and co-operation through focused meetings and workshops between the water sector and the Department of Environmental Affairs and Tourism (DEA) and other relevant government departments should be intensified to ensure stakeholder buy-in to an environmentally and financially sustainable solution to WTR management. A concerted effort should be made by water practitioners to engage with the DEA and provide the necessary technical input to assist the Legislators and Regulators with the creation of appropriate legislation for WTR management especially with challenges with respect to the blanket classification of WTR with other hazardous wastes. Separate legislation that is focused specifically on WTR management should be formulated. The fact that most of the contaminants found in the WTR emanate from the raw water indicates that the blanket classification of WTR as hazardous should be re-evaluated and input should be gathered from both regulators and water practitioners. This will reduce the cost of analysis and ensure adherence to relevant regulations including measurable environmental compliance.

Alternate WTR management strategies

- Piloting of a strategy like that implemented at Netherlands which involves a business plan to create industry partners for re-use of WTR.
- Strategic partnerships between local water service providers and water service authorities should be developed. This will ensure that users and suppliers are aware of the other's goals and concerns. Water Services Authorities may then lobby national government with the water service providers speaking from a point of collective knowledge/ experience.

Further research

- WTR management for advanced water treatment processes - Research into WTR from advanced water treatment should also be undertaken. These include, inter alia, pre-oxidation, membrane filtration, activated carbon.
- The tendency for heavy metals to be leached from polymer-based WTR needs to be investigated since this is the most widely used coagulant at most waterworks. No research can be found in the literature that deals with the remobilization of trace elements from drinking water plant residue. The existing literature is concerned chiefly with the effects of releasing heavy metals from sewage sludge, sediments, and landfill waste.
- The impact created from land application of WTR should be investigated particularly focussing on licence applications. The previous study done by Hughes and Titshall (2005) at the Midmar Water Treatment Plant residue on the dedicated land disposal site can be used as a follow up. The outcomes could then form a basis for a legislative re-assessment that may result in more appropriate and cost-effective disposal options.

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ACRONYMS & ABBREVIATIONS

Alum	Aluminium Sulphate
ACH	Aluminium Chlorohydrate
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
BDEW	Bundesverband der Energie und Wasserwirtschaft e.V. Berlin
BDS	Blue Drop System
BTEX	Benzene, Toluene, Ethyl benzene And Xylene
C/KWh	Cents per Kilowatt hour
CoC	Chemicals of Concern
DEA	Department of Environmental Affairs
DOC	Dissolved Organic Carbon
DWS	Department of Water and Sanitation
ECA	Environmental Conservation Act
EPA	Environmental Protection Agency
GHS	Globally Harmonized System of classification and labelling of chemicals
GNR	General Notice Regulation
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
KWh	Kilowatt hour
L	Litres
LCT	Leachable Concentration Threshold
MEC	Member of Executive Council
ML/d	Mega litres per day
m/m	Mass per Mass
Mn	Manganese
mg/L	Milligrams per litre
NEMA	National Environmental Management Act
NEMWA	National Environmental Management Waste Act
NTU	Nephelometric Turbidity Unit
NWA	National Water Act
NWMS	National Waste Management Strategy
O&M	Operation and Maintenance

PAC	Powdered Activated Carbon
PACl	Polyaluminium Chloride
PCB	Polychlorinated Biphenyl
SABS	South African Bureau of Standards
SANS	South African National Standard
SV1	Soil Screening Value 1
tDS	Ton of Dry Solids dried at 105° C overnight
TC	Total Concentration Threshold
TCLP	Toxicity Characteristics Leaching Procedure
TC	Aqua Regia Total Concentration
TCU	True Colour Unit
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WCMR	Waste Classification Management Regulation
WISA	Water Institute of Southern Africa
WRC	Water Research Commission
WML	Waste Management Licence
WTR	Water Treatment Residue
WTP	Water Treatment Plant
WWTP	Waste Water Treatment Plant

DEFINITIONS

- **Contaminated** means the presence of a substance or microorganism above its normal level of concentration which may adversely affect, directly or indirectly, the quality of soil or the environment.
- **Dedicated Land Disposal** refers to disposal site at which WTR is applied to the surface of the land on a routine basis but where the objective is disposal and not utilisation as in land application for agricultural purposes.
- **Classification-**whether a waste is hazardous based on the nature of its physical, health and environmental hazardous properties using SANS 10234
- **Dewatering** the processes used to reduce the water content of residue to minimise transport volumes and improve handling characteristics.
- **Disposal** means the burial, deposit, discharge, abandoning, dumping, placing or release of any waste into, or onto, any land
- **Lagoon** means the containment of waste in excavations and includes evaporation dams, earth cells, sewage treatment facilities and sludge farms
- **Land application** means the Spraying or spreading of residue onto the land surface; the injection of residue below the land surface; or the incorporation of residue into the soil so that it can either condition the soil or fertilise crops or vegetation grown in the soil.
- **Liner** is layer of impenetrable material/sheeting placed beneath a landfill and designed to direct leachate to a collection drain or sump. May be made of building construction materials, synthetic materials, or a combination thereof;
- **Soil Screening Value 1** means soil quality values that are protective of both human health and Eco toxicological risk for multi-exposure pathways, inclusive of contaminant migration to the water resource
- **Management strategy** refers to the planning, design, and operation of facilities to reuse or dispose of water treatment residues. The objective of residues management is usually to minimize the amount of material that must ultimately be disposed.
- **Recycle** means a process where waste is reclaimed for further use, which process involves the separation of waste from a waste stream for further use and the processing of that separated material as a product or raw material
- **Reuse** means to utilise the whole, a portion of or a specific part of any substance, material or object from the waste stream for a similar or different purpose without changing the form or properties of such substance, material or object;
- **SANS 10234** means the latest edition of the South African National Standard Globally Harmonised System of Classification and Labelling of Chemicals (GHS)
- **Sewer** is pipe or conduit which is used for the conveyance of sewage or industrial effluents;
- **Storage** means the accumulation of waste in a manner that does not constitute treatment or disposal of that waste.
- **Temporary storage** means a once off storage of waste for a period not exceeding 90 days
- **Water Treatment Residue** (WTR) is solid waste generated by potable water treatment plants, predominantly collected during physical-chemical removal processes such as coagulation, flocculation and sedimentation

PART 1

CURRENT PRACTICES AND PROSPECTIVE MANAGEMENT STRATEGIES FOR WATER TREATMENT RESIDUES HANDLING, DISPOSAL AND REUSE

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

Water treatment residues (WTR) refer to the by-products formed during the production of potable water (Bourgeois, et al., 2004). These by-products include organic and inorganic compounds in liquid, solid and gaseous forms. The characteristics and quantity of this waste stream depend on the source of the raw water (surface vs. ground and impounded vs. non-impounded) and the type of treatment process applied to the raw water. This project will focus on what is generally known as drinking water sludge which will hereafter be referred to as potable water treatment residues. Water treatment residues comprise typically 3-10% of the conventional drinking water plant throughput, with approximately 90-95% of the waste stream produced at the clarification stage of the water treatment process (Bourgeois, et al., 2004).

Traditionally in South Africa, WTR was disposed to a water source and later WTR was disposed to landfill (Hughes, et al., 2000). Due to an increase in the number and size of water treatment works coupled with the deterioration of source water quality, the continuous production of WTR has increased to a point where current management strategy have become unsustainable. The main challenges are the environmental impact of WTR, the economic burden on the stakeholders to treat and dispose of this waste and the engineering requirements to develop sustainable WTR management strategies. Water treatment resides (WTR) management refers to the planning, design, and operation of facilities to reuse or dispose of water treatment residues. The objective of residues management is to minimize the amount of material that must ultimately be disposed. This is achieved by recovering recyclable materials and reducing the water content of the residue and volume (AWWARF, 1996). The choice of a possible treatment train is based on the identified disposal options and the required final cake solids concentration (Table 1-1). Methods and costs of transportation may affect the decision of "how dry is dry enough". The two major types of WTR are generated from lime softening and conventional coagulation process. The cost of transporting and ultimate disposal of the residues makes up the major fraction of residue management costs, and the most economical solution is to reduce the quantity of material before ultimate disposal (Crittenden, et al., 2005).

Table 1-1: Cake solids concentration (from Cornwell 2010)

Process	Residue Solids Concentration %	
	Lime WTR	Coagulant WTR
Gravity thickening	15-30	3-4
Dissolved Air Flotation	3-5	3-5
Scroll Centrifuge	55-65	20-30
Belt Filter Press	10-15	20-25
Vacuum Filter	45-65	25-35
Pressure filter	55-70	35-45
Diaphragm filter press		30-40
Sand drying beds	50	20-25
Storage lagoons	50-60	7-15

Other considerations include minimising environmental impacts and meeting discharge requirements established by government regulatory agencies. In the past, insufficient attention was given to WTR during the planning and design stages of water treatment plants (WTP). However, due to the increasing environmental concerns and subsequent regulations governing disposal of waste from drinking water plants, WTR management and disposal methods have had to improve accordingly (DWAF, 1998). For this reason, alternatives for WTR reuse or disposal options needed to be investigated. An approach currently being implemented globally is to utilise a hierarchy of management strategies when dealing with waste. It involves finding and implementing methods to reduce, recycle or reuse waste products sustainably. Disposal to landfill sites was to be considered as the last option. This hierarchy is displayed in Figure 1-1.

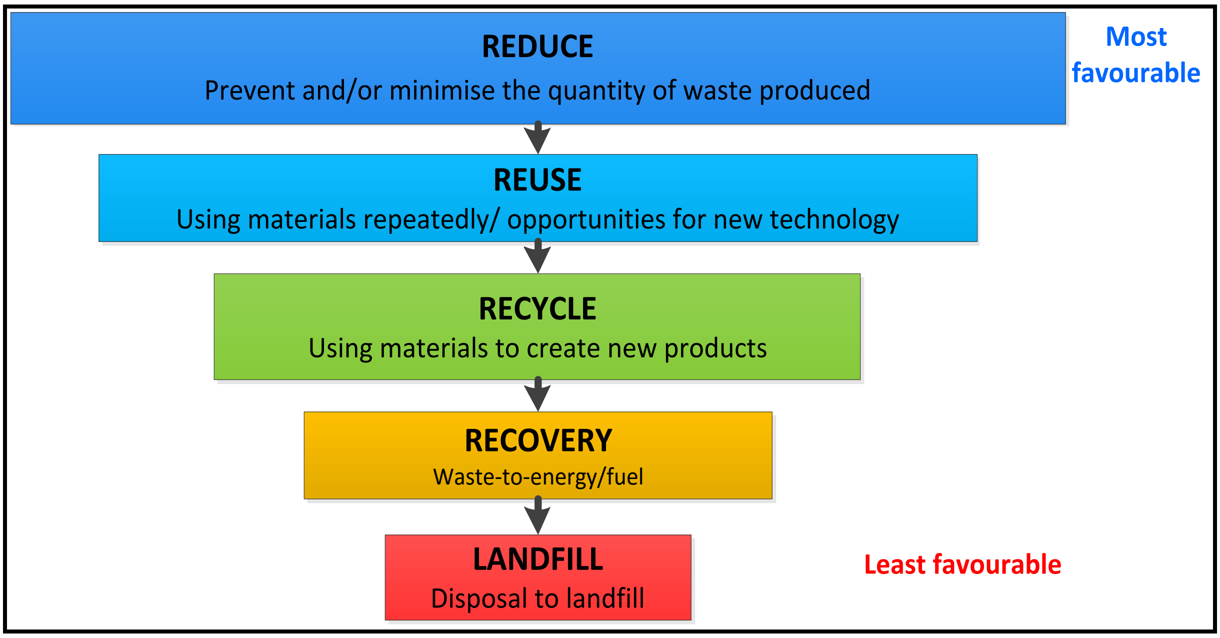

Figure 1-1: Waste management hierarchy (adapted from NWMS, 2011)

Figure 1-2 shows residues handling flow schematic with each of the process.

1.2 AIM OF THE PROJECT

The project aimed to establish a consolidated document containing current practices in WTR management, treatment objectives, alternate options for their respective reuse under South African conditions and life cycle cost estimates. Findings from this project will help to give a clearer direction on future strategies for WTR management and assist water treatment practitioners develop their own sustainable WTR management programmes.

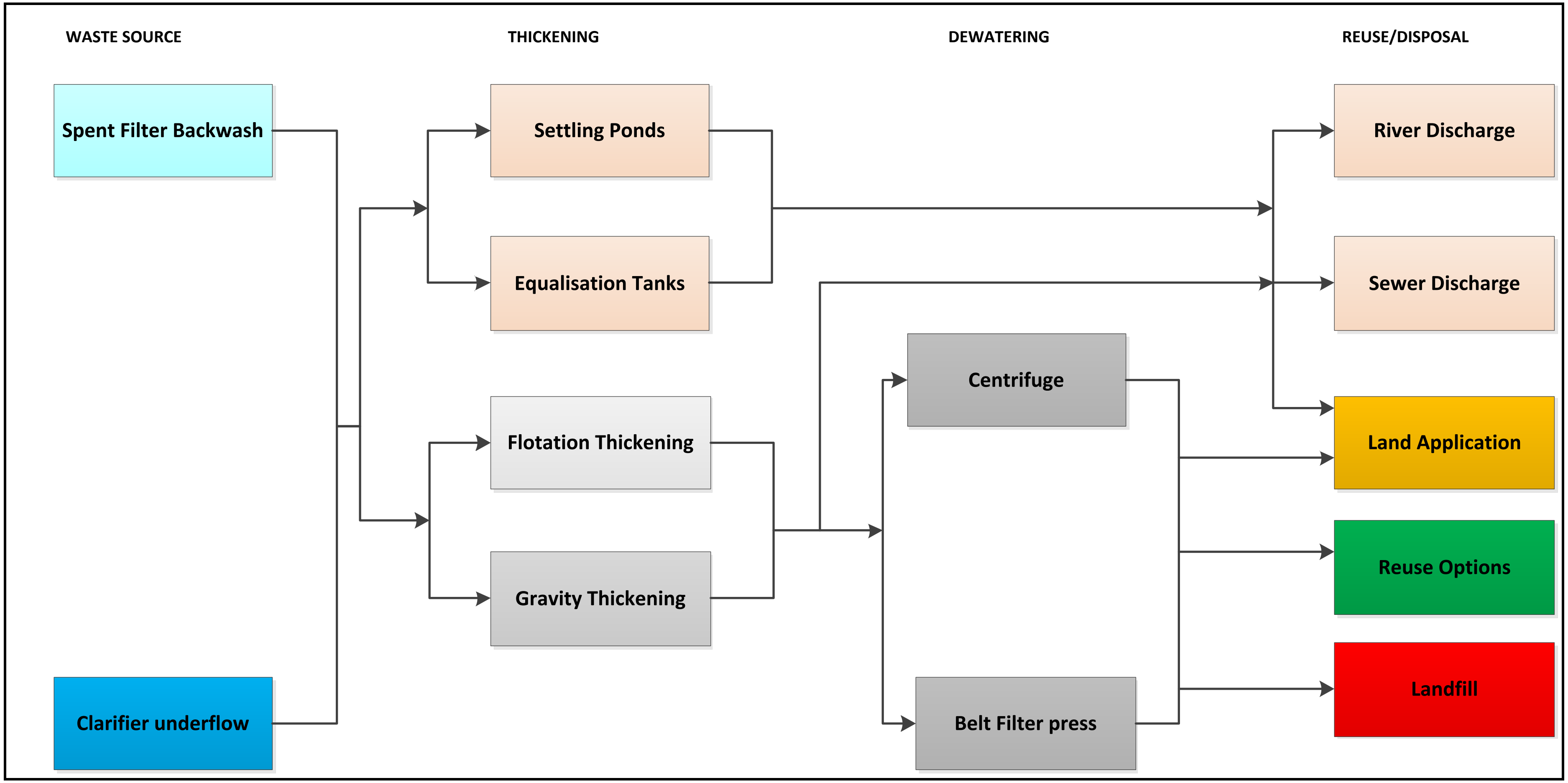

Figure 1-2: Available Options for WTR Management (adapted from AWWARF, 1990)

1.3 OBJECTIVES

The following were the objectives of the project:

- To develop a sustainable and reliable method of managing water treatment residues in South Africa.
- Compile a reference document describing current practices in water treatment residue management and treatment objectives.
- To provide alternate options for their respective reuse under South African conditions and establish direct and indirect life cycle cost estimates of their management.
- To provide an overview of the current WTR management practises in South Africa and internationally. This will include a database of current practices at major South African treatment plants.
- Document challenges and problems based on WTR management and assess whether the current practices comply with legislation.
- Recommend future WTR management strategies, including areas for further research and skill requirements based on best practices, as well as aspects of monitoring and quality assurance that should be implemented and adopted by water utilities.

1.4 SCOPE AND LIMITATIONS

This project is confined to conventional drinking water plants treating more than 2 Megalitres of water per day (ML/d). Blue Drop considers small treatment plants to be between 0.5-2 ML/d. Raw water feed to small water treatment plants is generally borehole water where the treatment process is limited to direct filtration followed by disinfection or in some cases only disinfection. Therefore, the generation of WTR is minimal in small treatment plants. According to South African National Standards (SANS 241:2015) a drinking water supply system includes all stages from the point of water abstraction to the consumer point of use. These stages include: catchments (including groundwater systems); river source waters; storage dams and abstraction; drinking water treatment system; treated water reservoirs and distribution systems, and point-of-use. For the purposes of this study the focus was on conventional water treatment which typically consists of pre-treatment, coagulation, flocculation, sedimentation, filtration and disinfection. Figure 1-3 below shows a block diagram of a typical water treatment plant including sources of WTR in the process train.

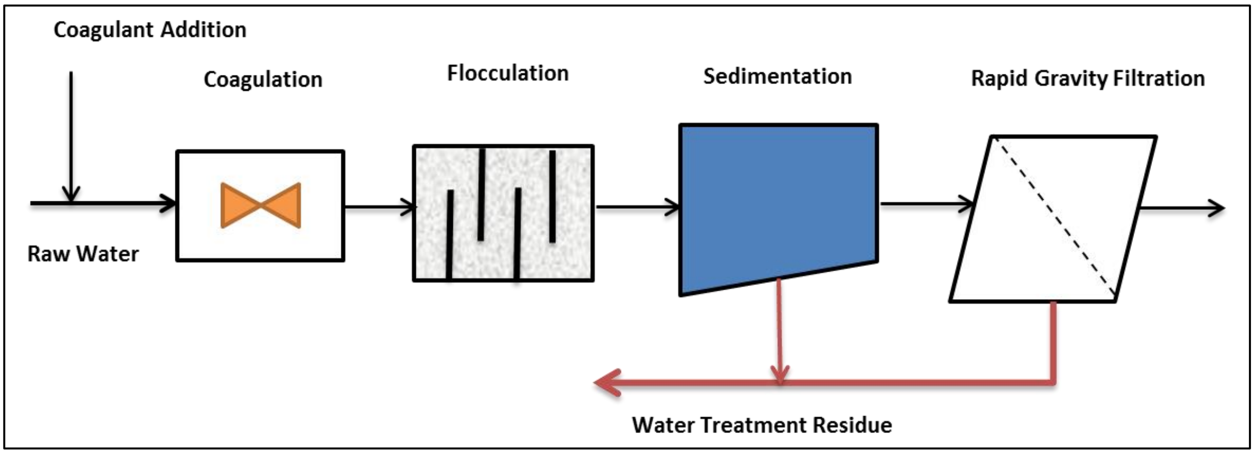

Figure 1-3: Conventional water treatment process

CHAPTER 2: LEGISLATIVE FRAMEWORK FOR WATER TREATMENT RESIDUE MANAGEMENT

2.1 INTRODUCTION

In September 2000, leaders of 189 countries, including 147 Heads of State and Government met at the United Nations in New York and endorsed the Millennium Declaration, which is a commitment to work together to build a safer, more prosperous and equitable world. The declaration was translated into a roadmap setting out eight goals known as the Millennium Development Goals (MDGs). Goal number 7 was to ensure environmental sustainability, achievable by integrating principles of sustainable development into country policies and programmes and to reverse the loss of environmental resources. According to the United Nations Millennium Development Goals report for 2015 only goal number 7 was achieved in 2010 which was 5 years ahead of schedule.

2.2 REGULATORY AUTHORITY

The Minister of Environmental Affairs is responsible for the licencing of hazardous waste management activities and the Member of Executive Council (MEC) is the licencing authority for general waste producing activities and those listed in GNR 921. Section 74 of NEMWA caters for the application of exemptions, provided reasonable motivation and supporting documents are offered.

- The Minister is also responsible for regulating waste management activities that will affect more than one province or across international boundaries.
- Or any activities where two or more waste management activities are to be undertaken at the same facility.

The applications to section 43 must be done through the provincial body if it is for general waste and to the National Department of Environmental Affairs for Hazardous waste licencing. A disposal site permit, issued by the Minister or Member of the Executive Council (MEC) informs users in terms of waste disposal standards, waste classification and monitoring that would be required for disposal of WTR. However certain activities can be exempt from acquiring licences (WML) in terms of the new legislation emanating from the NEMWA amendment act, Regulations, Norms and Standards from 2013.

2.3 NATIONAL ENVIRONMENTAL MANAGEMENT: WASTE ACT (ACT NO. 59 OF 2008)

2.3.1 Overview

The National Environmental Management: Waste Act (Act No 59 of 2008) is a framework legislation developed under NEMA as amended. In terms of NEMWA, listed waste management activities that have, or are likely to have a detrimental effect on the environment must be licenced according to section 20 and Chapter 5 of the Act. (Published under Government Notice No. 921 of 29 November 2013). The National Environmental Management Waste Act (NEMWA, Act No 59 of 2008) in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998), “as amended” has evolved over the years. This was primarily to conserve the natural resources and to minimise the effects caused using processed material towards the environment. The NEMWA was promulgated to ensure commitment towards environmental sustainability as agreed upon during declaration of Millennium Development Goals for 2015. In terms of section 20 of NEMWA a producer of all waste regulated may not commence, undertake or conduct waste management activity without a Waste Management Licence (WML) or in compliance with the Norms and Standards. A disposal site permit, issued by the Minister or MEC informs users in terms of waste disposal standards, waste classification and monitoring that would be required for disposal of WTR. The aim of enforcing the requirements of WMLs is to license the listed waste management activities and regulate the management of waste to protect the health of the people as well as the environment (Golder, 2015). Under NEMWA, WTR management activities that require a Waste Management Licence include: (i) storage, such as settling ponds or lagoons; (ii) treatment, changing the physical or chemical composition of the WTR (iii) reuse, recycling and recovery and (iv) disposal to land.

2.3.2 **Classification of WTR under NEMWA**

The National Environmental Management Waste Act (NEMWA) classifies water treatment residue as waste whereby, waste is defined as:

a) any substance, material or object, that is unwanted, rejected, abandoned, discarded or disposed of, or that is intended or required to be discarded or disposed of, by the holder of that substance, material or object, whether such substance, material or object can be re-used, recycled or recovered and includes all wastes as defined in Schedule 3 to this Act; or

b) any other substance, material or object that is not included in Schedule 3 that may be defined as a waste by the Minister by notice in the Gazette" (National Environmental Management: Waste Act 59 of 2008 as amended).

Any waste or portion of waste referred to in paragraphs (a) and (b) ceases to be considered waste:

i. Once an application for its re-use, recycling or recovery has been approved or, after such approval, once it is, or has been re-used, recycled or recovered;
ii. Where approval is not required, once a waste is, or has been re-used, recycled or recovered;
iii. Where the Minister has, in terms of section 74, exempted any waste or a portion of waste generated by a process from the definition of waste; or
iv. Where the Minister has, in the prescribed manner, excluded any waste stream or a portion of a waste stream from the definition of waste.

*"**Disposal**" means the burial, deposit, discharge, abandoning, dumping, placing or release of any waste into, or onto, any land*
*"**Recycle**" means a process where waste is reclaimed for further use, which process involves the separation of waste from a waste stream for further use and the processing of that separated material as a product or raw material*
*"**Reuse**" means to utilise the whole, a portion of or a specific part of any substance, material or object from the waste stream for a similar or different purpose without changing the form or properties of such substance, material or object; [Definition of "re-use" substituted by s. 1 of Act 26/2014]*
*"**Storage**" means the accumulation of waste in a manner that does not constitute treatment or disposal of that waste.*

In terms of the general notice (GN R. 634) of the Waste Classification and Management Regulation 4 (WCMR), "*all waste generators must ensure that the waste they generate is classified in accordance with SANS 10234 within 180 days of generation, except in cases where the waste is on the pre-classified list*" (Annexure 1 of GN R.634). Waste classification according to South African National Standard (SANS) 10234 is based on the Global Harmonised System and indicates the physical, health and environmental hazards. The SANS 10234 covers the harmonised criteria for classification of potentially hazardous substances and mixtures, including wastes, in terms of its intrinsic properties or hazards. The standard does not contain threshold concentrations for chemicals to determine potential risk. If a chemical is present in the material, it is considered to have potential risk. The classification criteria include:

- Physical hazards (explosiveness, flammability, oxidising, etc.);
- Health hazards (toxicity, carcinogenicity, corrosiveness etc.); and
- Environmental hazards (aquatic toxicity, bioaccumulation, etc.).

2.3.3 **Types of wastes**

According to General Notices GN R921 as amended; the *List of Waste Management Activities That Have, Or Are Likely to Have a Detrimental Effect on the Environment* from the National Environmental Management: Waste Act, 2008 (Act No 59 of 2008) as amended waste activities are distinguished as category A, B and C. The list is selected for those activities that are applicable for WTR management. A Waste Management Licence (WML) is required for category A and B. Category C waste only needs to comply with National Norms and Standards as determined by the Minister.

- Category A requires a Basic Assessment to inform
- Category B requires a Scoping & EIA to inform

2.3.3.1 *Category A waste*

- *The recycling of hazardous waste more than 500 kg but less than 1 ton per day calculated as a monthly average, excluding recycling that takes place as an integral part of an internal manufacturing process within the same premises.*
- *The treatment of hazardous waste using any form of treatment at a facility that has the capacity to process more than 500 kg but less than 1 ton per day excluding the treatment of effluent, wastewater or sewage.*
- *The remediation of contaminated land*

2.3.3.2 *Category B waste*

- *The storage of hazardous waste in lagoons excluding the storage of effluent, wastewater or sewage.*
- *The recycling of hazardous waste more than 1 ton per day, excluding recycling that takes place as an integral part of an internal manufacturing process within the same premises.*
- *The recovery of waste including refining, utilisation, or co-processing of the waste at a facility that process in excess of 1 ton of hazardous waste per day, excluding recovery that takes place as an integral part of an internal manufacturing process within the same premises.*
- *The treatment of hazardous waste in excess of 1 ton per day calculated as a monthly average; using any form of treatment excluding the storage of effluent, wastewater or sewage.*
- *The treatment of hazardous waste in lagoons excluding the storage of effluent, wastewater or sewage.*
- *The disposal of any quantity of hazardous waste to land*

2.3.3.3 *Category C waste*

- *The storage of hazardous waste at a facility that has the capacity to store in excess of 80* m^3 *of hazardous waste at any one time, excluding the storage hazardous waste in lagoons or temporary storage of such waste.*

2.4 NATIONAL WATER ACT (NWA, 1998)

The National Water Act (NWA, 1998) limits the direct discharge of WTR into watercourses. The NWA under section 20 forbids any discharge of a pollutant to any water body (including wetlands) without a disposal permit. The direct discharge of untreated residues to most surface water is currently controlled by the waste discharge charge system described in Section 21 of the National Water Act (NWA, 1998). Discharge of residue from WTP into a water course falls under Section 21 of the NWA and should be authorised accordingly Section 21(g). The discharge of drinking water residues to sanitary sewer requires a permit whereby the discharge must comply with discharge limits. The pre-treatment requirements are usually site specific and intended to ensure that the operation of the wastewater works is not upset by the acceptance of the water treatment residue. The limits further ensure that quantity or quality of the WTR do not adversely impact the final method wastewater works sludge such as land application.

2.5 GLOBAL OVERVIEW OF WTR MANAGEMENT

Very few continents or countries have regulations pertaining specifically to WTR management. The more established regulations and legislation exist in Europe, Australia, the United States of America, Namibia and New Zealand.

2.5.1 Australia

In Australia, the relevant legislation guiding WTR management is the Environment Protection Act, 1993, specifically Section 25. The Australian government also provides guidelines for WTR for land application (Helserman, 2013) where it promotes and enforces a waste hierarchy. The most preferable option is to avoid WTR generation, followed by, reduction, reuse, recycling, recovery, treatment and finally WTR disposal. The aim is to achieve sustainable WTR management by applying the waste hierarchy in conjunction with environmentally sustainable development (USEPA, 2011).

2.5.2 United States of America

In America, the regulatory agency governing waste management is the United States Environmental Protection Agency (USEPA). There are currently no regulations pertaining specifically to WTR. Water treatment residues are defined as an industrial waste by the existing Water Pollution Control Act of 1972 and listed as solid waste under 40 CFR Part 257. Regulations applicable for management of WTR are the Clean Water Act, which governs the discharge of residue back in to a watercourse and the Criteria for Classification of Solid Waste Disposal Facilities and Practises (40 CFR Part 257); Resource Conservation and Recovery Act; Comprehensive Environmental Response; Compensation and Liability Act and Clean Air Act, which governs other methods of reuse and/ or disposal of WTR (Helserman, 2013).

2.5.3 Europe

The European Union has a reputable waste management policy, which was established in the Waste Framework Directive 75/442/EEC, and the Sixth Environment Action Programme “Environment 2010: our future, our choice”. These directives and guidelines use a waste hierarchy that places waste prevention as the preference, followed by recycling and reuse, and lastly disposal. Disposal is only an option once all other options have been exhausted (Helserman, 2013). Environmental concerns in Europe are pushing towards recycling, but restrictions imposed render these options difficult and costly. A case study is included in Section 5.4 about the waste management strategy that is applied in the Netherlands.

2.5.4 **Namibia**

The Department of Water Affairs and Forestry in Namibia compiled the Guidelines for disposal of solids from water and wastewater treatment processes in 2012. This has however not been regularly updated.

2.5.5 **New Zealand**

In New Zealand guidelines for WTR management were developed for the purpose of assisting water suppliers, and other water treatment consultants and stakeholders in selecting and implementing environmentally friendly methods of disposal ((NZWWA, 2008). The guidelines characterise the water treatment process and WTR produced including a discussion on the various options available for disposal.

2.6 **SUMMARY**

Table 2-1 shows the main legal framework which are imposing restrictions on the WTR management and disposal. Proper management of WTR requires treatment plants to compile and implement waste management plans for both new and existing sites. The type of management process to be used depends primarily on the type of residues produced. The general procedure that must be followed by Water Service Providers as steps towards effective and lawful WTR management practises is given in Part 2 of this document.

Table 2-1: Legal framework applicable to WTR management

- National Water Act, 1998 (Act No. 36 of 1998);
- Water Services Act 1997, (Act 108 of 1997);
- National Environmental Management Act, 1998 (Act No. 107 of 1998);
- National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008):
    - Waste Classification and Management Regulations (GN R 634)
    - National Norms and Standards for the Assessment of Waste for Landfill Disposal (No. R. 635)
    - National Norms and Standards for Disposal of Waste to Landfill (GN R 636)
    - National Norms and Standards for the Remediation of Contaminated Land and Soil Quality (GN R 331)
    - National Waste Information Regulations, (GN R 625)
    - List of Waste Management Activities that have, or are likely to have a detrimental effect on the environment, (GN R 921)
    - National Norms and Standards for extraction, flaring for recovery of landfill gas; scrapping or recovery of motor vehicle; storage of waste (GN R 926)
    - Fees for consideration and processing of applications for Waste Management Licences and Transfer and Renewal thereof (GN R 142)
- National Environmental Management Air Quality Act, 2004 (Act No. 39 of 200);
- The National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004); and
- The National Heritage Resources Act, 1999 (Act No. 25 of 1999).

CHAPTER 3: REVIEW OF WATER TREATMENT RESIDUE HANDLING, DISPOSAL AND RECYCLING OPTIONS

3.1 INTRODUCTION

Water treatment residue management strategies are highly dependent on the physical and chemical characteristics of the water treatment residue. These characteristics are determined by the raw water quality and the treatment process. Since 1994, South Africa has seen the closure of many landfill sites for both social and environmental reasons (DWAF, 1998). International agreements have placed increasing pressure on the South African government to improve their environmental policy (DWAF, 1998). The South African legislative framework has thus been focusing more on environmental responsibility and duty (Umgeni Water, 2014). Internationally landfilling of WTR is no longer considered a sustainable waste management practice. WTR disposal through landfill has been declared to be illegal in some jurisdictions, including several European Union countries (e.g. Germany).

3.2 CHARACTERISTICS OF WATER TREATMENT RESIDUES

Water treatment residue management strategies are highly dependent on the physical and chemical characteristics of the water treatment residue. These characteristics are determined by the raw water quality and the treatment process.

3.2.1 Factors Influencing Composition of Water Treatment Residues

3.2.1.1 *Raw water characteristics*

Raw water sources for conventional treatment plants are generally ground water or surface water. Ground water is obtained from underground aquifers; whilst surface water is obtained from rivers, lakes and dams. The factors that influence the quality of the source water include both naturally occurring factors such as:

- Climate change
- Geology
- Soil characteristics
- Land cover
- Hydrology
- Precipitation and runoff and
- Wildlife

Anthropogenic factors include:

- Land management practices
- Discharge to/or from point and nonpoint sources (USEPA, 2011)

Water treatment plant design, type and quantity of treatment chemicals used are strongly influenced by raw water quality.

3.2.1.2 *Treatment process*

The treatment process affects WTR by unit operations used and chemicals added. According to United States Environmental Protection Agency (USEPA, 2011) water treatment plant residues can be broadly categorised into two groups and these include:

- Residues from clarification and spent filter backwash water - These residues are from conventional treatment processes that follows coagulation, sedimentation, filtration, and disinfection of surface water. The major constituents removed are turbidity, colour, bacteria, algae, some organic compounds, and sometimes iron and/or manganese.
- Residues generated from softening applications, for the removal of calcium and magnesium by the addition of lime, sodium hydroxide, and/or soda ash.

The sources of WTR in a conventional drinking water treatment plant are mainly the liquid-solid separation processes, namely, the clarification/sedimentation and filter backwash processes (Figure 3-1). At the clarification or sedimentation stage, settled and agglomerated solids are periodically removed by desludging. The WTR contains solids, precipitates and other contaminants removed from the source water including residual solids from chemicals added during the treatment processes. Most of the contaminants are found in the raw water with some metals added into the process during coagulation. Naturally occurring contaminants in raw water include microorganisms from animal life and soil, runoff from point and non-point sources (USEPA, 2011). Chemical coagulants consist of trace metal impurities, organic compounds, silica and monomers that end up in the residue. Other contaminants such as microorganisms, natural organic matter, clay and silt particles results from filter backwash water. Broadly, the composition of water treatment residues depends on the raw water quality and the treatment processes used, and each one of these factors is elaborated on in the sub-sections that follow.

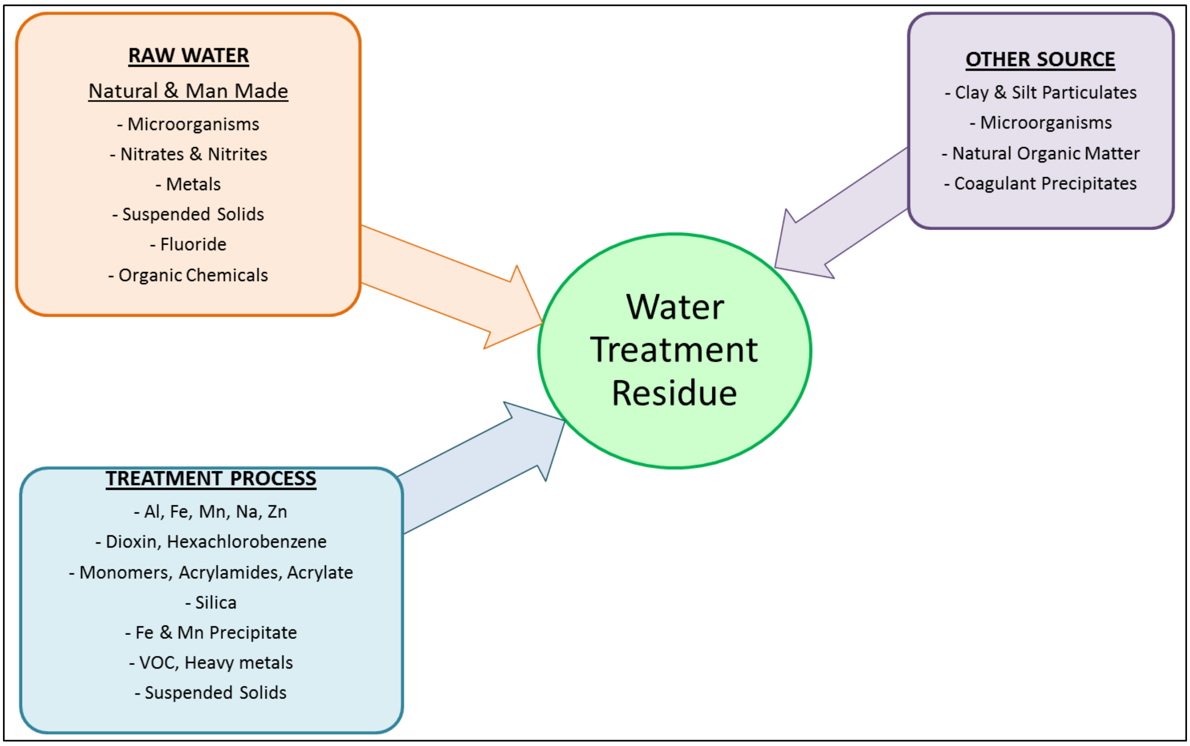

Figure 3-1: Sources of water treatment residue contaminants

3.2.1.3 *Raw water*

Raw water sources for conventional treatment plants are generally ground water or surface water. Ground water is obtained from underground aquifers; whilst surface water is obtained from rivers, lakes and dams. The factors that influence the quality of the source water include both naturally occurring factors such as: climate change; geology, soil characteristics, land cover; hydrology, precipitation and runoff, and wildlife. Anthropogenic factors include: land management practices, and discharge to/or from point and nonpoint sources (USEPA, 2011). Water treatment plant design, type and quantity of treatment chemicals used are strongly influenced by raw water quality.

3.2.1.4 *Treatment processes*

The treatment process affects WTR by unit operations used and chemicals added. Sources of WTR in a conventional drinking water treatment works are mainly from solids removed from the clarification/ sedimentation and the filter backwash water. At the clarification or sedimentation stage, settled and agglomerated solids are periodically removed by desludging. Based on the water treatment processes, water treatment residue can be categorised as shown in Table 3-1. The process of coagulation and flocculation generates the bulk of the water treatment residue during the water treatment process. Since coagulant WTR make up 70% of all WTR from conventional processes (Norris, 2012), more attention will be focused on this type of residues. The type and amount of coagulant used has significant effect on the quantity and characteristics of WTR produced.

Table 3-1: Types of water treatment residues

Water Treatment Residue Type	Generation Process
Pre-sedimentation WTR	High turbidity waters are pre-treated in a sedimentation processes, to remove clays, silts and sands
Lime WTR	Occur in softening plants where lime and sometimes soda ash are used to remove water hardness. When softening, surface water the WTR is variable and contains, metal hydroxides, calcium carbonate, silt. Softening of ground water produces a purer residue consisting of calcium carbonate, magnesium hydroxide and unreacted lime. This is because ground water tends to have low turbidity, colour and unwanted organics. According to the USEPA, 2011 softened sludge is also easier to dewater and compact.
Iron and Manganese WTR	This water treatment residue is produced by oxidation processes which remove iron and manganese from the raw water as precipitates and is normally generated by the filter backwash.
Coagulant WTR	These residues are produced from the use of various coagulant chemicals used to facilitate downstream flocculation of particles. The waste stream consists of solids removed from the flocculated water. It may also contain pre-treatment chemicals.

Table 3-2 shows the effect of different coagulants on the WTR properties. Coagulant residues are formed when aluminium salts, ferric salts or polymers are added to raw water (Ippolito et al., 2011). These materials act as effective coagulants by destabilising dispersed particles, and causing them to collide (Elliot et al., 1990). Pre-treatment chemicals are also evident in coagulant WTR.

Table 3-2: Effect of coagulant type on WTR properties

Type of Coagulant	Application	Effect on WTR	WTR Environmental effect
Aluminium salt coagulants	Widely used internationally.	Due to its reaction mechanism produces more WTR than polymeric coagulants which has good settleability but poor dewaterability (Zhao and Bache, 2002)	• Trace metals toxic to aquatic and animal life. • Leaching of chemicals into ground water • Chemical take up by plants
Iron salt coagulants	Widely used internationally, very like aluminium salt coagulants but with higher iron concentrations and lower aluminium concentrations.	Due to its reaction mechanism produces more WTR than polymeric coagulants which has good settleability but poor dewaterability (Herselman, 2013)	• Trace metals toxic to aquatic and animal life. • Leaching of chemicals into ground water • Chemical take up by plants
Polymeric Coagulants • Cationic • Anionic • Non-ionic	Increasing applicability in South Africa, mainly used as a Floc aid internationally.	Produces a smaller volume WTR than metal-based coagulants (Warden, 1983). Polymeric WTR has good dewaterability (Bolto and Gregory, 2007).	• Monomers toxic to animal and aquatic life. • Affects the porosity of certain soils.

3.2.2 Physical Characteristics of Water Treatment Residues

Understanding the physical properties of WTR was considered essential for determining the optimum processing, disposal and/ or reuse options available. Current literature varies significantly in terms of the physical properties due to the various unit processes and operating conditions at water treatment plants. The physical characteristics of interest are dewaterability, handleability, flow characteristics, physical consistency; particles size distribution, specific gravity, specific resistance, compaction, total solids, shear strength and pozzolanic properties (Herselman, 2009; Herselman, 2013). Other characteristics of WTR, such as pore structure water retention characteristics and aeration have not been widely investigated, and limited information is available (Park et al, 2010). Table 3-3 lists some critical WTR physical properties and method of analysis. The main constituents in WTR are silt, clays and humic substances. These make up the major portion of suspended solids in WTR (Park et al, 2010; USEPA, 2011). Treatment chemicals including coagulants used during the process bind the silt and clay together forming solid structures when dried in downstream WTR treatment processes. Air dried WTR specifically forms an aggregate with a gravel-like texture. The macro pores between the WTR granules make water movement easy, and micro pores within the aggregates, enhance the water retention ability (Park et al, 2010). If WTR is discharged into a water body the solids can settle to the bottom of the water body potentially causing benthic smothering and the pollutants contained in the WTR can have negative impacts on the water body through re-suspension (USEPA, 2011). The increased turbidity of WTR can limit the growth of rooted aquatic vegetation by reducing the amount of light penetration available. The solids can also clog fish gills.

Table 3-3: Description of specific WTR physical properties

Property	Description
Particle size distribution	Determined using ASTM procedure D422-63 (A modification for WTR is that the samples cannot be completely dried, as this prevents the particles from rewetting). WTR is more uniform and has finer particle sizes than natural topsoil.
Specific Gravity	Determined using ASTM procedure D854-92. This property has a significant effect on WTR characterisation and compaction. WTR are normally lower than natural topsoil, attributable to the higher organic content in WTR.
Specific Resistance	This is the resistance to fluid flow exerted by a cake of unit weight of dry solids per unit area of the filter (i.e. it is a measure of the filterability of WTR). It is the principal design parameter used for mechanical dewatering systems.
Compaction	Determined using ASTM procedure D558-96 (A modification for WTR is that the samples cannot be completely dried as this would cause destruction of soil structure and calcification of particles). This property effects settlement, strength, shrinking and swelling of WTR.
Shear Strength	This property is an indication of the material performance under pressure from compaction. The shear strength of WTR varies depending on solids content, generally higher with increasing solids content.

The physical consistency of metal ion coagulants can be seen below in Table 3-4 (Herselman, 2013). All coagulant residues dry irreversibly when exposed to the atmosphere (Warden, 1983) therefore WTR treatment, collection, application methods are very important.

Table 3-4: Metal based coagulant WTR consistency

Solid Content (m/m)	Physical Consistency of WTR
0-5%	Liquid
8-12%	Spongy, semi-liquid
18-25%	Soft Clay
40-50%	Stiff Clay

3.2.3 **Chemical characteristics of water treatment residues**

The important chemical characteristics of WTR when considering re-use/ disposal options are the pH, nutrients, trace elements and organic pollutants (Titshall and Hughes, 2005).

3.2.3.1 *pH*

The pH of the WTR influences the mobility of various elements in soil when used for land application (Herselman, 2013). Water treatment residue with a significant difference in pH to the environment can have detrimental effects on the surrounding environment. Tests done by Titshall and Hughes (2005) found that the pH of WTR in South Africa were neutral to alkaline (a pH range of 6 to 9).

3.2.3.2 *Nutrients*

Nutrients contained in WTR can be used to determine the applicability range of the material. High concentrations of nutrients could be detrimental to surface and ground water sources, causing contamination (Herselman, 2013). The four most important nutrients in WTR are phosphorus, nitrogen, potassium and sulphur, which are all essential elements. Nitrogen is a part of proteins and nucleic acids and is therefore vital to all life forms and is also the main nutrient required by plant life. Potassium exists as ions, mainly in the cells. Phosphorus is part of the cell's DNA and plays a central role in the metabolism.

3.2.3.3 *Trace metals*

Heavy metal concentrations in WTR are generally lower than in sewage sludge. The trace elements and metal ions in WTR may be present in various concentrations depending on the raw water source and treatment process used. The metals are measured in different forms including total, plant available and leachable (Herselman, 2013). The large quantities of iron and aluminium hydrous oxides found in WTR are also known to fix phosphorus in soils, which are required by plant life for growth (Park et al, 2010). Metals are potentially toxic to phytoplankton, zooplankton and higher aquatic life (both plants and animals) and nitrogen as both ammonia and ammonium can be directly toxic to fish and various other aquatic organisms (USEPA, 2011).

3.2.3.4 *Organics*

The organic carbon content of the WTR normally ranges from 0.5 to 16.7% and will positively impact the soil for land application (Herselman, 2013). A study by Stackelberg et al. (2007), investigated the efficiency of conventional drinking water treatment plants in the removal of 113 organic compounds including: pharmaceuticals, detergents degraded compounds, flame retardants, plasticizers, polycyclic aromatic hydrocarbons, fragrances, flavourants, pesticides, insect repellents, plant and animal steroids. Raw water and WTR samples were taken and it was found that clarification accounted for 15% removal of the average inlet concentration of 32 compounds. Disinfection and granular activated carbon filters accounted for 85% removal of the compounds that were removed. The study shows that conventional clarification and sand filtration does not remove organic compounds and pass through the process. Since these compounds are not removed their concentrations in the WTR are low to negligible. Previous studies conducted by Professor Hughes (Titshall and Hughes, 2005) and Herselman (2013) show that the organic pollutants, infectious substances and pesticides in WTR do not require monitoring.

3.2.4 **Microbiological characteristics of water treatment residues**

Residue constituents of concern contained in the WTR and liquid wastes from treatment processes and thickening operations may include:

- Indicator microorganisms (Helmiths, *E. coli,* etc.)
- Giardia cysts and Cryptosporidium oocytes

Most microorganisms are found in the filter backwash water, which is why most of treatment plants in South Africa separate the clarifier underflow and the filter backwash water. In a study undertaken by Umgeni Water (2014) a total of 12 potable water treatment plants were sampled and residue analysed. It was found that volatile organic compounds, semi-volatile organic compounds and total petroleum hydrocarbons concentrations were not of concern. However elevated concentrations of *E. coli* and coliforms were observed in some of the water treatment plants. Of importance is that the microbiological quality of the WTR should be analysed immediately after clarifier underflow sampling before the residue is dried off to get a true representation of the WTR microbiological quality.

3.3 METHODS FOR HANDLING WATER TREATMENT RESIDUES

The treatment methodologies are listed by general categories of conditioning, thickening and dewatering.

3.3.1 Conditioning

Conditioning is generally a pre-treatment requirement that accelerates solid/liquid separation. Conditioning of WTP residues is accomplished by either chemical or physical processes. Physical conditioning processes are uneconomical and ineffective. These include pre-coat or nonreactive additives, freeze-thaw conditioning and thermal conditioning at high temperatures. Chemical conditioning involves the dosing of chemicals such as ferric chloride, aluminium sulphate, organic polyelectrolytes, lime, and soda ash (Lin & Green, 1987). The most successful polyelectrolyte utilised are high molecular weight anionic type with typical dosages of 2-6 kg/dry ton solids. The polyelectrolytes used for conditioning are normally polyacrylamides which are different to the polyelectrolytes used for coagulation and flocculation. Ferric chloride, aluminium sulphate or lime, which is used for the precipitation of phosphates, has the added advantage of producing WTR with improved settling characteristics. There is no clear-cut, accepted conditioning method practiced for a given type of WTR. A conditioning agent that works well at one plant may not work at a similar plant. Therefore, a series of jar tests are done to select the chemicals that results in the most settleable WTR within a short time.

3.3.2 Thickening

Thickening is generally used to increase the solids content of the WTR. This is done by gravity thickening and removing a fraction of the supernatant. This volume reduction of WTR is beneficial to subsequent treatment processes, usually dewatering (Lin & Green, 1987). Thickening reduces both capital and operational costs for the next treatment phase, due to treating a lower volume of waste, which is still pumpable. Thickening tanks can also serve as equalization facilities to provide a uniform feed to the dewatering step. In the water industry, the most common thickening process utilised is gravitational thickening. Other methods include gravity belt thickeners, and dissolved air flotation thickeners (Table 3-5). The addition of polymer significantly improves the performance of thickeners.

Table 3-5: Comparison of thickening methods

Thickening Methods		
Method	Advantage	Disadvantage
Linear Screen	0.5% – 2% WTR is thickened to 4% - 10%	Moving parts, energy requirements & capital cost
Gravity Thickener	A thickened WTR of 2-8% dry solids is produced (McLane, 2004). Operating costs are relatively low Continuous operation	Relatively large footprint Requires conditioning chemicals
Gravity Belt Thickener	Produces a pumpable thickened residue. Proven technology	Performing a gravity belt thickening requires about 50 kWh/ton dry mass and water (Evuti & Lawal, 2011). Short media life, Sensitive to incoming feed characteristics.
Dissolved Air Flotation (DAF)	Effective removal of low density solids. Effective for treating filter backwash water usually 2% to 5% residue is produced Continuous operation	Not effective in treating clarifier residue only 3.5 to 9.6% dry solids were obtained. Complex process & high operation costs

Vacuum Filtration	Successfully used in dewatering lime water treatment (Lin & Green, 1987).	Complex technology, Requires conditioning chemicals High operation and maintenance costs. There are no known installations in South Africa (WRC 124/1/04, 2004). Limited success when used for coagulated WTR, (Lin & Green, 1987).

3.3.2.1 *Gravity thickening*

Gravity thickeners are generally circular settling basins equipped with either a scraper mechanism at the bottom of sludge hoppers (Figure 3-2). They may be operated as continuous flow or as batch 'fill and draw' thickeners. For continuous flow thickeners, the residues normally enter the thickener near the centre of the basin and are distributed radially. The thickener feed pump works at constant output, switching off at low level in the balancing tank and on at high level. This means that the thickener stops occasionally, but so long as the operation of the rake is not interrupted, performance is quickly re-established when the feed is restarted.

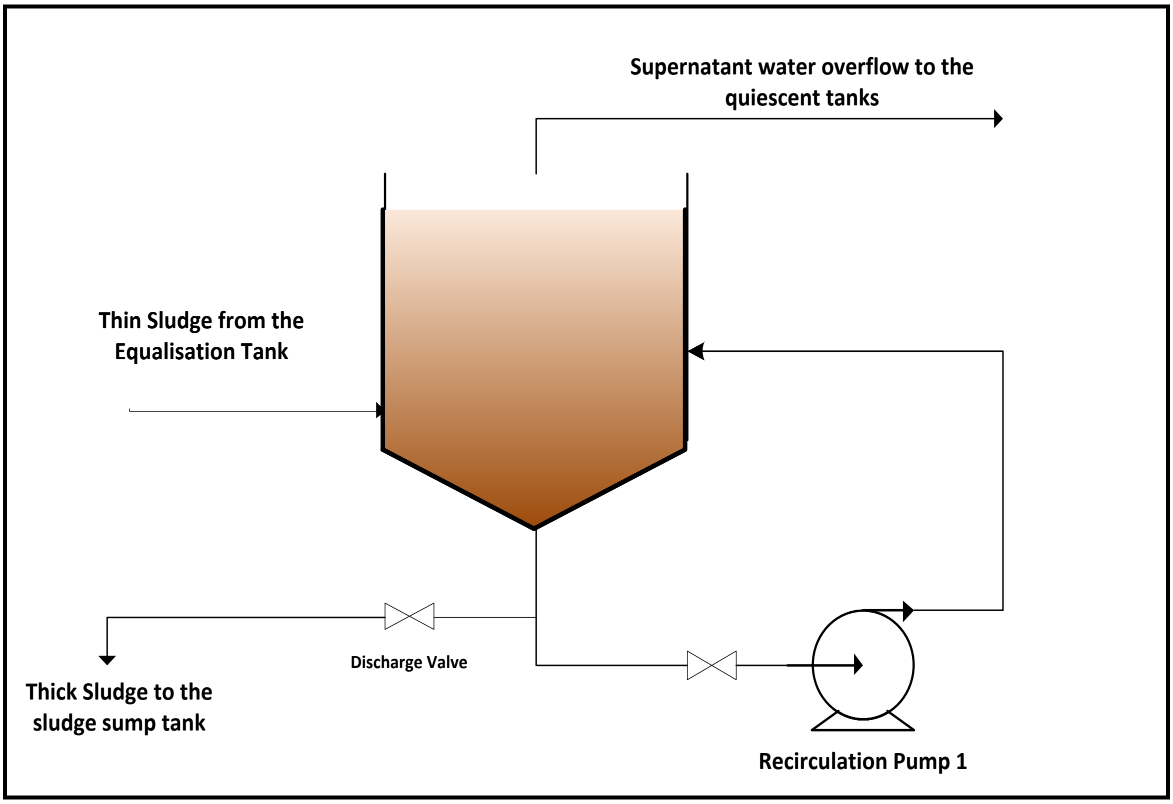

Figure 3-2: Continuous gravity thickener arrangement

It is good practice not to store thickened residue in the thickener, separate storage must be provided. This may however be costly for small works because:

- This works only when the specific gravity of the solids is greater than 1.0
- Supernatant with turbidity in the range 4-8 NTU may be recycled to the works inlet or be discharged.

- Residues thickened in gravity thickeners may require conditioning with polymer.
- Metallic hydroxide residues, which come from either clarifier operations or backwashing of filters thicken to only approximately 1 to 3% solids
- Residues with high TSS solids can thicken to 5 to 20% solids
- Process requires energy of about 50 kWh/ton WTR

3.3.2.2 *Flotation thickening*

There are a few WTP using flotation thickening in South Africa but this technology may be used in the future because of the increasingly eutrophic nature of some source waters. Two plants from the survey currently use DAF technology for water treatment. Flotation thickening is a solids handling option for residue concentrates consisting of:

- Low-density particles such as algae
- Dissolved organic matter such as natural colour
- Low-to moderate turbidity water that produces low density Floc
- Low temperature water

Flotation thickening can be performed through any of three techniques.

- ***Dissolved air flotation thickening (DAF)***: Small air bubbles (50 to 100 µm in diameter) are generated in a basin as the gas returns to the vapour phase in solution after having been supersaturated in the solution (Figure 3-3).

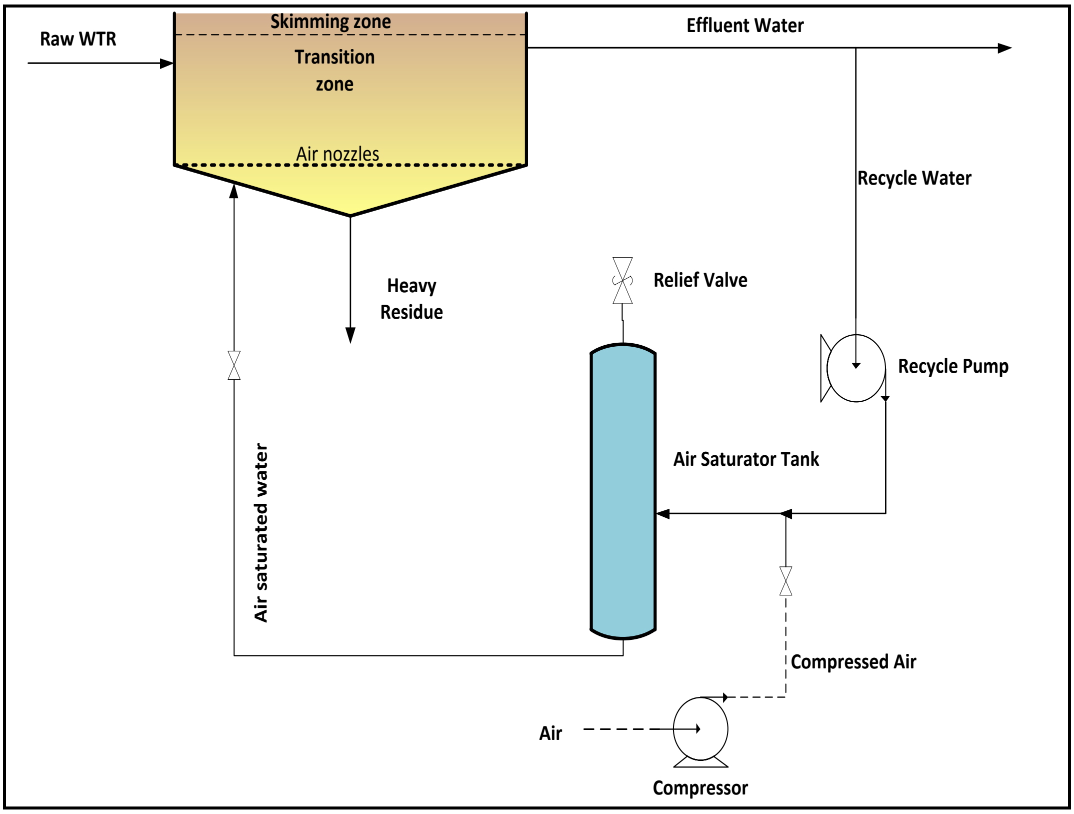

Figure 3-3: Dissolved air flotation process

- Generation is accomplished by pressurising air and the liquid stream together with subsequent release at the inlet of the flotation tank. The excess air over the saturation value in water emerges as small bubbles which attach themselves to the solid particles and float as scum.

3.3.3 **Dewatering**

Following thickening, the WTR is further concentrated by mechanical or non-mechanical dewatering methods (Lin & Green, 1987). Non-mechanical dewatering can be used to successfully dewater the WTR at a lower cost but takes longer. Case studies showed that most American plants optimise their process by dewatering the WTR and using the solid waste for landfill, land application or topsoil manufacture. The supernatant is recycled to the head of works or mixed with the raw water to reduce plant upset conditions (McCormick, et al., 2009). Table 3-6 shows a comparison of between different dewatering methods.

3.3.3.1 *Drying*

The drying of dewatered WTP residues was historically motivated by the economics of reducing transportation and disposal costs by reducing solids volume and water content.

3.3.3.2 *Solar drying beds or evaporation ponds*

Solar drying refers to those methods of sludge dewatering that remove moisture by natural evaporation, gravity or induced drainage. This process is less complex, easier to operate in terms of low maintenance costs and ease of cleaning; and require less operational energy than mechanical systems. They require a great deal of land area, can emit odours, are dependent on climatic conditions, and are labour intensive. Rainfall is a major factor in the effectiveness of this option since rain reverts drying of the WTR. Drying depends on the evaporation mechanism and only effective when located where evaporation rates are high. Drying times vary from 2 to 3 weeks in summer to 2 or 3 months in winter depending on weather conditions. This is the most common method used in South Africa. They are usually located within the WTP so there are no transportation costs involved.

3.3.3.3 *Sand drying beds*

WTR is dewatered on a sand drying bed by three mechanisms: drainage, decanting, and evaporation. First, the water is drained from the residue, into the sand, and out the underdrain system consisting of a series of lateral collection pipes. This process may last a few days until the sand is clogged with fine particles or until all the free water has drained away. Decanting can occur once a supernatant layer has formed. Water remaining after initial drainage and decanting is removed by evaporation over a period of time necessary to achieve the desired final solids concentration. Sand beds are more effective for dewatering lime residues than residues produced by coagulation with alum. In areas of high precipitation, covered sand beds have been used. Sand drying beds range in complexity from dumping the residues in a clear area to dewater naturally, to a well-designed bed with sophisticated automated drying systems. These are suitable for small plants generating small quantities or WTR and are effective in hot climates. High maintenance costs are involved during the removal of the sludge layer on the drying beds.

Table 3-6: Comparison of dewatering methods

Method	Advantage	Disadvantage
	Mechanical Dewatering	
Centrifuge	Lime-softening residue was reported to be easily dewatered due to its high calcium carbonate content, with resultant cake solids of 55 to 70% solids by weight. Alum WTR is less efficient, with cake solids of 12 to 20 (Lin & Green, 1987). Continuous operation Relatively compact footprint Possible automation Low odour's due to enclosed design	Long-term mechanical performance considerations must be carefully assessed when specifying the machine type. High Noise High energy consumption High investment costs High operator attention required. Cannot be run unattended overnight Long downtime for major parts replacement
Belt Filter	A WTR dry solid of 12-25% is achieved for chemically conditioned WTR (Lin & Green, 1987) Continuous operation Easy to operate Moderate investment costs Low energy use	Moving parts and electrical requirements Limited water content reduction Cleaning water consumption Supervision necessary Relatively large footprint Odors must be mitigated with an exhaust hood or building ventilation
Filter Press	High dewatering, between 30 - 45% solids by weight Sludge structure Possible automation Investment costs are reduced with increasing capacities	Electricity needs are about 30-40 kWh/t DM. High Operating costs Discontinuous operation Low productivity Consumption of mineral conditioner Supervision necessary
	Non-Mechanical Dewatering	
Drying Beds	Easy to operate Adapted for small WTP Functions throughout year Low operation costs High DM content reached	Land required Weather dependency Risk of odours Workforce requirements Difficulty in removal of dewatered sludge
Lagoons	Easy to operate and low cost Adapted for small WTP Functions throughout year High DM content reached	Land and workforce required Weather dependency Risk of odours Difficulty in removal of dewatered sludge
Freeze - Thaw	No Supervision Low operation costs High DM content	Land required Weather dependency Mechanical option requires high energy and high cost

3.3.3.4 *Lagoons*

Lagoons are generally operated in a cyclic sequence: fill, settle, decant. This cycle is repeated until the lagoon is full or if the decanted liquid can no longer meet discharge limits. Solids settle to the bottom of the lagoon and liquid can be decanted from various points and levels in the lagoon after a period of hours or days. The solids are then removed for final disposal. The decanted water is often returned to the head of works. Alum sludge usually contains ±5% solids while a softening sludge can produce approximately 50% solids (Lin & Green, 1987). The lagoon is filled over a long-time period (approximately a year) and then allowed to dry while another lagoon is filled. The solids never really dry unless the pond is eventually drained and the solids undergo evaporation. Contractors can also be hired to dredge the wet solids from the lagoon bottom and haul them away for dewatering and disposal. Liners made of high-density polyethylene (HDPE), leachate collection systems, and monitoring wells are common features of lagoon designs. The overall land area for a dewatering lagoon and a sand bed system are similar with only the fill/dry/clean cycles are differing. Lagoon drying capabilities are:

- 6-10% solids for metal hydroxide solids retained for 1 to 3 months
- 20-30% solids concentrations for lime sludge retained for 1 to 3 months
- The approximate time required to reach final solid concentration is about 12 months

A lagoon that is left to "revert to nature" will take a long time to dry out. After the supernatant, has been drained out or allowed to evaporate, the sludge at the surface forms a crust, giving the appearance that the lagoon is now filled with dry residue. The crust-covered lagoon can be compared with a frozen pond - the surface may or may not support the weight of a human or stock. Therefore, it is important to fence off the lagoon and to ensure that it remains fenced off. It may take many years before the waste dries out to the base of the lagoon. There will be a large amount of shrinkage during the drying out process.

3.3.3.5 *Centrifuge*

Centrifugal dewatering of solids is a process that uses centrifugal force developed by fast rotation of a cylindrical bowl to separate solids from liquids (Figure 3-4). Centrifuges are very sensitive to changes in the concentration or composition of the waste residue, and the amount of polymer applied. The scroll pushes the collected solids along the bowl wall to the tapered end for final dewatering and discharge. Simultaneously, water flows in the opposite direction and overflows an annular weir. Organic polymers are usually used for flocculation as they improve concentrate clarity and increase the dewatering capacity. Dosages can vary from 3-7 kg polymer / tonne WTR solids.

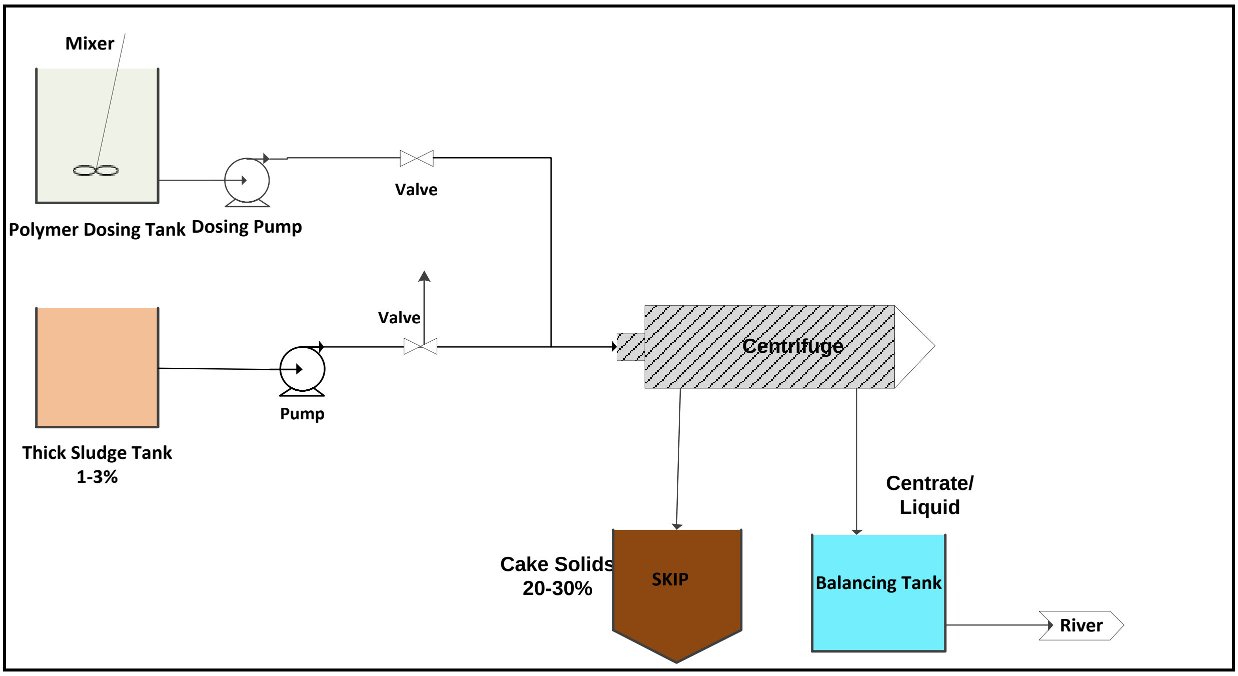

Figure 3-4: Centrifuge dewatering

3.3.3.6 *Belt filter presses*

During the process WTR is sandwiched between two porous belts which are passed over and under rollers of various diameters. As the roller diameter decreases, pressure is increasingly exerted on the residue, squeezing out water. The method is very simple in concept but complex in operation. A typical belt filter press consists of a chemical conditioning stage, a gravity drainage stage, and a compression dewatering stage as indicated in Figure 3-4. Belt filter presses can be used to dewater the residues produced from either lime softening processes or alum coagulation. Lime softening residues dewater very readily and are efficiently dewatered on belt filter presses. Organic coagulant residues are more difficult to dewater because of the gelatinous nature of the solids. Coagulant residues must be dewatered at low pressure. Pure alum residue may dewater to 15-20% or more solids, whereas slurry produced from river water which has silt and sand entrained will more easily dewater producing a drier cake.

To ensure optimum performance, solids must first be conditioned with polyelectrolyte. Polyelectrolyte produces a larger, stronger floc that allows free water to drain more readily from the solids in the gravity drainage zone of the belt press. To achieve proper residue conditioning, then it is first diluted to between 0.25 and 0.50 percent by weight before it is applied to the feed residue and mixed. The required mixing time depends on residue characteristics and type of polyelectrolyte used determined from jar test and pilot evaluations.

3.3.3.7 *Freeze thaw*

Freezing thawing can be done naturally or artificially. This method was initially developed for sewage sludge but has proven to be successful for the treatment of WTR. In this process, water is removed from the WTR, producing small granular particles that settle rapidly, resulting in a volume reduction of up to 83%.
This method of dewatering poses minimal application in the South African context. This process has no benefit for lime residues (Lin & Green, 1987). Overseas it is used on alum residue which release bonded water from cells through the Freeze-thaw process to change the consistency of the sludge from gelatinous to granular; which is then easier to dewater. The granular particles often resemble coffee grounds in both size and appearance, and they do not break apart even after vigorous agitation. The process involves the following steps:

- Ice crystals are formed from water molecules
- Residue floc particles are rejected to get frozen by the growing ice crystal
- This forces the floc particles to become consolidated at the boundaries between ice crystals
- After freezing is complete, the sludge is no longer a suspension of floc particles but a matrix of ice crystals and solid particles
- When the ice crystals thaw, the particles remain consolidated and do not dissolve. The solids separate from liquids

Typically, the volume reduction is well over 70 percent, and solids concentrations may reach as high as 80 percent when freeze-thaw is followed by evaporation.

3.3.3.8 *Vacuum assisted drying beds*

This method is reported as expensive, time consuming and problematic. The technology applies a vacuum to the underside of rigid, porous media plates on which chemically conditioned sludge is placed.

3.3.3.9 *Wedgewire beds*

The wedgewire, or wedge-water, process is physically similar to the vacuum assisted bed. The base of the bed incorporates a wedgewire screen which holds and drains the sludge.

3.3.3.10 *Pressure filters*

Consists of rows of vertical plates between which WTR is injected under pressure. Filtrate is collected before separating the plates. The cake then falls and is collected. In some cases, membranes are placed between the plates, which can be filled with water in order to improve the dewatering rate.

- Good dewatering between 30-45% solids by weight are generally achieved
- The investment costs however are quite high, especially for high capacities
- Electricity needs are about 30-40 kWh/ton dry mass

3.3.3.11 *Vacuum filters*

It has been used to some extent in the water treatment industry to dewater lime residues. No conditioning is required when dewatering lime residue. Vacuum filters are not recommended for coagulation sludge. This process has not been used in South African for thickening of sludge as it is associated with high operation and maintenance costs. The equipment imposes a heavy structural load on foundations.

3.4 LAND APPLICATION OF WATER TREATMENT RESIDUE

3.4.1 Introduction

The definition of land application was stated by Titshall and Hughes (2005) as *'the intimate mixing or dispersion of wastes into the zone of the soil-plant system, with the objective of microbial stabilisation, adsorption, immobilisation, selective dispersion or crop recovery, leading to an environmentally acceptable assimilation of the waste*'.

Land based application of WTR involves the controlled spreading of the WTR onto or incorporated into the surface layer of soil. Historically the most notable land application of waterworks residue is the use of lime softening sludge for agricultural limestone. Lime addition to agricultural soil is a common practice where the soil pH is too low for optimal plant growth. Lime has the ability of modifying the balance between acidity and alkalinity in the soil. Soil pH should be maintained at 6.5 or above to minimize crop uptake of metals (USEPA, 1996). In addition, lime residues increase the porosity of tight soils, rendering the soils more workable for agricultural purposes. Aldeeb et al. (2003) found that when lime WTR is blended or added to natural topsoil as landfill cover, it improves the natural topsoil properties by increasing the overall particle size distribution and releasing the bonded water, allowing better drainage.

Aluminium coagulant residues have the consistency of very fine soils when dry. A study indicated that alum residues improve the physical characteristics of soil media but inhibit plant growth by adsorbing phosphorus (Helserman, 2013). It is important to note that WTR's have high phosphorus sorption capacities (Hughes , et al., 2005). In addition, results show that WTR treated soils release less phosphorus therefore this characteristic of the WTR can greatly benefit areas where there is leaching or loss of phosphorus into groundwater or surface water bodies.

Application of aluminium salt WTR at rates that are not considered excessive (<20 tDS/ha) does not cause environmental degradation. Aluminium salt WTR are applied as a liquid unless the water treatment plant has dewatering capabilities. Liquid aluminium salt WTR can be applied with a liquid manure spreader, (like lime residues) or with conventional irrigation equipment. Aluminium salt WTR contains few if any plant nutrients (usually low in nitrogen), it may contribute other beneficial properties such as improving soil structure, increasing water retention and minimising fertiliser run off. Ferric coagulant residues are very similar to aluminium salt WTR where they can increase water retention and improve the soil structure; however as with aluminium WTR large doses inhibit plant growth (Helserman, 2013). Ferric based WTR also have application in the cement production industry as iron plays an important role in the production of cement (Miroslav, 2008). Polymeric residues have lower levels of trace metals and generally improve water retention and the hydraulic conductivity of the soil (Herselman, 2007). A laboratory study was conducted where four different South African soil types were mixed with polyacrylamide WTR. Results indicated a decrease in bulk density and evaporation, and an increase in water retention and hydraulic conductivity due to the ability of the polymer to bind the silt and clay into gravel sized aggregates. Indications are that large quantities of WTR may be required to notice effects on the soil inherent physical properties (Hughes, et al., 2000).

For land application, the effects on soil properties and plant growth of the application of WTR must be taken into account. A classification analysis based on British standard BS 3882 revealed that WTR could be classified as ‘economy grade-high clay content’ soil indicating its possible use as soil or as part of soil making materials. Concerns raised are the lack of potassium and other nutrients in the residue which make it incompatible with commercial grade fertilisers. The limiting metal levels are important, for long term land application, as it determines the useful life of application sites based on cumulative metal loadings. Options available for the land application of drinking water treatment residues include agricultural use, silvicultural (forest) application, and application for reclamation of disturbed and reclaimed land (Helserman, 2009). Once land application is identified as a desirable option, the utility will need to find end users and determine the specific requirements of the user.

3.4.2 ***A*****gricultural use**

Agricultural use of WTR includes applications on farms and croplands, forests, public parks, plant nurseries, roadsides, golf courses, lawns and residential gardens. Factors critical to success of agricultural use of Water treatment plant residues include:

- Heavy metals and organic contaminants
- Lack of agricultural land within viable distance
- Community resistance to such applications

Thus, depending on these factors, agricultural use of WTR can have either a positive or negative effect on soils and plants. Consideration must be given to the nature of the WTR to determine any potential negative impacts the material may have if applied to land. Titshall and Hughes (2005) concluded that land application of WTR is safe and is likely to have no negative impacts on soils, vegetation or groundwater even at very high disposal rates that are unlikely to occur in the field. However, a possible concern with South African WTR is the elevated manganese concentration found in a large number of water treatment plants (Trollip, et al., 2013). This concern was also highlighted by (Moodley & Hughes, 2006) who found that soil incubated with WTR released Mn after 60 days due to soil acidification and reducing conditions. In a recent characterisation study performed by Umgeni Water on 12 WTPs varying in raw water source, treatment chemicals and disposal methods; the constituent were below Waste Classification and Management Regulation (2013) limits in most cases, allowing for disposal to a general landfill site was manganese (Mn). According to a study done by (Trollip, et al., 2013), the main source of Mn was found to be from brown lime, which is used as a treatment chemical and from Mn present in the raw water. The Mn found in the raw water and treatment chemicals, cause a high residual Mn in the concentrated WTR due to the high volumes of water treated. It was also noted that the environmental effects of Mn are unclear and not considered detrimental internationally. This implies a need to review the regulatory limit for manganese in WTR. Water treatment residue may also be beneficially used to treat eutrophic soils. Investigations suggest that application of WTR to eutrophic soils may be a viable option for binding soluble reactive phosphorus (P) as an insoluble precipitate. The precipitation of P from the soils will make it unreactive, allowing agricultural users to use the biosolids or litter to utilise the nitrogen sources. Using alum based WTR as potting media may also improve the air and water holding capacity of soils (Lin & Green, 1987). Iron based WTR added to acid soils can further depress the pH of the soil and mobilise the metals considered toxic to plants such as copper, zinc, cadmium, manganese, etc. Experiments showed that direct application of the iron based WTR produced excellent forage growth but had detrimental/ toxic effects on the feeding cattle if the iron level in the biosolids was greater than 4% by weight (Lind, 1997). However, composted material or biosolids with iron content below 4% applied well in advance of feeding showed minimal effect (Lin & Green, 1987)

Poultry litter is commonly used as an inexpensive N fertiliser and applied to permanent pastures without incorporation, which increases the P concentration in surface agricultural runoff. Research done indicated that for regions of high poultry production, the addition of aluminium (Al) or iron (Fe) based WTR can significantly reduce the soluble P in both manure and soils (Dayton, et al., 2003). When poultry litter was treated with the WTR, the water-soluble P was reduced up to 87% depending on the dose and incubation period. It also increased the pH of the litter, (Meals, et al., 2008). (Okuda, et al., 2014), stated that indiscriminate addition of WTR to soils can result in excessive immobilisation of soluble phosphorus, leading to crop deficiencies. The maximum phosphate sorption capacity of WTR was determined to be 85-175 mg P/kg (P-max), which is more than 85 times that of natural soils. Ferric based WTR showed the highest phosphate adsorptive capacity (2960 mg/kg), followed by lime (1390 mg/kg) and alum (1110 mg/kg).

(Meals, et al., 2008) studied the use of alum based WTR blended with animal manure to lower the soluble P concentrations in runoff from manure application sites to noncritical levels, while still containing fertiliser value for crops. Experiments showed that with increasing percentage of WTR added, improved the reduction of manure soluble P concentration. A WTR dose of 5-10 by dry weight could achieve a 20-30% reduction in soluble P content of liquid dairy manure with minimal, if any, environmental risk. Tests done by (Dayton, et al., 2003) by addition of aluminium based WTR to box plots treated with poultry litter reduced the P concentration in runoff from 85% to 14%. Therefore, treating animal manure with moderate dosages of WTR could allow treatment of greater volumes of manure. This in turn would spread potential soluble P reduction across a broad surface area where P runoff was problematic. Higher dosages can also be applied to areas where excessive P concentrations pose a risk. The use of aluminium or iron based WTR as a P sorbent could provide significant economic and environmental benefits to municipalities by preserving the surface water quality.

3.4.3 **Turfgrass sod farming**

Turfgrass sod farming is the practice of cultivating instant lawn on land irrigated with WTR. When the lawn is harvested, a layer of WTR is also removed and transported to the land where the lawn sods are planted. Turfgrass is used on golf courses or soccer grounds, where the grass root zones must resist compaction, drain rapidly and provide adequate moisture, nutrition and aeration to produce high quality turfgrass (Park, et al., 2010). The study done by (Park, et al., 2010) showed that WTR can be used as an alternative to sand due to its superior physical characteristics i.e. water retention capacity, nutrient value, etc. It proved to be of a higher quality for use as a growing medium for turfgrass than the use of sand.

3.4.4 **Soil amendment**

An incubation study of sewage sludge treated soil done in Malaysia by (Ishak & Abdullah, 2014)) using various application concentrations of WTR (2.5 to 40%) showed that sludge addition reduces the release of Zn from sewage sludge. Application at 40% WTR produced the lowest Zn concentration in the soil solution. WTR can therefore be used for soil amendment to fix Zn in contaminated soils. Addition of the WTR to corn plants significantly reduced the uptake of Zn by the plants. In addition, the use of more than 40% WTR mixed with sewage can also reduce the uptake of Cu by corn.

3.4.5 **Land reclamation**

Water treatment residues in combination with other fertilizers may benefit reclamation efforts. WTR can be used to treat a particular site of concern. For example, lime residues can be used to control soil pH just as they do in agriculture. In these cases, however, the pH adjustment may be more critical because mine solids can be very low in pH. In addition, aluminium salt coagulant residues can control runoff of excess phosphate into surface waters, due to phosphate sorption. Care must be taken to ensure that the site is suitable for use of WTR and that management practices are in place to protect public health and the environment. On a mine reclamation site, WTR may actually be used as a topsoil replacement.

3.4.6 **Application to landfill site**

Recent research has indicated that blending WTR with natural topsoil can enhance the physical properties of the residue, making them suitable for reuse such as landfill cover material. Studies done by (Aldeeb, et al., 2003) tested the properties of alum-coagulated WTR, based on the engineering properties for ultimate land disposal as sanitary landfill cover material. The properties of residues alone proved unsuitable for landfill cover application; however, when blended with natural topsoil resulted in a mixture with physical and engineering characteristics similar to that of clay soils. Clayey soils are accepted for use as landfill cover. An optimum blend ratio, based on the WTR samples tested, was found to be 20% residue and 80% natural topsoil, which reduced the plasticity index of WTR sufficiently that it, becomes feasible for use as landfill cover. Blending with natural topsoil also improved the particle size distribution, raised the specific gravity, improved compaction characteristics and increased the shear strength of the residues making them suitable for requirements of landfill cover material.

3.5 ONSITE AND OFFSITE DISPOSAL

3.5.1 **Onsite**

Generally, on site disposal consists of evaporation ponds whereby large ponds are filled with WTR and then the clear water evaporates and the sludge is allowed to dry. Similar to drying beds once the residue is dry it can be removed and sent to landfill. Due to high evaporation rates and the perceived availability of land in South Africa, the use of evaporating ponds is often favoured (Trollip, et al., 2013). The normal practice is to have two dams side by side and alternate use (DWA, 2002). Drying ponds may become costly as legislature has demanded that the WTR be classified and that the correct linings and preparation procedures for these ponds be used in accordance with the WTR hazard ratings (Golder, 2014).

3.5.2 **Off-site**

Off-site disposal refers to dedicated land disposal sites. These sites are coming under scrutiny due to environmental concerns. Water treatment residues must be classified and then disposed of in accordance with government legislation however. (Marx, et al., 2004), has considered this a viable option for ultimate disposal in South Africa. This method is currently used by the Cape Metropolitan Council and Johannesburg Water Goudkoppies WWTW.

3.6 DISCHARGE TO SEWER

This option is economically attractive as the transfer of disposal liability is passed to the WWTP (Helserman, 2013). The availability of WTR discharge to a waste water treatment plant (WWTP) include: the potential to increase plant treatment efficiency by enhancing the sewage sludge conditioning and enhance phosphate removal during wastewater treatment. The residue coagulating capacity in the WTR can also improve dehydration of the WWTP sludge (Babatunde & Zhao, 2007). Factors to take in to consideration if disposal to a WWTP include:

- The Water Treatment Plant should be nearby to a sewerage system.
- The WWTP must have sufficient capacity to be able to treat the WTR, diluted reasonably, and not upset the biological nature of the WWTP.
- Time of day during which the WTR shall be discharged to the WWTP should be arranged in advance. For instance, if the WTR stream is stored and discharged at night when the WWTP experiences lower loadings.

Discharge to a sewer will require some information about the chemical nature of the residue that will be discharged, as well as quantity and timing of flow (Table 3-7). Disposal to a sewer facility usually requires easy access to a sewer line, but for small systems, it may be possible to temporarily store residues on site, and then haul them periodically to the wastewater treatment works.

Table 3-7: Parameters monitored when considering sewer discharge

	Aluminium
Biological oxygen demand (mg/L)	Arsenic
Total suspended solids (mg/L)	Cadmium
Total phosphorous (mg/L)	Chromium
Nitrate (mg/L)	Copper
Chemical oxygen demand (mg/L)	Iron
Fats, oil and grease (mg/L)	Lead
Faecal coliform (number/100 ml)	Mercury
pH	Molybdenum
Total nitrogen (mg/L)	Nickel
Total coliform (number/100 ml)	Selenium
	Zinc

The following discharge limits apply to discharge of wastewater into a water resource as promulgated in the general and special authorisations, NWA, 1999. Each municipality may use different equations to calculate the trade effluent costs. The general rate in cents per kilolitre for the additional charge for the disposal of trade effluent to the sewage disposal system is determined in accordance with the formula:

$$Charge = X + v\left(\frac{C}{R}\right) + Z\left(\frac{B}{S}\right)$$

Where:

X = the prescribed rate for the conveyance and preliminary treatment of sewage and shall include all operational, repairs, maintenance and annual capital costs less an allowance, determined by an authorised officer
V = prescribed rate for treatment in the treatment works for effluent having a prescribed chemical oxygen demand value
R = the prescribed chemical oxygen demand value
C = Actual chemical oxygen demand value
Z = prescribed rate for treatment in the treatment works for effluent having a prescribed settleable solids value
B = the volume of settleable matter in one litre of the trade effluent, measured after settlement in the laboratory for one hour.
S = is the prescribed settleable solids value

The development of cost- effective adsorbents from by-products is gaining attention as an alternative to commonly use adsorbents. It was reported that sintered WTR adsorbed significant amounts of toxins from a synthesised toxic wastewater and noted in particular that the sintering process can effectively prevent the release of harmful substances in the waterworks residue to the environment (adsorption capacities of 1.40 mg/g at pH 4.6 for Cr (iii) & 0.43 mg/g at pH 6.0 for Hg (ii) were observed) (Babatunde & Zhao, 2007). A survey done at Hamburg Water Works showed that WTR composed of iron hydroxides discharged into sewers settled with the same speed or slower than other substances contained in the waste water. This shows that there is no risk that more sediment would be collected in the sewers. A test from sulphide elimination in wastewater in sewer also showed that continuous feeding of iron sludge contributes to elimination of the sulphides (Miroslav, 2008).

Research has shown that WTR can also be used as a sewerage system coagulant. The treatment cost of WTR for sewerage system tested in Japan, the construction cost for combined WTR treatment for a sewerage system is much lower than for individual WTR treatment methods. It was discovered that under certain conditions of optimal sludge addition, the treatment and final sludge characteristics at the WWTP were improved significantly. In France, aluminium hydroxide sludge discharged to a sewer in a treatment plant proved successful with 94% phosphate removal and a dose of 3.5 mmole/ L Alum sludge (Babatunde & Zhao, 2007). Re-use of the sludge in municipal wastewater treatment plants can also have negative effects. The total volume of the sludge increases and the sludge cannot be decomposed by biological procedures. Consequently, the sludge handling system becomes more loaded. This can also influence the activation processes (Miroslav, 2008).

3.7 DISCHARGE TO WATER SOURCE

There is now increasing concern on the impact to the aquatic environment (Helserman, 2009). The direct disposal of WTR to watercourses is now illegal (National Water Act No 36 of 1998), whereby licencing and monitoring is required. Permits are available from the Department of Water Affairs and Sanitation (DWAS) and the Department of Environmental Affairs (DEA). Monitoring is required depending on the daily volume discharge, the specific municipal bylaws per region and type of permit granted whereby Oil and grease and biotic index monitoring may also be required. Periodic discharges of accumulated sludge from settling tanks can possibly disrupt stable ecosystems more than a continuous low-level discharge.

3.8 RECOVERY OF TREATMENT CHEMICALS

3.8.1 Overview

The large scale of water treatments plants requires vast quantities of coagulant and flocculent chemicals, resulting in the production of large quantities of WTR. One of the methods currently being investigated by the water industry is to reduce the cost of chemicals required by finding an economically and environmentally viable method for recycling and recovery of coagulants. This has been highlighted by the UK Water Research body as a key step towards minimising chemical usage in water treatment (Keeley et al. 2014). Efforts exist to recover alumina from the water treatment residue during the water treatment or to use the alumina sludge for wastewater treatment or as a secondary raw material. The iron sludge can also be used for wastewater treatment. There are several methods of recovery of coagulants from WTR's such as acidification, alkalization, ion exchange and membrane separation. However, a combination of these methods may be used to achieve a higher recovery (Evuti & Lawal, 2011). The application of recovered coagulant in wastewater treatment process is being used at the Orly WWTP in France where coagulant recovered from aluminium salt WTR through acidification is recycled with fresh coagulant. It was noted that the coagulant purity recovered from WTR may not be sufficient to justify their re-use, and economically the recovery process is expensive and laborious. Another concern is coagulant contamination due to heavy metal accumulation in the residue (Batunde, et al., 2011). The amphoteric nature of aluminium oxide also permits aluminium sulphate recovery from water treatment residue under alkaline conditions. The highest removal efficiencies were found at the pH ranges of (11.4-11.8) and (11.2-11.6) using sodium hydroxide and calcium hydroxide respectively. The alkaline digestion process has the same limitations as the acid digestion process because of the high amounts of natural organic matter that is present in the recovered solution (Evuti & Lawal, 2011).

In one study by Keeley et al. (2014), polymeric Ultrafiltration (UF) membranes were compared in their readiness to permeate alum and ferric coagulants, while rejecting organic compounds and pathogens present in the WTR. The permeate quality and performance was then compared to commercially available coagulants and raw untreated WTR. Overall it was surmised that UF based coagulant recovery did not consistently meet the requirements at a practical level of recovery efficiency, due to the lack of selectivity by UF for coagulant ions. This is despite potentially reducing net chemical costs. It was stated that use of recovered coagulant in waste water treatment works would be more suitable as the organic content is less closely regulated. (Okuda, et al., 2014), showed a significant difference in the efficiency of aluminium removal from thickened and sun-dried residue. Thickened residue washed at pH 3 showed aluminium reduction of up to 80%, whereas sun-dried residue required washing at pH 1 to achieve the same results. The percentage of aluminium removed from acid washed WTR decreased with increased residue drying time. Experiments conducted using both sun-dried unwashed and sun-dried acid washed WTR in a soil mixture to grow Japanese mustard spinach, showed that the use of washed residue results in an increase of available phosphorus and decrease of aluminium for plant growth. The properties of washed residue are therefore sufficient for use in ploughed soils, eliminating the inhibition of plant growth.

Pilot trials were also conducted by Umgeni Water to recover aluminium from WTR of Hazelmere Water Works for several years. The pilot plant was designed as a simultaneous coagulant recovery and sludge dewatering unit. The process consisted of sulphuric acid addition to the WTR, followed by settling, supernatant withdrawal and solids collection. The results of these trials gave consistent aluminium recovery of greater than 70%, therefore substantiating its applicability and successful implementation within South Africa. The process was only terminated due to change in the type of coagulant used (from alum to a cationic polymeric coagulant). One of the disadvantages discovered in this process was the abrasive effect the acid solution had on porous material and the front loader used (Rajagopaul, 1995).

3.8.2 **Technologies for coagulant recovery**

3.8.2.1 *Aquacritox*

Aquacritox® is a new technology that uses Super Critical Water Oxidation (SCWO) to treat wet organic wastes. During the SCWO process, the wet residue is subjected to elevated temperature and pressure (374°C and 221 bars) above the critical point. These conditions cause the water to reach a 'super critical' phase. At this stage, oxygen is added, creating rapid oxidation that converts all organic material in the residue into CO_2, nitrogen and clean water. The nitrogen can be safely released into the atmosphere and CO_2 can sold or used. All the residues matter produced are said to be non-hazardous, allowing easy separation of inorganic materials. With this process, coagulants in WTR can be recovered. Extensive trials performed for alum based WTR showed that for every tonne of alum residue processed, with 50% organic, 50% inorganic and 17 total dry solids, the organic matter was fully destructed and approximately 85 kg of aluminium hydroxide recovered (O'Regan. 2012).

3.8.2.2 *REAL process*

Another method for coagulant recovery is called the REAL process, which can be used to recover aluminium from alum, based WTR (Babatunde & Zhao, 2007). The process comprises of four steps:

- Dissolution of aluminium hydroxide in the WTR by adding sulphuric acid,
- Using ultrafiltration to separate the suspended matter and large molecules (approximately 15 to 20% dry solids).
- Concentration of the permeate solution using Nanofiltration.
- Precipitation using the concentrate from the third step with potassium sulphate to form pure crystal (potassium aluminium sulphate).

Long-time pilot scale tests done at Vasteras Water Works in Sweden showed that the recovered potassium aluminium sulphate recovered from the WTR is comparable to standard aluminium sulphate (Stendahl, et al., 2006).

3.8.3 **Recycling of Flocculated WTR**

An option for reducing the WTR volumes is to recycle the flocculated waste from the clarifiers or sedimentation tanks on a water treatment plant. Recycling of the settled chemical Floc back to the incoming raw water can cause good Floc formation with exceptionally good suspended solids removal and filtering characteristics. Full scale trials were done at a water treatment plant in Fort Madison, IOWA that proved successful enough that the plant continued to use recirculation for the next 7 years. The plant uses ferric sulphate as a coagulant. It was found that pumping the settled residue directly from the sedimentation tank and combining it with the lime slurry fed into the raw water produced the best water quality and most reproducible results. Recirculating proved especially effective in eliminating the water quality problems associated with fluctuations during heavy rainfall and cold-water conditions. The following advantages were observed by the plant: (1) The method was simple to initiate, (2) Can replace bentonite usage in plants with low turbidity raw water, and (3) Reduced the cost lime usage by approximately 17%. This is because previously the lack of bonding between lime and the floc caused lime to deposit on equipment surfaces.
Backwash water was not recycling due to concerns about recirculating microbiological content (McLane, 2004). A study was conducted in Dublin where aluminium WTR was used as a substrate for a constructed wetland to treat waste water from an animal farm. The study showed potential as a low-cost pollutant removal system from wastewater, with minimal aluminium leaching (Batunde, et al., 2011).

3.9 WATER TREATMENT RESIDUE REUSE

The most researched reuse of the WTR in South Africa was in the cement and brick manufacture and explained in more detail in the Technical Support Document WRC Report No. 1723/1/13. Water treatment plants that use lime softening generate large quantities of lime residues. Coal-fired power plants traditionally use finely ground limestone for flue gas desulfurization to lower the sulphur dioxide emissions produced by burning coal. Because lime softening residues are chemically more reactive than limestone, power plants can reduce their demand for desulfurization agents by switching from limestone to softening plant residues.

3.9.1 Brick making

Since 1985 in the United Kingdom, research has been undertaken to investigate the use of WTR as a colorant or clay substitute in brick making (Dunster and Petavratzi, 2007). During the studies properties and performance of iron and aluminium coagulant WTR as a brick making material in the extrusion process were tested. The study concluded that it is technically feasible to use WTR as a clay substitute with iron coagulants giving good colour. The manufacturers however are reluctant to use WTR as it does not offer more value to the process relative to the current materials (Dunster & Petavratzi, 2007). More research was undertaken in Nigeria following on from Dunster and Petavratzi (2007) study which concluded that clay burnt bricks could be manufactured by using WTR as a clay substitute. In Nigeria, the brick factories are in close proximity to the clay quarries which are in most cases also owned by the brick manufacturer (Anyakora, 2013). There are concerns in the uncertainty of the products compressive strength and shrinkage characteristics. From a legislative perspective, there is no waste management license required to use WTR in the process. The WTR is supplied as a product to meet a defined specification (such as chemical analysis, ceramic property assessment, carbon/ sulphur testing, loss- on- ignition, fired colour, etc. (Dunster & Petavratzi, 2007)

3.9.2 Building low cost houses

A brick is traditionally made by wetting clay, pressing it into a mould, which creates blocks. These blocks are then fired in a kiln until they are hard. Low cost bricks do not require firing in a kiln, they are left to dry out in the sun. The process of making bricks generally consists of the following steps: (1) Gathering, crushing, grinding, screening, and mixing the raw materials producing the brick, (2) The setting, drying, firing, and (3) Packaging and inventorying is the final processing in the manufacture of bricks. The first two steps can be eliminated when using WTR that has been properly thickened especially from the process that used lime during the treatment process. A standard do-it-yourself Hydraform stock brick making machine costs about R2 600 and is capable to produce about 6 bricks per drop and 3000 bricks per day with the correct amount of labour (Table 3-8).

Table 3-8: Brick making machinery

	Hydra Form Machine	Regular Hollow brick machinery
Capital Cost	R2 600	R11 168
Bricks per drop	6	4
Daily Production	3000	2000

When compared with a regular hollow brick making machinery 6-inch hollow that costs R11 168. And is capable for an output of 4 per drop and daily production of 2 000 bricks. An advantage of Hydraform brick making machines is that they are portable and the blocks can be produced anywhere, training can take place on the job and rural development is easier as the machine can be transported to remote areas. The substantial cost savings are due to the use of freely-available subsoil which is the main raw material. The blocks do not require costly burning. Transport costs are minimised since block production takes place on site and unskilled labour can be trained in both block making and building with Hydraform blocks. A seven-person team can produce 1500 bricks per day. The blocks can be produced with sandy soil with clay content between 5-20% and silt content of 5-25%. Silts with low clay content below 10% will be difficult to handle when coming out of the machine. Soils with a high clay and silt content above 35-40% will need to be blended with a sandy soil. The soil must be free of organic material and not to contain harmful quantities of salts and should contain enough clay to bind the block so that they may be handled immediately after manufacture without disintegrating (Hydraform, 2016). Of concern in this use is the variability in the final product made from such sludge's due to the variability in the final product. This method has been used in the Netherlands with success. The WTR is required to be of high quality and considered a water treatment plant product and not a waste.

3.9.3 **Cement & cementations materials**

Water treatment residue has clay like properties and should be useful in the construction industry. It was discovered that, the preferred WTR should have low chlorine levels as chlorine could corrode the cement kiln and block the duct. A review on residue incorporation into cement noted the following: (1) When drying at 105°C, the residue suffered agglomeration and had to be ground before use; (2) Residue (dewatered or heated at 105°C) prevents the setting and hardening of paste and mortar; (3) Thermally treated residue decreases the compressive strength of mortar, but increases its consistency; (4) Compressive strength decreased with increase in residue content and treatment temperature; and (5) Residue treated at 700°C induced the formation of lime and calcium aluminates. There are also concerns of the possible inclusion of other deleterious components such as iron which could produce rust stains, hydrogen generation and retardation of the setting process due to remobilisation of zinc and lead at high pH (12 to 14), and possible concrete expansion due to alkali- silica reaction from the glass contents in the waste material (Babatunde & Zhao, 2007). However, Miroslav (2008) stated that iron based WTR can be used as an admixture into cement. This was discovered during of full scale tests carried out at Torgau Water Works in a cement kiln. The WTR was first dewatered in a mobile filter press to a dry weight of 35-40%. The results indicated that the iron based WTR can be used as an admixture. WTR quality differs for different plants, process operations and water sources and raw materials used for the production can differ too. It is therefore recommended that small scale tests be carried out to test the possible mixtures. In the Durban area, three companies were contacted to determine whether local WTR's were suitable for use in the cement processing industry. The high sodium concentration found in the WTR's made them unsuitable for use, as the sodium affected the cement-making process.

3.9.4 **Reuse in pavement & geotechnical works**

This use has yet to be widely studied. There is the possibility of using WTR as geotechnical work material (waste containment barriers, soil modelling, structural fills) and incorporation into construction materials (bitumous mixtures, sub-base material for road construction) and as landfill liner (Babatunde & Zhao, 2007).

CHAPTER 4: CURRENT PRACTICES IN WATER RESIDUE MANAGEMENT - CASE STUDIES

4.1 INTRODUCTION

Questionnaires (Appendix A) were distributed electronically, and followed up telephonically, to all water boards and municipalities to obtain information on their water treatment plants' WTR: chemical characteristics, handling, treatment and disposal methods. The objective of the questionnaire was to categorise the water treatment works so that representative waterworks for each category could be visited. The questionnaire approach was marginally effective as only 8 out of 232 water utilities responded. A representative number of plants was then selected for site visit, based on:

- Location
- Type of coagulant
- Treatment chemicals
- High and low turbidity raw water

4.2 SITE VISITS

The site visits served as means to determine the status quo of WTR management and production in South Africa. Generally, within a province the same treatment chemicals and processes are used for water purification, so one water treatment plant within a province was considered representative. Water boards and metros who were also water suppliers were contacted and site visits to the largest capacity waterworks in each province was arranged. Generally, within a province the same treatment chemicals and processes are used for water purification, so the one water treatment plant was considered representative. In cases where different chemicals or processes were used more than one plant per province was contacted and sampled. Process information, in varying degrees of detail, was obtained from 81 waterworks nationwide. The largest capacity water treatment plants were visited in Gauteng, Western Cape, Northern Cape, KwaZulu-Natal, North West Province and Eastern Cape. Six Water Boards, one Metro and three District Municipalities operating a total of 28 water treatment works took part in the site visits and sampling exercise. This ensured a diverse sampling pool and provided a representative snapshot of WTR management in the areas being sampled. Nine of these plants were selected for further investigation as national case studies. The 9 plants selected as case studies were using different techniques for water treatment residue management. The plants were mostly run by water boards which meant information was more readily available and the largest and smallest capacity plant in South Africa was amongst one of the case studies.

Water works operated by Amatola Water, Magalies Water, Rand Water, Umgeni Water and uThukela Water were selected as case studies. Two government entities, namely Sol Plaatjie local municipal and City of Cape Town volunteered. The case studies are presented as follows:

- Process Description.
- Water treatment residue quantities and treatment processes.
- Methods of WTR disposal – challenges and advantages.
- WTR reuse initiatives (if any) – successes and limitations

4.2.1 **Zuikerbosch Purification Plant, Rand Water (Vereeniging, Gauteng)**

4.2.1.1 *Site description*

There are currently 12 water boards with the largest Water Board (in terms of capacity treated) being Rand Water. Rand Water services the Gauteng Province as well as parts of Mpumalanga, Free State and North-West Provinces in South Africa. Rand Water became a bulk water supplier in 1903 with water being supplied from underground wells. As demand increased over the years, Rand Water began utilising the Vaal River System as its primary source of raw water. Today Rand Water treats basically all of its water at two water treatment plants situated in Vereeniging. Zuikerbosch is the largest water treatment plant operated by Rand Water.

4.2.1.2 *Water treatment process description*

The nominal treatment capacity of this plant is 3 600 ML/d and all raw water is sourced from the Vaal Dam. Rand Water utilises a conventional treatment process that is somewhat unique in that lime and activated silica are the preferred coagulation chemicals. This treatment regime is favoured as it has certain water quality advantages, but polymeric coagulants are often employed when they are a more cost-effective option and the raw water quality permits such treatment. The coagulation chemicals are dosed before a unique spiral flocculation system, seen in Figure 4-1, for which Rand Water holds a patent. This system is said to enhance the coagulation and flocculation of the raw water thus increasing sedimentation efficiency. During the summer months, powered activated carbon may be dosed to remove algal metabolites such as geosmin and other undesirable compounds. Ferric chloride is often used on the dual sedimentation systems as a secondary coagulant before the sand filters. The sand filter backwash water is usually returned to the head of works. The flow diagram in Figure 4-2Figure 4-2 illustrates the process train for the Zuikerbosch water treatment works.

Figure 4-1: Spiral flocculator (Source: Rand Water)

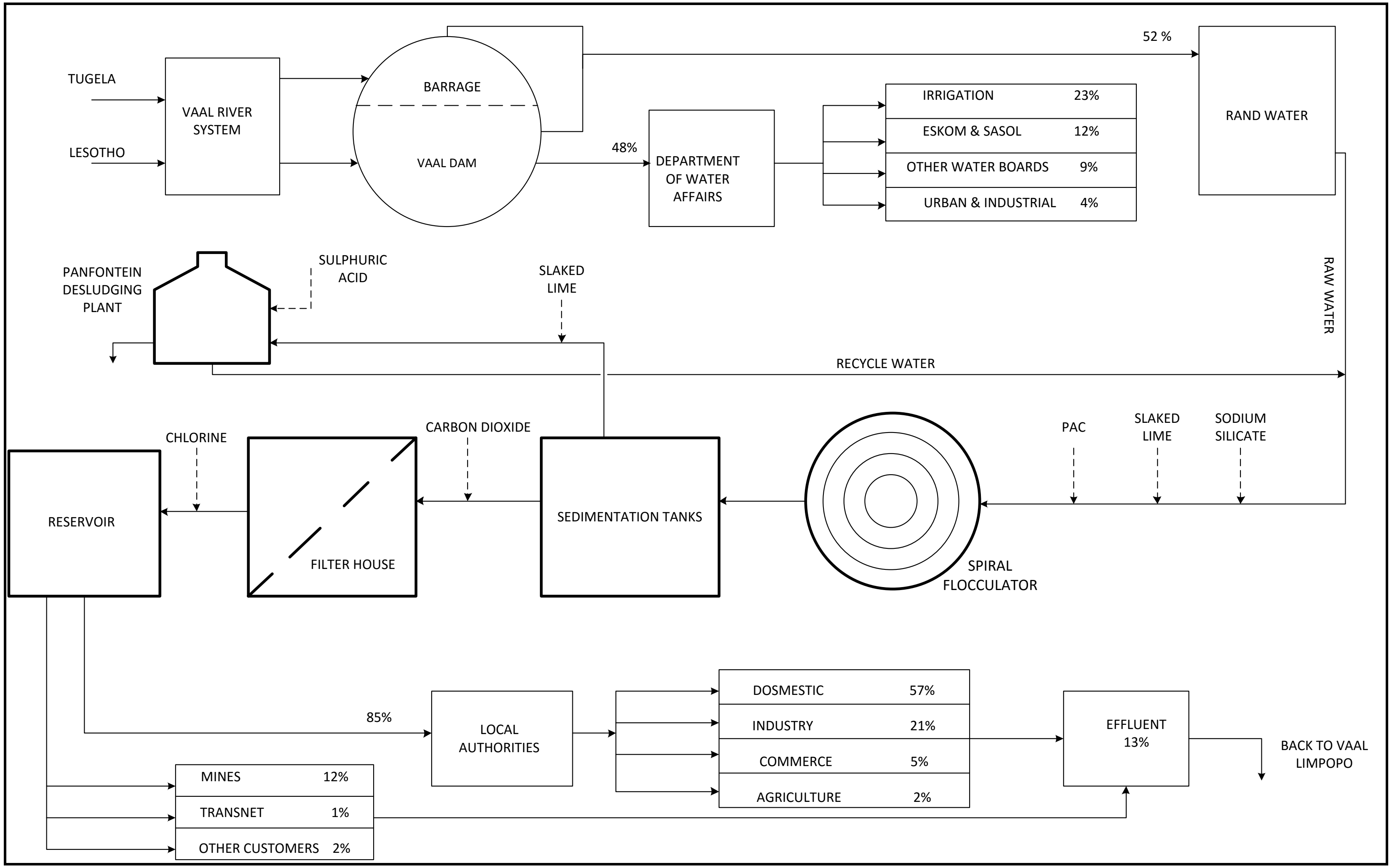

Figure 4-2: Zuikerbosch flow diagram (Source: Rand Water)

4.2.1.3 *Water treatment residue treatment and disposal*

Rand Water has a robust treatment process which can deal with relatively large variations in source water quality. Current treatment challenges include increased biological pollution from semi-functional waste water treatment works and potential increases in salinity due to mining activity. Algal related problems are mainly restricted to the summer months, although no major incidents have been experienced in recent years. The main constituents of the Rand Water WTR are aluminosilicates, with lesser quantities of organic matter, calcium, magnesium and iron. The proportion of calcium carbonate in the WTR may increase significantly when most of the treatment systems employ hydrated lime as the primary coagulant. A high amount of WTR mass (15%–30%) is lost on ignition, which is mainly attributed to the organic matter and water content. WTR was originally pumped into disused underground coal mines, but challenges in this regard led to the temporary use of settling lagoons followed by the construction of the Panfontein WTR disposal site in 1993. This site was progressively upgraded to comprise a total of 92 drying ponds. The WTR from the Zuikerbosch sedimentation tanks is removed at about 2% solids content and transported to a central sump, where it is dosed with lime to a pH between 10 and 12. All WTR produced at Rand Water is directed to this sump at the Zuikerbosch treatment plant, including that of the other treatment works in Vereeniging. The WTR is then pumped to the Panfontein site, which is located approximately 3 km away from Zuikerbosch. The Panfontein treatment train is illustrated in Figure 4-3.

The WTR is thickened to approximately 16% - 20% m/v using an organic flocculant and high rate gravity thickeners. The thickened residue is transported to the adjacent drying paddocks where it is sprayed onto the land using standard irrigation equipment. Panfontein treats about 500-600 tonnes of dry solids per day. The water recovered at Panfontein is returned to the canal supplying raw water to the Zuikerbosch treatment works. Twenty drying ponds were upgraded in 2014 at a cost of around R230 million, as the existing ponds were rapidly approaching capacity. Changes relating to the NEMWA legislation at the time meant that the upgraded ponds had to be lined with a 1.5 mm HDPE lining, along with other prescribed construction requirements. This increased the cost of the ponds and highlighted the need for a more viable WTR management option in the long term. Rand Water has enough land for more drying paddocks but the financial outlay is not feasible for this form of disposal/ storage to continue.

4.2.1.4 *Water treatment residue reuse*

Rand Water is very proactive and has undertaken vigorous investigations into economic, environmentally friendly WTR reuse methods:

- An international challenge has recently been sent out for a long term, sustainable management option for Rand Water's WTR.
- Dried residue with higher calcium carbonate content has been used as an aid in soil conditioning; this product cannot be registered as agricultural lime as agricultural lime requires ≥70% calcium carbonate by mass. The cost of adding calcium carbonate to the WTR increases the cost of the WTR reducing its competitiveness with products which are already on the market.
- Pilot investigations relating to the manufacture of bricks, building blocks and cement yielded several viable options. However, logistical costs and in some cases process complexity rendered the proposals economically unfeasible at full scale. In addition, the variability in the composition of the WTR was detrimental to certain applications, for example the production of hot-fired bricks.
- Studies on WTR for use in road construction, ceramic tiles and treating acid mine drainage showed that the WTR could be used for these applications. Once again, however, the transportation costs and additional processing costs limited the sustainability of these options.

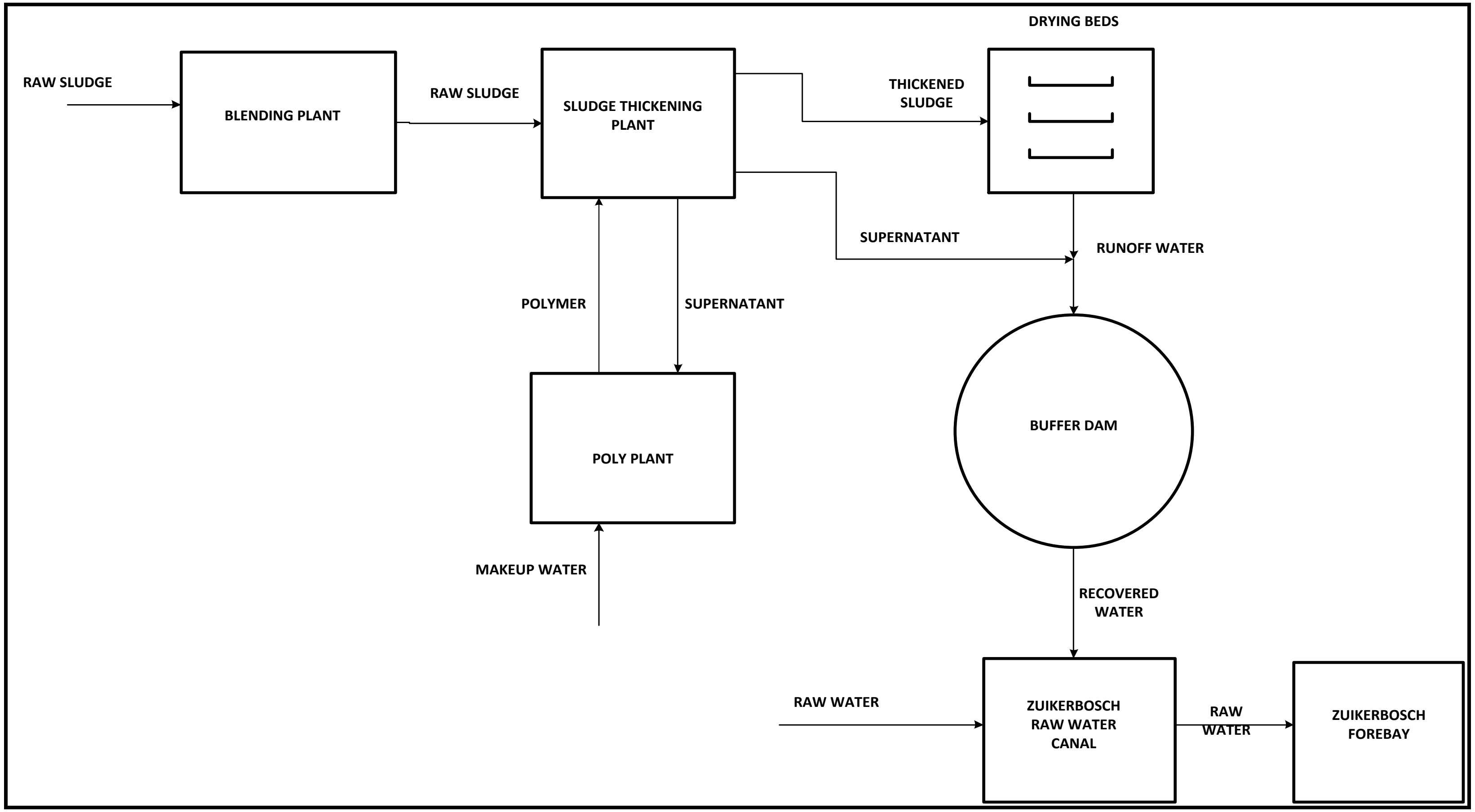

Figure 4-3: Panfontein flow diagram

4.2.2 **Vaalkop Water Treatment Works, Magalies Water (Beestekraal, North West Province)**

4.2.2.1 *Site description*

Magalies Water is a bulk water supplier (water board) servicing parts of the North-West Province, Gauteng, Limpopo and Mpumalanga. Vaalkop Water Treatment Works belongs to Magalies Water. Vaalkop is located in Beestekraal near the Vaalkop Dam which is the work's raw water source.

4.2.2.2 *Water treatment process description*

The last upgrade which is identical to the last 3, adding 30 ML/d to the treatment capacity was completed in 2014, the layout of which is shown in Figure 4-4. During the past 44 years, Vaalkop has been upgraded 4 times and is now a 240 ML/d plant. The plant was built in 1970 and started out with a capacity of 18 ML/d. The plant was upgraded in 1979 to treat 30 ML/d. By the year 2000 similar upgrades took place increasing the plant to 210 ML/d. The raw water entering Vaalkop treatment works is eutrophic and as such dissolved air flotation (DAF) is used as a solids removal process. What makes Vaalkop unique is that they use COCODAF, which is a DAF unit that sits on top of a sand filtration unit i.e. Flotation and filtration happen in one unit. Water treatment residue treatment and disposal

Magalies Water operates in a mining environment; which impacts negatively on the quality of the raw water that is treated. The impacts on water treatment include:

- Cost of raw water
- Plant upgrades
- Greater awareness on environmental impact and,
- A more stringent legislative framework.

4.2.2.3 *Water treatment residue treatment and disposal*

Magalies Water had to implement a WTR and backwash water management strategy (Figure 4-5). Many studies have been undertaken since 1988. The options explored were landfill, lagooning, and even a tailings dam. Due to the annual fluctuation of the WTR production from 0.05 ton/ML to 1 ton/ML conventional mechanical thickening methods proved too costly. A tailings dam would have meant that the land it was on would eventually be lost so lagooning became the only viable option. Vaalkop waterworks is situated on a large piece of land, making it possible in 1990 for two large settling ponds/ lagoons to be built to thicken the WTR. The water treatment residue was allowed to dry and was stored on the Vaalkop waterworks site. In 1999 the system was upgraded to its current state which consists of two bigger settling ponds. The WTR flows by gravity to the settling ponds, which have a 3-day retention time. Earth wall baffles are built into the lagoons to ensure plug flow. The supernatant flows through reeds to a pump station and is recycled to the head of works while the WTR builds up in the lagoon. Once the lagoon is full it is taken out of commission and left to dry. The dry WTR which resembles clay is removed, mixed with soil for ease of handling and stored on site. A diagram of the settling pond system is illustrated in the figure below. In 2006 a characterisation of the WTR showed that it was non-hazardous implying that no lining was required under the settling ponds or the storage area. At the time, the Department of Water Affairs required that boreholes be sunk to monitor the water table under the settling ponds and WTR storage area. A study in 2013 indicated that the Vaalkop WTR was classified hazardous mainly due to the decrease in raw water quality because of mining activities. High levels of iron, manganese, molybdenum and strontium have been detected in the raw water. Magalies Water was investigating options for a management strategy to ensure the safe cost effective and legal disposal or reuse of their WTR.

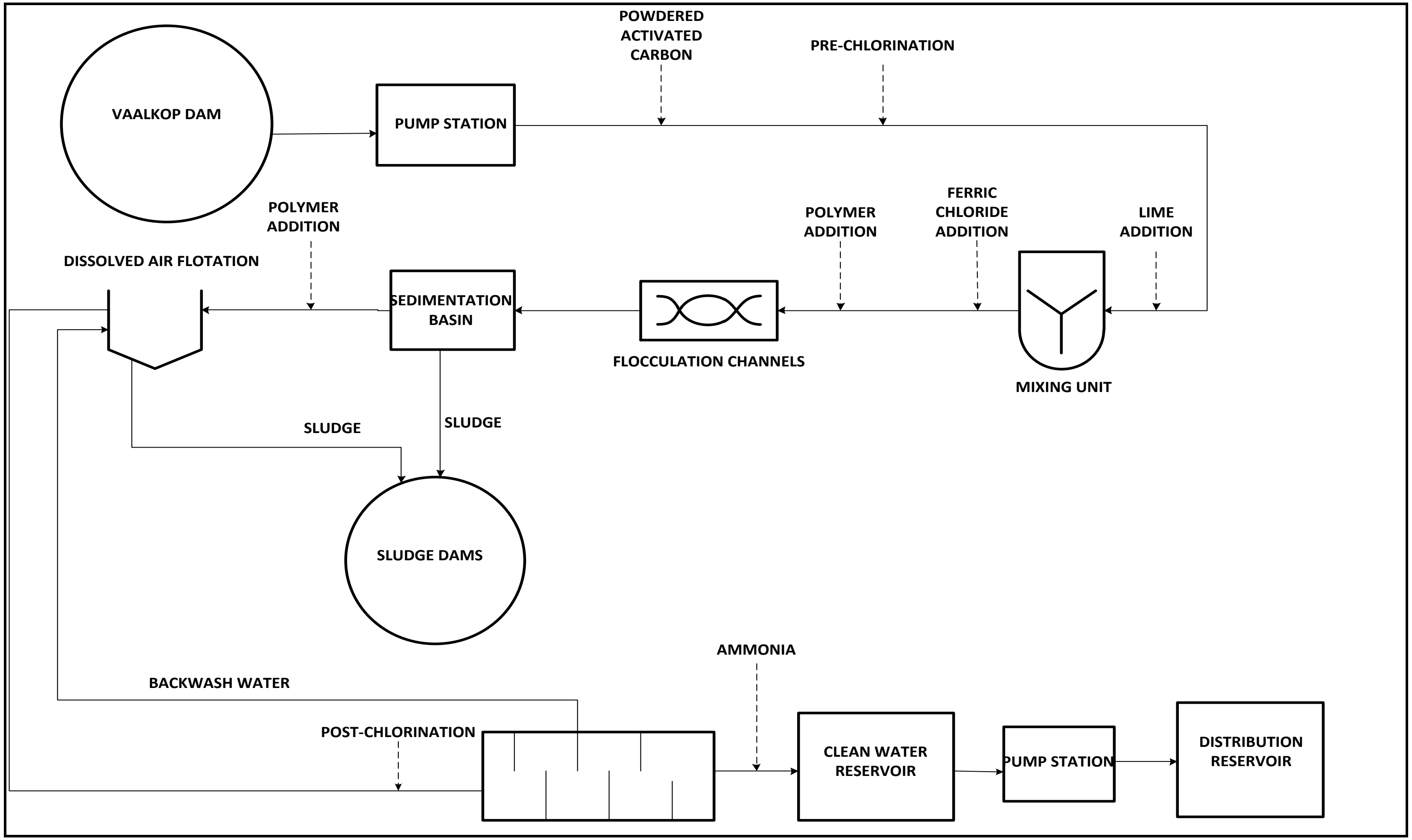

Figure 4-4: Vaalkop plants 3, 4 and 5 (Source: Magalies Water)

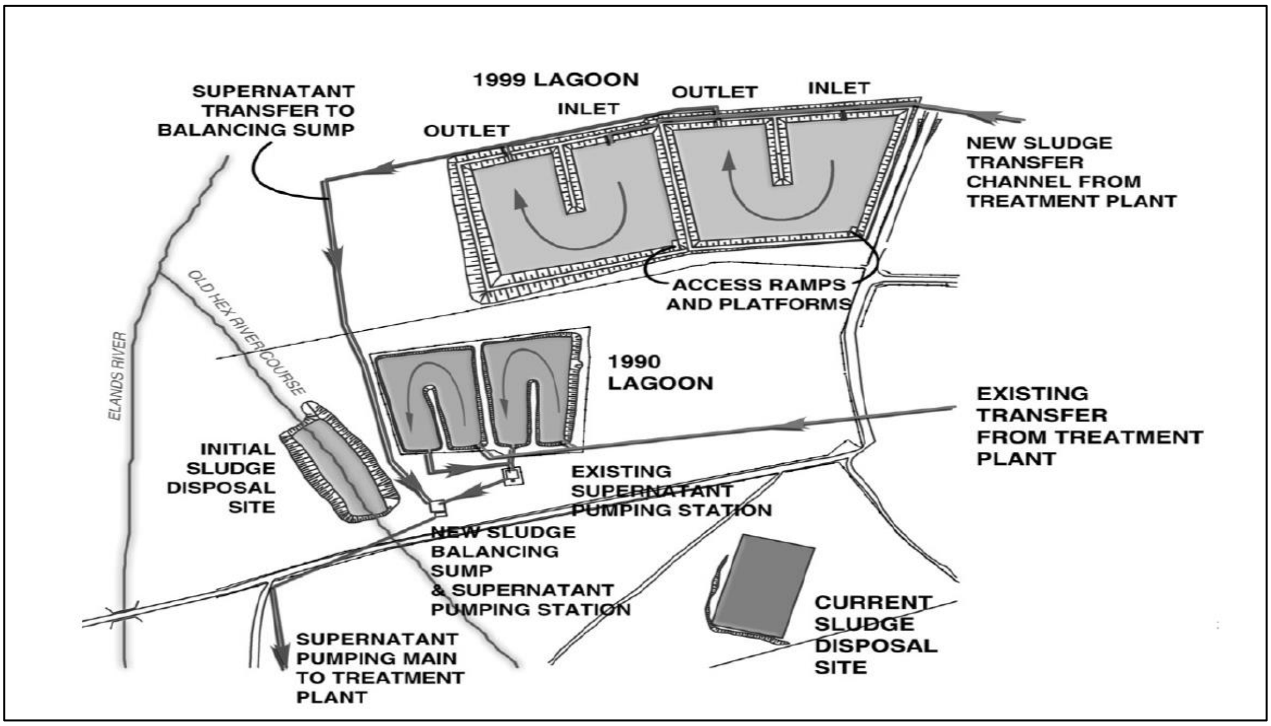

Figure 4-5: Layout of WTR treatment system (Source: Magalies Water)

4.2.3 **Amatola Water Board (Eastern Cape)**

4.2.3.1 *Site description*

Amatola Water operates medium sized water works that are near each other and the water treatment processes and WTR handling were all very similar; the case study incorporated the entire group of waterworks.

4.2.3.2 *Water treatment process description*

The water treatment works run by Amatola Water are all conventional works consisting of coagulation, clarification and filtration (Figure 4-6). Nahoon and Laing water works are the exception as these plants also use dissolved air flotation after the clarification step.

4.2.3.3 *Water treatment residue treatment and disposal*

As indicated in the waterworks flow diagram sludge ponds are used to dewater the WTR, where the supernatant is recovered and sent to the head of works while, the solids build up and are disposed on site every two years. The total cost of disposal for the water treatment works is R9 000 000 every two years.
The disposal sites have flourishing plant and animal life. From observation, there were no significant adverse effects on the environment. Historical classification test data were not available during the time of the case study.

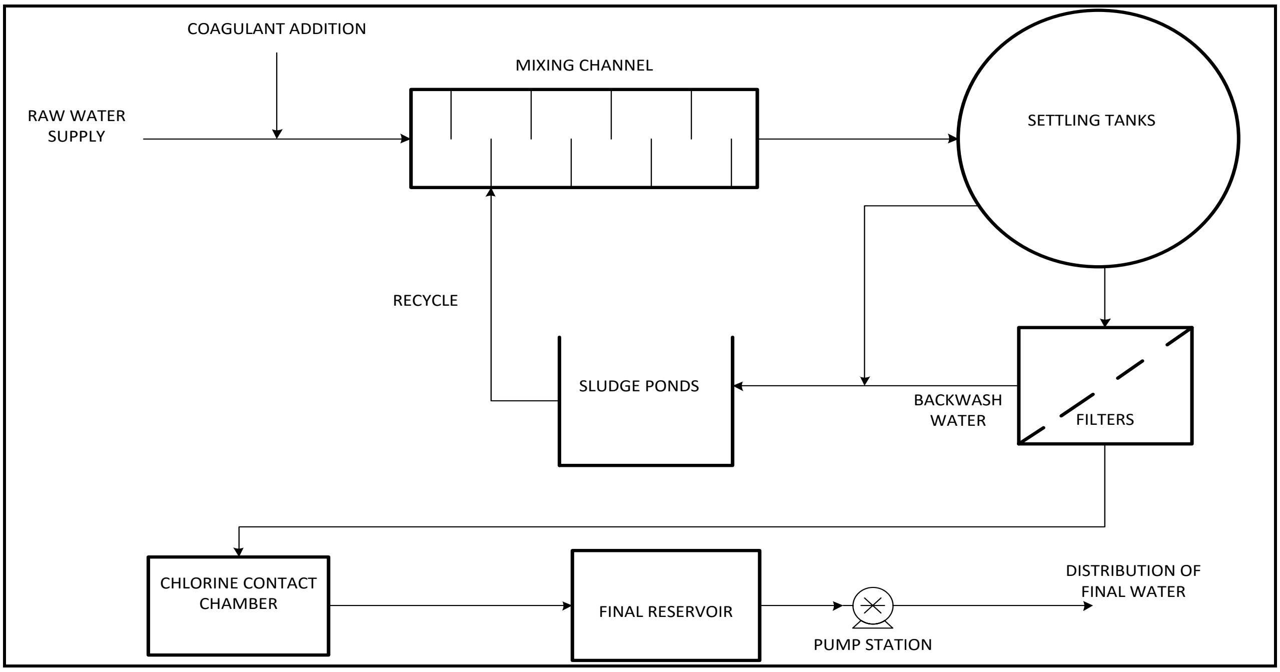

Figure 4-6: General diagram of Amatola water treatment works (Source: Amatola Water)

4.2.4 **Riverton Water Treatment Works, Sol Plaatje Municipality (Kimberley, Northern Cape)**

4.2.4.1 *Site description*

Certain Municipalities do not contract out their bulk water services but manage water treatment plants themselves. One such Municipality is Sol Plaatje Municipality. The Riverton waterworks consists of two plants a few kilometres apart; the old plant, built in 1813 which was later upgraded to 50 ML/d and a new plant with a design capacity of 165 ML/d.

4.2.4.2 *Water treatment process description*

The major cause of concern was high variability in turbidity. These two plants use conventional water treatment processes that include coagulation, clarification, filtration and disinfection. The treatment train of the old plant was more sophisticated than that of the new plant, as there was a coagulant mixing chamber downstream of the head of works and horizontal sedimentation basins precede the circular clarifiers. The clarifiers are manually desludged a few times a day when the automatic sludge removal system was not operating efficiently. Figure 4-7 shows the flow diagram of the old plant upgrades.

4.2.4.3 *Water treatment residue treatment and disposal*

Analysis results of the WTR were not available. The water treatment plants require a lot of maintenance and more efficient operation. WTR disposal is currently not a priority. No tests, studies or upgrades of the WTR system are planned.

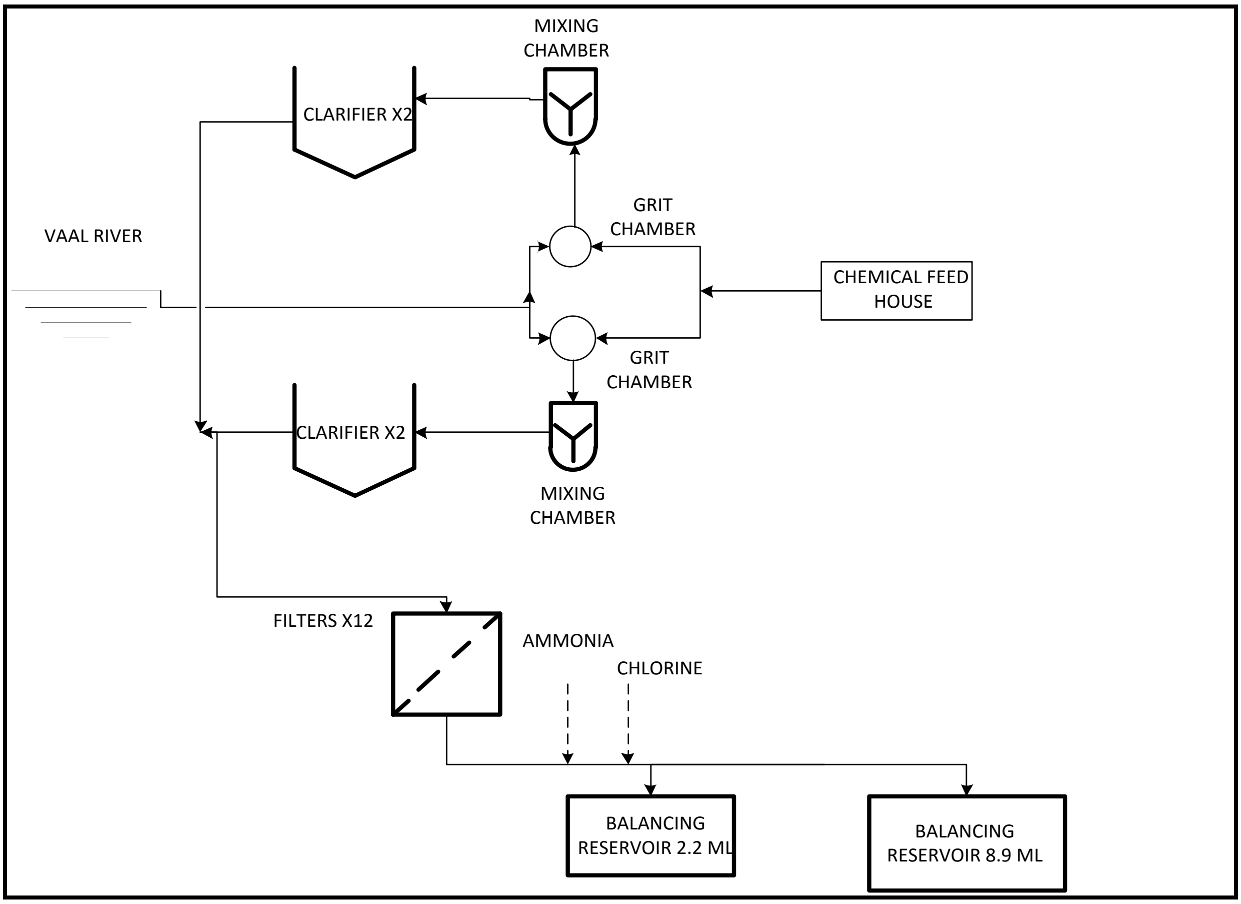

Figure 4-7: Flow diagrams of the old plant upgrades (Source: Sol Plaatje Municipality)

4.2.5 **Biggarsberg Water Treatment Works, uThukela Water (Dundee, KwaZulu-Natal)**

4.2.5.1 *Site description*

This treatment works is located in Northern KwaZulu-Natal and operated by uThukela Water Board.

4.2.5.2 *Water treatment process description*

The water treatment works' process train is illustrated in
Figure 4-8. The water treatment residue flows to sludge drying beds. The supernatant from the drying beds enters a sludge storage dam where further settling occurs. The overflow from the dam is tested and then allowed to overflow into the Mpati River.

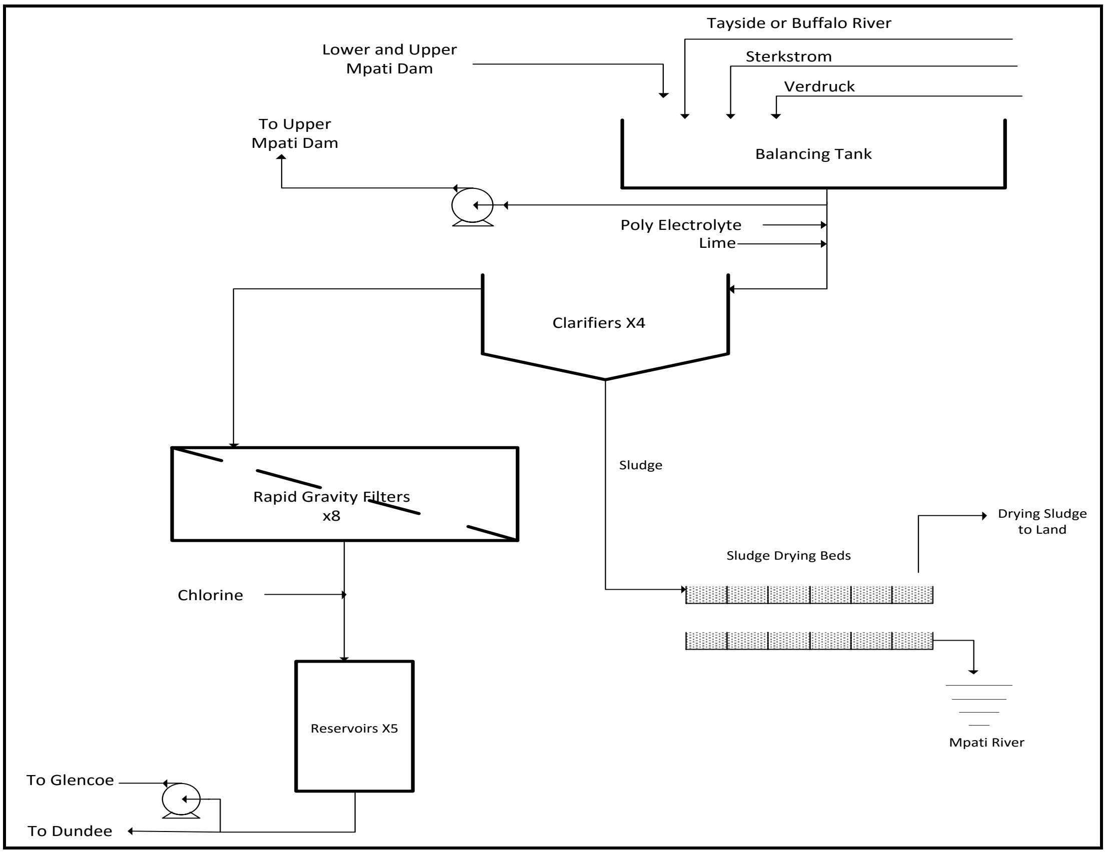

Figure 4-8: Biggarsberg water treatment works

4.2.5.3 *Water treatment residue treatment and disposal*

The study found that the WTR overflow from the settling ponds and storage dam was causing a WTR layer to develop along the river bed and there was a possibility that iron and manganese levels were becoming elevated where the WTR had settled. The report prompted an upgrade of the drying beds and storage tanks which have since been completed. Heavy rains do still cause untreated WTR to overflow into the river and surrounding areas. A solution is being investigated.

4.2.6 **Durban Heights Water Treatment Works, Umgeni Water (Durban, KwaZulu-Natal)**

4.2.6.1 *Site description*

Durban Heights water treatment works is operated by Umgeni Water and services central areas in eThekwini. Umgeni water services, coastal KwaZulu-Natal, Pietermaritzburg, parts of Eastern Cape and Northern KwaZulu-Natal.

4.2.6.2 *Water treatment process description*

Durban Heights has a design capacity of 615 ML/d and follows the treatment train shown in Figure 4-9 below. Instead of the conventional circular clarifiers, Durban Heights utilises pulsation clarifiers. Pulsation clarifiers utilise a vacuum system which is controlled to create pulses which keeps the sludge blanket suspended above the bottom of the clarifier.

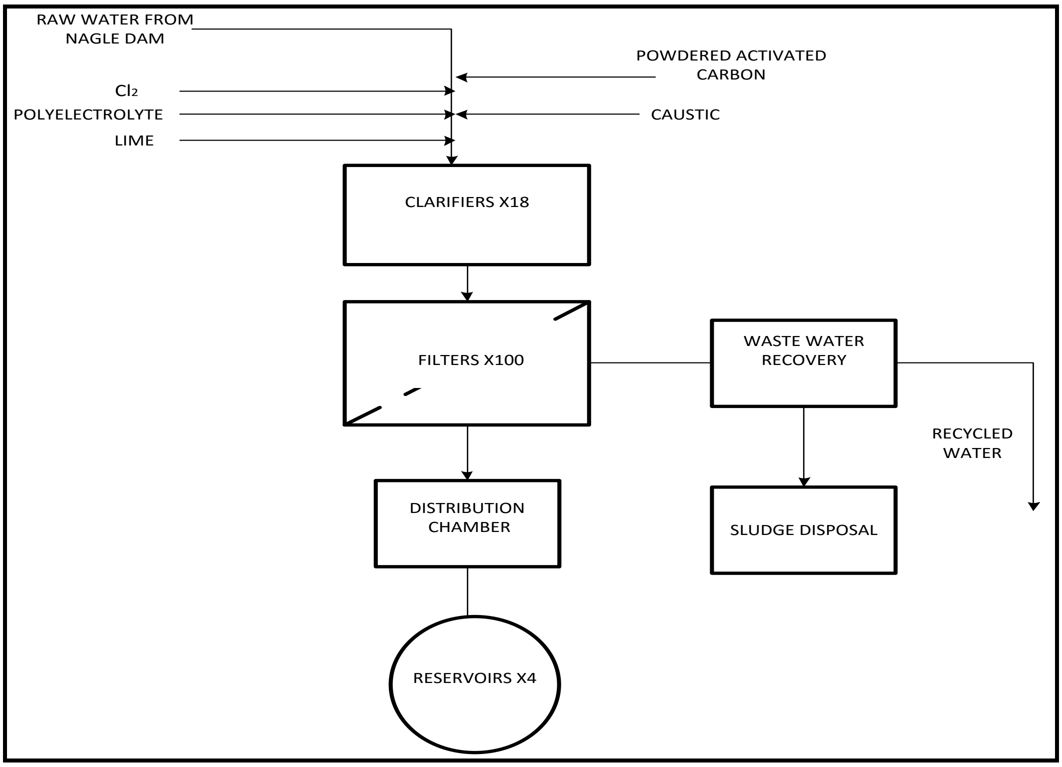

Figure 4-9: Durban Heights process flow diagram

4.2.6.3 *Water treatment residue treatment and disposal*

The WTR from the clarifiers is collected and pumped to the sludge treatment plant. A process flow diagram of the sludge treatment plant is indicated in Figure 4-10. The water treatment residue is thickened and centrifuged. The recovered water is sent to the water treatment plant's head of works while the WTR is collected and disposed of at a municipal landfill site. The transportation and disposal of the WTR is contracted out; the cost of disposing WTR using municipal landfill was more than R724 000 in 2014 and is steadily increasing. With the high cost and stringent legislation Umgeni Water is exploring other avenues of disposal that are environmentally friendly and economical. The water treatment residue constituent of concern is manganese and barium. Although investigations into alternative disposal methods are currently underway, the focus is on reliable, efficient WTR dewatering technologies which have acceptable operating costs. A full-scale dewatering system will be purchased on completion of the study and installed on an Umgeni Water site. The outcome of the testing results will determine whether or not to go ahead with implementation of the dewatering system company wide.

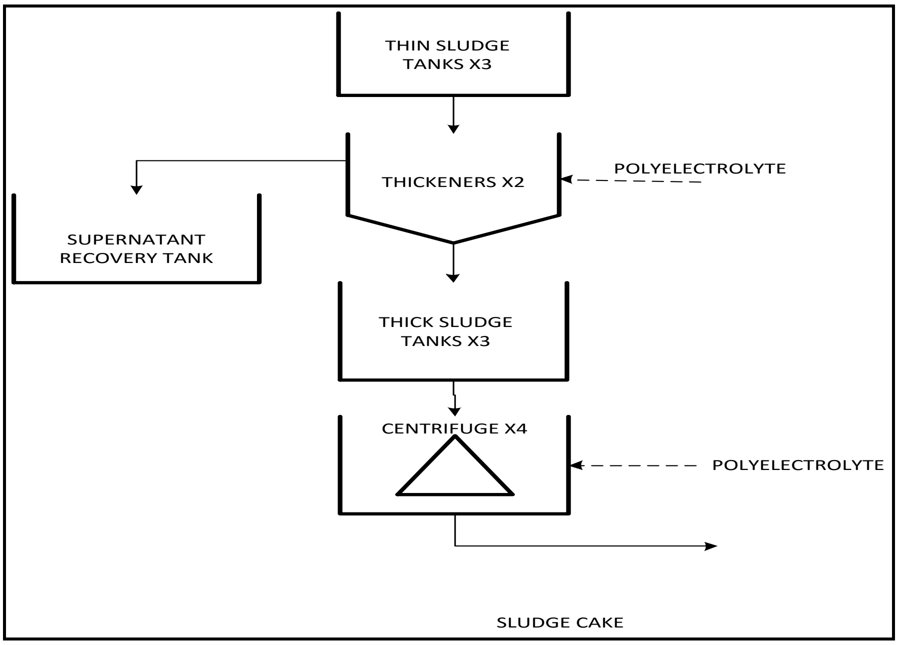

Figure 4-10: Durban Heights WTR treatment process train

4.2.7 Midmar Water Treatment Works, Umgeni Water (Pietermaritzburg, KwaZulu-Natal)

4.2.7.1 *Site description*

Midmar Water Treatment Works is owned by Umgeni water and outputs 250 ML/d of treated water. It is in the process of being upgraded to 375 ML/d. The water works was built in 1996 and delivers water to areas in Pietermaritzburg, all the way to Kloof.

4.2.7.2 *Water treatment process description*

Raw water abstracted from Midmar Dam is pre-treated with chlorine gas and bentonite. Coagulation uses a polymer dosed before an in-line static mixer, after which lime is added prior to the coagulated water entering four ultra-pulsator type clarifiers. Clarified water gravitates and splits into twelve rapid gravity sand filters. Disinfection of the filtered water is achieved using chlorination (Figure 4-11). Lime, poly and at times bentonite are dosed into the raw water pipeline which has an inline flash mixer. Lime is added to raise the pH of the raw water to about 8.2. After flocculation, the water enters a four-way splitter box, which evenly distributes the flocculated water into 4 ultra-pulsators. These pulsators have inclined plates, which assist with the settling out of heavier flocs, which are discharged to the sludge treatment plant. The clarified water from the pulsators are then directed to 12 rapid gravity Degremont V type filters, each having a maximum filtration rate of 6.2 m/h. Water collected from filter backwashing are directed to the Mill Falls backwash plant where it is clarified and filtered.

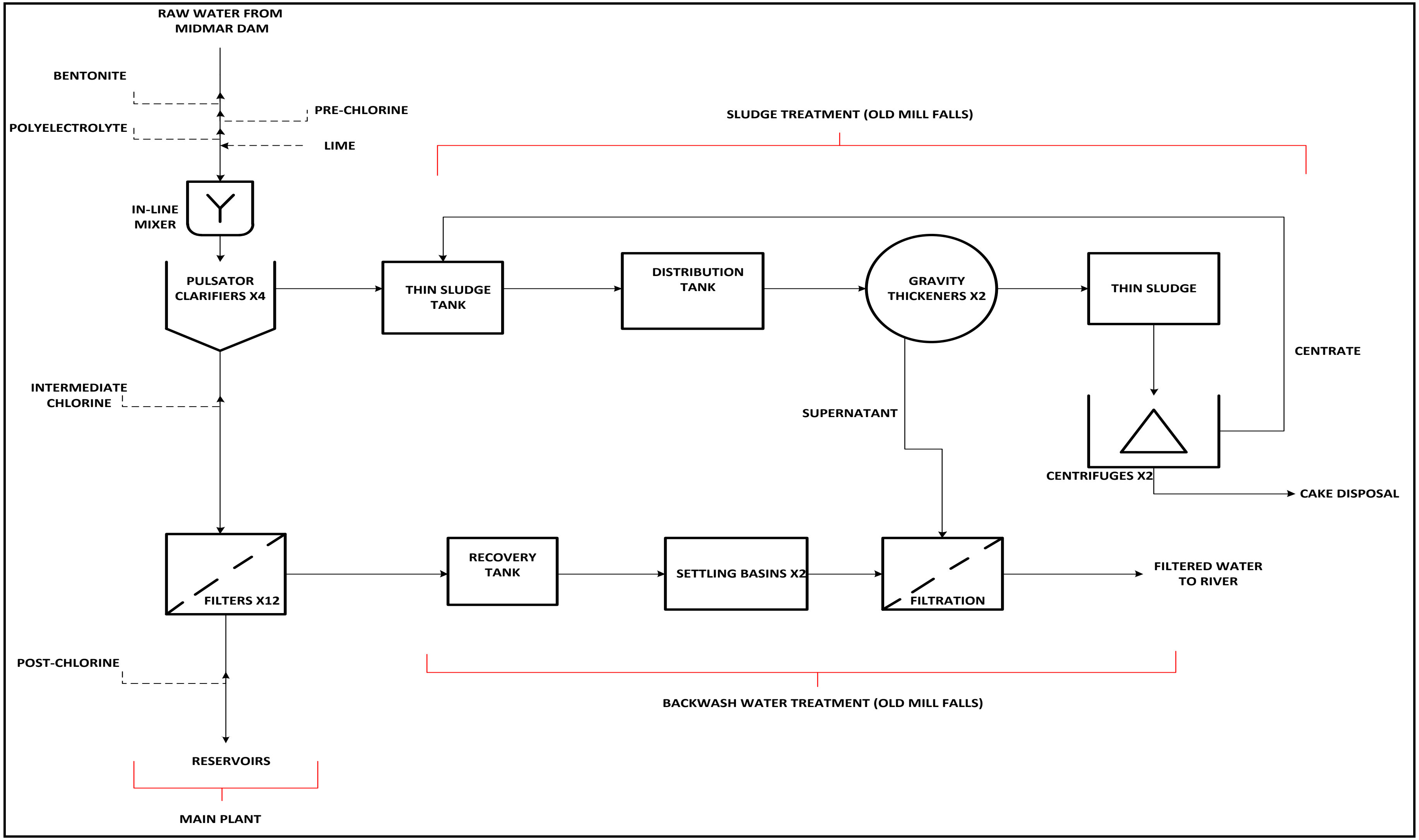

Figure 4-11: Midmar water works process train

4.2.7.3 *Water treatment residue treatment and disposal*

Filter backwash water and sludge from the clarifiers are treated at the sludge and backwash water treatment plant. The backwash water is recovered and allowed to flow by gravity to settling basins. The settled backwash water is filtered and released into the Umgeni River. The water treatment residue from this plant and the main plant is sent to the sludge treatment plant, where the WTR is thickened and centrifuged. The thickener supernatant is filtered and released into the Umgeni River while the thickened sludge is used as a soil conditioner at a nearby farm owned by Umgeni Water. The greatest technical challenge with this method was to determine how to spread the WTR on to the Farm. The WTR was collected from the Midmar works, with a solid content of 24-28%, by tractor. Initially, air drying the WTR and spreading it as a powder was considered; this required a large laydown area as WTR dries incrementally more slowly as the outer layers dry. After some investigation, the best option for WTR application was to spread the WTR using a muck spreader. This method discharged a thin layer of WTR in a 3 m wide band adjacent to the path of the vehicle. Many studies (both internal and external) have been undertaken on the Brookdale farm to determine the impact of the WTR application. Two studies are part of the literature review for this project. It was determined that WTR improved the soil water retention, hydraulic conductivity, increased aeration and the crop yield was unaffected. Soil analysis in 2005 has shown that the WTR constituents have not polluted the soil or the water table. The main constituent of concern for Midmar WTR has been Manganese.

4.2.8 **DV Harris Water Treatment Works, Umgeni Water (Pietermaritzburg, KwaZulu-Natal)**

4.2.8.1 *Site description*

DV Harris Water Treatment Works was supplying potable water to Pietermaritzburg, since 1974, before Midmar Water Treatment works was built. It was thought that once the Midmar works was built DV Harris would be decommissioned however due to the high-water demand DV Harris is still producing good quality potable water.

4.2.8.2 *Water treatment process description and water treatment residue treatment and disposal*

The process treatment stream of DV Harris is illustrated in Figure 4-12. The water treatment residue produced by DV Harris Water Treatment Works is collected in a sludge holding tank which uses an air injection at the bottom of the tank to keep the solids suspended. The WTR is then disposed of via the city sewer network.

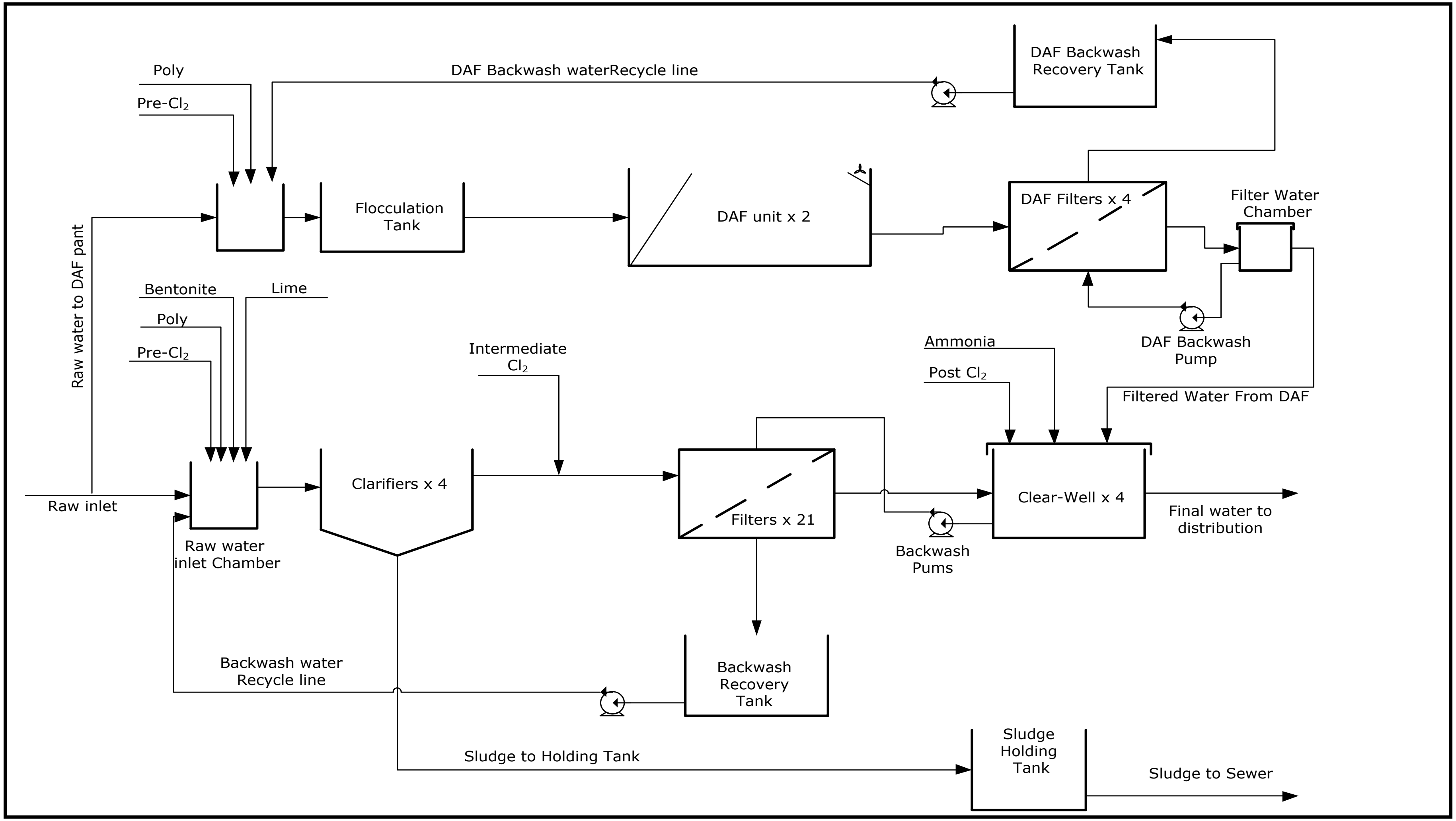

Figure 4-12: DV Harris Water treatment works

4.2.9 **Faure Water Treatment Works, City of Cape Town (Cape Town, Western Cape)**

4.2.9.1 *Site description*

The City of Cape Town is a Metropolis in the Western Cape Province. Faure Water Treatment Works is the largest water works in the Western Cape.

4.2.9.2 *Water treatment process description*

Faure Water Treatment Works has a design capacity of 500 ML/d but is currently treating only 350 ML/d. Faure has two abstraction sources: Riversonderend and Palmiet Rivier. The raw water obtained from Palmiet has a high Ultraviolet absorbance as this water has high colour due to humic and fulvic acids. To treat the high colour ferric sulphate is the coagulant used (Figure 4-13).

4.2.9.3 *Water treatment residue treatment and disposal*

The filter backwash water is pumped to the head of works while the WTR is thickened in two sludge tanks. The supernatant is pumped to the head of works while the thickened WTR is dewatered by centrifuge and made ready for transport. In the past Faure was able to dispose of the WTR in a landfill for non-hazardous waste. Recent analysis has revealed elevated levels of manganese, iron and aluminium which requires WTR disposal to a hazardous landfill. Faure disposes WTR at an annual cost of R7 million, which includes both maintenance and hazardous disposal. A successful feasibility study was undertaken to determine the viability of coagulant recovery as ferric sulphate was the coagulant utilised. The project did not proceed as acceptable contract terms could not be agreed upon. Currently, the main avenue of investigation at Faure is dewatering. A drier WTR will reduce the cost of transportation to the landfill site.

4.2.10 **Summary of findings**

A summary of findings from site visits is shown in Table 4.1and Table 4 2 shows WTR management in other selected case studies, including details on the cost. From both Tables, the cost of WTR handling and disposal is not just dependant on the capacity of the water treatment works. The costs generally include licencing costs, transportation, chemical and disposal costs. Water treatment residue management costs are not considered part of potable water production and in most cases, contractors look after transportation and disposal. Utilities therefore are only aware of how much they pay out per contract. The breakdown of costs into operational costs such as power and chemical usage for WTR treatment is not easy as utilities tend to focus on the overall operational costs of the plant. Together with new regulations and the Guidelines for the Utilisation and Disposal of Water Treatment Residues (Helserman, 2009), a study done by Umgeni Water on 12 Water Treatment Plants within KwaZulu-Natal identified the following potential management options for its WTR (Umgeni Water, 2014):

- Land application to agricultural land and forests
- Land reclamation
- On-site and off-site disposal
- Discharge to a WWTP
- Discharge to the source stream
- Re-use in brick making and Portland cement

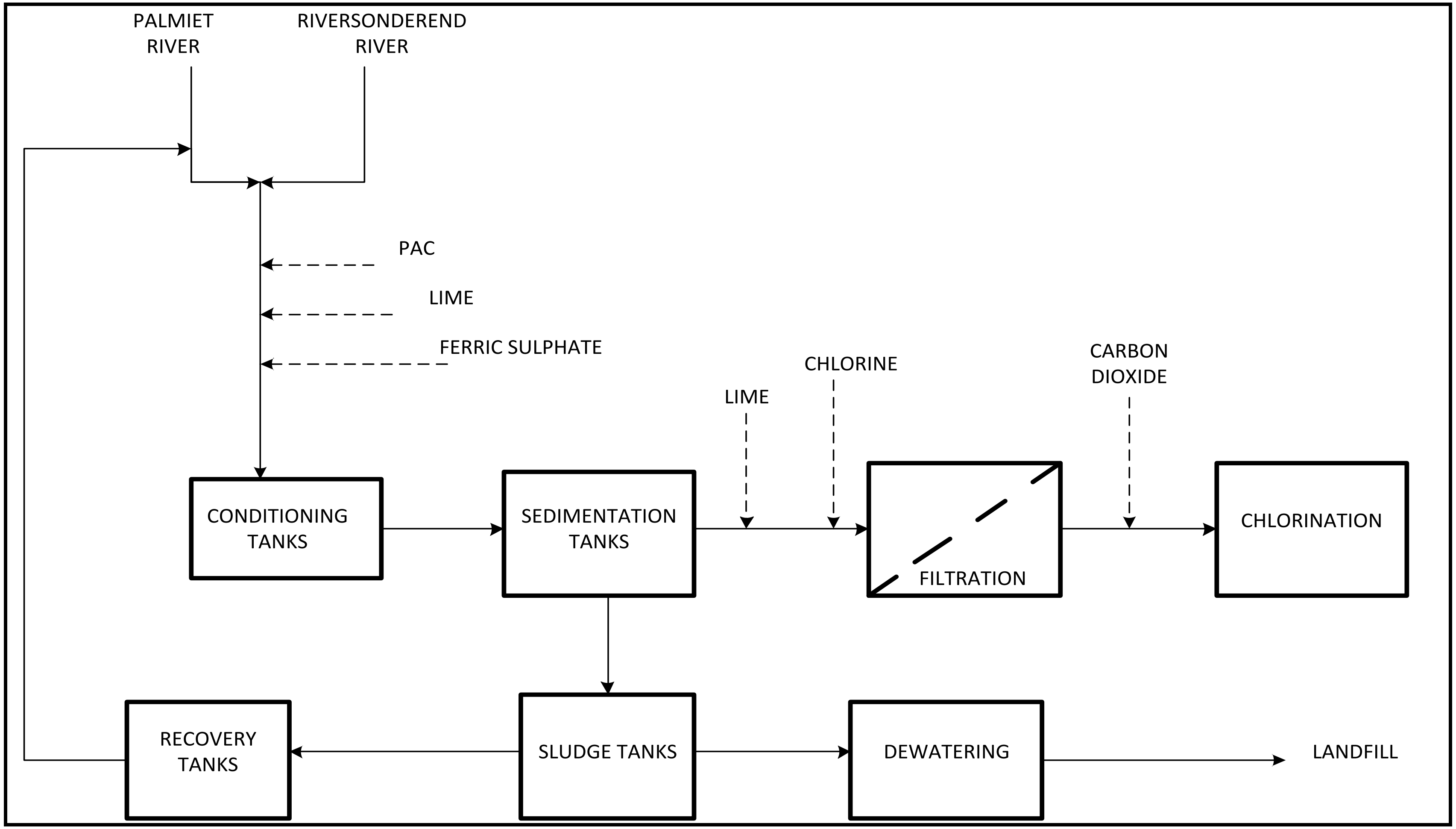

Figure 4-13: Faure process flow diagram (Source: City of Cape Town)

Plant 23 and Plant 20 on the table dispose of WTR in the same way and Plant 23 produces less WTR than Plant 20 but the cost of disposal is much higher for plant 20. The large difference in cost occurs as Plant 20 is much further away from the disposal site than Plant 23, the main difference occurs because of transportation costs. Currently, both Plant 23 and Plant 20 are focussing on dewatering technologies to reduce the cost of WTR transportation.

Plant 21 has more than double the capacity of Plant 24 and the WTR disposal method is the same; the WTR management costs are similar. On further investigation is was found that Plant 24 uses the WTR discharge tank as an overflow tank for other operations on the WTP, since the municipality is paid per volume of WTR discharged this increases the WTR treatment costs. Inefficient operational management and plant design can prove very costly at a waterworks.

During the site visits and the correspondence with management of the water utilities it became apparent that few were aware that WTR is categorised as a waste, therefore its disposal and reuse is regulated by the National Environmental Management Waste Act No. 59 of 2008 as amended by National Environmental Management Laws Amendment Act 25 of 2014. Some were even discharging in accordance with the sludge guidelines that were created for wastewater sludge. In many waterworks it was found that as little money as possible is spent on WTR management. The increasing cost of disposal is highlighting the need for WTR management.

Some managers felt that as WTR comes from the raw water source and that it should not be considered hazardous understanding the effect of the impact of the load or concentration. Many of the municipal run water treatment works are having trouble in producing compliant potable water so the matter of treating and managing waste is of very low priority.

The case studies show that the cost of current WTR management strategies can become very high. The managers of the case studies all stated that the cost of WTR treatment and disposal was the pivotal factor in their choice of management strategy. Dewatering equipment and transportation were the most expensive part of WTR management.

WTR is being continuously generated and therefore cannot continue to be dumped; the status quo cannot remain the same. A few of the larger water utilities have highlighted WTR management as a risk and have engaged in research to find sustainable WTR management options.

The site visits have shown that many of the disposal/ reuse options researched in the literature review are being utilised in South Africa. The common disposal method observed during the study was onsite disposal after settling ponds. Of the sample set only two water works were reusing the WTR; one for land application and one for soil conditioning, while the rest disposed.

Table 4-1: Overview of WTR disposal methods in selected case studies in South Africa

Plant name	Water Treatment Process	WTR Generated	Method of Disposal	Advantage of Disposal Method	Disadvantage of Disposal Method
Zuikerbosch Water Treatment Works, Rand Water	Conventional	500-600 t/d (as dry solids)	Treatment at Panfontein (mainly thickening) then drying paddocks	In line with current South African legislative and environmental requirements with the use of special liners and isolated land	• High capital and operational costs • Requires large areas of land which may require rehabilitation for other uses
Vaalkop Water Treatment Works, Magalies Water	Conventional with COCODAF	Up to 1 tDS/ ML treated	Settling Ponds then Disposal on site	• Low operational costs • No Transportation of WTR required • Only requires annual inspection and cleaning	• Environmental Impact is unknown • Does not fulfil current South African legislative requirements as no liners or boreholes. • Requires large areas of land
Amatola Water Board	Conventional	Estimated at 3.4 tDS/d	Settling Ponds then disposal on site	• Low operational costs • No Transportation of WTR required • Only requires annual inspection and cleaning	• Environmental Impact is unknown • Does not fulfil Current South African legislative requirements - no liners or boreholes. • Disposed near water source. • High annual costs of WTR removal

Plant name	Water Treatment Process	WTR Generated	Method of Disposal	Advantage of Disposal Method	Disadvantage of Disposal Method
Riverton Water Treatment Works, Sol Plaatje Municipality	Conventional	Estimated at 4 ML/d at <1% solid content	Disposal to source	• Low operational and capital costs • No Transportation of WTR	• Environmental Impact is unknown • Does not fulfil Current South African legislative requirements
Biggarsberg Water Treatment Works, uThukela Water	Conventional	Estimated at 0.9 tDS/d	Drying beds then on-site Disposal	• Low operational costs • No Transportation of WTR required	• Environmental Impact is unknown • Environmental risk due to overflow • Does not fulfil current South African legislative requirements
Durban Heights Water Treatment Works, Umgeni Water	Conventional	Estimated at 10 tDS/d	Centrifugation then disposal to landfill	• In line with Environmental and Current South African Legislative requirements	• High operational costs
Midmar Water Treatment Works, Umgeni Water	Conventional	Estimated at 5.5 tDS/d	Centrifugation then land application	• Low Operating Cost as farmer collects WTR • Studies have shown no adverse effects to crops and land	• Continuous analysis of environmental effects • Current South African legislative requirements – licencing
DV Harris Water Treatment Works, Umgeni Water	Conventional	Estimated at 2.4 tDS/d	Discharge to sewer	• No transportation or thickening of WTR required.	• Cost is per volume discharged – paying for a lot of water (plant efficiency

Plant name	Water Treatment Process	WTR Generated	Method of Disposal	Advantage of Disposal Method	Disadvantage of Disposal Method
				• In line with Current environmental and South African Legislative requirements • Dilution of waste water works influent as well as enhancing primary settling (Zhao, 2010)	is paramount in cost reduction) • Increased load on municipal infrastructure and waste water works.
Faure Water Treatment Works, City of Cape Town	Conventional	Estimated at 27 tDS/d	Centrifugation then disposal to landfill	• In line with environmental and current South African legislative requirements	• High operational costs

Table 4-2: Summary of WTR management in selected case studies

Name of Water Treatment Works	Raw Water Source	Design Flow (ML/d)	Treatment Train	Chemicals Used	Average WTR Production (tDS/d)	Average WTR Cost (R per annum)	WTR Management & Disposal
Plant 2 Gauteng	River	3890	Conventional	Poly, Activated Silica, Lime	500	R16 000 000	Thickening & Drying Paddocks
Plant 4 Western Cape	River	350	Conventional	CO_2, Lime, Ferric Sulphate	27	R7 000 000	Centrifuge & Hazardous Landfill
Plant 5 KwaZulu-Natal	River	22	Conventional	Poly, Lime	1	R10 300	Centrifuge and site Disposal
Plant 8 KwaZulu-Natal	River	15	Conventional	Poly, Lime	0.9	R1 300 000	Thickening & Drying Beds
Plant 16 Eastern Cape	River	30	Coag – Floc – Sed – DAF – Filt - Dis	Poly, Lime	1	R600 000	Thickening & Settling ponds
Plant 14 Eastern Cape	Dam	18	Conventional	Poly, Lime	1	R600 000	Thickening & Settling ponds
Plant 15 Eastern Cape	Dam	40	Coag – Floc – Sed – DAFF - Dis	Poly, Lime	1.4	R600 000	Thickening & Settling ponds
Plant 19 North West	Dam	210	Coag – floc – Sed – DAFF - Dis	Poly, Lime	1	R20 000	Settling Lagoons
Plant 20 KwaZulu-Natal	Dam	615	Conventional	Poly, Lime	9.7	R725 000	Thickening, Centrifuge & Landfill
Plant 21 KwaZulu-Natal	Dam	350	Conventional	Poly, Lime, $KMnO_4$ (when required)	5	R555 000	Thickening & Discharge to Sewer
Plant 23 KwaZulu-Natal	Dam	250	Conventional	Poly, Lime	5.5	R360 000	Thickening, Centrifuge & Land Application
Plant 24 KwaZulu-Natal	Dam	140	Conventional + DAF system	Poly, Lime	2.4	R520 000	Discharge to Sewer
Plant 25 KwaZulu-Natal	Dam	3.1	Conventional	Poly, Lime, $KMnO_4$	0.6	R1000	On-site disposal
Plant 28 KwaZulu-Natal	Dam	45	Conventional	Poly, Lime	1.4	R3500	Thickening & on-site Disposal

4.3 INTERNATIONAL CASE STUDY – NETHERLANDS

4.3.1 Background

The Netherlands is a small country of 41526 km^2 compared to South Africa's 1219090 km^2 and is less than half the size of Kwazulu-Natal (Table 4-3). The country has experienced similar concerns to South Africa when it comes to water treatment residue management. Twenty years ago, the Netherlands were dealing with the same WTR management issues as South Africa is currently dealing with. All of the WTR generated in the Netherlands before 1995 was disposed and currently more than 90% of all the WTR generated are reused.

Table 4-3: Differences between South Africa and the Netherlands

Netherlands	South Africa
Generates 170 000 tDS WTR / annum	Rand water alone generates 183 000 tDS/ WTR /annum
Raw water has low turbidity	Raw water high turbidity due to clays and silt
Small country & population (3% the size of South Africa)	Large country & population
Government Environmental Initiative Incentivising WTR use	Waste Management Licences required for all uses other than disposal.
Good research implementation strategies	Difficulties implementing developments from research

However, the innovative WTR management ideas implemented in the Netherlands are still relevant to South Africa. In the early 1990's the Water Companies in the Netherlands, raised concern that with the increased generation of WTR and the increased cost of disposal; their WTR management strategies were unsustainable. Water treatment residue was considered a waste and required licencing if alternative WTR management activities were chosen.

4.3.2 Innovative WTR Management System

In 1995, the Water Boards came together and opened a separate business called Restoffenunie (RU) which means Residues/ Waste Union to find alternatives to landfilling. The business of producing potable water is very important and the Dutch Water Boards decided that because WTR management was a national problem, they would fund common resources to focus on the WTR management issues so that they could focus on their core business of producing potable water. The role of RU was to ensure WTR quality, search for WTR applications, mediate between clients (WTR users) and shareholders (Water Boards/ Companies), oversee WTR sale/ disposal logistics, ensure financial settlement and finalise all required documentation and permits. The water companies (shareholders) paid for all the costs incurred by RU in accordance with their waste capacity and eligibility for reuse. Approximately 90% of the profit was paid back to the Water Boards while 10% was retained by RU. An illustration of the cash flow model is depicted in Figure 4-14. Restoffenunie has built up a substantial body of knowledge since its inception and acts as a knowledge centre for the shareholders. Collaboration and knowledge sharing is key to the sustained success of this management system. By monitoring societal and political developments RU is able to exert timely influence for both its shareholders and clients on the legal and regulatory frameworks, which is vital in WTR reuse.

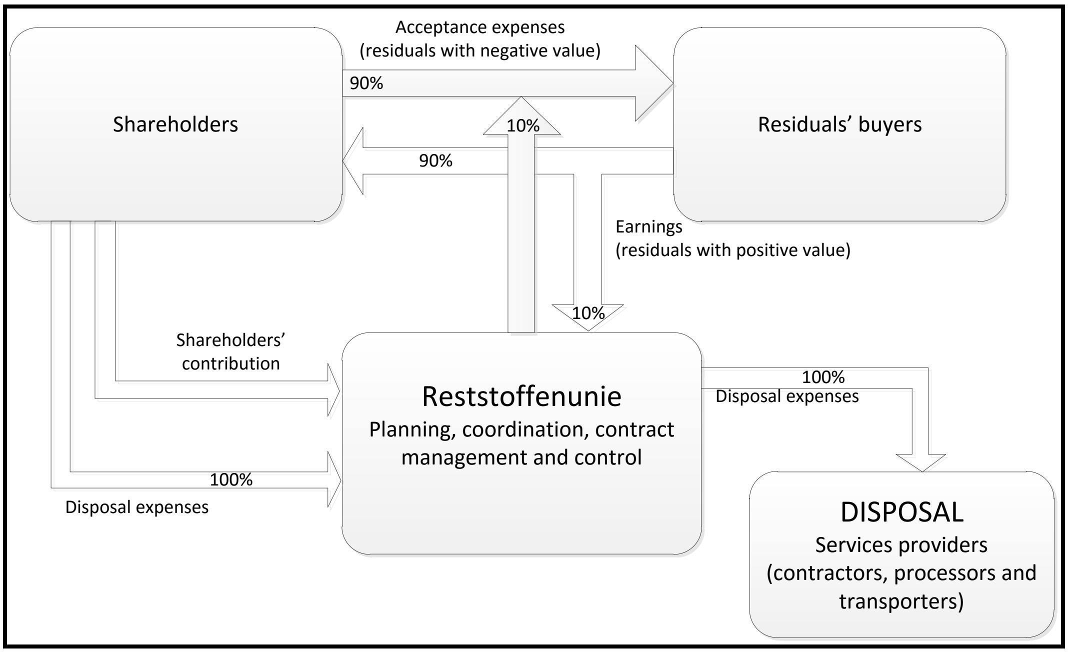

Figure 4-14: Restoffenunie cash flow model

4.3.3 **Operating Strategy of Restoffenunie**

4.3.3.1 *Legislation*

Legislation did not allow for the sale or donation of WTR to a third party. While performing research and creating market demand Restoffenunie simultaneously set out to lobby the government to convert the definition of WTR from waste to by-product. They undertook testing to ensure the safety of the WTR and suitability for WTR to be used in different industries. Ten years later the European Waste Framework Directive and the Environmental Management Act created a legal framework to classify specific residues as by-products. Water treatment residue was deemed a saleable by-product of water treatment. Restoffenunie has commissioned KWR Water Cycle Research Institute to test determination methods against those in Dutch legislature to serve as input to the sampling and analysis protocol for WTR in the Netherlands. The Netherlands has a National Environmental Policy Plan which is a strategy to ensure an environmentally sustainable country in 25 years. Policies and incentives are put in place to ensure environmental sustainability. This initiative has increased the marketability of WTR due to its sustainability as a raw material and a final product in some cases. Manufactures would spend more money on a sustainable raw material over a cheaper synthetic material.

4.3.3.2 *How RU achieved marketability*

Restoffenunie started by paying potential customers to use waste in their processes at a reduced cost, which decreased the cost of WTR management for the water boards and started creating WTR demand. In 2005 as demand for WTR increased, profitability started increasing as customers started to pay RU for the WTR. Research into market development and product development is on-going. The model for Restoffenunie is working so well for the drinking water sector that they are now applying it to the wastewater sector.

Restoffenunie advise that to make WTR marketable one should:

- Start small – RU contacted local small business and established relationships. They then used the small businesses as case studies and proof of sustainability to entice large businesses and industrial players.
- Don't expect to make a profit – Cost was the driver for moving to reuse however if the reuse option only saved money it was still worthwhile.
- Undertake research and development – finding new uses and new markets for WTR is paramount to RU's success.
- Have continued interaction with governmental departments – an open dialogue has been maintained and annual reports tabled even when not requested. This made it easier to get governmental buy-in. The government initiative also aided in market buy-in.
- Change mind-set – New plants must be designed and old plants must be run as if both water and the WTR are water treatment products. Only in this way can valuable, marketable WTR be generated.
- Change objective – When the WTR management strategic objective prioritised sustainability above cost the process started moving forward.

4.3.3.3 *Challenges Faced*

The main challenge faced was that water treatment plant operators still saw WTR as a waste and as such it was hard to reduce impurities caused by improper storage and handling. Water treatment residue and other wastes would be dumped together; during collection sand and other impurities would be collected as well. This is an on-going challenge but the Water Boards themselves, manage this problem. Some solutions were to mechanically separate the waste storage sites e.g. separate lagoons for clarifier and filter wastes; add cement linings to lagoons and storage areas and implement procedural changes to operation. Another challenge faced was transportation costs: where possible WTR is sold to local businesses as close as possible to the plants. The 2020 initiative is also a way to incentivise small companies close to the works to buy WTR instead of imported materials.

4.3.4 **High Value WTR Products Sold in the Netherlands**

4.3.4.1 *Ferric hydroxide:*

Ferric coagulants are the most commonly used coagulants in the Netherlands as it was found using research that ferric WTR is more valuable than WTR generated using other coagulants. When using ferric coagulants, a by-product of the coagulation process is ferric hydroxide. The raw water of the Netherlands generally has a low suspended solids composition which means that the bulk of the solids making up the WTR are ferric hydroxide (Table 4-4).

Table 4-4: Ferric Hydroxide WTR composition

Material	**Composition (m/m)**
$Fe_2O_3.3H_2O$	80-100%
Inert (Sand)	1-10%
Ca	<0.1-5%
P	0.1-4%
Al	<0.1-0.3%
Mg	<0.1-0.3%
Mn	<0.1-4%
Dry matter	7.5-30%

Due to this characteristic air drying the WTR can achieve ferric hydroxide with the composition shown in Table 4-4 (based on weight per dry substance). This product is used in the removal of phosphates and sulphur, in the production of biogas, odour control and as a raw material in the brick and building material industries.

4.3.4.2 *Lime Sludge:*

The lime sludge (softening sludge) is used as inorganic fertiliser (authorised under the Dutch Fertiliser Act) and the composition is shown in Table 4-5.

Table 4-5: Lime WTR composition

Material	**Composition (m/m)**
$CaCO_3$	85-100%
Inert (Sand)	<0.1-15%
Fe	<0.1-4%
Al	<0.1-0.3%
Mg	<0.1-2%
Mn	<0.1-0.4%
Dry matter	20-40%

4.3.4.3 *Lime Pellets:*

Lime pellets are a by-product of the crystallisation softening method, whereby $CaCO_3$ is precipitated out of the water by increasing the water pH. The content of the $CaCO_3$ drops from 2.2mmol/l to 1.7mmol/L. The pellets are formed on a seed material. These pellets are widely used in the production of glass, turf, carpets, kitty litter, road building and floor insulation. This product is currently being enhanced so that the sand used to seed the crystallisation will be changed to lime granules which will in turn produce a pure lime pellet. Currently the composition of the lime products is as follows:

Table 4-6: Lime pellets composition

Material	**Composition (m/m)**
$CaCO_3$	85-100%
Inert (Sand)	<0.1-15%
Fe	<0.1-0.75%
Al	<0.1-0.3%
Mg	<0.1-0.2%
Mn	<0.1-0.0.3%
Dry matter	1-5%

4.3.5 **Innovative Use of RU Knowledge and Principles in the Philippines**

A Philippine water service provider was facing environmental and financial difficulties with managing the increasing WTR generation from five water treatment works. ARCADIS and RU worked together to develop an economically feasible and environmentally sustainable WTR management strategy for them. The water treatment train was conventional South African water treatment, using Polyaluminium chloride as a coagulant in dry season and alum in the wet season. The sludge characteristics were as follows:

- Similar properties to clay, solids content greater than 35%
- Narrow size distribution band

- High iron and aluminium ion content
- Low permeability
- Good water retention
- Slightly increased nitrogen, phosphorus and potassium concentrations

The management strategy was to have two clients always to avoid send the WTR to landfill. The Sludge could be used for phosphate binding in a waste water treatment works and manufacture of clay items. On implementing the WTR strategies recommended the financial forecasts were as follows:

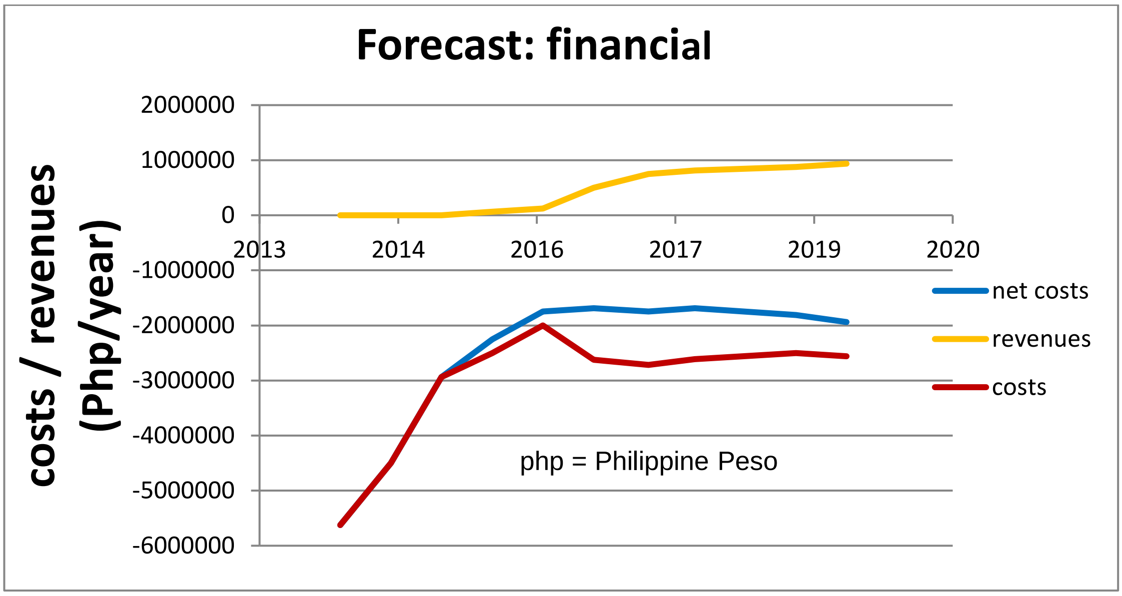

Figure 4-15: Financial forecasting of WTR strategies (Source: ARCADIS)

No treatment modifications were required however certain findings such as WTR recycle and a different coagulant would help to increase the value of the WTR and reduce chemical costs. No challenges have been experienced as implementation is yet to begin.

4.4 SUMMARY

The Netherlands and South Africa have similar water regulatory systems:

- Government ministries legislate and regulate the water, wastewater and waste sectors; South Africa has the Department of Water Affairs & Sanitation and the Department of Environmental Affairs, while Netherlands has the Ministry of Infrastructure and the Environment.
- In both countries, government departments are represented at a provincial level.
- In both countries, each province has Water Boards or Water Companies run as parastatals or run by the municipality.
- In both countries, where Water Companies are used treatment costs are presented to the municipalities annually for approval. Final tariffs are then set by the municipalities.

The similarities mentioned above indicate that the Dutch model can be applied in South Africa.

4.4.1 **Collaboration between the main stakeholders in the water sector**

The idea of collaboration is very important in the Netherlands. If water utilities work together towards a solution the process would move forward faster and more efficiently. Only through collaboration was the Netherlands able to initiate a change in legislation. Through collaboration comes standardisation which is attractive to industries who would want to use WTR as a raw material or product.

4.4.2 **Research and Development**

South Africa is already aware of the importance of research & development but creating a mechanism or forum whereby research leads to implementation is where the Netherlands has excelled. An example of this can be seen in the lime pellet production. The process for lime pellet production requires a seed material for crystallisation. The Netherlands used an Australian sand product as seeding however; this decreased the purity of the lime pellet as a product. The market request to RU was that a pure pellet would be required. Research was undertaken in collaboration with DELFT University and WATERNET (Weesperkarspel WTP) which resulted in the development a method using lime as a seeding material. This method has been taken forward and will be implemented on full scale water treatment plants.

4.4.3 **Change of Mind-set**

The site visits have shown that many of the disposal/ reuse options researched in the literature review are being utilised in South Africa. The common disposal method observed during the study was onsite disposal after settling ponds. Of the sample set only two water works were reusing the WTR; one for land application and one for soil conditioning, while the rest disposed. Experiences from international case studies indicate that strategic partnerships between local water service providers and water service authorities should be developed. This will ensure that the users and suppliers are aware of the other's goals and concerns. The Water Services Authorities will then be able to lobby national government with the water service providers speaking from a point of knowledge/ experience.

When choosing a WTR management strategy, sustainability should be prioritised over cost as a criterion. If the South African water industry can show that WTR can be used over the long term as a raw material and help achieve South Africa's environmental goals; the country can work towards making changes that would make these strategies cost effective and economically viable for all stakeholders.

Finally, in South Africa there is a need to change thinking about WTR. Water treatment residue is a not a waste issue; it should be considered in water treatment plant design and treated as a by-product. In the Netherlands water utilities treat WTR as a value-added product and treat its production in the same way they look at the production of water. Simple, practical modifications can create change, which in turn will create value. It might be worthwhile to investigate the feasibility of using a model similar to RU to create industry partners for re-use strategies and undertake research into a market for possible reuse products.

PART 2

GUIDELINES AND GOOD PRACTICES FOR WATER TREATMENT RESIDUES HANDLING, DISPOSAL AND REUSE IN SOUTH AFRICA

CHAPTER 5: GUIDELINE OVERVIEW

5.1 NEED FOR THIS GUIDELINE

During a survey of South African water treatment plants, it was found that plants have stock-piles of WTR and need short term practical methods of disposal other than landfill. This chapter elaborates on the South African water industry's desire to ensure that WTR management is based on local best practice, providing safe disposal or reuse and achieving acceptable low social, cultural and environmental impacts. Best practice is as a way of doing things for a given water treatment plant at a given time. As such best practice principles and approaches should evolve to accommodate innovative solutions as and when they are developed. The solution for WTR management is not "one-size fits all" as it involves managing each potential risk with the best available technology appropriate to the circumstances. This is influenced by local climatic, geographic and environmental conditions as well as legislation pertaining to management and disposal of the residue. This knowledge can be used to examine other drinking water residue management planning strategies, cost considerations (capital and operating), program delivery approaches, issues and challenges, and opportunities for improvement to one's WTR management system.

5.2 OBJECTIVES OF THE GUIDELINE

The intention of this guideline is to provide a strategic framework and not a detailed discussion on disposal options, but rather to provide sufficient information to assist with the decision-making process.

5.3 INTENDED USERS

- Water Service providers and Water Service Authorities – who are required to effectively implement, manage, operate and monitor a WTR management strategy.
- Water Engineers – to serve as a baseline for the development of improved treatment methods, disposal options and monitoring protocols that will assist the water industry to improve.
- Regulatory authorities – to assess compliance in applicable cases such as land reclamation and agricultural use.
- The guideline focuses on the management options which are applicable to the South African conditions.
- Landfill site owners/operators – to manage the WTR accepted on the site and the criteria for WTR acceptance.

CHAPTER 6: GUIDANCE ON CHARACTERIZATION OF WATER TREATMENT RESIDUES

6.1 INTRODUCTION

The objective for undertaking the WTR characterisation is to:

- Investigate how raw water and treatment chemicals contribute to the composition of WTR.
- Determine the national trend of prevailing WTR constituents of concern, in accordance with current legislation.

6.2 ESTIMATING THE QUANTITY OF WATER TREATMENT RESIDUES GENERATED

6.2.1 Models for estimating WTR production

The amount of WTR generated can be predicted using many estimation models that considers the plant inflow rate and dosed chemical concentrations, and other models are based on the raw water constituents. These are briefly explained below.

6.2.1.1 *Individual WTR estimation from alum and iron coagulants*

The amount of residue generated from Alum and Iron coagulation can be estimated by the following equations (Davis, 2010) .

$\mathrm{Ms} = \mathrm{Q} \times (0.44\mathrm{Al} + \mathrm{TSS} + \mathrm{M})$ ………………………………………………………………… (Eq 1)

$\mathrm{Ms} = \mathrm{Q} \times (2.9\mathrm{Fe} + \mathrm{TSS} + \mathrm{M})$ ………………………………………………………………… (Eq 2)

Where M_s = mass of dry WTR produced, kg/d
Q = plant flow, ML /d
Al = alum dose, mg/L
Fe = iron dose in mg/L expressed as mg/L of Fe
TSS = total suspended solids in raw water, mg/L
M = miscellaneous chemical additions such as clay, polymer, and carbon, mg/L
Table 6-1 shows the contribution factors of some of the chemicals determined experimentally (gram of additional WTR suspended solids for each gram of chemical added) (Van Duuren , 1997). For example, 1 g of $FeCl_3$ added to the raw water contributes to 0.65 g of suspended solids in the WTR.

Table 6-1: Estimation of the contribution factors of different chemicals

Coagulant	Factor
Alum	0.922
Ferric chloride	0.65
Ferric sulphate	0.54
Polyelectrolyte	1
Bentonite	1
Powdered Activated Carbon	1

6.2.1.2 *WTR estimation based on Dissolved Organic Carbon Removal*

This approach involves estimating WTR production by calculating the expected solids using (AWWA, 2011).

$$\text{WTR Generated (kg/d)} = \text{Q} \times (\text{TSS} + 0.44 * \text{Alum} + 2.9 * \text{Fe} + \text{A} + \text{DOCr}) \text{ .... (Eq 3)}$$

Where: TSS = total suspended solids in the raw water (mg/L) (TSS method described in Appendix B)
Q = Flow rate ML/d
Alum = Aluminium dose as mg/l 17.1 per cent Al_2O_3
Fe = mg/L of Fe^{3+} added
DOC_r = Dissolved organic carbon removed.
A = Polymeric coagulant, Bentonite, lime chemicals (mg/L)

6.2.1.3 *WTR estimation based on clarifier underflow*

According to the (AWWARF, 1996) water treatment residue volumes from sedimentation basins were estimated to be 0.1 to 3 percent of the plant raw water flow. The American Water Works Association (AWWA, 2011) estimated the WTR volume to be approximately 0.6 percent.

6.2.1.4 *WTR estimation based on raw water treated (Bourgeois, et al., 2004)*

Daily WTR Production (tDS/d) = [0.03 to 0.1] *Raw water treated (ML/d) …………………….. (Eq 4)

6.2.1.5 *WTR estimation based on multiple parameters*

A method by USEPA (1996), uses multiple parameters to estimate WTR. Table 6-2 illustrates the impact of chemical dose on the quantity of solids that results from different contaminants and chemicals used during the treatment process.

Table 6-2: Impact of chemical dose on volume of residue produced (USEPA, 1996)

Parameter	Units	Typical Solids Production (mg/L TSS)
Algae	count/mL	0.0003
True Colour	TCU	0.033
Polymer	mg/L polymer	1
PACl	mg/L as PACl	0.27
Ferric Coagulants	mg/L as Iron	2.9
Alum	mg/L as $Al_2(SO_4)^{3-}.14H_2O$	0.33 – 0.44
Turbidity	NTU	1 - 2
Lime Softening	mg/L as Mg^{2+} removed mg/L as Ca^{2+} removed	2.6 2
Iron	mg/L Iron	1.9 (using oxygen, chlorine or chlorine dioxide) 2.43 (using KMnO4)
Manganese	mg/L Manganese	1.58 (using oxygen, chlorine or chlorine dioxide) 2.64 (using $KMnO_4$)
Example: 1 count/mL of algae will generate 0.0003 mg/L TSS; 1 NTU will generate 1-2 mg/L TSS and 1 mg/L as PACl will generate 0.27 of mg/L TSS		

6.2.2 **Validation of WTR production models**

6.2.2.1 *Selection of plants*

To illustrate the application of various legislation and other criteria for WTR characterisation a sample set consisting of 15 plants was used. In total, there are over 600 water treatment plants in South Africa, ranging in size from 2 ML/d to 3000 ML/d. The sample set comprised of 15 water treatment plants, which represent about 3.6% of the total plants in the country. Only the larger more accessible plants were included in the survey. These plants comprised of those operated by the larger water boards in South Africa (Figure 6-1). Data on most of the smaller plants were non-existent, incomplete or not updated. Data from the 2014 national blue drop list shows that 86% of the water treatment plants in South Africa are managed by the local municipalities while the sample set contains only 20% municipal run water treatment plants. Nationally only 14% of WTP are run by water boards but this 14% produce 43% of the water consumed in South Africa.

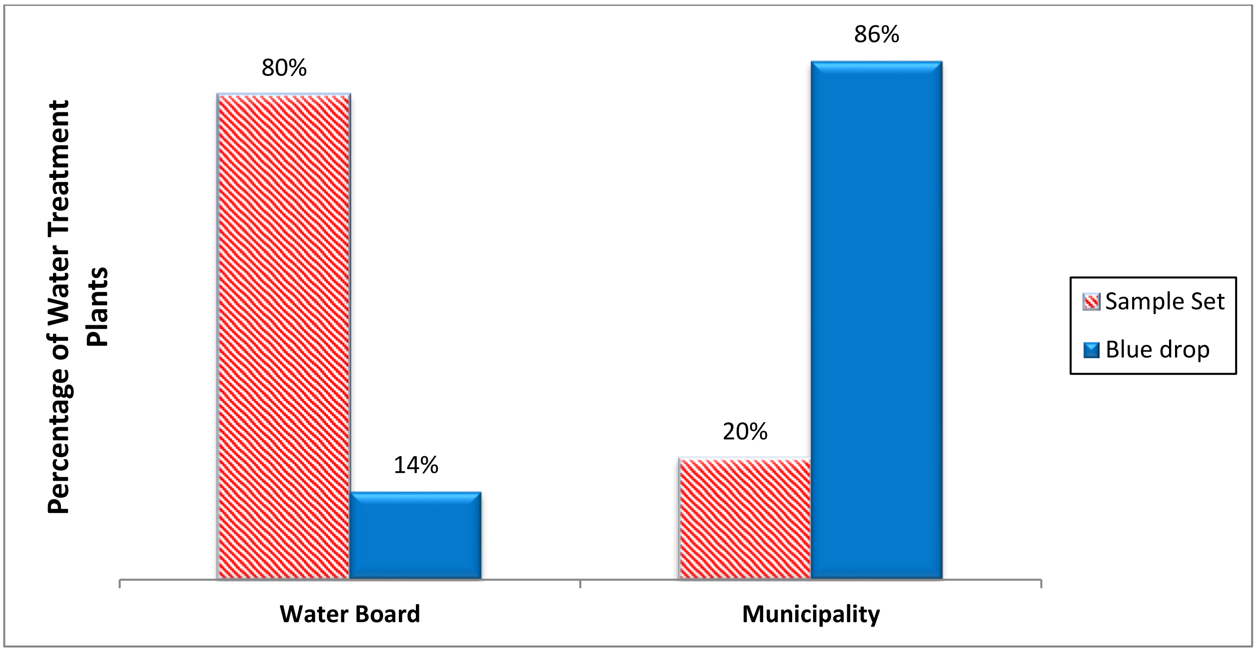

Figure 6-1: Comparison of management between sample set and blue drop list plants

The sample set of treatment plants selected indicate that 53% of the treatment plants had a design capacity above 50 ML/d and 47% had a capacity below 50 ML/d. However, for comparison purposes the 2014 blue drop list (BDS) was also analysed (Figure 6-2). From a total of 387 plants 91% of the plants were below 50ML/d and only 9% above 50 ML/d. Figure 6-2 also indicates that the sample set of visited treatment plants was evenly distributed in terms of capacity but not representational of the national WTP as most plants are below 50 ML/d.

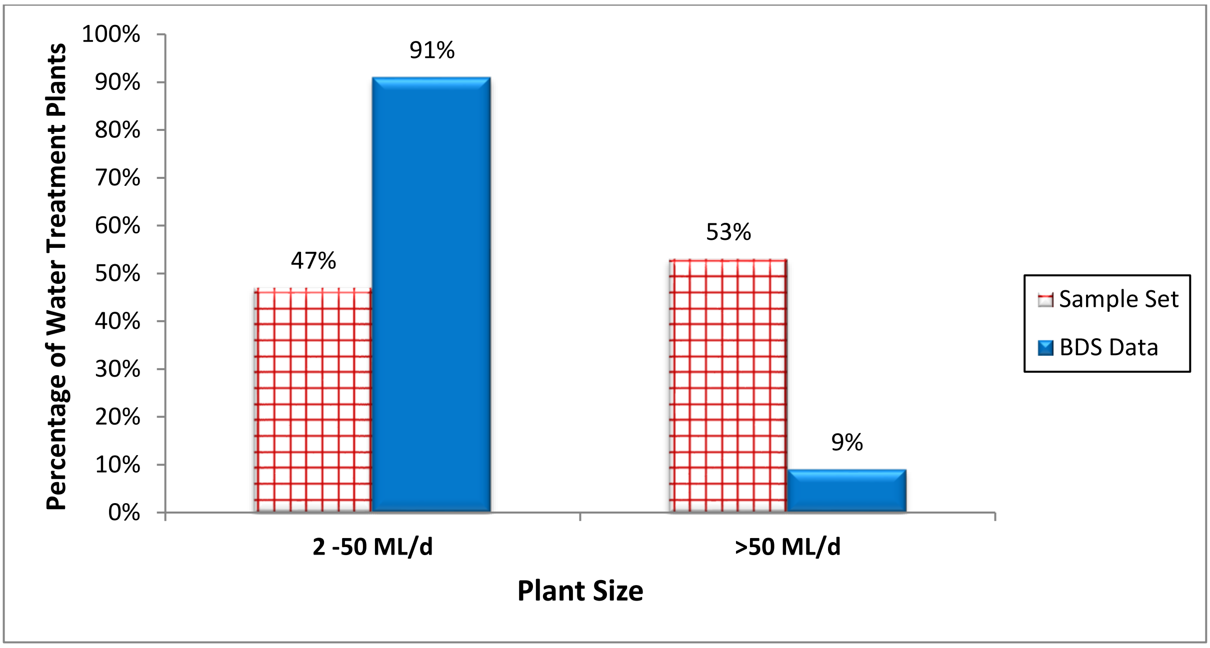

Figure 6-2: Comparison of sample set and blue drop list plant design capacity

6.2.2.2 *Calculation of WTR production*

An exercise was undertaken to estimate the WTR production of water treatment plants in South Africa. Where the required data was available, WTR production by each plant was estimated based on the dissolved organic carbon removal approach (Eq. 3 - refer to Section 6.2.1.2). Table 6-3 shows a comparison between some of the calculated WTR production and the average daily WTR production values obtained for the various water treatment plants (WTP) that made relevant process data available.

Table 6-3: WTR Estimation

WTP No	Calculated WTR Generation (dry ton/day)	Actual WTR Generation (dry ton/day)
5	1.9	1
20	14.7	9.7
21	1.5	5
23	4.8	5.5
24	3.8	2.4
28	3.2	1.4

Figure 6-3 shows a correlation of coefficient R^2 of 0.893 between the measured and calculated WTR. This method depends on the accuracy of the plant process data and may be regarded as a reasonable approximation as is evidenced from the correlation co-efficient. The time at which the measurement is taken is also important as WTR generation fluctuates depending on the season and raw water. The coagulant dosage used in the calculation was an average value. Variations in coagulant dose may have also contributed to the relative inaccuracy.

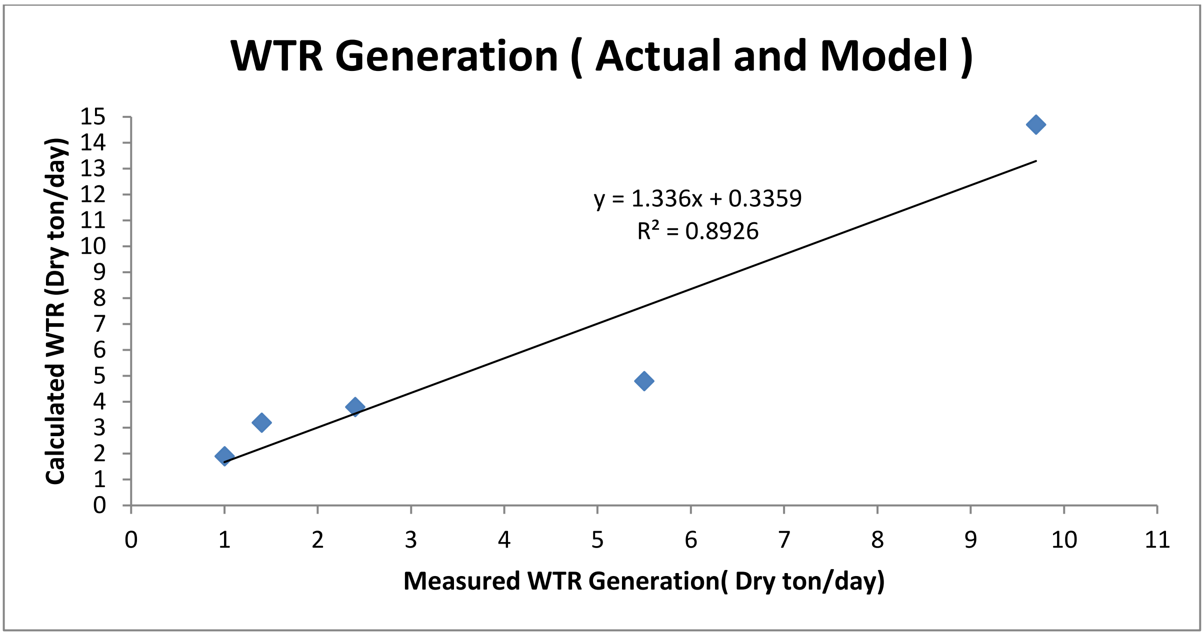

Figure 6-3: WTR generation model correlation

6.2.3 Estimating national WTR production

In 1997, the global WTR generation in 1997 was estimated to be 10 000 tDS/day (Dharmappa , et al., 1997), relative to a world population in 1997 of 5.862 billion (World Bank). In 2005, Hughes et al. (2005) estimated that 405 000 tDS/annum WTR was generated nationally with the assumption that data collected represent two thirds of the treatment facilities in South Africa.

Currently (in 2016), the national WTR generation capacity was estimated as 300 000-ton dry solids (tDS) per day annum. This average was estimated by assuming that the treatment plants are operating at full capacity using an AWWA assumption of 5% (v/v) (Bourgeois et al., 2004, AWWA, 2011) of the incoming raw water which is converted into WTR. For example, a 50 ML/d plant will produce 2.5 ton of WTR per day. In addition, the estimation of WTR on a national scale was made using the following assumptions:

- Solids comprise 5% of the raw water flow. This is the midpoint of the range (1–10%) postulated by Bourgeois et al., (2004) (refer to Section 6.2.1.4 above).
- 387 WTP in South Africa with capacities greater than 2 ML/d (from 2014 Blue Drop List)

The discrepancy between the current estimation and the WRC report by (Hughes , et al., 2005) indicates that more accurate data is required to get a good estimate of WTR generated nationally. The estimated value is expected to increase considering the numerous plant upgrades and new water treatment plants that have been commissioned. The current global WTR production was estimated at 12400 dry tonnes/day (4 526 000 tDS/annum) relative to a world population of 7.256 billion. This was based on the estimate that WTR dry mass production in the USA was more than 1 000 000 tDS/year (assuming a solids content of 10%) (AWWARF, 1996). South Africa then produces about 1/16 of the world's WTR.

A comparison of the actual WTR produced and the estimated national average in Figure 6-4 indicates that about 71% of the national WTR is handled at one site, which is generated by two plants operated by Rand Water at the Panfontein disposal facility. During a one-year period about 183 000 tons of residue is handled at this facility alone. The 15 treatment plants selected for the validation exercise represent about 3.6% of the total plants in the country. However, these plants generate approximately 80% of the national WTR. This suggests that the sample set was a good snapshot of WTR management and in this regard the chosen plants should be considered to give a well representation.

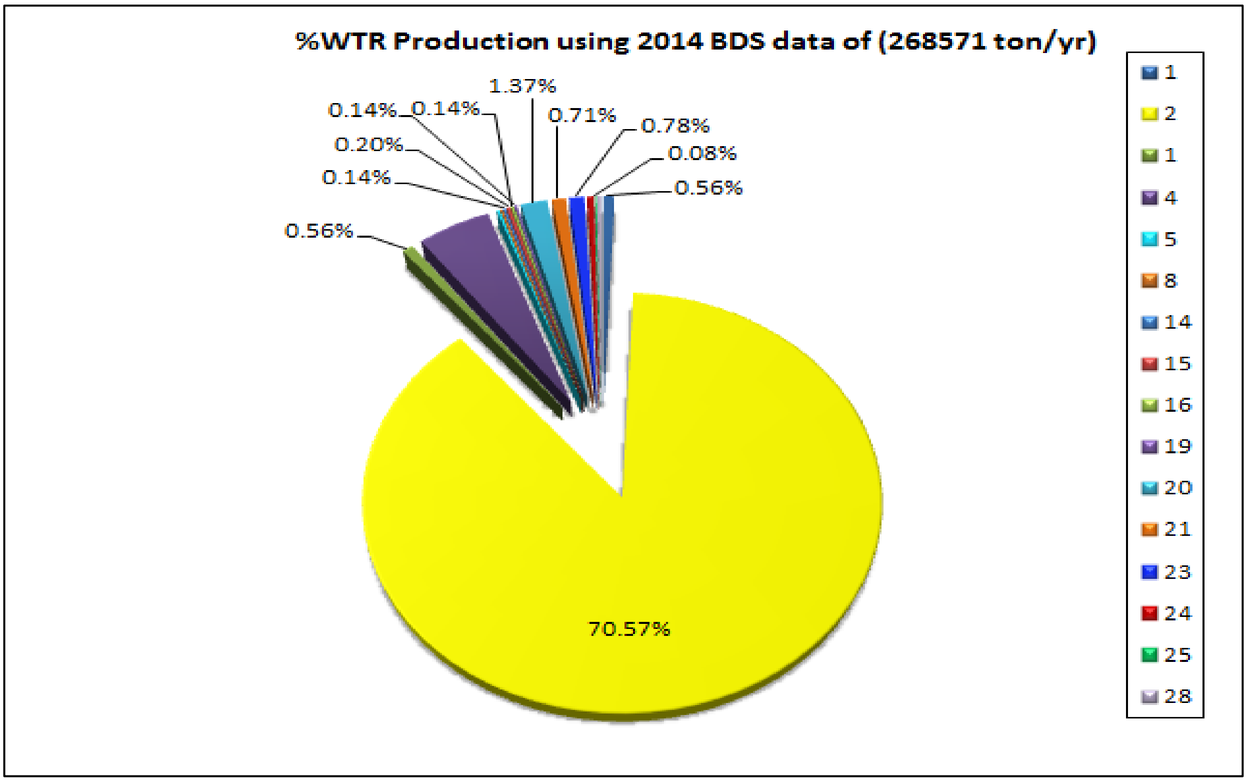

Figure 6-4: Contribution of plant WTR to national production average

6.2.4 Example: Estimating WTR generation in a plant using alum

A water treatment plant with a design capacity of 3 ML/d is dosed with alum for coagulation. No other chemicals are currently added. The following data and that in Table 6-4 was collected over a 1-year period to estimate the amount of water treatment residue generated by the plant.

- Dissolved Organic Carbon (DOC) composes 90 to 99% of the TOC for surface waters used for drinking water. For groundwater, Particulate Organic Carbon is nearly zero so the DOC is essentially equal to the TOC
- Solids concentrations for WTR produced with alum or iron coagulants and for low to moderate turbidity raw waters is about 0.1 to 1.0 percent
- Solids concentration from properly operated clarifier underflow is typically between 0.6 -1% solids
- The procedure to determine the TSS is detailed in in Appendix B.

Table 6-4: Drinking waterworks WTR production estimation

Parameter	Value	Unit
Plant flow rate, *Q*	2.7	ML/d
Alum dose, *Alum*	45	mg/L Al_2O_3
TOC raw (95 percentile)	14.4	mg/L
TOC final (95 percentile)	5.5	mg/L
DOC raw(95% of TOC)	14.3	mg/L
DOC final (95% of TOC)	5.2	mg/L
TSS (95 percentile)	37.4	mg/L
A	0	mg/L

WTR production was estimated based on the dissolved organic carbon removal approach (Eq. 3 - refer to Section 6.2.1.2) as follows:

WTR generated = Q*(TSS+ 0.44* Alum + 2.9* Fe + A + DOCr)

$$DOC_r = 14.3 - 5.2 = 9.1\ mg/L$$

$$WTR\ Generated\ (kg/d) = 2.7 * (37.4 + 0.44 * 45 + 2.9 * 0 + 0 + 9.1$$
$$= 178.96\ kg/d\ \textbf{dry solids}$$

$$Clarifier\ WTR\ expectected\ volume\ (max) = \frac{178.96}{0.006} = 28926\ kg/dor\ m^3/d$$

$$Clarifier\ WTR\ expectected\ volume\ (min) = \frac{178.96}{0.01} = 17896\ kg/dor\ m^3/d$$

$$WTR\ production\ rate = 1.8\ to\ 2.9\ ton/d$$

6.3 CLASSIFICATION OF WATER TREATMENT RESIDUES

6.3.1 Overview

In terms of the general notice (GN R. 634) of the Waste Classification and Management Regulation 4 (WCMR),

"*all waste generators must ensure that the waste they generate is classified in accordance with SANS 10234 within 180 days of generation, except in cases where the waste is on the pre-classified list*" (Annexure 1 of GN R.634).

6.3.2 WTR classification using SANS 10234

The SANS 10234 classification of WTRs is Class 12 (Eco-toxic) due to the elevated concentrations of Manganese in the sample determined using the USEPA TCLP method. The SANS 10234 Class 10 classification is due to the total lead concentrations in samples and determined using the AQUA REGIA digestion method.

6.3.2.1 *United States Environmental Protection Act TCLP method*

The threshold limits set by the National Environmental Management: Waste Act for leachable metals is tabulated in Table 6-5. The leachable concentration of a certain element is denoted by LC. The leachable concentration threshold of a certain element is denoted by LCT. There are 4 threshold limits: LCT0, LCT1, LCT2 and LCT3.

- LCT0 is the lowest value of the standard for human health effects listed for drinking water (SANS: 241)
- LCT1 is LCT0 multiplied by the Australian State of Victoria dilution attenuating factor of 50
- LCT2 is LCT1 multiplied by 2 and
- LCT3 is LCT2 multiplied by 4

Table 6-5: Legislated TCLP leachable limits

Parameter	Units	LCT0	LCT1	LCT2	LCT3
Arsenic, As	mg/L	0.01	0.5	1	4
Boron, B	mg/L	0.5	25	50	200
Barium, Ba	mg/L	0.7	35	70	280
Cadmium, Cd	mg/L	0.003	0.15	0.3	1.2
Cobalt, Co	mg/L	0.5	25	50	200
Chromium, Cr	mg/L	0.1	5	10	40
Chromium VI, Cr(VI)	mg/L	0.05	2.5	5	20
Copper, Cu	mg/L	2	100	200	800
Mercury, Hg	mg/L	0.006	0.3	0.6	2.4
Manganese, Mn	mg/L	0.5	25	50	200
Molybdenum, Mo	mg/L	0.07	3.5	7	28
Nickel,Ni	mg/L	0.07	3.5	7	28
Lead, Pb	mg/L	0.01	0.5	1	4
Antimony, Sb	mg/L	0.02	1	2	8
Selenium, Se	mg/L	0.01	0.5	1	4
Vanadium, V	mg/L	0.2	10	20	80
Zinc, Zn	mg/L	5	250	500	2000

6.3.2.2 *Aqua Regia Digestion*

The threshold limits set by the National Environmental Management: Waste Act for total metals are as indicated in Table 6-6. The total concentration of a certain element is denoted by TC. The total concentration threshold of a certain element is denoted by TCT. There are 3 threshold limits: TCT0, TCT1 and TCT2.

- The TCT1 has been derived from land remediation limits determined by the Department of Environmental Affairs “Framework for the Management of Contaminated Land”.
- TCT2 is TCT1 multiplied by the Australian State of Victoria factor of 4.

- TCT0 is the limits that have been obtained from South African Soil Screening (or Australian values if South African values were not available). If both Australian and South African values were not available TCT0 was calculated by dividing TCT1 by 100.

Table 6-6: Legislated Aqua Regia **threshold limits**

Parameter	Units	TCT0	TCT1	TCT2
Arsenic, As	mg/kg	5.8	500	2000
Boron, B	mg/kg	150	15000	60000
Barium, Ba	mg/kg	62.5	6250	25000
Cadmium	mg/kg	7.5	260	1040
Cobalt, Co	mg/kg	50	5000	20000
Chromium, Cr	mg/kg	46000	800000	N/A
Chromium VI, Cr(VI)	mg/kg	6.5	500	2000
Copper, Cu	mg/kg	16	19500	78000
Mercury, Hg	mg/kg	0.93	160	640
Manganese, Mn	mg/kg	1000	25000	100000
Molybdenum, Mo	mg/kg	40	1000	4000
Nickel,Ni	mg/kg	91	10600	42400
Lead, Pb	mg/kg	20	1900	7600
Antimony, Sb	mg/kg	10	75	300
Selenium, Se	mg/kg	10	50	200
Vanadium, V	mg/kg	150	2680	10720
Zinc, Zn	mg/kg	240	160000	640000

6.3.3 Example: WTR classification using the USEPA TCLP and Aqua Regia methods

6.3.3.1 *Sample collection and analysis*

Raw water and WTR samples were obtained from 28 water treatment plants. Samples of raw water were collected in 2 x 25 L plastic containers and 4 kg samples of WTR were collected in buckets. Where it was not possible to obtain dewatered WTR samples, dilute WTR (clarifier underflow) was collected. All the WTR samples collected were then air-dried and once completely dry, the samples were milled in preparation of the classification testing. The water treatment residue constituents analysed in both the TCLP testing and the Aqua Regia and the SANS 10234 classification results are indicated in Appendix C2.

6.3.3.2 *WTR classification using the USEPA TCLP method*

The threshold limits set by the National Environmental Management Waste Act (Act No. 59 of 2008) for leachable metals is tabulated in Table 6-5. The leachable concentration of a certain element is denoted by LC. A summary of TCLP analysis whereby constituents of concern were found to be above the threshold limit for the 28 WTR samples is presented in Figure 6-5. The graph shows the number of plants generating waste with the specific elevated constituents of concern. In highly acidic conditions, 26 of the WTR tested, contained leachable manganese concentrations above the minimum threshold limit (LCT0). WTR from 23 plants had elevated leachable concentrations of Barium. Only 11 of the 28 WTP were affected by elevated concentrations of lead.

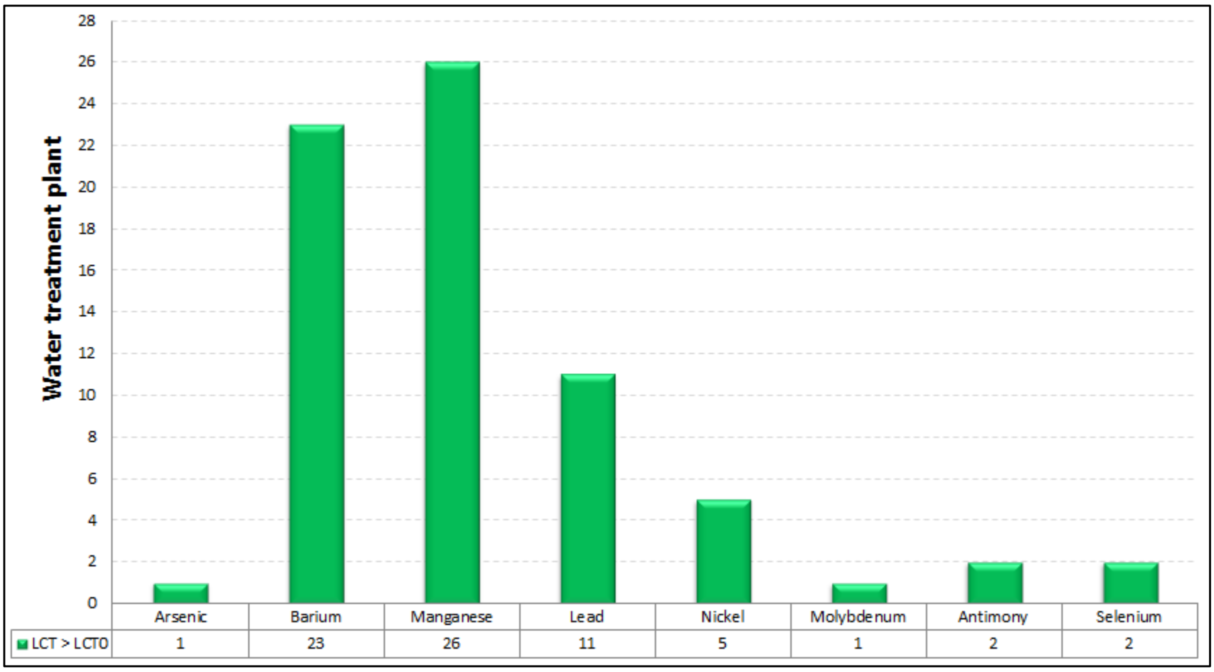

Figure 6-5: Water treatment plant summarised TCLP results

Nickel in WTR was present in samples obtained from 5 plants while antimony was found to leach in elevated concentrations in very few WTP samples, with the leachable concentrations falling above LCT0. The other measured parameters analysed, were found in leachable concentrations that fell below the minimum threshold limit; with most of these constituents being analytically undetectable (cadmium, chromium, mercury, molybdenum, antimony, selenium, vanadium, zinc). The Australian Leaching method (AS4439), which is prescribed in the Government legislation, is a more realistic method of testing leachability. The method allows for the use of different reagents depending on the disposal method. This means that for the purposes of this project, where the WTR would be left on land and not come into contact with a highly acidic environment, water would have been utilised as the leaching reagent. Using a water reagent would have decreased the concentrations of the leached constituents. This method however is not readily available for purchase and should perhaps be included for sale by the South African Bureau of Standards (SABS) as it is the legislated analytical leaching method.

6.3.3.3 *WTR classification using the Aqua Regia Digestion method*

The threshold limits set by the National Environmental Management Waste Act (Act No. 59 of 2008) for total metals are as indicated in Table 6-6. A summary of Aqua Regia digestion analysis where constituents were found to be above the threshold limit for the 28 WTR samples is presented in Figure 6-6. The graph shows the number of plants generating waste with the specific elevated constituent of concern. Twelve elements were found to be above the minimum threshold limit, with none falling outside TCT1. Most of the WTP are affected by elevated WTR concentrations of barium, copper, manganese and lead. Arsenic also occurred above threshold limits in 13 WTR samples. The results of these analyses provide a basis for the development of management strategies for specific WTR and what further analysis would be required once a management strategy is chosen.

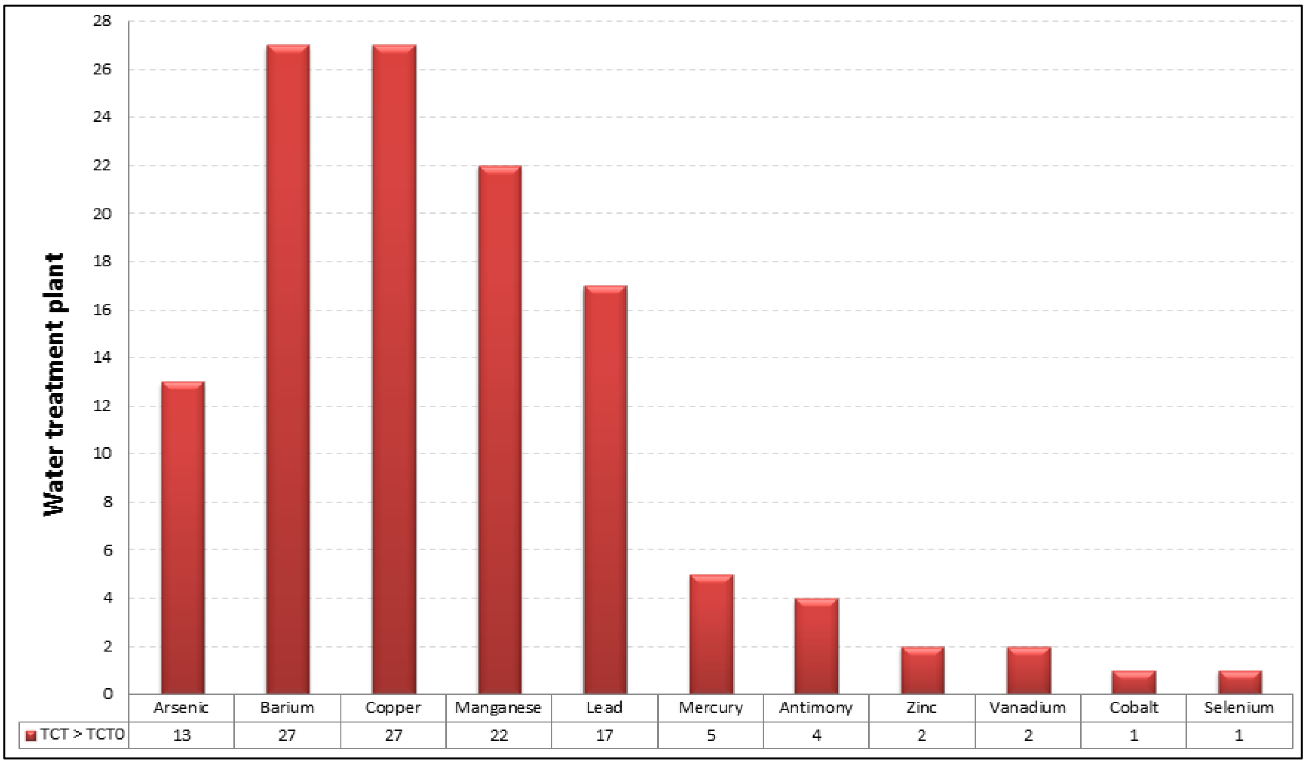

Figure 6-6: Water treatment plant summarised Aqua Regia results

6.3.3.4 *Summary*

Due to the nature of the WTR, physical hazards were eliminated and emphasis was placed on the Eco- toxic and the carcinogenic potential of the residue.

- The SANS 10234 classification of the WTR is Class 12 (Eco-toxic) due to the elevated concentrations of Manganese in the sample determined using the USEPA TCLP method.
- The SANS 10234 Class 10 classification is due to the total lead concentrations in samples and determined using the AQUA REGIA digestion method.

6.4 DETERMINING THE SOURCES OF IMPURITIES IN WTR

6.4.1 **Introduction**

The hazardous nature of WTR is derived from the raw water and the addition of treatment chemicals. From feedback and research, it was found that the chemicals most widely used in South African water treatment were:

- Lime – brown and white
- Polymeric coagulants – mainly the polyamines and polymeric coagulant blends
- Aluminium Sulphate
- Ferric Sulphate

WTP with differing chemical dosing, raw water compositions, abstraction sources and locations share chemicals of concern such as barium, copper, manganese, lead and arsenic. Figure 6-7 shows the flow diagram of a conventional water treatment process and the source of WTR.

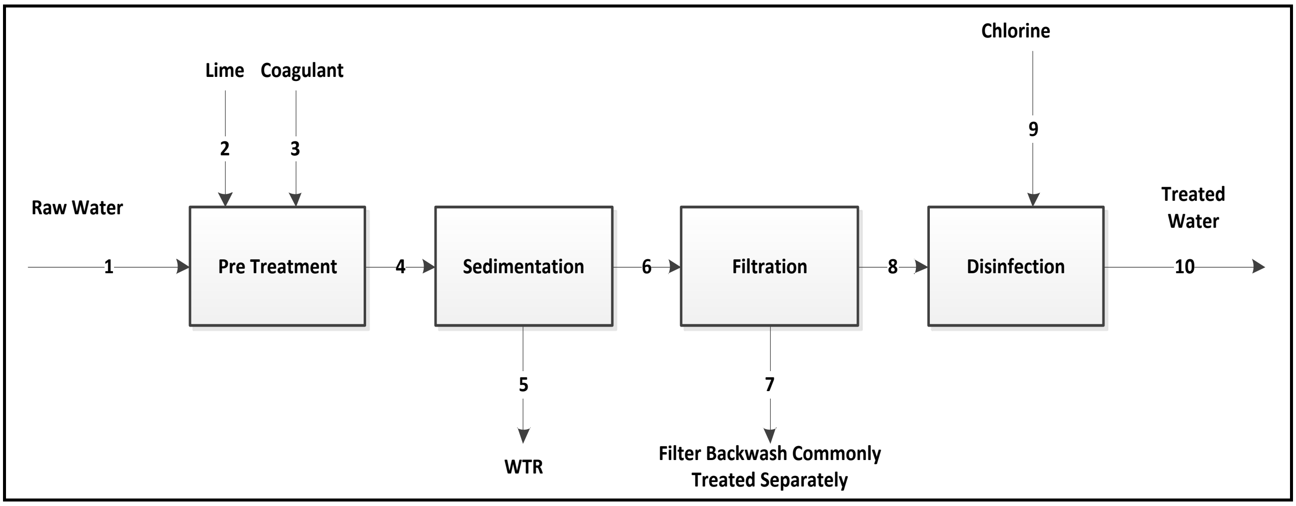

Figure 6-7: Conventional water treatment plant process train

6.4.2 Method for determining the source of impurities in WTR

A mass balance equation (Equation 5) is used to develop a mass balance over a treatment plant.

$Input = Output$

$$Stream\ 1 + Stream\ 2 + Stream\ 3 = Stream\ 4$$
$$Stream\ 5 = Stream\ 4 - Stream\ 6$$

This result in $stream\ 5\ (WTR) = stream\ 1 + stream\ 2 + stream\ 3 - stream\ 6$ ……..… (Eq 5)

That is for each impurity:

Stream 5 impurities (Solids) = Impurities Stream 1 (solids + Liquid) + Impurities Stream 2 + Impurities Stream 3 – Impurities Stream 6 (solids + liquid)

Most of the solids are removed at stream 5. The impurities will be in solution therefore stream 6 can be estimated as having a negligible solids impurity concentration. To comply with the SANS 241:2015 drinking water requirement impurities in the liquid portion of stream 6 are also negligible. For the other streams from Figure 6-7 analysis was done to determine the concentration of impurities.

6.4.3 Example: Determining the source of impurities from lime

To verify the applicability of Eq. 5 above, a metal analysis survey was conducted to confirm the source of impurities in lime. A trend found during site visits and database investigation is that in South Africa most bulk water treatment plants use lime for pH adjustment and to add alkalinity to water. There are two types of lime, commonly known as, brown lime and white lime. Due to cost and availability brown lime is the most extensively used lime variant. Brown lime and white lime samples were analysed using nitric acid digestion (Refer to Appendix C1).

Table 6-7 below shows the results obtained.

Table 6-7: Lime nitric acid digestion results

Metal	White Lime Concentration (g/kg)	Brown Lime Concentration (g/kg)
Aluminium, Al (total)	1.85	0.398
Arsenic, As	0.003	0.002
Cadmium, Cd	0.001	0.001
Cobalt, Co	0.01	0.01
Chromium, Cr	0.012	0.005
Copper, Cu	0.05	0.05
Iron, Fe	2.26	0.630
Mercury, Hg	0.0005	0.0005
Manganese, Mn	0.01	1.27
Molybdenum, Mo	0.01	0.01
Sodium, Na	2	2
Nickel, Ni	0.01	0.01
Lead, Pb	0.004	0.004
Antimony, Sb	0.002	0.002
Silica, Si	4.91	1
Vanadium, V	0.01	0.01
Zinc, Zn	0.03	0.03

The data shows that brown lime has an elevated manganese concentration when compared with white lime however this does not mean that lime is the main WTR contributor of manganese. Using the average lime dosing rates for each WTP in the sample set (refer to Section 6.3.3.1), the lime contribution to the WTR impurities was calculated. The calculations show that the impurity contribution of lime to the WTR, for all the WTP, was in the same order of magnitude. The orders of magnitude are presented in Table 6-8. Results obtained show that lime alone does not contribute enough impurities to deem the WTR hazardous. This means stream 2 is negligible.

Table 6-8: Lime WTR impurity contribution

Metal	White Lime Contribution (mg/kg)	Brown Lime Contribution (mg/kg)	Lowest WTR Total Concentration Threshold Limit (mg/kg)
Arsenic, As	1×10^{-4}	1×10^{-4}	5.8
Cadmium, Cd	1×10^{-4}	1×10^{-4}	7.5
Cobalt, Co	1×10^{-3}	1×10^{-3}	50
Chromium, Cr	1×10^{-3}	1×10^{-4}	46000
Copper, Cu	1×10^{-3}	1×10^{-3}	16
Mercury, Hg	1×10^{-5}	1×10^{-5}	0.93
Manganese, Mn	1×10^{-3}	1×10^{-1}	1000
Molybdenum, Mo	1×10^{-3}	1×10^{-3}	40
Nickel, Ni	1×10^{-3}	1×10^{-3}	91
Lead, Pb	1×10^{-4}	1×10^{-4}	20
Antimony, Sb	1×10^{-4}	1×10^{-4}	10
Vanadium, V	1×10^{-3}	1×10^{-3}	150
Zinc, Zn	1×10^{-3}	1×10^{-3}	240

6.4.4 **Example: Determining the source of impurities from polymeric coagulants**

All the coagulants used by the sample set of WTP (refer to Section 6.3.3.1) were analysed, Table 6-9 shows the results obtained. In Table 6-9 level of impurities in the polymeric coagulants (polyamines, PAC, ACH, etc.) are undetectable by SANAS accredited methods. The iron coagulants do have elevated levels of manganese but are only used by a single plant in the sample pool. At the maximum dosing rate for the WTP the manganese concentration from ferric sulphate is almost undetectable in the WTR. Table 6-9 shows that the coagulant is not the major WTR impurity contributor i.e. stream 3 is negligible. The equation is now simplified (stream 5) WTR (Solids) = (stream 1) raw water (solids + liquid). On completion of the raw water analysis it was found that the impurities in the raw water liquid component were negligible. These results predict that the bulk of the contamination results from the raw water suspended solids. To test this hypothesis raw water was filtered and the suspended solids digested to see the impact the raw water solids have on the WTR for selected WTP.

Table 6-9: Total metals in coagulants used

Metal	**Polymeric Coagulants (Poly) Used by Selected WTP (g metal/kg Poly)**	**Ferric Coagulants Used by Selected WTP (g metal/kg Fe)**
Arsenic	Undetectable	Undetectable
Boron	Undetectable	0.295
Barium	Undetectable	Undetectable
Cadmium	Undetectable	Undetectable
Cobalt	Undetectable	Undetectable
Chromium	Undetectable	Undetectable
Copper	Undetectable	Undetectable
Mercury	Undetectable	Undetectable
Manganese	Undetectable	0.285
Molybdenum	Undetectable	Undetectable
Nickel	Undetectable	0.0222
Lead	Undetectable	Undetectable
Antimony	Undetectable	Undetectable
Selenium	Undetectable	Undetectable
Vanadium	Undetectable	Undetectable
Zinc	Undetectable	0.05

6.4.5 **Example: Determining the sources of Manganese in WTR**

An assessment was conducted at Umgeni water's Durban Heights Water Works in 2014 to determine the main source of manganese in the treatment works using a mass balance. It was found that the major contributor of manganese in the treatment works is the raw water followed by lime (Table 6-10).

Table 6-10: Manganese mass balance

Total inputs of Manganese (kg/d)		**Total outputs of Manganese (kg/d)**	
Raw	20.92	Final water	1.74
Lime	4.00	Sludge cake	19.08
Polyelectrolyte	0.06		
Sludge polyelectrolyte	0.00001		
Total	24.98		20.83
Manganese balance (%)			83.36

CHAPTER 7: BENCHMARKING WTR MANAGEMENT OPTIONS IN SOUTH AFRICA

7.1 INTRODUCTION

7.1.1 Definitions of benchmarking

Benchmarking is defined as a process for continuous improvement that involves the measurement of performance. It is a process where organisations share ideas and working principles that are directed towards improving their performances (Bhagwan, 2002). There are many definitions of benchmarking, and each is specific for a particular industry, and these definitions are specific and goal orientated. A more relevant definition towards the water industry is given by (Makaya & Hensel, 2014).

"Benchmarking is a powerful management tool that can be used for comparing one's business processes and performance metrics with the industry's best and/or best practices. It is usually used by water utility managers, policy makers, regulators and financial institutions for different purposes with the target of improving water services and optimizing operations."

- *"Benchmarking is simply about making comparisons with other organisations and then learning the lessons that these comparisons throw up". The European Benchmarking Code of Conduct*
- *"Benchmarking is the continuous process of measuring products, services and practices against the toughest competitors or those companies recognised as industry leaders". The Xerox Corporation*
- *"Benchmarking is structured methods that identifies worldwide best practices and associated performance measures and adapts them to improve quality and performance". American Water Works Association (Bhagwan, 2002)*

There are three types of benchmarking according to AWWA Research Foundation (AWWARF, 2003)

1. Metric benchmarking, which is a quantitative comparative assessment that enables utilities to track performance over time by comparison against a baseline.
2. Process benchmarking involves first identifying specific work segments to be improved through continuous developments and comparing the working methods.
3. Business practices benchmarking is the process of seeking out and studying the best business practices that produce superior performance.

The water sector in Germany formed what is known as the German Association of Energy and Water industries where benchmarking is carried out on the basis of five performance indicators called the 5-pillar model (Figure 7-1). It was suggested that the success of the benchmarking initiative by Bundesverband der Energie und Wasserwirtschaft e.V. Berlin (BDEW) was due to the voluntary involvement of other treatment works and confidentiality of the results. During the 2015 benchmark, consistency and the compatibility of data was also noted as a prerequisite for successful benchmarking. An excerpt from the report states that "*approved technical standards and adherence to strict legal requirements leads to high quality and the long-term safety of the German drinking water supply and wastewater disposal*".

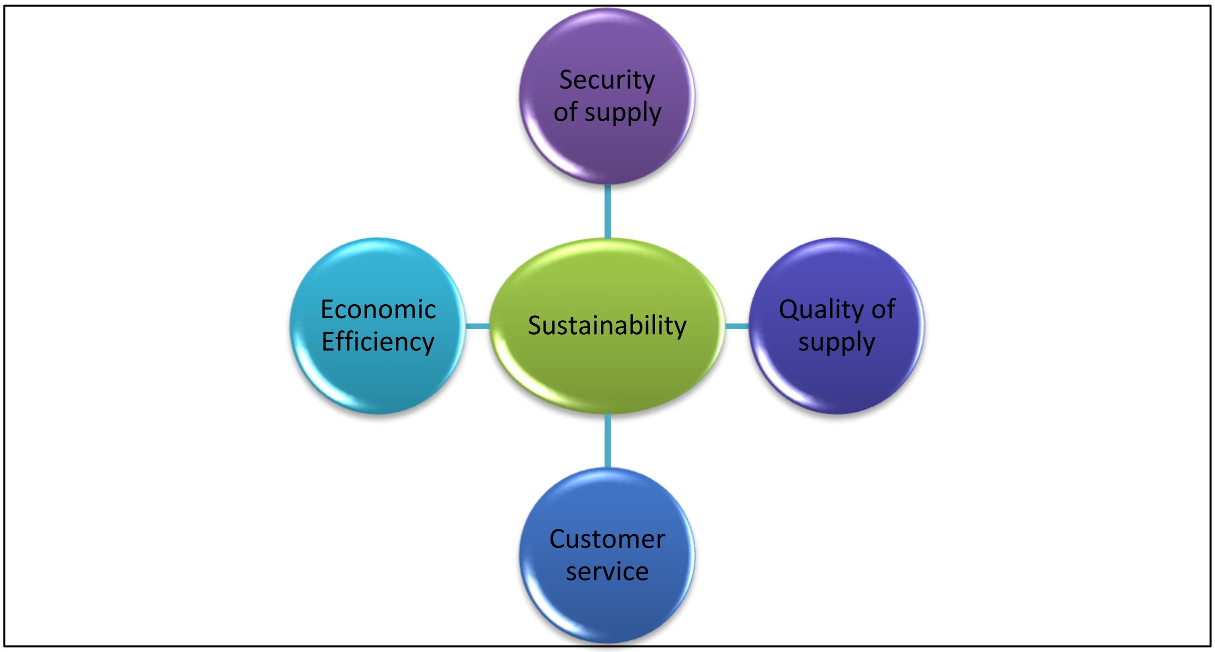

Figure 7-1: Five-pillar model of benchmarking

7.1.2 Purpose of benchmarking WTR management

The intention of water treatment residue (WTR) management benchmarking is to help the public sector understand how WTR management practices are conducted in South Africa. The benchmarking practices will also promote development of decision support tools to improve the overall management and operational processes of treatment plants. The performance of different WTR management options were evaluated based on environmental, operational and financial aspects of the current practices used for WTR handling and disposal. This knowledge can be used to examine other drinking water residue management planning strategies, cost considerations (capital and operating), challenges faced, and opportunities for improvement to one's own WTR management system.

Performance assessment and benchmarking are tools that can also be used to make service providers more accountable towards environmental compliance, efficiency and to measure progress while improving performance. Lack of reliable data and information is the main stumbling block in developing countries especially in South Africa. A major challenge for comparing, and eventually benchmarking, water treatment residue management activities was the lack of available information. This emanates from the fact that WTR generation and management is not monitored. Little is recorded after WTR is removed from the sedimentation process. Locally it was found that water utility managers should understand the importance of data collection, verification, record keeping, and processing to the success of the water treatment plant management. Once the information is available it can be compared with similar WTPs elsewhere in the country or with international best practice standards. A utility would then establish how it is performing, identify areas for improvement, and help indicate a plan of action in terms of WTR management. Criteria was compared against widely accepted key standard performance indicators and benchmarking the WTR management activities against other utilities around the country for purposes of development of decision support tools for better management of the system.

7.2 BENCHMARKING METHODOLOGY

7.2.1 Research design and data collection

The sample size of 15 water treatment plants represents about 3.6% of the total plants in the country. Those 15 plants generate approximately 80% of the national WTR (refer to Section 6.2). Eight water utilities were used as the main source of data and information from 15 water treatment plants. Structured questionnaires were used to interview key staff on the general performance of the WTR management section of the WTP. Data was also obtained from annual reports, project study reports, and related documents. Field observations were also conducted by the research team to assess the condition of the water supply system including the management and operation practices of the WTP. The research team also made site visits to observe the management process and operation procedures of the treatment plants and conduct interviews with plant personnel. The water survey asked about design flows , raw water sources and disposal methods. It then looked into treament objectives, process and residue management. The chosen process indicators, except the opinion indicators, were related to one year of operation (i.e. 2014).

7.2.2 Data analysis and presentation

Simple statistical and mathematical calculations were conducted and the results were presented in graphical and tabular formats. There is no perfect management strategy as they differ per treatment plant and site-specific conditions. Performance targets for each plant are governed by the legal implications. The benchmarking exercise is used to present the results to give a snapshot and not comparing in terms of which plant is performing better.

7.2.3 Selection of performance indicators

Performance indicators for water treatment residue management were based on the guidelines for the implementation of benchmarking practices in the provision of water services in South Africa (WRC Report TT 168/02, 2002). These guidelines were designed for local authorities to benchmark their activities with a view of encouraging better water and sanitation services delivery in a more effective and efficient manner. The intent of this work was more specific. It aimed to assess one of the activities of the drinking water supply, i.e. WTR management, in contrast with the overall performance of the management entities. Although not specifically defined as performance indicators, other disposal costs were included with intention to inform the audience about indicators which could not be determined from the sample surveyed and to encourage future data recording for these factors.

Due to varying plant conditions and management, the aim was to keep the benchmarking exercise as simple as possible and yet comprehensive to cover the South African context with the available data. Comparison with international WTP will establish areas for improvement, especially in terms of data collection and record keeping. This benchmarking exercise was developed to meet the specific objectives of this project within the defined scope and boundaries. Three general performance categories were selected, namely:

1. Environmental factors - waste reduction, potential for reuse (based on characteristics of the WTR) and compliance to relevant legislative requirements, e.g., NEMWA and other relevant waste management legislation.
2. Engineering aspects - process performance, operation and maintenance, land requirements.
3. Financial aspects – an assessment of costs of WTR handling and disposal. Economy of scale cost estimates.

According to Haider et al, 2014 selected performance indicators should be clearly defined, easy and cost effective to measure and verify, understandable, and relevant to a specific water supply system. During the study, more emphasis was placed on selection of indicators according to the following criteria:

- **Understandability** - The indicator should be understandable to both the utility operators and the general public
- **Measurability** - The data should be easy to measure and relatively easy to calculate
- **Comparability** - The indicators should be comparable with similar utilities in the country as well as with other international water treatment plants

The performance categories and the corresponding performance indicators are shown in Figure 7-2 below.

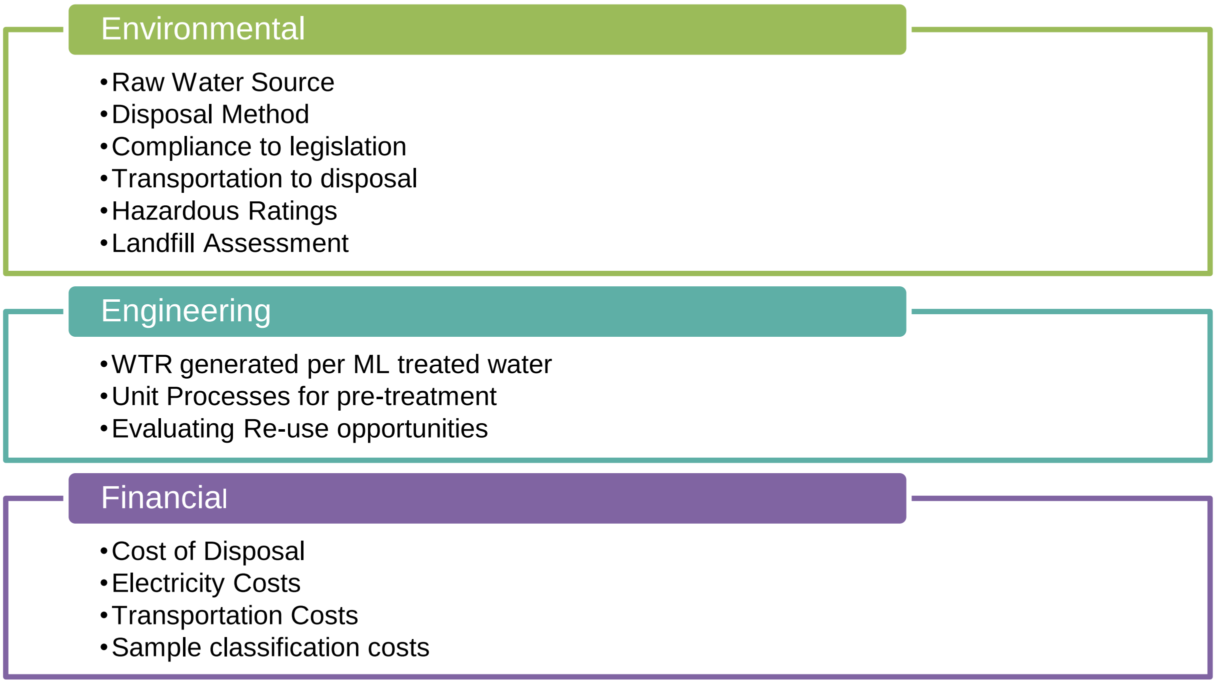

Figure 7-2: Performance indicators selected for benchmarking

The adopted performance indicators for the purpose of this study are described below:

7.2.3.1 *Environmental indicators*

An environmental indicator is a quantitative measure that can be used to illustrate and analyse environmental management issues including trends and progress over time. This can help provide insight into conservation and compliance towards regulations. Indicators included in this group allow the assessment of the environmental impact of WTR generation and disposal. In terms of WTR treatment and discharge, indicators were defined by the percentage of disposal facilities where WTR are disposed on-site within the WTP or pumped to sewer and percentage distribution to landfills of WTR disposal including transportation. The compliance to regulation was also considered in terms of percentage of non-compliances. This considered the conducting of monitoring activities and the availability of disposal and discharge permits. For this group six indicator were defined.

7.2.3.2 *Engineering indicators*

This group of indicators aims to assess the performance on operation and maintenance activities. This included the unit processes that were utilised during the pre-treatment of the WTR before disposal or a lack thereof and emphasis is based on:

- No treatment
- Pre-treatment: gravity thickening, chemical addition
- Pre-treatment and dewatering: mechanical dewatering and settling ponds
- The amount of WTR generated per plant capacity

7.2.3.3 *Financial and economic indicators*

Financial assessment of WTR benchmark was accomplished with three indicators. These include disposal costs per ton of WTR, treatment costs and capital unit costs. This is because the treatment plants could not differentiate between disposal costs and treatment costs. Due to the unavailability of data, the treatment and electricity costs were determined using other disposal cost indicators, to give a baseline for managers who want to improve on the current WTR management process and when constructing new plants.

7.3 RESULTS AND DISCUSSION

7.3.1 Environmental Indicators

The following charts are based on 15 South African water treatment plants which include the 7 largest water works in South Africa.

7.3.1.1 *Raw water source*

Raw water source contributes more towards the WTR quality and this determines the applicable disposal method. Figure 7-3 indicates that impounded surface water abstraction is the main source of raw water within the sample set. Dam water is the most important resource for drinking water abstraction due to the safety of supply and ease of treatment, while river abstraction has highly variable raw water parameters especially during the current climate conditions. In a benchmarking study carried out in 2010 it was found that German water utilities abstract 61% of their raw water from the ground; 12% from dams and only 1% from river water.

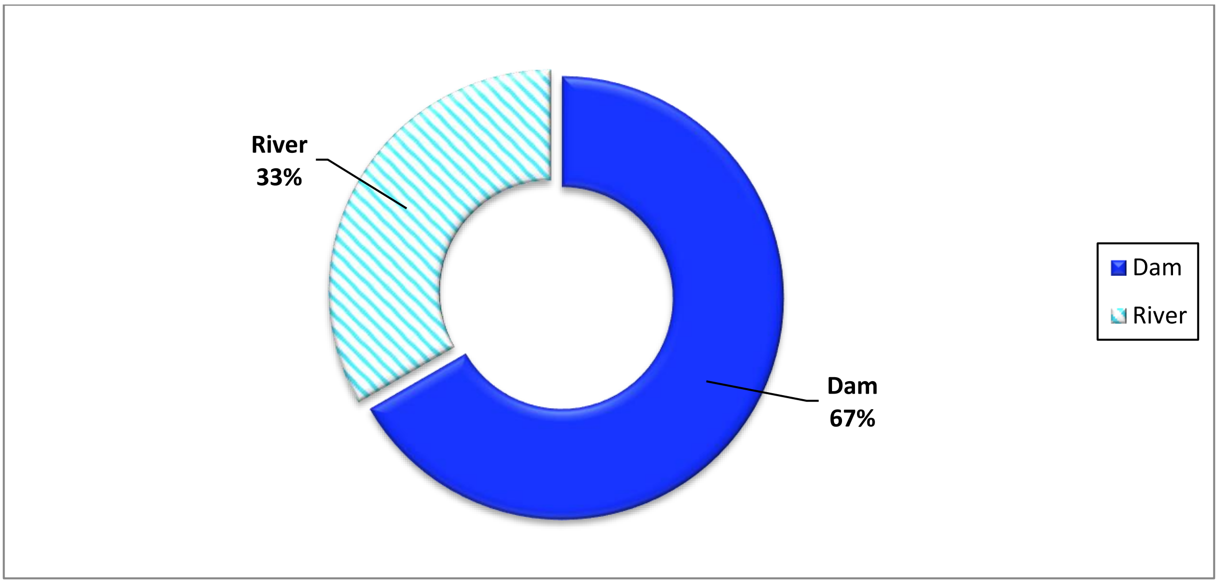

Figure 7-3: Raw Water Source

7.3.1.2 *Disposal method*

In South Africa, the current disposal practices include off-site disposal to landfill, on-site disposal to dedicated land and discharge into rivers and sewers (Figure 7-4). On-site disposal involves the storage of WTR onsite or on a dedicated piece of land such as settling ponds and drying paddocks for more than 18 months according to National Environmental Management: Waste Act 59 of 2008. This practice is conducted by 33% of the plants within the sample set (i.e. 5 out of 15) due to readily available land in South Africa. In the Netherlands, a company known as Restoffenunie (RU) was founded in 1995 to find sustainable use of WTR from all the treatment plants. During the year 2012, 93% of the residues were disposed of via the RU and 7% by the individual water companies. 95% of the WTR handled by RU is reused with only 5 % being disposed to landfill. In South Africa, it the responsibility for each treatment plant to dispose of the WTR that they generate in a responsible manner. The difference between the two countries is that RU is applying a reuse strategy and in SA the disposal strategy is utilised.

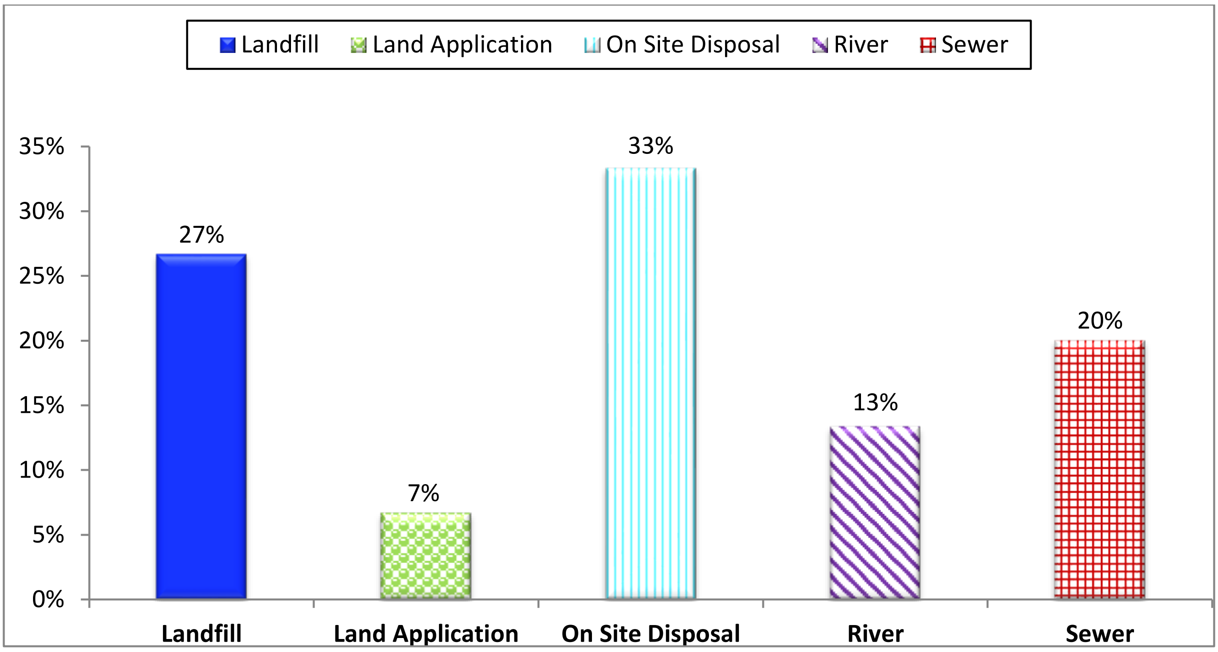

Figure 7-4: Final disposal option

7.3.1.3 *Compliance to legislation*

Compliance to legislation refers to disposal methods that are licenced for disposal. The sample set consists of 53% of the water treatment plants surveyed that were not compliant to NEMWA 2008. Included in the 47% of compliant water treatment plants are those holding landfill and sewer disposal permits. Possible reasons for non-compliance are the following:

- This is partly because settling ponds which are used for on-site disposal are not lined with the HDPE membrane to avoid and minimise groundwater seepage.
- Land application is also not licenced despise all the studies which were undertaken previously. The Department of Environmental affairs was included in the steering committee of this project to give clarity into the licencing procedure.

7.3.1.4 *Transportation to disposal*

With the intention of trying to minimise carbon emissions, transportation is minimised between WTR generating sites and disposal areas (Table 7-1). In 2014 Rand Water submitted a challenge to the innovation hub to find solutions to the WTR management by partnering with other organisations to find a suitable technology or commercialised solution. Previous studies undertaken by Rand Water to solve the challenges in WTR management were not feasible due to transport costs between the storage site and proposed processing or end-user sites (Rand Water, 2014).

Table 7-1: Transportation method

Transportation Method	
Road Haulage	27%
Pumping	33%
On-site (No transport)	40%

7.3.1.5 *Hazardous ratings*

Figures 7-5 and 7-6 shows results of the TCLP and Aqua Regia results for the 15 water treatment plants according to SANS 10234. The obtained results indicate the presence of both manganese and lead in the residue. Figure 7-6 shows that WTR from 93% of the treatment plants contained manganese concentrations above 0.5 mg/L resulting in the WTR to be classified as Eco-toxic. SANS 10234 does not have limits or guidelines for chemicals contained in WTR. These limits were adopted from the national norms and standards for the remediation of contaminated land and soil quality, NEMWA, 2008. WTR was deemed carcinogenic when the lead concentrations were above 20 mg/kg. The classification exercise identified two extremes in the level of WTR toxicity and how they were disposed:

- High levels of mercury in the WTR at plant 4 were disposed of at a Class A landfill at a relatively high disposal cost. The WTR was both Eco toxic and carcinogenic due to lead and manganese.
- WTR from plant 1 had low levels of the indicator chemicals, lead and manganese. The WTR was disposed directly into the river without any pre-treatment.

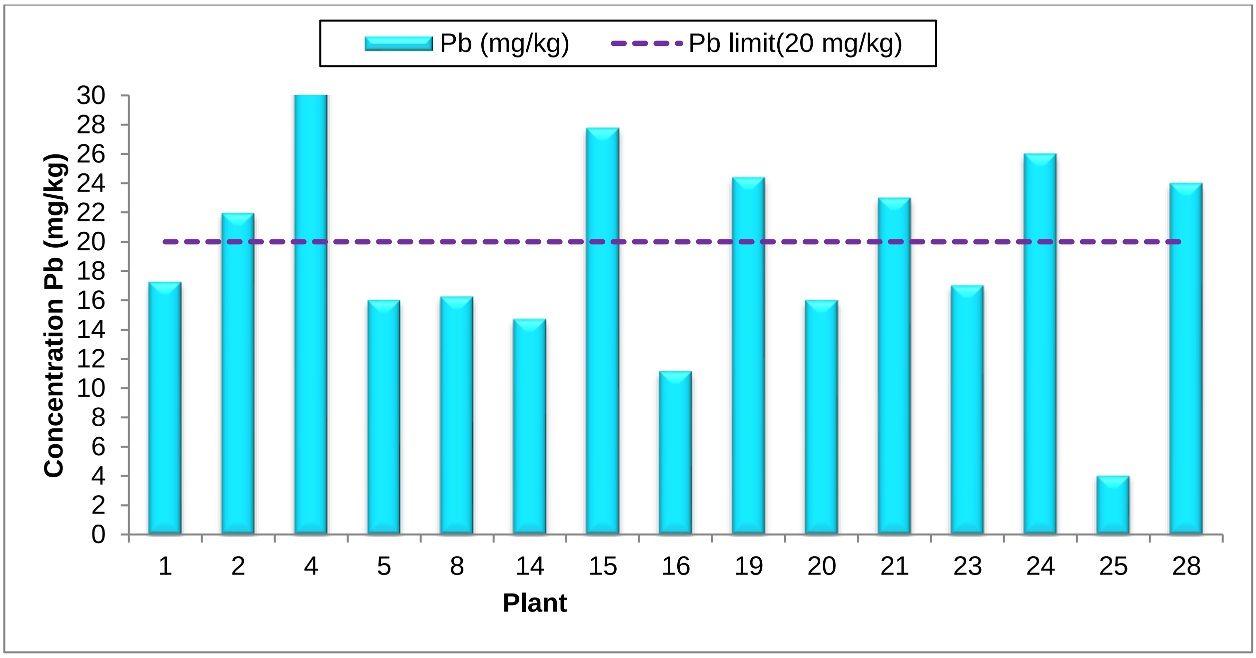

Figure 7-5: Analysis of Lead using Aqua Regia

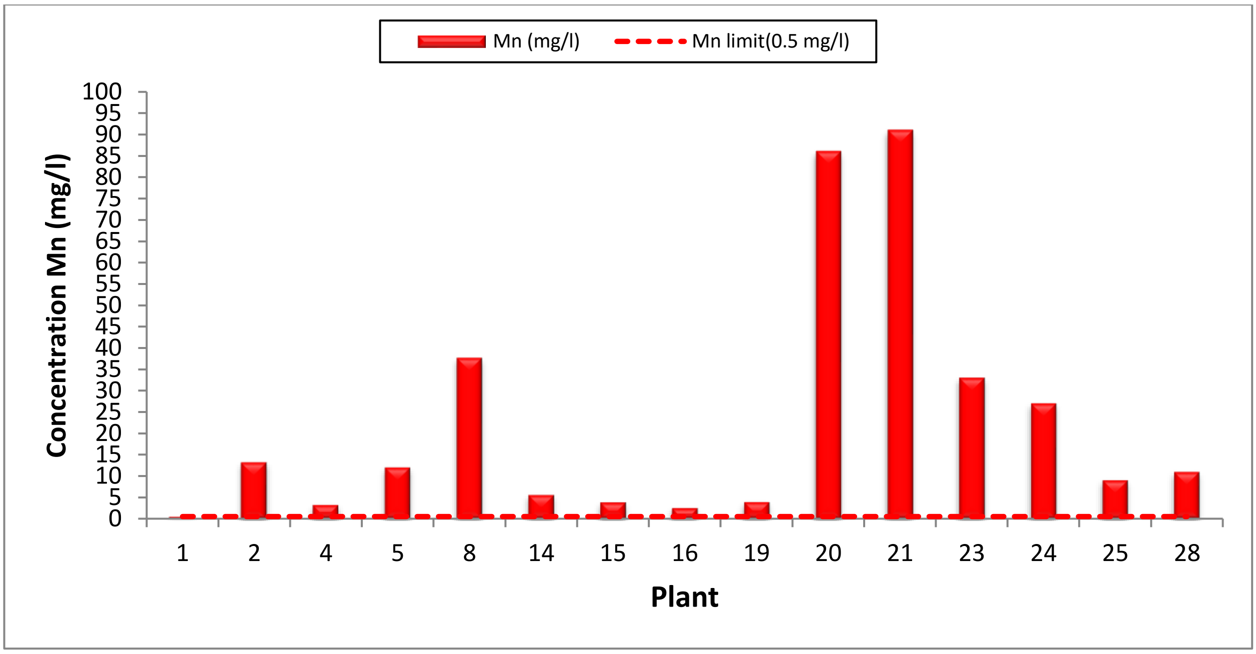

Figure 7-6: Analysis of Manganese using TCLP method

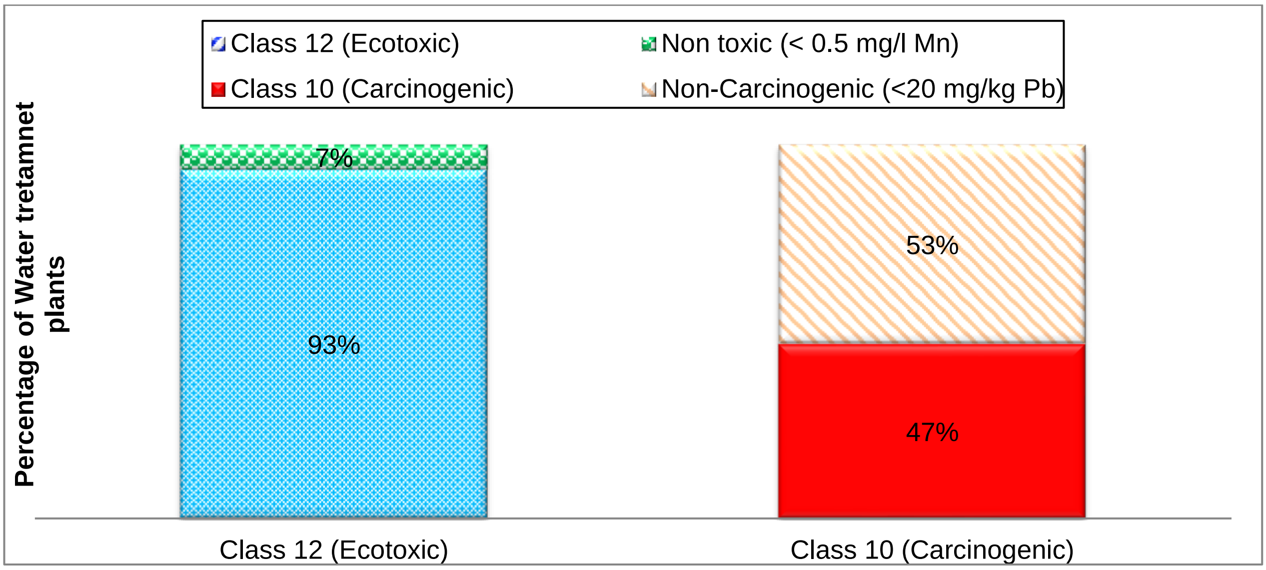

Figure 7-7: The SANS 10234 classifications

7.3.1.6 *Landfill Assessment*

In terms of Regulation 8 of the Waste Classification and Management Regulation, waste must be assessed in accordance with the norms and standards for assessment of waste for landfill disposal prior to disposal. The Waste Classification and Management Regulation requires the total concentrations of constituents as well as leachable concentrations (1:20 deionised water extracts or 1:20 TCLP extracts).

- Type 0 waste is unacceptable and requires pre-treatment prior to disposal
- Type 1 waste is disposed of at a hazardous waste landfill
- Type 2 and 3 wastes are disposed at lined landfill sites

- Type 4 waste is considered to have insignificant impact on the receiving environment

The standard containment barrier design and landfill disposal requirements for different types of waste are indicated in Table 7-2. The flow diagram for waste assessment based on the WCMR.

Table 7-2: Landfill disposal requirements

Waste Type	Landfill Disposal Requirements
Type 0	Disposal not allowed
Type 1	Class A or Hh/HH landfill
Type 2	Class B or GLB+ landfill
Type 3	Class C or GLB+ landfill
Type 4	Class D or GSB-landfill

According to Figure 7-8, 60% of the WTR characterised WTR was found analysed and found to be in the 'less hazardous' (Type 3) category of landfill disposal sites. One plant due to the presence of mercury in the waste is not fit for disposal at a hazardous landfill. This type of WTR poses a challenge for the treatment plant to dispose it safely without any environmental consequences.

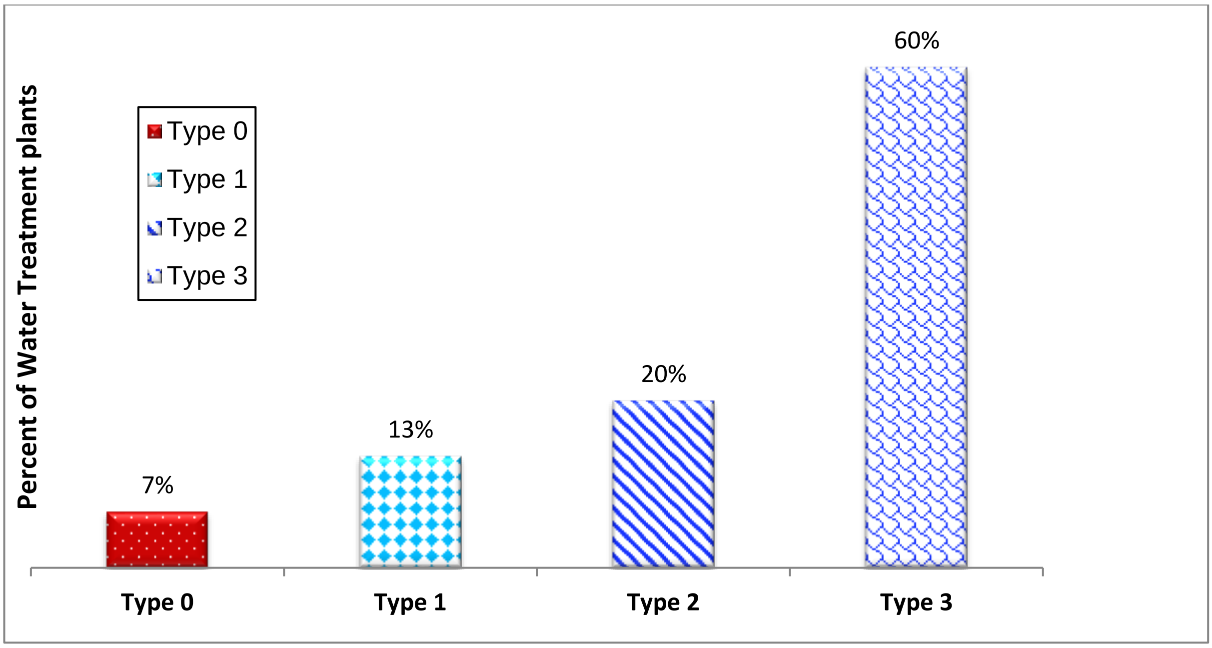

Figure 7-8: Classification of WTR from surveyed plants for landfill disposal

7.3.2 Engineering Indicators

7.3.2.1 *WTR generated per Megalitres treated water*

The pre-treatment method utilised by the water treatment plant determines the quantity of the WTR produced. Thickening and dewatering process produced a concentrated WTR that is small compared to when the WTR is not pre-treated and disposed "as is". From Figure 7-9 and 7-10, about 67% of the WTPs convert less than 5% of the raw water flow into residue. The average for all the plants is 4.9%. The influence of raw water turbidity is also observed on the amount of WTR produced, a direct relationship between NTU and WTR is observed for all plants. An increase in turbidity results in the production of more residues per megalitres of treated water.

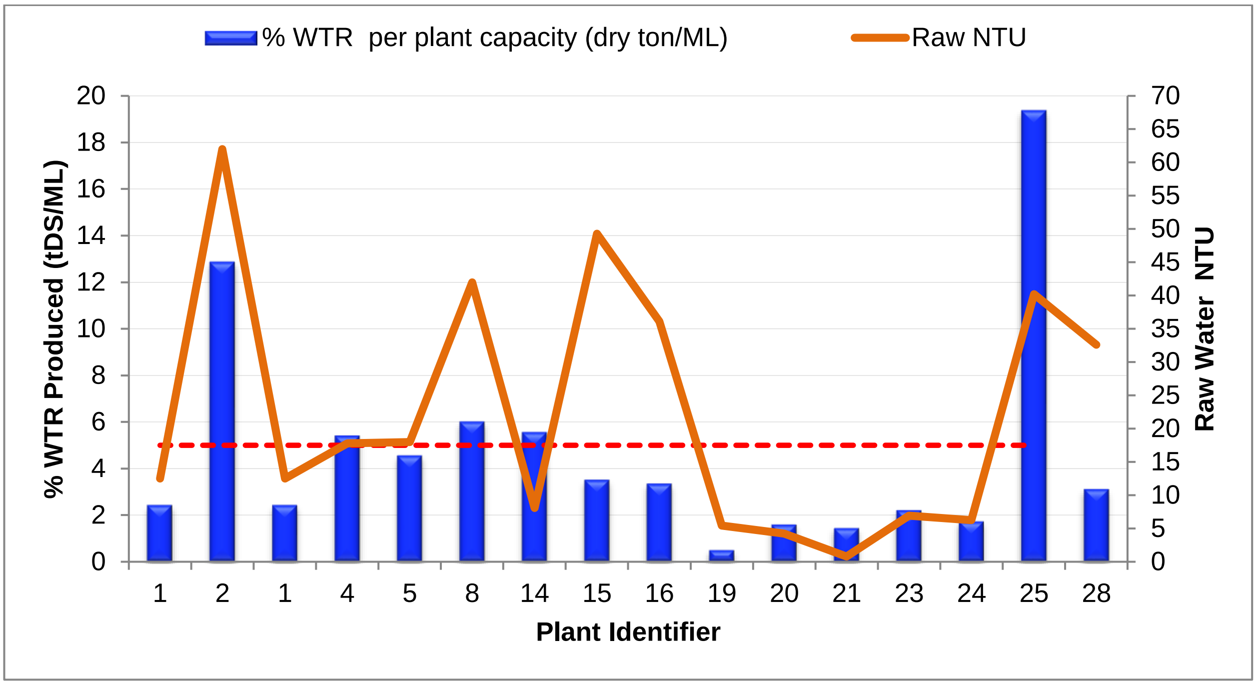

Figure 7-9: WTR produced per plant capacity

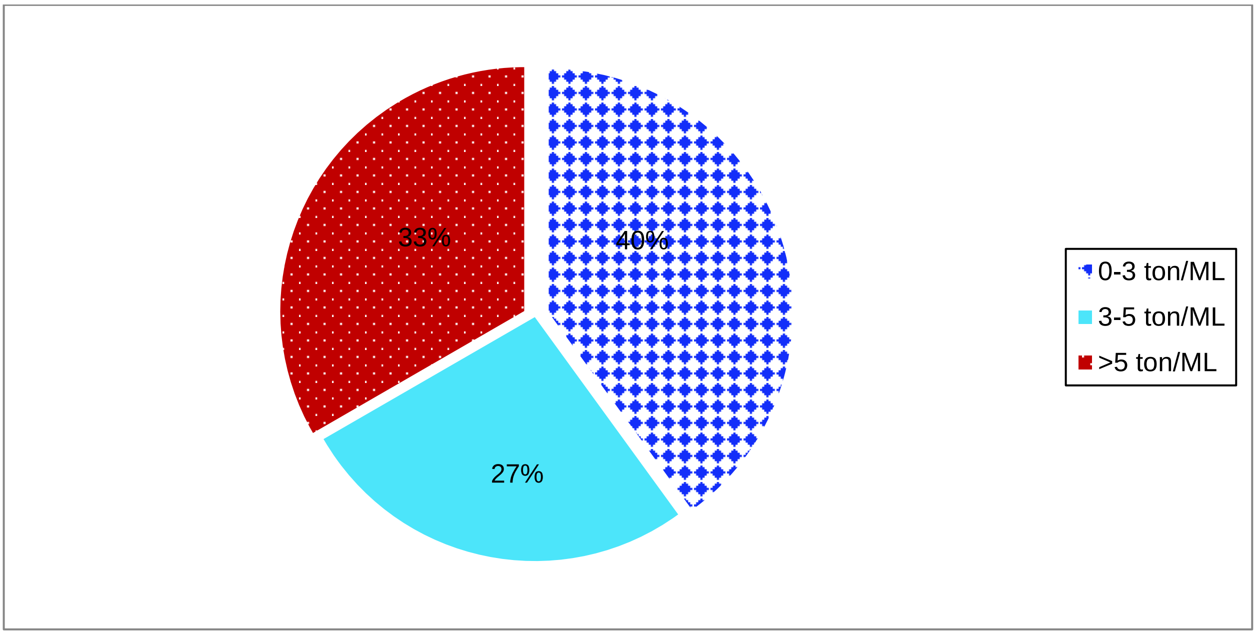

Figure 7-10: Percentage distribution of WTR generation per plant capacity (tDS/ML)

Analysis of plant production data is shown in Figure 7-11. Water treatment plants 4, 8 and 25 produces more than 5% WTR from the raw water inflow into the treatment works. This is indicated when the dotted blue bars are taller than the red bars. The plants (4, 8 and 25) plants utilise settling ponds for WTR Management. Plant 2 was not included in the graphs because about 500 ton of WTR is produced per day and that is not comparable with the rest of the plants due to the magnitude of the residue. The calculation for the WTR using a 5% design capacity for the treatment plants result in an expected residue of only 200 tons per day. This implies that the treatment plants at site 2 produce 40% more WTR than what is expected. This was attributed to the nature of the raw water and the coagulant dosing regimen used during purification.

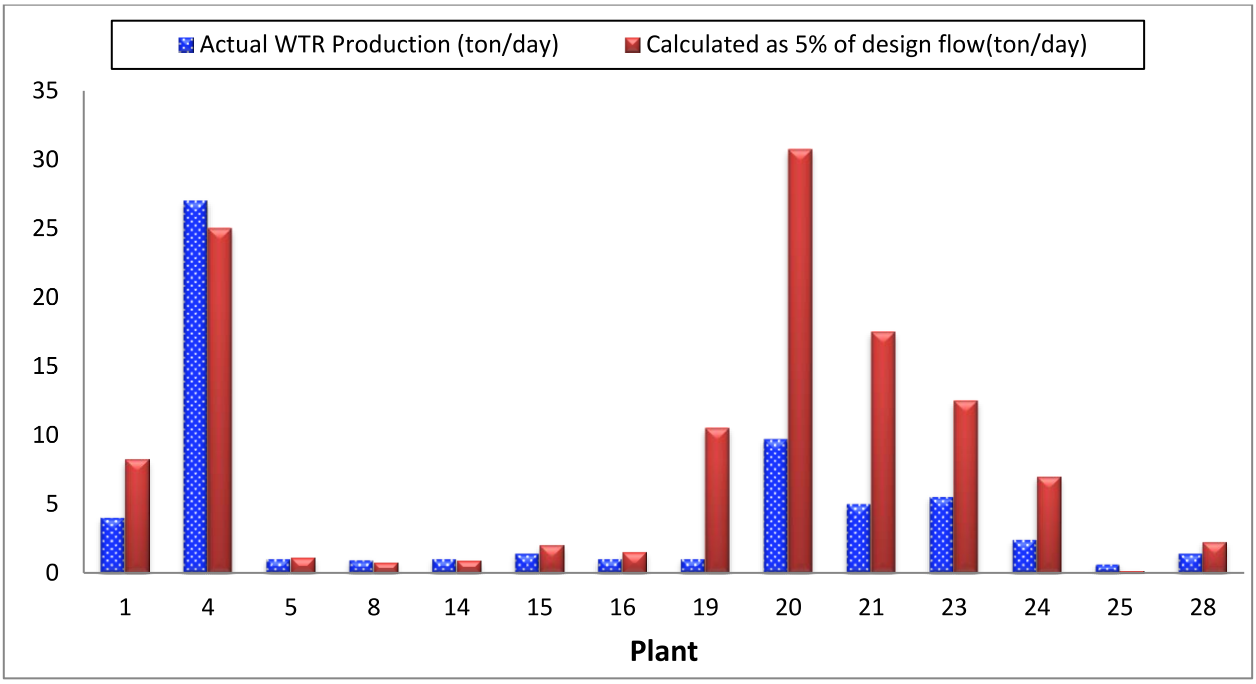

Figure 7-11: Actual WTR vs. Estimated WTR

7.3.2.2 *Unit Processes for pre-treatment*

The unit processes that are utilised include mechanical and non-mechanical, each with the purpose of reducing the liquid content within the residue.

- No treatment: direct discharge to river or sewer
- Pre-treatment: gravity thickening, chemical addition
- Pre-treatment and dewatering: mechanical dewatering and settling ponds

The general form of water treatment residue pre-treatment includes thickening and dewatering and was the most used form in the sample set at 47% (Figure 7-12). Dewatering may be either mechanical with the use of a centrifuge or non-mechanical (settling lagoons or drying beds). The use of both thickening and dewatering involves the addition of a polymer to enhance solid-liquid separation and this cost is included into the pre-treatment budget. The use of settling ponds as a dewatering method alone does not involve the addition of a chemical as the WTR is just pumped into a pond system and allowed to dry naturally. Overall, 73% of the WTP in the sample set are using mechanical methods for dewatering and 27% non- mechanical methods.

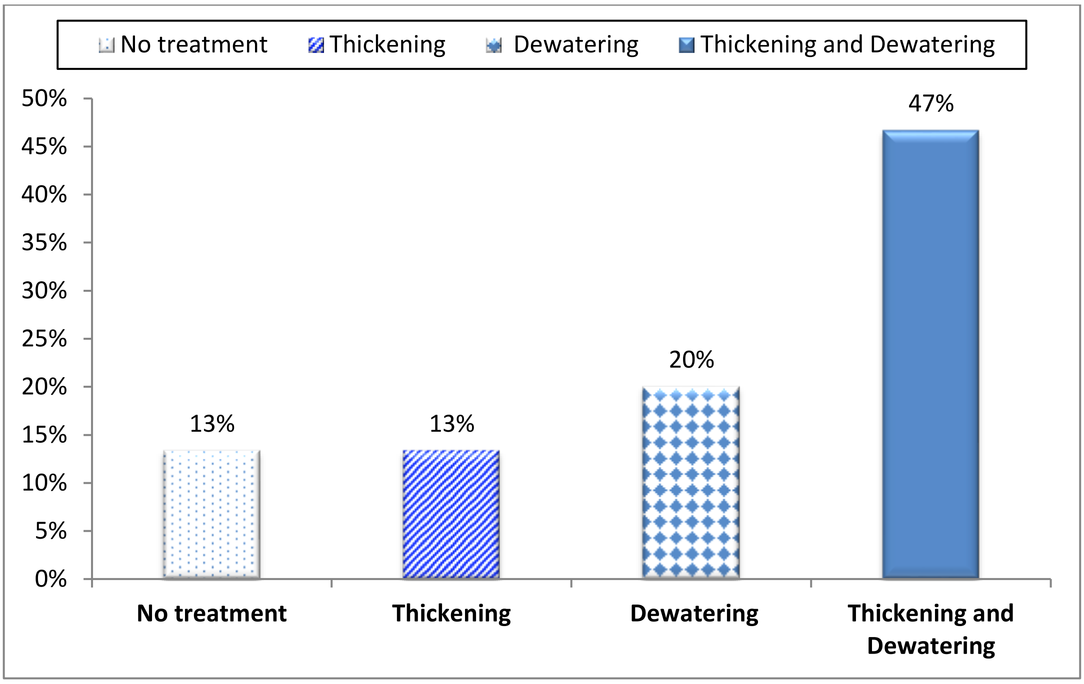

Figure 7-12: Pre-treatment methods

7.3.2.3 *Evaluating Re-use opportunities*

Only 53% of the waterworks and utilities surveyed and visited undertook at least a basic WTR characterisation study (as per the National Norms and Standards for the Assessment of Waste for Landfill Disposal). Half of these went further and performed detailed environmental impact studies while proactively exploring alternate disposal and reuse options.

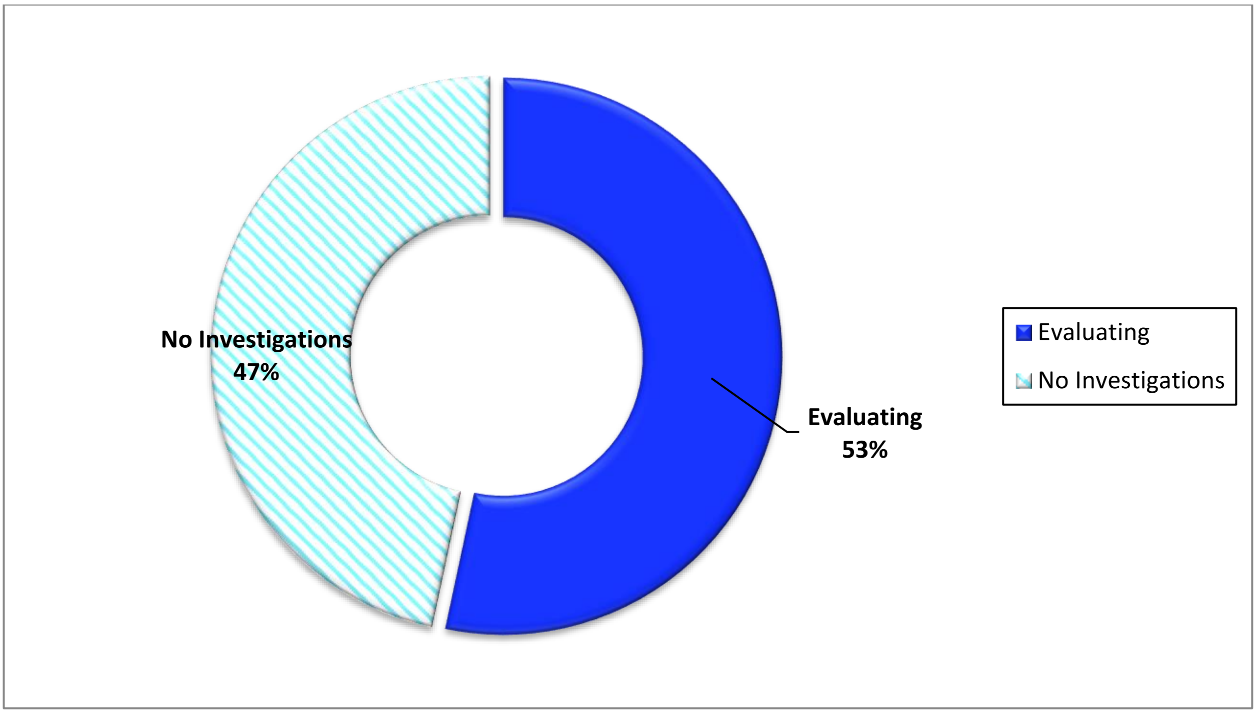

Figure 7-13: Research into alternate WTR disposal and reuse options

The financial and operational impact of the amended legislation had a greater effect on larger bulk water suppliers due to the amount of WTR generated. It was found that only these large water utilities that are investigating environmentally sustainable, economically viable methods of WTR reuse and disposal. They have the financial capability, human resources and technical capability to conduct research. Some of the smaller treatments plants are aware of the need for analysis and dewatering but are not looking at finding solutions for dewatering or reuse because it is not a priority to them. From the sample set three plants were investigating reuse opportunities and one was investigating land application.

7.3.3 Financial Indicators

7.3.3.1 *Plant Disposal Costs*

Disposal costs were inclusive of pumping costs, chemicals costs, transport costs and other overheads and this influences the total cost of managing WTR as a by-product of water treatment. Figure 7-14 indicates the disposal costs of the 15 water treatment plants and the costs are very variable from R0 to the most expensive at around R4000 per ton. Three WTP, with disposal costs above R1000, were disregarded as the costs were assumptions from the WTP personnel and could not provide documentation for the given values. The treatment plants with verified costs are those below R1000 ton. The disposal of a ton of WTR onsite in drying paddocks after thickening costed R88 per ton. Land application at a dedicated piece of agricultural land costs R178 per ton and disposal at a hazardous landfill costed one plant R710 due to the mercury content in the WTR. To verify and compare the WTR management costs that were obtained from the site visits, unit operational costs were calculate at a cost per ton production (Figure 7-15). An average was calculated for similar disposal options and this indicates some correlation in some management options and no-correlation in other options. Documentation of WTR related costs need to be encouraged on a national scale to apply the developed benchmarking criteria with more accuracy.

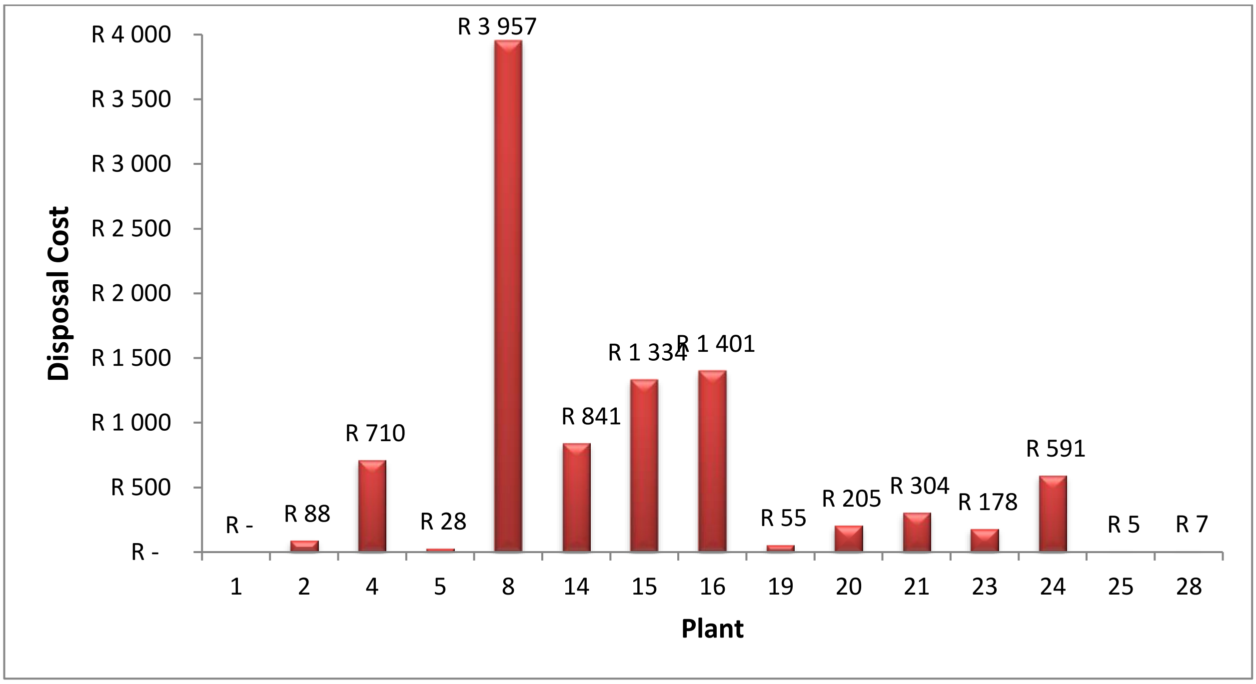

Figure 7-14: Plant disposal costs (R/ton)

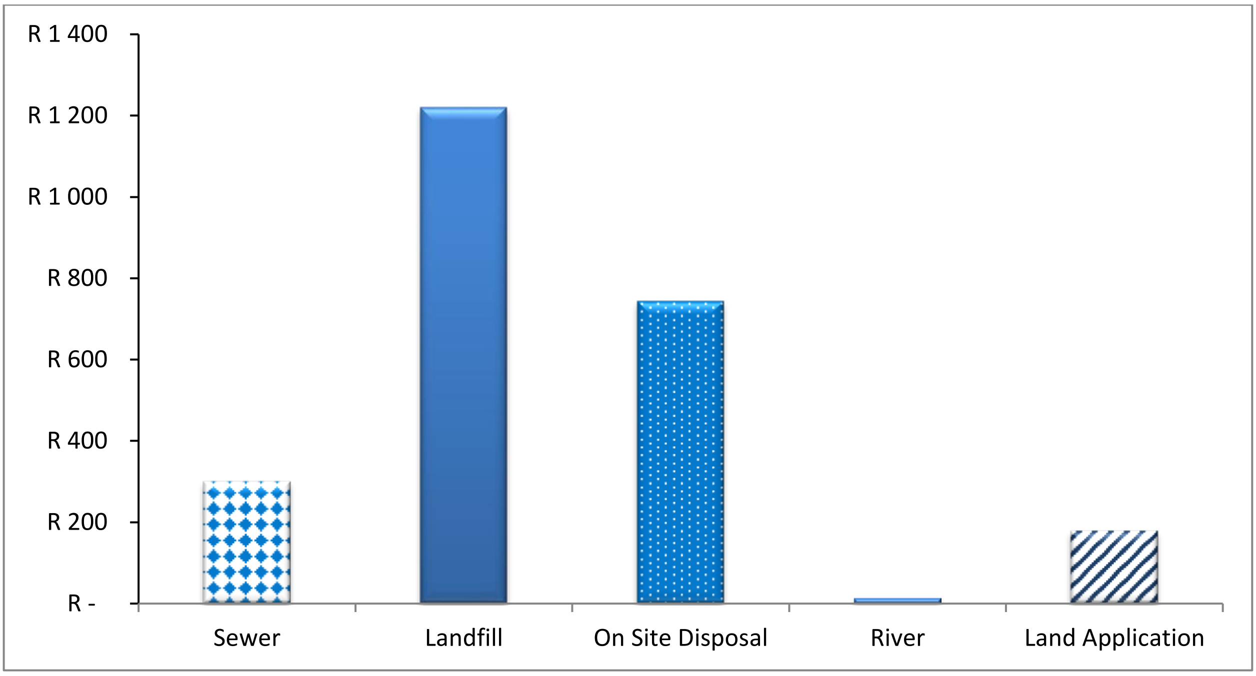

Figure 7-15: Water treatment residue disposal cost per ton (R/ton)

7.3.3.2 *Unit Electricity Costs*

The absence of specific operational costs from the site visits prompted the project team to consider design information pertinent to the equipment. This is discussed using cost to give estimates into the operational costs by assuming all the equipment was properly maintained. In the calculations, an electricity tariff of R1.446 per kilowatt hour is assumed using the 2015 Eskom tariffs (Table 7-3).

Table 7-3: Unit energy consumption

Equipment (@ 1 ton/day)	kW	Operational Hours per day	kWh	R/kWh	Cost per day	Cost per month	Cost Per annum
Thickener	2.2	24	52.8	1.446	R 76	R 2 290	R 836 019
Centrifuge	30	8	240	1.446	R 347	R 10 411	R 3 800 088
Coagulant pump	3	12	36	1.446	R 52	R 1 562	R 570 013
Coagulant tank stirrer	2.2	24	52.8	1.446	R 76	R 2 290	R 836 019
WTR transfer pump	11	8	88	1.446	R 127	R 3 817	R 1 393 366
Stirrers/motor	3	24	72	1.446	R 104	R 3 123	R 1 140 026
Total	51.4	8	411.2	1.446	R 783	R 23 495	R 8 575 532

7.3.3.3 *Transportation Costs*

The transport costs associated with a 7m^3 skip that is used to transport water treatment residue from the site to the landfill disposal site (Table 7-4). Transportation costs are dependent on the distance from the WTP to the landfill site.

Table 7-4: Transportation Costs

Transport	
Transport per load	R 1 110
Tipping fee per ton	R 490
Bin Rental per month	R 480
Cost of chemicals required per skip	R 220
Cost of 1 skip	**≈R 2 300**

7.3.3.4 *Classification Costs*

The classification of WTR for either land application or landfill disposal should be conducted before the waste is disposed. The cost of a full physical, chemical and biological analysis costs approximately R20 000 from an accredited ISO 17025 laboratory.

7.3.3.5 *Estimation of WTR Management Costs*

Land application is being used by a few plants in the country and should be further investigated (Figure 7-16). Another option that is not considered and should be explored is the beneficial reuse of WTR for other purposes. There is still room for improvement in terms of WTR management to achieve best practice scores and the "*Guidelines on best practices of WTR management*" can be used in the selection of a best management strategy.

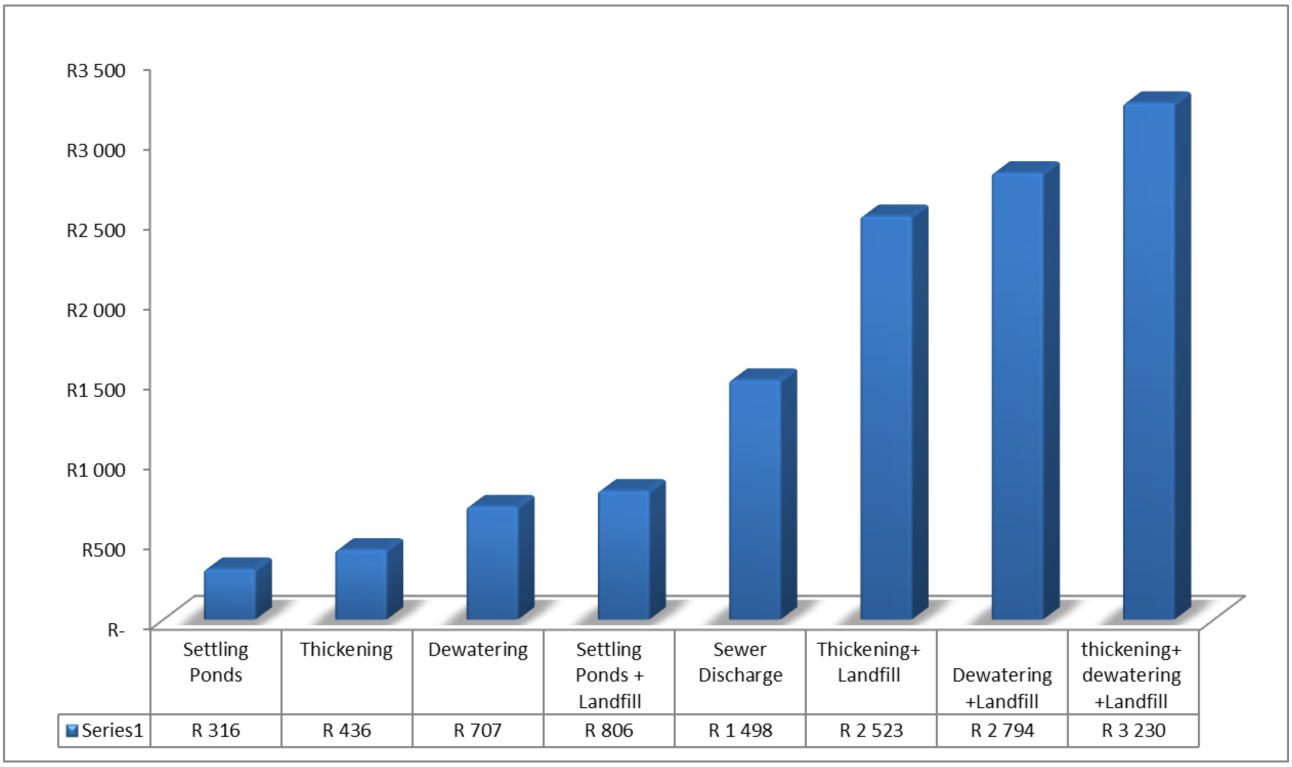

Figure 7-16: Estimation of WTR management costs (R/tDS)

7.4 CHALLENGES

WTR handling and management is not a closely monitored activity so very few records regarding WTR are kept. Since WTR generation, handling and disposal is not monitored water treatment managers could not provide the required information. Some provided unverifiable information and others did not want to divulge information that they did record as they were not sure if their management activities were contravening legislation. The use of surveys to collect data could lead to data gaps, collection of erroneous data, inconsistency in data definition and a low response by participants. To mitigate these challenges water treatment managers should be given a set of performance indicators that should be recorded together with operational data. They should be encouraged to participate in inter-plant benchmarking to help in the performance management of WTR nationally.

7.5 SUMMARY

The correct selection of performance indicators is crucial to ensure that benchmarking is successful between different water treatment plants. The data that is compared should be easy to collect and should not create more work for WTP personnel as there are plants that are sometimes under resourced. From the blue drop list it was noted that the majority of treatment plants are below 50 ML/d and generate a small quantity of WTR. These plants are generally managed by the municipality and account for 86% of the national WTPs.

This benchmarking exercise provided a snapshot of the current challenges faced by plant managers of both medium and large national water treatment plants regarding WTR management. Larger water utilities have the financial capacity to get involved in looking for solutions to safely dispose or reuse the WTR in an environmentally acceptable way whereas smaller water service providers are not able to get involved in any studies.

From the sample set 53% of the plants were not compliant to legislation and some of these plants were operated by water utilities that have the capacity and resources to investigate alternative methods of WTR reuse and disposal.

Extrapolation from the sample set to national this indicates that WTR is a major issue that was continually being ignored. The inclusion of WTR management into the blue drop status is a useful intervention that will help in ensuring that WTR is properly managed.

The following were observed during the execution of the project:

- Water treatment disposal always required a unique solution specific to the location and water treatment plants concerned
- Benchmarking is a tool that offers the opportunity to improve the performance of the entire water sector.
- Major source of raw water abstraction is surface water and this affects the quality of the resultant WTR quality due to contaminants in the raw water
- Onsite disposal is the most favourable disposal method due to availability of land and this result in 53% of non-compliance of WTR disposal to legislation due to use of unlined ponds according to standard containment barrier design and also a lack of permits.
- The use of storing WTR onsite or disposal should be discouraged as most plants use this method as the final disposal option without acquiring the necessary permits and WML
- There is correlation between the quantity of raw water treated and the amount of WTR produced with an average of 4.9%
- The use of landfill as a disposal method results in increased costs for WTR management because of the costs incurred during pre-treatment when mechanical dewatering is considered

The SANS 10234 classification indicates that 60% of the WTR is rated as type 3 which can be disposed of at a class C landfill. However, the presence of manganese and lead in the WTR makes the residue to be classified as Eco toxic and carcinogenic respectively. One treatment plant WTR is classified as a type 0 wastes due to the presence of Mercury in the residue, and this causes the WTR to be disposed at a hazardous landfill at a cost of about R710/ton.

A recommendation for land application practices is to consider the inherent metal concentrations in the soil and then compare them with the concentrations from the residue. That way the contribution of the WTR on soil physical and chemical characteristics will be clearly comparable instead of using the limits from the NEMWA norms and standards.

The work involved in this research produced valuable insights into the benefits of benchmarking for performance evaluation of drinking water utilities, even though the data for indicators obtained through the data collection process was limited. Plant managers are encouraged to keep record of activities happening at entire value chain from source to tap and the resultant waste produced instead of focussing only on the treatment process parameters. This way a holistic management approach of the water supply chain is enforced and sections of the process such as WTR management can be effectively managed as individual process entity. This can then be included in the budget when planning for treatment plant cost management.

CHAPTER 8: A STRATEGY FOR INTEGRATED WATER TREATMENT RESIDUE MANAGEMENT

8.1 INTRODUCTION

An integrated WTR management system considers the impact of WTR across the whole water value chain. It is also based on the premise that WTR management is the responsibility of all stakeholders including water treatment practitioners, Government and civil society. Figure 4-1 indicates a generic WTR management strategy framework to help water treatment practitioners to develop their own management strategies. Commitment at all levels of the value chain including all stakeholders is pivotal to the success of any WTR strategy. Before anything can be achieved a mind-set, change is required in the water sector. Water treatment residue must be viewed as a by-product and not a waste. If waterworks are designed for both potable water production and to reduce WTR while ensuring a physically and chemically consistent, higher value WTR, then WTR management will become sustainable.

8.2 MANAGEMENT OPTIONS

A water treatment residue management strategy determines the criteria around which a management activity is chosen. From discussions with South African utilities it was established that the major criterion for WTR management is cost reduction. In the Netherlands where, environmental impact and sustainability are the highest weighted criteria WTR management is moving to reduction and reuse, and away from disposal. In South Africa, currently there are only three WTR management activities in use, namely disposal, storage and land application. With recent legislation review, other innovative ways identified such as reuse should be identified and storage minimised.

8.2.1 Selection of Residue Management Plans

Developing a successful management plan requires an understanding of the value of residue characterization and the regulatory requirements, tailoring the treatment options to the requirements of the available disposal alternatives, and then developing rational evaluation criteria. The technical criteria used to select the final management plan differ from user to user; economic, cultural, social, and environmental factors are also site-specific and are typically included in any final selection (Figure 8-2).

The first and most favourable approach for achieving sustainable management would be for water service providers to optimise the water treatment processes for reducing the amount of WTR produced.
This could be achieved by:

- Optimising the source water intake conditions that will provide the best possible raw water quality (i.e. reduced suspended solids) to be treated
- Optimising pH to reduce amount of chemicals used
- Optimising the filtration process and filter media
- Returning backwash water to head of works
- Considering waste generation when selecting treatment chemicals

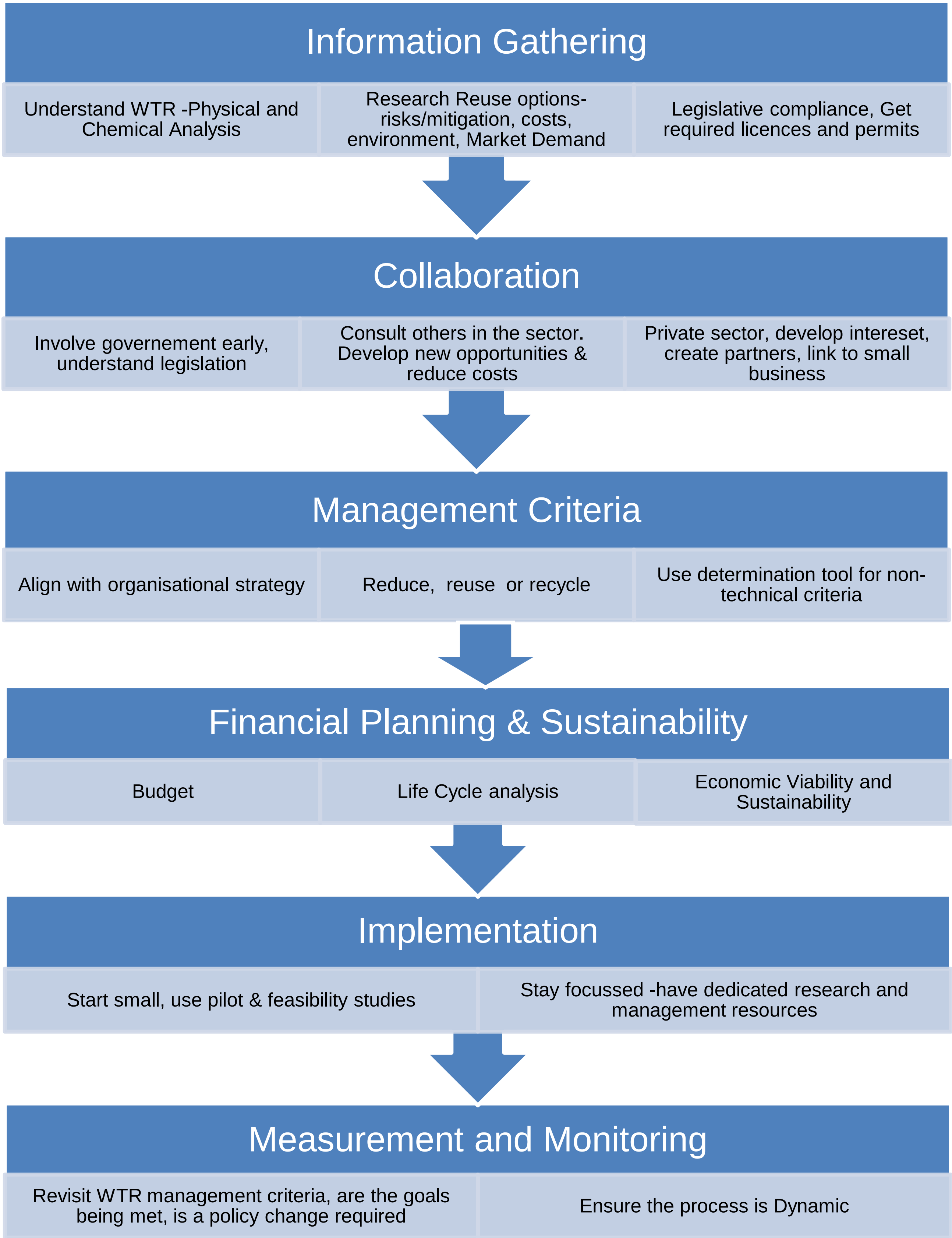

Figure 8-2: Schematic showing considerations for developing a successful WRT management plan

8.2.2 **Factors to consider when selecting a management strategy**

Aspects that the utility will have to consider deciding if chosen management strategy is truly a viable option include: (AWWARF 1996)

- Distance to end user (this greatly impacts total costs, since transport is expensive)
- Residue application design (how to apply or reuse the WTR)
- Agricultural methods
- Storage of residues
- Application rates
- Monitoring and reporting

In many cases, small systems may find that using liquid residues for irrigation could be a beneficial reuse alternative. Liquid applications are only economically attractive when application sites are within proximity to the water treatment plant, or if relatively small quantities of residues are generated.
The cost effectiveness of residue handling can be very site specific and key factors include:

- Waste volumes
- Waste characteristics
- Cost impacts of sewer discharge at WWTP
- Tipping costs for disposal at landfill
- Distance from WTP to landfill
- Polymer dosage requirements

Water quality requirements in receiving body of water

8.2.3 **Aspects of Monitoring and Quality Assurance**

Continuous monitoring of WTR would assist with defining the quantity and quality of the residue. Plant records over a one-year period are desirable to characterise WTR and use for future predictions. In the absence of reliable data, the most conservative data or assumptions available (worst-case scenario) should be used for quantification. Long-term variation of the raw water quality should also be considered since it influences the quality and quantity of the WTR generated.

WTR handling and management is not a closely monitored activity so very few records regarding WTR are kept. Since WTR generation, handling and disposal is not monitored water treatment managers could not provide the required information during the site visits. Some provided unverifiable information and others did not want to divulge information that they did record as they were not sure if their management activities were contravening legislation.

The use of surveys during data collection lead to data gaps, collection of erroneous data, inconsistency in data definition and a low response by participants. To mitigate these challenges water treatment managers should be given a set of performance indicators that should be recorded together with operational data. They should be encouraged to participate in inter-plant benchmarking to help in the performance management of WTR nationally. Waste generators are mandated by law to keep records for 5 years, including details of the waste manager when transferred.

8.4 DEVELOPMENT OF WATER TREATMENT RESIDUE MANAGEMENT PLAN

The following steps need to be considered when developing a comprehensive water treatment residue management plan (Figure 8-3).

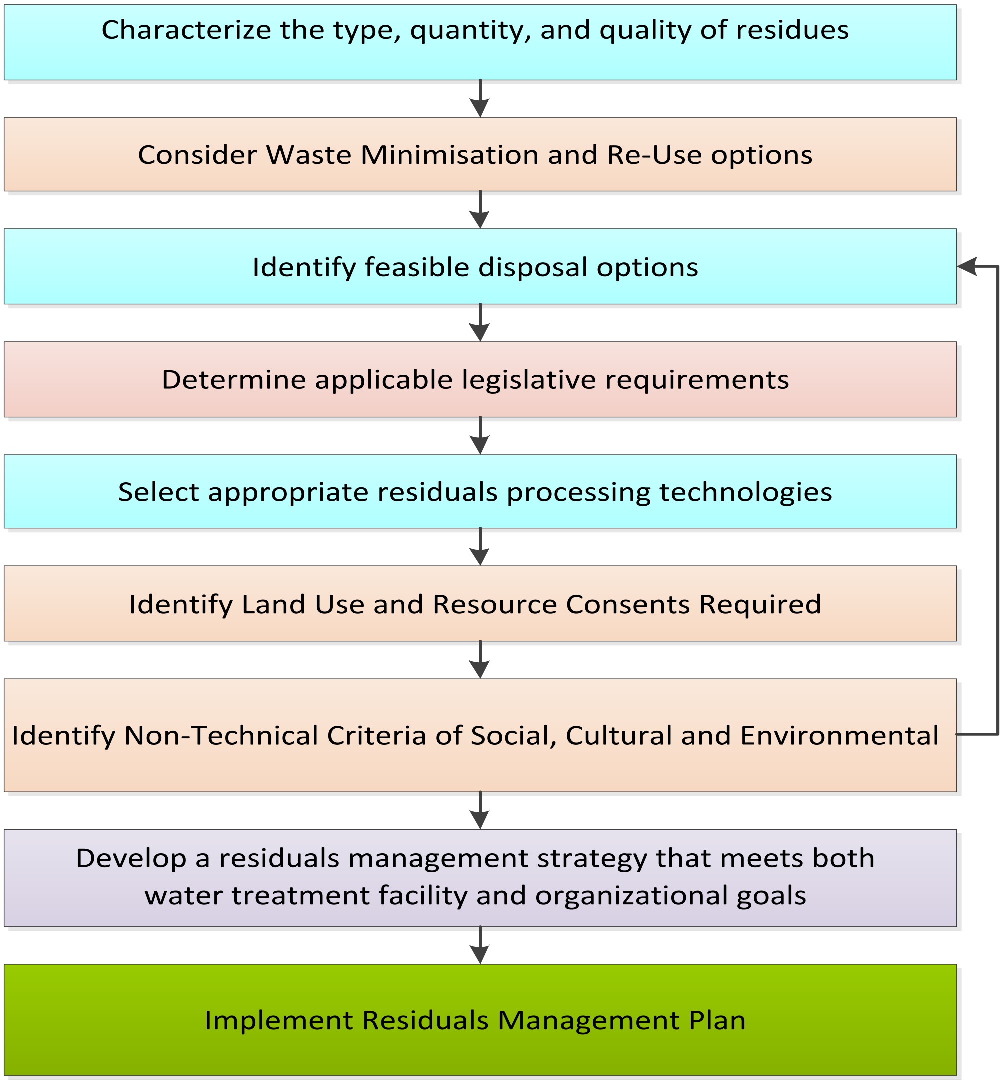

Figure 8-3: Process for developing a residue management plan

8.4.1 Water Treatment Residue Characterisation

To assess how to manage WTR, the following must first be established:

- Whether the residue produced are solids or liquids
- Chemical and physical characteristics of the material
- Quantity of material produced

A detailed characterization of the residue to be disposed is required in terms of quality (key constituents of concern) and quantity (flow or volume) data with statistics (minimum, maximum, average, rate of change/variation).

8.4.1.1 *Characterisation of WTR (solid or liquid)*

The type of coagulant used during the coagulation process affects the characteristics of the WTR generated and impacts which disposal options are feasible.

Table 8-1: WTR waste stream types

Process Type	Waste Streams	Contaminant Categories	Disposal Method
Coagulation	Aluminium or Ferric hydroxide Polymer, Lime, Polyaluminium chloride, Activated Silica, PAC residue	Metals Suspended solids, Organics, Radionuclides, Biological, Inorganics	Landfilling Disposal to sewer Land application Surface discharge Re-use options
Filtration	Filter backwash water	Metals Suspended solids Organics Biological Radionuclides, Inorganics	Recycle to head of works Surface discharge (disinfection) Disposal to sewer

8.4.1.2 *Composition and type of residues*

A lengthy discussion is given about classification of waste in Chapter 6, the procedure is given in Figure 8-4.

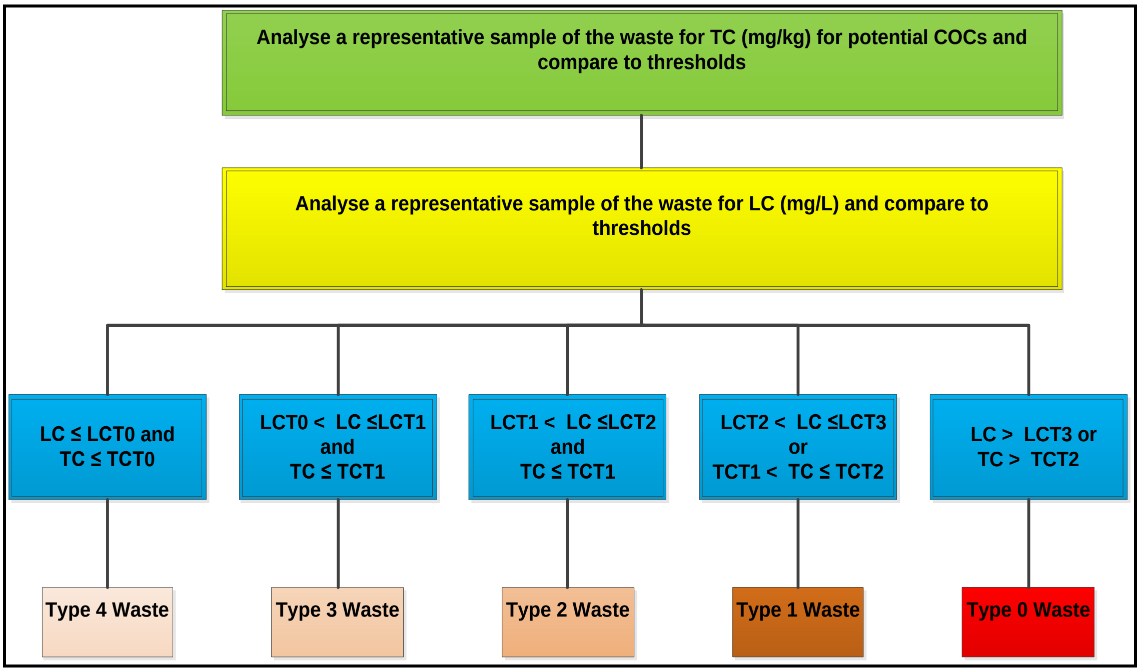

Figure 8-4: Flow diagram for waste assessment based on the Waste Classification and Management Regulation

8.4.1.3 *Cost of sample analysis*

The cost of analysis for WTR in accordance with the National Environmental Management Waste Act No. 59 of 2008 is approximately ±R20 000 per sample for the suite from an accredited laboratory. This includes the analysis of:

- Physical characteristics (pH, TSS, total VOC, sVOC, Volatile fatty acids)
- Nutrients (Total Kjeldahl Nitrogen, Total Phosphorous, Potassium)
- Metals & micro elements (TCLP, Heavy Metals by ICP-MS and Aqua-Regia digestion)
- Organics, pesticides & herbicides (Poly aromatic hydrocarbons, BTEX, PCB, chlorinated pesticides
- Microbiological quality (Helmith Ova, *E. coli*, Coliforms)

Each sample must be submitted in the correct sample container for different kinds of analysis and the volume of the WTR required for analysis must be communicated with the testing laboratory.

8.4.1.4 *Quantity of WTR Generated*

Estimation models given in Section 6.2 are useful to predict the amount of WTR generated. An example on how to use one of the equations is given in Appendix D.

8.5 WASTE MINIMISATION AND RE-USE OPTIONS

According to the waste hierarchy Figure 1-1 , waste generation must be reduced as much as possible. The trend should therefore be to replace WTR disposal with WTR reuse and where possible design water treatment plants with to reduce WTR generation. The project findings suggest that there must be a mind-set change across the water industry value chain and its stakeholders in treating WTR as a reusable commodity rather than a waste. The ability to reuse WTR is site specific depending on logistics, WRT characteristics, volumes, etc. Minimisation of impacts: Where complete pollution prevention is not possible, ensure that all management measures are in place to minimise impacts on the surrounding environment, especially water resources.

8.5.1 Reduction of Quantity

The volume of WTR requiring disposal can be a major issue if temporary storage capacity onsite is limited and volume is large (Figure 8-5). Mechanical dewatering can increase the solids concentration and reduce the volume.

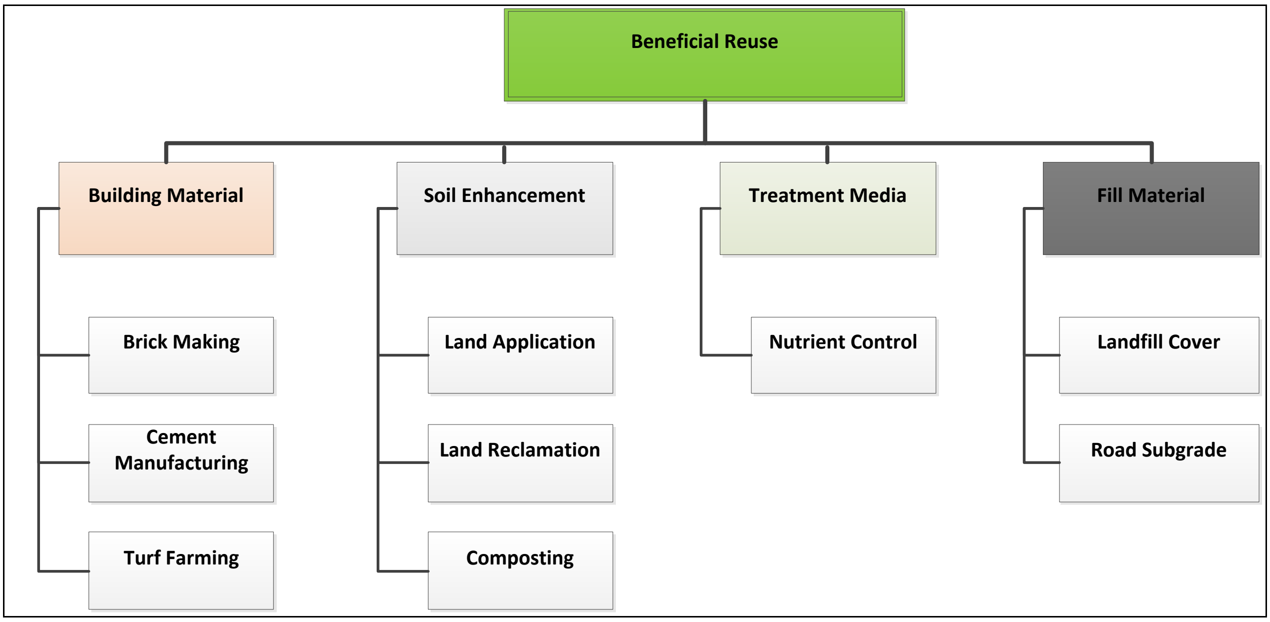

Figure 8-5: Organisation of Reuse options (adapted from USEPA, 2010)

Table 8-2: Summary of reuse options

Specific Use	Advantage	Disadvantage	Criteria
		Wastewater Treatment	
Coagulant Reuse	No disposal costs Sludge volume reduction	High cost capital and operational costs. Contamination through impurities. Complex process.	• Can replace Bentonite usage in plants with low turbidity raw water • Alum Coagulant • Iron based coagulant
As an influent	Known to help with settle ability and pollutant removal	Dilution of WWTW influent so WTR.	• Increased load on WWTW but is a reasonable option. • WTR metal analysis required • Available plant loading capacity
As conditioner or absorbent	Research has shown potential in these uses	Transportation of WTR Lab scale research done	• More research required • Polymeric coagulant
As constructed wetland substrate	Enhance phosphate removal, increased process efficiency	Operational logistics Increased capital cost	• Research was done on a small scale, internationally. • More local research required •
		Building and Construction	
Brickmaking	Sustainable source of material.	Variable WTR Characteristics Technically viable, hard sell to manufacturers. More research required.	• blocks can be produced with sandy soil with clay content between 5-20% • Silts with low clay content below 10% will be difficult to handle • Soils with a high clay and silt content above 35-40% will need to be blended with a sandy soil • Distance from WTP to manufacture
Cement Manufacture	High solids concentration Similar chemical characteristics to clay (internationally)	Risk of upsetting the cement process.	• Can explore different avenues for low cost housing as a cement type plaster. • WTR metal analysis required

Liners for sanitary landfill, geotechnical material	Reduced material cost	Variable WTR Characteristics	• Requires more research
		Land Based Applications	
Land reclamation	Improved water retention and soil conditioning. Effective P reduction in laden soils	Risk of leaching metals, phytotoxicity	• Legal implications and long-term effects • WTR metal analysis • High lime content • high clay content
Land Application	Low cost disposal	Possible environmental effect	• Requires analysis of metals • Heavy metals and organic contaminants • Lack of agricultural land within viable distance • Community resistance to such applications • lime concentration • agricultural lime requires 70% calcium carbonate by mass

8.6 WATER TREATMENT RESIDUE DISPOSAL OPTIONS

The intention of this guideline is to provide a strategic framework and not a detailed discussion on disposal options, but rather to provide sufficient information to assist with the decision-making process (Figure 8-6). The selection of an appropriate management strategy is site specific and considers of the resulting residues to be disposed. It is thus important to also consider the different pre-treatment technologies available at this stage and identify appropriate waste disposal and/or management options (including monitoring) for all the waste streams. The management costs associated with each strategy include disposal cost (based on volume for untreated residue and on mass for treated WTR) and transportation cost (distance to transport to final disposal site). This also includes the WTR characterisation costs that will dictate the appropriate area for disposal. Risks associated with the disposal of WTR relate to stability, disposal site design and location, the constituents of concern in the WTR and their hazardousness, possible groundwater pollution, pollution of surface runoff as well as valuable land surface area utilised for surface disposal. Contact of disposed residue with water (ground and surface) should be prevented or where prevention is not possible be minimised as per waste management hierarchy. Thus, the disposal site should be above the groundwater table, underlain by an impermeably layer (synthetic liner) or layer of low permeability (unfractured bedrock or clay) and contoured and capped following closure. The management options applicable for South African conditions are either on-site within the treatment plant or off-site on dedicated land. The following are possible disposal options for the potable water treatment residue:

a) Land application to agricultural land, forests and for land reclamation
b) On-site disposal on dedicated land or in lagoons
c) Off-site disposal on landfill including:
- Co-disposal with municipal solid waste;
- Use as daily landfill cover;
- Mono-disposal of WTR; and
- Co-disposal with wastewater sludge

d) Discharge of WTR to a wastewater treatment plant (WWTP) via sewer line
e) WTR reuse - although WTR do not have the inherent fertilizer value of wastewater sludge, the following reuse alternatives can be considered:
- Recovery of coagulants;
- Use in making bricks and Portland cement (high solids)

f) The direct discharge to source stream is not encouraged since it is not an environmentally responsible management option.

On-site in settling ponds: Can be used for low strength streams with small volumes. Discuss ultimate destiny and liability with authorities. Clarifier/thickener WTR can settle and the treated water is decanted for reuse to the head of works or discharged. Additional pumping costs should be considered for the decanted water. *This is for temporary purposes as legislation permits on-site storage for only 90 days.*

- The soils with clay content <20% should not be considered for storage unless the site is to be lined and soil pH should be maintained above 6.5.
- Depth to aquifer must be greater than 5 m
- Distance from surface water/borehole must be greater than 200m.

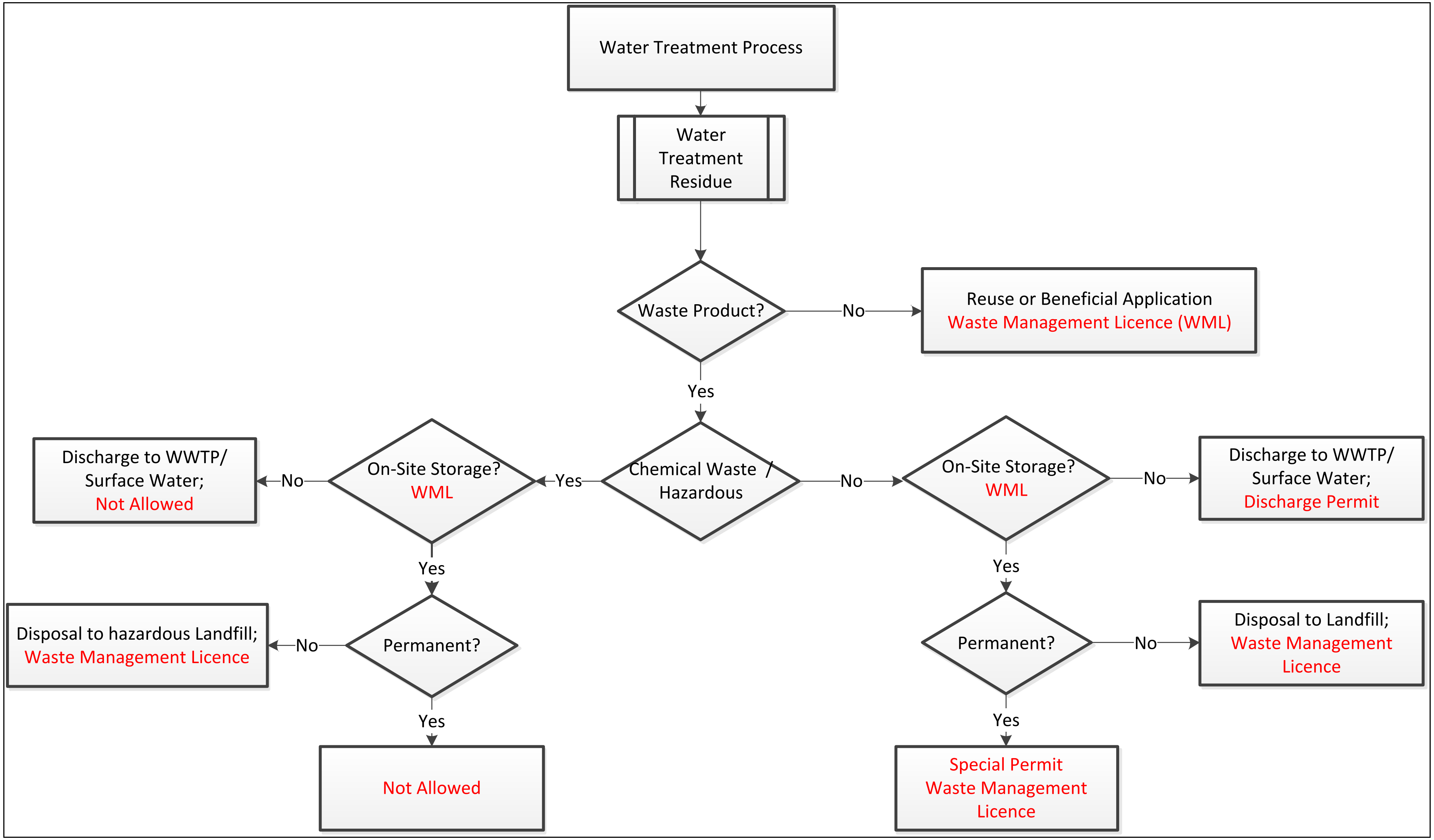

Figure 8-6: Procedure for waste disposal selection

Off-site: Smaller quantities and hazardous waste types should be disposed to an authorised waste disposal site in the area. Disposal cost depends on volume of WTR to be removed and transported, the distance to be transported and disposal cost (tipping fees, depending on volume and toxicity). The solids content of a residue is one of the criteria used to define the acceptable limits of a disposal option. This is used in conjunction with the characterisation of the WTR. The common methods of WTP residue disposal used in the water industry and the required solids concentrations for disposal are indicated in Table 8-3 below.

Table 8-3: Solid content requirements

Residue Disposal Options	Residue Solids Content %
Land application	1-20
Landfilling	> 20
Direct stream discharge	0.2-8
Discharge to sewer	0.2-8

8.6.1 Closure and remediation plans for disposal sites

Once the operation of a disposal site has ceased or after WTR is removed for onsite storage and taken to permanent disposal duty of care applies to ensure sustained acceptability of the storage site. Remediation and closure plan is required for all sites and should be developed by a responsible person. Aspects that should be addressed include:

- Remedial design to address identified problem areas (or future problems);
- Size of the disposal site (localised waste pile or large area irrigated with WTR);
- Extent of pollution – sites where metals have not migrated down the soil profile will require a less complicated rehabilitation plan than sites where groundwater contamination has already occurred;
- Future land-use;
- Final landscaping and re-vegetation;
- Permanent storm water diversion measures, run-off control and anti-erosion measures; and post-closure monitoring plan and implementation.

8.6.1 Land Application

Application of drinking water treatment residues is being considered because of the high cost of other disposal methods. Options available for the land application of drinking water treatment residues include agricultural use, silvicultural (forest) and for land reclamation. During the implementation of land application as a management strategy; parameters such as pH control, crop selection and availability, application rates, and fertilizer requirements must be included in the management planning. The required procedure to be followed when implementing this strategy is outlined in Figure 8-7. When considering land application, the initial characterisation is done to evaluate the inherent metal concentrations in the soil and then compare them with the concentrations from the residue. That way the contribution or impact of the WTR on soil physical and chemical characteristics will be clearly comparable instead of using the limits from the NEMWA, 2008 norms and standards alone. A soil sample analysis is undertaken together with the soil physical characteristics which will be used as a baseline. Physical properties such as soil bulk density, porosity, hydraulic conductivity should be determined and pH are maintained between 6.5 and 9. The application rate of WTR will also depend on these results as well as the results of the soil investigation.

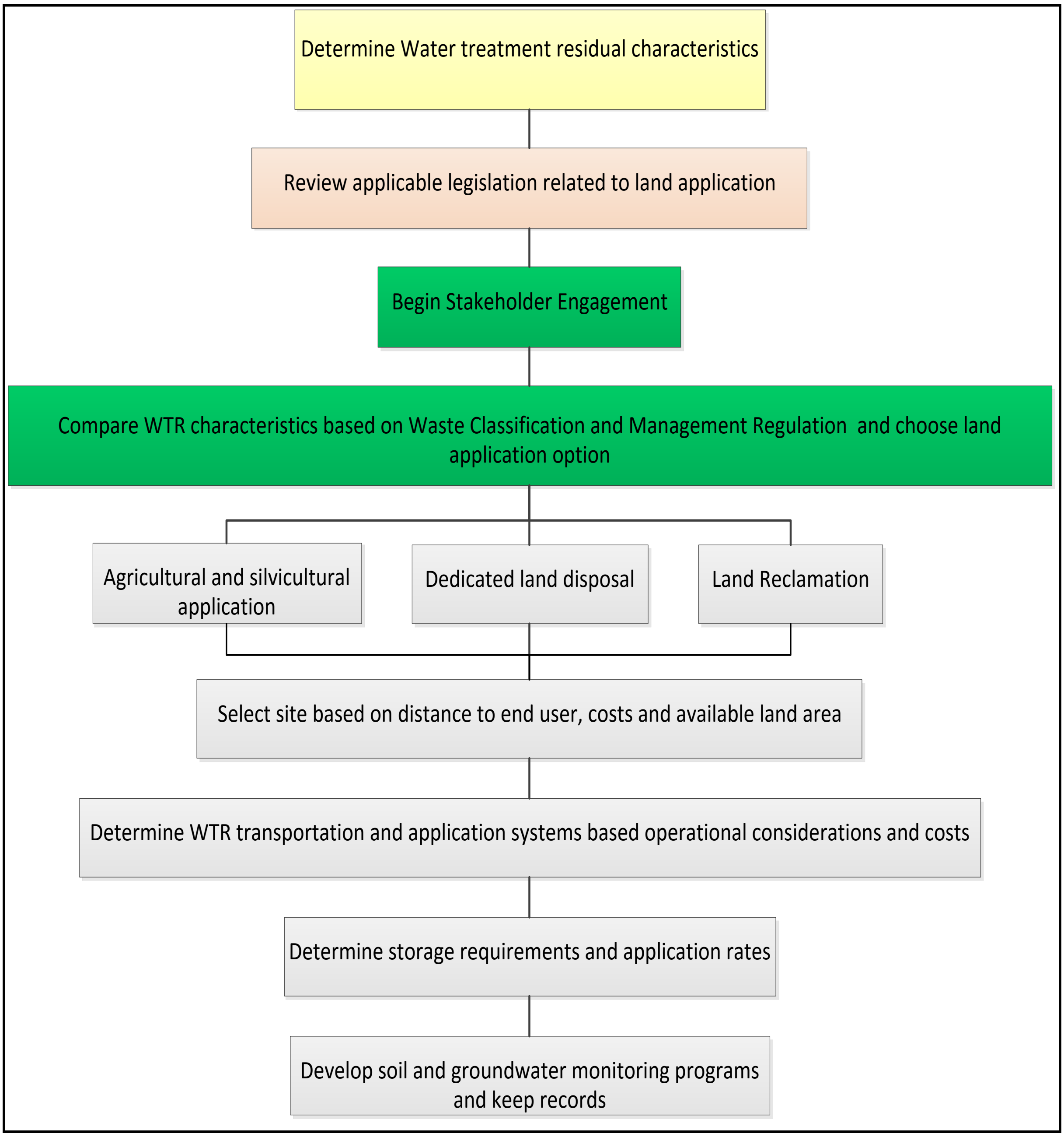

Figure 8-7: Planning procedure for land application

Once land application is selected as the preferred disposal option, the next step is to evaluate the land application site, costs associated with the site and the potential social and environmental impacts on the site (Figure 8-8). This will enable the waste generator/user to collect baseline data that can be used to assess the impact of land application over a period.

It is recommended that the "**Soil Screening Value 1**" from the *national norms and standards for the remediation of contaminated land and soil quality* (NEMWA, 2008) be used for this characterization. Soil Screening Value 1 (SSV1) means soil quality values that are protective of both human health and Eco toxicological risk for multi-exposure pathways, inclusive of contaminant migration to the water resource (NEMWA, 2008).

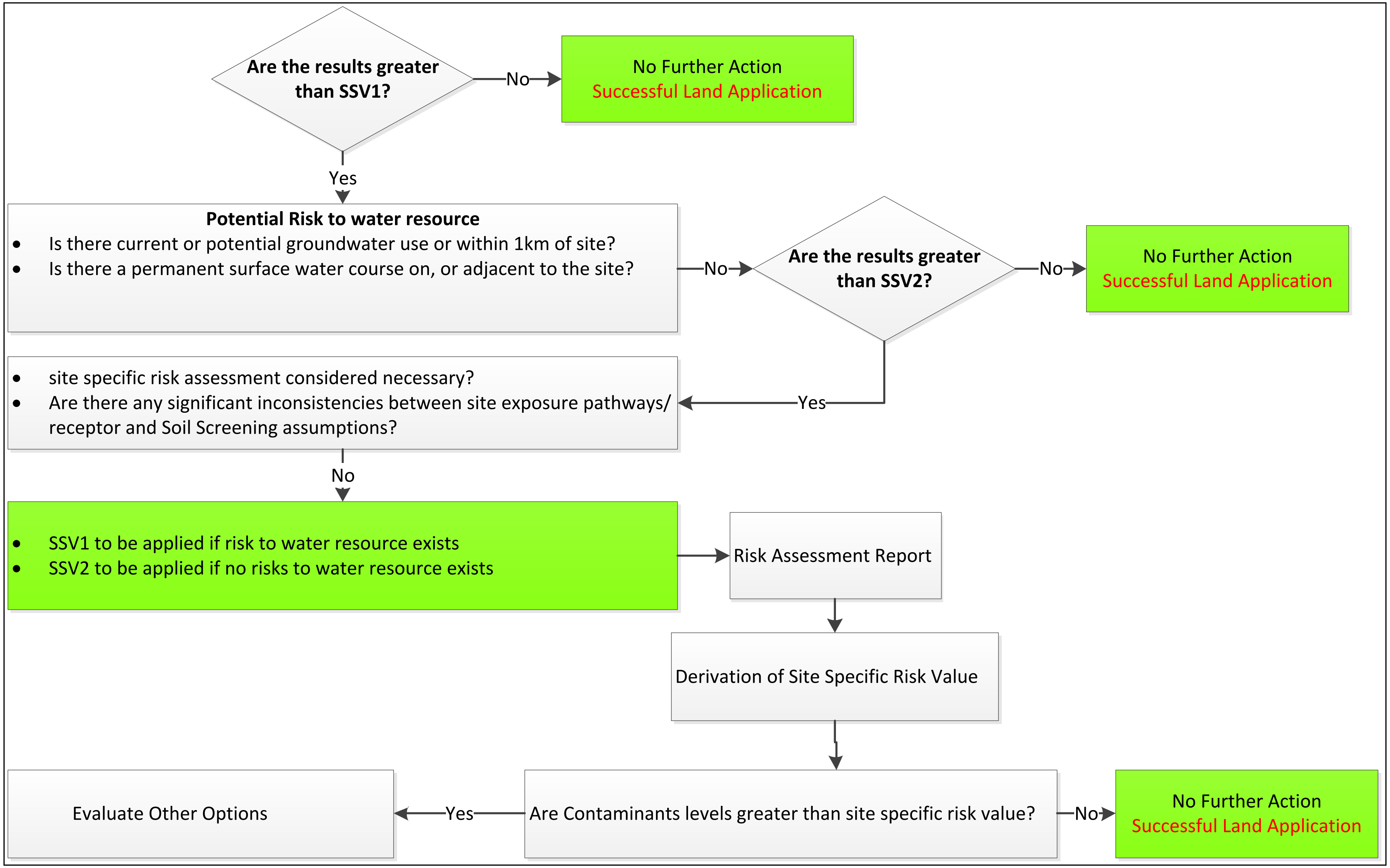

Figure 8-8: Land application decision tree-risk assessment (Adapted from Framework for the Management of Contaminated Land, 2010)

Sites which are identified where the total metal content of the WTR exceeds SSV1 as indicated in Table 8-4 land application of WTR is not permissible. The concentration of Al, Fe and Mn should also be measured because the concentrations of these elements in the WTR might be elevated and additional application might be toxic to crops. This are then compared with the inherent soil concentrations.

Table 8-4: Soil Screening value 1 concentrations

Constituent	Total Concentration (mg/kg)
Arsenic (As)	5.8
Cadmium (Cd)	7.5
Chromium (Cr VI)	6.5
Cobalt	300
Copper (Cu)	16
Lead (Pb)	20
Manganese	740
Mercury(Hg)	0.93
Nickel(Ni)	91
Vanadium	150
Zinc(Zn)	240

For agricultural use the available or soluble concentrations of Al, Fe and Mn are more important than the total concentrations, which are strongly influenced by the pH and redox (especially for Mn) conditions in the soil. The normal ranges of soluble Al, Fe and Mn in soils are as follows: (Herselman, 2013):

- Al: 0.4 mg/L at neutral pH and 5mg/L in acidic soils (pH <4.5);
- Fe: 0.03 – 0.55 mg/L at neutral pH and up to 2 mg/L in acidic soils; and
- Mn: 10 mg/L in normal soils.

8.6.1.1 *Application rate*

The WTR needs to be applied at agronomic rates, which are determined using agricultural methods. A Soils specialist must evaluate the soil and site to determine appropriate loading rates.The impact of alum or iron WTR on land is a reduction of the equilibrium phosphorus concentration. This is the amount of phosphorus immediately available to plant roots. As a general rule, a maximum loading of 2.2 to 4.4 kg/m^2 of WTR is required to prevent phosphorus deficiencies (Okuda et al, 2014). WTR and soil analyses are required to determine the site specific proper loading rates.

8.6.1.2 *Buffer zones for groundwater and surface water (Herselman, 2013)*

Areas to which WTR is applied for agricultural purposes must meet the following requirements:

- Depth to aquifer > 5 m
- Distance to surface water or borehole > 200 m

The above requirements can be relaxed by the regulatory authority for specific cases if it can be shown that groundwater and surface water is adequately protected.

8.6.1.3 *Monitoring requirements for land application sites*

At least three composite samples of WTR should be analysed. Soil samples must be simultaneously analysed for Soil Screening Values and compared with the baseline values. Should unacceptable contaminants levels be detected in groundwater, this option has to be terminated. The frequency for WTR monitoring could be relaxed if the producer can prove that the quality of WTR remains constant. Monitoring needs to be at least biannually to account for seasonal variation; and can be increased when WTR quality is inconsistent. Run-off should be collected to protect the surrounding environment from contaminated storm water.

8.6.1.4 *Record keeping requirements*

A waste management licence requires that certain records must be kept by the waste generator and user for a period of 5 years. These records need to be accessible always. The following records need to be kept:

- Copy of WML
- Detailed description of WTR management process
- The contract between the waste generator and user (if applicable)
- Initial site investigation/baseline data of soils, surface- and groundwater;
- Quantity of WTR applied to land
- Classification results of WTR and soils.
- Surface waters and groundwater should also be monitored if they are in close proximity with the disposal site
- It is recognised that plants will experience problems from time to time. Document any operational problems that could affect the WTR management by detailing:
    - Nature of the problem
    - Duration of the problem
    - What was done with off-spec residue
    - How the problem was rectified

8.6.2 **Landfill Disposal**

Landfilling requires WTR that has a solids content of 20 – 40% (Babatunde & Zhao, 2007) as well as total and leachable impurity concentrations in accordance with the National Norms and Standards for the Assessment of Waste for Landfill Disposal (GN R. 635) (refer to Chapter 2). According to GN R 635 "*The specific type of waste for disposal to landfill must be determined by comparing the total concentration and leachable concentration of the elements and chemical substances in the waste with the Threshold Limits (TCT and LCT) specified in the Norms and Standards*."

Landfilling as a disposal method requires the chosen WTR management activity to include; WTR characterisation, handling, treatment and final disposal. The required management activity is set out in Figure 8-9.

8.6.2.1 *Landfill Assessment*

The standard containment barrier design and landfill disposal requirements for different types of waste are indicated in Table 8-5.

Table 8-5: Landfill disposal requirements

Waste Type	**Landfill Disposal Requirements**
Type 0	Disposal not allowed
Type 1	Class A or Hh/HH landfill
Type 2	Class B or GLB+ landfill
Type 3	Class C or GLB+ landfill
Type 4	Class D or GSB-landfill

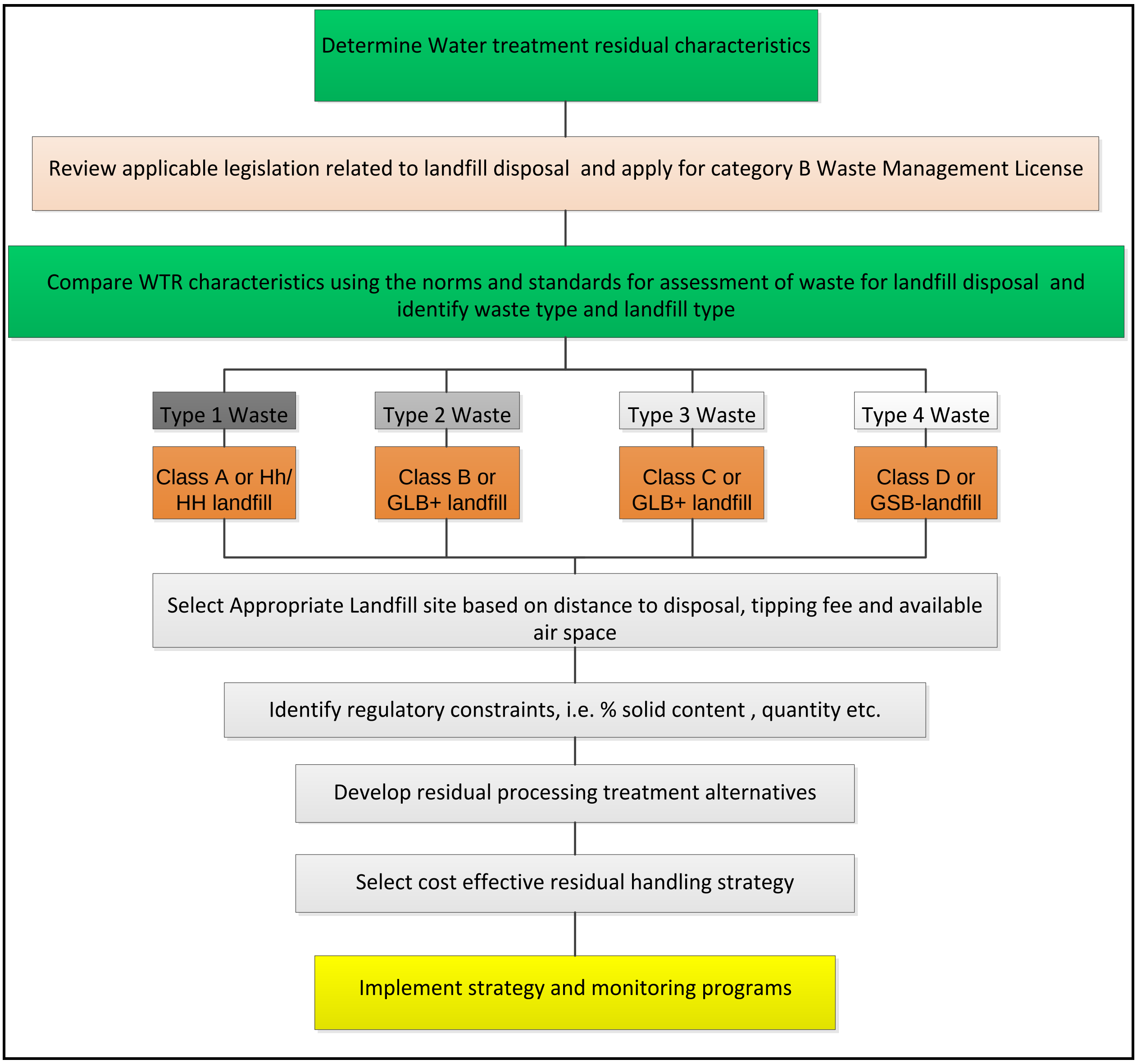

Figure 8-9: Basic procedure for disposal on landfill

The main costs associated with disposal to a landfill are those involved with transporting the material to the landfill and the tipping fees. Transporters and managers cannot accept unclassified waste (from Aug 2016 if the waste was classified). The hazardous criteria applicable to drinking water treatment residue are the pH, Aqua Regia and the AS leaching procedure results of the waste material. A full classification for one sample in 2014 costs ±R20000 with a 15-20-day turnaround time for results. Re-testing is required every 5 years according to Waste Classification and Management Regulations. Tipping fees at the majority of South Africa's landfill sites are between R100/t and R750/t. For many municipalities, the current tipping fees do not reflect the full financial costs of landfilling, with municipal estimates suggesting that full financial costs are much higher than current tipping fees. The different landfill classes are indicated in Table 8-6 whereby landfills with B+ require the use of liners for the collection of leachate. A study carried out in Cape Town by Dr Godfrey found that disposal to landfill should also consider the externalities, including social and environmental costs, associated with landfilling, which were estimated at R111/tDS. This also does not reflect the economic value of the resources lost in the waste streams. However, implementation of the National Norms and Standards for Disposal of Waste to Landfill, gazetted by the DEA, could result in a 50% increase in landfill disposal costs for general waste and a 20% increase in landfill disposal costs for hazardous waste (Burger, 2014).

Table 8-6: Landfill classification

Waste type	Waste volumes	Water balance
G - General waste H - Hazardous waste	Communal (C) - <25 t/day Small (S) - 25-150 t/day Medium (M) - 150-500 t/day Large (L) - >500 t/day	B+ - precipitation exceeds Evaporation B- - evaporation exceeds precipitation

Recent analysis conducted in this project has revealed elevated levels of manganese, iron and aluminium which requires WTR disposal to a hazardous landfill. A landfill is designed to accommodate daily waste for a period of 30-50 years, after which the land will have to be rehabilitated and a new landfill constructed. A general class B landfill may require a land area of about 16 hectares when fully operational and the capital cost ranging between R30 million to R40 million.

8.6.2.2 *Management requirements for landfill site*

The different WTR show different characteristics at different solids content and thus no minimum solids content can be recommended. This will depend on the WTR and the landfill operator. This requirement should be based on site specific investigation and specific landfill site requirements. The minimum solid content required for general landfills is 25% solids; disposal into hazardous landfills (class A) can accommodate dilute WTR of 20% solids by mass. It is fairly easy to determine the mass percentage of a waste stream. The pre-treatment requirements for landfill disposal follow the sequence of steps:

- *Waste Source – Thickening – Chemical Addition – Dewatering – Collection + Transportation – Disposal.* This option is used by treatments plants with the financial outlay.
- A different approach uses *Settling ponds – collection – hauling to landfill.* The most common method used in rural plants at remote areas. WTR in settling ponds takes approximately 1 year to dry to the desired solids concentration required for landfill disposal; and legislation permits temporary storage for only 90 days. Residuals haulers who will collect and transport solids must be trained and licensed or certified.

8.6.2.3 *Run-off and Leachate Collection*

Run-off is rainwater that drains over the land and runs off the land surface, while leachate is liquid originating from excess moisture in the residue or rainwater percolating through the disposal site. Run-off needs to be collected and disposed according to the license agreement. Leachate needs to be collected to prevent possible contamination of surface water and groundwater. If the disposal site has a liner and a leachate collection system, such a system must be properly maintained and inspected on a regular basis. Collected leachate should be recycled alternative appropriate treatment system.

8.6.2.4 *Monitoring requirements for landfill sites*

The management of WTR once disposed at the landfill is regulated and managed using “Minimum Requirements for Waste Disposal by Landfill (Latest edition), to ensure compliance. The responsibility is passed to the landfill operator for management, but the generator is still liable for duty of care to ensure that the WTR is properly managed.

8.6.2.5 *Record keeping requirements*

A waste management licence requires that certain records must be kept by the waste generator and user for a period of 5 years. These records need to be accessible at all times. The following records need to be kept:

- Copy of WML of the receiving landfill

- Legal contract between the waste generator and landfill operator
- Physical address, permit number and identity of the landfill operator
- Quantity of WTR disposed
- Classification results of WTR and soils.
- Details of the waste transporter and permit
- The hauler truck route can also be provided if available

8.6.3 Discharge to Sewer

This option is economically attractive as the transfer of disposal liability is passed to the WWTP (Helserman, 2013). Water treatment plants in South Africa practice this disposal method secondary to onsite lagoons. Water treatment plants (WTP) shall not discharge effluent without a municipal permit. Discharge to sewer as a WTR management activity requires very little pre-treatment handling as seen in Figure 8-10 below.

Sequence: *Waste source – Equalisation tank - Discharge & monitoring*

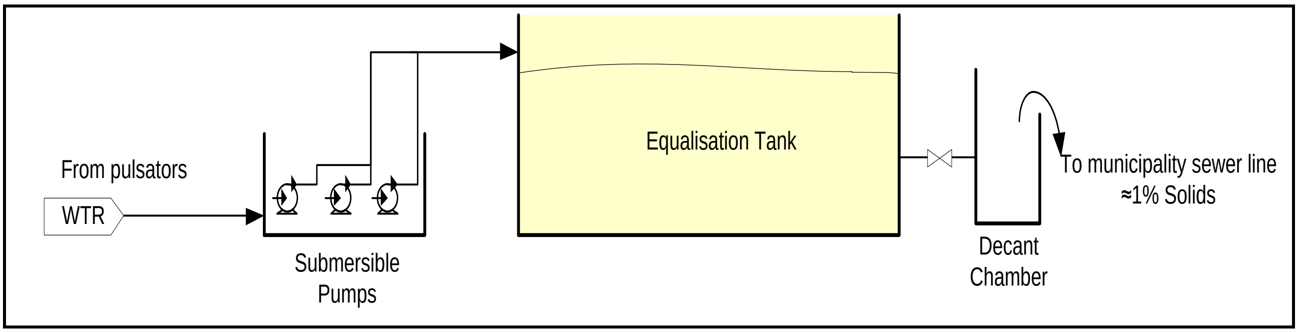

Figure 8-10: Sewer Discharge Management Option

The use of this disposal strategy requires adequate treatment capacity at a WWTP so that it may accept residuals and charge a trade effluent fee. The discharge of WTR should have a low solid content (approximately 1%), this will ensure that WTR flows easily in the sewer pipelines and does not cause any unnecessary blockages. This method of disposal is only possible when there is an agreement between the WTP and WWTP management/ municipality. Transparency is encouraged; The WTP should provide information concerning WTR quality and quantity, dry solids content, pH, nutrients, heavy metals and other relevant parameters. Table 8-7 illustrates the parameter limits between a WTP and a WWTP legal agreement contract.

Table 8-7: Sewer discharge limits

Parameter	Allowable Limits
pH	6-8
Electrical Conductivity	256 mS/m
Total Suspended Solids	10 to 155 mg/L
Free Residual Chlorine	0.1
Chemical Oxygen Demand	3.2 mg/L
Oil & Grease	0 mg/L

Discharging to a sewer will require initial characterisation of the residue and some information about the volume discharged and timing of flow (Figure 8-11). There must be easy access to a sewer line, but for small systems, it may be possible to temporarily store residuals on site, and then haul them periodically to the wastewater treatment works. Transportation charges will apply and this seldom supersede the disposal tariffs. The disposal of WTR is managed using the trade effluent disposal bylaws when discharged into the local municipal sewer. The maximum allowable volume is 10 000 m^3 per month at 1% solids. The disposal permit is valid for a one-year period and reviewed annually. All non-compliance incidents must be communicated and remedial action taken appropriately. To ensure the licence is not revoked, meter readings need to be submitted to the municipality monthly. Discharge times are usually restricted to periods between 21:00 and 06:00 each day to ensure no surcharging of sewers.

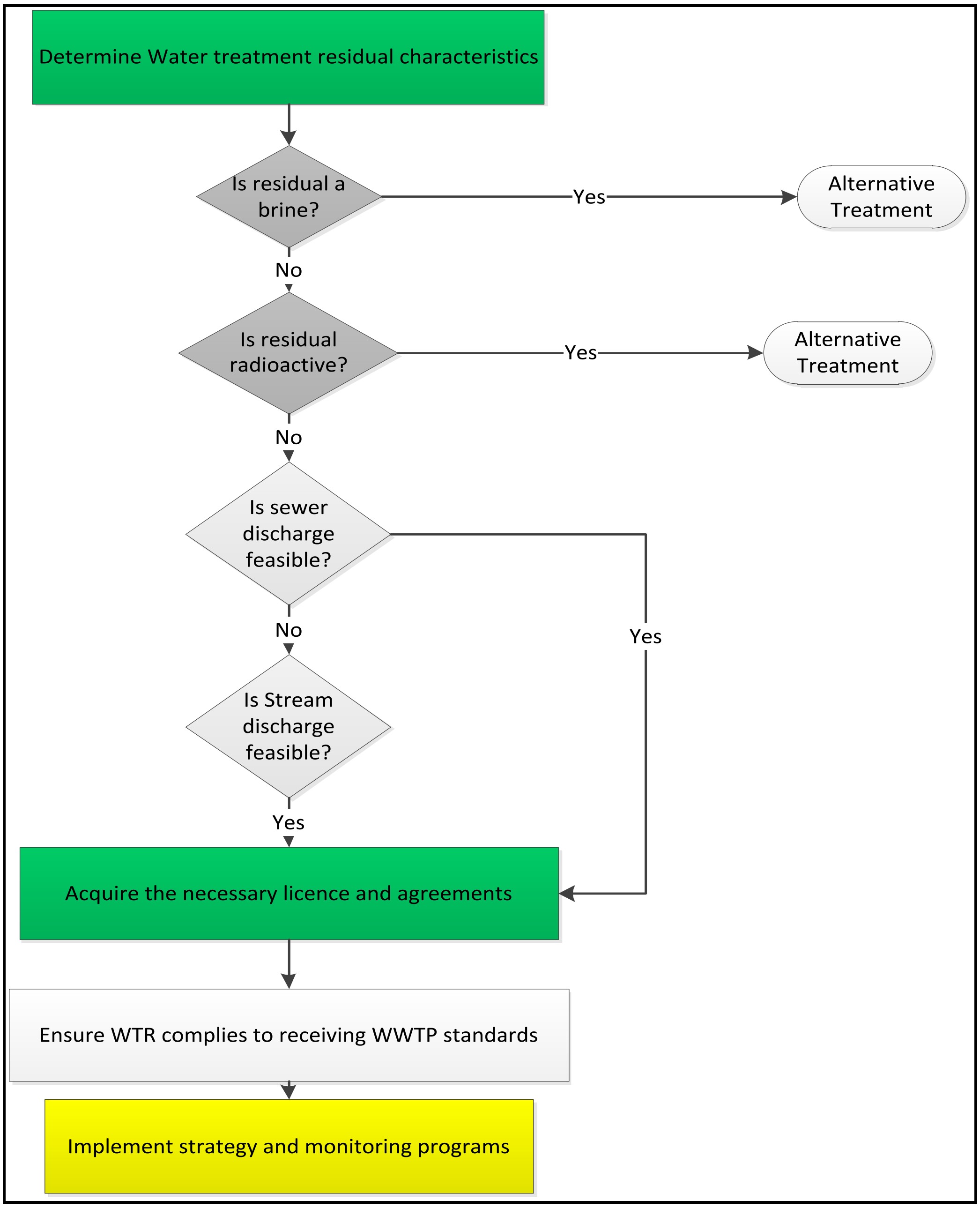

Figure 8-11: Liquid WTR Discharge

8.6.3.1 *Monitoring requirements*

The cost of disposal can be estimated at R 1 500 trade effluent monitoring charge per month and disposal costs of R 3 000/m^3 (Table 8-8). When disposing in excess a calculation is used to calculate the cost per volume discharged. The figures above are for the EThekwini Municipality. Charges can vary per municipality due to site specific conditions. It is recommended that WTP consider thickening of the residue to the range of 0.85 – 1.0% solids for extended periods and monitoring the cost implications. Increasing the concentration of solids would reduce the volume discharged to Municipal sewer which could consequently reduce the cost associated with disposal. The WTP can further consider onsite pre-treatment, should the savings realised by increasing the solids concentration prior to discharge to municipal sewer not be sufficient.

Table 8-8: Sewer discharge monitoring requirements

Discharge volume on any given day	Monitoring requirements
< 50 cubic meters	None
50 to 100 m^3	pH Electrical Conductivity (mS/m)
100 to 1000 m^3	pH Electrical Conductivity (mS/m) Chemical Oxygen Demand (mg/l)
1 000 to 5 000 m^3	pH Electrical Conductivity (mS/m) Chemical Oxygen Demand (mg/L) Ammonia as Nitrogen (mg/L) Nitrate/Nitrite as Nitrogen (mg/L) Free Chlorine (mg/L) Suspended Solids (mg/L) Ortho-Phosphate as Phosphorous (mg/L)

8.6.3.2 *Record keeping requirements*

The following records need to be kept for this management strategy:

- Copy of WUA
- Legal contract between the WTP and WWTP
- Volume of WTR discharged
- Characterisation results of WTR
- Out of range values and date of each non-compliance

8.6.4 **Discharge to Water Source**

To preserve water resources and ensure good source water quality the South African government is trying to move away from discharging to a water source (Figure 8-12). Permits however, are available from the Department of Water Affairs and Sanitation (DWAS) and the Department of Environmental Affairs (DEA). Monitoring is required depending on the daily volume discharge, the specific municipal bylaws per area and type of permit granted whereby oil and grease and biotic index monitoring may also be required.

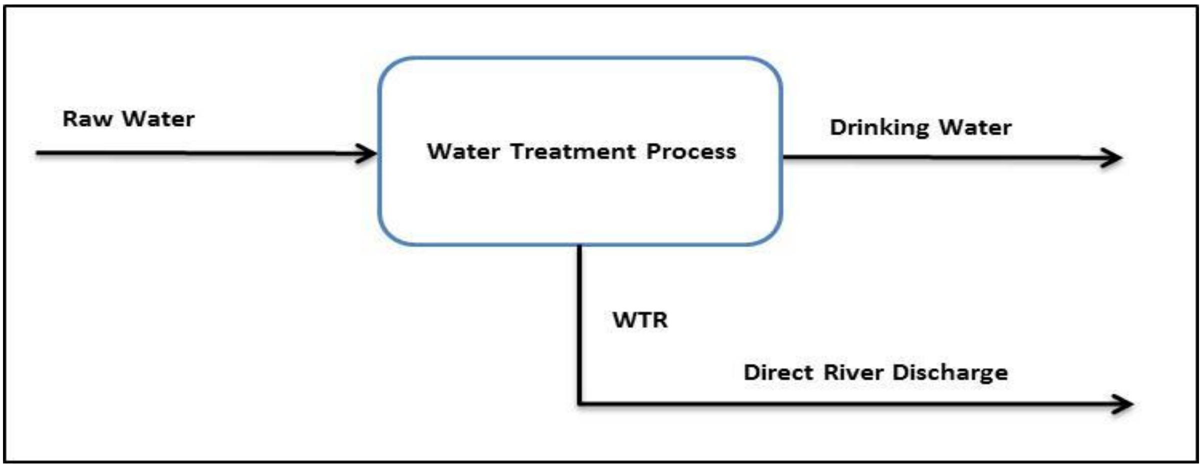

Figure 8-12: Surface water discharge

This form of disposal is to be investigated thoroughly before pursuing it as a course of action, as it may have large environmental impact.

Table 8-9: Summary of disposal options

Process	Advantages	Disadvantages
Thickening & Drying Paddocks	Complies with legislation and environmental requirements with the use of special liners and isolated land	High capital and operational costs Requires large areas of land which may require rehabilitation for other uses
On-site disposal	Low operational costs No transportation of WTR required Only requires annual inspection and cleaning	Environmental Impact is unknown Does not comply with legislation; Requires liners or boreholes. Requires large areas of land High annual costs of WTR removal
Surface water discharge	Low operational and capital costs No transportation of WTR required	Environmental Impact is unknown Does not comply with Current South African legislative
Dewatering & Landfill	Complies with current legislative and environmental requirements	High operational costs
Land Application	Low Operating Cost as user collects WTR	Continuous analysis of environmental effects Current legislative requirements – Licencing an issue
Discharge to Sewer	No transportation or thickening of WTR required. Complies with Current environmental and South African Legislative requirements	Cost is per volume discharged Increased load on municipal infrastructure and waste water works.

8.7 APPLICABLE LEGISLATIVE REQUIREMENTS

All waste generators must ensure that the waste they generate is classified in accordance with SANS 10234 within 180 days of generation, except in cases where the waste is on the pre-classified list". Waste must be reclassified every 5 years, or within 30 days of modification to the process or activity that generated the waste, changes in raw materials or other inputs (refer to Figure 8-13). The applicable legislation governing the utilisation and disposal of WTR is controlled by the: (The exhaustive list is given in Chapter 2.

- National Water Act, 1998 (Act No. 36 of 1998) and the
- National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008).

Table 8-10 shows examples of permits required for WRT disposal. Duty of care is mentioned in section 16 of National Environmental Management: Waste Act (NEMWA, 2008) whereby every holder of waste has a duty of care to:

- Reduce, re-use, recycle the waste
- Manage not to cause any harm and dispose in environmentally sound manner

If selling products that generate hazardous waste, inform public impact of waste on health and environment.

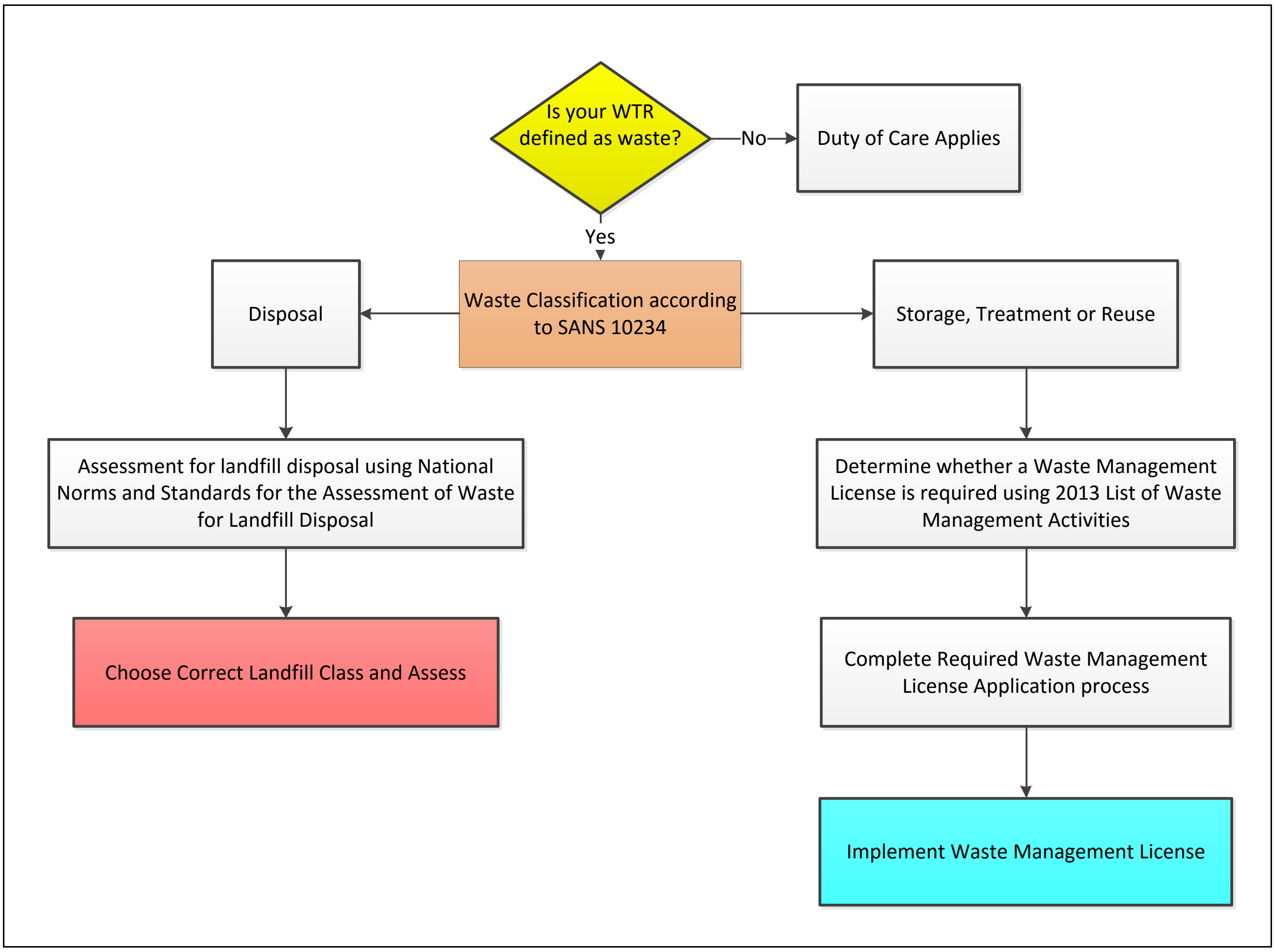

Figure 8-13: Procedure for waste management legislation

Table 8-10: Permits applicable for WTR disposal

Disposal Option	Permit Requirements
Discharge to surface water	• System must have a discharge permit (obtainable from DWS). • And comply with quality / discharge limits
Discharge to Sewer	• A Water Use Authorisation • System must meet discharge requirements of the WWTW in terms of loadings • Contractual agreement between WTP and the WWTP
Ocean Disposal	• Special Permit obtainable from the DEA in conjunction with South African Maritime Safety Authority
Landfill Disposal	• Waste Management Licence
On site disposal (Permanent lagoon)	• Waste Management Licence • A Water Use Authorisation
Reuse (Usable or saleable product)	• Waste Management Licence • SABS Approval • Exemptions under section 9 of Waste Classification and Management Regulation R
Land application	• Waste Management Licence
Agricultural land	• Waste Management Licence • Producer must have a legal contract with the user
Land Reclamation	• Waste Management Licence

8.7.1 **Activities Requiring a Waste Management Licence**

Waste management activities are divided into Category A, B and C as indicated in Chapter 2.

- A WML is required for Category A and B.
- Category A requires a Basic Assessment to inform
- Category B requires a Scoping & EIA to inform

Applications are made to the provincial Department of Environmental Affairs (DEA) for general waste and to the national DEA if waste is classified as hazardous. The Department of Water and Sanitation must concur with WML for any disposal license. The DEA and DWAS have a period of 60 days to comment on the application for disposal licences (Figure 8-14).

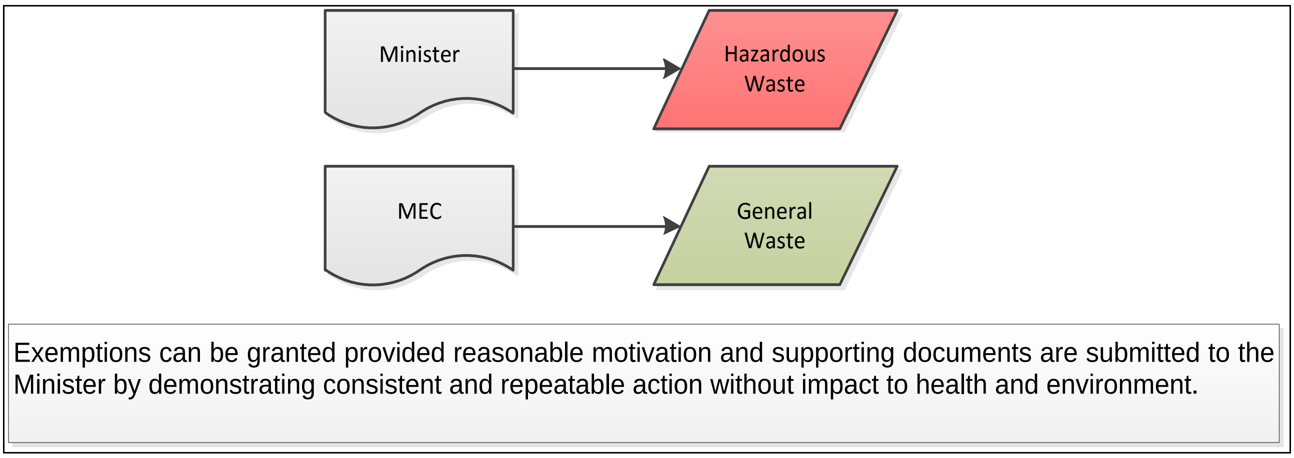

Figure 8-14: Responsible authority for licencing of WML

8.7.3 Cost of Waste Management Licence Applications

Table 8-11: WML application fees

Application	Fee
Application for a waste management licence for Which basic assessment is required in terms of the Act	R2000
Application for a waste management licence for which Scoping & EIA is required in terms of the Act	R10 000
Application for a transfer of a waste management licence in or for the renewal of a waste management licence	R2000

8.8 CRITERIA DEVELOPMENT

The most appropriate WTR management option can be chosen with the use of an evaluation framework. The framework was developed based on the five components that address the broad definition of the environment and sustainability as described in the National Framework for Sustainable Development, (2008).

Table 8-12: Criteria Development

Component	Description
Natural	Related to the protection of natural and physical environment (e.g. air, land, water and biota), inclusive of natural heritage and environmentally sensitive areas
Social	Evaluates potential effects on residents, agricultural uses, businesses, community features and historical/archaeological and heritage components.
Technical	Components that considers the technical suitability and other engineering aspects.
Financial	Comparison of the potential financial costs
Legal	Compliance to legislation and water quality standards

Each criterion is assessed for the specific situation and given a numeric value. The values are totalled for each management option and compared. The optioned that achieved the highest score is then considered. The magnitude of impact is classified as zero, low and high impact.

Table 8-13: Criteria Scaling

Value	Impact	Description
+1	Low	Indicates a positive/ good response from the disposal option
-1	Negative	Natural, cultural or social functions or processes are altered to the extent that they will temporarily or permanently cease
0	Zero	Affects the environment in such a way that natural, cultural and soil functions and processes are not affected

The criteria are then weighed according to criterion importance. This is a subjective weighing and is site specific. For example, the Final score is calculated from:

$$= A \times \sum NEF + B \times \sum SEF + C \times \sum TF + D \times \sum FF$$

Whereby

- NEF are the Physical Environmental Factors
- SEF the Social Environmental Factors
- TF are the Technical Factors
- And FF the Financial Factors

In this document A is chosen as 0.35, B = 0.1, C = 0.2 and D = 0.35 for comparison. This weighing criterion can be variable depending on the management of a specific WTP on what they consider as important for management. This involves Costs, Environmental Impacts, and the simplicity of the process; the percentage summation should equal 100% or 1, for ease of calculation.

$$\sum A + B + C + D = 1$$

8.8.1 **Natural Environmental Factors**

8.8.1.1 *Habitat values*

Habitat is defined as a natural environment composed of both living organisms and physical components that function together as an ecological unit. This also refer to an area which provides direct support for a given species, population or community and is inclusive of all environmental features such as air quality, vegetation and soil characteristics, and water supply.

Periodic discharges of accumulated WTR from settling tanks can possibly disrupt stable ecosystems more than a continuous low-level discharge.

Evaluation Criteria

- Potential effects on fisheries/aquatic habitat
- Potential effects on woodlands, trees, and other terrestrial vegetation (e.g., number and significance of trees removed and/or disturbed, extent of loss/disturbance of grass/vegetation); and
- Potential effects on sensitive species habitat (e.g., proximity to vulnerable or endangered regional rare amphibians, birds and other wildlife).

Rating:

- Pre-treated residue that is discharged to sewer or landfill is rated as 0.
- WTR reuse activities are rated as +1 because they reuse material that would have been disposed for beneficial purposes.
- WTR discharge to river or construction of handling facilities are rated as -1

8.8.1.2 *Soil suitability*

Soil suitability refers to whether the disposed residue is suitable for the chosen activity. The solids percentage and the legislated thresholds are used for land disposal.

- If the metal content values are greater than the SSV1 0 the scoring value is -1 and implies not suitable.
- If the stream is discharged into the sewer the scoring value is 0 because the soil is not "directly" impacted.
- Reuse activities or use for soil remediation are rated as +1 when the contaminants levels are below the Threshold level 0

8.8.1.3 *Air utilities and noise*

- All operations that involve the transportation or hauling from one place to another affect the air quality negatively because of the vehicle emissions and rated as -1. And all energy intensive operations that utilise electricity affect the environment negatively these will be graded -1. These include equipment with a power consumption of above 2 kWh used during pre-treatment. An energy baseline study for Umgeni Water plants found that pumps and motors account for major WTW operating costs and are rated around 2 kWh and above
- Reduction of carbon footprint would be rated as +1 (i.e. no transportation and electricity consuming applications)
- Pre-treatment equipment with a power consumption of below 2 kWh are rated as 0

8.8.1.4 *Land Use*

- Options requiring the purchase of a new piece of land or property are rated as -1
- Those that use an On-site or within 100 m of the site are rated 0
- Those that do not use land are rated as +1; such as sewer discharge and ocean discharge.

8.8.2 **Social Environmental Factors**

8.8.2.1 *Health and safety perceptions*

Health and safety perception emanate from how the public view a particular WTR management activity and is very subjective depending on the education level of the population. This is true for most misunderstood processes, such as the use of WTR for crop irrigation and is rated as -1. Public participation is encouraged in most of the Environmental Impact Assessment studies for such reasons.
Evaluation Criteria

- Potential for temporary disruption (e.g., dust, noise, vibration) during construction to residences and businesses and agricultural operations;
- Potential for temporary disruption during operations (e.g., increased truck traffic);

8.8.2.2 *Family Resettlement*

- An option that causes physical and/or economic displacement of people is rated as -1, such as buying off a piece of land for waste handling and disposal.
- Waste management activity that has no impact on population dynamics is give a 0

8.8.2.3 *Lifestyle/quality of life*

Options that create local community empowerment are rated as +1 such as the making of clay pots and beads by the local community. Brick making is also rated as +1 as it creates local entrepreneurs.

8.8.3 **Technical Factors**

8.8.3.1 *Land area*

Land area requirements are influenced by costs and the national average cost of One hectare of land was calculated to be R200 000 which varies per province and the location of the vacant land. This might be a cost burden for small plants located at urban areas and may cost much less for plants located at deep rural areas where land is cheaper and readily available.

- An area requirement of more than one hectares = (-1)
- An Area requirement of less than one hectare = 0
- No area requirements = +1

8.8.3.2 *Effluent Quality*

The effluent quality is directly linked to cost since very dilute WTR requires no pre-treatment and discharged “As is”. Disposal methods which require the WTR to have high solids percentages use WTR treatment methods which may sky rocket the entire WTR Strategy cost.

- No pre-treatment or Solids concentration of 1-8% = +1
- Use of existing equipment or Solids concentration of 8-20 = 0
- If WTR requires any pre-treatment because of the disposal it will incur a rating of (-1)

8.8.3.3 *Conveyance and Transportation*

Most municipalities charge waste acceptance tariffs depending on where the waste originates from, within the local municipality. The acceptable distance for disposal by haulage is set for 100km by major metropolitan municipalities in South Africa and also other local or district municipalities. This is because large trucks on the road tend to affect neighbours and other road users and contribute to carbon emissions.

- Transport of WTR to more than 100km = (-1)
- Transport to less than 100km = 0
- No transport = +1

8.8.3.4 *Flexibility or Complexity*

The Complexity of a process is determined using Table 8-14. A flexible process can be changed by using a different coagulant to produce WTR that is suitable for a process. The changing of a flexible process does not need to incur any additional costs.

Table 8-14: Process complexity

	Simple Process		Complex Process	
Low	**LSS**	**LSC**	**LCS**	**LCC**
Medium	**MSS**	**MSC**	**MCS**	**MCC**
High	**HSS**	**HSC**	**HCS**	**HCC**
	L=Low Solids M=medium Solids H=High Solids S=Simple Operations C=Complex Operations S=Single Unit Process C= Combined Unit Process e.g. MCS stands for a process producing medium solids (<20%) and is a complex operation utilising a single unit process			
	• Complex processes are rated at -1 • Simple process at +1 • Medium Solids using combined processes have a score of 0			

8.8.4 **Financial Factors**

8.8.4.1 *Construction cost*

The choice for rating construction costs will be considered on a case by case basis and if three options are considered the disposal option with the highest cost will be given a rating of -1 and the one with the "middle" value given a rating of 0 and the lowest cost given a +1 rating. Construction costs are mostly the capital expenditure costs for any disposal option. Landfill Construction was used as the basis for this benchmarking exercise.

- A Capex cost of above R1 Million is rated as -1
- A Capex cost of below R1 Million is rated as 0
- No construction Cost is rated as +1

8.8.4.2 *Operation and Maintenance*

According to the Australian Energy Regulator 2012, a process is considered sustainable if the Annual Operation and Maintenance (O&M) costs are less than 5% of the Capital Expenditure. This has been adopted as a basis.

- If O&M costs are greater than 5% of Capex then the score is -1
- If O&M costs are less than 5% of Capex then the score is 0
- Activities generating a profit from the sale of products made from the WTR have a score of +1

If the Capex values are not available use the energy consumption per appliance, specified in kWh.

8.8.4.3 *Monitoring*

Activities requiring continuous monitoring have additional cost implications that are recurring on a periodic basis, either monthly, or annual monitoring costs, such as soil quality monitoring, effluent discharge monitoring etc. and are given a rating of -1. Disposal Options that do not require monitoring are given a rating of +1.

8.8.4.4 *Compliance to legislation*

The process or activity either is compliant or not.

- If it complies it is rated as +1
- And (-1) if it does not comply.
- If the process can obtain a licence or lobby for the activity then it is rated as 0.

Table 8-15: Residue Disposal Options Performance Matrix (*Adapted from* NZWWA, 2008)

RESIDUE MANAGEMENT ACTIVITIES PERFORMANCE MATRIX					
Evaluation Criteria	**Management Activities**				
	Land Application	**Sewer Discharge**	**Landfill**	**Return to Source**	**Best Practice Score**
Physical Environment Factors (35%)					
Habitat values	-1	-1	0	-1	**0**
Soil suitability	1	0	1	0	**0**
Air and Noise	-1	0	-1	0	**0**
Land use	-1	0	1	0	**1**
Subtotal	**-2**	**-1**	**1**	**-1**	**1**
Social Environment Factors (10%)					
Family resettlement/ Community disruption	-1	0	0	0	**0**
Health & Safety perceptions	-1	-1	-1	-1	**1**
Lifestyle/quality of life	1	0	0	0	**1**
Subtotal	**-1**	**-1**	**-1**	**-1**	**2**
Technical Factors (20%)					
Land area	-1	0	-1	0	**0**
Effluent quality	-1	1	-1	1	**1**
Conveyance	0	1	-1	1	**1**
Flexibility/complexity	1	0	0	0	**1**
Subtotal	**-1**	**2**	**-3**	**2**	**3**
Financial Factors (35%)					
Construction	-1	0	-1	0	**0**
Operation and Maintenance	1	0	0	0	**0**
Property acquisition costs	-1	0	0	0	**0**
Disposal Cost per ton	0	0	-1	0	**0**
Monitoring (Yes or No)	-1	-1	-1	-1	**1**
Complies to legislation					
Yes/No or permit obtainable	1	0	1	-1	1
Subtotal	**-1**	**-1**	**2**	**-2**	**2**
TOTAL SCORE	**-1.35**	**-0.4**	**0.35**	**-0.75**	**1.85**

This management activity matrix agrees with what is currently happening with WTR management in South Africa. Landfilling and sewer discharge are the most commonly applied methods of disposal in the country, which was evident from the site visits as shown in the table below. The current WTR management conditions favour landfill as WTR management activity due to land availability and low tipping rates.
Sample calculation for Land Application Score

$$= 0.35 \times \sum NEF + 0.1 \times \sum SEF + 0.2 \times \sum TF + 0.35 \times \sum FF$$
$$= 0.35 \times \sum(-2) + 0.1 \times \sum(-1) + 0.2 \times \sum(-1) + 0.35 \times \sum(-1) = (-\mathbf{1.35})$$

Disposal Method	**Score**
Land Application	-1.35
Sewer Discharge	-0.4
Landfill	0.35
Return to Source	-0.75

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

In many waterworks it was found that as little money as possible is spent on WTR management. The increasing cost of disposal is highlighting the need for WTR management. The research done locally and internationally concluded that the land application of WTR over the medium term (5 years) was not detrimental to its receiving environment however; there are no studies that cover the long-term effects to confirm this. An in-depth study should be done to evaluate the impact created by Midmar water treatment plant residue on the dedicated land disposal site as a follow up to Hughes and Titshall (2005). The effects of WTR on surface water have also not been widely researched. A case study on the effects of WTR on surface water in South Africa should also be undertaken to ascertain the possible long-term effects WTR has on the aquatic environment.

The water sector is faced with many challenges with respect to WTR management in South Africa. These include but are not limited to relatively high WTR conditioning and disposal costs, shortage of land for disposal, low calorific value and suitability of the WTR for commercial use. The blanket classification of WTR as hazardous with other solid wastes also contributes to the fact that approximately half of the waterworks surveyed were non-compliant to legislation in respect of WTR management. The outcomes of these projects could then form a basis for the possible re-assessment of the current legislation and may produce a more cost-effective disposal option. Water treatment disposal always required a unique solution specific to the location and water treatment plants concerned. The work involved in this research, produced valuable insights into the benefits of benchmarking for performance evaluation of drinking water utilities. The response to the survey and other instruments used to establish current practices in water treatment residue management and treatment objectives was poor. However, four water utilities that generated over 70% of the estimated annual national WTR participated in the survey.

Water treatment residual management strategies are complex processes that vary per treatment plant, per region and per province. However, there are similarities in the way waste is generated and ultimately managed. The WTR management strategy that each treatment plant selects depends on the values and priorities of the works and can be influenced by availability of options, convenience, regulatory requirements, policy or municipal resolutions and overall costs. A set of guidelines were developed to assist waterworks managers to initiate a WTR management strategy appropriate for their own circumstances. Critical WTR strategic drivers impacting on the economic and environmental sustainability were identified and rated. Developing a successful management plan requires an understanding of the value of residue characterization and the regulatory requirements, tailoring the treatment options to the requirements of the available management alternatives, and then developing rational evaluation criteria. An integrated WTR management strategy is proposed where a hierarchal approach viz. reduce, recycle, reuse should be considered before disposal. From a bench marking exercise of participating water utilities it was proposed that water treatments plants should put in place monitoring programmes to document WTR production, conditioning and disposal costs.

9.2 RECOMMENDATIONS

9.2.1 Project Recommendations

- The development of an integrated management strategy like that implemented in the Netherlands which involves the collaboration of water treatment plans, industry partners and the government to research, market and reduce the disposal of WTR.
- Strategic partnerships between local water service providers and water service authorities should be developed. This will ensure that the users and suppliers are aware of the other's goals and concerns.

The Water Services Authorities will then be able to lobby national government with the water service providers speaking from a point of knowledge/ experience.

9.2.2 Policy Recommendations

The current legislation that is regulating waste management does not distinguish between water treatment residue (WTR) and sludge from waste water treatment works (WWTW's). They are both considered as waste and hence require authorisation in terms of its treatment and/or reuse. Under the current legislation the options available to practitioners are:

- Apply for a waste management licence (WML) for the treatment/reuse of WTR. This is the simplest and least onerous option for dealing with WTR;
- To follow the Regulation 9 route of the Waste Classification and Management Regulations (WCMR) promulgated under NEMWA. Using this method requires historical scientific and technical data to exclude WTR from being a waste if used for specific purposes. This is an onerous process as it does not have any timeframes for the Department to process such applications but is a good process in the long term as it reduces the administrative burden of applying for WML's for specific uses of WTR.
- To cater for the lengthy processing of Regulation 9 applications, an exemption can be considered in terms of Section 74 of NEMWA if a Regulation 9 application has been lodged.

It is recommended that:

- A streamlined approach to authorisation of this waste stream is agreed upon with DEA while the Regulation 9 process is undertaken.

As a way forward:

- A workshop needs to be held with DEA, DWS and key stakeholders in the water sector to sensitise the regulators to the challenges faced by the sector due to the current legislation.
- As water treatment is regulated by DWS and WTR management regulated by DEA the licensing requirements currently faced by new water treatment works are confusing. There is a need for a procedure to show water utilities how to go about licensing their activities.
- An integrated forum of regulators and the water sector is required to relook at the regulations regarding WTR management. The regulations need to be enforceable but also appropriate for WTR management.

9.3 AREAS OF FURTHER RESEARCH AND SKILL REQUIREMENTS

- The tendency for heavy metals to be leached from polymer-based WTR needs to be investigated since this is the most widely used coagulant at most waterworks. No research can be found in the literature that deals with the remobilization of trace elements from drinking water plant residue. The existing literature is concerned chiefly with the effects of releasing heavy metals from sewage sludge, sediments, and landfill waste.
- The impact created from land application of WTR should be investigated particularly focussing on licence applications. The previous study done by Hughes and Titshall (2005) at the Midmar Water Treatment Plant residue on the dedicated land disposal site can be used as a follow up. This would then form a basis for possible legislative leniency and a cost-effective disposal option.

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APPENDICES

APPENDIX A: Questionnaire for Water Treatment Plants

This questionnaire is to obtain information from all the drinking water treatment plants in South Africa. If there is more than one plant under your management or forming part of your organisation, please complete a separate questionnaire for each plant.

Contact Person:____

Plant Address: ____

Tel:____________________________

Email Address:____

Fax:____________________________

1) Where is/are the source/s of abstraction of the facilities raw water? (if there are more than one source list them in order of greatest volume taken)

2) What volume of sludge is produced? (Please include annual trends if available)

3) What are your plant's unit operations? (e.g. Coagulation, flocculation, clarification, filtration, disinfection, pH control etc.) Give a process train/ process flow diagram if possible?

4) What chemicals and flocculants are added to purify the raw water? (tick applicable)

Lime: ☐ Bentonite: ☐ Alum: ☐ Ferric Chloride: ☐ Activated Silica: ☐

Polyelectrolytes: ☐ Please specify type: ____________________

Other: ☐ Please specify: ____________________

5) What is the dosage rates of each chemical added? (give ppm or mg/l if possible)

6) How is the sludge thickened?

Centrifuge: ☐ Settling ponds or lagoons: ☐

Chemical additives (Please specify) ☐ ____________________

Other (Please specify) ☐ ____________________

7) What is the solids content of the sludge produced after thickening? ____________________

8) How is the sludge currently disposed of?
Landfill: ☐ Land Treatment: ☐ Sewer Discharge: ☐ River Discharge: ☐

Other (Please specify): ☐ ____________________

9) How is the sludge transported to the disposal site?

Road (Truck etc.): ☐ Pipeline: ☐ On site disposal: ☐

10) Have any studies been conducted that are related to the disposal, characterisation or use of the sludge
Yes: ☐ No: ☐

11) If yes would you send us a copy of the report or if it is the public domain where could we find it?
____
____

12) How much money do you estimate that you spend on sludge removal/disposal per annum?
____
____

13) Please send us raw water quality for your plant and sludge quality/ classification if available

APPENDIX B: TSS and CST test Procedures

TSS Procedure

Apparatus required

- Evaporating dish made of high-silica glass,
- Whatman Filter paper.
- Drying oven, for operation at 103 to 105℃.
- Desiccator.
- Analytical balance Magnetic stirrer.
- 50 ml plastic beaker and a vacuum filter flask.

Procedure

- Place the filter paper on top of the evaporating dish and allow drying in the drying oven for 5 minutes.
- Cool the dried evaporating dish and filter paper in the desiccator for 10 minutes.
- Weigh the filter paper with the evaporating dish and record the mass as B.
- Stir the bulk sample with the magnetic stirrer to ensure a well-mixed solution.
- Sample 50 mL of the solution to be measured.
- Place the Whatman filter paper into the vacuum filter flask and filter the known volume.
- Dry the remaining suspended solids on the filter paper in the oven for 30 minute at 103 to 105℃.
- Cool the evaporating dish with the filter paper and suspended solids in the desiccator for 10 minute.
- Weigh the cooled evaporating dish with filter paper containing the suspended solids and record this mass as A.

CST Procedure

Procedure for determining the optimum dosage

- Pour 200 mL of sample into beakers marked with stirring duration of 10, 30 and 60 seconds.
- Add coagulant into each of the beakers.
- Place the beakers into a stirrer and stir for the duration noted on the beaker.
- Determine the CST of each sample by pouring 5 mL of the sample into the CST unit.
- Allow the CST test to run and record the time taken to complete the run.
- Repeat for all samples.

Procedure for determining the optimum settling rate

- 12 x 100 mL measuring cylinders were filled with the samples used when determining the optimum dosage
- All samples were allowed to settle for 15 minutes and thereafter, the sludge level in all beakers was checked.

The results obtained from the two steps were compared and the optimum dosage and stirring time were selected based on the highest and lowest settling rate noted from the system

APPENDIX C

C1 - Experimental Procedures

Experimental Procedures:

Leachability Tests for Inorganics and Organics in Solid Wastes by Organic Acid Extraction (TCLP)

Apparatus:

1. Agitation apparatus capable of rotating the extraction vessel (30$\pm$2 revolutions per minute).
2. Extraction bottles for inorganics

Solutions:

1. Glacial acetic acid, sodium hydroxide diluted to a volume of 1 litre.
2. Glacial acetic acid diluted to a volume of 1 litre with double distilled water.

Method:

1. Determine which TCLP solution should be used by doing a preliminary evaluation.
2. Weigh out 100 gram of the dry waste which passes through a 9.5 mm sieve and add to the extraction bottle.
3. Add 2 litres of the appropriate TCLP solution and close bottle tightly.
4. Agitate for 20 hours.
5. Filter through a glass fibre filter and collect filtrate. Record pH.
6. Take aliquot samples from filtrate for metal determination and immediately acidify to a pH smaller than 2.
7. Analyse using a sensitive appropriate technique for different metals.
8. If analysis cannot be done be performed immediately after extraction acidify and store at 4°C.

The detailed procedure reference: Department of Water Affairs and Forestry, “Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste,” 2nd Edition, 1998.

Aqua Regia Procedure:

The full analysis was completed by the Umgeni Water Laboratory using microwave assisted digestion.

Aqua regia microwave - assisted digestion:

1. Weigh a well – mixed sample of 0.500 g to the nearest 0.001 g in a weighing boat.
2. Carefully transfer this weighed sample into a fluorocarbon sample vessel equipped with a single – ported cap and a pressure relief valve.
3. Using a a 10mL measuring cylinder, add 10 ± 0.1 mL aqua regia (3:1 HCl: HNO3) (in a fume hood). If a vigorous reaction occurs, allow the reaction to stop before capping the vessel. Cap the vessel and torque the cap until it is tight enough. Place the vessels in the microwave carousel.

Microwave parameters used for sample digestion

Temperature control (°C)	Ramping time (min)	Holding time (min)	Cooling time (min)
180	15	15	15

C2 - Summary of WTR Analysis

TCLP Results:

Parameter		LCT0	LCT1	LCT2	LCT3	Plant 1	Plant 2	Plant3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8
Arsenic, As	mg/l	0.01	0.5	1	4	0.00409	0.002	0.00254	0.003	<0.01	<0.01	<0.01	0.0028
Boron, B	mg/l	0.5	25	50	200	0.128	0.0632	0.14	<0.02	<0.025	<0.025	<0.025	0.155
Barium, Ba	mg/l	0.7	35	70	280	0.688	4.005	0.647	0.054	1.07	0.858	1.27	4.99
Cadmium, Cd	mg/l	0.003	0.15	0.3	1.2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cobalt, Co	mg/l	0.5	25	50	200	0.0413	<0.01	0.0248	<0.01	<0.025	<0.025	<0.025	0.05
Chromium, Cr	mg/l	0.1	5	10	40	<0.005	0.0065	0.00541	<0.005	<0.025	<0.025	<0.025	BD
Copper, Cu	mg/l	2	100	200	800	0.46	<0.05	<0.05	<0.05	<0.025	<0.025	<0.025	<0.05
Mercury, Hg	mg/l	0.006	0.3	0.6	2.4	<0.0005	<0.0005	0.00053	<0.0005	<0.001	<0.001	<0.001	<0.0005
Manganese, Mn	mg/l	0.5	25	50	200	0.46	13.2	23.5	3.23	12	3.97	6.27	43.10
Molydenum, Mo	mg/l	0.07	3.5	7	28	<0.01	<0.01	<0.01	<0.01	<0.025	<0.025	<0.025	<0.01
Nickel,Ni	mg/l	0.07	3.5	7	28	0.123	0.125	0.246	0.022	<0.025	<0.025	<0.025	0.23
Lead, Pb	mg/l	0.01	0.5	1	4	0.00931	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	0.02
Antimony, Sb	mg/l	0.02	1	2	8	<0.002	<0.002	<0.002	<0.002	<0.01	<0.010	<0.01	<0.002
Selenium, Se	mg/l	0.01	0.5	1	4	<0.002	<0.002	<0.002	0.003	<0.002	<0.002	<0.002	<0.002
Vanadium, V	mg/l	0.2	10	20	80	<0.01	<0.01	<0.01	<0.01	<0.025	<0.025	<0.025	<0.01
Zinc, Zn	mg/l	5	250	500	2000	<0.03	<0.03	0.1	0.04	<0.2	<0.025	0.5	0.10

TCLP Results:

Parameter		LCT0	LCT1	LCT2	LCT3	Plant 9	Plant 10	Plant 11	Plant 12	Plant 13	Plant 14	Plant 15	Plant 16	Plant 17	Plant 18
Arsenic, As	mg/l	0.01	0.5	1	4	0.0036	<0.002	<0.002	0.0032	0.00478	<0.002	<0.002	<0.002	<0.002	0.0111
Boron, B	mg/l	0.5	25	50	200	0.0946	0.09	0.117	0.0282	0.358	0.0394	0.0581	0.0891	0.0265	0.489
Barium, Ba	mg/l	0.7	35	70	280	1.42	1.751	2.33	1.572	1.108	0.916	1.172	0.3 82	1.398	2.285
Cadmium, Cd	mg/l	0.003	0.15	0.3	1.2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.00153
Cobalt, Co	mg/l	0.5	25	50	200	<0.01	<0.01	0.0187	0.012	<0.01	0.0435	<0.01	<0.01	0.0119	0.0882
Chromium, Cr	mg/l	0.1	5	10	40	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.0062
Copper, Cu	mg/l	2	100	200	800	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mercury, Hg	mg/l	0.006	0.3	0.6	2.4	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.00062
Manganese, Mn	mg/l	0.5	25	50	200	5.83	7.32	9.95	7.82	7.14	5.59	3.86	2.53	4.35	11.1
Molydenum, Mo	mg/l	0.07	3.5	7	28	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nickel,Ni	mg/l	0.07	3.5	7	28	0.0403	0.0289	0.038	0.0297	0.0158	0.505	0.0122	0.0164	0.033	0.261
Lead, Pb	mg/l	0.01	0.5	1	4	0.0311	0.0293	0.0316	0.0249	0.0306	0.0264	0.0246	0.0343	0.0273	0.00931
Antimony, Sb	mg/l	0.02	1	2	8	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Selenium, Se	mg/l	0.01	0.5	1	4	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Vanadium, V	mg/l	0.2	10	20	80	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc, Zn	mg/l	5	250	500	2000	0.05	0.03	0.1	0.23	<0.03	0.17	<0.03	<0.03	0.09	0.14

TCLP Results:

Parameter		LCT0	LCT1	LCT2	LCT3	Plant 19	Plant 20	Plant 21	Plant 22	Plant 23	Plant 24	Plant 25	Plant 26	Plant 27	Plant 28
Arsenic, As	mg/l	0.01	0.5	1	4	<0.002	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Boron, B	mg/l	0.5	25	50	200	0.0503	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Barium, Ba	mg/l	0.7	35	70	280	1.036	2.51	3.3	2.62	2.17	1.43	0.1	1.16	1.05	1.32
Cadmium, Cd	mg/l	0.003	0.15	0.3	1.2	<0.001	Below detection								
Cobalt, Co	mg/l	0.5	25	50	200	<0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Chromium, Cr	mg/l	0.1	5	10	40	<0.005	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Copper, Cu	mg/l	2	100	200	800	BD	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Mercury, Hg	mg/l	0.006	0.3	0.6	2.4	<0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese, Mn	mg/l	0.5	25	50	200	<0.0005	86	91	79	33	27	9	6.45	17	11
Molydenum, Mo	mg/l	0.07	3.5	7	28	3.89	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Nickel,Ni	mg/l	0.07	3.5	7	28	<0.01	0.047	0.1	<0.025	0.032	0.027	<0.025	<0.025	<0.025	<0.025
Lead, Pb	mg/l	0.01	0.5	1	4	0.17	Below Detection								
Antimony, Sb	mg/l	0.02	1	2	8	0.0278	0.013	0	<0.010	0.027	<0.010	<0.010	<0.010	<0.01	<0.010
Selenium, Se	mg/l	0.01	0.5	1	4	<0.002	Below Detection								
Vanadium, V	mg/l	0.2	10	20	80	<0.002	<0.025	<0.025	<0.025	0.037	<0.025	<0.025	0.031	<0.025	<0.025
Zinc, Zn	mg/l	5	250	500	2000	<0.01	0.112	0.1	0.205	<0.025	0.029	0.03	0.804	<0.025	0.066

Aqua Regia Results

Parameter		TCT0	TCT1	TCT2	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8
Arsenic, As	mg/kg	5.8	500	2000	10.484	6.155	14.514	0.44	<4	<4	14	5.377
Boron, B	mg/kg	150	15000	60000	15.539	5.192	12.915	24	<10	<10	<10	10.585
Barium, Ba	mg/kg	62.5	6250	25000	212.116	285.443	241.796	25	544	376	288	611.190
Cadmium	mg/kg	7.5	260	1040	0.037	0.065	0.056	0.01	<2	<2	<2	BD
Cobalt, Co	mg/kg	50	5000	20000	19.267	18.297	30.261	0.2	<10	11	12	15.186
Chromium, Cr	mg/kg	46000	800000	N/A	103.281	148.690	138.498	4.97	107	92	174	152.495
Copper, Cu	mg/kg	16	19500	78000	35.090	43.432	48.799	1.79	22	40	16	41.147
Mercury, Hg	mg/kg	0.93	160	640	0.312	0.175	0.436	2.09	<0.4	<0.4	<0.4	0.070
Manganese, Mn	mg/kg	1000	25000	100000	1448.509	1590.983	2533.689	11	9600	1065	1496	1453.330
Molydenum, Mo	mg/kg	40	1000	4000	BD	BD	0.262	0.64	<10	<10	<10	BD
Nickel,Ni	mg/kg	91	10600	42400	5.579	5.916	8.018	1.39	25	47	32	6.058
Lead, Pb	mg/kg	20	1900	7600	17.240	21.935	17.413	0.4	16	29	30	17.805
Antimony, Sb	mg/kg	10	75	300	BD	BD	BD	BD	<4	6.4	11	0.147
Selenium, Se	mg/kg	10	50	200	3.915	3.523	3.007	4.87	<8	<8	<8	5.660
Vanadium, V	mg/kg	150	2680	10720	93.546	102.092	132.523	0.33	71	136	106	126.959
Zinc, Zn	mg/kg	240	160000	640000	100.223	106.790	93.837	10.73	55	82	136	96.253
BD = Below detection												

Aqua Regia Results:

Parameter		TCT0	TCT1	TCT2	Plant 9	Plant 10	Plant 11	Plant 12	Plant 13	Plant 14	Plant 15	Plant 16	Plant 17	Plant 18
Arsenic, As	mg/kg	5.8	500	2000	13.251	10.853	8.512	16.21	14.444	5.279	15.084	8.549	3.159	8.785
Boron, B	mg/kg	150	15000	60000	23.477	32.348	20.837	34.95	22.183	7.132	15.019	8.156	6.528	14.708
Barium, Ba	mg/kg	62.5	6250	25000	344.139	531.885	464.248	508.09	533.437	259.029	408.802	281.018	532.747	439.316
Cadmium	mg/kg	7.5	260	1040	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD
Cobalt, Co	mg/kg	50	5000	20000	12.511	11.955	16.370	18.64	16.589	14.591	17.943	21.560	88.209	14.304
Chromium, Cr	mg/kg	46000	800000	N/A	88.661	67.122	88.612	109.07	103.490	115.747	108.505	396.043	141.817	120.133
Copper, Cu	mg/kg	16	19500	78000	32.084	23.918	34.713	42.65	29.275	29.132	40.993	52.172	54.516	34.337
Mercury, Hg	mg/kg	0.93	160	640	0.482	0.545	0.929	3.99	BD	1.152	0.189	0.792	0.120	90.730
Manganese, Mn	mg/kg	1000	25000	100000	768.652	798.089	1963.797	1037.72	1495.341	443.475	1406.012	1550.234	4532.640	407.431
Molydenum, Mo	mg/kg	40	1000	4000	BD	BD	BD	BD	BD	BD	BD	0.374	BD	BD
Nickel,Ni	mg/kg	91	10600	42400	3.618	2.807	3.931	3.79	3.898	3.979	4.501	19.570	7.228	4.921
Lead, Pb	mg/kg	20	1900	7600	19.699	22.169	27.937	36.85	29.543	14.716	27.752	24.393	11.144	20.121
Antimony, Sb	mg/kg	10	75	300	0.536	0.301	0.190	0.68	0.353	0.131	0.503	0.299	0.150	0.195
Selenium, Se	mg/kg	10	50	200	5.842	6.266	8.138	7.28	6.662	4.972	10.932	6.915	6.646	5.665
Vanadium, V	mg/kg	150	2680	10720	101.712	98.025	101.399	159.16	127.167	103.554	119.699	149.185	290.179	128.866
Zinc, Zn	mg/kg	240	160000	640000	83.036	120.337	119.459	143.69	85.124	62.929	1849.725	161.139	52.455	110.136
BD = Below detection														

Aqua Regia Results:

Parameter		TCT0	TCT1	TCT2	Plant 19	Plant 20	Plant 21	Plant 22	Plant 23	Plant 24	Plant 25	Plant 26	Plant 27	Plant 28
Arsenic, As	mg/kg	5.8	500	2000	8.549	<4	<4	<4	<4	<4	<4	<4	<4	<4
Boron, B	mg/kg	150	15000	60000	8.156	<10	16	<10	<10	<10	<10	<10	<10	<10
Barium, Ba	mg/kg	62.5	6250	25000	281.018	494	914	340	562	471	87	464	304	533
Cadmium	mg/kg	7.5	260	1040	BD	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cobalt, Co	mg/kg	50	5000	20000	21.560	14	<10	<10	13	11	<10	18	<10	10
Chromium, Cr	mg/kg	46000	800000	N/A	17.947	66	24	39	94	77	41	48	29	81
Chromium VI, Cr(VI)	mg/kg	6.5	500	2000	396.043	BD	BD	BD	BD	BD	BD	BD	BD	BD
Copper, Cu	mg/kg	16	19500	78000	52.172	90	28	12	49	37	20	35	30	32
Mercury, Hg	mg/kg	0.93	160	640	0.792	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Manganese, Mn	mg/kg	1000	25000	100000	1550.234	9600	20000	7600	7600	5200	1546	1489	5200	3117
Molydenum, Mo	mg/kg	40	1000	4000	0.374	<10	<10	<10	<10	<10	<10	<10	<10	<10
Nickel,Ni	mg/kg	91	10600	42400	19.570	44	26	18	63	43	18	25	17	42
Lead, Pb	mg/kg	20	1900	7600	24.393	16	23	21	17	26	<8.00	18	32	24
Antimony, Sb	mg/kg	10	75	300	0.299	<4	14	<4	6.4	11	<4	<4	<4	<4
Selenium, Se	mg/kg	10	50	200	6.915	<8	<8	<8	<8	<8	<8	<8	<8	<8
Vanadium, V	mg/kg	150	2680	10720	149.185	82	33	42	110	88	54	129	34	94
Zinc, Zn	mg/kg	240	160000	640000	161.139	86	91	140	76	76	47	358	256	108
BD = Below detection														

APPENDIX D: Sample Calculations

Sample Calculations

Plant flow rate: 350 000 m3/d
Mass Flow rate: 350 000 * density(water) / 24 = 14583333.33 kg/h
Average lime dose: 8.25 mg/l
Mass of lime dosed = 8.25 * mass flow rate / 1000 = 120.31 kg/h
Assumptions:

1. All lime will go into the WTR
2. Sludge out of clarification is 5% of throughput (Bourgeois et al., 2004)

Sludge mass flow rate = 0.05 * 14583333.33 = 729166.67 kg/h
For one impurity, say manganese in white lime:
Manganese concentration in white lime = 0.01 g/kg (experimental determination)
Manganese flow rate = 0.01*120.31 = 1.203 g/h
Concentration of manganese in sludge = 1.203 *1000 / 729166.67 = 0.00165 mg/kg
The order of magnitude is 1×10^{-3} mg/kg

Another Way
Plant flow rate: 350 000 m3/d = 350 MLD
Sludge mass flow rate = 0.05 * 350 MLD = 17.5 ton/d

$$Mass\ of\ lime\ dosed = \frac{8.25mg}{l} \times \frac{350 * 10^6 l}{d} \times \frac{kg}{10^6 mg} = 2887.44 kg/d$$

Concentration of manganese in sludge = 2887.44*0.01*1000/(17.5*10^6) = 0.00165 mg/kg