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Water Management Practices of South African Electricity Power Plants

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A Research Report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand. The research fulfilled the requirements for the degree of Master of Science in Engineering.

Date: 13 May 2024

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University of the Witwatersrand, Johannesburg

Faculty of **Engineering and the Built Environment**

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Lastly, I honour my grandmother and her predecessors for instilling in me the significance of education. With determination, I aspire to make them proud by pursuing a PhD.

I acknowledge the Lord Almighty, in whom all things are possible. Thank you.

Abstract

South African (SA) power plants are experiencing several challenges when managing water usage and containing it within their clean and dirty water dams (leading to water wastage and pollution). Numerous reasons have been provided to explain the increased water usage. However, the key issue is understanding the causes of high-water use that leads to dam overflows and pollution of the natural water streams/rivers and groundwater system.

The main aim of this research, thus, sought to establish the causes of high-water usage in thermal power plants in South Africa. The objective to identify where and how water wastage occurs in the system, any variations from the power plants' standard operating procedures (SOPs) contributing to water wastage and finally, recommend solutions to address the gaps. Qualitative research was conducted through semi-structured interviews at two power plants (namely Power Plant 1 and Power Plant 2) to provide an understanding and detailed information on water use at thermal power plants in South Africa. The standard operating procedures and policies that govern and control water processes were analysed.

As a result, the study showed that the most significant cause that came out of the interviews was leadership, followed by financial constraints, negligence (of the plant and water) and lastly, maintenance. Water management is failing and needs to be improved, with the primary challenges being maintenance and a lack of leadership decision-making. Further research on the remaining power plants will be required to determine the generalisability of the findings.

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List of Abbreviations

BA	Basic Assessment
CO2	Carbon Dioxide
CCS	CO2 Capture and Storage
CW	Cooling Water
CoC	Cycles Of Concentration
DWS	Department Of Water and Sanitation
EIA	Environmental Impact Assessment
FGD	Flue Gas Desulphurisation
GM	General Manager
ISO	International Organisation for Standardisation
IVRS	Integrated Vaal River System
MW	Megawatts
MCWAP	Mokolo Crocodile Water Augmentation Project
NWA	National Water Act
PC	Pulverized Coal-Fired
SA	South African
SHEQ	Safety Health Quality Environment
SOPs	Standard Operating Procedures
SDG	Sustainable Development Goals
USA	United States of America
WISA	Water Institute of Southern Africa
WUL	Water Use Licence
ZLD	Zero Liquid Discharge
ZLED	Zero Liquid Effluent Discharge

Units of Measurement List

l/kWhSO	Litres per kilowatt hour sent out
l/kWh	Litres per kilowatt hour
kWh	Kilowatt-hour
MW	Megawatts
kWhSO	Kilowatt-hour sent out
MWh	Megawatt hour
m3/h	Cubic meter per hour

CHAPTER 1

INTRODUCTION

1.1. Background

The Sustainable Development Goals (SDG) are a worldwide partnership's urgent demand for action by all developed and developing countries. SDG 6 relates to achieving universal access to and sustainable management of water and sanitation. To accomplish these two goals, SDG 7 refers to ensuring access to affordable, dependable, sustainable, and modern energy (United Nations, 2015). Therefore, water must be conserved and managed correctly in all electricity production processes to ensure sustainable growth. The complex interdependency between water and energy, thus, poses new challenges for policymakers to achieve a safe, secure and sustainable supply of water and power in the future (Pan et al., 2018)). There is a need to reduce water usage (in terms of abstraction) and pollution (in terms of effluent discharge) of the natural water resource to conform with legal requirements and protect and preserve the natural water resource for all water users. One of the initiatives to conserve and protect water is the Zero Liquid Effluent Discharge (ZLED) policy, which South African power plants have adopted. However, it has been identified that effluent generation from power plants is increasing, which leads to an indirect increase in water usage for a power plant and can potentially compromise the ZLED policy (Pather, 2004).

Using freshwater resources for industrial applications, particularly electricity production, places an increased burden on South Africa's freshwater resources. Electricity production is one of the biggest consumers of water in South Africa (Pather, 2004; Thopil and Pouris, 2015). Similarly, Jin *et al.* (2019) indicate that electric power generation is a significant driver of water stress worldwide. This situation will likely be exacerbated due to growing energy demands and climatic change. Meeting the demand for fresh water and energy has been a significant challenge for society over the coming decades (Jin *et al.*, 2019). According to Holland *et al.* (2015), most of the estimated 35 million km^3 of global freshwater is inaccessible. Recent estimates put renewable freshwater resources in between 40,000 and 66,000 $km^3 \cdot y^{-1}$, of which ~10% is appropriated for human use (Holland *et al.*, 2015). Around three in every ten people living in Sub-Saharan Africa had improved drinking water accessibility on premises in 2020. The water coverage available when needed was higher, at nearly 60 percent. However, when considering the quality of water, only 36 percent of Sub-Saharan Africa's population had access to drinking water free from contamination (Kamer, 2022). In 2022, about 400 million people in Sub-Saharan Africa cannot access essential water services (Koncagül and Tran, 2022).

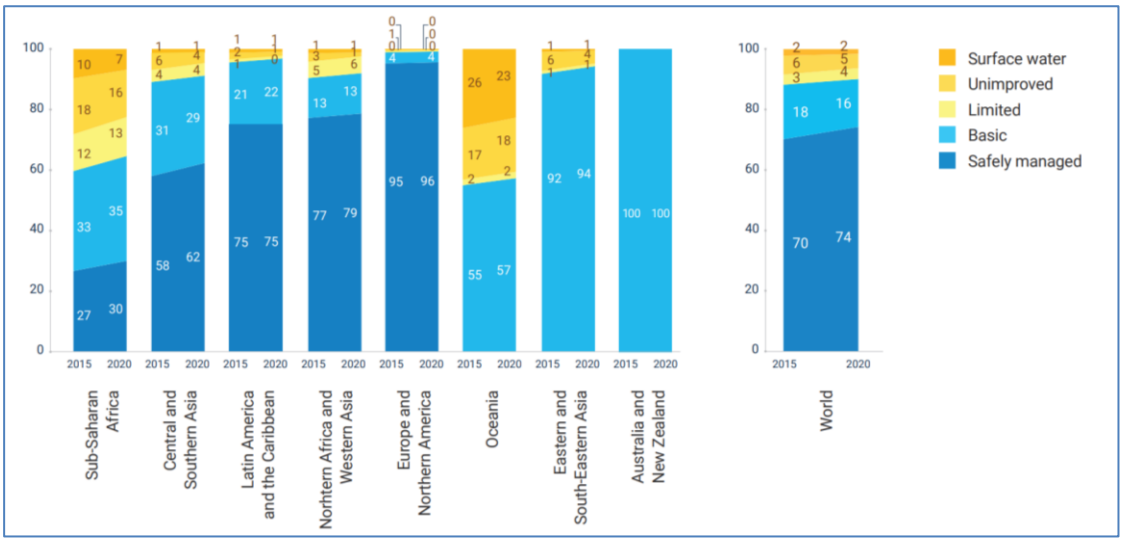


Figure 1: Regional and global drinking water coverage, 2015–2020 (%). Note: Five SDG regions had estimates for safely managed drinking water services in 2020 (Koncagül and Tran, 2022).

Thopil and Pouris (2015) indicate that South Africa (SA) relies heavily on non-renewable electricity generation, with 90% of the electricity generated from coal. Though diversification of electricity generation technologies is underway in SA, coal is still expected to play a dominant role in the near future when considering the commodity's abundance locally (Thopil and Pouris, 2015).

Eskom's coal-fired power plants are notably significant water consumers, which raises concerns when one takes into account that these facilities are often situated in water-scarce regions. This situation becomes even more alarming as South Africa's demand for limited water resources steadily rises. Concurrently, Eskom's water consumption escalates due to the heightened electricity demand. Consequently, as the nation's water reserves dwindle, there is a looming realisation that the power utility might become incapable of generating any electricity without an adequate water supply. Water is a critical primary resource used in the generation of electricity (Kramer, 2022). According to Eskom (2020), SA's coal thermal power plants have implemented a comprehensive water strategy to maintain their strategic user status and comply with applicable legislation. Furthermore, SA's largest electricity producer has implemented water strategy plans to reduce water use and ensure compliance (Eskom, 2020). Regrettably, as reported by Eskom (2020), the implementation of water strategy plans has not reduced water usage at coal-fired power stations. Water performance remains unsatisfactory, attributed to the following factors:

1. Poor technical performance of coal-fired stations.
2. Ageing plant infrastructure.
3. Lengthy lead times for addressing the root causes of high-water consumption, including:
    a) Plant leaks.
    b) Inadequate maintenance of critical areas contributes to subpar site water management (Eskom, 2020).

Herbst (2013) highlights that specific water use for electricity generation for 2019 was worse than the set target and has deteriorated slightly compared to the previous year. The targets are benchmarked against each plant's historical and theoretical water consumption. Although compliance is a significant focus area for SA thermal power plants, Eskom (2020) outlines five Operational Health Dashboard contraventions, with three related to water issues. Additionally, the fleet recorded 59 environmental legal contravention incidents against a tolerance level of 18 (2019: 24, restated); 39 were water-related incidents.

Freshwater Supply Schemes for South African Power Plants

SA's coal thermal power plants receive raw freshwater from several water supply systems, as indicated in Figure 2 below. For example:

- The Komati Water Scheme supplies water to Komati, Duvha, Hendrina and Arnot power plants via the Komati Water Scheme directly from the Nooitgedacht Dam.
- Vygeboom Dam and Gemsbokhoek Weir Dam feed water into Nooitgedacht Dam and then to the power plants.
- Should there be low water levels in the Komati Water Scheme dams, the system will pump water from the Usutu Water Scheme for consistent water supply.

The primary purpose of the water is for cooling, the most extensive use in wet-cooled power plants (Govender, 2018).

Kramer 2022, explains that the water catchment areas where the SA power utility built many of its power plants are relatively water-scarce, necessitating inter-basin transfers. The possibility of a lack of water supply is growing in many semi-arid regions due to rising water pressure. To address the challenge of water unavailability, inter-basin water transfers are built to ensure water is moved from one river basin where it is available to another basin where water is less available or could be used better for human development (Rollason et al., 2022). These engineering techniques, which aim to guarantee a steady water supply, frequently require large-scale infrastructure, including tunnels, pumping systems, and reservoirs. As a result, the expenses related to these actions may be high (Sun et al., 2021; Ma et al., 2020). The Department of Water and Sanitation (DWS) must authorise the transfer. Govender (2018) points out that over the years, surrounding utilities and mines have collaborated with the government to construct various water supply schemes. These schemes must supply water to the power plants and other partnered users. These schemes consist of dams, pipelines, pumping stations, and reservoirs. They are interlinked and operated as a system (see Figure 2). For example, when water levels in the Integrated Vaal River System (IVRS) stood at 65% for June 2020 (as opposed to June 2019: 72%) (due to lower dam levels at Katse, Mohale, Vaal and Sterkfontein), water transfers from Tugela River to Sterkfontein Dam were delayed because of resources and financial constraints for the Mokolo Crocodile Water Augmentation Project (MCWAP) (Eskom, 2020). The delay impacted the supply of water to the Matla, Kriel, Medupi and Matimba power plants and the progression of the flue gas desulphurisation (FGD) plant installation at the

Medupi power plant. Coal-fired thermal power plants are Medupi, Matimba, Duvha, Komati, Hendrina, Arnot, Kusile, Kendal, Kriel, Camden, Matla, Tutuka and Majuba power stations.

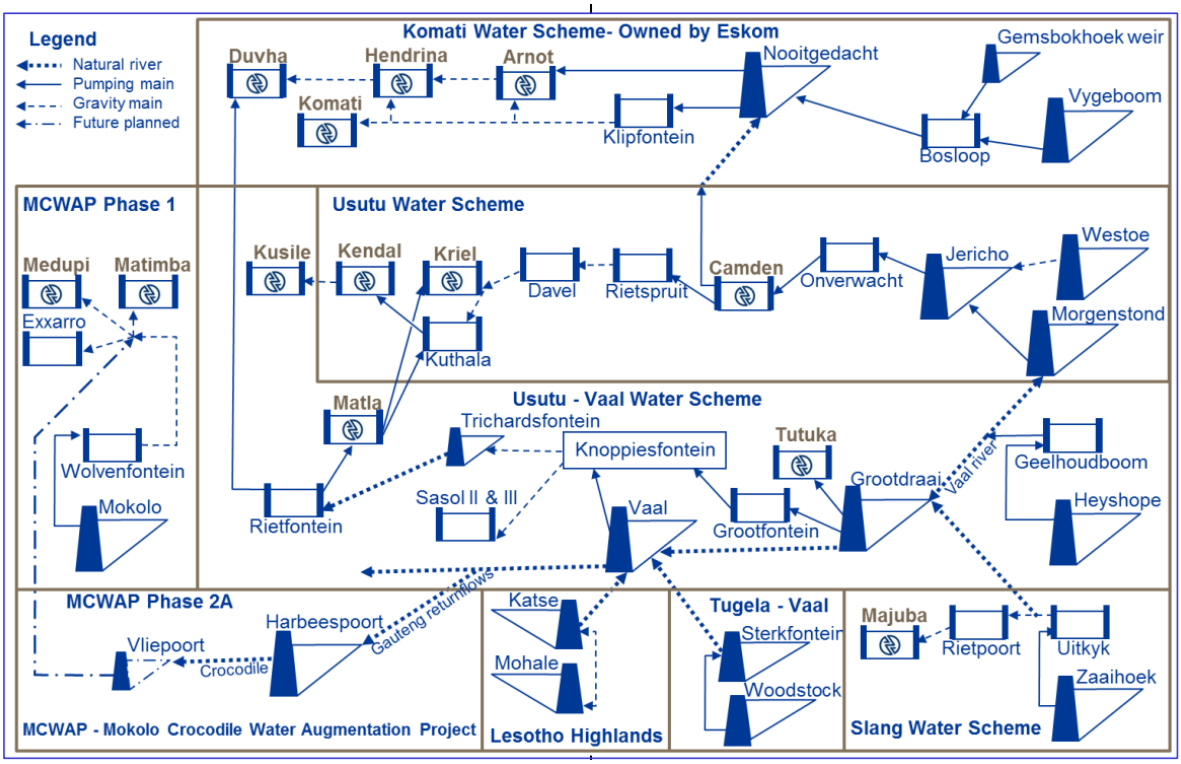


Figure 2: Interdependence of the South African energy plants' water schemes (Govender, 2018)[1]

1.2. Research Problem

SA power plants are currently experiencing several challenges when managing water usage and containing it within their dams, whether within the clean or dirty water dams. Numerous reasons have been provided to explain the increased water usage (Eskom, 2020). However, the key issue is understanding the cause of this high-water usage, leading to dam overflows and eventually pollution of the natural water streams/rivers and groundwater system. Not only does this lead to pollution, but it has also been speculated that water is being wasted (Eskom, 2020).

Understanding the root causes of water overuse is necessary for power plants to optimise water management, meet legal requirements and identify opportunities for improvement. For this study, two power stations were analysed, power plants 1 and 2. The researcher chose these plants based on their proximity to each other regarding location. Although the plants experience the same climatic conditions and struggle with water management, these power plants have experienced water wastage. The evidence reflected in occurring dam overflow incidents that have taken place, as well as not meeting the water use target and regulated limits which are key performance indicators to measure environmental performance

[1] The full water scheme is shared to provide understanding of Eskom's raw water network; however, the author could not share the specific power plants to maintain the power plants' anonymous.

(Eskom, 2015). As a result, the power utility investigated the root cause of water wastage. However, the water wastage issue remained unanswered as overflows continued, with all power plants (including Power Plants 1 and 2) struggling to meet the annual water-use target in 2020 (Eskom, 2020). The business has indicated in its internal monthly environmental reports that as of October 2020, Power Plant 1, with a water use target of 2.19 l/kWhSO, performed at 2.45 l/kWhSO and Power Plants 2, with a water use target of 2.03, performed at 2.18 l/kWhSO year-to-date, emphasising questionable water management practices. This study will investigate the cause of high-water usage at these two SA thermal power plants.

1.3. Critical Research Question

The critical research question is, thus: What are the causes of high-water usage in Power Plants 1 and 2?

1.4. Objectives

The objectives of the study are to:

1.4.1. Analyse the incidences and areas contributing to excessive water usage particularly focusing on areas leading to dam overflows and environmental contamination.

1.4.2. Identify deviations from standard operating procedures (SOPs) to determine if they contribute to excessive water usage and impact water management effectiveness.

1.4.3. Describe the inefficiencies and gaps within the water management systems to aid future development of a targeted, evidence-based strategy that enhances water conservation and operational efficiency.

1.5 Summary of Research Method

A qualitative research technique was used for this study to provide an understanding and in-depth information regarding water usage in SA thermal power plants. The proposed research design was semi-structured interviews and an analysis of standard operational procedures (SOPs) and policies which govern and drive water management at two SA power plants (namely Power Plant 1 and Power Plant 2). The researcher selected the power plants mentioned earlier due to the availability of data and accessibility to the relevant stakeholders of the power plants to interview. Semi-structured interviews were conducted with appropriate water management stakeholders, from operators to management. The procedures and policies provided the water management requirements, and the interviews provided the administered operating mode at the power plant. The sample consisted of 10 participants comprised of four water treatment plant operators/managers, two environmental management officers or managers/operators of the outside plant, specifically the clean and

dirty water dams. The SOPs were collected from the power plant of interest and level one operational procedure from the Generation Division Head Office's department responsible for power generation sustainability. The interviews were conducted in person or telephonically with the identified stakeholders to establish the current operational processes—the six-phase approach by Braun and Clarke (2012) to conduct thematic data analysis—a gap analysis to identify gaps within the operational processes through the interviews. Triangulation was performed using multiple data collection and analysis methods to remove bias and test study validity and reliability. The last step was to formulate recommendations which will assist in addressing the areas of concerns and issues identified from the gap analysis.

It is critical to obtain all permissions and ethical clearance (ethical clearance number: MIAEC 004/21) to ensure that the quality of the research is not compromised, considering the ethical requirements.

1.6 Delimitations

The focus of this study is South Africa's power utility. The study could have been for all coal-fired power plants; however, two power plants were considered due to the limited time to complete the study. Firstly, the study focussed only on coal-fired power plants because of the significant water losses. Secondly, the appropriateness of selecting power plants 1 and 2 is their location. These plants are found in the same water catchment area in South Africa and receive water from the same water scheme. In other words, the water quality received is similar, and water impacts on surface and groundwater would be in the same catchment.
The interviews were aimed at both the power plants' internal staff and corporate, technical and research employees to establish a complete picture of the status; unfortunately, due to interviewees assisting with mitigating load shedding and operational pressures, which compromised the availability of interviewees. As a result, the researcher interviewed ten interviewees, which did not significantly impact the quality of the results. To maintain the anonymity of the interviewees and power plants 1 and 2, information provided on the two plants will not provide location and name. In South Africa, coal-fired power plants are owned by the monopoly, and therefore most data and references will be from the power utility or international sources.

1.8 Outline of Chapters

- Chapter 1: Introduction

  Introduces the research topic. This chapter provides the importance of water in terms of the SDGs. The complex interdependency between water and energy, thus, poses new challenges for policymakers to achieve a safe, secure, and sustainable supply of water and energy in the future (Pan et al., 2018)). Finally, the chapter provides a background to the research study, including the research problem and objective of the paper.

- Chapter 2: Literature Review

  The literature review section of the paper then delves deeper into the research topic and objective, showing the study's importance and outlining water usage methods in thermoelectric power plants as well as the constraints in water availability. The literature review's themes include water usage in thermoelectric power plants, freshwater supply schemes for South African power plants, limitations in water availability and water management.

- Chapter 3: Research Method

  A qualitative research approach was used for this study to provide an understanding and in-depth information regarding water usage in SA thermal power plants. The research instruments for the study were semi-structured interviews with management at two SA power plants (namely Power Plant 1 and Power Plant 2). Due to the availability of data and the accessibility of the pertinent power plant stakeholders for interviews, the researcher chose these two plants. Chapter 3 covers the research design, sampling, data collection and analysis procedures, reliability, validity, and ethical considerations.

- Chapter 4: Research Findings, Analysis, and Interpretation of Data

  This chapter covers the analysis of the results obtained for power plants 1 and 2 to assist in the following:

  - Identifying where water wastage within the power plants is taking place,
  - Identify the gap in water management, and
  - Show deviations in plant operations to the utility's water management strategy and supporting standard operating procedures.

  In addition, the chapter discusses the research findings, analysis of the obtained data & information, and further interprets and discusses the results.

- Chapter 5: Discussion

  Within this chapter, a discussion of the results for further understanding of water management practices.

- Chapter 6: Conclusion and Recommendation

  This chapter concludes the study and establishes that water management is complex and dynamic, in thermal power plant's numerous role players in water management and several systems that need to

be operated, managed, and controlled. Water is the primary driver of electricity production; however, conflicting priorities led to the neglect of water. Without water, there will be no electricity. The growing constraints in water availability leave electricity generation vulnerable, especially because South Africa is a water-stressed country. Therefore, it is critical that leadership provides direction more efficiently and instils sound consequence management practices in the business to move towards thought leadership ultimately.

CHAPTER 2

LITERATURE REVIEW

This literature review outlines water usage practices within thermoelectric power plants and the constraints on water availability. The literature review's themes include water usage in thermoelectric power plants, freshwater supply schemes for South African power plants, limitations in water availability and water management.

2.1. Water Usage in Thermoelectric Power Plants

Water Consumption and Withdrawal in Thermoelectric Power Plants

Water consumption and withdrawal are distinguished in Thopil and Pouris (2016) as defined by U.S. Geological Survey. “Withdrawal” is the amount of water removed from the ground or diverted from a water source for use. At the same time, “consumption” refers to the amount of water evaporated, transpired, incorporated into products or crops, or otherwise removed from the immediate water environment. Energy production accounts for 10% of global water withdrawals, while thermoelectric power plants, including fossil fuels and nuclear, account for more than 80% of global electricity generation. According to Feeley III et al. (2008), each kilowatt-hour (kWh) of thermoelectric generation requires the withdrawal of ~94,6 litres of water, primarily used for cooling purposes. However, power plants also use water for FGD devices, ash handling, wastewater treatment, and wash water. Besides water withdrawals and consumption for cooling in thermoelectric generation, some water is used in the extraction, processing, and transport of fuels in electricity generation (Pan *et al.*, 2018). Pan *et al.* (2018) indicates that the options for source water for thermoelectric power plants include (i) natural surface water, (ii) underground water, (iii) reclaimed water, and (iv) treated potable water. According to Delgado and Herzog (2012), many alternatives are available, but most times, they are costly, whereas many states do not price water. Hence, unless regulations force power plants to do otherwise, it nearly always makes economic sense to use a wet cooling tower, which results in increased electricity output compared to a dry or hybrid system. Jin *et al.* (2019) argue that Coal thermal power plant's infrastructure is the largest water user among all fuel-powered thermal plants. A pulverized coal-fired (PC)

power plant with CO_2 capture and storage (CCS) uses about twice the amount of water per kWh than a PC power plant without CCS (Delgado and Herzog, 2012). Jin *et al.* (2019) further state that nuclear power has the lowest water consumption per power production unit due to the high electricity output over generally longer lifetimes. Thopil and Pouris (2015) opine that Water usage in electricity generation primarily depends on the type of technology used. A few international studies mention that the range of water used per kWh varies from 0.08 litres/kWh to 0.2 litres/kWh for recirculating cooling technology types in coal power plants (Thopil and Pouris, 2015). Jin *et al.* (2019) describe Coal power plants with closed-loop cooling technology as the most significant water consumers and plants with once-through cooling technology as leading water withdrawers.

Thermoelectric power plants traditionally have required vast volumes of water to condense steam from the turbine exhaust (Pan *et al.*, 2018). Pan *et al.* (2018) further explain that the performance of thermoelectric power generation largely relies on water cooling systems, and thermoelectric plants withdraw enormous quantities of water for cooling. Figure 3 below, although focusing on the cooling system, shows the typical water uses within a thermal power plant.

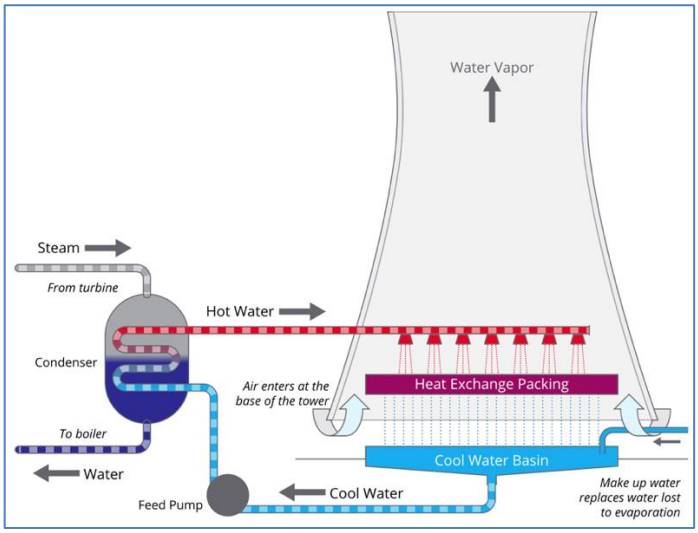


Figure 3: Typical Water Processes within a Thermal Power Plant (Reimers, 2018).

The typical water processes within a thermal power plant are explained below:

- Demineralized water is gradually heated to create steam, transforming heat energy into mechanical energy, and turning (driving) the turbine to generate electricity.
- Mechanical energy is converted into electrical energy in the connected generator, latent heat is released in the condenser, and the condensate is returned to the boiler for reheating (Gude, 2015).
- The cooling process where natural (raw) water is utilised to cool the steam within the condenser,
- Water is used for cleaning components of the plant.

Of all these processes, the wet cooling water system consumes about 80% to 90% of the water through evaporation (Pather, 2004).

According to Muthuraman (2016), thermal power plant water requirements are governed by several factors. These factors are the quality of raw water, type of condenser cooling system, quality of coal, ash utilisation, variety of ash disposal systems, and wastewater management (Muthuraman, 2016). The typical breakdown of water consumption, taken as 4000 m^3/h, for a typical 2x500 MW plant with wet ash disposal without recycling of ash pond water is indicated in

Table 1 below. Cooling tower makeup amounts to = 3450 / 4000 = 86 % of the total water requirement (Muthuraman, 2016).

Table 1: Types of Water consumption in a thermal power plant (Muthuraman, 2016)

No.	Usage	Quantity [m3/h]
1.	Cooling towers make up	3450
2.	Ash disposal	1300*
3.	Demin water make-up	120
4.	Clarifier sludge	110
5.	Potable & service water	250
6.	Coal dust suppression	70
	Total	**4000**

**To be tapped from the cooling water system as blowdown water and not considered consumptive water*.

Carpenter (2017) further discusses the various ways the existence of water in a thermal power plant, including its associated water-steam and flue gas paths illustrated in

Figure 4. Broadly classified as:

- Unavoidable losses include evaporation of recirculated water in wet cooling towers and minor steam leaks.
- Losses to forming products, such as gypsum, from the wet FGD scrubber.
- Deliberate blowdown from various recirculating streams, including boiler feedwater and FGD streams.
- Cooling water.
- Blowdown is necessary to preserve water quality and remove impurities.
- Handling products, such as ash sluicing.

Figure 2 indicates where water is lost and added (water makeup).

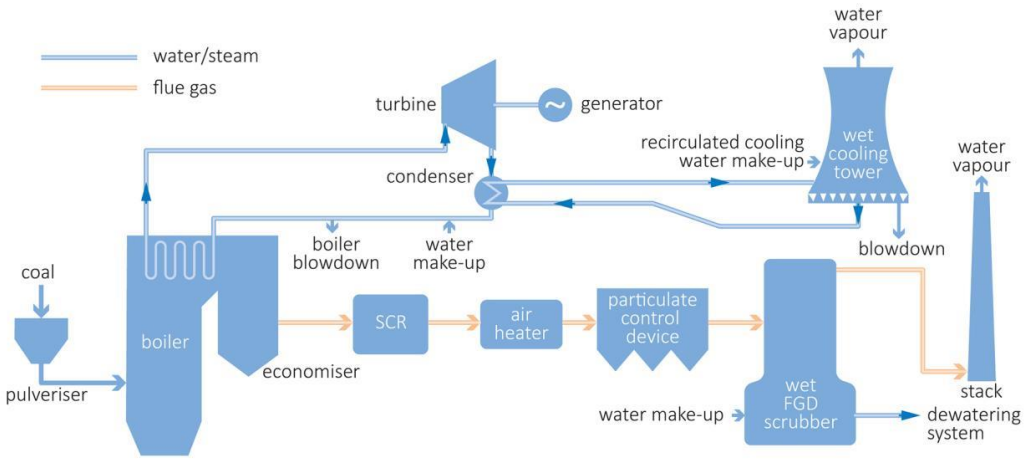


Figure 4: Schematic of a power plant showing where water is lost and added (Carpenter, 2017)

Vassolo and Döll (2005) show the computation of thermoelectric power water use: each thermal power station's annual water withdrawal and consumption are estimated first, adding all stations' water uses. The total water withdrawal for each power plant is then calculated by multiplying the annual power generation (MWh/year) by the power plant's water intensity (water withdrawal per power generation unit, m3/MWh). The total annual thermoelectric power water withdrawal (TWW, in m^3/year) is then calculated as the sum of the withdrawals of all the power stations. For example, the total water used in the cooling of thermal power stations for Africa in 1995 was ~3,637 and 344 $x10^6$ m^3/year for withdrawals and cooling, respectively (Vassolo and Döll, 2005). Yang and Dziegielewski (2007) indicate that thermoelectric power generation is responsible for the most significant annual volume of water withdrawals in the United States of America (USA). It is, however, only a distant third after irrigation and industrial sectors in consumptive use.

Similarly, Pan *et al.* 2018 indicate that thermoelectric power generation accounts for about 10% of China's freshwater withdrawal. Yang and Dziegielewski (2007) expressed concern that much fewer water-use studies have been conducted for thermoelectric generation than in other water-using sectors. These authors opine that one possible reason is that thermoelectric water use is assumed to be strictly determined by physical laws. Yang and Dziegielewski (2007) add that factor like water source, fuel type and operational conditions besides cooling system type influence thermoelectric water withdrawal and consumption. Power plants also tend to have lower unit water use when they are run with higher operational and thermal efficiencies (Yang and Dziegielewski, 2007). Yang and Dziegielewski (2007) also mention differences in the amounts of unit thermoelectric water withdrawal and consumption that may be attributed to some inefficiency in water use.

Causes of High-Water Usage in Thermal Power Plants

A study in China showed that the water consumption of coal-fired power plants was 3.5 km^3, accounting for 11% of total industrial water consumption in China (Zang et al., 2017). Eighty-four percent of this water consumption was from plants with closed-cycle cooling. China's average water intensity of coal-fired power plants was 1.15 l/kWh, while the intensity for closed-cycle cooling was 3–10 times higher than that for other

cooling technologies (Zang et al., 2017). In addition, about 75% of water consumption was from regions with absolute or chronic water scarcity (Zang et al., 2017).

A study by Lui et al. (2015) deduced that energy conservation and water conservation are obtained simultaneously in American lignite power plants. The calculation revealed that the air-cooling unit needs (unlike wet cooling) no makeup water and even produces some water as it generates power when the water carrying coefficient is higher than 40 g/MJ. The power plant firing high moisture lignite becomes more environmentally friendly with higher power generation efficiency and a lower water makeup rate than the one firing low moisture lignite. Dry-cooling systems use air instead of water to cool the exhaust of steam turbines. It is an effective method to decrease the total water use of power plants by more than 90%. The trade-offs to these water savings are higher costs and lower efficiencies (Lui et al., 2015). Similarly, pollutant control systems, e.g., carbon capture and storage (CCS) and flue gas desulphurisation (FGD), also increase the water use of power plants (Lui et al., 2015).

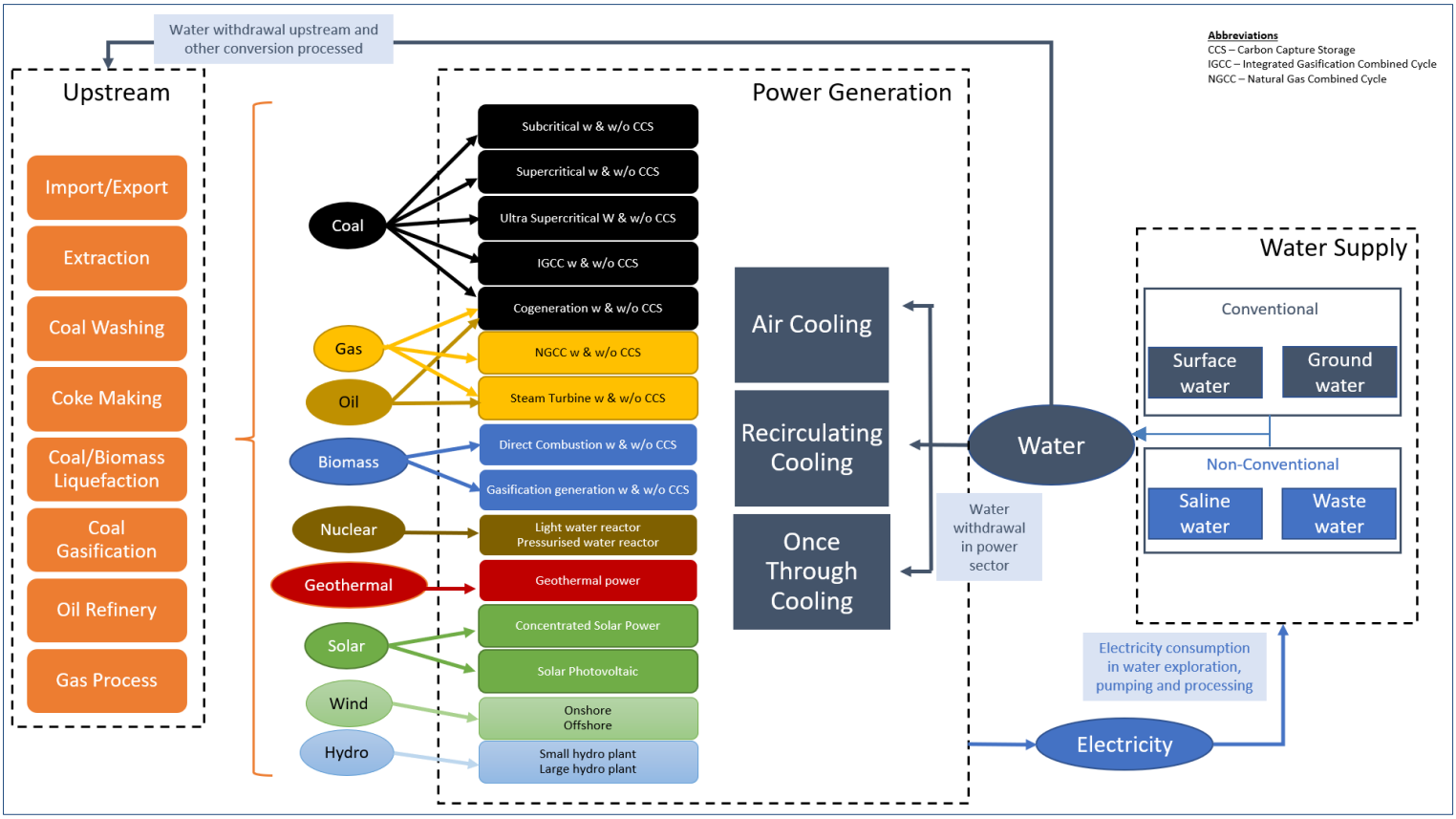


Figure 5: Water module integrated into China TIMES power and upstream sector by Huang et al. (2017)

Figure 4 above demonstrates the water withdrawal module for China; it also indicates the water withdrawn purely for power production cooling systems and upstream activities. A paper by W. Huang et al. (2017) showed that in China, like in South Africa, the power sector is a significant water consumer, accounting for about 7% of the total in 2012. The water withdrawal in the power sector is mainly affected by technologies' activity level, fuel type, and cooling type. Power generation is expected to increase from 4518 TW h in 2010 to 13,270 TW h in 2050, with water withdrawal from 59 Gm^3 to 104 Gm^3. Introducing water constraints for

China will switch technology and cooling type portfolio, thus altering water withdrawal (Huang et al., 2017). Coal-fired power plants produce emissions, and technologies to reduce emissions also pose a water issue because they require high cooling water and do not favour reducing water withdrawal. The increase in water cost in China encourages the shift from once-through cooling to air cooling and the adoption of low-water-intensity power plant technologies (W. Huang et al., 2017).

2.2. Constraints in Water Availability

Roehrkasten, Schaeuble, and Helgenberger (2015) highlight that it is primarily hydropower generation that has been affected by water constraints. However, nuclear and coal power plants have been switched off temporarily or have had to be operated at reduced load due to water constraints which have been the case, especially in the USA, Europe, and Australia. Numerous examples of water-related incidents compromise power generation from coal and nuclear. As per Merschmann, Vasquez, Szklo and Schaeffer (2013), if thermal power plants are installed in hydrographic regions where water levels are critical, the lack of available water may limit the implementation of CO_2 capture. Therefore, the thermal power plants in these regions are the most vulnerable from the viewpoint of water stress. Carpenter (2017) adds that the vulnerability of the electricity generation industry to constraints in water availability is widespread and growing.

Moreover, significant areas of almost every continent face a high level of water stress, including large regions of China, India, South Africa (SA), and the United States of America (USA), the four top thermal coal-consuming countries in the world (Carpenter, 2017). Carpenter (2017) further points out that the electricity generation industry in the water-abundant North-East region of the USA is facing issues of water quality and temperature. Power plants have had to close at times to ensure they do not exceed the permitted water discharge temperature. As a result, the number of plants affected will likely increase, with severe economic consequences. Furthermore, groundwater supplies are diminishing, with an estimated 20% of the world's aquifers already overexploited and deteriorating water quality (Carpenter, 2017). Carpenter (2017) adds that competition between power plant operators and other water users will likely escalate, and climate change could further exacerbate the situation. In addition, government regulatory restraints may impose limits on or increase the cost of freshwater usage by power plants. These factors pressure power plant operators to reduce water consumption and look for alternative or supplementary non-fresh water sources (Carpenter, 2017). To assess the vulnerability of the world's current thermoelectric power-generation system to changing climate and water resources, Van Vliet, Wiberg, Leduc, and Riahi (2016) used a coupled hydrological–electricity modelling framework with data on 1,427 thermoelectric power plants. They forecasted reductions in usable capacity for 81–86% of the thermoelectric power plants worldwide for 2040–2069 (Van Vliet *et al.*, 2016).

2.3. Water Management

Gjorgiev and Sansavini (2018) indicate that water management practices must be sound because reliable power generation from thermal power plants highly depends on reliable access to fresh water, making thermal generation vulnerable to water scarcity and stresses the importance of minimising water wastage within a power plant (Gjorgiev and Sansavini, 2018). China Water Risk (2012) explains that zero-liquid discharge (ZLD) policies and technologies have been used in various plants to manage water in China. Similarly, van Zyl and Premlall (2005) indicate that all Eskom plants operate on a ZLD policy in SA. Therefore, no polluted water is allowed to leave the site under any conditions, and the only way water mostly leaves the confines of the station is by evaporation from the cooling towers. Van Zyl and Premlall (2005) further explain that all effluents produced are collected and stored in dams on the power station site. This water is then re-used for functions that can accept lower-quality water. In this way, the amount of wastewater recycled is maximised, and the quantity of raw water required is minimised (van Zyl and Premlall, 2005). Likewise, GE (2013) adds that this has been seen as the solution to help plants to meet discharge and water reuse requirements, enabling the plants to maximise water reuse and assist in better managing produced water. Van Zyl and Premlall (2005) point out that unlike Eskom power stations, municipal power stations use *once-through systems* utilising municipal water as a water source. After usage, most water is disposed-off to the municipal sewer. Lubega and Stillwell (2018) highlight a gap in the literature regarding tools to support decision-making in near-term operations planning time scales under the constraints of existing infrastructure. Particularly when analysing and addressing the critical long-term planning challenges of thermal power plant water requirements and vulnerabilities (Lubega and Stillwell, 2018). Lubega and Stillwell (2018) concluded that there is a benefit in having a shared language which can permit involvement from and discussion between power plant operators, power grid operators, and environmental authorities, which can allow for an integrated approach to water management where regulation meets operational procedures.

2.4. Conceptual Framework

Figure 5 below is a conceptual model developed from the above literature review and used to create the interview questions for this research. The conceptual model divided water management into three parts; the factors contributing towards water management, the challenges experienced in power plants regarding water management and solutions provided within literature which will or can solve the water management issues in each category. Appendix 1 – Literature Assessment categorised the constraints into four thematic areas, namely:

1. Technical Challenges
2. Water Chemistry
3. Cooling System
4. Other Constraints

The literature provided constraints, the factors contributing to water usage, the challenges experienced for each constraint and solutions. The literature clearly states the solutions, which are both human-related and technological. Requiring an integration of the two is to improve water usage and management in power plants. The conceptual framework and literature review guided the development of the following propositions:

- The solution around effective policies and procedures would relate to **Water Governance Strategy and Operational Procedures.**
- The challenge of poor plant performance, high water usage, consumption and withdrawal and the factor of performance pressure would relate to the **Power Plant's Water Performance**
- The factor of strict legal requirements is related to **Power Plant's Water-Related Legal Non-Compliances**
- Technical challenges are the primary constraint and are referred to several times in literature as part of the challenges and solutions to water management; therefore, looking into the **Status of Water-Related Infrastructure/Systems** would be critical.

The conceptual model also shows that one solution can resolve challenges caused by two factors. Two or more factors can or are experiencing the same or similar challenges. In this way, if one focuses on a solution that resolves more than one challenge, resolving most of the water issues.

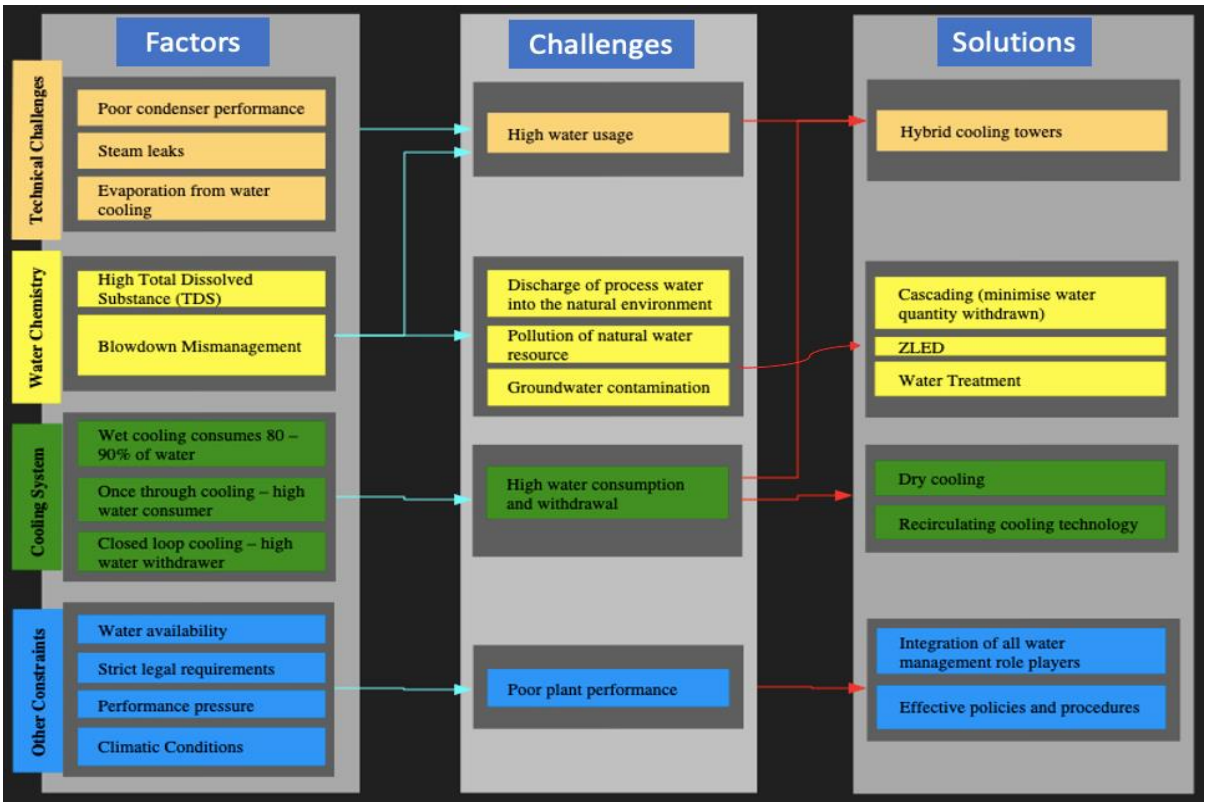


Figure 6: Conceptual Model Depicting Water Management Constraints, Challenges and Solutions

CHAPTER 3

RESEARCH METHOD

3.1 Research Design

A qualitative research approach was used for this study to provide an understanding and in-depth information regarding water usage in SA thermal power plants. Qualitative research in this study was most appropriate as several factors could contribute to water wastage in a power plant and obtaining real-life experience from the technical experts assisted in providing a better understanding. A qualitative research study uses a naturalistic approach that seeks to understand phenomena in context-specific settings, produces findings derived from real-world environments where the "phenomenon of interest unfold naturally" (Golfashani, 2003). Researchers can utilise the information obtained from the study to generate hypotheses that can then be tested by quantitative methods (Patton and Cochran, 2002).

3.2 Research Instruments

The research instruments for the study were semi-structured interviews with management at two SA power plants (namely Power Plant 1 and Power Plant 2).

These two power plants were selected due to the availability of data and accessibility to the relevant stakeholders of the power plants to interview.

Semi-structured Interview

Semi-structured interviews were conducted with relevant water management stakeholders, from operators to management. The interviews were more conversational, allowing for an open response in the participants' words rather than a 'yes or no' answer (Mussardo, 2019). A less structured interview is essential to model and theory building, unlike a more structured interview needed for model and theory testing. This form of interviewing has some degree of predetermined order but still ensures flexibility in how the participants address issues (Rocco, 2003).

The literature provided context for the water management challenge, and a conceptual framework was built based on the literature review assessment (see Appendix 1). The framework's conclusions were then used to develop key interview questions. As mentioned in Chapter 2.4, the research and consolidation of water management factors, challenges, and solutions resulted in four focus themes that aided in developing interview questions. Questions were constructed using experience, literature, and, most

importantly, the conceptual framework (aligned with the Rose-Wengraf Model of the research process, Wengraf 2001).

The interview protocol probed, among other things:

- Water Governance Strategy and Operational Procedures
- Power Plant's Water Performance
- Power Plant's Water-Related Legal Non-Compliances
- Status of Water-Related Infrastructure/Systems

The procedures and policies provided the water management requirements, and the interviews provided the reality of the operating mode administered at the power plant. Stakeholder interviews ensured that water management practices were sound and carried out per the regulations. From these, an understanding of water management practices was developed, which allows for an analysis of whether water management practices are sound and identify whether there is water wastage and where it is most likely taking place.

Semi-structured narrative interviews were carried out, with participants allowed to elaborate on their experience, knowledge, and abilities in water management, occasionally followed by lightly structured depth questions. Some questions necessitated more extensive narratives, while others only required one-word responses. The receptive and assertive strategies were utilised; the receptive approach empowers the interviewee, giving them a considerable measure of control in how they answer the relatively few and relatively open questions. The interviewer-assertive strategy enabled the interviewer to control the responses, provoke and illuminate self-contradiction, absences, provoke self-reflexivity and development; the interviewer encourages the respondents to explore the same situation from a variety of 'stand/view/points' (Wengraf, 2001). The questionnaire available in Appendix 4 was developed using the Wengraf Pyramid Model. The research question guided the development of the conceptual model, which eventually led to the formulation of theoretical questions based on the themes' propositions. These theoretical questions further guided the development of interview questions.

3.2 Sampling

Semi-structured interviews were conducted with appropriate stakeholders and experts, namely, four water treatment plant operator/manager, two environmental management officers or manager/operator of the outside plant, specifically the plant clean and dirty water dams. A total of 10 participants were interviewed based on their expertise and engagement with the water management process of a power plant and their availability. The 10 participants were selected based on the business's organisational structure to ensure that pertinent stakeholders (Generation Water Strategy Developers, Engineers, and Researchers) participate in this study. For consistency, data was collected for the two power plants, however, to ensure

that there is a depth of knowledge not only were the operators interviewed, but the study also interviewed stakeholders of water management who are involved in water management of the power plant of interest making this study rich data as mentioned by Fusch and Ness (2015). The sample interviewed in listed below:

- Engineer in research testing and development (RT&D)
- Water specialist in RT&D
- Senior Engineer in Risk and Sustainability (R&S) Environmental
- Senior Chemist in Generation Engineering Sustainability
- Power Plant 1 Senior Environmental Advisor
- Power Plant 1 Environmental Advisor
- Power Plant 2 Senior Environmental Advisor
- Power Plant 1 Water Plant Maintenance
- Power Plant 2 Water Plant Operator
- Power Plant 2 Water Plant Manager

Rich data is many-layered, intricate and detailed keeping in mind that one cannot assume data saturation has been reached just because one has exhausted the resources however the sample size that has been chosen must provide the best opportunity to reach data saturation (Fusch and Ness, 2015). These interviews assisted in conducting a gap analysis between the current mode of operation and the SOPs, the interviews also assisted in identifying areas where there was water wastage/over usage as well as getting expert advice on potential improvements that can be made.

3.3 Data Collection

The SOPs were collected from the power plants of interest and level one operational procedures from the Generation Division Head Office's department responsible for power generation sustainability. An email was sent to the responsible personnel requesting these procedures before they are obtained from the Hyperwave System which stores all policies and procedures for the business. All documents which govern water management for power plants starting with legal requirements and the SABS Standards to the power plants SOPs were identified. Once these documents were sourced, interviewees were asked how they feature these in their day-to-day work and how effective are these governance documents in ensuring sound water management, also to establish an understanding of the use of these documents the interviewees indicated their knowledge of the hierarchy of governance documents, their importance and use within the business. This was done to establish the use and effectiveness of these documents at the coal face, operational level.

Individual emails requesting participation were sent to the identified stakeholders, included in the email were the consent letter from the Eskom Environmental Manager and the participation form which stipulates how the personal information and data shared by the participants will be protected. Due to Covid 19 restrictions, interviews could only be conducted via Microsoft Teams Software. The interviews were held with the identified water management role players and water experts in the business to help establish the current operational processes of the two power plants. The questionnaire was shared with the participants before the interview, and the questions asked during the discussion were from the same questionnaire. The duration of each interview was an on average an hour and a half. Each interview was closed and protected to ensure no one gains access to the discussion and transcribed during the interviews. Anonymised transcripts and recordings are only accessible to the interviewer and will be destroyed after five years.

3.4 Data Analysis

The six-phase approach by Braun and Clarke (2012) was followed to conduct a thematic analysis of the data:

- Phase 1: familiarisation with data by reading transcripts of interviews and interview recordings conducted with stakeholders of interest.
- Phase 2: development of "a priori" themes from the conceptual framework in Chapter 2.
- Phase 3: organise data in a meaningful and systematic way to find alignment with the a priori themes assisting in reducing the large amount of data by grouping it.
- Phase 4: searching and developing for emergent themes where significant or interesting information about the data and/or research question.
- Phase 5: analyse and identify trends for the themes.
- Phase 6: producing a report.

One of the objectives for this study was to "recommend solutions to address the gaps," but before one can provide solutions to gaps, those gaps need to be identified. The question "What gaps have you identified in terms of water management on your site and within the organisation as a whole?" is included in the questionnaire. This question and the evaluation provided information about the gaps in power plant water management practices.

3.5 Reliability and Validity

A comprehensive triangulation method was employed ensure the reliability and validity of findings in the study, this approach, as outlined by Golfashani (2003), incorporates multiple methods of data collection and data analysis to enhance the study's credibility and minimize potential biases. Triangulation is

described by Golfashani as a crucial validity procedure that seeks convergence among various sources of information to establish themes or categories within the research.

An exhaustive collection and meticulous analysis of procedural documents, policies, and legislative frameworks relevant to the operations of thermal power plants were conducted. These documents provide essential insights into the regulatory and operational standards required for effective water management. Concurrently, an extensive literature review was performed to ensure the study is well-anchored within existing academic discourse and practical applications, thereby enhancing its theoretical foundation.

By integrating actual data from procedural documents with theoretical insights from the literature review, both content and construct validity were established. Content validity was ensured by aligning the study's themes directly with the core standards and procedures outlined in the collected documents, accurately reflecting actual practices and regulatory requirements. Construct validity was reinforced through the correlation of these practical insights with theoretical model, supporting the relationships and constructs explored in the study.

The synthesis of empirical and theoretical data led to the formulation of a robust conceptual model, which directed the development of interview themes and questions. This model ensured that each research element was deeply rooted in actual evidence and reflected the theoretical constructs under investigation. The meticulous alignment between the conceptual model, the derived themes, and the structured questions substantiates the conceptual model and the questionnaire detailed in Appendices 1, 2, and 4.

This methodological approach not only affirms the reliability and validity of the findings but also significantly enhances the overall robustness of the study. The structured, triangulated methodology ensures that the research outcomes are credible, actionable, and of significant value to both academia and industry practitioners, particularly in the context of environmental management and sustainability in South African thermal power plants and in upholding the integrity of the research.

3.6 Ethical consideration

To ensure that the quality of the research is not compromised ethical consideration was considered by ensuring that all permissions to conduct the study and ethical clearance (ethical clearance number: MIAEC 004/21) were obtained. The participants were notified of the following:

- Participation is voluntary and interviewees are allowed to withdraw from the interview at any point should they feel a need to do so.
- The information they share with the researcher will remain confidential. Pseudonyms will be used when reporting the data in the research report, or any other publications.

- The researcher may use quotes from their interview in the research report and publications ensuring that their identity is kept anonymous.
- The interview may be audio recorded.
- They will not be remunerated for participating in the study.

Before the interview interviewees were invited to participate in the interview via email, all ethical documentation and the process for the interviews was explained to the interviewees, this included the purpose of the discussion as well as the duration. Following this, appointments were set up via outlooks and the interviews took place over the MS Teams platform for two hours. Transcripts and written notes were taken for each discussion and to ensure that personal information of the interviewees was kept private, a numbering system was used e.g., interviewee 1. The transcripts will be kept safe, archived for 5 years, and destroyed afterwards.

CHAPTER 4

RESEARCH FINDINGS, ANALYSIS, AND INTERPRETATION OF DATA

The purpose of the interviews was to gain information and data from power plant 1 and 2, which would assist in identifying where water wastage within the power plants is taking place. The questions asked aided in conducting a gap assessment in water management and to see if deviations in plant operations are related to the utility's water management strategy and supporting standard operating procedures. This chapter presents the research findings from the interviews. It provides an analysis of the obtained data and information. The results are therefore represented in the following according to the propositions established in the conceptual model:

- Water Governance Strategy and Operational Procedures
- Power Plant's Water Performance
- Power Plant's Water-Related Legal Non-Compliances
- Status of Water-Related Infrastructure/Systems

The results are put forth in accordance with the thesis created from the topics identified in the conceptual framework that served as the basis for the interview questions. Then, the interviewees elaborate on any emerging themes.

4.1 Profile of the Sample

Ten power utility specialists were questioned as part of the sampling, three from each power plant (six respondents), who were plant operators, plant management, maintenance, and environmental advisors. The

remaining four interviewees represent head office activities such as governance, research, policy, and assurance from the Generation Division, Research, Testing and Development, and Risk and Sustainability Divisions.

Table 2: Profile of sample

Interviewee	Interview Professional Background	Specialisation
Interviewee 1	Engineer in research testing and development (RT&D)	Chemical Engineer
Interviewee 2	Water specialist in RT&D	Chemical Scientist
Interviewee 3	Senior Engineer in Risk and Sustainability (R&S) Environmental	Chemical Engineer
Interviewee 4	Senior Chemist in Generation Engineering Sustainability	Chemist
Interviewee 5	Power Plant 1 Senior Environmental Advisor	Environmental Specialist
Interviewee 6	Power Plant 1 Environmental Advisor	Environmental Specialist
Interviewee 7	Power Plant 2 Senior Environmental Advisor	Environmental Specialist
Interviewee 8	Power Plant 1 Water Plant Maintenance	Mechanical Engineering
Interviewee 9	Power Plant 2 Water Plant Operator	Plant Operator
Interviewee 10	Power Plant 2 Water Plant Manager	Chemist

4.2 Water Governance Strategy and Operational Procedures

When identifying the power utility's governance structure and documents it was evident that various internal governance documents have been developed and derived from environmental legislation and international standards such as ISO14001 (normative referenced documents in all water management procedures). ISO 14001 and legislative requirements and policies play a crucial role in shaping the environmental management practices of South African thermal power plants, particularly in water management. The SHEQ (Safety, Health, Environment, and Quality) Policy of these plants includes specific requirements of ISO 14001, which underscores the commitment to environmental management systems. The integration of the Eskom SHEQ policy with ISO 14001 aligns business operations with environmental, safety, and quality standards. Enhancing regulatory compliance, operational efficiency, risk management, stakeholder confidence, and corporate sustainability. Illustrated in Figure 6 below, is the hierarchy of governance documents and structures for water management for South African power plants, these documents have been developed to assist in improving operations and maintenance, compliance with environmental legislation, water standards created by South African Bureau of Standards (SABS) and other international water systems standards, the utility has developed the following strategic documents:

- The SHEQ Policy (the first one was developed in 2013 and it reviewed every three years),
- Environmental Management Strategy (the first one was developed in 2017 and it is reviewed every three years)
- In addition, the Water Management Strategy (the first one was developed in 2012 and it is reviewed every three years)

Meanwhile, the Generation Divisions Water Management Implementation Plan and Power Plant's SOPs (of which more than 10 water related procedures are available) are procedures utilised at the plant level to ensure all operations are in conformance and compliance with the standards and National Water Act.

The National Water Act (NWA) was developed in 1998, before the development of the NWA, before this legislation was developed, operations needed to comply with the repealed Environment Conservation Act 73 of 1989 intended to provide for the adequate protection and controlled utilisation of the environment and matters incidental thereto. This legislation mandates detailed management and conservation practices to protect water resources, which power plants must integrate into their operational strategies to maintain legal compliance.

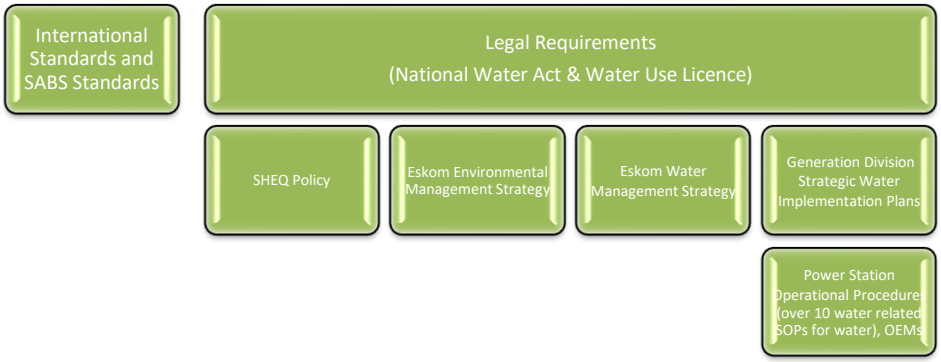


Figure 7: A Representation of the Hierarchy of Governance Documents and Structures for Water Management for South African Power Plants

In question 5 of the questionnaire, each participant was asked to rate the effectiveness of the current water management strategy and standard operating procedures implemented at your power plant (rating scale: 1 – 5, 5 being very effective and 1 not effective). Figure 7 represents the rating of the effectiveness of water management standard operating procedures and the water strategy and an average of 2.6 out of 5 (52%). As much as the score was 2.6 the responses from the interviewees contradicted the rating, what came out strongly from the interview comments was (see Appendix 2 and 3 analysis (Table 5) where the below data is sourced):

- There is no alignment between the water strategy and operational procedures.
- Operational procedures are not written in a language that the operators can understand.
- An ageing plant is being operated as if it is still new.
- The procedures and strategy are very well written but not easy to implement given the plant conditions and challenges.

"Everything is covered in the documents however when it comes to implementation it is an issue. The problem is the people, there is a shortage of people doing the work and lack of understanding of the work, a lack of disciplined execution, people are not doing what they are meant to do because there is no consequence management, it continues" said interviewee 4.

"In the previous financial year, power plant 1 only met the target once (one out of twelve months), failing to fulfil the total target. There are elements as a result of numerous unanticipated factors responsible for the failure, such as plant trips, water usage, and energy output, are interconnected and require maintenance. When a unit is down and we are not sending the megawatts we desire it affects water management as well as the unit sent out in megawatts (MW), water injector overflows and cooling tower overflows. There is also fire hydrant misuse, which needs to be controlled for cleaning the station. There are also several leaks leading to plant trips caused by boiler tube leaks, feed pump failures and condenser vacuum," said interviewee 8.

From the interviews it is shown that despite the presence of robust policies aligned with legislative and ISO standards, the research uncovered that actual policy implementation at the power plants has gaps. Standard Operating Procedures (SOPs) derived from these policies are not always effectively implemented or adhered to, leading to incidents of non-compliance.

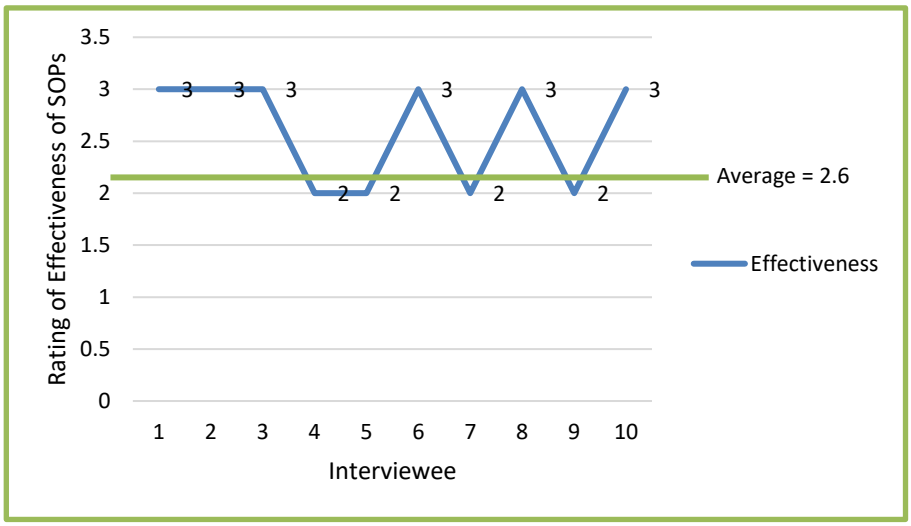


Figure 8: Effectiveness of Water Management SOPs.

4.3 Power Plant's Water-Related Legal Non-Compliances

Non-compliance to legislation for power plant 1 and 2 is highly linked to the site's conformance to SOPs and water management strategy. As mentioned in 4.1, the power utilities' procedures use environmental and water management legal requirements and standards to develop SOPs. Therefore, if a site has legal contraventions, they would not have followed the processes indicated within the standard operating procedures. The responses to question 7 to 10 of the questionnaire were linked to legal compliance challenges. From the analysis (Appendix 3, Table 9) of the answers, three categories (Figure 8) could be established as the root cause of water related non-compliance incidents, the non-compliance incident, and the resolution, which indicates measures that the plants can initiate to ensure that legal non-compliances are prevented. Interviewees 2, 5, 6, 7, 9 and 10 said that dam overflows are the most common type of water related legal contravention incidents that take place, interviewees 3, 4, 5, 8 and 10 said it was water release into environment & environmental contamination and interviewees 4 and 9 said water target exceedance.

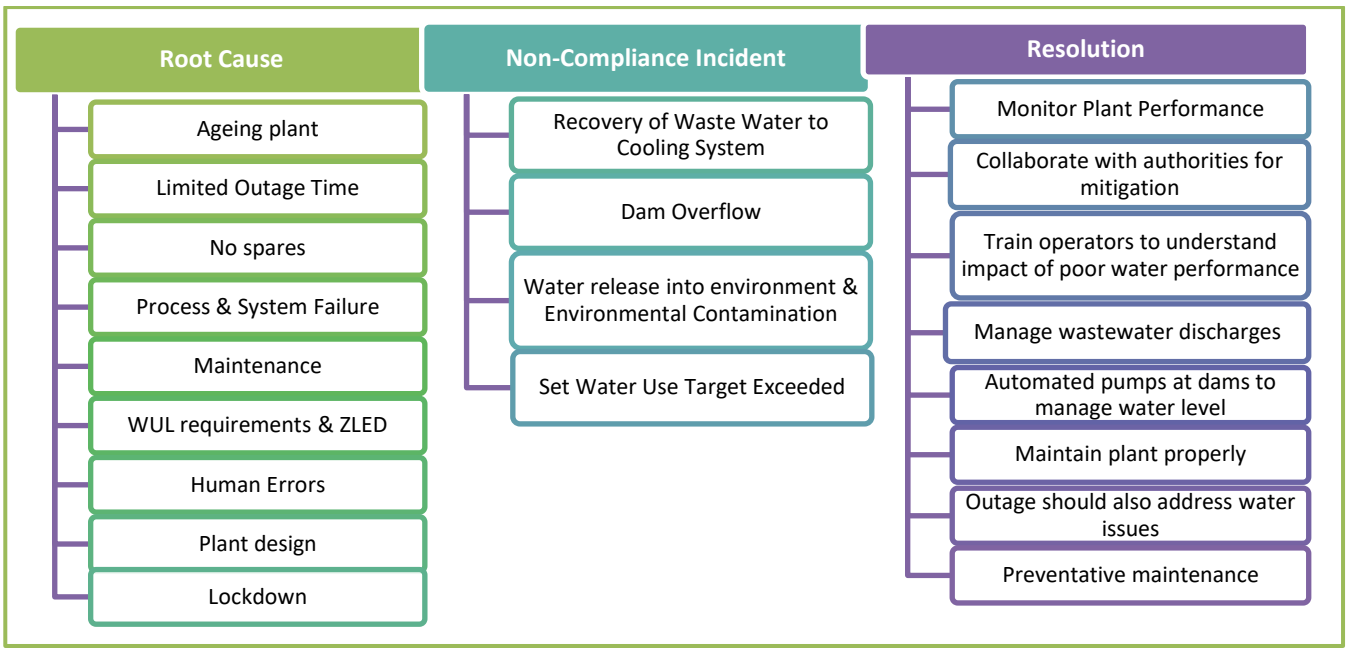


Figure 9: Outcome of interview analysis relating legal non-compliance.

Interviewee 2 mentioned that "the power utility's Incident Management Procedure has a good process; however, employees need to focus on the root cause of their problems, but this is not done thoroughly. Many of the incidents cannot be fixed using procedure only. Maintenance is a serious problem and leads to water losses and water non-compliances and environmental contamination is a consequence of a plant that is not running properly."

Interviewee 7 further added that "legal contravention incidents occur because of process and system failures for example management of the final effluent is an issue (where should this water go?); the dams are full, and they at times overflow in violation of ZLED policy, and non-compliance with the water use licence and the NWA. There are areas where everything works flawlessly, yet faults with the procedures persist. As a business, we must consider whether the capacity of wastewater dams is sufficient to manage the water from the system. We did not anticipate that the dam would fill; there should be a warning that there is a problem. The process is clearly flawed."

"Leaks at the station cause spillages and pollution of the groundwater resource. As a preventative measure, they conduct maintenance before it breaks down and ensure that scheduled maintenance occurs to prevent plant breakdowns. The SHEQ policy (aligned with ISO14001) guides the development of the environmental and water strategy and therefore my team's job is to conduct maintenance and to prevent water wastages. There are four types of leaks water leaks, oil leaks, ash leaks, steam leaks. At the outside plant, operators must manage water and oil leaks to prevent the degradation of the plant. He must repair leaks as soon as possible, when there are leaks in the plant and do preventative maintenance to prevent acid spillages. In terms of avoiding dam overflows, some areas are winning but in others, they are not" said interviewee 10.

The governance structure regarding water management is well-documented, but there are discrepancies between the written policies and their practical application. This misalignment often results in water management inefficiencies and legal non-compliance. There is a noted discrepancy between the robustness

of written procedures and their practical effectiveness in guiding operations, largely due to operational challenges and human factors such as insufficient training or lack of accountability.

4.3 Power Plant's Water Performance and the Status of Water-Related Infrastructure/Systems

In question 15 and 16 of the questionnaire, interviewees were asked, according to their experience and knowledge, what the major contributing factor towards water wastage or poor water performance is. The responses for this question were collated (using Appendix 2 information) and the frequency of each response noted.

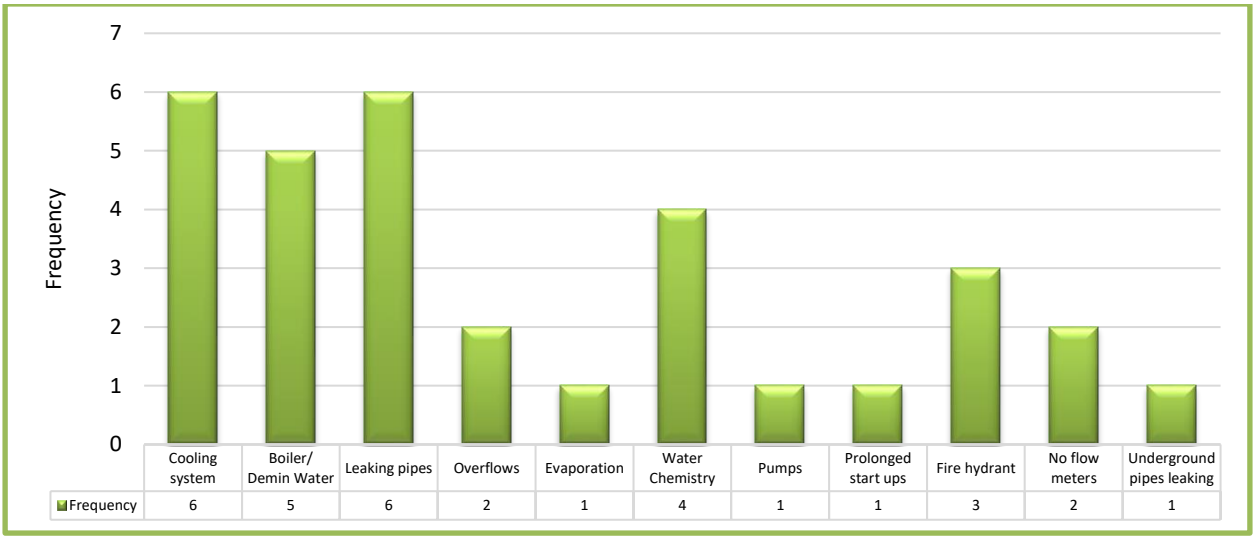


Figure 10: Power Plant Water Wastage.

Figure 9, summarises the analysis (Table 6 in Appendix 3) and indicates that the cooling system and leaking pipes were major contributing factors towards water wastage, followed by the boiler and demin water system. To note: some interviewees gave more than one factor. Table 6 in Appendix 6 demonstrates that interviewees 1, 3, 4, 6, 9, and 10 stated that the cooling system is to blame for excessive water waste in the plant, but interviewees 2, 3, 4, 8, 9, and 10 stated that pipe leaks are to blame. Surprisingly, the fire hydrant system was mentioned three times by interviewees 1, 5, and 8 at power plant 1. The fire hydrant system is being misused even though processes and procedures are in place to prevent this, they are ignored.

"The cooling water (CW) is the most important system on wet cooled stations, with 100ML a day lost and 90ML is lost to the CW some of the losses are due to evaporation at the cooling tower and others can be controlled through Cycles of Concentration (CoC). Leaks make it difficult to cycle up! Ash system and CW are co-dependant on each other. CoC is not met because of the constraints on the ash water system because ash pumps are often not working increasing water levels in the system. A lot of the systems are designed to have a huge safety margin, which has been highly abused" said interviewee 3.

"The fire hydrant system, employees use it for the wrong reasons for example, washing floors. There was an instruction that if someone wants to use this system, they must get approval from the General Manager (GM). A natural dam at plant 1 stores 1440ML of water and this water is lost through evaporation, it is water used

for cooling because it is within the cooling water specification – design is a problem because it is shallow." Interviewee 5. "The slurry plant – the original design of the slurry plant is a problem because there is no redundancy. You cannot maintain it properly because it cannot be out long. Therefore, this plant lacks maintenance, leading to plant failures and leaks and too much water going to the dams, which is incorrect. The water is usually pumped to the ash disposal facility, resulting in the water ash ratio at the ash dump not being balanced and posing structural issues and seepage (pollution) in the area."

4.5 Emerging Themes

Gaps in Water Management and External Factors Impacting Water Management

Table 3, Figure 10 and Figure 11 below show the identified gaps as well as external factors that are impacting on water management practices using Appendix 2 an analysis was conducted shown in table 7 and 8. They offer the results of a priority assessment that was conducted based on the responses from the interviews; with the gap or factor of highest concern or priority having the largest quadrilateral and the smallest receiving minimal responses from the interviewees. The respondents were asked the following questions (question 19 and 20):

19. Do you think any other external factors or influences contribute to plant water losses that should be incorporated into the site's SOPs?
20. What gaps have you identified regarding water management on your site and within the organisation?

The responses from each respondent were analysed, one table for gaps and another for external factors. The frequency (in Table 7 and 8) was calculated per interviewee, in some cases more than one answer was provided and therefore a mention from one interviewee will count as one e.g., if interviewee 1 responds to say that poor project planning this would then count as one and so on. This assessment and analysis aimed to establish emerging themes other than those in literature.

The respondents identified lack of strong leadership (identified by 5 interviewees) in the water management is an issue which further impacts on water management being neglected (1) and having a lack of prioritisation of maintenance (3) and projects (3) on water management systems such as pipes, slurry plant and cooling water system. Employees are not held accountable for negligence (3); therefore, accuracy in reviewing procedures (3) is lost due to a lack of oversight to ensure that work is conducted appropriately.

Table 3: Table reflecting the frequency that specific gaps were mentioned during the interviews.

Gaps in Water Management	Frequency
No Capital Investment/Budget	3
Poor Project Planning	3
Outdated/ Complex Procedures	3
Misalignment Between Divisions	2
Minimal Collaboration with External Stakeholders	3
No Strong Leadership	5
No Consequence for Negligence	3
Water is Neglected	1
No proper measurement of flow	2
Ageing Plant	1
Treating Symptoms not Root Cause	2
Procurement	2
Poor Maintenance of Systems	3

External Factors	Frequency
Water Quality Changed	3
Limited Outage for Maintenance/ Load Shedding Pressure	3
Interference from Head Office	2
Poor Enforcement from Authorities/ Unimplementable Licence Conditions	3
Positive Effect from NGO Interference	1
Procurement Process (Governance - Treasury)	2
Quality of Spares and Contractor Work	3
Environmental (Evaporation, High Rainfall)	1
Budget/Funding	3
Project Timelines Shifted (Lack of Urgency)	4
Coal Quality	1

Figure 10: below illustrates the gaps in water management practices brought up by the respondents during the interview. The biggest block indicates the most significant gap regarding the number of respondents who mentioned that issue as a gap. Of highest concern in the matter of not having strong leadership where 50% of the respondents felt that there is no strong leadership which was followed equally by (3) poor project planning, poor maintenance of systems, no consequence management, minimal collaboration with external stakeholders, outdated or complex procedure, no capital investment. Although a presumption that the ageing plant would be high, only one respondent expressed it as a gap and the fact that water management is neglected only one respondent expressed this.

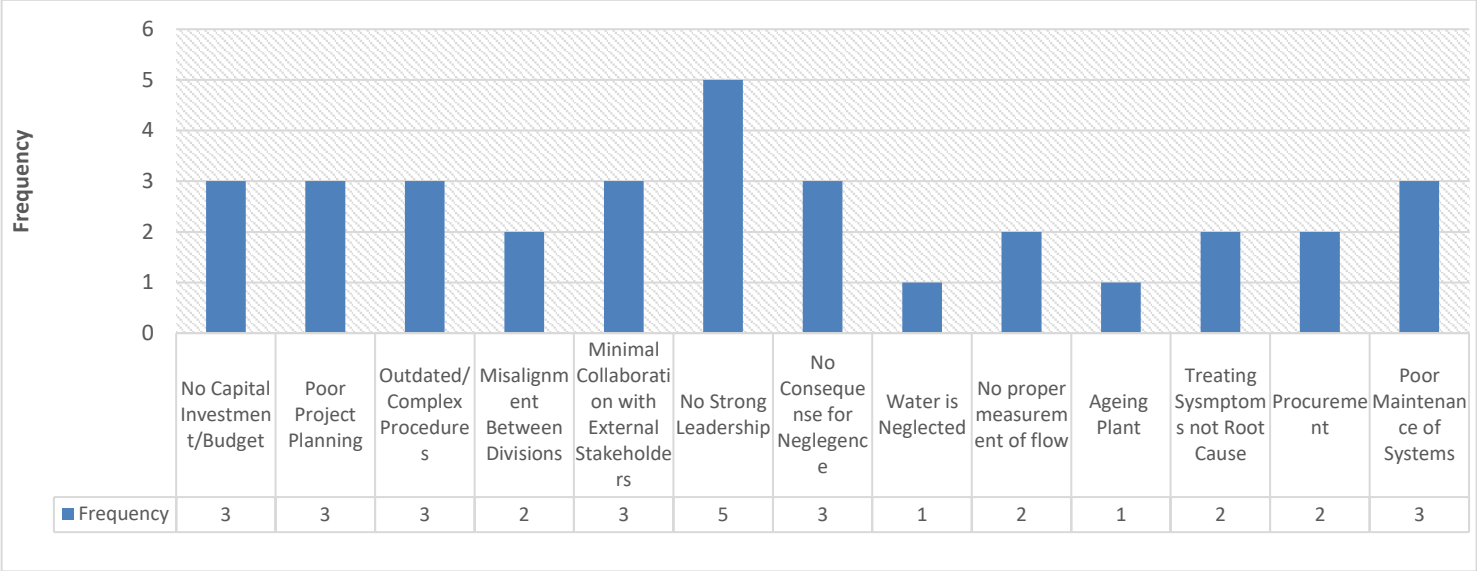


Figure 11: Identified Gaps in water management.

An analysis of external factors affecting water management was conducted similarly to the evaluation conducted for identified gaps in water management (Figure 11 below). Of highest concern was that project timelines are constantly shifted due to a lack of urgency for project execution. These external factors refer to factors beyond the power plant's control, so if project timelines are being shifted, this is due to an instruction

from top management (executive level). Equally 3 respondents (different 3 respondents for each) mentioned that limited outage is provided for maintenance of infrastructure, this is also caused by load shedding pressures, changes in raw water quality, poor enforcement from authorities/ difficult to implement licence conditions, quality of spares and contractor work, lack of budget/funding for projects.

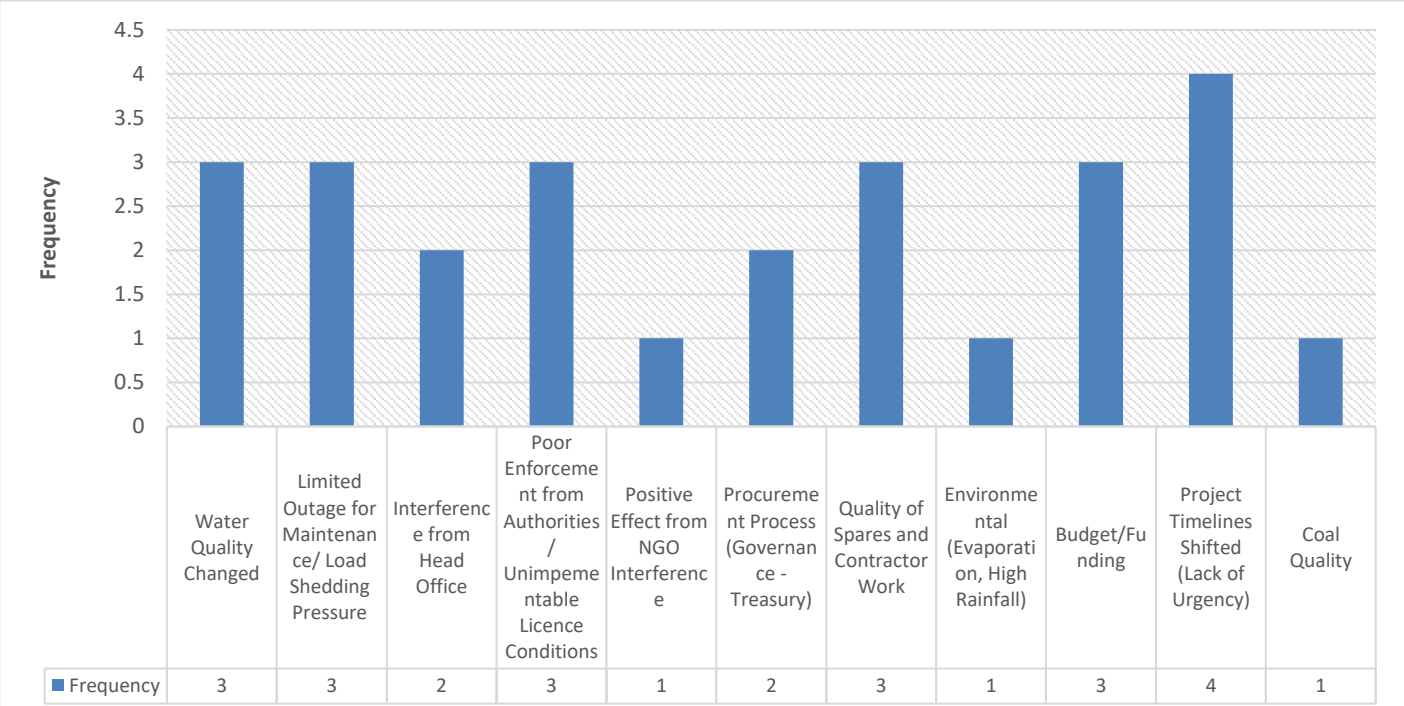


Figure 12: External Factors Impacting on Water Management

The identified gaps and external factors affecting water management provided new themes unavailable in literature. These themes are:

- Limited outage for maintenance
- Load shedding pressure
- Project execution
- Coal quality
- Capital investment, budget, and funding
- Procurement
- No strong leadership

"The gap I have identified in the business is the response time to leaks. Additionally, the plants are old, and the pipelines are corroded and leaking. The operators and maintenance are not following the maintenance strategy," said interviewee 6.

"The wastewater treatment system, if the treatment is good then water can be released to the environment, or the plant can reuse it into the system – at power plant 2 they are doing great treatment of water that is taken to the cooling system reducing the amount of make-up. Contracts would not be an issue if the stations were permitted to work independently and on their projects. The plant is heavily impacted by procurement, there

is too much red tape requiring the plant to go to local suppliers to get spares (poor quality) that are meant to be procured from the OEM and they charge more" said interviewee 9.

"One of the external factors or influences that is contributing to water losses is that authorities are not holding the utility accountable, but there is the pressure of load-shedding and production pressures which causes the business to choose between saving water and production. Due to procurement processes and requirements when ordering spares, the quality of the spares is compromised because the plant is required to go on open tender" interviewee 6 said.
"People do not understand the urgency of fixing leaks and other problems, for everyone else it is just water and when you open the tap there's water. The general worker is not unaware why they must act quickly, and threats are ineffective. As a result, many turn a blind eye and claim they were not present when the incident occurred. The utility employee that must fix the problem, do not do it anymore, it is the work that needs to be done by contractors (simple jobs), however, this could be because of resource issues instead of performing the work" said interviewee 9.

When further simplifying Figure 10 and 11, the following is established in terms of gaps/external factors affecting water management:

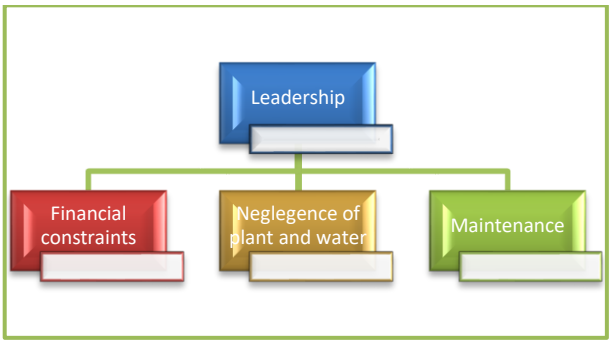


Figure 13: Model of gaps and external factors impacting water management.

The gaps and external factors model contrasts sharply with existing literature and the conceptual model. According to the respondents, the most fundamental concern is leadership, followed by financial constraints, neglect (of the plant and water), and maintenance. It is critical to note that financial constraints, neglect, and maintenance are all interconnected and ultimately traced back to leadership. The plant's maintenance is jeopardised when leadership fails to allocate funds appropriately or secure the necessary components. Similarly, the lack of a robust consequence management mechanism perpetuates neglect, gradually deteriorating the plant's state.

CHAPTER 5

DISCUSSION

The research findings have yielded valuable perspectives on the factors contributing to the elevated water consumption in Power Plants 1 and 2. Nevertheless, it is imperative to approach these findings with care, given the inherent limitations of the present study. This chapter undertakes a comprehensive examination of the research process. It encompasses an exploration of the study's design constraints and potential ramifications, alongside an assessment of how these limitations influence the interpretation of the results.

5.1 Discussion of Results

Water Governance Strategy and Operational Procedures

It is important for the utility to understand and implement the requirements of the National Water Act (NWA) and ISO14001 (through its SHEQ Policy) which are the highest level of governance pertaining to water management practices, the two governance documents must be well integrated into the business systems and operations.

The NWA provides a comprehensive framework for water resource management in South Africa, focusing on preventing pollution and promoting sustainable use. This study has found that thermal power plants, influenced by the restrictions of the NWA, have implemented robust water management strategies that align with legislative requirements. These strategies include stringent controls on wastewater treatment and water recycling, emphasising a commitment to environmental stewardship and resource conservation. However, navigating the complexities of the NWA poses substantial challenges, particularly regarding water use licensing and the technological demands of compliance. Delays and bureaucratic challenges in obtaining water use licenses have been identified as significant hinderances, affecting the operational efficiency of power plants. Moreover, the financial and technological strains associated with meeting the stringent requirements of NWA's have prompted a re-evaluation of current practices, suggesting a gap between policy and practice that could potentially hinder the sustainability objectives of these facilities.

The adoption of ISO 14001 standards within the SHEQ policy of the power utility has significantly influenced their environmental management systems, particularly in water management practices. ISO 14001 requires the establishment, maintenance, and continual improvement of an Environmental Management System (EMS), providing a framework for systematic water use and conservation. This research has revealed that while power plants are generally compliant with these standards, challenges remain, primarily due to aging infrastructure and the integration of these systems with existing operations. The need for continuous improvement under ISO 14001 has driven plants to adopt advanced water management technologies, which

although costly, have resulted in more sustainable water usage and reduced environmental impacts. Moreover, the standard's emphasis on compliance with environmental legislation has enhanced adherence to the National Water Act and other relevant regulations, ensuring that the plants meet legal standards for water use and pollution control. However, the process of continual environmental audits, essential for ISO certification, has highlighted areas where water management practices need strengthening, particularly in risk management and preventative actions against potential environmental hazards.

The impact of ISO 14001 and the NWA is profound, fostering an environment where compliance and sustainability are prioritised. However, for these benefits to be fully realised, certain recommendations should be considered. Enhancing investment in new water management technologies would address both the aging infrastructure issue and improve compliance efficiency. Furthermore, increasing training for plant personnel on the specifics of environmental compliance could bridge the gap between existing management practices and policy requirements. To foster smoother compliance with the NWA, it is also recommended that a more streamlined process for obtaining water use licenses be developed, possibly through closer collaboration between power plants and regulatory bodies. This would not only alleviate bureaucratic obstacles but also enhance the responsiveness of water management strategies to legislative changes. While ISO 14001 and the NWA have shaped water management practices towards greater sustainability, ongoing adjustments and enhancements in policy implementation, technology, and training are crucial for optimising water resource management in South African thermal power plants. This section provides a critical analysis of how environmental standards and legislative frameworks influence operational practices, offering a pathway for enhanced compliance and environmental performance.

The successful integration of ISO14001 and NWA was conducted through a business-wide Water Management Strategy developed for SA power plants to guide the business regarding its water management practices. This document covers legal and other requirements, operational procedures and specifications pertaining to plant water management. The business further developed a Generation Group: Strategic Water Management Implementation Plan to ensure that the strategy is implemented. From this power plants had to create a site-specific water management implementation plan. Therefore, to ensure that high-level initiatives were appropriately translated on the ground level, this study evaluated the effectiveness of these procedures based on two power plants' execution of the Water Management Implementation Plans. The study included the ZLD policy also developed by the business. These documents were referred to as Standard Operating Procedures (SOPs). From the literature review, China Water Risk (2012) explains that zero-liquid discharge (ZLD) policies and technologies have been utilised in various plants to manage water in China. Similarly, van Zyl and Premlall (2005) indicate that all Eskom plants operate on a ZLD policy in SA. Therefore, no polluted water is allowed to leave the site under any conditions, and the only way water mostly leaves the confines of the station is by evaporation from the cooling towers.

The literature review from China Water Risk (2012) reveals that the adoption of zero-liquid discharge (ZLD) policies and technologies in several Chinese plants are an effective approach to water management. Similarly, van Zyl and Premlall (2005) assert that all Eskom plants in South Africa adhere to ZLD policies. Consequently, this strict adherence ensures that contaminated water is prohibited from leaving the plant premises under any circumstances, with the primary means of water exiting the facility being through evaporation from the cooling towers.

However, the research findings also indicate that despite the presence of the ZLD policy and the development of corresponding operational procedures and guidelines, its effectiveness has been compromised. Respondents cite issues such as dam overflows, plant water leakages, and increased effluent discharge, which suggest that the ZLD approach has not been successful in the two plants under consideration. The deviation from standard operating procedures (SOPs) is a significant factor contributing to this ineffectiveness. Modifications, some of which are documented and some not, have been made to the plants, affecting their performance. Additionally, external factors like climate change have further impacted plant operations. Furthermore, the lack of funds has forced desperate measures to keep the power plants operational, potentially undermining the ZLD policy's intended outcomes.

When water management procedures are compromised at a power plant, a cascade of profound consequences unfolds. Environmental harm becomes a pressing concern, as polluted water may be discharged into natural ecosystems, causing water pollution and damage to aquatic life. Regulatory non-compliance materialises, potentially leading to legal issues, fines, and reputational damage. Resource scarcity is exacerbated, particularly in regions with water shortages, impacting local communities and other industries reliant on the same water sources. Equipment damage and operational disruptions become likely outcomes, with water quality issues potentially diminishing the efficiency and longevity of critical plant components. Financial costs soar as expenses mount for cleaning contaminated water, repairing damaged equipment, and addressing regulatory violations. Public perception may be damaged, eroding trust and relationships with customers and stakeholders. Operational inefficiency prevails as water waste and treatment expenses rise, while health and safety risks emerge, with polluted water posing hazards to plant workers and nearby communities. To avert these dire consequences, power plants must maintain robust, well-documented water management procedures, provide ongoing staff training, monitor water quality rigorously, invest in appropriate water treatment and recycling technologies, and ensure compliance with environmental regulations while actively engaging with local communities.

The reason for the development of a Water Management Strategy is important for power plants because the presence of a comprehensive water management strategy serves as a multifaceted asset. This strategy, carefully designed and implemented, brings forth a range of compelling benefits. It champions resource conservation, ensuring that water is used cautiously, which is especially crucial in regions where water is scarce. Financially, it leads to substantial cost savings by minimising water consumption, lowering treatment

expenses, and streamlining energy-intensive water-related processes. The company's environmental responsibility is underscored as it actively reduces its ecological footprint, aligning with sustainability goals and enhancing its reputation. This strategy encourages operational efficiency, optimising critical processes such as cooling and steam generation, resulting in smoother operations and reduced downtime. Regulatory compliance is a pivotal outcome, shielding the company from legal risks and fines. Furthermore, strong community relations are fostered, as responsible water management resonates positively with local stakeholders. When employees wholeheartedly adhere to this strategy, its full potential is realized, bringing about efficiency gains, reduced environmental impact, regulatory adherence, cost-effectiveness, and a positive reputation. In essence, a diligently followed water management strategy not only safeguards an energy company's present but also secures its resilience and sustainability in the face of evolving environmental dynamics.

Power Plant's Water-Related Legal Non-Compliances

Water legal contraventions by power generation in South Africa encompass a range of actions that violate water-related laws and regulations. These violations can include exceeding permitted water withdrawal limits, discharging polluted water into natural bodies without proper treatment, non-compliance with environmental impact assessments, unauthorized water usage, failure to implement water management plans, violations of Zero-Liquid Discharge (ZLD) requirements, non-compliance with water use licenses, infringing on water rights, failure to report incidents promptly, and non-adherence to water conservation and demand management plans. These contraventions can result in legal consequences, including fines, penalties, regulatory actions, and harm to a power plant's reputation. To avoid such issues, power plants must diligently adhere to the relevant water laws and regulations, promoting responsible and sustainable water management practices.

Interviewees 1, 2, 4, 7, 9 and 10 indicate that there was a specific concern regarding the Zero Liquid Discharge (ZLD) policy that it is not realistic and not in line with legislative requirements, ZLD has led plants to wrongly allocating water to systems that it can potentially damage. Although most literature only focusses on the benefits (pollution prevention and water conservation) of ZLD, the respondents tend to have a distinct perspective. As a result of the supply water quality which is deteriorated and an ageing power plant with numerous leaks and no opportunity of maintenance it becomes difficult to comply and hence the dam overflow legal contraventions experienced at both power plant 1 and 2.

Implementing ZLD in a developing country such as South Africa poses a formidable set of challenges stemming from limited financial resources, technical expertise, and infrastructure deficiencies. The high initial costs associated with ZLD systems can strain budgets already stretched thin by pressing socioeconomic needs. A scarcity of qualified professionals in water treatment and engineering, coupled with energy shortages, can hinder effective ZLD deployment. The need for extensive infrastructure modifications and the clash between water conservation and availability in water-scarce regions further complicate matters. Inadequate regulatory frameworks, coupled with weak waste management systems, can make compliance and

environmentally responsible disposal of ZLD byproducts difficult. Moreover, competing socioeconomic priorities and political and institutional factors can overshadow ZLD projects.

Although this is the case, the implementation of a ZLD policy in power generation is driven by a multifaceted set of critical reasons. Firstly, it stands as a robust commitment to environmental conservation, preventing the discharge of any liquids into natural ecosystems and safeguarding water quality, aquatic habitats, and ecosystems. Simultaneously, adherence to ZLD policies ensures compliance with stringent environmental regulations, mitigating the risk of legal complications, fines, and penalties. Furthermore, it plays a pivotal role in regions grappling with water scarcity, as ZLD effectively conserves precious water resources by recycling and reusing water within industrial processes. This approach not only strengthens resource efficiency but also offers potential cost reductions over time. Beyond economics, embracing ZLD aligns with corporate social responsibility and sustainability objectives, enhancing an organisation's reputation as an environmentally responsible and sustainable entity. Additionally, ZLD mitigates risks associated with water pollution, equipment damage, and environmental incidents while fostering long-term planning and resilience in the face of evolving environmental challenges. In the context of power generation, ZLD emerges as a vital component in reducing the environmental footprint, ensuring regulatory compliance, and supporting sustainable and responsible energy production.

Innovative financing, international collaborations, capacity-building efforts, and context-specific solutions offer avenues to address these challenges and promote responsible water management practices.

Compliance with the water legal framework in South African power plants holds significant importance across multiple dimensions. Beyond its legal mandate, it underscores a commitment to environmental stewardship, crucial in safeguarding local ecosystems and the nation's natural water resources. In a region grappling with water scarcity, adhering to these laws becomes a pivotal tool for mitigating resource challenges and promoting sustainable water management practices. Equally essential is its impact on community well-being, ensuring fair water allocation and reducing conflicts over access. Moreover, compliance minimises the environmental footprint of power generation, a critical aspect in minimising water pollution and habitat disruption. Legally, it safeguards power plants from potential fines and penalties while also enhancing their reputation as responsible and ethical entities. Beyond legality, it drives resource efficiency, long-term sustainability, and corporate social responsibility, altogether reinforcing the vital role of water compliance in the broader societal and environmental context.

Power Plant's Water Performance and Status of Water-Related Infrastructure/Systems

The literature assessment in Appendix 1 supports that the cooling system (in more than 50% of the literature assessed) is the highest withdrawer and consumer of water in coal-fired power plants and a supporting statement from the respondents mentioning that the highest water using system in the plant is where high

wastage is experienced. During the interviews it was stressed that the high-water use and losses in water especially from leakages have led to dam overflow incidents which are legal contraventions, in some instances this is clean water that can be recirculated in the plant and the rest is contaminated water and ash which leads to contamination of both ground and surface water. The ash sedimentation within the dams has reduced dam capacity and compromised the dam's structural safety.

Carpenter (2017) states that regulatory restraints by governments may impose limits on (which is the case for South African power plants) or increase the cost of freshwater usage by power plants and constraints in water availability factors are increasing the pressure on power plant operators to reduce water consumption and to look for alternative or supplementary non-fresh water sources.

5.2 Discussion of Objectives

Identify in the system where and how water wastage taking place.

Both literature and the interviews have indicated that Water wastage in South African power plants can occur at various stages of the power generation process. Some common areas where water wastage may take place include:

1. Cooling Systems: Power plants often use large quantities of water for cooling purposes, such as in cooling towers or as part of a once-through cooling system. Inefficient cooling systems or inadequate maintenance can lead to water wastage.

2. Water Treatment: Water used in power generation processes needs treatment, and ineffective treatment processes can result in water wastage. Additionally, the backwashing of filters and cleaning of treatment equipment can consume significant amounts of water.

3. Leaks and Pipe Breaks: Aging infrastructure or inadequate maintenance can lead to leaks or pipe breaks within the power plant's water distribution system, resulting in the loss of water.

4. Non-Recovery of Condensate: Power plants often generate steam for electricity production. When condensate (water formed from condensed steam) is not recovered and reused; it can contribute to water wastage.

5. Chemical Use: Improper dosing or handling of water treatment chemicals can lead to the need for excessive flushing or replacement of water, resulting in wastage.

6. Blowdown: Power plants may perform blowdown procedures to remove impurities from water in boilers or cooling systems. If not managed efficiently, this process can lead to significant water wastage.

7. Environmental Discharge: Some power plants may discharge treated water into the environment as part of their processes. If this discharge is not carefully managed to minimise wastage, it can contribute to environmental concerns.

8. Inefficient Water Recycling: In cases where water recycling and reuse practices are not optimized, power plants may use more freshwater than necessary, leading to wastage.

9. Inadequate Monitoring and Control: Lack of real-time monitoring and control systems to manage water usage can result in inefficiencies and wastage.

10. Legacy Systems: Older power plants may have legacy systems that are less water-efficient compared to modern technologies, leading to higher water consumption and wastage.

11. Coal Quality: The quality of coal used in coal-fired power plants does indeed exert an influence on water usage within these facilities. One critical factor is the moisture content of the coal. Coal with higher moisture content demands additional energy and water for drying before it can be efficiently combusted, thereby increasing water consumption. Conversely, drier coal reduces the need for this supplementary water. Furthermore, coal quality impacts combustion efficiency and heat rate, where higher moisture content can lead to reduced efficiency, potentially necessitating extra cooling water for maintaining optimal operational temperatures. Additionally, coal quality, particularly its ash content, influences the generation of ash byproducts during combustion, which can elevate water requirements for ash handling and disposal. Although coal quality is just one facet of water consumption in coal-fired power plants, it plays a noteworthy role alongside other operational factors and technologies in shaping overall water management strategies and environmental considerations.

As stated above, water wastage and usage occur mainly in the cooling water system. For the power utility, it is mainly due to the cooling water system not being operated according to the OEM, or Standard Operating Procedures. There are several reasons why this is the case, one of them being that both plants are aged and can no longer be operated as if they are “Rolls Royce Machine” (as mentioned by Interviewee 9) but rather review the procedures to incorporate the current status of the plant. Interviewee 9 added, “The power utility needs to consider that the plants are old, and refurbishment is not scheduled as it should. Power plant 2 was meant to be decommissioned at 30 years, now we are planning to run for the plant for 60 years. Old technology that doesn’t have readily spares because of the technology industrial developments.” Over and above this time

for maintenance requires plant shutdown and due to pressures of avoiding load shedding, opportunity of maintenance is difficult to obtain.

The interviews reflect that there is water wastage taking place predominantly due to leaks and at the cooling water system some of this due to negligence but ultimately due to production pressures which lead to poor, rushed or deferred maintenance and projects, lack of funding as well as the exhausting procurement process contribute significantly to the water management challenge.

Efforts to reduce water wastage in South African power plants often involve the implementation of water conservation measures, the use of advanced water treatment technologies, and the adoption of more efficient cooling systems. Additionally, regular maintenance and infrastructure upgrades are essential to minimise water losses due to leaks and pipe breaks. Given the importance of water in power generation and the challenges posed by water scarcity in some regions of South Africa, water management in power plants is a critical aspect of responsible and sustainable operation.

Identify any variations from the power plants standard operating procedures (SOPs) that are contributing to water wastage.

From the interviews, it was established that the business has reasonable procedures, which are written well however these procedures do not speak to the current conditions of the plant. Another interesting point was that the operators do not understand the language (complex English wording) utilised in the procedures and therefore lack interpretation for implementation. The utility has a system in place for reviewing procedures that are reviewed timeously, however, one should question the operators' involvement (not managers) in the developmental or review stage of the document. Conduct workshops with the operators where they can influence procedures. This way, procedures will talk to plant challenges and plant failures can be addressed during this time. A phrase that was used by one of the interviewees (Interviewee 1) was “maak n’ plan”, which is Afrikaans meaning “make a plan”; this was regarding the fact that because the procedures do not talk to the current plant conditions often time operators have to come up with “ways” of keeping the plant running.

Recommend solutions to address the gaps.

The questionnaire was used to identify gaps and external factors that influence water management, the outcome from this analysis highlighted that the fundamental gaps are in leadership. Leadership in terms of finance, maintenance and water being neglected. Leadership not only within the business but also from the authorities and government where decision making, and consequence management are poor. The authorities do not hold the business accountable for non-compliances, leading to complacency. In terms of obtaining funding for water projects, the procurement process does not facilitate quick turnaround time for projects. Projects are usually delayed or postponed. Procurement also influences the purchase of spares, leading to the plant not being maintained timeously. In contrast, the conceptual model's variables and difficulties are technical and chemistry-related, with technological solutions found to address the problems. These contrast

with the problems and causes that are recognized there and demonstrates the unique circumstances that South Africa faces in terms of managing its energy and water resources. Although there are certainly technical difficulties, the country faces a more complicated problem than, say, China, where issues with leadership are more problematic than problems with water management at power companies.

The quality of supply water poses a few risks such as delayed plant start-ups due to demin water availability the power plants that are being researched both received water from Usutu Scheme which today they also receive water from the Usutu Vaal Scheme where the Vaal Dam water is of lesser quality which therefore requires more treatment, premature blowdowns, waste of both water and money for treatment, and dam overflows. According to Gjorgiev and Sansavini (2018), having access to fresh water would help to ensure that power plants can operate as efficiently as possible. However, given that South Africa is a country with a water shortage and that power plants have been designated as strategic water users, this still poses a significant risk to the performance of power plants because there are limitations placed by the government on water usage per power plant. In addition to this, power utilities continue to use a lot of water because there is never enough time to maintain water leaks. Quick decision-making on projects, prompt response to plant breakdowns, and preventive maintenance could potentially help the power plants' water usage and management. Making quick decisions on projects will give power plants the chance to deal with problems quickly and effectively. Postponing projects and maintenance causes subsequent damage to other plant components, which can harm the plant even more than if the problem is dealt with right away. By addressing the issue of project and maintenance postponements can lead in an improvement in energy availability would result from a major reduction in problems like load shedding.

5.3 Discussion of Research Question

In pursuit of addressing the pivotal research inquiry – the cause of high-water usage in thermal power plants within South Africa – several factors contributing to water wastage have become known. The country's power facilities encounter distinct challenges that set them apart from their international counterparts. The burden of load shedding, the presence of an ageing plant fleet, and the scarcity of alternative energy resources have bestowed a multitude of complexities upon the utility, rendering decision-making a mammoth task due to the absence of apparent solutions. High water usage in thermal power plants within South Africa can be attributed to several factors:

1. Cooling Requirements: Thermal power plants, including coal-fired power plants, often rely on water for cooling purposes. Water is used in cooling towers or as part of once-through cooling systems to dissipate the heat generated during electricity production. The high temperatures associated with these processes necessitate substantial water volumes for effective cooling.

2. Outdated Cooling Technologies: Some older power plants in South Africa may still use less water-efficient cooling technologies, such as once-through cooling systems, which consume larger quantities of water compared to more modern and efficient alternatives.

3. Lack of Water Recycling: Inefficient or limited water recycling practices can contribute to high water usage. When condensate from steam generation is not effectively recovered and reused, power plants rely on freshwater sources for makeup water.

4. Environmental Regulations: Environmental regulations may require power plants to meet certain discharge temperature limits when returning water to the environment. To comply with these regulations, power plants may use more water for cooling than they would otherwise need.

5. Water Quality Standards: Maintaining water quality standards is essential to prevent scaling, corrosion, and fouling in power plant equipment. Achieving and maintaining these standards may require continuous water treatment and replacement, leading to higher water consumption.

6. Water Losses: Aging infrastructure or inadequate maintenance can result in water losses due to leaks and pipe breaks within the power plant's water distribution system.

7. Lack of Water Efficiency Measures: Some power plants may not have implemented water efficiency measures, such as optimising cooling systems, improving water treatment processes, or adopting advanced cooling technologies, which could help reduce water usage.

8. Geographic Location: The geographic location of power plants plays a role in water availability. Power plants located in water-scarce regions may face challenges in securing adequate water supplies for cooling.

Addressing the issue of high-water use in South African thermal power plants typically involves a multifaceted approach. This approach includes implementing strategies such as adopting more water-efficient cooling technologies, enhancing practices for recycling and reusing water, improving water treatment procedures, and conducting regular maintenance to minimise water losses. These measures collectively aim to optimise water usage while ensuring the dependable and efficient operation of power generation facilities. Furthermore, as concerns over water scarcity continue to grow, power plants are increasingly emphasising sustainable water management practices to mitigate their environmental impact.

This situation is further compounded by the requirement for additional resources and time, which are often limited for the leadership, thereby impeding the operational staff's capacity to properly maintain the plants and execute projects aimed at promoting effective water management practices. Consequently, this

combination of factors results in the excessive consumption of water and the subsequent losses observed within these power plants.

5.4 Discussion of the Result Deviations from the Conceptual Models

There is a degree of alignment observed between the gaps and external factors model, the existing literature, and the conceptual model. These sources collectively highlight that the technical, water-related, and legislative challenges are in line with the real-world situation in South Africa. This situation underscores, however, that the primary issue for South African power plants stems from leadership, which subsequently contributes to other challenges.

The technical difficulties encountered can be attributed to the neglect of the water plant, driven by a focus on increasing production to seemingly prevent load shedding. Meanwhile, the water management problems result from suboptimal decision-making regarding the power plant's priorities. It's worth noting that management sometimes fails to recognise the pivotal role of water in energy production, as the absence of steam would render energy production impossible. Moreover, the legislative requirements fail to account for the fact that these power plants were originally designed and constructed in a different environmental context. Consequently, some of these requirements necessitate modifications to the power plants, which can, on occasion, be detrimental to their overall performance.

The primary deficiency in water management within South African power plants primarily results from inadequate leadership, resulting in a shortage of funding and the neglect of both water plant facilities and maintenance. Consequently, when dissecting the discussion regarding these gaps:

1. Quick Decision-Making on Projects: Making swift decisions on projects is essential for power plants. It allows them to address issues promptly and effectively. Delaying projects can lead to further damage and potentially more significant problems down the line. Quick decision-making enables proactive problem-solving.
2. Prompt Response to Malfunctions: When malfunctions or issues arise within power plants, a rapid response is vital. Delaying responses can result in increased damage, higher repair costs, and potentially longer downtime. Promptly addressing malfunctions minimises their impact.
3. Preventive Maintenance: Regular preventive maintenance is crucial to prevent unexpected breakdowns and extend the lifespan of power plant equipment. Neglecting maintenance can lead to more extensive problems and higher maintenance costs in the long run.
4. Water Management: Effective water management is critical, especially in regions with limited water resources. Power plants need to optimise their water usage, minimise wastage, and ensure sustainable practices to support their operations.

5. Reducing Load Shedding: Efficient power plant operations can help reduce load shedding, ensuring a more stable and reliable energy supply for consumers. This, in turn, improves energy availability and reduces disruptions.

In summary, proactive decision-making, swift responses to issues, and a strong focus on preventive maintenance and sustainable water management are essential for the reliable and efficient operation of power plants. These practices not only enhance plant performance but also contribute to a more stable and available energy supply for communities and industries.

5.5 Discussion of limitations

The context of this research underscores the challenges faced by the electricity supply industry and the performance of power plants in the current environment. These challenges include not only technical and operational issues but also a heightened level of scrutiny and public attention from the media. Given these circumstances, it is natural for participants involved in discussions or research related to these issues to have reservations about openly sharing their insights and concerns.

To address these reservations, the research emphasises the absolute assurance of complete anonymity (which includes keeping the power plant name anonymous) for participants. This assurance is crucial in creating a safe and confidential space where participants can freely express their thoughts and observations regarding the challenges faced by the power generation sector.

The research focuses specifically on two power plants, but it is essential to maintain the confidentiality of these facilities. Consequently, the intricate and specific details about these power plants cannot be disclosed to protect their identities and ensure that no participant's anonymity is compromised. This cautious approach is taken to safeguard both the power plants' interests and the privacy of the individuals contributing to the research.

In the introductory chapter of the research, the primary sources of information and data originate mainly from Eskom, a significant player in South African coal-fired power generation. Eskom's substantial presence and influence in the sector make it a key source for technical details and performance data. By drawing on data from Eskom Integrated Reports, the research aims to maintain the precision and reliability of the dataset, which forms the basis for the study's analysis and conclusions.

Despite the research's focus on just two power plants, there is a belief that the insights gained from this study will have broad relevance. The challenges faced by these specific power plants are seen as characteristic of issues that extend beyond individual facilities. As such, the findings are expected to offer substantial insights applicable not only to all power plants in South Africa but also to similar facilities on a global scale.

Considering the potential significance of the research findings; there is a recommendation to consider expanding the scope of the research. This expansion would involve conducting similar investigations at a larger scale, encompassing all South African and other developing countries' coal-fired power plants. Such an approach would provide additional evidence and validation for the conclusions presented in the current report, further strengthening the research's contributions to the field of power generation and water management.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

Water management within thermal power plants is a multifaceted and ever-evolving endeavour. It involves a multitude of stakeholders and intricate systems that necessitate operation, supervision, and control. As one respondent articulated, water is the fundamental impetus behind electricity generation; its significance cannot be understated. Regrettably, water's importance often goes unrecognised, overshadowing the fact that the absence of water translates to the absence of electricity. The escalating constraints on water availability significantly jeopardise the security of electricity generation, particularly in the context of South Africa's water scarcity.

Evidently, water management encounters shortcomings and requires enhancement. Chief among these concerns are deficient maintenance practices and a need for more decisive actions from leadership. In summary, given the intricate nature of water management challenges, effective leadership must step forth to offer more streamlined guidance. Effective leadership entails instituting accountability practices within the organization and ultimately progressing toward pioneering thought leadership in the domain. It's clear from your description that the challenges faced by power plants in South Africa are multifaceted and have complex interconnections. Here's a breakdown of the key points of the research outcome:

1. **Leadership Issues:** The primary challenge appears to be related to leadership and decision-making within the power plants. Effective leadership is essential for setting priorities, making strategic decisions, and ensuring that maintenance and water management are given the necessary attention. Poor leadership can lead to neglect of critical aspects of plant operations.
2. **Technical Challenges:** Neglecting the water plant in favour of production can result in technical challenges. Maintenance and upkeep of plant equipment, including water-related systems, are essential for ensuring reliable and efficient energy production. Neglect can lead to breakdowns and reduced performance.

3. **Water Management:** Water is a fundamental resource for power plants, especially for generating steam, which is essential for energy production. Poor decision-making regarding water management can have severe consequences on plant operations. It's important to recognise the critical role of water in the energy generation process.
4. **Legislative Requirements:** Legislative requirements aligned with the current environmental and sustainability context is not aligned with the design (old) of power plants can create additional challenges. Compliance with current regulations may necessitate costly modifications that can negatively impact plant performance.

Addressing these challenges likely requires a comprehensive approach:

- **Effective Leadership:** Ensuring that leadership at power plants is focused on the long-term sustainability and reliability of operations is crucial. This includes setting priorities that balance production needs with maintenance and environmental considerations.
- **Technical Maintenance:** Prioritising regular maintenance and investment in equipment and infrastructure is essential to prevent technical challenges and breakdowns.
- **Water Management:** Implementing sound water management practices, including water recycling and efficient use, can help mitigate water-related issues.
- **Advocacy and Legislative Review:** Advocating for regulatory changes that consider the current operating context of power plants and incentivising environmentally friendly practices can help address legislative challenges.
- **Sustainability:** Emphasising sustainability in power plant operations, including responsible water use and reduced environmental impact, should be a long-term goal.

In conclusion, addressing the leadership and subsequent technical, water, and legislative challenges in South African power plants will require a coordinated effort involving leadership reforms, technical improvements, sound water management, and advocacy for updated regulations that align with modern environmental standards.

Recommendation

A visible disparity arises when the conceptual model is compared to the analysis findings, underscoring that South African power plants grapple with distinctive challenges and influences that deviate from the global context. This discrepancy warrants a proposition for additional research that encompasses all South African power plants.

Extending the scope of investigation to encompass all thermal power plants in South Africa is anticipated to yield a more comprehensive knowledge of water management practices within this specific domain. Such an

expanded study should particularly concentrate on the interplay between leadership, decision-making processes within thermal power plants, and their ramifications on water performance and adherence to legal requirements.

REFERENCES

Braun, V. and Clarke, V. (2012) 'APA handbook of research methods in psychology', in H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, & K. J. S. (Eds. . (ed.) *Thematic Analysis*. Volume 2. APA handbooks in psychology®, pp. 57–71.

Carpenter, A. M. (2017) *Water conservation in coal-fired power plants Water conservation in coal-fired power plants*, *IEA Clean Coal Centre*. London: © IEA Clean Coal Centre.

China Water Risk (2012) 'Zero Liquid Discharge – A Real Solution?', 12 January. Available at: https://www.chinawaterrisk.org/resources/analysis-reviews/zero-liquid-discharge-a-real-solution/.

Delgado, A. and Herzog, H.J., 2012. A simple model to help understand water use at power plants. *Massachusetts Institute of Technology*. https://energy.mit.edu/wp-content/uploads/2016/12/2012_AD_HJH_WorkingPaper-WaterUse_at_PowerPlants.pdf

Eskom (2015) *Integrated Report 2015*. Sunninghill. Available at: www.eskom.co.za.

Eskom (2020) *Integrated Report: Restoring Trust*. Sunninghill. Available at: www.eskom.co.za.

Feeley III, T.J., Skone, T.J., Stiegel Jr, G.J., McNemar, A., Nemeth, M., Schimmoller, B., Murphy, J.T. and Manfredo, L., 2008. Water: A critical resource in the thermoelectric power industry. *Energy*, *33*(1), pp.1-11. available from: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.151.9137&rep=rep1&type=pdf

Fusch, P. I. and Ness, L. R. (2015) 'Are We There Yet ? Data Saturation in Qualitative Research', 20(9), pp. 1408–1416.

GE (2013). *General Electric Works 2013 Annual Report*, *General Electric Company*. Available at: www.annualreports.com.

Gjorgiev, B. and Sansavini, G. (2018) 'Electrical power generation under policy constrained water-energy nexus', *Applied Energy*, 210(December 2016), pp. 568–579. doi: 10.1016/j.apenergy.2017.09.011.

Golfashani, N. (2003) 'Understanding Reliability and Validity in Qualitative Research', *The Qualitative Report*, 8(4), pp. 597–607. Available at: http://nsuworks.nova.edu/tqr%0Ahttp://nsuworks.nova.edu/tqr/vol8/iss4/6%0Ahttps://nsuworks.nova.edu/tqr/vol8/iss4/6.

Govender, D. (2018) 'Water Supply'. Sandton: Eskom Soc Ltd, pp. 3–4. Available at: www.eskom.co.za.

Gude, V. G. (2015) ‘Energy and water autarky of wastewater treatment and power generation systems’, *Renewable and Sustainable Energy Reviews*. Elsevier, 45, pp. 52–68. doi: 10.1016/j.rser.2015.01.055.

Herbst, D. (2013) *Eskom: Water Management Policy*, *Eskom*. Available at: www.eskom.co.za (Accessed: 3 January 2021).

Holland, R.A., Scott, K.A., Flörke, M., Brown, G., Ewers, R.M., Farmer, E., Kapos, V., Muggeridge, A., Scharlemann, J.P., Taylor, G. and Barrett, J., 2015. Global impacts of energy demand on the freshwater resources of nations. *Proceedings of the National Academy of Sciences*, *112*(48), pp. E6707-E6716. available from: https://www.pnas.org/content/pnas/112/48/E6707.full.pdf

HuangW., Ma D., Chen W. 2017. Connecting water and energy: Assessing the impacts of carbon and water constraints on China’s power sector. *Applied Energy*. 185, Part 2, pp. 1497-1505. ISSN 0306-2619. Available from: https://doi.org/10.1016/j.apenergy.2015.12.048.

Jin, Y., Behrens, P., Tukker, A. and Scherer, L., 2019. Water use of electricity technologies: A global meta-analysis. *Renewable and Sustainable Energy Reviews*, *115*, p.109391. available from: https://www.sciencedirect.com/science/article/pii/S1364032119305994

Kamer, L., 2022. Access to improved drinking water sources in Sub-Saharan Africa 2020. Available at: https://www.statista.com/statistics/1266701/access-to-improved-drinking-water-sources-in-sub-saharan-africa/#:~:text=Around%20three%20in%20every%20ten%20people%20living%20in,when%20needed%20was%20higher%2C%20at%20nearly%2060%20percent.

Kramer, A., 2022. Water use at South Africa’s coal power stations: A legal analysis. North West University. Orcid.org/0000-0002-3049-8626.

Koncagül, E. and Tran, M., 2022. The United Nations World Water Development Report 2022: groundwater: making the invisible visible; facts and figures. *UNESCO Digital Library*. Available at: https://unesdoc.unesco.org/ark:/48223/pf0000380733.

Kramer, A., 2022. Water use at South Africa’s coal power stations: A legal analysis. School of Environmental Law and Governance. North-West University. Available from: Orcid.org/0000-0002-3049-8626.

Levin, R. F. and Felman, H. (2013) ‘Conducting a Gap Analysis’, in Graubard, A. (ed.) *Teaching Evidence-Based Practice in Nursing: Second Edition*. New York: Springer Publishing Company, p. 107. Available at:

www.spingerpub.com.

Lubega, W. N. and Stillwell, A. S. (2018) 'Maintaining electric grid reliability under hydrologic drought and heat wave conditions', *Applied Energy*. Elsevier Ltd, 210, pp. 538–549. doi: 10.1016/j.apenergy.2017.06.091.

Liu M., Qin Y., Yan H., Han X., Daotong Chong D. (2015). Energy and water conservation at lignite-fired power plants using drying and water recovery technologies. *Energy Conversion and Management,* 105, pp.118-126. ISSN 0196-8904.

Ma, Y., Chang, J., Guo, A., Wu, L., Yang, J., Chen, L., 2020. Optimizing Inter-basin water transfers from multiple sources among interconnected River basins, *Journal of Hydrology.* Volume 590, 125461, ISSN 0022-1694. Available from: https://www.sciencedirect.com/science/article/pii/S0022169420309215

Merschmann, P.R.D.C., Vasquez, E., Szklo, A.S. and Schaeffer, R., 2013. Modeling water use demands for thermoelectric power plants with CCS in selected Brazilian water basins. *International Journal of Greenhouse Gas Control*, *13*, pp.87-101. Available from: https://www.sciencedirect.com/science/article/abs/pii/S1750583612003313

Mussardo (2019) 'Semi Structured Interview and Focus Group', *Statistical Field Theor*, 53(9), pp. 1689–1699.

Muthuraman, M. (2016) 'Reduction in Power Plant Specific Water Consumption', in *International Power Plant O&M conference*, p. 8. doi: 10.13140/RG.2.1.1403.1125.

Pan, S.Y., Snyder, S.W., Packman, A.I., Lin, Y.J. and Chiang, P.C., 2018. Cooling water use in thermoelectric power generation and its associated challenges for addressing water-energy nexus. *Water-Energy Nexus*, *1*(1), pp.26-41. Available from: https://www.sciencedirect.com/science/article/pii/S2588912517300085

Pather, V. (2004) 'Eskom and Water', *Proceedings of the 2004 Water Institute of Southern Africa (WISA) Biennial Conference*, (May), pp. 659–664.

Patton, M. Q. and Cochran, M. (2002) 'A Guide to Using Qualitative Research Methodology', *Medicins San Frontieres*, pp. 1–36.

Reimers, A. (2018) 'Making Electricity Consumes a Lot of Water. What's the Best Way to Fix That?', *Scientific American*, May. Available at: www.scientificamerican.com.

Rocco, T. S. (2003) ‘Qualitative Research Interviewing: Biographic Narrative and Semi-Structured Methods, by Tom Wengraf. Thousand Oaks, CA: Sage, 2001. 424 pp. $99 (hardcover); $33 (paperback).’, *Human Resource Development Quarterly*, 14(1), pp. 117–122. doi: 10.1002/hrdq.1054.

Roehrkasten, S., Schaeuble, D. and Helgenberger, S., 2015. Secure and sustainable power generation in a water-constrained world. *IASS⟨ https://doi. org/10.2312/iass, 23*. Available from: http://www.idaea.csic.es/medspring/sites/default/files/Secure-and-sustainable-power-generation-in-a-water-constrained-world.pdf

Rollason, E., Sinha, P., & Bracken, L. J. (2022). Interbasin water transfer in a changing world: A new conceptual model. *Progress in Physical Geography: Earth and Environment*, 46(3), 371–397. https://doi.org/10.1177/03091333211065004

Sun, S., Zhou, X., Liu, H., Jiang, Y., Zhou, H., Zhang, C., Fu, G., 2021. Unraveling the effect of inter-basin water transfer on reducing water scarcity and its inequality in China, *Water Research*, Volume 194, 116931, ISSN 0043-1354

Thopil, G. A. and Pouris, A., 2015. ‘Water Usage Forecasting in Coal Based Electricity Generation: The Case of South Africa’, *Energy Procedia*, 75, pp. 2813–2818. doi: 10.1016/j.egypro.2015.07.557.

Thopil, G.A. and Pouris, A., 2016. A 20-year forecast of water usage in electricity generation for South Africa amidst water scarce conditions. *Renewable and Sustainable Energy Reviews, 62*, pp.1106-1121. Available from: https://repository.up.ac.za/bitstream/handle/2263/54430/Thopil_20_2016.pdf?sequence=1

Van Vliet, M.T., Wiberg, D., Leduc, S. and Riahi, K., 2016. Power-generation system vulnerability and adaptation to changes in climate and water resources. *Nature Climate Change*, *6*(4), pp.375-380. Available from: https://www.nature.com/articles/nclimate2903

Van Zyl, H.D. and Premlall, K., 2005. *Water and Waste-water Management in the Power Generating Industry*. Water Research Commission. available from: http://www.wrc.org.za/wp-content/uploads/mdocs/TT240-05.pdf

Vassolo, S. and Döll, P., 2005. Global-scale gridded estimates of thermoelectric power and manufacturing water use. *Water Resources Research*, *41*(4). Available from: https://agupubs.onlinelibrary.wiley.com/doi/pdfdirect/10.1029/2004WR003360

Vassolo, S. and Döll, P., 2005. Global-scale gridded estimates of thermoelectric power and manufacturing

water use. *Water Resources Research*, *41*(4). Available from: https://agupubs.onlinelibrary.wiley.com/doi/pdfdirect/10.1029/2004WR003360

Wengraf, T. (2001) Qualitative Research Interviewing: Biographic Narrative and Semi-Structured Methods. Sage Publications, London, 7. https://doi.org/10.4135/9781849209717

Yang, X. and Dziegielewski, B. (2007) 'Water use by thermoelectric power plants in the United States', *Journal of the American Water Resources Association*, 43(1), pp. 160–169. doi: 10.1111/j.1752-1688.2007.00013.x.

Zhang X., Liu J., Tang Y., Zhao X., Yang H., Gerbens-Leenes P.W., van Vliet M.T.H., Yan J. (2017). China's coal-fired power plants impose pressure on water resources. Journal of Cleaner Production, Volume 161, pp 1171-1179, ISSN 0959-6526. Available from: https://www.sciencedirect.com/science/article/pii/S0959652617307485

Appendix 1 – Literature Assessment

Sources	Energy Technology and Water	Zero Liquid Discharge (ZLD)	Power Plant Internal System Water Usage/Losses	Factors affecting power plant water management	Constraints in water availability
Carpenter (2017)		1. The cooling system accounts for the most significant water usage (when water is the coolant). 2. Hybrid cooling towers can reduce water usage by 20–60% compared to evaporative wet cooling systems, whilst at the same time reducing energy use by 30–60% compared to dry cooling (depending on hybrid technology, weather conditions and how often the wet cooling system is employed). 3. Dry cooling systems, which use air instead of water as the cooling medium, could save substantial water. Some national governments and states are therefore promoting dry cooling to relieve pressure on water resources.		1. Unavoidable losses, such as evaporation of recirculated water in wet cooling towers, and minor steam leaks. 2. Losses to the formation of products, such as gypsum from the wet FGD scrubber. 3. Deliberate blowdown from various recirculating streams, including boiler feedwater, FGD streams 4. Cooling water. 5. Blowdown is necessary to preserve water quality and remove impurities. 6. Handling products, such as ash sluicing.	1. The vulnerability of the electricity generation industry to constraints in water availability is widespread and growing. Moreover, significant areas of almost every continent face a high level of water stress, including large regions of China, India, SA, and the USA, the four top thermal coal consuming countries in the world global electricity generation industry in the water-abundant North-East region of the USA is facing issues of water quality and temperature. Power plants have had to close at to ensure do not exceed the permitted water discharge temperature. The number of plants affected is likely to increase in the future, with severe economic consequences. 3. Groundwater supplies are diminishing with an estimated 20% of the world's aquifers already overexploited and the quality of the water is deteriorating. Consequently, competition between power

Sources	Energy Technology and Water	Zero Liquid Discharge (ZLD)	Power Plant Internal System Water Usage/Losses	Factors affecting power plant water management	Constraints in water availability
					plant operators and other water users is likely to escalate, and climate change could further exacerbate the situation. 4. Regulatory restraints by governments may impose limits on or increase the cost of freshwater usage by power plants. 5. Constraints in water availability factors are increasing the pressure on power plant operators to reduce water consumption and to look for alternative or supplementary non-fresh water sources.
China Water Risk (2012)		Zero liquid discharge (ZLD) policies and technologies have been used in various plants to manage water in China.			
Delgado and Herzog (2012)	1. A pulverized coal-fired (PC) power plant with CO_2 capture and storage (CCS) uses about twice the amount of water per kWh than a PC power plant without CCS	All Eskom plants follow a policy of zero liquid discharge, so water withdrawal and consumption are identical.			
Feeley III *et al.* (2008)	1. Each kilowatt-hour (kWh) of thermoelectric generation requires the withdrawal of ~ 94,6353litres of water, which is primarily used for cooling purposes.				
GE (2013)		1. maximising amount of wastewater recycled minimises the quantity of raw water required, and this has been seen as the solution to help plants to meet discharge and water reuse requirements,			

Sources	Energy Technology and Water	Zero Liquid Discharge (ZLD)	Power Plant Internal System Water Usage/Losses	Factors affecting power plant water management	Constraints in water availability
		enabling the plants to maximise water reuse and assist to manage produced water better.			
Jin *et al.* (2019)	1. Coal thermal power plant's infrastructure is the largest water user among all fuel-powered thermal plants. 2. Nuclear power has the lowest water consumption per unit of power production due to the high electricity output over generally longer lifetimes.		Coal power plants with closed-loop cooling technology are the most significant water consumers, and plants with once-through cooling technology as leading water withdrawers.		
Merschmann et al. (2013)		1. Due to the installation of an amine-based carbon capture system, results indicate that water withdrawal increases, respectively, by 102–121% and by 93–113% in thermal power plants equipped with once-trough cooling and closed cooling systems. 2. The implementation of CO_2 capture doubles the amount of water demanded.			If thermal power plants are installed in hydrographic regions where water levels are critical, the lack of available water may limit the implementation of CO_2 capture. Therefore, the thermal power plants in these regions are the most vulnerable from the viewpoint of water stress.
Muthuraman (2016)				Thermal power plant water requirements are governed by several factors. These factors are quality of raw water, type of condenser cooling system, quality of coal, ash utilisation, type of ash disposal system, and wastewater management aspects	
Pan *et al.* (2018)	1. Thermoelectric power plants traditionally have required large volumes of water to condense steam from the turbine exhaust. 2. Performance of thermoelectric power generation largely relies on water cooling systems, and thermoelectric plants withdraw large quantities of water for cooling.	1. The goal of ZLD, is to eliminate liquid waste leaving the facility. In other words, all wastewaters should be converted to dry form for ultimate disposal. 2. In the cooling systems, the goal to achieve ZLD is			

Sources	Energy Technology and Water	Zero Liquid Discharge (ZLD)	Power Plant Internal System Water Usage/Losses	Factors affecting power plant water management	Constraints in water availability
	3. In China, thermoelectric power generation accounts for about 10% of the total freshwater withdrawal.	through the deployment of treatment technologies to manage high TDS levels, low blow-down rates, and thus, high cycles of concentration. 3. ZLD involves three stages: pre-treatment (generate sludge), pre-concentration (produce reclaimed water), and evaporation/crystallization (produce distillate and solid salts). In the pre-concentration stage, cost-effective membrane processes are usually applied to push the water recovery ratio to 90–95%, and to ensure that effluent characteristics. avoid corrosion and temperature issues. Prior to the pre-concentration stage, a pre-treatment stage is typically required to protect the membranes from fouling and scaling by removing potentially problematic constituents such as suspended particles. and hardness. Evaporation/crystallization stage is regarded as the final step to eliminate the concentrated liquid waste through phase change with the input of energy.			
Pather (2004)	1. The wet cooling water system consumes about 80% to 90% of the water through evaporation.	Eskom adopted the ZLED (Zero Liquid Effluent Discharge) policy during 1987, in which all reasonable measures are taken to prevent pollution of water resources through establishing a hierarchy of water uses based on quality. Cascading the water from higher quality to lower quality uses enables extensive re-use. Where possible, water is lost only through evaporation, retaining the accompanying dissolved and suspended solids. The net result is that there is no deliberate discharge of pollutants to a	the wet cooling water system consumes about 80% to 90% of the water through evaporation		

Sources	Energy Technology and Water	Zero Liquid Discharge (ZLD)	Power Plant Internal System Water Usage/Losses	Factors affecting power plant water management	Constraints in water availability
		water resource under normal operating conditions and average climatic conditions			
Roehrkasten et al. (2015).	1. Considering the whole life cycle, wind turbines and solar PV systems consume about 0.1–14% and withdraw about 2–15% of the water typical thermo-electric power plants (coal or nuclear) use to generate 1 MWh of electricity. 2. Compared to other water-saving options for power generation, solar PV and wind are genuinely sustainable solution primarily due to their very low greenhouse gas emissions.		1. Power plants with recirculating cooling systems have much lower withdrawal, but the bulk of the withdrawn water is consumed. 2. In arid regions with decreased availability of cooling water new cooling technologies like dry cooling and hybrid cooling are used in some new power plants. 3. Dry cooling is a proven technological option to make power generation from thermal power plants less water intensive. If dry-cooling systems are used, the water demand of thermal power plants can be reduced to about 2% of the water demand that would otherwise apply with wet-cooling. 4. Dry cooling is not as efficient as wet cooling. This means a higher fuel demand and higher greenhouse gas emissions per MWh generated. 5. Dry-cooling systems have higher investment costs than equivalent wet-tower cooling systems (2 to 4 times), since air requires a much larger surface area for heat dissipation than water. 6. Given their larger cooling towers, dry-cooling systems have much greater land area requirements than wet-cooling systems		1. It is primarily hydropower generation affected by water constraints. 2. Nuclear and coal power plants have also been switched off temporarily or have had to be operated at reduced load due to water constraints. This has been the case especially in the USA, Europe, and Australia there are numerous examples of water-related incidents compromising power generation from coal and nuclear.
Thopil and Pouris (2015)	1. Water usage in electricity generation is primarily dependent on the type of technology used.		2. The range of water used per kWh varies from 0.08litres/kWh to 0.2litres/kWh for recirculating cooling technology type in coal power plants.		
Van Vliet *et al.* (2016)					1. Forecasted reductions in usable capacity for 81–86% of

Sources	Energy Technology and Water	Zero Liquid Discharge (ZLD)	Power Plant Internal System Water Usage/Losses	Factors affecting power plant water management	Constraints in water availability
					the thermoelectric power plants worldwide for 2040–2069. 2. Adaptation options such as increased plant efficiencies, replacement of cooling system types and fuel switches are effective alternatives to reduce the assessed vulnerability to changing climate and freshwater resources. Transitions in the electricity sector with a stronger focus on adaptation, in addition to mitigation, are thus highly recommended to sustain water–energy security in the coming decades.
van Zyl and Premlall (2005)		1. In SA, All Eskom plants operate on a ZLD policy. Therefore, no polluted water is allowed to leave the site under any conditions except through evaporation from the cooling towers	Unlike Eskom power stations, municipal power stations make use of *once through systems* utilizing municipal water as water source. After usage, most water is disposed-off to the municipal sewer.		
Yang and Dziegielewski (2007)	1. Thermoelectric power generation is responsible for the most significant annual volume of water withdrawals in the USA.			1. Besides cooling system type, both thermoelectric water withdrawal and consumption are also influenced by factors like water source, fuel type and operational conditions. 2. Power plants also tend to have lower unit water use when they are run with higher operational and thermal efficiencies.	

Appendix 2 – Interview Assessment Aligned to Propositions Established in the Conceptual Model

Interviewee	Interview Professional Background	System with Water Wastage	Procedure Effectiveness	Gaps	External Factors
Interviewee 1	Engineer in research testing and development (RT&D)	Water wastage takes place mainly at the cooling system.	3 Procedure effectiveness: Soundness of the strategy – 5 Application of the strategy and procedures – 1 Reasons – standard is 50+ pages it is too long and not simplified to the level of understanding of the operators – standard needs to be summarised and highlight key performance areas for them – this he has applied at power plant 1 and there was better understanding from the operators.	Gap is capital investment into mitigation and upgrading the plant – budget allocated for plant treatment has not changed over ten years. Update of guidelines and procedure should also include environmental employees so that water wastage can be discussed in detail with the correct experts. It is creating a balance between ops, maintenance, and environmental issues. Simplify too many procedures by utilising technology to assist in water performance monitoring, and reporting it will help with inclusion of all system owners on site as opposed to working in silos (e.g., chemistry, turbine engineering, environmental) There is a SCOT committee which gives instruction to the Care Groups to develop the document which gets sent to site for implementation through the technicians for operators to implement.	External factors: Third party activities, (water users polluting the system) affect water makeup into the system, requires water protocol to be revised. And we need to check the performance of the system. E.g., the water quality received at the station is way different to the initiation of the plant. Now we need to see whether we modify plant to accommodate these third-party contributions or the procedure.
Interviewee 2	Water specialist in RT&D	Water wastage is at the boiler (leaking pipes and overflow of the tanks leading more water going to the pollution control dams and ashing system)	3 - Procedure effectiveness: At power plant 2 – the rating will be 3 because the station has some water management challenges and they do not seem to be able to produce workable solutions	Gap: More integrated approach and collaboration with internal and external stakeholders. Gov coming into the party and being part of the solution and not policing stations need to be transparent and innovative to face their challenges. Internal – chemists, energy planners, water specialist – all water management	External factors: Training and awareness and plant status (condition of our plants e.g., piping systems (old = leakages). Plant not well maintained because of no outage time. Preventative maintenance is required and critical.

Interviewee	Interview Professional Background	System with Water Wastage	Procedure Effectiveness	Gaps	External Factors
				stakeholders must play their role and not leave it to one person. Stations are not involved in essential committee meetings where decisions are made or engagement with authorities takes place, a survey must be done on how they would want water engagements with authorities. Catchment meetings – Eskom's level of engagement here needs to be revisited, stations do not engage there and there is no transparency everyone wants to be seen as compliant and feel intimated to comment at the meeting. PIAIA you are not meant to disclose information unless it is formally asked for by the authorities.	
Interviewee 3	Senior Engineer in Risk and Sustainability (R&S) Environmental	Water wastage – Cooling water system (CW) is the most important system on wet cooled stations 100ML a day is lost and 90ML is to the CW some is due to evaporation and others can be controlled through cycles of concentration (CoC). Leaks make it difficult to cycle up! Ash system and CW are co-dependent. CoC is not met because of the constrain on ash water system because ash pumps not working increasing levels of water in the system. A lot of the systems are designed to have a huge safety margin, and this has been highly abused.	3 - Effectiveness of procedures – 3 – the strategy is sound on paper but translation into results is not coming through. Our strategy should encompass other things other than goals. Our procedures were writing for rolls Royce plant but to operationalise them on a system that is deteriorated and old and therefore will not work, we still have hope that the plant will be fully operational.	Everything to happen at the coal face, what needs to be done is well defined. Operationalising objectives of strategy into work instruction is NB. We ned to fix the car so that the people who drive it, can be able to drive it properly with clear targets of what they need to achieve. We need to focus on the people who are operating. Appoint a process engineer who will be able to integrate the systems and responsible parties and stakeholders—a strong individual.	External factors: Technical issues – water quality influences water use (poor quality leads to high vols used). Specific systems need to be available to address issue like the lime plant to accommodate water supply sources. Too much interference from head office, now working on building capacity at the coal face. The station should be able to operate independently. Sometimes helping hinders self-sufficiency of the plant. We have good legislation, but poor enforcement authorities are too lenient. Which gives us a licence to act with impunity. They are compromising government NGOs.

Interviewee	Interview Professional Background	System with Water Wastage	Procedure Effectiveness	Gaps	External Factors
					NGOs are the ones positively impacting by pushing authorities to force Eskom to comply.
Interviewee 4	Senior Chemist in Generation Engineering Sustainability	Wastage follows the usage. 80% of use is cooling but wastage is also happening there – leaks, blowdown through reduction of CoC. Demin wastage of overflows and leaks prolonged start-up. Potable water is the same. The bigger the usage, the bigger the wastage.	2 - Everything is covered in the documents however when it comes to implementation it is an issue – the problem is the people, there's a shortage of people doing the work and lack of understanding of the work – lack of disciplined execution, people are doing what they are meant to do because there's not consequence management it continues. Because of covid we have fallen behind a bit on training and water management does not produce megawatts wholistically especially looking at the biggest impact of pollution – so demin water is prioritised. Change mindset – authorities know but have not gotten Eskom in line. We have a false sense of security not to be shut down because the country needs electricity.	Lack of disciplined execution, consequence management and a water conscious culture has been eroded – serious questions are not being asked – sites are not challenged on their poor performance as in how come you are performing so poorly. Authorities do not follow up on non-compliances. Projects are not getting in implemented some been standing for 10years, funds get allocated and re-allocated not prioritised.	Authorities do not hold Eskom accountable for power station non-compliance due to pressures of load shedding and production pressures—the poor quality of the spares and the tedious procurement process.
Interviewee 5	Power Plant 1 Senior Environmental Advisor	Fire hydrant system – people use it for the wrong reasons, washing floors etc. there was an instruction that if someone wants to use this system, they must get approval from the general manager. Vaalpan natural dam – stores 1440Ml of water, water is lost through evaporation this water is used for cooling because it is within specification – design is a problem because it is shallow.	2/5 They are Adequate and suitable but not effective, people who are supposed to follow them are not doing what they are meant to be doing. WTP procedures are strictly complied with score is 2/5. Ashing and mixing clean and dirty water systems procedures are not followed.	Measurement – we do not adequately measure our water flow streams, flow meters are limited, and some sites (power plant 1) does not have flow meters therefore they cannot apportion which unit is using a lot of water. Even the pipelines are not separated to measure the flow into the units. Eskom culture – we do not want to transform to the current issues of the plant, we presume that everything is still intact not understanding that the plants are aging, with an aging plant it needs to be inspected and monitored. There must be an understanding that water is what runs the plant, so water over utilisation should not be undermined or	Evaporation when it is hot e.g., Vaalpan natural dam, seepage from reusing water at dams.

Interviewee	Interview Professional Background	System with Water Wastage	Procedure Effectiveness	Gaps	External Factors
				ignored of which there is lacking knowledge.	
Interviewee 6	Power Plant 1 Environmental Advisor	Cooling water system	3 – they are trying but the plant is old, and projects take time to execute.	The response time to leaks, plants are old lines are corroded and leaking. They are not following the maintenance strategy.	Budget
Interviewee 7	Power Plant 2 Senior Environmental Advisor	Site cannot account for water losses because there are no flow meters. Sometimes station does not have demin water (unit 3 coming from outage – is standing because of no demin water – it has been on outage for 6 months) due to processes and system failing.	2 - There is a misalignment between the strategy and what is happening. No, it has not been translated because strategy talks about specific water consumption and ZLED and none of those are achieved. The strategy also talks to projects that need to be implemented. What is in the strategy is impossible to conform with e.g., for the ash disposal facility, the strategy says ash facilities must be lined but these were build long ago and it is impossible to. Report monthly on discharges and station is in violation of strategy in terms of discharge, however, this is in line with NWA.	Fix the root cause before you fix the symptoms.	Project timelines are being shifted; you cannot get it right if you cannot get the basics straight. e.g., RO plant is a high-level objective – the process of getting finances. The power plant has nice dreams, but processes do not support these projects (Power Plant 2 Finance Committee) decision making can take a year. Governance processes do not support these projects. If a project costs R100mil you must go to national treasury for approvals, and this creates a lot of situations where projects are postponed. E.g., continuous ashing project has taken 5 years to implement, and to today it is not implemented.
Interviewee 8	Power Plant 1 Water Plant Maintenance	Leaks and unauthorised usage of fire hydrants – 1ML target – now sits at 2.6 and 3.5ML – (people problem)	3 - This FY met the target once last FY did not meet overall target, curve balls coming in here and there, areas that need focus. Plant trips – what we consume, and produce is linked. When unit is down and we are not sending megawatts, we desire it impacts on water management – unit sent out MW, water injector overflows and cooling tower overflows. Also, fire hydrant misuse – for cleaning the station – therefore needs to be controlled. Leaks Plant trips caused by boiler tube leaks, feed pump failures and condenser vacuum	Root cause analysis – is a problem – cannot be a player and referee. Someone independent who can run and manage water.	Supply of water is from Vaal and Usutu, but Vaal is worse quality water therefore requires more pre-treatment and takes much longer. Their plants are sometimes on outage – plan to say let us have a lime plant to deal with Vaal system, we had to modify the plant to accommodate Vaal.

Interviewee	Interview Professional Background	System with Water Wastage	Procedure Effectiveness	Gaps	External Factors
Interviewee 9	Power Plant 2 Water Plant Operator	1 megalitre/ 10 can have a larger impact than 1ML /1000. e.g., demin water needs to be treated more and therefore its expensive to lose this water. Leaks, (200ML/month) CW (3800 ML / month) leaks are large but are not seen because there is no flow meters. There are also systems where you would not know where you are losing water, and they are underground so leaking and seepages from the unlined dams cannot be seen or detected. It is challenging to maintain underground pipes because they are deep down.	2 - Long term goals which relate to money, spares, and legal aspect. These cannot be resolved with immediate implementation – very long term they will be effective currently we are putting measures in place for the future, power stations had a life cycle of 30 year but now at power plant 2, where the first unit was commissioned in 1979 and now it will only be decommissioned in 2040. The change of Eskom management, change of ruling government affects this – everyone comes with new ideas. E.g., On of the power stations will be converted into a hybrid a station. These stations cannot be closed because we sit indecision.	Wastewater treatment system – if the treatment is good, can be released to the environment or can be reuse it into the system – at power plant 2 they are doing excellent treatment that is taken to the cooling system reducing the amount of make-up. Previously, the power stations were working independently and working on things on their own. Contracts are a problem. Which is heavily impacted by procurement. Too much red tape and going to local suppliers to get spares that are meant to be procured from the OEM with poor quality and they charge more.	People do not understand the urgency of fixing leaks and other problems, for everyone else it is just water – when you open the tap there's water. The general Eskom worker is not fully equipped with why they must act quickly. Threats are not working – causes people to turn and blind eye and say they have not seen. Environment does not allow. The Eskom worker that must fix the problem, do not do it anymore – the work that needs to be done we get contractors, and it could be because of resource issues instead of performing the work.
Interviewee 10	Power Plant 2 Water Plant manager	Wastages mainly on the unit leakages, wet cooling plant CW is highest water user. Demin water – double regen (resin used for ion exchanged – resin gets clogged regen is the removal of these substances) – producing more effluent, through blowdown.	3 - They have not been implemented, but if they have, they would be effective, currently we are only fixing the leaks on the units, but it is on-going, and the station is pushing to reduce them, and it is effective. Because of the lack of finance, others have not been implemented because they are big projects (with costs ranging in billions of Rands) The engineering change process is taking place, one for the RO plant but ERA was rejected because of unrealistic time frames and the other projects the engineering mangers are still busy with them (cooling tower improvement of efficiency) strategy was presented but issues of environment that needed to be addressed such as timeframes did not accommodate authorisation (only accommodated a basic assessment (BA) and not environmental impact assessment (EIA)).	Procurement processes take forever, inferior spares from OEM but also include a third party (middleman).	The water use licence (WUL) does not make sense. Coal quality issues, producing too much ash for the slurry plant to take!! Rain readiness audits – useless because we know we know the problem is – we need money and good spares, time for outage – running the plant to the mill because people do not want to be suspended for non-performance. Water runs underground and is not seen therefore not serious.

Table 4: Responses to question 7 - 10 of the questionnaire

Interviewee	Response
Interviewee 1	The occurrence of water related legal contravention incidents especially in Power Plant 1 is where they recover wastewater directly to the cooling water system which has led to system fouling and condenser blockage. The cooling tower fills must be replaced at a cost of ~R500 million for the whole station. Human error has been the root cause of legal contravention incidents due to employees not continuously monitoring plant performance and identifying issues too late.
Interviewee 2	There has been a constant non-compliance at Power Plant 2 where there is a dam overflow and the plant is still mitigating however, it is taking long to implement. In the boiler there are leaking pipes and overflow of the tanks which leads to more water going to the pollution control dams and ashing system. Government authorities need to collaborate with the power utility to solve challenges rather than police the power plant, if an integrated approach is applied between the two there would be fewer legal non-compliances.
Interviewee 3	The power utility's Incident Management Procedure has a good process; however, employees need to focus on the root cause of their problems, but this is not done thoroughly. A lot of the incidents cannot be fixed using procedure only. Maintenance is a serious problem and leads to water losses and water non-compliances and environmental contamination is a consequence of a plant that is not running correctly.
Interviewee 4	Almost all the power plants are above their water use targets, which have been set under the NWA by the Department of Water and Sanitation. Sites need to understand the practicality to perform at a specific target by making them understand the linkages between the water targets and that energy produced affects water target when looking at the load factor and thermal efficiency of the plant against the water target and chemistry of the water. Cooling water usage is linked to chemistry blowdown. In reality on site, there is a conflict between maintaining the target and water chemistry, which affects the plant performance, quantity of water used and released into the environment.
Interviewee 5	The typical water related legal contravention incidents are dam overflows, pipe and tube leaks and activities of washing ash into the drains and dust and oil leaks when it rains, they reach water resources causing pollution and siltation. Oil spillages, coal and ash runoff into the dams causing siltation and groundwater pollution. To improve compliance, clean and wastewater discharges need to be managed or minimisation linked to overall water performance for example one of the plants is continuing to operate whilst their wastewater is running into the veld. In addition, Power Plant 2 has been discharging water for a long time into the environment therefore compromising ZLED policy. The main contributing factors to legal non-compliance are due to human behaviour, a problem of an aged plant there are certain pipes underground which cannot be reached and that result into significant water losses. To fix these plant issues will require a Power Plant's unit outage and it is challenging to get outage for opportunity for maintenance.
Interviewee 6	In Power Plant 1, dam overflows are the major area of non-compliance. Legal contravention incidents are mainly due to power plant not ensuring it has spares and pumps, there is also theft of panels. Power plants need to have automated pump systems to manage the level of the dams and go back to maintaining the plant properly. During an outage, they should include water related issues on the scope of work.
Interviewee 7	Legal contravention incidents occur because of process and system failures for example management of the final effluent is an issue (where should this water go?); the dams are complete, and they at times overflow in violation of ZLED policy, and in non-compliance with the water use licence and the NWA. There are areas where it works perfectly but there are issues in the processes. As a business we need to question whether the capacity of wastewater dams sufficient to take the water coming from the system? We did not foresee that the dam is getting full; there should be a warning that there is an issue. Clearly, the process is flawed.
Interviewee 8	The big issue is sitting with excess water, and it is not easy to get a method to treat the volumes of water, and there is so much red tape in terms of the legal requirements set out by DWS. We trying to solve this issue and treat a volume of dirty water to re-use. However, there is too much red tape to manage water. For example, the initial design of the plant was not incorporating the ZLED policy, power plants could release water into the environment, the plant attempted to run at ZLED, but now it is a requirement. There is no drain separation of dirty and clean water system at the plants, this does not allow for water cascading, as it should be because of the design.
Interviewee 9	Non – conformances due to lock down, flowmeter calibrations were not done but operationally, water usage was higher than what it should be, engineers checked why, projects were put in place to go back to original design. Sometimes the WUL does not make sense. There have been 7 dam and final cut overflow incidents, the utility defines these as incidents that are a result of a significant failure of business systems. managed to install pumps and redirect water to other dams, but the constraint is that we are still experiencing losses, plant needs to be maintained and leakages

	are minimised and sort out slurry plant issues. The system that is supposed to support is not working. The main problem is that plant is not fixing the root cause. Root cause is known (slurry plant) contaminating the system that we are meant to recover from so water is not usable.
Interviewee 10	Leaks at the station cause spillages and pollution of the groundwater resource. As a preventative measure, they conduct maintenance before it breaks down and ensure that scheduled maintenance occurs to prevent plant breakdowns. The SHEQ policy guides the development of the environmental and water strategy and therefore my team's job is to conduct maintenance and to avoid wastages of water. There are four types of leaks water leaks, oil leaks, ash leaks, steam leaks. At the outside plant, operators must manage water and oil leaks to prevent the degradation of the plant. He must repair leaks as soon as possible, when there are leaks in the plant and do preventative maintenance to avert acid spillages. In terms of avoiding dam overflows, some areas, they are winning, but in others, they are not.
Legend	Root Causes for Legal Contravention Incidents Type of Legal Contravention Incident Resolution

Appendix 3: Analysis Data

Table 5: Effectiveness of Water Management SOPs

Interviewee	1	2	3	4	5	6	7	8	9	10	Average
Effectiveness	3	3	3	2	2	3	2	3	2	3	2,6

Table 6: Analysis of the interview data for water wastage

Interviewee	1	2	3	4	5	6	7	8	9	10	Total System
Cooling system	1	1	1	1		1			1		6
Boiler/ Demin Water		1		1			1		1	1	5
Leaking pipes		1	1	1				1	1	1	6
Overflows		1		1							2
Evaporation			1								1
Water Chemistry			1	1					1	1	4
Pumps			1								1
Prolonged start-ups				1							1
Fire hydrant					1		1	1			3
No flow meters								1	1		2
Underground pipes leaking									1		1
Total Frequency	2	6	8	10	6	7	9	11	15	13	87

Table 7: Identified Gaps in water management.

Interviewee	1	2	3	4	5	6	I7	8	9	10	Gap Total
No Capital Investment/Budget	1		1		1						3
Poor Project Planning	1			1	1						3
Outdated/ Complex Procedures	1	1	1								3
Misalignment Between Divisions	1		1								2
Minimal Collaboration with External Stakeholders		1	1	1							3
No Strong Leadership		1	1	1				1	1		5
No Consequence for Negligence				1	1	1					3
Water is Neglected					1						1
No proper measurement of flow					1	1					2
Ageing Plant					1						1
Treating Symptoms, not Root Cause							1	1			2
Procurement									1	1	2
Poor Maintenance of Systems						1			1	1	3
Total	4	3	5	4	6	3	1	2	3	2	33

Table 8: External Factors Affecting Water Management

Interviewee	1	2	3	4	5	6	7	8	9	10	Total External Factors
Water Quality Changed	1		1					1			3
Limited Outage for Maintenance/ Load Shedding Pressure		1		1						1	3
Interference from Head Office			1							1	2
Poor Enforcement from Authorities/ difficult to implement Licence Conditions			1	1						1	3
Positive Effect of NGO Interference			1								1
Procurement Process (Governance - Treasury)				1			1				2
Quality of Spares and Contractor Work				1					1	1	3
Environmental (Evaporation, High Rainfall)					1						1
Budget/Funding						1	1			1	3
Project Timelines Shifted (Lack of Urgency)	1						1	1	1		4
Coal Quality										1	1
Total	2	1	4	4	1	1	3	2	2	6	26

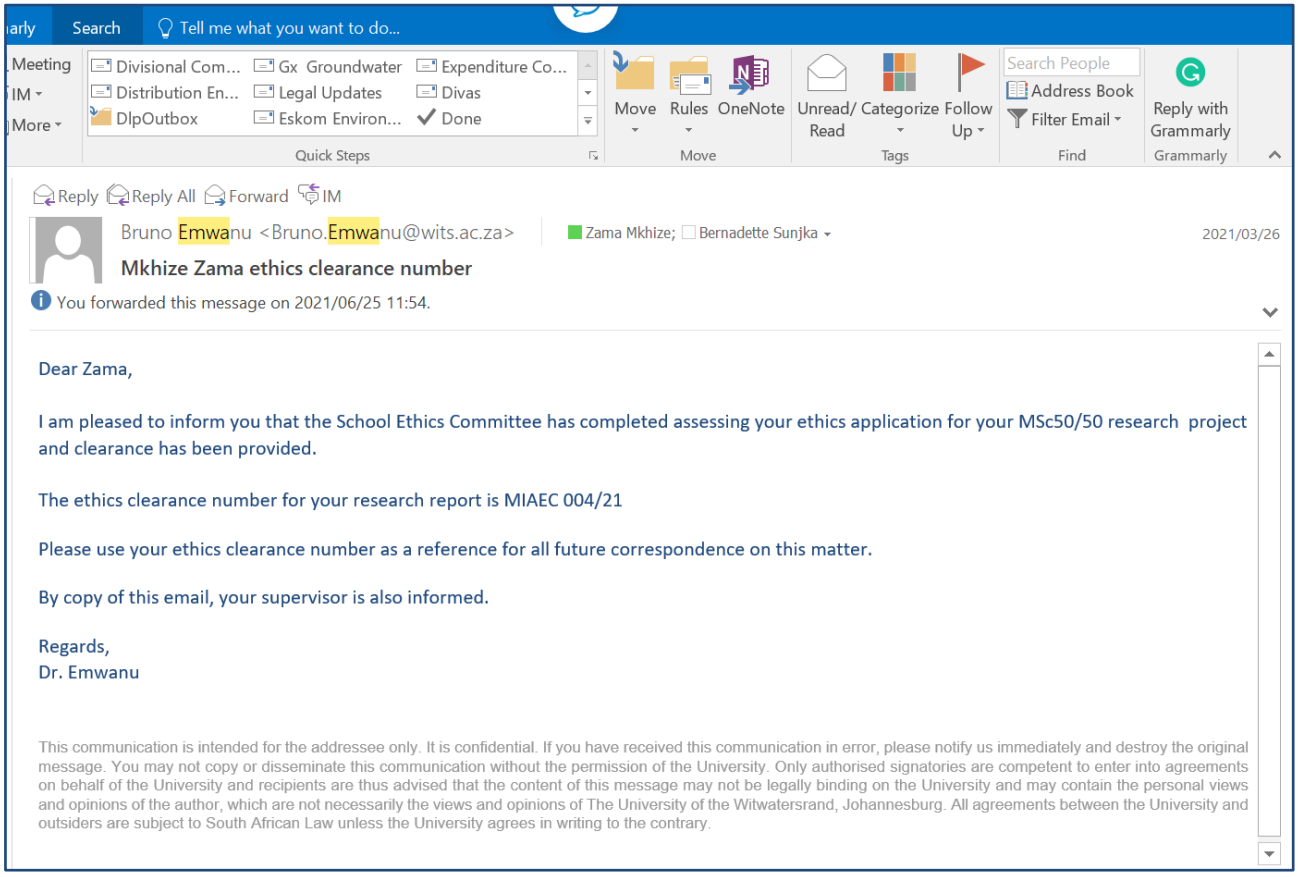
Table 9: Analysis of Power Plant's Water-Related Legal Non-Compliances

Interviewee	Root Causes	Incident	Resolution

1	system fouling and condenser blockage, Human error has been the root cause of legal contravention incidents	recover wastewater directly to the cooling water system	Continuously monitoring plant performance
2	boiler, there are leaking pipes and overflow of the tanks	dam overflow, more water going to the pollution control dams and ashing system	Government authorities need to collaborate with the power utility
3	plant that is not running properly	environmental contamination	focus on the root cause of their problems
4	conflict between maintaining the target and water chemistry, which affects the plant's performance,	Power plants are above their water use targets, quantity of water used and released into the environment	Sites need to understand the practicality of performing at a specific target by making them understand the linkages between the water targets and the energy produced
5	due to human behaviour, an aged plant, pipes underground that cannot be reached, little to no outage for maintenance	dam overflows, pipe, and tube leaks activities of washing ash into the drains and dust and oil leaks when it rains. They reach water resources, causing pollution and siltation, groundwater pollution, and discharging water for a long time into the environment	To improve compliance, clean and wastewater discharges must be managed or minimised to ensure overall water performance. For example, one of the plants is continuing to operate whilst their wastewater is running into the veld
6	not ensuring it has spares and pumps. There is also the theft of panels	dam overflows	automated pump systems to manage the level of the dams, maintaining the plant properly during an outage. They should include water-related issues
7	process and system failures	overflow	need to question whether the capacity of wastewater dams is sufficient to take the water coming from the system, warning that there is an issue
8	excess water, red tape in terms of the legal requirements, initial design of the plant not incorporating the ZLED, no drain separation of the dirty and clean water system	release water into the environment	
9	lockdown, flowmeter calibrations were not done, and WUL does not make sense; the main issue is that the plant is not fixing the root cause, contaminating the system we are meant to recover from, so water is unusable.	Water usage was higher, seven dam and final cut overflow incidents,	plant needs to be maintained, and leakages are minimised, and sort out slurry plant issues
10	four types of leaks: water leaks, oil leaks, ash leaks, steam leaks	spillages and pollution of the groundwater resource, dam overflows,	Installed pumps, plant needs to be maintained, leakages are minimised, and slurry plant issues are sorted out. Conduct maintenance before it breaks down and ensure that scheduled maintenance takes place to prevent plant breakdowns, preventative maintenance, outside plant, operators must manage water and oil leaks, repair leaks as soon as possible

Appendix 4: Ethical Clearance and Approval to Conduct Study

1. University of the Witwatersrand Schools Ethics Committee clearance



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Reply | Reply All | Forward | IM

Bruno Emwanu <Bruno.Emwanu@wits.ac.za> | Zama Mkhize; Bernadette Sunjka | 2021/03/26

Mkhize Zama ethics clearance number

You forwarded this message on 2021/06/25 11:54.

Dear Zama,

I am pleased to inform you that the School Ethics Committee has completed assessing your ethics application for your MSc50/50 research project and clearance has been provided.

The ethics clearance number for your research report is MIAEC 004/21

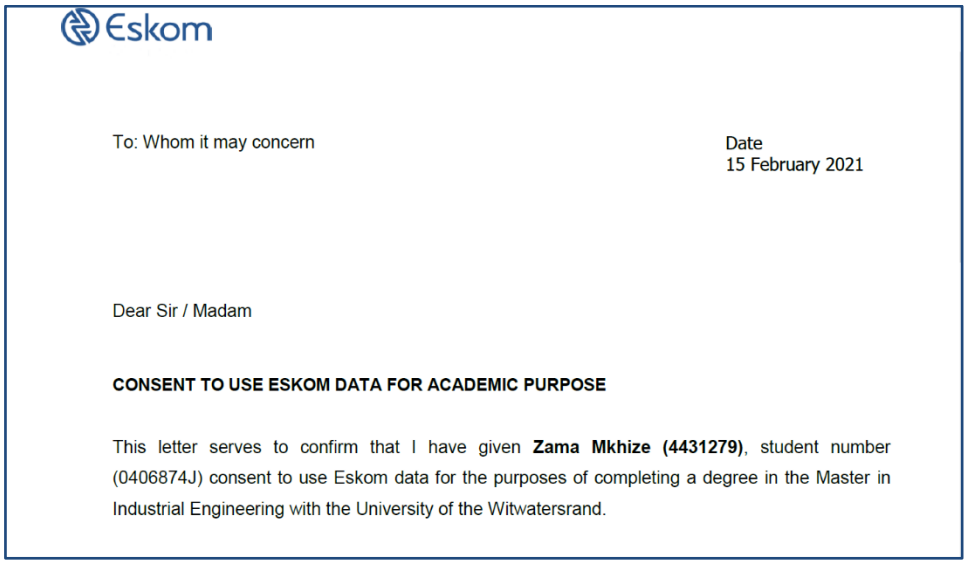
Please use your ethics clearance number as a reference for all future correspondence on this matter.

By copy of this email, your supervisor is also informed.

Regards,
Dr. Emwanu

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2. Approval and permission to conduct the study from the power utility



Eskom

To: Whom it may concern

Date
15 February 2021

Dear Sir / Madam

CONSENT TO USE ESKOM DATA FOR ACADEMIC PURPOSE

This letter serves to confirm that I have given **Zama Mkhize (4431279)**, student number (0406874J) consent to use Eskom data for the purposes of completing a degree in the Master in Industrial Engineering with the University of the Witwatersrand.

Title of study: *Water Management Practices of South African Electricity Power Plants*

Data to be used:

- Interview data from Eskom with sustainability, water and environmental managers within the Risk and Sustainability and at two power plants within the Generation Division.
- Archival data and water management strategy and supporting standard operating procedures related to water management process for Eskom's power plants.

The data is to be used for academic purposes only. The results of the study must be made available to Eskom on completion.

Your Sincerely



DEIDRE HERBST
Senior Manager
Risk and Sustainability Division

Appendix 5: Research Interview Questionnaire

Preamble:

- Thank you for taking the time to participate in this study.
- The purpose of this study is to explore whether the power utility's water management strategy and standard operations procedure have been implemented to manage water at the power plants.
- Please note that participation is voluntary and that you can decide to withdraw from the interview at any point should you feel a need to do so.
- The information you share with me will remain confidential. Pseudonyms will be used when reporting the data in the research report or other publications.

The purpose of the interview is to gain information and data from the power plant, which will assist in identifying the cause of water wastage within the power plant and conduct a gap assessment to see whether there are any deviations in plant operations and the utility's water management strategy and supporting procedures.

The interview will cover the following topics:

Water Governance Strategy and Operational Procedures
Power Plant's Water Performance
Power Plant's Water-Related Legal Non-Compliances
Status of Water-Related Infrastructure/Systems

1. Water Governance Strategy and Operational Procedures

    a. Water Management Strategy

        i. Are you aware that Eskom has a water management strategy?
        ii. What is your understanding of this strategy?
        iii. How does it apply to you and your daily work?
        iv. How have you translated this strategy for your power station's implementation?

    b. Water Management Implementation Plans and Site Water Management Standard Operating Procedures

        i. Gx water management plans? Are you aware? Have you started implementing it?
        ii. What procedures have you developed in your plant to ensure that water is protected and reserved?
        iii. Which procedure is most applicable to you and your work area?
        iv. When last were your site's water procedures reviewed?
        v. How have plant moderations been incorporated into your water management procedure?
        vi. How have you ensured that these operating procedures are adhered to on-site?

2. How would you rate the effectiveness of the current water management strategy and standard operating procedures implemented at your power plant? (From 1 – 5, 5 being very effective and one ineffective.) What would be impacting this effectiveness?

3. Please detail the governance structure that is used to manage water on-site. These must include:
    a. Roles and responsibilities
    b. Accountability and reporting structure
    c. Oversight committees and forums, etc.

4. How has the governance structure influenced procedure development? Have they enabled good water management practices on site? Have they been able to align procedures to plant operations through these structures?

5. Please indicate the status of the major water-related systems that could potentially lead to water losses and water-related legal non-compliance. Name the system and indicate the status as Good/Poor.

System	What is the related Procedure?	What is the status of the system?
Cooling water system (CoC, leaks)		
Demin water system (leaks)		
Potable water system (WTP, Supply systems)		
Plant drains system (siltation/contamination)		
Wastewater recovery system (pumps availability/pipelines)		
Ash Water Return system (ability to recover water)		
Ash dump/Dam (buffer/dam safety)		
Pollution Control Dams (level control, siltation, 1:50 requirements)		

6. Would you say the system is negatively impacted due to engineering/design, maintenance, or operations? In your own words, why would this be the case? Are these impacts/risks incorporated into your SOPs?

7. Has the power plant experienced any water-related incidents? What is the common water-related incidents that take place at the power plant?

8. Explain in detail the cause of water-related legal non-compliances in the last five years, detail actions that have been taken to address this trend and articulate constraints they faced in their efforts.

9. Of 5 incidents that have occurred, how many have resulted in the review of the site's SOPs?

10. What would you say are the major factors (at least three key factors) that have contributed to the increase in water-related legal non-compliance experienced by the plant? Please detail and explain factors in order of priority.

11. What plans did the plant put in place previously to address the above-listed major factors that contributed to the water-related legal contraventions? Were these plans successful, and what were the constraints in executing the plans to realize improvements?

12. Explain in detail the water use performance (L/kWhr) trends in the last five years. Was the performance good or bad? Please detail actions that were taken to address the deterioration/improvement and articulate constraints they faced in remedial efforts.

13. What are the significant factors (at least three key factors) contributing to the deterioration/improvement in water use performance in the last five years? Detail and explain factors in order of priority.

14. What plans did the plant put in place to address the above-listed major factors contributing to water performance deterioration/improvement on-site? Were these plans successful, and what were the constraints in executing the plans to realize improvements?

15. Which water systems have had the highest water wastage at your power plant?

16. Would you say the water management strategy clearly states where and how water wastage can be prevented at the power plant?

17. Do the standard operating procedures developed for the power plant allow for water conservation?

18. The design of the plant, does it allow for water conservation? How do plant modifications impact operations, and are these modifications incorporated into SOPs?

19. Do you think any other external factors or influences contribute to plant water losses that should be incorporated into the site's SOPs?

20. What gaps have you identified in terms of water management on your site and within the organisation as a whole?