

Effluent treatment and its re-use for the Kriel Power Station

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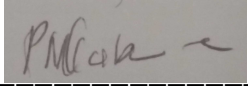
Dissertation submitted in partial fulfilment of the requirements for the degree *Magister Scientiae* in **Chemical Engineering** at the Potchefstroom Campus of the North-West University

Supervisor: Prof FB Waanders

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Declaration

I, **Palesa Mkabane** hereby certify that the work done on, “Effluent Treatment and its re-use for Kriel power station”, in this document is my own original study, except where otherwise stated as references or acknowledgement. Neither the substance nor any part of this report has been submitted for any other course at this or any other university.

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Date: _16 October 2015_____.

Abstract

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Kriel Power Station generates effluent of about 5 ML per day from different effluent streams of the pre-treatment plant. Currently the water is recovered into the effluent sump and pumped to the high level ash water sumps where a percentage is used for the ashing system while most water remains within the sump. There is a continuous intake of raw water to the cooling water (CW) system due to water losses through evaporation, effluent, leaks etc.

Due to water scarcity in South Africa, Eskom embarked on a drive to save and protect water resources. A proposal is made through this research to recover most effluent into the CW system in order to save water and to reduce the disposal to the environment. CW system is chosen as the best option for effluent recovery because there is more control over it on chemistry in terms of operation.

Different technologies are discussed as options on how to recover effluent water; treat it up to acceptable Eskom Cooling Water Chemistry Standards and re-use it into the station's cooling water (CW) system. The study revealed savings of about R14.6 M per year if effluent could be reused in the CW instead of fresh raw water intake for make-up; which can be invested into initiating effluent recovery project.

Keywords: effluent, cooling water, zero liquid effluent discharge

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Any opinion, finding or conclusion or recommendation expressed in this material is that of the author(s) and the NRF does not accept any liability in this regard.

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- The senior chemists for laboratory and cooling water systems at Kriel power station.
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Chapter 1

1. Problem Statement

1.1. Introduction

Water is a scarce commodity globally and South Africa is no exception. In fact South Africa is regarded as a water scarce country and hence there is a need to preserve and re-use. The country is facing challenges in deterioration of water quality despite its quantity limitations. Access to water is crucial to ensure economic growth and sustainability. It is envisaged that more pressure in the future will be placed on the country's limited water resources.

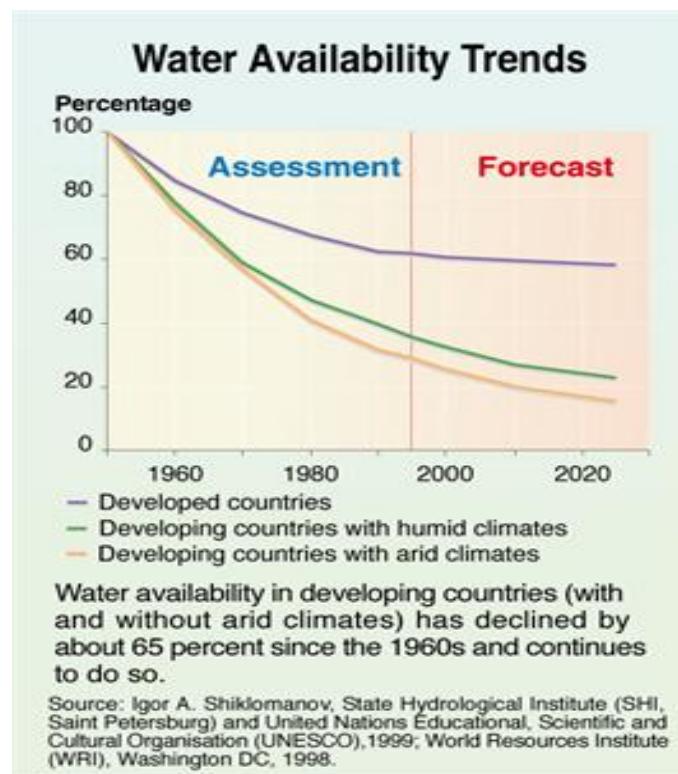


Figure 1-1 Global Water availability trends ([1])

An illustration in Figure 1.1 shows water availability trends globally specifically for developing countries including South Africa. It can be noted that from the beginning of the 20th century there has been a serious decline in water availability mainly due to socio-economic growth factors in these countries. The National Water Bill states that the main object of the bill is to provide for the management of the nation's water resources; so as to enable the achievement of sustainable use of water for the benefit of all water

users ([1]). To that end it is necessary to provide for the protection of the quality of water resources and for the integrated management of water resources with delegation of powers to institutions at regional or catchment level so as to enable everyone to participate in the processes.

The Bill accordingly seeks to provide for the protection, use, development, conservation, management and control of the nation's water resources, taking into account the need to:

- (a) meet the basic human needs of present and future generations;
- (b) promote equitable access to water;
- (c) redress the results of past racial and gender discrimination;
- (d) promote the efficient, sustainable and beneficial use of water in the public interest;
- (e) facilitate social and economic development;
- (f) provide for growing demands for water use;
- (g) protect aquatic and associated ecosystems and their biological diversity;
- (h) reduce and prevent pollution and degradation of water resources;
- (i) meet international obligations
- (j) promote dam safety; and
- (k) manage floods and droughts.

It is through this Act that the available water reserves can be protected for current and future generation and ensure that stringent measures can be applied to those who exploit water resources.

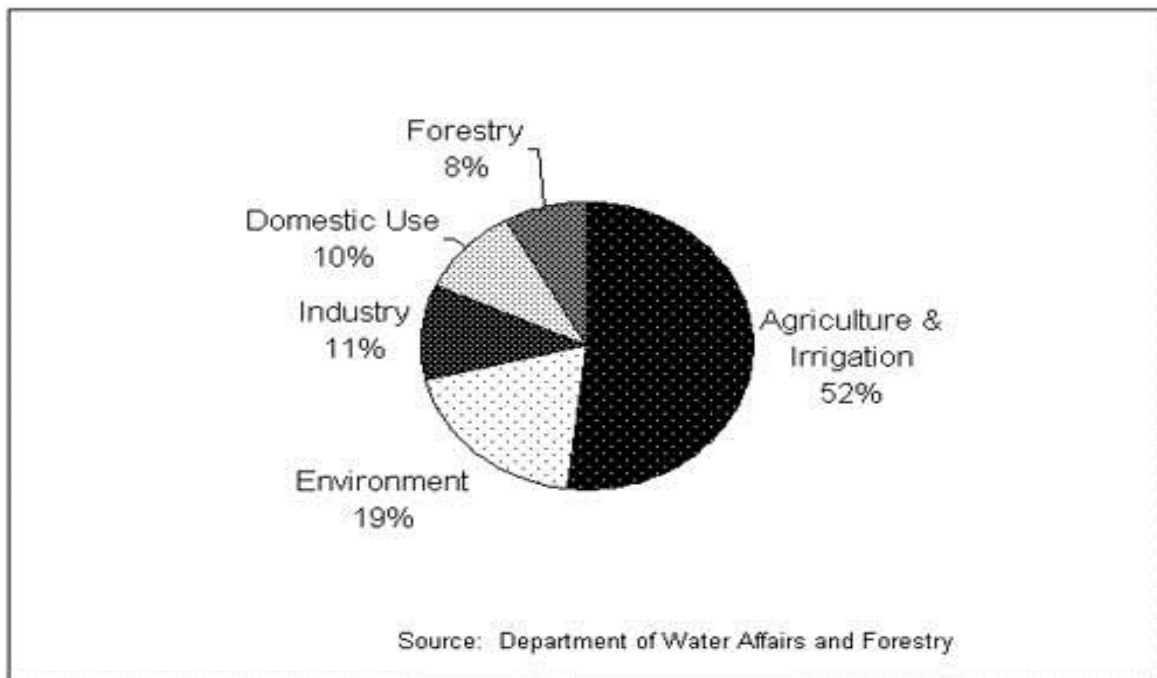


Figure 1-2 Water usage in South Africa ([2])

Figure 1.2 shows water use by sector in South Africa, with forest plantations using an estimated 8% of the 21 billion m³ available water ([2]). The amount of water actually used by plantations is controversial, as different studies report different results. Scott 1998 uses flow reduction curves to estimate that the 1.5 million ha (1.18% of land area) reduce total runoff in South Africa by about 3% (1,417 million m³ per year), which equates to mean incremental water use about 100 mm per year. Other research, however, shows substantially different estimates of water use by plantations at about 400 million m³ per year ([3]).

The water usage statistics are on an increase due to population increase and number of people who now have access to clean water as part of the post-apartheid government's water policy of providing water for all humans.

The power industry is the second largest water user other than agriculture in the country; therefore Eskom has embarked on a drive to save and protect water resources through water management initiatives across its coal fired power stations.

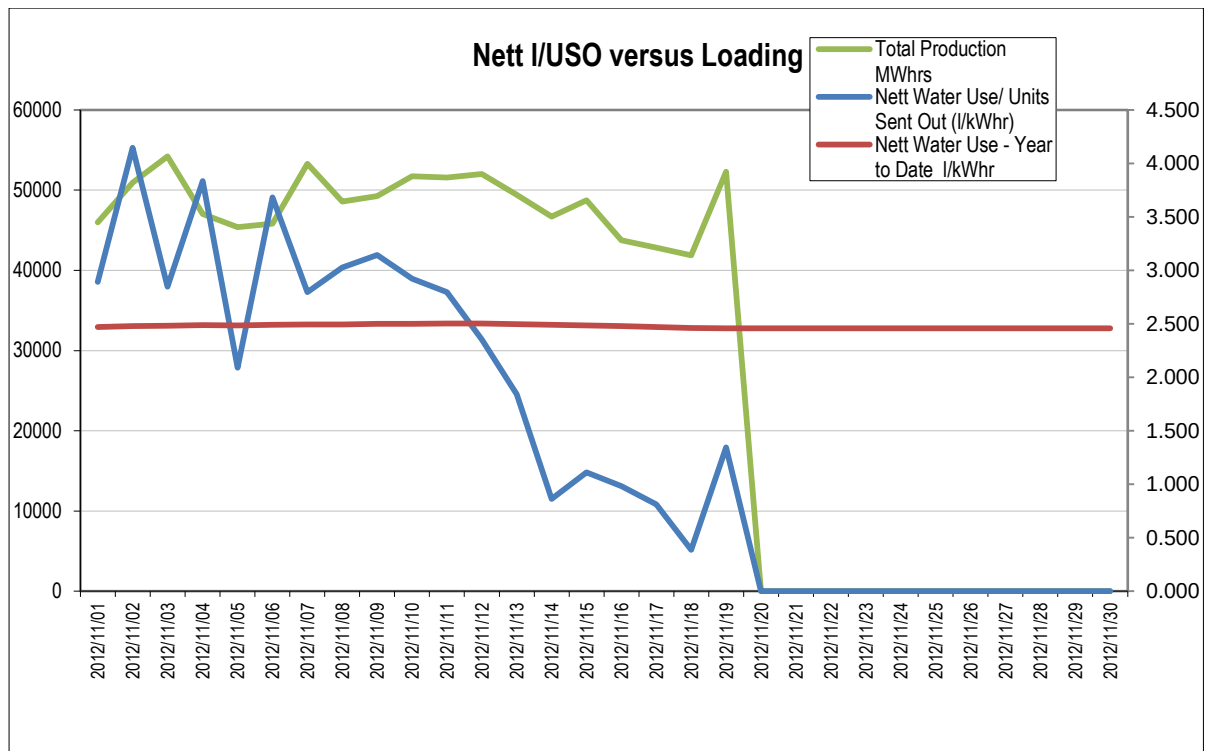


Figure 1-3 Nett litres of water used per unit generated of electricity in November 2012, Kriel power station ([5])

Figure 1.3 illustrates the measurements of water used to produce one kilowatt of electricity; Eskom set monthly targets of water usage when producing electricity and enforce penalties such as performance bonuses when these are not met. These measurements support the drive to save and protect water resources as part of the vision of Eskom and the government. It can be observed that there were more litres of water used to produce electricity, above the target until on the 12th November when the water line dropped below the target.

Kriel Power Station generates effluent of about 3ML and 4ML per day; 5ML being the maximum from different effluent streams excluding sewage which originates from the pre-treatment plant. Currently the water is recovered into the effluent sump and pumped to the high level ash water sumps where a percentage is used for the ashing system and most water just remains within the sump. There is a continuous intake of raw water to the cooling water (CW) system due to water losses through evaporation, effluent, leaks, blow downs etc. Although not much can be done about the evaporation; it is

assumed that something can be done with the re-treating of the effluent and blow downs and the prevention of leaks.

A proposal is made through this project to recover most effluent into the CW system in order to save water, reduce the disposal to the environment and achieve Eskom's Zero Liquid Effluent Discharge (ZLED) policy. The policy ([4]) states that Eskom will endeavour to apply ZLED policy to prevent the pollution of water resources unless the Receiving Water Quality Objectives of DWAF specifies otherwise. Where pollution prevention measures do not suffice, Eskom will implement a hierarchy of strategies namely:

1. water/effluent re-use and minimisation
2. water/effluent treatment, and
3. licence application motivating a controlled discharge.

The prolonged storage of effluent into the ash sump poses a risk of seepage into environment when the sump lining start aging. ZLED is defined as no liquid discharge into the environment, in principle. So often zero discharge and zero liquid discharge are used in the same meaning. Practically, the concept of zero discharge means:

- 1) recovery of reusable water or other materials from waste water;
- 2) minimisation or, no discharge of polluting substances into the environment from the water treatment plant ([5]).

The CW system is chosen as the best option to recover water because there is more chemistry control in terms of operation. Since the power station is a business which its survival highly depends on costs; the decision on effluent recovery into the CW system is dependent on the techno-economic viability of the process. By recovering and re-using effluent water; fresh water intake will be reduced at Kriel Power Station and this will result in better compliance to the ZLED policy.

Effluent recovery and re-use can be complex because the water generally contains high levels of total dissolved solids (TDS) which are generally very corrosive. There are different effluent sources from water treatment plant within the power station with different chemical compositions, namely:

- sand filter backwash

- raw water clarifier blow downs
- CPP's (Condensate Polishing Plant): regeneration effluents, resin ABROS (Air Bump Rinse Operations) and rinse water
- Demineralisation plant: regeneration effluents, resin backwashing and rinsing.

Water from different effluent sources will have to be classified in terms of their chemical composition in order to find the best solution for treatment and re-use.

1.2. Key Research Questions

1.2.1. What are the limitations when recovering effluent water to the CW system?

1.2.2. How much of fresh raw water intake will be saved when recovering effluent into the CW system in volume and in Rands?

1.3. Problem Statement and Objective

The objective of the research is to design a system that will recover most effluent water; treat it up to acceptable Eskom Cooling Water Chemistry Standards ([6]) and re-use it into the station's cooling water (CW) system.

1.4. Project Scope

The scope covers a literature study on what has been done on effluent recovery for a power industry. It also discusses effluent sample results which were taken from different effluent sources at Kriel Power Station. The chemistry content of these sample results will then be compared to the CW chemistry requirements; and be assessed on which recovery method will be best suitable for effluent recovery.

Chapter 2

2. Literature

2.1. Water scarcity in South Africa

Access to fresh clean water is considered as a basic right as stipulated in the South African Constitution. The availability of fresh water is also key to industrial and economic development. South Africa is, however a water-stressed country and fresh water is considered a scarce resource which needs to be well-managed and protected against pollution, uncontrolled use and wastage. This also includes the protection of wetlands and groundwater sources. The National Water Act exist in the country to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account amongst other factors: meeting the basic human needs of present and future generations, promoting equitable access to water, redressing the results of past racial and gender discrimination and promoting the efficient, sustainable and beneficial use of water in the public interest ([1]).

South Africa is fundamentally a semi-arid and water scarce country with a mean annual rainfall of 490mm, which is half the world average, with only 9% of that rainfall ending up as run-off water to rivers ([7]). Rainfall displays a distinct decreasing trend from east to west over South Africa and is highly variable [8]within and between years with recurrent droughts; this results in highly variable river levels, dam storage and groundwater storage over time ([7]). The water use from the majority of the catchment area of South Africa exceeds the availability on an annual basis ([9]).

In 2004, 98% of South Africa's surface water yield, as well as 41% of the annual usable potential of groundwater were allocated for use ([10]). Of this allocation, 60% went to agricultural activities, 27% to domestic demand, 23% to urban needs, 4% to rural, 6% to mining and bulk industry, 3% to afforestation and power generation utilised only 2% ([9]). The close interconnectedness between the climate and the hydrological cycle means that water resources will be impacted on by climate change and this will place increased pressure on water resources and ultimately threatening the sustainability of future availability ([9]). Schulze et al. ([11]) state that

water resources are directly impacted on by current climate variability and it is expected that climate change could impact on resources significantly in the future. The most significant impacts of climate change on water resources are the potential changes in the intensity and seasonality of rainfall. While some regions may receive more surface water flow, future problems are likely to include water scarcity, increased demand for water, and water quality deterioration.

The Department of Water and Environmental Affairs outlines the pressures on South Africa's natural water resources as well as the need to manage these resources wisely ([12]). In the 1960s and 1970s, Eskom realised the limitations in South Africa's water resources and investigated and tested the use of dry cooling technology for its new coal-fired power stations. Today, the total dry cooled installed capacity is 10 477 megawatts. Dry-cooling technology does not rely on evaporative cooling for the functioning of the main cooling systems. As a result dry cooled power stations use approximately 15 times less water than conventional wet cooled power stations. Eskom's leading role in this field is attested to by the fact that it operates the largest indirect dry cooled power station (Kendal- 4 116 Megawatts) and the largest direct dry cooled power station (Matimba-3 990 megawatts) in the world ([8]). The investment in dry-cooling results in an estimated combined saving of over 200 megaliters of water per day (ML/day), or in excess of 90 million cubic metres per annum.

The National Water Resource Strategy ([12]) released by the Department of Water and Environmental Affairs outlines the pressures on South Africa's natural water resources as well as the need to manage these resources wisely. Every power station, or power generation entity, has the responsibility to effectively manage their water consumption and save water while not compromising on generating power.

2.2. Importance of Water and Kriel Power station

A need has been identified at Kriel Power Station to recover most of the effluent generated within the Power Station to treat the effluent and re-use it within the main cooling water system. Eskom, producing 95% of South

Africa's power, is one of South Africa's biggest water consumers, and therefore Eskom is responsible for establishing effective water management procedures and research initiatives. Every power station, or power generation entity, has the responsibility to effectively manage their water consumption and save water while not compromising on generating power. This must be done in order to contribute to protecting South Africa's natural water resources and conserve water in line with the national policy ([13]). The goal of water management within the power generation sector is to limit water consumption and to eliminate the contamination of natural water resources ([8]). The problem Eskom is currently facing is that older power stations that are still in operation and will be in operation for at least the next twenty years; make use of large quantities of water for cooling and ash removal purposes ([14]).

There are many technologies and processes in use which have been proven successfully for the recovering and treating of effluent water and some are discussed in this chapter. Some technologies remove certain species of contaminants whereby additional treatment techniques still have to be applied downstream to ensure the desired specifications.

Process choice and identification of a process also depends on the user's requirements i.e. potable water production from the effluent would require more stringent and complex systems to ensure the correct specifications are obtained as it will be for human consumption. Other factors can include materials of construction where corrosiveness or fouling factor of water will play a major role and the quality of the feed water to the system will have to match the material tolerances. Fouling of equipment not only results in inefficient heat transfer and increased costs, but in micro-biologically induced corrosion (generally anaerobic) is enhanced. Siliceous suspended matter can also give rise to erosion or corrosion of pump internals, volutes, heat exchanger tubing and pipe-work [6]. Asset selection and management thus play an important role in defining the best solution in effluent recovery in terms of equipment requirements for a sustainable operational system and the environment.

Over the last two decades, Eskom has introduced a number of innovative technologies to save water. These include dry cooling - both direct and indirect, desalination of polluted mine water for use at power

stations, use of limited pumped storage and hydropower potential and technical improvements in treatment regimes to maximise the beneficial use of water. The company has taken a pro-active stance in its efforts to conserve water, in some cases even pre-empting new legislation in implementing efficient and effective water use practices. It has constantly striven to improve on its water use targets, continually researching and implementing new technologies to reduce or limit water use, and working closely with the Department of Water Affairs and Forestry (DWAF) to contribute towards long-term water resource planning and management. This commitment is documented in Eskom's Water Management Policy ([8] [4]).

Kriel power station is a 3600 MW generating coal fired fuel power plant and it consists of six units each producing 600 MW. About 3 ML per day of demineralized water is supplied to six boilers to produce steam that will drive the turbine that eventually produces electricity. Kriel is a typical example of a Rankine Cycle power plant whereby steam from the boiler sent to the turbine, passes through the condenser and then it is recycled back to the boiler, (see Figure 2.1).

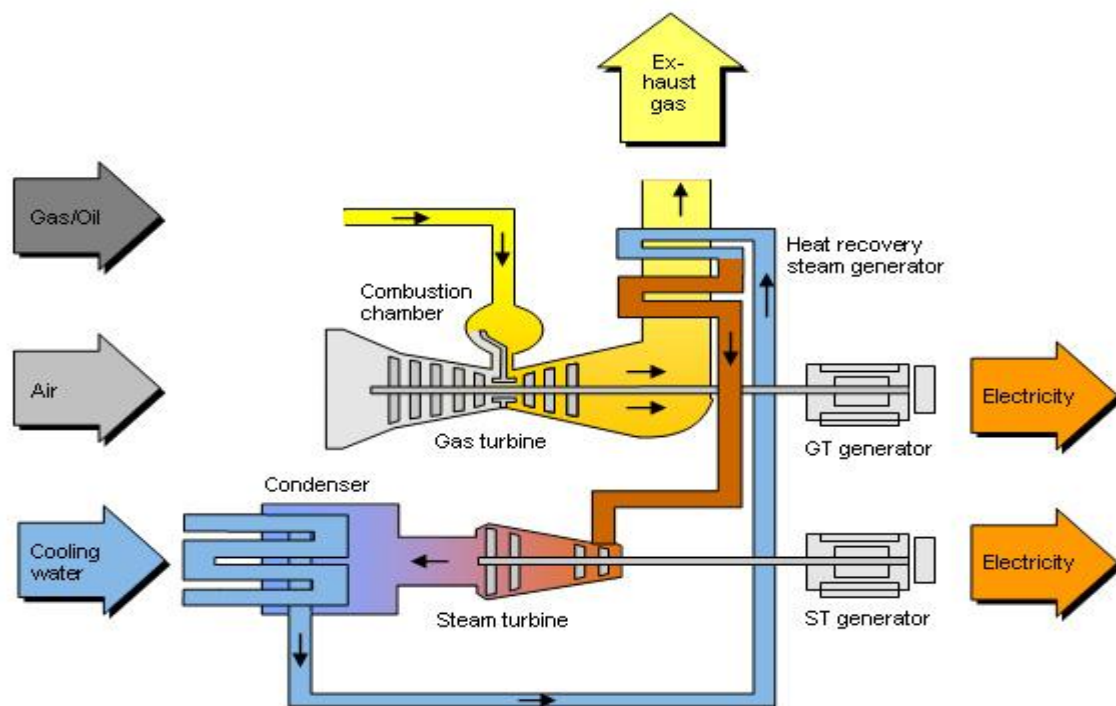


Figure 2-1 Rankine Cycle Power Plant example ([11])

One of the main auxiliaries at Kriel power station is the water treatment plant (WTP). The main function of the WTP is to clarify and treat raw water up to required chemistry specifications in order to produce potable, demineralised and cooling water (CW) for the power station. Potable water is used for human consumption, kitchen and bathroom facilities; whereas demineralized water is used to generate steam in the boiler which is sent through to drive the turbine for electricity production. The CW is used to cool steam bleeds from the turbine which is the feed water recycle as well as providing cooling to other auxiliaries in the main plants.

While the process of treating raw water is taking place at the WTP; there are many “by-products” which are formed and they are not wanted as part of the final product and are collectively referred to as effluents. Effluent is contaminated and unwanted water generated from water treatment plant processes that does not meet required “clean water” specifications and also poses an environmental impact. Effluent water generally contains high levels of total dissolved solids (TDS) which are very corrosive. Kriel Power Station generates effluent of approximately 3ML to 4ML per day; 5ML being the maximum from different effluent streams excluding sewage which originates from the pre-treatment plant.

There different effluent sources generated from WTP are recovered into the effluent sump at the WTP and then pumped to the high level effluent water sumps whereby about 20% is used for the ashing system to drive coarse ash from the boiler to the ash dams.

Most of the effluent remains in these dams as their holding capacity, to reduce the disposal to the environment and to achieve Eskom’s Zero Liquid Effluent Discharge (ZLED) policy. The Eskom’s Water Management Policy ([4], states that Eskom will endeavour to apply ZLED policy to prevent the pollution of water resources unless the Receiving Water Quality Objectives of DWAF specifies otherwise. The prolonged storage of effluent into the ash sumps poses a risk of seepage into environment when the sump lining start aging; hence proactive civil preventative maintenance has been applied to inspect these dams over a certain frequency of years to address this risk. There is a water hierarchy within Kriel power station in terms of costs and chemistry specifications requirements and it is as follows:

- a) Potable Water: it is water produced for human consumption and it is guided by Eskom's Water Quality Standard for Potable water ([15]) to ensure that the aesthetic, chemical, microbiological and physical quality is at an acceptable level on potable water chemistry for the health of the people consuming the water.
- b) Demineralised Water: the water is produced for steam generation that will produce electricity and it is guided by Eskom's Chemistry Standard for Coal Fired Units with Once Through Boilers operating at 17 MPa ([16]) to ensure that the material of construction for equipment handling this water lasts up to its end of life as well as resin that produce the water.
- c) Cooling Water: it is water used mainly for the removal of heat off the feed water through the condenser as well as supplying cooling for auxiliaries; the water specifications are guided by the Chemistry Standard for Cooling Water from Eskom ([6]) to ensure that the water is up to required specifications for the protection of condenser tubes and auxiliaries.

Cooling water allows for a better chemistry control in terms of operation as compared to the other two, demineralised and potable. It is therefore chosen as the best option to recover the effluent to. There is a continuous intake of fresh raw water daily into the cooling towers due to water losses through evaporation, effluent, leaks, blow downs etc. The main objective of this project is to discuss best options of recovering effluent into the CW system in order to save water, reduce the disposal to the environment (to the holding sump capacity) and achieve Eskom's Zero Liquid Effluent Discharge (ZLED) policy. Eskom adopted the ZLED policy during 1987, in terms of which all reasonable measures are taken to prevent pollution of water resources through the establishment of 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 water resource under normal operating conditions and average climatic conditions ([8]).

The Department of Water Affairs is currently charging Kriel power station almost R8000 per ML of raw water. Research has shown that South Africa is currently facing challenges in the deterioration of water quality, despite its quantity limitations and furthermore to ensure sustainability on the economic growth success ([17]). There is a guarantee of more pressures in the future on limited water resources hence the need to have projects such as this one to save water and saving the environment.

2.3. Cooling water standard

The Eskom Cooling Water standard establishes targets, upper and lower bound values for chemical parameters in open evaporative recirculated cooling systems. Specific modes of operation apply at individual power stations according to the plant which is installed, in particular, the quality of the make-up water supply. The objectives of this standard are to formulate agreed chemical conditions which will ensure the most cost effective operation of a cooling water system. The focus is on important aspects such as overall water management, cost effective treatment and control, the availability and efficiency of the process and plant in contact with the cooling water ([6]).

The limits and ranges reflect practical and achievable chemistry that can be maintained through the application of sound water treatment and water management techniques, whilst taking cognisance of specific limitations. Recommendations from such organisations as EPRI (Electric power research institute) and VGB (Vereinigung Der Grosskraftwerksbetreiber) with respect to modern power plant practices have been considered for implementation of such techniques.

2.3.1 Turbidity

Turbidity in cooling water results from the presence of silt, clay, pulverised fuel ash, coal dust precipitated salts and algae. The source of these suspended particles is the make-up water, internal microbiological growth and/or dust particles scrubbed from the air being supplied to the cooling tower. Turbidity is a general term used to describe the optical opacity of water containing any form of insoluble suspended solids matter.

Suspended matter is responsible for fouling of pipe-work, heat exchanger surfaces, cooling tower packings and drift eliminators, particularly where the velocities are low or have been reduced intentionally. Fouling of heat exchanger surfaces not only results in inefficient heat transfer and hence increased cost but, in addition, microbiologically induced corrosion (generally anaerobic) is enhanced. Suspended materials can also co-precipitate with calcium carbonate and calcium sulphate.

Algae, fungi and bacterial growths flourish in the cooling tower environment and conditions such as the presence or absence of sunlight and adequate food supply sustain such growth.

The limit for turbidity has been specified as <100 Formazin turbidity units (FTUs). However, this must not be taken as a mandate to operate at the maximum levels. Generally, the turbidity should be controlled as low as cost-effectively possible. During flooding conditions the turbidity of raw water supplies can rise dramatically over a period of a few days. During these periods, stations may well depend on their reservoirs to supply water until the turbidity subsides. Extended operation of condensers above 100 FTU thresholds has proven to be detrimental to the condenser tubes. Severe thinning of condenser tubes has been experienced where the threshold was regularly exceeded.

2.3.2 Conductivity at 25°C

The conductivity at 25°C is a function of the total dissolved ionic solids. For the raw water currently being supplied to Eskom's coal fired plant, ***the limit for the concentrated cooling water system has been set at < 4000 µS/cm at 25°C.*** This is an arbitrary limit and has been set to minimise galvanic corrosion in highly saline/oxygenated water, to prevent damage to adjacent vegetation by salts released by the cooling tower drift, and to allow sufficient high cycles of concentration to be obtained in order to maintain zero liquid effluent discharge. Conductivity levels of Eskom cooling water samples range between 960 to 3050 µS/cm.

It must be clearly understood that the conductivity limit must not be viewed in isolation as some ions are significantly more corrosive than others, e.g. chloride ions are more corrosive than sulphate with respect to metallic components.

2.3.3 Alkalinity, pH, calcium hardness, conductivity and calcium carbonate (precipitation potential and sulphate concentration)

All five parameters are inter-related and, as such, the limits specified must be viewed in conjunction with one another. The objective in controlling this group of parameters is to:

- minimise corrosion by maintaining adequate protective alkalinity,
- prevent/minimise the leaching of calcium from asbestos cement drift eliminators or cooling tower packings,
- avoid precipitation of calcium carbonate scale on heat exchanger surfaces and on the cooling tower packings,
- allow effective removal of alkalinity by precipitation processes, and
- minimise the use of sulphuric acid as a neutralising agent for alkalinity.

A problem which has arisen more frequently is the low calcium concentration of the cooling water in the so-called bottom-end problems, which is primarily as a result of the sodium alkalinity in the make-up water. Water contains sodium alkalinity when the "M" alkalinity > total hardness. M-alkalinity is a measure of the amount of acid it takes to drop the pH to approximately 4.3. Alkalinity is defined as the acid absorbing property of water. There is also P-alkalinity which is a measure of the amount of acid required to drop the pH to approximately 8.3. The major acid absorbing constituents that are typically dealt with are hydroxide (OH^-), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions ([18]). The sodium alkalinity converts to soda ash during the lime treatment process and precipitate the calcium associated with sulphates as calcium carbonate. The parameters for cooling water at selected Eskom power stations are presented in Table 1.

Table 1: Summary of cooling water quality at Eskom power stations

Parameters	Range
Alkalinity Total (as CaCO_3)	Between 90 and 200 mg/l
pH @ 25 °C	8.1 to 8.6
Calcium hardness (as CaCO_3)	Between 200 and 750 mg/l
Conductivity @ 25 °C ($\mu\text{S}/\text{cm}$)	Between 960 and 3050
Calcium (as CaCO_3)	Between 200 and 50 mg/kg

2.3.4 Calcium phosphate

The ortho-phosphate that comes from sewage is very reactive with calcium and the limit is set at 0.5 mg/l as PO_4 so as to avoid calcium phosphate, particularly at elevated cooling water temperatures experienced at the outlet of the condensers and coolers. It is recommended that treated sewage water be introduced via cold lime softening clarifiers. This will prevent the accumulation of phosphate in the cooling water system.

2.3.5 Nitrate and Nitrite

Whilst no limits are specified as yet for nitrate and nitrite it is necessary for these parameters to be measured as discharge of blow-down to the environment may be required. Nitrate and nitrite are indicators of both industrial and domestic pollution of water supplies mainly from sewage and sewage effluent. Nitrate levels in the Eskom cooling water range between 0.1 and 11 mg/l, while that of nitrite ranges between 0.02 and 0.42 mg/l.

2.3.6 Algae

Algae, like fungi, are relatively large organisms and are normally coloured green or blue green by the presence of chlorophyll. Sunlight is necessary for growth and the most effective control method is the exclusion of sunlight. Deposits of dead algae provide food for bacteria and fungi, since they act as filters and catch other organisms. Algae are not known to cause corrosion directly, except for occasional occurrence under algae deposits. Algae growth is mainly responsible for the blockage of cooling tower screens and massive build-up in the clarifier launders.

2.3.7 Bacteria

Excessive biofilm can be seen with the naked eyes when large colonies of bacteria are present. Species are identified with the aid of a microscope at a magnification of 800 times or more. Each type of bacteria has a specific action and often is referred to by its effect on materials. Some classes of bacteria cause slime, corrosion and gas production. Bacteria common in cooling water systems, are the slime-formers, they produce a slimy, gelatinous deposit that can clog heat exchanger tubes, increase friction losses and shield heat exchanger surfaces from inhibitors and the cooling medium. In reverse osmosis, the back diffusion of the concentrated salt is

retarded by slimy layers on the membrane surfaces, thus affecting the osmotic pressure and the permeate quality.

Sulphide-producing bacteria produce chemicals that results directly in the corrosion of metals. These bacteria convert water soluble sulphur compounds to hydrogen sulphide. *Clostridium* is also a hydrogen sulphide producer but not a sulphate reducer. This conversion usually starts with sulphates that either occur naturally or come from the addition of sulphuric acid for alkalinity control.

Hydrogen sulphide is acidic and aggressively attacks metals, principally mild steel, but also stainless steel and copper alloys. However, most metals are subjected to corrosion under low pH, reducing conditions and the presence of sulphides.

In a recirculating cooling-water system, corrosion due to these organisms can occur at a rapid rate and perforation of a 16 mm mild steel coupon within 60 days has been recorded. Using chlorine to control these organisms is not effective because:

- The organisms are usually covered by slime masses that prevent the chlorine from reaching the sulphide producers; and
- The hydrogen sulphite surrounding these organisms reacts with chlorine to form chloride salts that negate the effect of chlorine.
- The efficiency of chlorine at the elevated pH levels found in cooling water is limited.

Special toxicants are necessary to control these bacteria and favourable temperature and high raw water make-up further complicate control. The application of biocides provides a limited protection due to factors already mentioned. Bio-dispersants capable of controlling the attachment of slime producing bacteria have provided the most cost effective control for these bacteria. Bio-dispersants can provide sufficient protection in areas where water flow conditions are such that the dispersant can function, areas such as stagnant low flow and under deposits may still be subjected to microbial corrosion.

Table 2: Cooling water standards for biological quality

Component	Unit	Standard
Total aerobic bacteria	CFU/ml	10^4 CFU/ml (target)
Total anaerobic bacteria	CFU/ml	10^3 CFU/ml (target)

2.4. Cooling Water contamination

The quality of the available make-up water is evaluated as a critical factor during the design stage of a power station. Needs such as the use of third party effluents are often not foreseen during the design stage. South African surface water sources (rivers and dams) are challenged with declining quality and recent reports indicate that at least one third of South African rivers are eutrophic (i.e. contain excessive levels of phosphates and nitrates), while another one third of the rivers are considered borderline eutrophic. Most of the rivers that fall within the above categories are within Eskom power stations water supply regions ([18]).

Raw water from the Vaal catchment area has high suspended solid levels (up to 200 ppm), as well as high levels of iron, manganese, aluminium and copper and the rising sulphate levels of these water sources are also a growing concern. It is believed that the quality of process water used by Eskom has the highest nutrient levels in the world, as both phosphate and nitrate levels are excessively high ([19]). High nitrogen levels in water tend to attack metals resulting in a highly corrosive compound.

The recovery of the station drains to the cooling water system is often a source of contamination of the cooling water. Contaminants that typically find their way into the cooling water systems along this route are:

- Organic solvents
- Dispersed or dissolved lubricants, or as free oil
- Ash particles
- Spent regenerants (NaOH and H₂SO₄)

- Soaps and detergents
- Chemical inhibitors from auxiliary cooling systems.

These products can be detrimental to the treatment processes and condenser performance. They are also excellent nutrients for microorganisms thus often resulting in microbial contamination. Spent regenerants will adversely increase the blow down requirements and often cause damage to the concrete drain systems.

2.5. Treatment options and technical brief

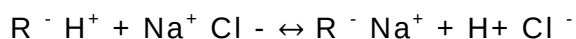
There are many technologies and processes which have been proven as the best options for recovering and treating effluent water, and some will be discussed in the following sections. Some technologies remove certain parts of contaminants whereby additional processes still have to be applied downstream to ensure a further removal depending on the required specifications. Chosen processes also depends on the user's requirements i.e. potable generation from effluent would require more stringent and complex systems to ensure that the best specifications are obtained as the water produced will be for human consumption.

2.5.1 Ion Exchange Technology

Ion exchange is a chemical reaction process whereby an ion from a solution is exchanged for a similarly charged ion attached to an immobile solid particle. These solid ion exchange particles are naturally occurring, inorganic zeolites or synthetically produced organic resins. Ion exchange materials are insoluble substances containing loosely held ions which are able to be exchanged with other ions in solutions which come in contact with them. These exchanges take place without any physical alteration to the ion exchange material ([20]).

Ion exchange is used in water treatment processes to replace undesirable ions present in water with more desirable ions. It is achieved by passing

water through a bed of insoluble synthetic polymeric beads of ion exchange resins. There are essentially two basic types of ion exchange resins; cation and anion exchange resins. There are two categories of cation exchange resin namely; strong and weak acid exchange resins. The strong acid resin can neutralise strong bases and convert neutral salts into their corresponding acids. The weak cation acid resin of cation resin is only effective in alkaline conditions. Weak acid cation resin is only able to neutralise strong bases. R^- below refers to the fixed polymer phase of the cation exchange resin.



The anion exchange resins also have two categories; strong and weak base types. Like the strong acid cation resins, the strong base anion resins can operate over a wide pH range. These resins can neutralise strong acids and convert neutral salts into their corresponding bases. The weak base exchangers are only effective in acidic solutions and exchange only ions such as chloride, nitrate and sulphate, but not silica or bicarbonate ([21])

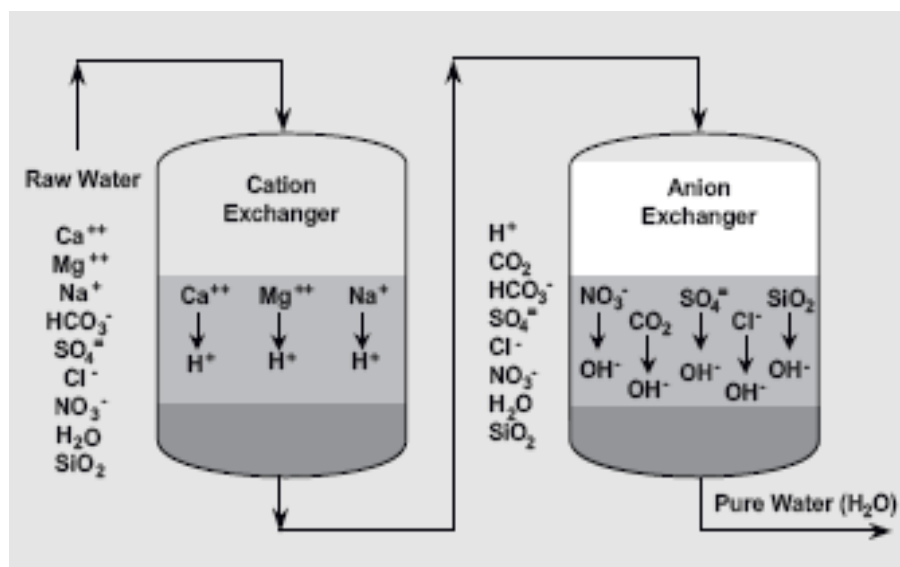
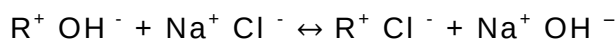


Figure 2-2 Ion Exchange Units used in the removal of anions and cations ([18])

All natural water contains, in various concentrations; dissolved salts which dissociate in water to form charged ions. These ions need to be removed from the water because of their adverse effects in the boiler and turbine

plant, namely scaling and corrosion. The process works by bringing the solution containing the mineral ions into contact with special ion-exchange material (in the form of resin beads). These beads have hydrogen or hydroxide ions on their surface. These surface ions are exchanged for other ions in the solution; positively charged ions are called cations and negatively charged ions are called anions ([22]).

Ion exchange currently remains the preferred and economic choice of treating water containing low total dissolved salts for the purpose of producing deionised makeup water. The technology is widely used in Eskom power plants and is highly reliable in achieving the expected specifications for the production of the demineralised water. A fully regenerated resin i.e. cation is loaded with H^+ ions and water passing over the resin beads enters the porous structure and the ions in the water displace the H^+ ions from the exchanged sights where one H^+ is exchanged per Na^+ or K^+ ([23]).

2.5.2 Clarification Technology

Suspended matter in the raw water supplies is removed by various methods to provide water suitable for domestic purposes and most industrial requirements. Clarification is used extensively throughout the Eskom water treatment plants and has been proven reliable and affordable. The suspended matter in raw water may consist of large solids, settleable by gravity alone without any external aids, and nonsettleable material, often colloidal in nature. The matter removal is a clarification process which is generally accomplished by a combination of the following processes within clarification: coagulation, flocculation, and sedimentation. The combination of these three processes is referred to as conventional clarification.

The performance of the clarification device is enhanced by reducing the number of smaller particles through flocculation. The result is a higher unit capacity and improved overflow quality because of the formation of faster settling, larger agglomerates from the finer particles. Floc shear and breakup in the aeration system is not necessarily detrimental, because this increases the surface area and decreases the diffusion resistance ([24]).

Coagulation is the process of destabilization by charge neutralization and once neutralized; the particles no longer repel one another and can be

brought together. The removal of suspended particles which will not settle by gravity alone requires the addition of chemical compounds commonly referred to as coagulants. Particulate materials comprising dispersions may range in size from 0.1 to 100 μm . Materials within this particle size range are termed colloids; the small size of colloids coupled with their surface charge is primarily responsible for establishing conditions favourable for the creation of dispersions. Stabilizing factors associated with colloidal dispersions are electrostatic charge and hydration; these surface phenomena are of greater relative importance due to the large surface area to total volume ratio of a dispersion of small particles ([25]). Coagulation is necessary for the removal of the colloidal-sized suspended matter.

Flocculation is the process of bringing together the destabilized, or "coagulated," particles to form a larger agglomeration namely "floc." When two colloidal particles join together to form a floc, they become chemically bridged into a three-dimensional network and the chemical bridging process is called flocculation. Colloids are always negatively charged in natural and waste waters. Under a microscope the colloidal matter can be made to move around under the action of an electrical field. The coagulant species are therefore adsorbed onto the surface of the turbidity particles and they become coated with the coagulant.

The mechanical flocculation of raw wastewater to improve the removal of total suspended solids (TSS) and biochemical oxygen demand for 5 days (BOD_5) has been practiced for a long time. Combined flocculation and sedimentation ([26]) was discussed with the performance of centrally driven mechanical flocculators in circular clarifiers. It was found that these units; without chemical addition, performed better than conventional clarifiers. The enhanced performance is recognized today to be the result of optimizing the flocculation potential of the incoming particulates.

Sedimentation refers to the physical removal from suspension or settling, that occurs once the particles have been coagulated and flocculated. Sedimentation without prior coagulation results in the removal of only relatively coarse suspended solids, leaving behind some parts of the matter not being removed. Sedimentation is the final step in the clarification process. Flocculated water from the slow mixing phase flows to the settling zone where aggregated floc particles settle out. As then aggregated or

conglomerated floc settles, clarified (clear) water rises and is separated from the sediment. Settled floc particles are removed in a thickened state (as sludge) from the bottom of the sedimentation vessel. Clarified water typically overflows from the surface and is treated further through filtration equipment.

Critical to success are good mixing and flocculation zones before the sedimentation and filter units, to generate sufficient particle size of solids for removal. This also will decrease the chemical dosing requirements ([26]).

2.5.3 Filtration Technology

Filtration is the process of passing settled water through a porous medium to remove any remaining matter held in suspension. In water purification, the matter to be removed is colloidal in size and includes suspended silt, clay, organic colloids, and microorganisms, including algae, bacteria, and viruses.

Filtration could be considered a very fine form of separation, since the filter media is intended to physically remove impurities. However, filtration is intended to remove very small impurities that remain after the separation process. There are various filtration technologies such as sand filters, cartridge filtration, online filtration and membrane filtration. These technologies can target very fine particles such as sand and silt, microscopic particles such as bacteria and algae, molecular constituents such as viruses and acids, and even ionic impurities such as salts and metals. The costs associated with filtration greatly increase as the targeted impurities decrease in size.

Filters are divided into two general classes, depending on their filter media: granular and preformed. Granular filters are depth-type filters using individual grains in layers, such as sand charcoal or combinations of these, as a filter medium. Preformed filters can be screen, surface, or depth type, ranging in thickness from a single thin membrane element to a thick filter mat ([27]).

Filtration involves the mechanisms of adsorption (physical and chemical), straining, sedimentation, interception, diffusion and inertial compaction. It does not remove dissolved solids, but may be used together with a softening process which does reduce the concentration of dissolved solids. Filtration is used in addition to regular coagulation and sedimentation for removal of solids from surface water or wastewater. It prepares the water for use as potable, boiler, or cooling water make-up at the power plants.

2.5.4 Membrane Technology

Membrane processes have been used increasingly for the production of pure water from fresh water and seawater. The processes are also being applied in process and wastewater systems. Membrane microfiltration is replacing conventional clarification and filtration processes. However, waters with high levels of suspended solids still require to be treated by conventional clarification techniques. Over the years membrane technology has been expensive and relatively experimental; recently the technology is advancing quickly and becoming less expensive, improving performance, and extending life expectancy. A membrane is a permeable or semi-permeable, solid phase (polymer, inorganic or metal), which controls the relative rates of transport of certain species present in the source water and restricts their motion. Generally, membranes work by selectively allowing some constituents to pass through the membrane while blocking the passage of others ([28]).

Membrane technologies is a general term for removing contaminants from feed water by means of a thin, porous barrier called a membrane. It is based on a process known as cross-flow filtration that allows for continuous treatment of input liquid streams. In this type of process, the pressurized raw water inlet flows parallel to a porous semipermeable membrane filter. The fact that this system is pressurised, water is forced through the filter membrane. The clean permeate passes through the semipermeable membrane, and the unwanted particles remain in the concentrate stream that is discharged to the sewer.

Common membrane processes include ultrafiltration (UF), reverse osmosis (RO), electro dialysis (ED) and electro dialysis reversal (EDR). These processes (with the exception of UF) reduce most ions; RO and UF systems also provide efficient reduction of non-ionised organics and particulates. UF membrane porosity is too large for ion rejection; the UF process is used to reduce contaminants, such as oil and grease, and suspended solids. Due to the concentrate stream continuously removing contaminants; these pressure-driven membrane technologies requires only occasional backwashing and cleaning ([29]).

RO membranes are designed for removal of dissolved solids with high efficiency, but adversely affected or fouled by suspended solids, colloidal material or scale. Common examples of such foul-ants are calcium precipitates, metal oxides, colloidal silica and various organics. Industrial side-stream wastewater typically contains most, if not all, of these fouling substances. Once fouled, limited by its membrane material properties, only mild cleaning chemicals such as citric acid and detergent can be used to restore the flux. Stronger or more effective cleaning chemicals such as sulphuric acid, hydrochloric acid, bleach, and peroxide cannot be applied as they will cause irreversible damages to the RO membranes. Appropriate pre-treatment must be provided to achieve stable performance of RO membranes.

Attention has recently been given to municipal wastewater treatment plant effluents as a source of industrial and agricultural reuse water throughout the world. Several recent publications have portrayed the use of membrane technologies on secondary and tertiary effluents as relatively recent occurrences. However, facilities have been utilizing such membranes on wastewater streams for many years. One of the pioneering sites to use reverse osmosis (RO) technology for effluent reuse in power production witnessed enviable operational experiences and membrane life expectancies ([30]).

In operation for over eight years, the facility utilized the secondary effluent from a municipal treatment facility as the sole source of feed water to a 49 Megawatt natural gas power turbine facility in Lodi, Calif. As evidenced by this project's success and by the successes of subsequent effluent-fed power facilities; effluent reuse has become a significant advantage in

locating new power production facilities. The power companies that have embraced the reuse of treated municipal waste water have been welcomed more openly in the pursuit of regional approvals and received more political endorsements of projects ([30]).

EPRI is collaborating with Sandia National Laboratories and WEN Engineering to evaluate the feasibility of integrating membrane distillation water treatment technology with cooling tower systems for unconventional types of water treatment systems that could serve as alternatives to freshwater for makeup water. Membrane distillation (MD) technology uses latent energy from waste heat to drive a membrane separation process that removes salts and other total dissolved solids from an unconventional water type such as brackish groundwater or seawater. By using waste heat sources at a power plant, MD could desalinate water without added energy costs, representing a new low-cost method to treat brackish groundwater for makeup water. The technology may also represent an innovation that allows many power plants in semi-arid areas to maintain full utilization of wet-cooling systems by using alternative sources of water ([31]). Membrane distillation technology cuts energy costs by using latent energy from waste heat to drive a membrane separation process that removes salts and other total dissolved solids (TDS) from an unconventional water type such as brackish groundwater or seawater.

Research still continues on this technology to assess the economic feasibility of integrating MD water treatment technology into wet cooling tower technology. Economic analysis will also evaluate a combined wet cooling plus MD system versus a dry cooling system.

2.5.5 Pinch Analysis Technology

Pinch analysis is a process integration tool which was initially used for heat and mass transfer analogies ([32]). The technique involves the conservation of energy through optimisation of heat exchanger networks. A similar approach is now applied to the design of water-using systems that conform to the usage of patterns described in the Water Research Council (WRC) report (851/1/03). The pinch concept encompasses waste minimisation and pollution prevention by developing mass exchanger

networks (MEN) which minimum flow networks minimise the amount of fresh water intake and wastewater produced ([32]).

A method of optimal Mass Exchanger Networks (MEN) can be described as a mass exchanger with any direct-contact mass transfer unit that employs a lean phase namely Mass Separating Agent (MSA), to selectively remove certain components from the rich phase ([32]). The mass exchange processes includes processes such as liquid-liquid extraction, liquid-gas absorption (scrubbing), liquid-solid absorption, ion-exchange, leaching and stripping. Process integration currently provides a reliable methodology for resource conservation, sustainable design and process optimization.

A key tool for process integration is pinch analysis which has been applied to heat exchanger networks, mass exchanger networks, water networks, hydrogen networks, carbon-constrained energy sector planning, as well as Carbon Capture and Storage (CCS). An experimental study was conducted whereby the pinch analysis approach was extended to target and design Cooling Water Networks (CWNs). Although pinch analysis techniques have been extensively used for heat exchanger networks and water networks; CWNs and their energy implications due to interactions with cooling towers have received relatively little attention. The key research work in cooling water system design was done by ([33]) which focused on the system as a whole from a process systems engineering viewpoint. The objective of this work is to develop a straightforward wholly-analytical methodology to target and design CWNs. The minimum CW flow target for maximum-reuse CWNs that maximize cooling tower performance is simply determined without any graphical constructions by using the Unified Targeting Algorithm (UTA) ([33]).

Multiple networks are then synthesized, all satisfying the target, through elegant application of the Enhanced Nearest Neighbors Algorithm (NNA). Unlike the water main method, the Enhanced NNA can importantly be applied directly to problems without a pinch as it was demonstrated in the experiment. Another major advantage is that the UTA and NNA can both be fruitfully utilized as a unified methodology for diverse process integration problems. Specifically, the NNA has been extensively used for synthesis of various networks including water networks, hydrogen networks, carbon emission networks and material reuse networks for resource conservation.

The Enhanced NNA was originally proposed by Shenoy ([34]) for fixed contaminant-load water networks. It has been extended here to CWNs, which are fixed heat load networks. The key feature of the Enhanced NNA is the priority to Local Recycle (LR) matches for fixed load operations. By attempting to choose the cleanest available source (rather than the nearest neighbor) as the neighbor source for the LR match, the amount of the cleanest source is minimized and the amount of the LR match is simultaneously maximized. Since this maximized LR match is subsequently eliminated for a fixed load operation, there is a decrease in the number of matches and the CW flow-through rate through the cooler (and consequently the network cost).

Chapter 3

3. Experimental Data Analysis

Kriel Power Station generates effluent of about 5 ML per day from different effluent streams of the water pre-treatment plant. A need has been identified at the power station to recover most of this effluent; treat and re-use it within the main cooling water (CW) system. In order to address the need of the project, samples from different effluent sources have been taken for analysis to determine their chemistry content and compare it to CW chemistry requirements.

The sample results will then assist in making a decision on which alternative will be best suitable to achieve an objective of the proposed idea by comparing them with the required chemistry specifications of the CW system.

3.1. Experimental Method

Effluent samples were taken from Kriel power station from different effluent sources generated from the water treatment plant (WTP) processes where different chemical compositions occur, as elaborated in Chapter 2. The samples were then taken to the research, technology and development centre (RT&D) for analysis. The facility consists of various water laboratories namely:

- Preparation laboratory whereby samples were prepared and separated according to their priority and to be allocated to different laboratories. Samples were preserved by filtering to remove suspended solids, then 1 mL of concentrated Nitric acid was added to 250 mL of that particular sample. As for high alkaline samples, the volume of Nitric acid was increased until a pH of less than 2 was achieved.

Basic analysis such as pH, turbidity and total dissolved solids (TDS) were measured at this laboratory.

- Gas Chromatography (GC) laboratory where analysis for total organic carbon (TOC) and dissolved organic carbon (DOC) were conducted. The analysis instrument called GC-MS, model: 7890A-5895C MSD was manufactured by Agilent Technologies, supplied by Chemetrix; separates and analyses compounds that can be vaporized without decomposition.
- Ion Chromatography (IC) laboratory that specialises in anion analysis. Ion chromatograph instrument system used was called Dionex ICS-1500 that operates on Chrome Leon software. Dionex ICS-1500 was sold and distributed under Thermo –Scientific brand. It is manufactured from Dionex Corporation 1228 Titany Way, Sunnyvale, California 94088-3603.
The analysis instrument allowed the separation of ions and polar molecules based on their affinity to the ion exchanger. The laboratory is also called the “clean laboratory” as the IC machine is very sensitive to chlorine cleaning agents and dust particles.
- Inductively Coupled Plasma laboratory uses Optical emission spectroscopy (ICP-OES) instrument; model Spectro Arcos FHE16, serial number 09007507 from New Germany for cation analysis. It is a type of spectroscopy that uses plasma to excite atoms or ions to emit electromagnetic radiation at wavelengths characteristic of a particular element. The intensity of the emission is an indication of the concentration of a particular element within the sample
- Microbiology laboratory where the presence of microscopic organisms in water such as bacteria, fungi, legionella and algae are determined by filtering a specific amount of water through a 0.45 µm membrane which traps the bacteria in the water and put in a plate containing nutrient which will support the growth then incubate for 24 hrs. The specific volume of water depends on the turbidity of the sample.

To check for the effectiveness of any chemical dosed, a total plate count was conducted whereby 1ml of the sample and do a pour plate method and incubate for 48hrs. The total plate count test was for any microorganisms that were present in water, it was not microbe specific whilst the filtration method was microbe specific, and this laboratory recommends on which chemicals to best control the growth of these organisms.

All effluent samples were analysed and certified according to South African National Accreditation System (SANAS) standards (see Appendices). Sometimes the samples are filtered to get rid of particles that can cause blockages on analysis machines prior to commencement of analysis. The experiments discussed in this chapter were done on an IC and ICP on effluent analysis.

The total hardness shown in the analysis is expressed as:

- Total hardness = Calcium Hardness + Magnesium Hardness, expressed as CaCO_3 in mg/L (milligram per litre).

Alkalinity of water is the capacity to neutralize acid to a specific endpoint. Total alkalinity or methyl orange alkalinity end point is pH 4.5 while phenolphthalein alkalinity endpoint is at pH 8.3. ([35]). Total Alkalinity as CaCO_3 from the samples represents “M” alkalinity which is a measure of the amount of acid it takes to drop the pH to approximately 4.3 to remove hardness.

For liquids such as water, mg/L = ppm (parts per million)

1 L of water weighs 1 kg or 1000 g,

$$1 \text{ mg} = \frac{1}{1\,000\,000} \text{ of a kg, } \therefore 1 \text{ mg/L} = 1 \text{ mg/kg} = 1 \text{ mg/million mg} = \text{ppm}$$

and mg/L = ppm

3.1.1 Ion Chromatography (IC) schematics

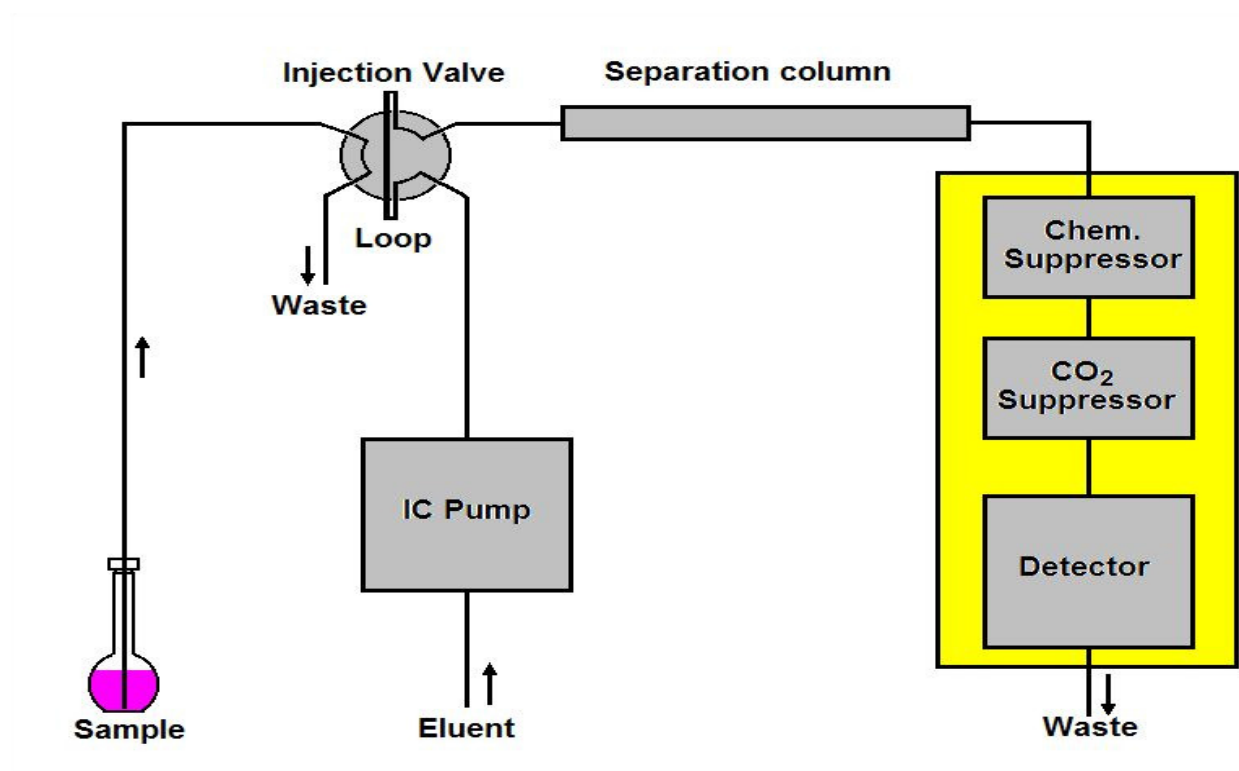


Figure 3-1 Schematic flow diagram of ion chromatography analysis ([29]).

A water sample was injected into a stream of carbonate-bicarbonate eluent or carrier and passed through a series of ion exchangers. The anions of interest were separated on the basis of their relative affinities for a low capacity, strongly basic anion exchanger (guard and separator column). The separated anions were directed onto a strongly acidic cation exchanger (suppressor column) where they were converted to their highly conductive acid form and the carbonate-bicarbonate eluent was converted to a weakly conductive carbonic acid.

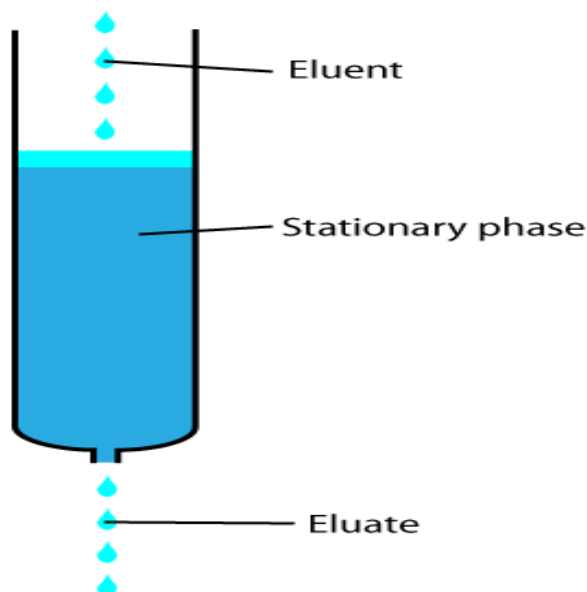


Figure 3-2: Illustration of how an eluent transports the sample to be analysed.

The illustration (Figure 3.2) indicates elution process of extracting one material from another by washing with a solvent; washing of loaded ion-exchange resins to remove captured ions. The separated anions in their acid form are measured by conductivity and are identified on the basis of retention time as compared to standards. Quantitation was measured by the peak area or peak height.

Ion Chromatography uses an instrument called Dionex (ICS-1500) supplied by Metrohm for analysis. Since the IC's purpose is to detect anions within the water sample; these are the elements that are normally present within the type of water that Kriel and other power stations have and include **species such as Cl_2 (chloride), F^- (fluoride), NO^- (nitric oxide), NO_2^- (nitrite), Br^- (bromine) and SO_4^{2-} (sulphates).** Samples were analysed into two categories namely;

- low range samples which were those detected in parts per billion (ppb) with values of 5 to 100 ppb,
- and high range samples which were detected in parts per million (ppm) with values up to 100 ppm and thus were normally the highly concentrated samples.



Figure 3-3 Photograph showing the IC standards and QC samples that were prepared (left) and IC analyser pump drawing a sample from the holder into the instrument (right).

1) General

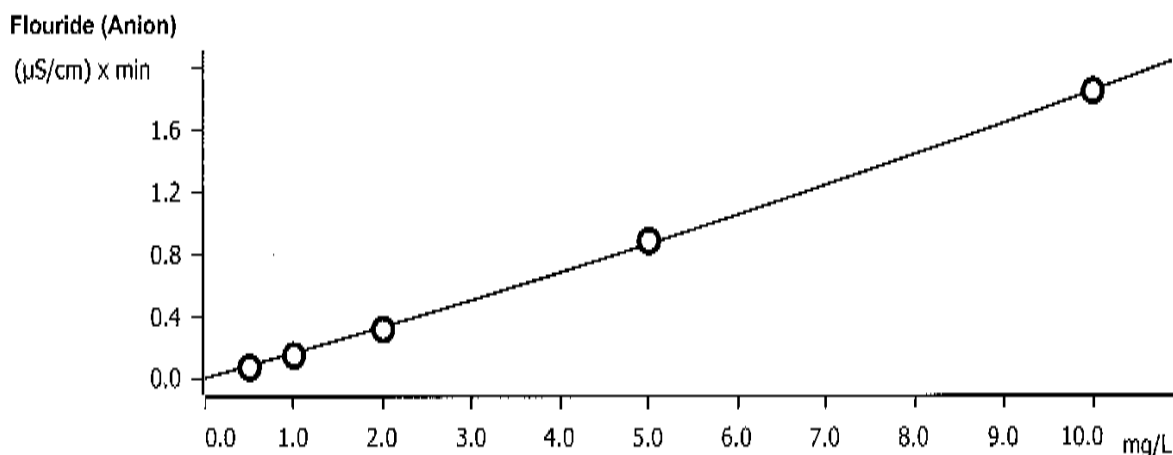
The IC analysis instrument consists of a suppressor that suppresses the conductivity of anions so that the ones intended can be detected for analysis. If there was no suppression; it will not be possible to detect these anions as they will be on the same conductivity range as the cations- this is how cations are differentiated from anions on the IC analyser. In all these samples, the pH was irrelevant.

2) Ion Chromatography Analysis

- Salts were prepared for standard samples prior to analysis of the real sample. Standards are those samples that have a solution with a known concentration of an analyte.
- Anion standard solution of concentration 1000 mg/L was prepared from anion salts. The required amount of salt which had been oven dried to a constant weight at $105^{\circ}\text{C} \pm 5^{\circ}\text{C}$ is weighed and dissolved in 1000 mL of ultrapure water. The salts used for the preparation of the standards must be of the best quality i.e.

Guaranteed Reagent (GR Grade) or Analytical Reagent (AR Grade).

- Standards were run first on the analysis instrument to create a calibration curve. The curve has to be a straight line graph with 99.9% coefficient of detection, which indicates the level of accuracy (see Figure 3.3).



Function: $A = 0.0159097 \times Q + 2.48949 \times 10^{-5} \times Q^2$
 Relative standard deviation 3.064829 %
 Correlation coefficient 0.999728

Sample type	Index	Conc.	Volume	Dilution	Sample amount	Area	Ident
Standard 1	1	0.500	10.0	1.0	1.0	0.067002	Standard 1
Standard 2	1	1.000	10.0	1.0	1.0	0.143336	Standard 2
Standard 4	1	2.000	10.0	1.0	1.0	0.311662	Standard 4
Standard 10	1	5.000	10.0	1.0	1.0	0.877346	Standard 10
Standard 20	1	10.000	10.0	1.0	1.0	1.835885	Standard 20

Figure 3-4 A standard graph detected after standards have been run

A quality control (QC) sample was also prepared following standard samples; however a QC was prepared from the same salts as the standards but from different supplier to detect if the same readings could be obtained which will prove accuracy.

- During the analysis, high affinity anions of the sample were detected first and the retention time was noted. The retention time is the time taken for the detector to pick up the concentration of a sample. The retention time might differ but a guiding time is stipulated by the supplier of the IC machine. On the analysis graph there were different peaks, some with smaller and others with wider areas which are an interpretation of low to high concentrations respectively (see Figure 3.4).
- If the curve was way out of the standard curve- with high concentrations; a sample was then diluted in order to get the true reflection of the presence of contaminants in water. The sample was diluted with demineralized water which was highly pure and would not have affected the sample at all.
- The sample concentration after dilution should never exceed the standard sample;
10 times dilution= 10 ml of demineralised water.
The sample anion analyte concentration after dilution should never exceed the highest analyte standard ;10 times dilution is done by adding 10 mL of concentrated sample into 100 mL flask and dilute with ultrapure water up to the mark.
- If the concentration of the sample was not within the standard range, then a re-dilution was done as the sample might be too concentrated, provided the QC was proven right.
- After every 10th sample analysis a QC sample was also run to confirm accuracy.
- There were times when the anion peaks appeared on the analysis graph at the same retention time and it became impossible to differentiate between anions. In such a case a sample was spiked; meaning a side sample was prepared as an analyte of a known concentration higher than the one intended and then added to the previous sample analysed in one bottle.

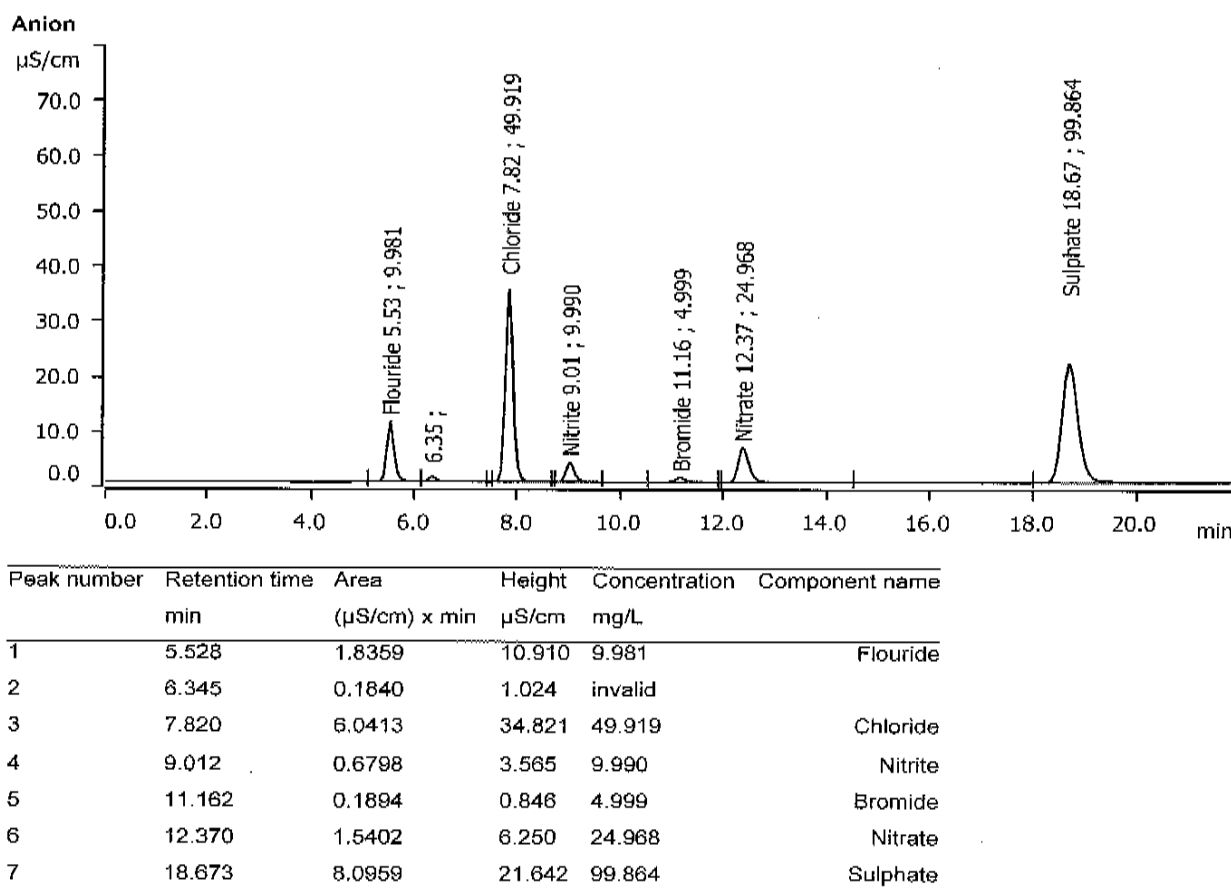


Figure 3-5 Retention time versus sample concentration graph

Figure 3.4 indicates that chloride had the highest concentration of 49 mg/L on this particular water sample, though its retention time was 7 minutes, still detected faster than nitrite, bromide, nitrate and sulphate.

3.1.2 Inductively Coupled Plasma (ICP) basis of method

The ICP technique is based upon the spontaneous emission of photons from atoms and ions that have been excited in a RF discharge. Liquid and gas samples may be injected directly into the instrument, while solid samples require extraction or acid digestion so that the analytes will be present in a solution. The sample solution is converted to an aerosol and directed into the central channel of the plasma ([36]).

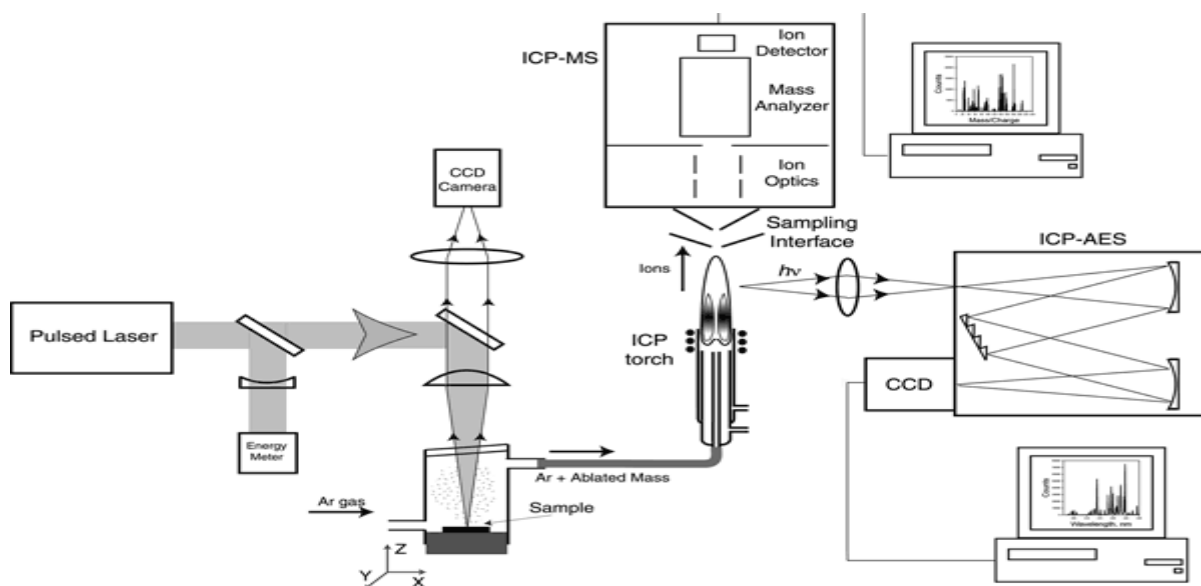


Figure 3-6 Schematic flow diagram of Inductively Coupled Plasma analysis ([37]).

At its core the inductively coupled plasma (ICP) sustains a temperature of approximately 839°C, so the aerosol is quickly vaporized. Analyte elements are liberated as free atoms in the gaseous state. Further collisional excitation within the plasma imparts additional energy to the atoms, promoting them to excited states. Sufficient energy is often available to convert the atoms to ions and subsequently promote the ions to excited states. The total number of photons is directly proportional to the concentration of the originating element in the sample.

The instrument consists of three main components namely:

1. The sample introduction system- which is made up of the pump (delivers the sample to the nebuliser from the sample vial), the nebuliser (the sample combines with argon to form an aerosol) and a spray chamber (separation of the sample, smaller droplets go to the plasma and bigger ones to the drain).
2. Plasma where excitation of ions occur.
3. Spectrometer (used to isolate light from the various wavelengths corresponding to the various emission lines)

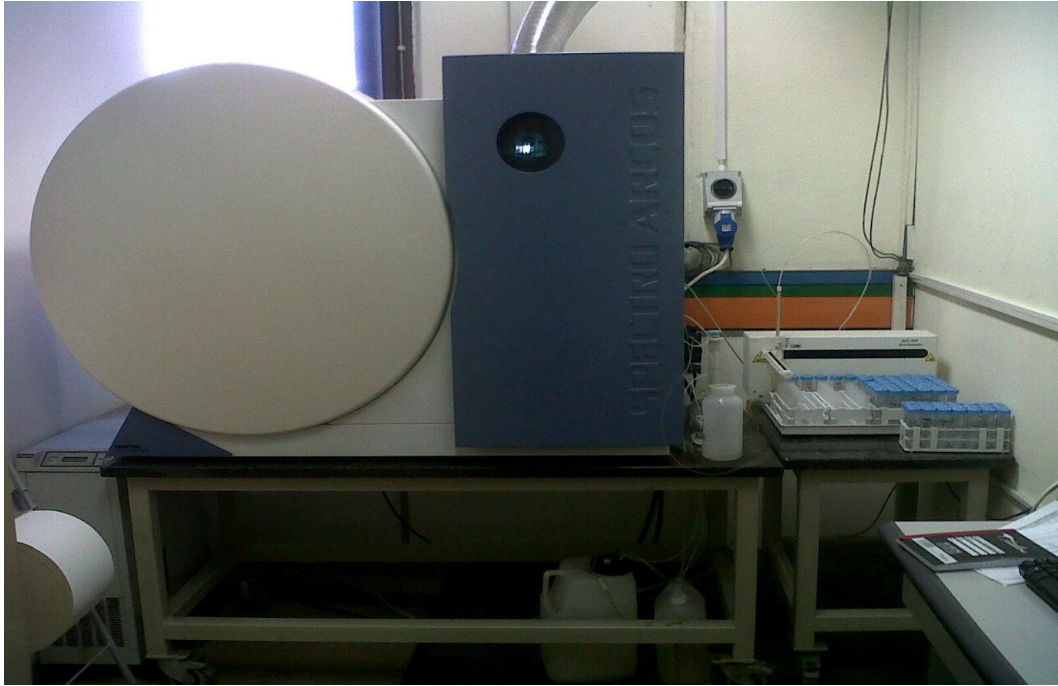


Figure 3-7 ICP analyser at Eskom R&D, Rosherville.

There are different types of ICP methods:

- Lights method: a method used to analyse for Na, Mg, K and Ca.
- Set 1b method which detects Al, Ba, Be, B, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sr, Zn and
- Method 417 for V, Mo, Si, Sn and Sb.

The following cations were the ones analysed within the effluent water: **sodium (Na), magnesium (Mg), potassium (K) and calcium (Ca)**. Unlike with the IC, with cation analysis; all samples needs to be at $\text{pH} < 2$ to ensure that all elements remain in solution to prevent the ions from adsorbing to the sample container.



Figure 3-8 Samples lined up for ICP analysis at R&D- Rosherville.

1) General

The QC and calibration standards must be from different suppliers to ensure validity of the results. Sometimes the sample analysis results become out of range from standards, and then the sample is diluted with a calculated amount of demineralised water as stipulated by solutions guidelines. Dilution is not always recommended as it involves human errors with measurements.

2) Inductively Coupled Plasma Analysis:

- Working standards were prepared from a 1000ppm stock solution.
- Only the “lights” methods were done for analysis.
- All working standards last up to a year.
- Nitric acid was used to preserve the samples and standards
- The instrument was flushed with argon each time before the plasma was ignited.
- The plasma was then ignited and the system was left for 30 minutes to warm up.

➤ **Lights method preparations:**

- In this method; 1 blank, 4 calibration standard samples and 1 QC were used respectively. A blank was prepared with pure demineralized water and nitric acid.
- The calibration range for the lights method was 0-60ppm for Na, Mg and Ca and 0-20ppm for K.
- It took 3 minutes for the instrument to analyse each sample, in one analysis the sample was read 3 times and an average of the 3 readings was taken.
- Method validation was done for each method to determine the best parameters to be used to analyse the different elements e.g. the wavelengths, measure conditions, etc.

➤ **Preparations for standard samples for light method:**

- For the blank sample, 4ml of nitric acid (HNO₃) was added to a 1000ml of UHP water and stored in a High Density Polyethylene (HDPE) bottle.
- All the standards were prepared by pipetting the required volume of the 1000mg/L of each element into a 1000ml volumetric flask, 4ml HNO₃ was added and made up in deionised water and stored in HDPE bottles with a shelf life of 12 months.

Table 3.1: Different standards prepared for cations for calibration

Element	STD 1 mg/l	STD 2 mg/l	STD 3 mg/l	STD 4 mg/l
Ca	10	20	40	60
K	2	5	10	20
Mg	10	20	40	60
Na	10	20	40	60

➤ **Preparations for quality control (QC) standard: lights method**

- QC: The quality control was prepared by pipetting the required volume of the 1000mg/L of each element into a 1000ml volumetric flask, 4ml HNO₃ was added and made up in deionized water and stored in HDPE (High Density Polyethylene) bottles with a shelf life of 12 months.

Table 3.2: Quality control preparation of cation samples

Element	(QC) mg/l
Ca	25
K	5.0
Mg	25
Na	25

Chapter 4

4. Results and Discussions

A total of 9 effluent samples from different effluent streams of the water pre-treatment plant were analysed with Ion Chromatography (IC) and Inductively Coupled Plasma (ICP) instruments respectively as discussed in chapter 3. In this chapter; the results of these analyses and how the chemistry of these samples compares to the chemistry specifications of the cooling water (CW) at Kriel Power Station is discussed. The CW system has been chosen as a destination solution for recovery and treatment of effluent water generated from different sources of water treatment processes.

The CW system is regarded as the best option to recover effluent water from, because there is more chemical control in terms of operation and it is the system that uses most water in the station (see figure 4.1).

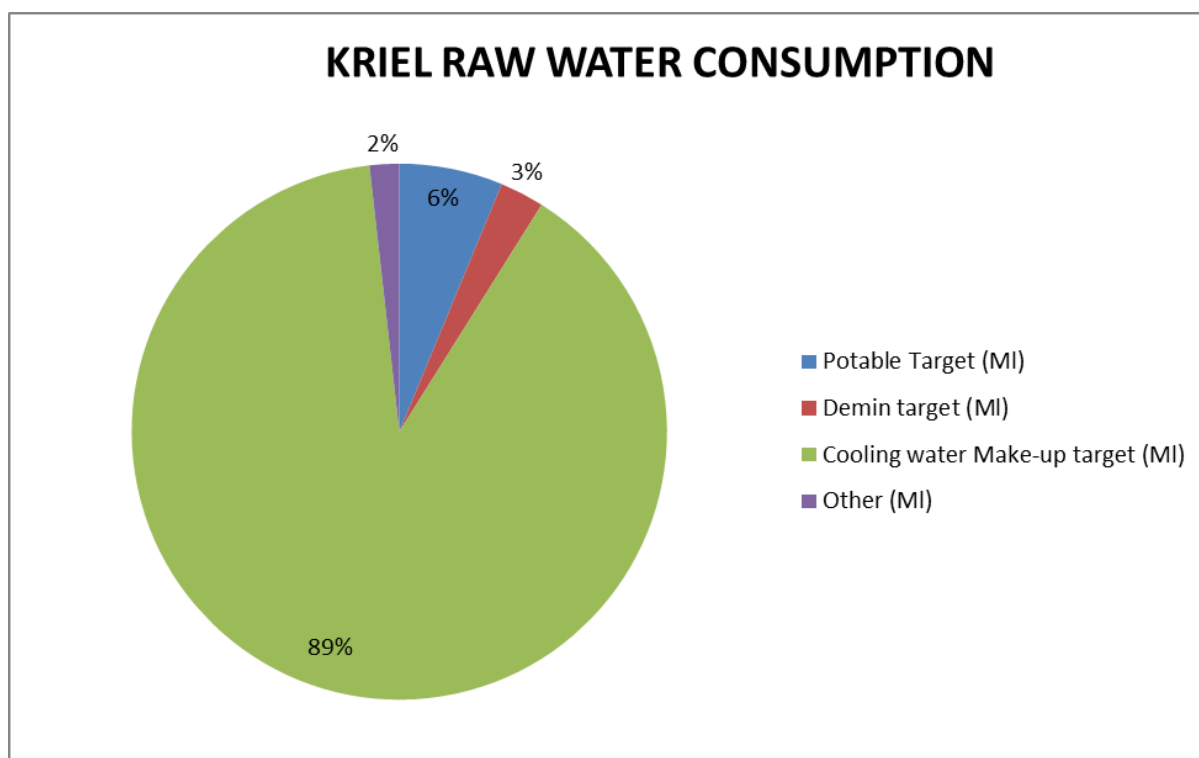


Figure 4-1 Kriel Power Station water consumption average January to November 2014 ([30]).

The power station is a business unit which generates and sells electrical power and its viability highly depends on costs. Effluent recovery into the CW system is also dependent on the techno-economic viability of the process. Comparisons were done to other water streams within the power station which are demineralised and potable water respectively in relation to capital and operational expenditure to motivate the effluent recovery into the CW.

By recovering and re-using effluent water; fresh raw water intake will be reduced at Kriel power station, which will save money for the business and improve compliance to the Zero Liquid Effluent Discharge (ZLED) policy. ZLED is defined as no liquid discharge into the environment. So often zero discharge and zero liquid discharge are used in the same meaning. Practically, the concept of zero discharge means:

- 1) Recovery of reusable water or other materials from waste water;
- 2) Minimisation or, no discharge of polluting substances into the environment from the water treatment plant;

These two points mean the processes utilized for waste water treatment does not generate any additional pollutants, and production of waste is minimized by suitable selection of unit processes and adjusting operating parameters. As far as possible; the pollutants in the wastewater are transferred into solid phase i.e. sludge is stored in a secured landfill; and the recovery of reusable materials, especially water is achieved ([5]).

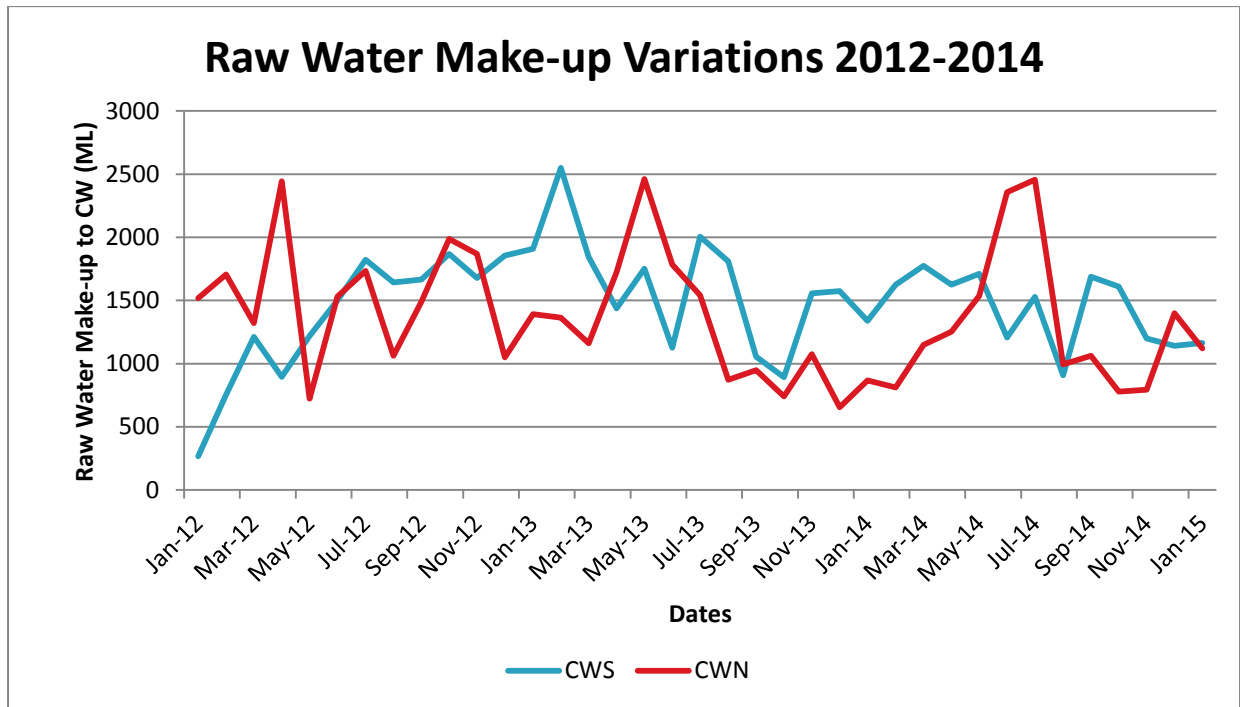


Figure 4-2 Kriel Power Station CW raw water make up average January 2012 to November 2014 ([30]).

Currently the Department of Water Affairs (DWA) sells raw water for R8000 per mega litre (ML), and on average Kriel used 1800 and 2400 ML for both winter and summer months respectively on raw water make up in the CW system (Figure 4.2). The clean water dam effluent recovery into the CW system project was conducted concurrently to the effluent treatment and re-use project. The clean water dam called Vaalpan; is not a man-made, but rather a natural impoundment with natural inhabitants such as fish and other water animals. The source of the water to the dam is from all station drains, and during rainy seasons the dam has a tendency of overflowing which then affects the wetlands around it and raises environmental concerns because not all water from station drains is considered clean water; though it was meant for clean water. Another disadvantage is that it sometimes contains impurities such as ash, oil, coal fines etc. The clean water dam effluent was initially recovered directly to the cooling towers where hot CW is being cooled with the natural draught and then recirculated to the condenser and other cooling auxiliaries. An immediate decrease on the fresh water make up intake was noticed (Figure 4.3), but the system experienced major chemistry upsets as a consequence of this recovery.

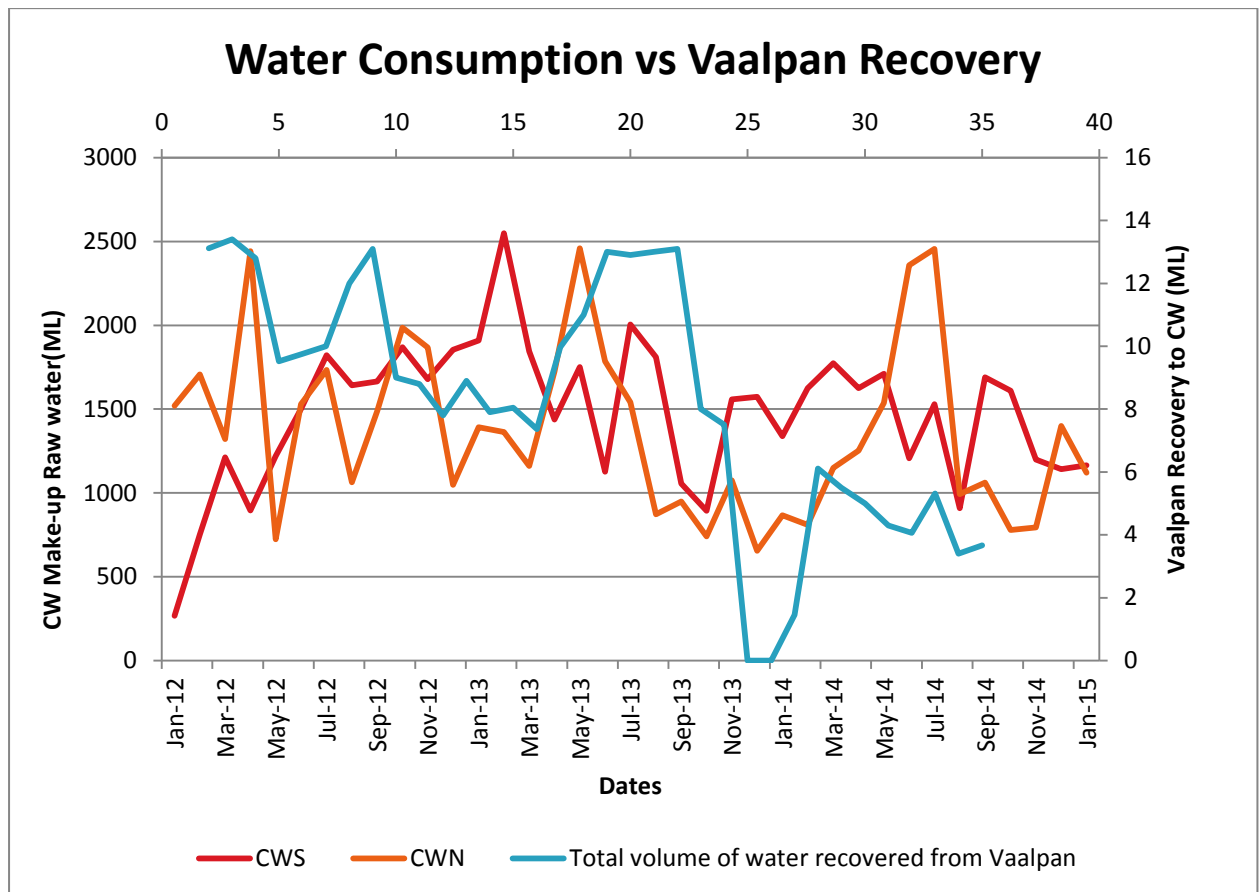


Figure 4.3: Kriel Power Station CW Vaalpan water recovery into the CW system, January 2012 to January 2015 ([38]).

The decision was changed to direct the dam effluent recovery to the CW clarification plant whereby hot lime softening is used in conjunction with chemicals for coagulation, flocculation and sedimentation prior to the CW being circulated back between the condenser and the cooling towers. The process is referred to as “hot lime softening” because it is the treatment of the water in the hot CW duct.

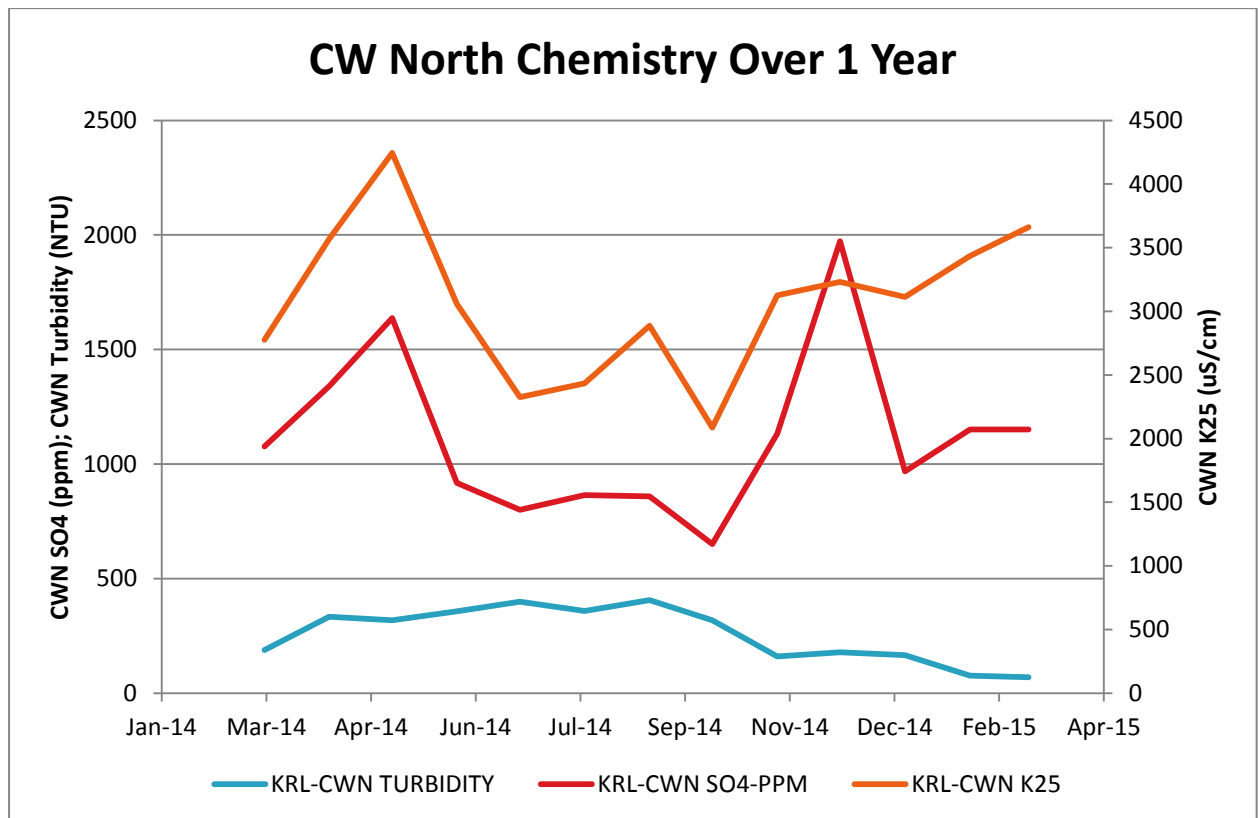


Figure 4-3 CW north side chemistry from January 2014 to February 2015 ([31] [32])

There has been a significant improvement in CW chemistry and specifications requirements were met while decreasing the fresh water intake into the CW system from June 2014 (Figure 4.3). It was noted that the sulphates and conductivity were a challenge especially in November 2014. This project served as one of the reasons that support the recovery of effluent streams generated from water treatment processes that had been sampled, analysed and which will be discussed in this chapter to compare their chemistry to the CW chemistry to avoid chemical excursions that were experienced through the “clean dam effluent recovery” project. A further benefit will be a cost one for a reduction on fresh water intake and conformance to environment according to ZLED policy.

The initial priority on specifications became the cooling water clarifier inlet from the circuit (Table 4.1) and then the clarifier outlet (Table 4.2), as the effluent inlet (Table 4.3) should not be out of specification more than the cooling water in the circuit which is sent to clarifiers for treatment. The compatibility analysis is crucial to allow a higher number of cycles of

concentration (COC) to be achieved, which results in a lower volume of blow down production. These specifications were used to compare the experimental values obtained as shown in Tables 4.4 to 4.12.

Table 4.1: Cooling Water specifications for the main circuit [39]

Parameters measured	Cooling Water Target Values
pH	8.1 – 8.6
Turbidity	< 100 NTU
M-alkalinity	80 – 120 mg/kg (as CaCO ₃)
P-alkalinity	< 7.5 mg/kg (as CaCO ₃)
Conductivity	< 4000 µS/cm
Total Hardness	< 400 mg/kg (as CaCO ₃)
Calcium hardness	200 – 500 mg/kg (as CaCO ₃)
Silica	< 150 mg/kg (as SiO ₂)
Calcium Carbonate Precipitation Potential (CCPP)	10 – 30 mg/kg (as CaCO ₃)
Sludge Percentage	5 – 16%

Table 4.2: Cooling Water Clarifier outlet operating specifications [39].

Parameters measured	Clarifier Outlet Target Values
pH	9.9 – 10.2
Turbidity	< 5 NTU
M-alkalinity	< 50 mg/kg (as CaCO ₃)
Sludge Percentage	5 – 16%

Table 4.3: Waste water recovery into the Cooling Water [39]

Parameters measured	Target Values
Conductivity	< main circuit CW conductivity
Oil	< 5 mg/kg
Chloride (Cl)	< 400 mg/kg (as Cl)
Sulphate (SO ₄)	< 1000 ppm
Calcium (Ca)	< 500 mg/kg(as CaCO ₃)
Magnesium (Mg)	< 150 mg/kg as CaCO ₃)

4.1. Interpretation of parameters

A thorough explanation of these parameters and their impact on the power station life cycle has been provided in chapter 2 (Literature review). All analysed samples were expressed in the units of mg/L except for pH which was considered dimensionless since it was expressed by an activity of a proton H⁺; when the concentrations of the protons and hydroxide ions are equal, the logarithm of the molar hydrogen ion concentration yields a value of 7. A pH of 7 therefore indicates water which is neither acidic nor alkaline and is portrayed as having a neutral pH. In practice, few waters have a pH of exactly 7 ([35]).

Turbidity was expressed in Nephelometric Turbidity Units (NTU) which meant the amount of suspended solids present in water and was evident in appearance with natural eye.

Conductivity was temperature dependent; and in metals, conductivity decreases with temperature and in non-conductors it increases with temperature. In water, electrical current flow increases with temperature and conductivity meters are normally equipped to automatically correct values to 25 degrees Celsius (°C) giving the specific electrical conductivity ([35]).

It should be noted that for pure water, the density is 1 kg/L (kilogram per litre);

∴ mg/kg (milligram per kilogram) of water = mg/L.

The two main cations that cause water hardness are calcium (Ca) and magnesium (Mg). Calcium is dissolved in water as it passes over and through limestone deposits. Magnesium is dissolved as water passes over and through dolomite and other magnesium bearing formations. Although there are other mineral cations that can lead water hardness, these two are the most dominant. The hot lime softening process used at Kriel power station is considered to be more effective than cold lime softening because the solubility of calcium and magnesium are reduced with increased temperatures.

4.1.1 Condensate Polishing Plant (CPP) cation rinse sample

The sample shown in Table 4.4 indicates the conductivity of 9 $\mu\text{S}/\text{cm}$ which was extremely low, when compared to the CW standard of less than 4000 $\mu\text{S}/\text{cm}$ conductivity, which means there was a low amount of dissolved solids present.

Table 4.4: Analyses results of the Condensate Polishing Plant cation rinse sample

Component	Unit	Value
Total Alkalinity as CaCO_3	mg/L	1.9
Conductivity	$\mu\text{S}/\text{cm}$	9
pH at 25°C		6.17
Sulphates as SO_4	mg/L	3.51
Chloride (Cl)	mg/L	0.04
Calcium (Ca) as CaCO_3	mg/L	0.01
Magnesium (Mg) as CaCO_3	mg/L	0.02
Total Hardness as CaCO_3	mg/L	0.03
Turbidity	NTU	1.03

The sulphates on this sample were at 3.51 mg/L which were very low when compared to the effluent recovery specification into the CW which refers to

less than 1000 ppm; sulphates are specified for the prolonged protection of the concrete structures such as clarifiers and cooling towers. At Kriel power station, these concrete structures are classified under “weak concrete” and can only bear sulphates less than 1000 mg/L.

Chlorides were detected to be 0.04 mg/L and the specification tolerance on chlorides is less than 400 mg/kg for effluent recovery into the CW for the concrete long term plant health. The standard mentions that if chlorides are not managed within these specifications, they attack the metal reinforcement on these concrete structures. Calcium and magnesium as CaCO_3 were both detected to be 0.01 and 0.02 mg/L respectively; which were extremely low when compared to the effluent recovery specification requirements into the CW of less than 500 mg/L and 150 mg/L respectively. Both these parameters form total hardness of water which encourages scaling on piping when softening processes are not effective.

The turbidity value was 1.03 NTU which was extremely low when compared to the CW clarifier outlet maximum of less than 15 NTU. Turbidity occurs as a result of suspended matter in water and is mainly treated by coagulation during the process of clarification whereby the matter will settle at the bottom of the clarifier. In this case only a small amount of coagulant will be required to treat this effluent as the turbidity value is fairly low compared to the specification.

The pH was 6.17 at 25°C; which was slightly below the neutral mark of 7. Should more volumes of this sample be recovered into the CW, a significant amount of lime on the clarification process would be required to raise the pH to a range of 9.9 – 10.2 as required by the specifications. Total alkalinity as CaCO_3 was 1.9 mg/L at pH 6.17 which was far lower than 50 mg/L for clarifier outlet CW chemistry standard requirement as stated in table 4.2, indicating that the water softening process would be faster as the water hardness is at minimal.

4.1.2 Demineralised (Demin) Water Plant cation backwash sample

The total alkalinity of the sample shown in Table 4.5 was extremely low at a value of less than 0.343 mg/L as CaCO_3 when compared to other effluent samples; the clarifier outlet into the CW circuit requires alkalinity of less than 50 mg/L. The calcium hardness value was 0.35 mg/L which was far lower than the specification of effluent recovery of less than 500 mg/L as

CaCO₃ and magnesium hardness was 0.25 mg/L which was also far lower than the specification of less than 150 mg/L as CaCO₃.

Table 4.5: Analyses results of the Demin Water Plant cation backwash sample.

Component	Unit	Value
Total Alkalinity as CaCO ₃	mg/L	<0.343
Conductivity	µS/cm	35
pH at 25°C		4.36
Sulphates as SO ₄	mg/L	12.56
Chloride (Cl)	mg/L	0.59
Calcium (Ca) as CaCO ₃	mg/L	0.35
Magnesium (Mg) as CaCO ₃	mg/L	0.25
Total Hardness as CaCO ₃	mg/L	0.60
Turbidity	NTU	3.33

The total hardness was detected to be 0.60 mg/L which was lower than the CW circuit specification of less than 400 mg/L as CaCO₃. Total hardness and alkalinity parameters are inter-related; the limits specified must be viewed in conjunction with one another and both are removed effectively through lime softening clarification process which is currently on the CW treatment. On such low values; the softening process will be faster when compared to effluent treatment with high alkalinity and high hardness values.

The conductivity parameter was 35 µS/cm and was lower than the specification of less than 4000 µS/cm on CW circuit turbidity; meaning the water contained a fairly low amount of dissolved solids. Conductivity is grouped with alkalinity and hardness in terms of lime softening process, for hardness removal. Chlorides were detected to be 0.59 mg/L and the specification on chlorides is less than 400 mg/kg while sulphates were 12.56 mg/L in comparison with CW requirements of less than 1000 ppm for effluent recovery into the CW; for concrete tolerance. Turbidity value was

detected as 3.33 NTU which was lower than 15 NTU maximum specifications on CW clarifier outlet. The water had minimal suspended solids which meant the coagulation process would be faster within the clarifier.

The pH was very acidic at a value of 4.36 which was expected as the effluent was taken after the backwash of the H^+ resin which was regenerated with sulphuric acid previously. More lime dosing would be required on this effluent water recovery into the CW system to raise the pH to the required specifications of 9.9 to 10.2 CW clarifier outlet. At these pH ranges, the hardness parameters i.e. calcium and magnesium precipitate out which they should settle in the clarifiers instead of settling in the main circuit system on ducts and piping to form scaling.

4.1.3 Pre-treatment Plant sand filter backwash sample

In the sand filter backwash sample; a total alkalinity of 28.9 mg/L as $CaCO_3$ was observed which was less than the clarifier specification of 50 mg/L. Alkalinity is one of the elements determining the rate of softening process and in this case it would be faster as it was lower than the specification.

Table 4.6: Analyses results of the pre-treatment sand filter backwash sample.

Component	Unit	Value
Total Alkalinity as $CaCO_3$	mg/L	28.9
Conductivity	$\mu S/cm$	88
pH at 25°C		7.16
Sulphates as SO_4	mg/L	9.37
Chloride (Cl)	mg/L	7.68
Calcium (Ca) as $CaCO_3$	mg/L	14.24
Magnesium (Mg) as $CaCO_3$	mg/L	9.88
Total Hardness as $CaCO_3$	mg/L	24.12
Turbidity	NTU	41.7

Conductivity was 88 $\mu S/cm$ which was lower when compared to the CW circuit standard of less than 4000 $\mu S/cm$; indicating a minimal amount of

dissolved solids for this sample. The pH was at 7.16 when compared to the standard requirements of pH 9.9 to 10.1 CW clarifier outlet range and the moderate dose of lime softening process would assist to elevate the pH to required values as the water was very neutral as potable ranges.

The sulphates on this sample were at 9.37 mg/L which were very low when compared to the effluent recovery specification into the CW which refers to less than 1000 mg/L; the recovery of the sample shall not impact on concrete structures. The chlorides were detected to be 7.68 mg/L and the specification tolerance on chlorides is less than 400 mg/kg for effluent recovery into the CW for the concrete protection. The conductivity and chloride of the sample are very low which would not affect the CW system at all. These two parameters are crucial to achieve longer cycles of concentration within the CW circuit while prohibiting the leach of alkaline properties from concrete.

The turbidity was 41.7 mg/L which was extremely high when compared to the standard specification range of 5 to 15 NTU for CW clarifiers, though it was within specification for the main CW circuit. However the clarifier specification is crucial in this case as the guidance attained from the clean water dam recovery project proved the advantages of recovering effluent through clarification, hence the importance of clarifier turbidity specification. To be able to control high turbidities for the sand filter backwash recovery; more flocculent would be needed with the clarification process at the lime softening plant.

The total hardness was low at a value of 24.12 mg/L when compared to specification requirement of less than 400 mg/L as CaCO_3 which was a combination of calcium and magnesium hardness as CaCO_3 . The recovery into CW clarification would not delay the softening process as the water was at minimal hardness.

4.1.4 Demin Water Plant anion backwash sample

The sample shown in Table 4.7 indicates the total alkalinity of 7 mg/L as CaCO_3 which was extremely low for this sample, when compared to the CW clarifier specification requirement of 50 mg/L. The conductivity was detected to be 22 $\mu\text{S}/\text{cm}$ which was lower than the specification of less than 4000 $\mu\text{S}/\text{cm}$ on CW main circuit.

Table 4.7: Analyses results of the Demin Water Plant anion backwash sample

Component	Unit	Value
Total Alkalinity as CaCO ₃	mg/L	7
Conductivity	µS/cm	22
pH at 25°C		7.43
Sulphates as SO ₄	mg/L	2.55
Chloride (Cl)	mg/L	1.72
Calcium (Ca) as CaCO ₃	mg/L	1.17
Magnesium (Mg) as CaCO ₃	mg/L	2.80
Total Hardness as CaCO ₃	mg/L	3.97
Turbidity	NTU	2.44

The calcium and magnesium hardness were 1.17 mg/L and 2.80 mg/L respectively; both lower than specification of less than 500 mg/L and 150 mg/L respectively for effluent recovery. These three parameters are grouped together with regard to the effectiveness of lime softening process with hardness removal. Their minimal values shall encourage a speedily softening process with minimal usage of chemicals.

The pH was 7.43 which was neutral, only minimum amount of lime on the clarification process would be required to raise the pH to a range of 9.9 – 10.2 as required by the specifications; should more volumes of this sample be recovered into the CW. Chloride was detected at 1.72 mg/L while the CW specification requirement is less than 400 mg/kg and sulphates were 2.55 mg/L when compared to the specification of less than 1000 mg/L; both parameters are extremely low which would benefit the concrete plant. Turbidity was 2.44 NTU which was lower than the specification maximum of 15 NTU on CW clarifier outlet.

4.1.5 Demin Water Plant cation rinse sample

The total alkalinity value for the demin cation rinse sample was low at a value of 2.5 mg/L as CaCO₃ when compared to CW clarifier outlet

specification of 50 mg/L; total hardness was 0.03 mg/L as CaCO_3 which represents the combination of calcium and magnesium, the hardness parameter was low when compared to the specification requirement of less than 400 mg/L.

Table 4.8: Analyses results of the Demin Water Plant cation rinse sample.

Component	Unit	Value
Total Alkalinity as CaCO_3	mg/L	2.5
Conductivity	$\mu\text{S}/\text{cm}$	5
pH at 25°C		7.53
Sulphates as SO_4	mg/L	0.27
Chloride (Cl)	mg/L	0.03
Calcium (Ca) as CaCO_3	mg/L	0.01
Magnesium (Mg) as CaCO_3	mg/L	0.02
Total Hardness as CaCO_3	mg/L	0.03
Turbidity	NTU	0.735

Alkalinity and hardness determine the water softening rate which would be faster for the recovery of this sample as these parameters were low when compared to specification requirements.

The conductivity was detected at 5 $\mu\text{S}/\text{cm}$ which was low when compared to specification requirement of less than 4000 $\mu\text{S}/\text{cm}$, which meant the amount of dissolved solids was very low on this sample. The turbidity was 0.735 mg/L which was low and within acceptable specification requirements when compared to 15 NTU of the CW standard.

The pH was neutral at a value of 7.53; significant recovery volumes of this sample would require moderate lime dosing to raise the pH to 9.9-10.2 to meet clarifier outlet specification, so that the pH can be raised to a range of 8.1-8.6 in the CW circuit. Sulphates were 0.27 mg/L and chlorides of 0.03 mg/L respectively; both these parameters are important for the protection of CW concrete structures against weakening.

4.1.6 Demin Water Plant anion rinse sample

The total alkalinity of the sample shown in Table 4.9 was 4.4 mg/L as CaCO_3 , while the CW clarifier specification requires 50 mg/L and the total hardness as CaCO_3 is 0.42 mg/L which was lower than the clarifier outlet specification of less than 400 mg/L.

Table 4.9: Analyses results of the Demin Water Plant anion rinse sample.

Component	Unit	Value
Total Alkalinity as CaCO_3	mg/L	4.4
Conductivity	$\mu\text{S}/\text{cm}$	5
pH at 25°C		7.84
Sulphates as SO_4	mg/L	0.04
Chloride (Cl)	mg/L	0.03
Calcium (Ca) as CaCO_3	mg/L	0.40
Magnesium (Mg) as CaCO_3	mg/L	0.02
Total Hardness as CaCO_3	mg/L	0.42
Turbidity	NTU	0.264

Low hardness requires less amount of hardness chemical treatment within the clarification process. These two parameters are crucial including pH; as they will determine the rate of softening process on clarifiers which would be faster for this sample as the values were very low compared to specifications. The pH was towards the alkaline range at a value of 7.84 which would require a minimal amount of lime dosage to pick it up to the required specifications of 9.9- 10.2.

The conductivity was 5 $\mu\text{S}/\text{cm}$ while the CW specification requires a value less than 4000 $\mu\text{S}/\text{cm}$; which means this effluent would have more cycles of concentration within the CW circuit as it had fewer amounts of dissolved solids. Sulphates on this sample were at 0.04 mg/L which were very low when compared to the effluent recovery specification into the CW which refers to less than 1000 ppm; and chlorides were 0.03 mg/L with CW

requirements of less than 400 mg/L. Both these parameters are crucial for the long term plant health of CW concrete structures, which is a recovery destination of choice for this effluent.

The turbidity was very low at a value of 0.264 NTU against the specification requirement of less than 15 NTU for CW clarifiers. Turbidity is key in the clarification process as it determines the rate of flocculation and the amount of flocculent to be dosed which would be minimal for this sample.

4.1.7 Pre-treatment Plant clarifier 1 blow down sample

The total alkalinity of 61.9 mg/L as CaCO_3 was detected for the sample shown in Table 4.10, which was higher than the CW clarifier specification of 50 mg/L. Total hardness was 28.65 mg/L as CaCO_3 which was low when compared to specification requirement of less than 400 mg/L; which indicated the combination of calcium and magnesium as CaCO_3 .

Table 4.10: Analyses results of the Pre-treatment Water Plant clarifier 1 blow down sample.

Component	Unit	Value
Total Alkalinity as CaCO_3	mg/L	61.9
Conductivity	$\mu\text{S}/\text{cm}$	151
pH at 25°C		7.27
Sulphates as SO_4	mg/L	12.72
Chloride (Cl)	mg/L	9.92
Calcium (Ca) as CaCO_3	mg/L	15.48
Magnesium (Mg) as CaCO_3	mg/L	13.17
Total Hardness as CaCO_3	mg/L	28.65
Turbidity	NTU	1440

Both alkalinity and hardness determine the rate of the softening process in hardness removal within clarification. A significant volume of this sample would impact the clarification process by slowing it down and requiring increased dosage of lime and coagulant to achieve the required specifications.

The conductivity was found to be 151 $\mu\text{S}/\text{cm}$, which was lower than the CW effluent recovery requirement of less than 4000 $\mu\text{S}/\text{cm}$, meaning that the sample had a lesser amount of dissolved solids. The sulphates were detected to be 12.72 mg/L while chlorides were 9.92 mg/L; both these parameters were low when compared to the CW specification requirements of 1000 mg/L and less than 400 mg/L respectively.

High sulphates and chlorides impact on the integrity of CW concrete structures such as cooling towers and clarifiers. The pH of this sample was 7.27 which was lower than CW clarifier outlet requirement of a range 9.9 to 10.2 so that the hardness parameters would precipitate out within the clarifier. The turbidity was 1440 NTU, which was extremely high when compared to CW clarifier outlet of less than 15 NTU and CW circuit of less than 100 NTU. The sample had high amounts of suspended solids which would require significant flocculent to drop it to required values through clarification process.

4.1.8 Pre-treatment Plant clarifier 2 blow down sample

The total alkalinity of the sample shown in Table 4.11 was 53.6 mg/L as CaCO_3 , while the CW clarifier specification requires 50 mg/L; the sample was slightly off specification requirements. Lime softening process would decrease the alkalinity to the required specifications.

Table 4.11: Analyses results of the Pre-treatment Water Plant clarifier 2 blow down sample

Component	Unit	Value
Total Alkalinity as CaCO_3	mg/L	53.6
Conductivity	$\mu\text{S}/\text{cm}$	130
pH at 25°C		7.24
Sulphates as SO_4	mg/L	8.14
Chloride (Cl)	mg/L	8.38
Calcium (Ca) as CaCO_3	mg/L	15.98
Magnesium (Mg) as CaCO_3	mg/L	11.93
Total Hardness as CaCO_3	mg/L	27.91
Turbidity	NTU	753

The conductivity was detected at 130 $\mu\text{S}/\text{cm}$ which was lower than the CW specification requirement of less than 4000 $\mu\text{S}/\text{cm}$, meaning the sample had less number of dissolved solids.

The pH was 7.24, a value slightly above neutral; should this effluent sample be recovered into the CW system; it would undergo lime softening process in order to raise the pH to 9.9-10.2 to meet clarifier outlet specification. Sulphates were detected at 8.14 mg/L which were very low when compared to the effluent recovery specification into the CW of less than 1000 mg/L; chlorides were 8.38 mg/L with CW requirements of less than 400 mg/L; therefore the recovery of this sample shall not impact on CW concrete structures.

The total hardness as CaCO_3 was 27.91 mg/L which was lower than the clarifier outlet specification of less than 400 mg/L. Low hardness requires fewer amounts of lime softening and hardness treatment chemicals within the clarification process. Total hardness represents a combination of calcium and magnesium as CaCO_3 .

4.1.9 Pre-treatment Plant clarifier 3 blow down sample

The total alkalinity value for the sample shown in Table 4.12 was 29.4 mg/L as CaCO_3 when compared to CW clarifier outlet specification of 50 mg/L and the total hardness was 24.53 mg/L as CaCO_3 when compared to the specification requirement of less than 400 mg/L. Both alkalinity and hardness can be removed effectively with the CW lime softening process which has been identified as a possible option for the recovery of this effluent sample.

Table 4.12: Analyses results of the Pre-treatment Water Plant clarifier 3 blow down sample

Component	Unit	Value
Total Alkalinity as CaCO_3	mg/L	29.4
Conductivity	$\mu\text{S}/\text{cm}$	93
pH at 25°C		7.39
Sulphates as SO_4	mg/L	8.99
Chloride (Cl)	mg/L	7.77
Calcium (Ca) as CaCO_3	mg/L	14.24
Magnesium (Mg) as CaCO_3	mg/L	10.29
Total Hardness as CaCO_3	mg/L	24.53
Turbidity	NTU	30.8

The conductivity was 93 $\mu\text{S}/\text{cm}$, which was lower than the CW specification requirement of less than 4000 $\mu\text{S}/\text{cm}$, meaning the sample had less number of dissolved solids. Sulphates were detected at 8.99 mg/L which were very low when compared to the effluent recovery specification into the CW of less than 1000 mg/L while chlorides were 7.77 mg/L when compared to CW requirements of less than 400 mg/L; both these parameters are crucial for the long term plant health of CW concrete structures.

The pH was 7.39 which would have to be raised to a range of pH 9.9 to 10.2 as per CW specifications requirement; should this effluent be recovered into the CW system. The turbidity was 30.8 NTU; which was higher when compared to CW clarifier outlet of less than 15 NTU, but less than CW circuit turbidity of less than 100 NTU.

4.2. Discussions

The analyses shown in Table 4.8 and 4.9 had the same conductivity, but it was the lowest conductivity out of all effluent samples which was 5 $\mu\text{S}/\text{cm}$; while the sample shown in Table 4.10 had the highest conductivity of 151 $\mu\text{S}/\text{cm}$ even though they were lower than CW specification of less than 4000 $\mu\text{S}/\text{cm}$. Low conductivity indicate low amount of dissolved solids which is advantageous in CW for longer cycles of concentrations. These two samples were taken after a backwash and regeneration process which was followed by rinse of H^+ and OH^- resin respectively; whereby all the fouling and organics had been dispersed out of the process already, hence such low conductivities.

The sample shown in Table 4.5 had the lowest pH of 4.36 when compared to all other samples; the sample was taken after the backwash of the cation H^+ resin which normally undergoes regeneration with sulphuric acid; though the regeneration occurs after the backwash, it was assumed that the acid was picked up from the previous regeneration process hence the pH was low. The lower the pH, the more acidic the effluent which is a disadvantage for CW steel ducts and piping as they would be corroded. Higher pH is recommendable; only within CW chemistry specification ranges as beyond 10.2 values, scaling would be formed which would hinder heat transfer efficiencies on heat exchangers as well as shrinking pipe diameters due to scale build up. The pH is controlled at a range 9.9 to 10.2 in the clarifier to allow all the hardness to precipitate out within the clarifier instead of settling in piping and ducts.

The analyses of the sample shown in Table 4.10 had the highest total alkalinity of all samples at a value of 61.9 mg/L; though it was above the CW clarifier requirements of 50 mg/L, it was still within acceptable CW circuit specification requirements of 80 to 120 mg/L. Alkalinity is a measure of hardness, the higher the alkalinity the more chances of the water to form scaling which is a disadvantage on plant performance. These analyses also had the highest turbidity of 1440 NTU when compared to all other samples; while the CW specification requirements are less than 15 NTU and the main circuit requires less than 100 NTU. High turbidity indicate high amount of suspended solids which will not settle out in CW clarifiers. The

disadvantage of high turbidity is that it forms erosion which might end up as corrosion; especially on systems with high velocities as the solids can be anything from silt, stones or gravel etc.

Sulphates and chlorides of all samples were low, but the sample shown in Table 4.10 had the highest of these parameters at 12.72 mg/L and 9.92 mg/L respectively. High sulphates and chlorides weaken the concrete structures while they leach alkaline properties from concrete which CW plant is mostly made of.

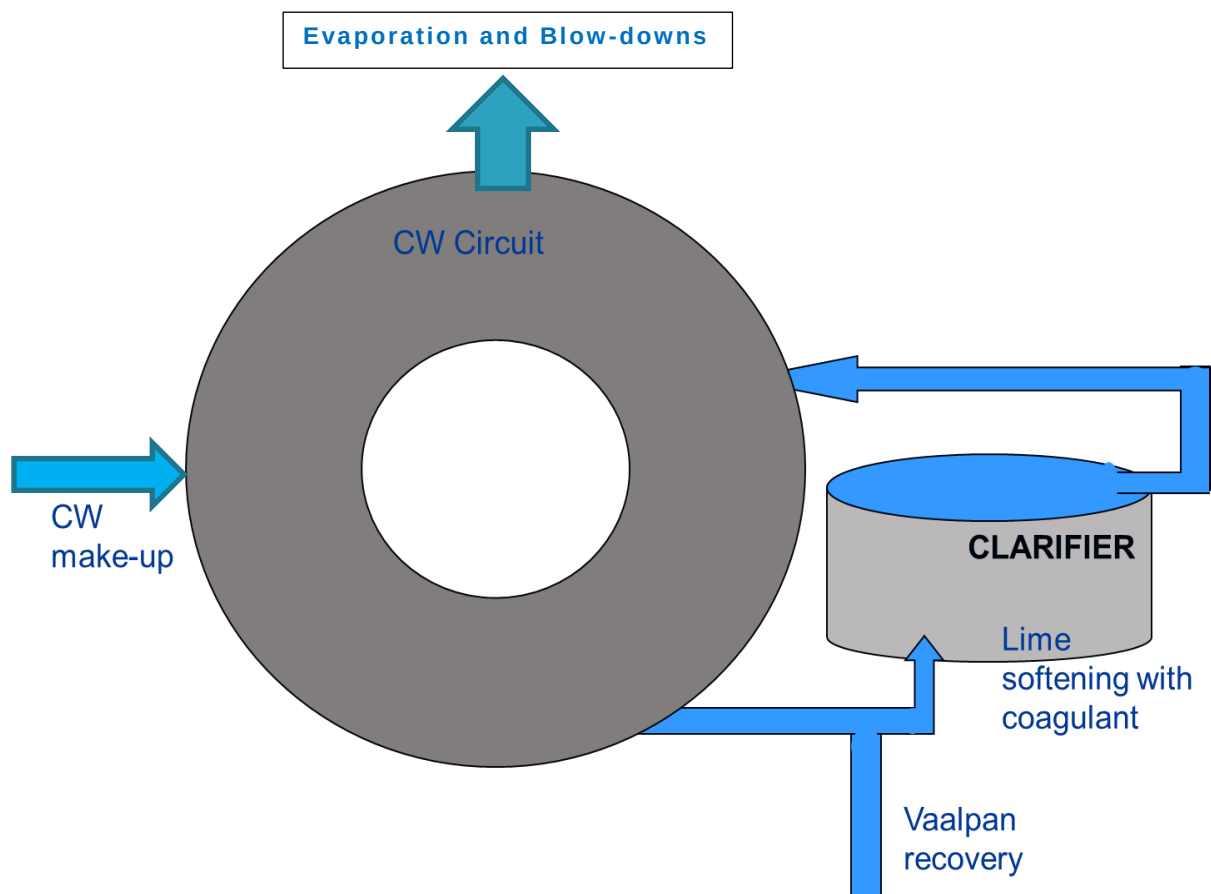


Figure 4-4 Illustration of the CW circuit diagram

At Kriel power station; if the clarifier chemistry outlet is on specification, the main circuit turns to be on specification too as the clarifier feeds the circuit.

Chapter 5

5. Technical and Economic Evaluations

5.1. Technical

Kriel Power Station makes use of a wet cooling system where spent steam from the turbine is recovered by means of condensation (process of converting vapour to liquid). Raw water is used as cooling medium for this purpose. During condensation, the temperature of the cooling medium is raised and needs to be cooled down by the cooling towers. This water, called the “hot duct”, has high alkalinity (“hard water”) and is softened in the lime plant to reduce the scaling potential in the condensers.

The status quo of the current cooling water (CW) treatment facility at Kriel power station has proven to be effective in treating the current CW and the clean dam (Vaalpan) effluent recovery water; but only through continuous process optimisation. The water source to the CW system was changed in 2006 from Usutu to the Vaal water scheme supply. The plant struggled for many years since it was not designed for Vaal water quality which is more abrasive and extremely dirty when compared to the Usutu scheme (see Table 5.1).

Table 5.1: Current Average Cost and Consumption on chemicals

Parameter	Usutu	Vaal	Units
pH	6.9	8.69	
Turbidity	2	187	NTU
M-Alkalinity as CaCO_3	23	215	mg/L
Conductivity	3	3070	$\mu\text{S/cm}$
Sulphate as SO_4	1	420	mg/L

The Kriel CW system was designed to treat water received from the Usutu scheme. A few modifications such as installing an educator after the rotary feeder to replace the slurry feeder were done to address the chemistry and maintenance challenges without much success. An educator operates as a venturi that sucks through lime at a high velocity from the rotary feeder while feed water creates a high pressure as sprays within the educator (see Figure 5.1). The cooling water lime treatment plant uses lime (Ca(OH)_2) and

polyelectrolyte as a flocculant through a clarification process in order to treat the CW.

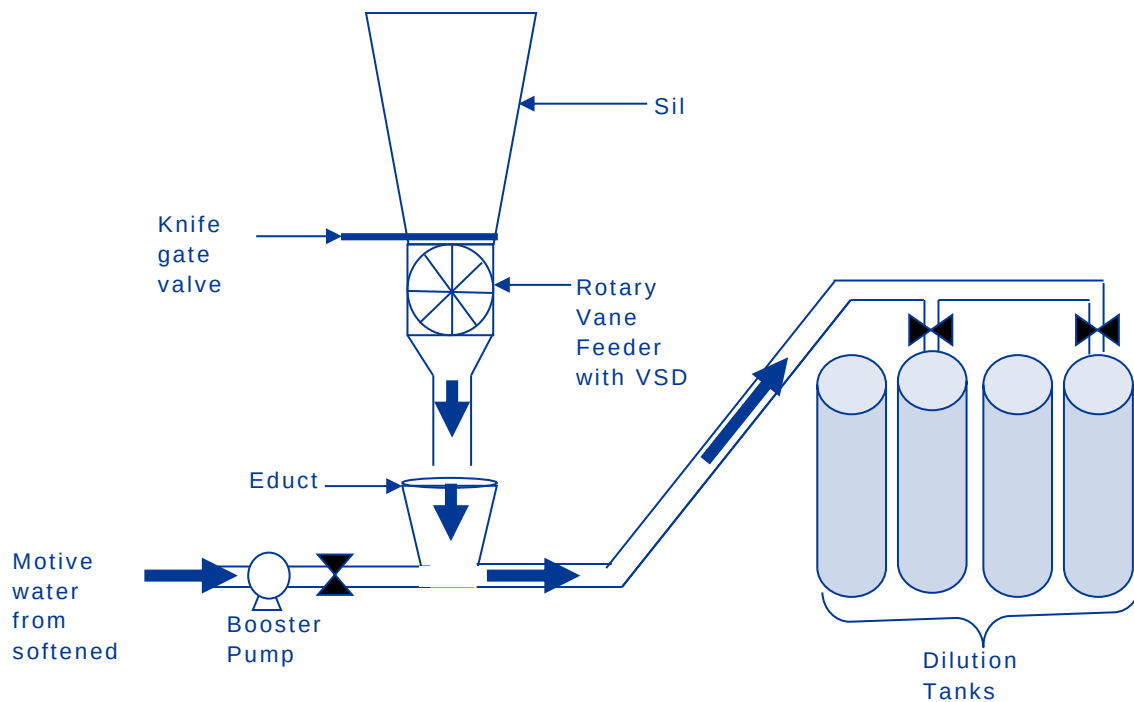
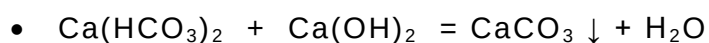
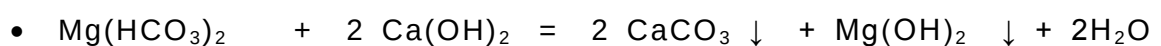


Figure 5-1 Illustration of cooling water lime treatment plant at Kriel power station

An illustration in Figure 5.1 and Figure 5.2 show the flow path of lime from the silo as directed by the motive water which goes through mixing tanks and then to clarifiers where it mixes with the CW and the flocculant. Sludge is generated from the clarification process through coagulation, flocculation and sedimentation and it discharges out at the bottom of the clarifier while treated the CW overflows into launders at the top of the clarifier and then flows into the main system. Equation 1 to equation 3 highlights the three main chemical reactions that occur throughout the lime softening process:



Equation 1



Equation 2



Equation 3

Lime treatment removes alkalinity and hardness salts by means of the precipitation of calcium carbonate and magnesium hydroxide in the clarifiers which is then removed by blow downs (sludge).

The key chemistry specifications that ensure the CW required quality ([6]) are:

- Turbidity: <10 NTU
- pH: 9.9 – 10.2
- Optimum Treatment: 2P-Alkalinity = M-Alkalinity
- Optimum Sludge Bed: 15%

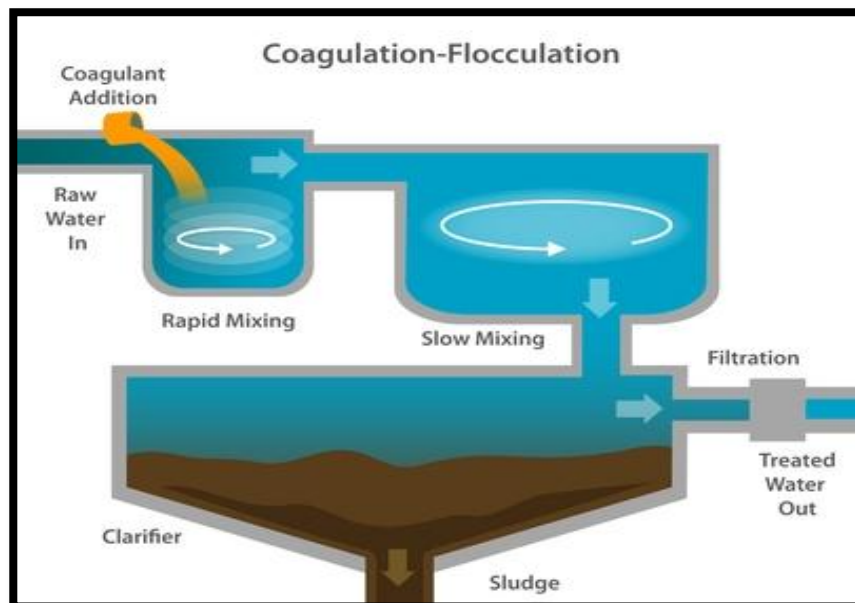


Figure 5-2: Illustration of a typical clarification process

The CW Calcium Carbonate Precipitate Potential (CCPP), is the main chemistry index for monitoring the scaling potential within the circuit trended around an average value of 10 since 2010 until May 2014 as per the Laboratory Information Management System ([40]). According to the chemistry standard, the CCPP should operate at a maximum of approximately 0.75 ([6]). The deterioration on the CW chemistry was evident through condenser tube leaks, high vacuum pressure on condensers, generator cold gas high temperatures etc., which are all reported in the load losses on the generating unit impacting the main

electricity supply to the grid. The CW chemistry has therefore become one of the main indirect contributors to Unplanned Capability Loss Factor (UCLF), which is a key performance indicator that the power station is measured on for all the unplanned activities that affect the loss of megawatts to the grid.

Since June 2014, an optimization study was conducted on the CW plant to evaluate its performance limitations with the current feed water chemistry. The optimisation began by conducting flow dynamics on the lime discharging from the lime feeder through a series of bag tests which essentially measured the quantity of lime dosed per minute. Following the bag tests, CW jar tests were performed in the laboratory to ascertain the optimal dose rates for lime and polyelectrolyte/flocculant. During these tests, concentrations that gave optimal specifications, based on turbidity, were noted and recorded. An operating model using a Microsoft Excel programme was then developed with the results from the bag tests and jar tests as a baseline to optimise and improve the CW chemistry through the lime dosing plant. The CW CCPP had improved drastically since then which is an improvement to the scaling of the circuit thus proving that the plant could still work but only on continuous monitoring (Figure 5.3).

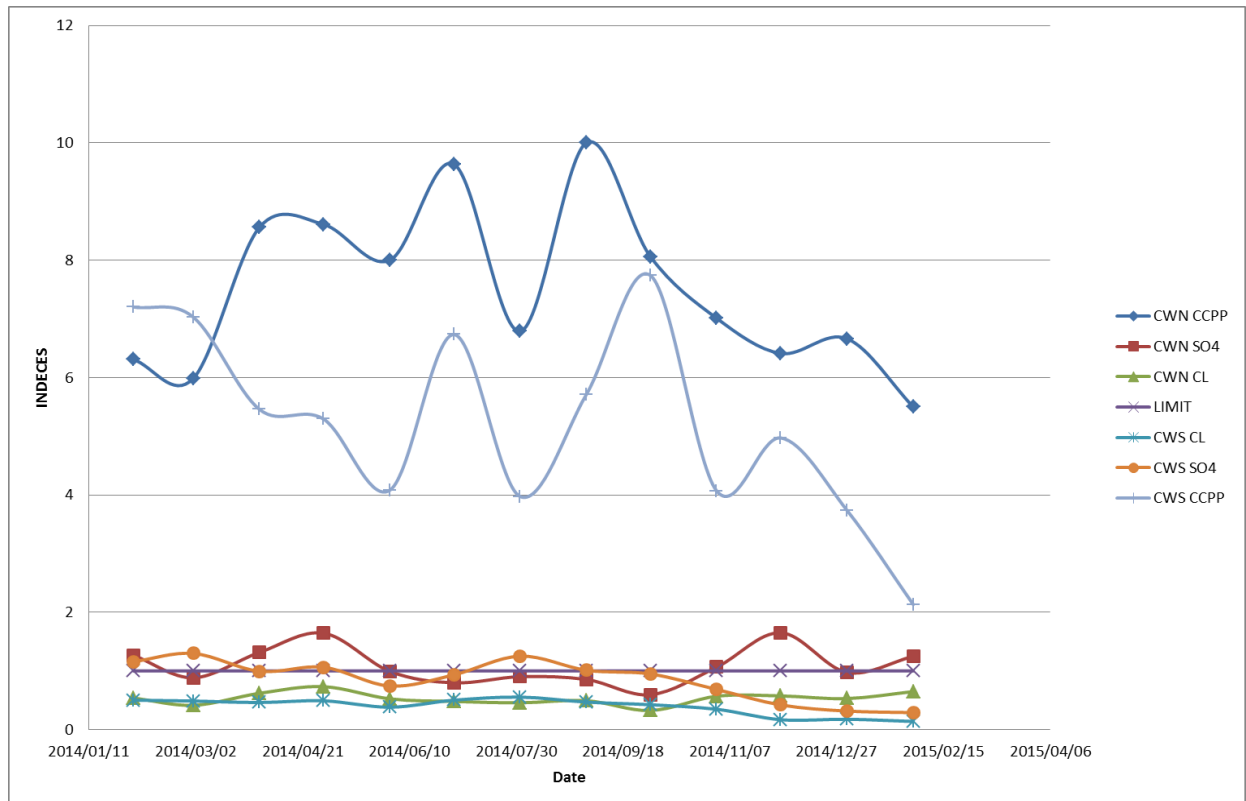


Figure 5-3 Cooling water chemistry indexes Jan 2014 to February 2015 ([32])

The graphs shown in Figure 5.3 indicate the critical chemistry gate keepers on the CW system which include sulphates (SO₄), chlorides (CL) and CWN CCPP (north) and CWS CCPP (south) respectively. High sulphates and chlorides weaken the concrete structures; they leach alkaline properties from the concrete which the CW plant is mostly made of as discussed in chapter 4. The CCPP indicates the ability of the CW to scale the system on both north and south side of the station. There are two identical CW lime treatment plants at the Kriel power station, where the North plant supplies CW from Unit 1 up to Unit 3 and the South plant supplies CW from Unit 4 up to Unit 6. It can be seen from Figure 5.3 that the CCPP was indicating a downward trend; however it was still operating well above the CCPP specification, which could only translate to long term damage of the plant.

Other critical CW chemistry parameters such as alkalinity and turbidity had shown a significant improvement too since the optimisation had begun; because the correct amount of chemicals was dosed for the correct amount of CW as seen in Table 5.2. The average consumption of industrial-grade lime, coagulant and flocculant are shown based on the maximum cooling

water flow rate (250L/s). The amount of coagulant consumed is based on the jar tests conducted at Eskom s' research facility in Rosherville.

Table 5.2: Average Consumption of Coagulant, flocculant and lime

Average consumption			
Dosage	Industrial-grade lime	Coagulant	Flocculant
Concentration (ppm)	133.3	5.00	0.20
Concentration (g/l)	0.11	5.0E-03	2.0E-04

A significant reduction in volume of freshwater intake was noticed specifically when optimisation begun because the cycles of concentration on the CW had improved, resulting in minimal/reduced blow downs, hence less effluent was generated. As a result the effluent dam levels could be sustained with limited recovery to the plant, and make-up involved more fresh water intake as seen in Figure 5.4.

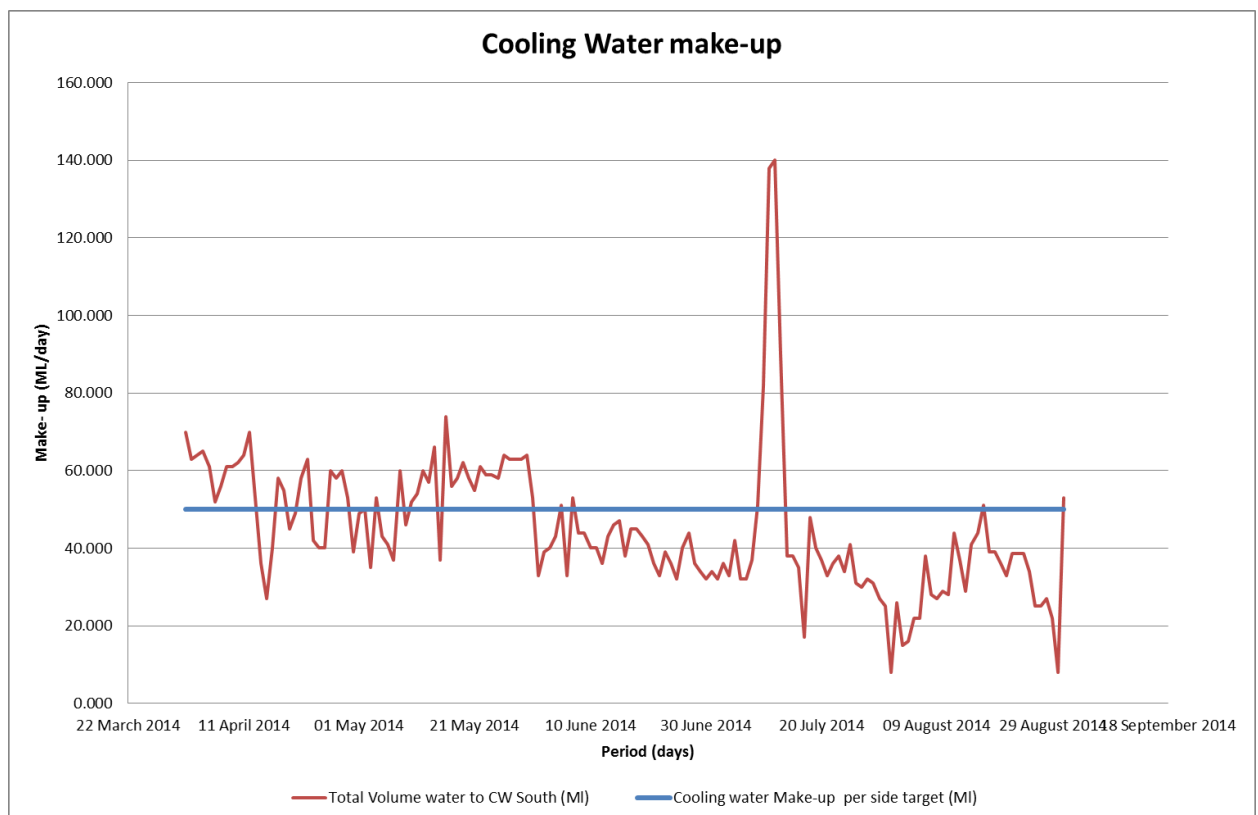


Figure 5-4: Cooling water make-up March 2014 to August 2014 ([38])

The spike seen in Figure 5.4 was recorded on the Water Accounting Framework (WAF) for the beginning of July and was the result of a defective make-up valve on the south plant which did not respond correctly to a close signal, this valve had therefore remained open and resulted in an increase in water levels for approximately 4 days.

5.2. Economic Evaluation

The operational expenditure (OPEX) estimates were determined based on the current chemical consumption costs for CW treatment, raw water CW make up costs and the maintenance call out costs. Each cost was calculated based on a reference cost of the previous financial year and adjusted accordingly to cater for price inflation. The savings achieved on the chemical consumption costs was as a result of the optimization process conducted on the CW plant. Previously chemical dosage was increased with the knowledge that the raw water chemistry change from the Usutu scheme to the Vaal scheme required a significantly higher chemical dosing regimen to achieve results within specification.

Chemical dosage was done without proper optimisation hence the plant never reached required chemistry specifications even though the dose rates were increasing. Jar tests have proven how much volumes of chemicals are needed for the specific volume of CW as shown in Table 5.3. The table shows the current operational costs of the North and South lime plant. The station is currently using 1529 tons of industrial-grade lime per year and 55 tons of flocculant. The combined cost of the two chemicals per year is R 7 460 532.

Table 5.3: Current Average Cost and Consumption on chemicals

Improved Chemical Costs					
Lime	Price (R/ton)	Mass (ton/wk)	Mass (ton/yr)	Total Cost per site (R/yr)	Total Cost per station (R/yr)
Industrial-grade	1 529	30	1560	2 384 616	4 769 232
Flocculant	24 450	1.1	55	1 345 650	2 691 300
Total				3 730 266	7 460 532

Table 5.4 shows the maximum cooling water flow rate into the clarifiers (250l/s); however the station is currently operating at an average flow rate that is below 200l/s.

Table 5.4: Cooling Water Flow rate into clarifiers

Cooling Water Treatment				
Flow (L/h) per clarifier	45000 0	Main CW flow	250	L/s

Table 5.5 shows the average operational cost after the optimisation has been carried out. The station will be using 526 tons of industrial-grade lime per year and 20 tons of coagulant and 1 ton of flocculant per year. The combined cost of the chemicals will be R 3 768 680.00. This means that after the optimisation, the total economic savings of the station will be R 3 691 851.00 per year.

Table 5.5: Chemical Costs after optimisation

Improved Chemical Costs							
Chemical	Cost per ton(R/ton)	Mass (kg/hr)	Mass (kg/wk)	Mass (ton/yr)	Cost per Clarifier (R/yr)	Total Cost per site (R/yr)	Total Cost per station (R/yr)
Industrial-grade	1 529	60	10080	526	803 431.36	1 606 863	3 213 725
Coagulant	13 100	2.25	378	20	258 201	258 201	516 402
Flocculent	24 450	0	15	1	19 276	19 276	38 553
Total					1 080 908.74	1 884 340	3 768 680
						Savings	3 691 851

The Department of Water Affairs (DWA) sells raw water to Kriel power station at R 8000 per mega litre (ML). On average, 1800 ML and 2400 ML for the winter and summer months was consumed respectively on raw water make up into the CW system. A maximum of 5 ML effluent water is generated daily from the pre-treatment plant which contributes to other effluent generated from different parts of the power generating plant. In summary; since 1 ML of raw water costs R8000 and 5 ML of effluent could be recovered from the water pre-treatment plants, there will be a saving of about R14.6M/year. These savings are based on the effluent generated only from the water treatment plant processes. The rest of the effluent will continue to support the station's wet ashing system whereby effluent is

used as motive water to transport ash from the boiler hoppers to the ash dams.

5.3. Conclusion

It can thus be concluded that the saving due to chemical use, which amounts to R3.7M /year, and the saving due to water that could be recovered after treatment, which amounts to R14.6M /year, gives an overall saving of about R 18M/year.

Chapter 6

6. Conclusions and Recommendations

6.1. Conclusions

The aim of this research project was to propose a treatment facility that would treat effluent water generated from pre-treatment plants and recover it into Kriel power station's cooling water (CW) system in order to reduce fresh water intake while assisting the station to conform to the Zero Liquid Effluent Discharge (ZLED) policy. The CW system was chosen as the best option to recover effluent water because there is more freedom of chemistry control in terms of operation. Since the power station is a business which survival highly depends on costs; the decision on effluent recovery into the CW system also depends on life cycle costing of the plant. The literature study in chapter 2 has addressed a broad spectrum of different technologies available in the market that have been proven to be suitable for effluent treatment and reuse. One of the technologies or methods mentioned was clarification; which consists of coagulation, flocculation and sedimentation which is already available and is used at Kriel power station for the CW treatment.

In chapter 3, different analysis methods were described for all effluent samples collected for this study in order to provide a chemistry baseline indicating the deviations from the specification of CW chemistry. Chapter 4 sample results indicated that out of a total of 9 samples that were analysed; only 1 sample, namely cation backwash water from the demineralised, had the lowest pH of 4.36 and only 1 sample had the highest total alkalinity of 61.9 mg/L, conductivity of 151 $\mu\text{S}/\text{cm}$ and turbidity of 1440 NTU which was the pre-treatment clarifier 1 blow down sample. The latter sample also had higher sulphates and chlorides of 12.72 mg/L and 9.92 mg/L respectively out of all samples analysed even though both parameters were still within specified CW chemistry ranges. Additionally, there were 2 samples that had the lowest conductivity of 5 $\mu\text{S}/\text{cm}$ out of all effluent samples; namely the cation and anion rinse samples from the demineralised water plant.

It is therefore concluded that only 12% of the total effluent generated at the pre-treatment plants was acidic, based on the analytical chemistry results.

Only 12% of the total effluent water had a degree of extreme hardness and suspended solids, while 22% of the effluent was extremely low in its total dissolved solids concentration. The 54% remainder of the effluent water was fairly moderate with regards to their chemistry specifications when compared to the CW chemistry specifications; a few were slightly above specification but mostly within specifications. It is also concluded that the current CW lime dosing plant at Kriel power station can only perform as desired if process optimisation is performed continuously, and the treatment capacity is limited due to the intake of Vaal River water (lower quality water as compared to Usutu) which prevents operation at maximum flow rate of 250 L/s. Optimisation, with Vaal water, was proven to be at a maximum of 200 L/s on each clarifier and for the station to mitigate scaling, erosion and corrosion challenges; the CW has to be treated fully, i.e.: treat a maximum of 250 L/s per clarifier.

The technical evaluations in chapter 5 has proven challenges of not having a continuous monitoring system on the CW system i.e. excess chemicals dosed which is unnecessarily and costly; which resulted in a non performing plant at a huge cost. A non performing CW system, at a power plant such as Kriel, impacts on the entire life cycle cost of the plant. The chemistry requirements will continuously be out of specification which would lead to more blow downs whilst increasing fresh water intake. Metal and concrete structures continue to deteriorate as a result of operating the CW system out of the chemistry specifications. This affects the operational and maintenance (OPEX) costs with unplanned refurbishments (CAPEX). It is concluded that thorough studies were not conducted during the raw water change implementation from the Usutu River scheme to the Vaal River scheme for the CW system as to what the impact would be on plant performance.

It is feasible to recover extra effluent into the current CW plant; however the plant was designed to treat 250 L/s maximum per clarifier, currently it is treating 200 L/s plus 50 L/s from the clean water dam, Vaalpan (Chapter 4) and therefore treating a total of 225 L/s per clarifier with great difficulty.

It is further concluded that only a margin of 25 L/s is left per clarifier to accommodate extra water capacity. As a result, an expansion of the current facility would be needed to accommodate 58 L/s (5 ML/day). The CW

treatment plant consists of 2 clarifiers per side; therefore 254 L/s would be treated per clarifier which is 2% more than the available design margin limit. The current savings of **R14 600 000** (R14.6 M) can be used to expand the plant to accommodate the extra 5 ML of effluent, while **R3 691 851** obtained from chemical dosage optimisation can be used to buy chemicals for the effluent treatment depending on how much capacity would be needed.

6.2. Recommendations

- It is recommended that a feasibility study be conducted to confirm the required design parameters for the expansion of the current CW plant to accommodate an extra 5 ML of effluent recovery.
- It is an easier option based on conclusions to expand on the current clarification technology in terms of costs on human capital and infrastructure as it is a familiar existing process and the project will not commence from inception.
- A risk assessment has to be conducted on either the expansion option or on starting a new facility altogether, depending on the feasibility study outcomes.

Appendices

A. Effluent Samples

Central Water Laboratory

Final Task Report

Report Reference

WL2012-010245

Attention	Palesa Mkabane
Client Name	Kriel Power Station
Address	
Fax	086 658 3457
Telephone	017 615 2175

Date 2013/08/07
Tel. No. +27 11 629 5104
Fax. No. +27 11 629 5574

Report Title WMC

TEST RESULTS FOR THE ANALYSIS OF WATER
SAMPLES

Number of Samples 9

Description of Samples ACCEPTABLE

Date Registered 13-July-2012

Date Reported 07-August-2013

Task Comments:

Please note that Se, As and Hg were subcontracted and their detection limit is <0.002ppm <0.001ppm and 0.001ppm respectively.

Approved By : _____

Khomotso Mohale

Senior Technician

011 629 5104

Date : _____

Tests marked "Not SANAS accredited" in this report are not included in the SANAS Schedule of Accreditation for this laboratory.

Opinions and interpretations expressed herein are outside the scope of SANAS accreditation,
PLEASE NOTE: The test results relate only to the specified samples tested as identified in this report.

This test report shall not be reproduced except in full, without written approval of ESKOM holdings (Cleveland) Chemical Technologies.

Eskom Central Water Laboratory Test Results



Laboratory Number T0055

Sample ID	3940282	WMC-2012-07-13/03	WL2012-010245
CPP Rinse cation water sample			
Component	Unit	Value	
Alkalinity Total	mg/l CaCO ₃	1.9	
Aluminium as Al	mg/l	0.04	
Arsenic as As	µg/l	<1.000	
Barium as Ba	mg/l	<0.005	
Beryllium as Be	mg/l	<0.005	
Boron as B	mg/l	0.05	
Calcium as Ca	mg/l	<0.005	
Cadmium as Cd	mg/l	<0.005	
Chloride as Cl	mg/l	0.04	
Conductivity	µS/cm	9	
Cobalt as Co	mg/l	0.01	
Chromium as Cr	mg/l	0.01	
Copper as Cu	mg/l	0.05	
Iron as Fe	mg/l	0.02	
Flouride as F	mg/l	<0.030	
Mercury as Hg	µg/l	2.0	
Potassium as K	mg/l	0.52	
Magnesium as Mg	mg/l	<0.005	
Manganese as Mn	mg/l	0.01	
Molybdenum as Mo	mg/l	<0.005	
Sodium as Na	mg/l	1.6	
Nickel as Ni	mg/l	0.01	
Nitrate as N	mg/l	<0.02	
Lead as Pb	mg/l	<0.007	
pH @ 25 °C		6.17	
Phosphorus as P	mg/l	<0.005	
Selenium as Se	µg/l	<2.000	
Tin as Sn	mg/l	<0.005	
Sulphate as SO ₄	mg/l	3.51	
Strontium as Sr	mg/l	<0.005	
Ca Hardness as CaCO ₃	mg/l	0.01	
Mg Hardness as CaCO ₃	mg/l	0.02	
Total Hardness as CaCO ₃	mg/l	0.03	
Turbidity	NTU	1.03	
Vanadium as V	mg/l	<0.005	
Zinc as Zn	mg/l	0.04	

Eskom Central Water Laboratory Test Results



Laboratory Number T0055

Sample ID	3940283	WMC-2012-07-13/04	WL2012-010245
Cation Backwash Demin water sample			
Component	Unit	Value	
Alkalinity Total	mg/l CaCO ₃	<0.343	
Aluminium as Al	mg/l	0.37	
Arsenic as As	µg/l	<1.000	
Barium as Ba	mg/l	<0.005	
Beryllium as Be	mg/l	<0.005	
Boron as B	mg/l	0.03	
Calcium as Ca	mg/l	0.14	
Cadmium as Cd	mg/l	<0.005	
Chloride as Cl	mg/l	0.59	
Conductivity	µS/cm	35	
Cobalt as Co	mg/l	0.01	
Chromium as Cr	mg/l	<0.005	
Copper as Cu	mg/l	0.03	
Iron as Fe	mg/l	0.04	
Flouride as F	mg/l	0.07	
Mercury as Hg	µg/l	<1.000	
Potassium as K	mg/l	0.60	
Magnesium as Mg	mg/l	0.06	
Manganese as Mn	mg/l	0.01	
Molybdenum as Mo	mg/l	<0.005	
Sodium as Na	mg/l	1.9	
Nickel as Ni	mg/l	<0.005	
Nitrate as N	mg/l	0.02	
Lead as Pb	mg/l	<0.007	
pH @ 25 °C		4.36	
Phosphorus as P	mg/l	<0.005	
Selenium as Se	µg/l	<2.000	
Tin as Sn	mg/l	<0.005	
Sulphate as SO ₄	mg/l	12.56	
Strontium as Sr	mg/l	<0.005	
Ca Hardness as CaCO ₃	mg/l	0.35	
Mg Hardness as CaCO ₃	mg/l	0.25	
Total Hardness as CaCO ₃	mg/l	0.60	
Turbidity	NTU	3.33	
Vanadium as V	mg/l	<0.005	
Zinc as Zn	mg/l	0.01	

Eskom Central Water Laboratory Test Results



Laboratory Number T0055

Sample ID	3940284	WMC-2012-07-13/05	WL2012-010245
Sand filter Backwash water sample			
Component	Unit	Value	
Alkalinity Total	mg/l CaCO ₃	28.9	
Aluminium as Al	mg/l	0.03	
Arsenic as As	µg/l	<1.000	
Barium as Ba	mg/l	0.01	
Beryllium as Be	mg/l	<0.005	
Boron as B	mg/l	0.03	
Calcium as Ca	mg/l	5.7	
Cadmium as Cd	mg/l	<0.005	
Chloride as Cl	mg/l	7.68	
Conductivity	µS/cm	88	
Cobalt as Co	mg/l	0.01	
Chromium as Cr	mg/l	<0.005	
Copper as Cu	mg/l	0.03	
Iron as Fe	mg/l	<0.005	
Flouride as F	mg/l	0.07	
Mercury as Hg	µg/l	<1.000	
Potassium as K	mg/l	1.7	
Magnesium as Mg	mg/l	2.4	
Manganese as Mn	mg/l	0.02	
Molybdenum as Mo	mg/l	<0.005	
Sodium as Na	mg/l	6.4	
Nickel as Ni	mg/l	<0.005	
Nitrate as N	mg/l	0.12	
Lead as Pb	mg/l	<0.007	
pH @ 25 °C		7.16	
Phosphorus as P	mg/l	<0.005	
Selenium as Se	µg/l	<2.000	
Tin as Sn	mg/l	<0.005	
Sulphate as SO ₄	mg/l	9.37	
Strontium as Sr	mg/l	0.04	
Ca Hardness as CaCO ₃	mg/l	14.24	
Mg Hardness as CaCO ₃	mg/l	9.88	
Total Hardness as CaCO ₃	mg/l	24.12	
Turbidity	NTU	41.7	
Vanadium as V	mg/l	<0.005	
Zinc as Zn	mg/l	0.02	

Eskom Central Water Laboratory Test Results



Laboratory Number T0055

Sample ID	3940285	WMC-2012-07-13/06	WL2012-010245
Anion Backwash Demin water sample			
Component	Unit	Value	
Alkalinity Total	mg/l CaCO ₃	7.0	
Aluminium as Al	mg/l	<0.005	
Arsenic as As	µg/l	<1.000	
Barium as Ba	mg/l	<0.005	
Beryllium as Be	mg/l	<0.005	
Boron as B	mg/l	0.02	
Calcium as Ca	mg/l	0.47	
Cadmium as Cd	mg/l	<0.005	
Chloride as Cl	mg/l	1.72	
Conductivity	µS/cm	22	
Cobalt as Co	mg/l	0.01	
Chromium as Cr	mg/l	<0.005	
Copper as Cu	mg/l	0.04	
Iron as Fe	mg/l	<0.005	
Flouride as F	mg/l	0.05	
Mercury as Hg	µg/l	<1.000	
Potassium as K	mg/l	0.52	
Magnesium as Mg	mg/l	0.68	
Manganese as Mn	mg/l	0.01	
Molybdenum as Mo	mg/l	<0.005	
Sodium as Na	mg/l	2.8	
Nickel as Ni	mg/l	<0.005	
Nitrate as N	mg/l	0.03	
Lead as Pb	mg/l	<0.007	
pH @ 25 °C		7.43	
Phosphorus as P	mg/l	<0.005	
Selenium as Se	µg/l	<2.000	
Tin as Sn	mg/l	<0.005	
Sulphate as SO ₄	mg/l	2.55	
Strontium as Sr	mg/l	0.01	
Ca Hardness as CaCO ₃	mg/l	1.17	
Mg Hardness as CaCO ₃	mg/l	2.80	
Total Hardness as CaCO ₃	mg/l	3.97	
Turbidity	NTU	2.44	
Vanadium as V	mg/l	<0.005	
Zinc as Zn	mg/l	0.04	

Eskom Central Water Laboratory Test Results



Laboratory Number T0055

Sample ID	3940286	WMC-2012-07-13/07	WL2012-010245
Cation Rinse Demin water sample			
Component	Unit	Value	
Alkalinity Total	mg/l CaCO ₃	2.5	
Aluminium as Al	mg/l	<0.005	
Arsenic as As	µg/l	<1.000	
Barium as Ba	mg/l	<0.005	
Beryllium as Be	mg/l	<0.005	
Boron as B	mg/l	0.03	
Calcium as Ca	mg/l	<0.005	
Cadmium as Cd	mg/l	<0.005	
Chloride as Cl	mg/l	0.03	
Conductivity	µS/cm	5	
Cobalt as Co	mg/l	0.01	
Chromium as Cr	mg/l	<0.005	
Copper as Cu	mg/l	0.03	
Iron as Fe	mg/l	0.02	
Flouride as F	mg/l	0.09	
Mercury as Hg	µg/l	<1.000	
Potassium as K	mg/l	0.52	
Magnesium as Mg	mg/l	<0.005	
Manganese as Mn	mg/l	<0.005	
Molybdenum as Mo	mg/l	<0.005	
Sodium as Na	mg/l	1.7	
Nickel as Ni	mg/l	<0.005	
Nitrate as N	mg/l	<0.02	
Lead as Pb	mg/l	<0.007	
pH @ 25 °C		7.53	
Phosphorus as P	mg/l	<0.005	
Selenium as Se	µg/l	<2.000	
Tin as Sn	mg/l	<0.005	
Sulphate as SO ₄	mg/l	0.27	
Strontium as Sr	mg/l	<0.005	
Ca Hardness as CaCO ₃	mg/l	0.01	
Mg Hardness as CaCO ₃	mg/l	0.02	
Total Hardness as CaCO ₃	mg/l	0.03	
Turbidity	NTU	0.735	
Vanadium as V	mg/l	<0.005	
Zinc as Zn	mg/l	0.02	

Eskom Central Water Laboratory Test Results



Laboratory Number T0055

Sample ID	3940287	WMC-2012-07-13/08	WL2012-010245
Anion Rinse Demin water sample			
Component	Unit	Value	
Alkalinity Total	mg/l CaCO ₃	4.4	
Aluminium as Al	mg/l	<0.005	
Arsenic as As	µg/l	<1.000	
Barium as Ba	mg/l	<0.005	
Beryllium as Be	mg/l	<0.005	
Boron as B	mg/l	0.01	
Calcium as Ca	mg/l	0.16	
Cadmium as Cd	mg/l	<0.005	
Chloride as Cl	mg/l	0.03	
Conductivity	µS/cm	5	
Cobalt as Co	mg/l	0.01	
Chromium as Cr	mg/l	<0.005	
Copper as Cu	mg/l	0.03	
Iron as Fe	mg/l	<0.005	
Flouride as F	mg/l	<0.030	
Mercury as Hg	µg/l	<1.000	
Potassium as K	mg/l	0.52	
Magnesium as Mg	mg/l	<0.005	
Manganese as Mn	mg/l	<0.005	
Molybdenum as Mo	mg/l	<0.005	
Sodium as Na	mg/l	2.2	
Nickel as Ni	mg/l	<0.005	
Nitrate as N	mg/l	<0.02	
Lead as Pb	mg/l	<0.007	
pH @ 25 °C		7.84	
Phosphorus as P	mg/l	<0.005	
Selenium as Se	µg/l	<2.000	
Tin as Sn	mg/l	<0.005	
Sulphate as SO ₄	mg/l	0.04	
Strontium as Sr	mg/l	<0.005	
Ca Hardness as CaCO ₃	mg/l	0.40	
Mg Hardness as CaCO ₃	mg/l	0.02	
Total Hardness as CaCO ₃	mg/l	0.42	
Turbidity	NTU	0.264	
Vanadium as V	mg/l	<0.005	
Zinc as Zn	mg/l	0.01	

Eskom Central Water Laboratory Test Results



Laboratory Number T0055

Sample ID	3940288	WMC-2012-07-13/09	WL2012-010245
Clarifier Blow down1			
water sample			
Component	Unit	Value	
Alkalinity Total	mg/l CaCO ₃	61.9	
Aluminium as Al	mg/l	0.02	
Arsenic as As	µg/l	7.0	
Barium as Ba	mg/l	0.16	
Beryllium as Be	mg/l	<0.005	
Boron as B	mg/l	0.02	
Calcium as Ca	mg/l	6.2	
Cadmium as Cd	mg/l	<0.005	
Chloride as Cl	mg/l	9.92	
Conductivity	µS/cm	151	
Cobalt as Co	mg/l	0.01	
Chromium as Cr	mg/l	<0.005	
Copper as Cu	mg/l	0.03	
Iron as Fe	mg/l	<0.005	
Flouride as F	mg/l	0.16	
Mercury as Hg	µg/l	<1.000	
Potassium as K	mg/l	2.3	
Magnesium as Mg	mg/l	3.2	
Manganese as Mn	mg/l	4.7	
Molybdenum as Mo	mg/l	<0.005	
Sodium as Na	mg/l	6.5	
Nickel as Ni	mg/l	<0.005	
Nitrate as N	mg/l	0.04	
Lead as Pb	mg/l	<0.007	
pH @ 25 °C		7.27	
Phosphorus as P	mg/l	<0.005	
Selenium as Se	µg/l	<2.000	
Tin as Sn	mg/l	<0.005	
Sulphate as SO ₄	mg/l	12.72	
Strontium as Sr	mg/l	0.05	
Ca Hardness as CaCO ₃	mg/l	15.48	
Mg Hardness as CaCO ₃	mg/l	13.17	
Total Hardness as CaCO ₃	mg/l	28.65	
Turbidity	NTU	1440	
Vanadium as V	mg/l	<0.005	
Zinc as Zn	mg/l	0.02	

Eskom Central Water Laboratory Test Results



Laboratory Number T0055

Sample ID	3940289	WMC-2012-07-13/10	WL2012-010245
Clarifier Blow down2 water sample			
Component	Unit	Value	
Alkalinity Total	mg/l CaCO ₃	53.6	
Aluminium as Al	mg/l	0.01	
Arsenic as As	µg/l	<1.000	
Barium as Ba	mg/l	0.14	
Beryllium as Be	mg/l	<0.005	
Boron as B	mg/l	0.02	
Calcium as Ca	mg/l	6.4	
Cadmium as Cd	mg/l	<0.005	
Chloride as Cl	mg/l	8.38	
Conductivity	µS/cm	130	
Cobalt as Co	mg/l	0.01	
Chromium as Cr	mg/l	<0.005	
Copper as Cu	mg/l	0.03	
Iron as Fe	mg/l	0.01	
Flouride as F	mg/l	0.08	
Mercury as Hg	µg/l	<1.000	
Potassium as K	mg/l	2.0	
Magnesium as Mg	mg/l	2.9	
Manganese as Mn	mg/l	3.4	
Molybdenum as Mo	mg/l	<0.005	
Sodium as Na	mg/l	6.7	
Nickel as Ni	mg/l	<0.005	
Nitrate as N	mg/l	0.03	
Lead as Pb	mg/l	<0.007	
pH @ 25 °C		7.24	
Phosphorus as P	mg/l	<0.005	
Selenium as Se	µg/l	<2.000	
Tin as Sn	mg/l	<0.005	
Sulphate as SO ₄	mg/l	8.16	
Strontium as Sr	mg/l	0.05	
Ca Hardness as CaCO ₃	mg/l	15.98	
Mg Hardness as CaCO ₃	mg/l	11.93	
Total Hardness as CaCO ₃	mg/l	27.91	
Turbidity	NTU	753	
Vanadium as V	mg/l	<0.005	
Zinc as Zn	mg/l	0.02	

Eskom Central Water Laboratory Test Results



Laboratory Number T0055

Sample ID	3940290	WMC-2012-07-13/11	WL2012-010245
Clarifier Blow down3			
water sample			
Component	Unit	Value	
Alkalinity Total	mg/l CaCO ₃	29.4	
Aluminium as Al	mg/l	0.05	
Arsenic as As	µg/l	<1.000	
Barium as Ba	mg/l	0.01	
Beryllium as Be	mg/l	<0.005	
Boron as B	mg/l	0.01	
Calcium as Ca	mg/l	5.7	
Cadmium as Cd	mg/l	<0.005	
Chloride as Cl	mg/l	7.77	
Conductivity	µS/cm	93	
Cobalt as Co	mg/l	0.01	
Chromium as Cr	mg/l	<0.005	
Copper as Cu	mg/l	0.03	
Iron as Fe	mg/l	<0.005	
Flouride as F	mg/l	0.19	
Mercury as Hg	µg/l	<1.000	
Potassium as K	mg/l	1.7	
Magnesium as Mg	mg/l	2.5	
Manganese as Mn	mg/l	0.01	
Molybdenum as Mo	mg/l	<0.005	
Sodium as Na	mg/l	5.3	
Nickel as Ni	mg/l	<0.005	
Nitrate as N	mg/l	0.13	
Lead as Pb	mg/l	<0.007	
pH @ 25 °C		7.39	
Phosphorus as P	mg/l	<0.005	
Selenium as Se	µg/l	<2.000	
Tin as Sn	mg/l	<0.005	
Sulphate as SO ₄	mg/l	8.99	
Strontium as Sr	mg/l	0.04	
Ca Hardness as CaCO ₃	mg/l	14.24	
Mg Hardness as CaCO ₃	mg/l	10.29	
Total Hardness as CaCO ₃	mg/l	24.53	
Turbidity	NTU	30.8	
Vanadium as V	mg/l	<0.005	
Zinc as Zn	mg/l	0.01	

The analyses were performed using the following methods:

Alkalinity Total	ESKOM METHOD NO 304	Accredited
Aluminium ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Arsenic Hydride (µg/l)	ESKOM METHOD NO 424	Not Accredited
Barium ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Beryllium ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Boron ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Cadmium ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Calcium ICP (mg/l)	ESKOM METHOD NO 415	Accredited
Chloride IC (mg/l)	ESKOM METHOD NO 307	Accredited
Chromium ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Cobalt ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Conductivity @ 25 °C (µS/cm)	ESKOM METHOD NO 302A	Accredited
Copper ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Flouride IC (mg/l)	ESKOM METHOD NO 307	Not Accredited
Iron ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Lead ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Magnesium ICP (mg/l)	ESKOM METHOD NO 415	Accredited
Manganese ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Mercury Hydride (µg/l)	ESKOM METHOD NO 424	Not Accredited
Molybdenum ICP (mg/l)	ESKOM METHOD NO 417	Not Accredited
Nickel ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Nitrate as N IC (mg/l)	ESKOM METHOD NO 307	Accredited
pH @ 25 °C	ESKOM METHOD NO 300A	Accredited
Phosphorus ICP (mg/l)	ESKOM METHOD NO 417	Not Accredited
Potassium ICP (mg/l)	ESKOM METHOD NO 415	Accredited
Selenium Hydride (µg/l)	ESKOM METHOD NO 424	Not Accredited
Sodium ICP (mg/l)	ESKOM METHOD NO 415	Accredited
Strontium ICP (mg/l)	ESKOM METHOD NO 412	Accredited
Sulphate IC (mg/l)	ESKOM METHOD NO 307	Accredited
Tin ICP (mg/l)	ESKOM METHOD NO 417	Not Accredited
Total Hardness (mg/l)	ESKOM METHOD NO 015	Not Accredited
Turbidity	ESKOM METHOD NO 418	Not Accredited
Vanadium ICP (mg/l)	ESKOM METHOD NO 417	Not Accredited
Zinc ICP (mg/l)	ESKOM METHOD NO 412	Accredited

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5. All water samples are preserved according to procedure P511 unless otherwise stated.
6. Unless otherwise specified all analyses on water samples give the dissolved constituents.

End of the Report

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