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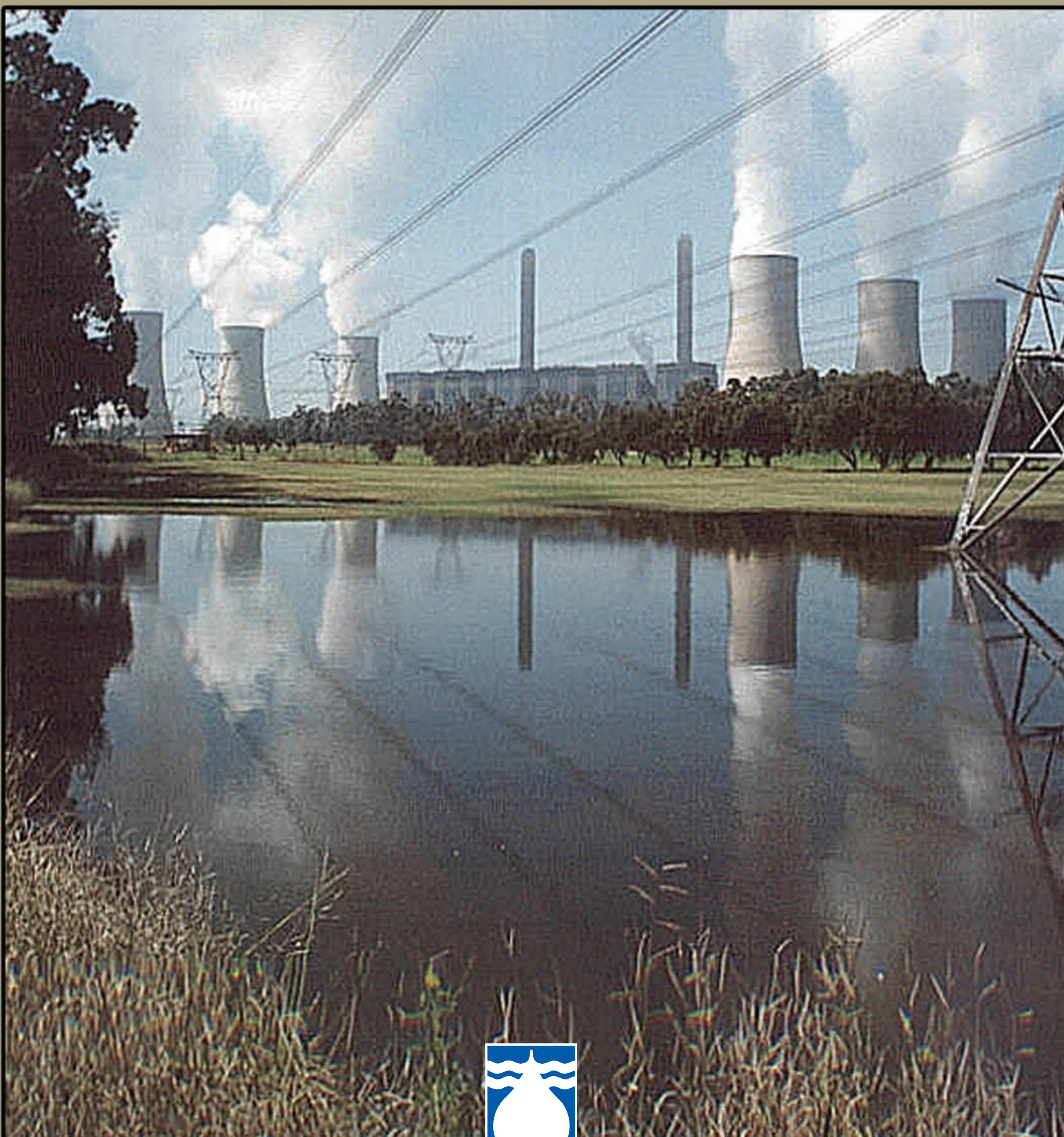
WATER AND WASTEWATER MANAGEMENT IN THE POWER GENERATING INDUSTRY



WATER AND WASTE-WATER MANAGEMENT IN THE POWER GENERATING INDUSTRY

Report to the Water Research Commission

by

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FOREWORD

Access to water and water availability remains a key factor in ensuring the sustainability of development in Southern Africa. The need for guidelines to reduce water intake and to promote better management of this valuable resource is therefore of national interest.

The Water Research Commission (WRC) contracted the Department of Chemical and Metallurgical Engineering from Tshwane University of Technology to undertake a National Industrial Water and Waste-water Survey (NATSURV) focussing on the Power Generating Industry.

Results obtained in this survey form the basis of this Guide on Water and Waste-water Management in the Power Generating Industry.

This guide is expected to be of value not only to industry itself, but also to other interested parties such as municipalities, administrators, researchers and consultants in the water and effluent field. It may be noted that, when assessing water use for domestic and industrial purposes, the water consumed indirectly for power generation should be included in the overall water audit.

SUMMARY

Twenty nine power stations situated countrywide collectively produces approximately 192 000 GW of electricity per annum. To achieve this, approximately 245 000 Ml of water is consumed. The effluent produced is much less than this, as up to 80% of this water is lost through evaporation in cooling towers.

Four major types of power generating processes utilized in South Africa have been identified, namely Coal-fired, Nuclear, Hydro-Electric and Gas Turbine Power Generating Processes. Of these, Coal Fired Processes has the highest water consumption.

The average raw water intake / unit sent out (RWI) is dependent upon the type of power generating process, whether open or closed loop cycles are used, the type of cooling and ashing processes utilized, as well as the quality of raw water. The average RWI was found to be 1.95 l/kWh for recycling wet-cooled coal-fired plants, 6.5 l/kWh for once-through wet-cooled coal-fired plants, 0.09 l/kWh for dry-cooled coal fired plants and 0.073 l/kWh for nuclear plants. Hydro-electric processes do not consume any water, but merely uses the energy in it, and no water is required for power production in gas turbine plants.

Improvements in the RWI can be achieved through the use of dry-cooled systems and water recycling in the case of municipal plants. It is suggested that target RWI's are set at a maximum of 2.5 l/kWh for wet-cooled coal-fired processes and 0.8 l/kWh for dry-cooled power generating processes.

The power generating industry continually assesses the management of water resources and complies with water legislation as determined by the Department of Water Affairs and Forestry. The National Water Act requires all power stations to be registered as water users. In recent years, measures have been taken to reduce the water intake and pollution potential of power generating stations. These measures included the installation of dry-cooling and dry ashing systems, the installation of desalination plants to treat mine water which can be used to supplement raw water sources, as well as improved management and operation of processes (the Zero Liquid Effluent Discharge (ZLED) philosophy that encompasses a number of measures such as reuse, recycling and cascading water use in terms of water quality systems).

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1. INTRODUCTION

Electricity is a basic necessity for the economic development of a country. The survival of industrial undertakings and social structures depend heavily upon low cost and uninterrupted supply of electrical energy.

At present, approximately 192 000 GWh of electricity per annum is produced in South Africa by twenty-nine power stations situated countrywide. The amount of electricity generated is constantly increasing to meet demands. For example, the total amount of power generated increased from 150 000 GWh in 1992 to 192 000 GWh in 2002, which indicates a growth of almost 20%.

Water is one of the major resources required to generate electricity in South Africa, especially in coal-fired power generation plants. To produce 192 000 GWh of electricity, approximately 245 000 Ml of water per annum is consumed, the equivalent of almost 9% of the total capacity of the Vaal Dam. Power Generating Plants use water in enormous quantities compared to other industries.

Water consumption in South Africa is rapidly out spacing available resources. Conservative studies predict that the country's maximum sustainable population of eighty million people will be reached in 2020 with dire consequences; there will not be sufficient water unless better use is made of resources available. It has therefore become imperative to ensure that efficient water consumption and water management techniques are employed and continued, especially in industries consuming large amounts of water, such as the power generating industry.

There are three main role players responsible for Power Generation in South Africa, namely

- Eskom,
- the Government (Municipal Power Stations) and
- Public Private Partnerships (Independent Power Producers).

Eskom has 24 power stations situated countrywide which supply approximately 95% of the electricity in South Africa. There are

- 13 coal-fired stations, the majority situated in Mpumalanga,
- one nuclear power station in the Western Cape,
- two pumped storage stations in the Drakensberg and Western Cape,
- six hydroelectric stations (two along the Gariep River, two along the Umtata River, and one each along the Mbashe and Ncora rivers),
- as well as 2 gas-turbine stations in Cape Town and East London respectively.

Apart from Eskom Power Stations, there are 5 smaller coal-fired stations operated by either regional Municipalities or Public Private Partnerships. These include the

- Athlone Power Station, operated by the City of Cape Town,
- Kelvin Power Station, operated by AES Sirocco & Global African Power,
- Rooiwal and Pretoria West Power Stations, operated by the City of Tshwane and
- Bloemfontein Power Station operated by the Bloemfontein Municipality.

The generating capacity of these stations is shown in Table 1.

The coal fired and nuclear power stations are the only power stations that are fully operated at all times. These stations are referred to as ‘base-load’ power stations, which operate on a 24-hour basis to ensure a constant supply of energy for normal daily consumption.

Hydroelectric and pumped storage schemes are only used during South Africa’s peak periods, such as the early hours of the morning and evenings. Gas-turbine power stations are only used during extreme emergencies due to their very high operating costs.

TABLE 1 : The Net Generating Capacity of Different Types of Power Generating Plants

TYPE	NET MAXIMUM CAPACITY (MW)	% OF TOTAL
Coal-Fired: Eskom Municipal & Private	 34 882 900	 87.7 1.5
Nuclear	1 930	4.9
Pumped Storage	1 400	3.5
Hydro-electric	600	1.5
Gas-turbine	342	0.9

During this study, it was found that most of the power stations operated by municipalities are no longer profitable as municipally run entities due to existing technology as well as lack of capital. Most of these stations, which could in the past generate up to 180 MW, are at present only re-fired in winter times to generate approximately 90 MW.

The Kelvin Power Station in Johannesburg was recently successfully converted to a Public Private Partnership. A decision has also been taken by the City of Cape Town to convert the Athlone power station to either an Independent Power Producer or a Public Private Partnership which will only produce peak power and will have a long term purchase agreement with Cape town.

2. PROCESS RESUMÈ

2.1 Introduction

In principle, a power generation process occurs in two loops or circuits (Figure 1), in which the working fluid for both circuits is water.

The main components of the *primary circuit* include a

- steam generator (either a boiler or reactor),
- steam turbine,
- condenser and
- feedwater pump.

Water must be boiled to produce steam, which requires the input of latent heat. When the steam is condensed in the condenser, the latent heat is released and passed into the cooling water, in the *secondary circuit.*

The secondary circuit contains the
- condenser,
- cooling tower and
- recirculating pump.

The condenser is the main part which joins the primary and secondary circuits.

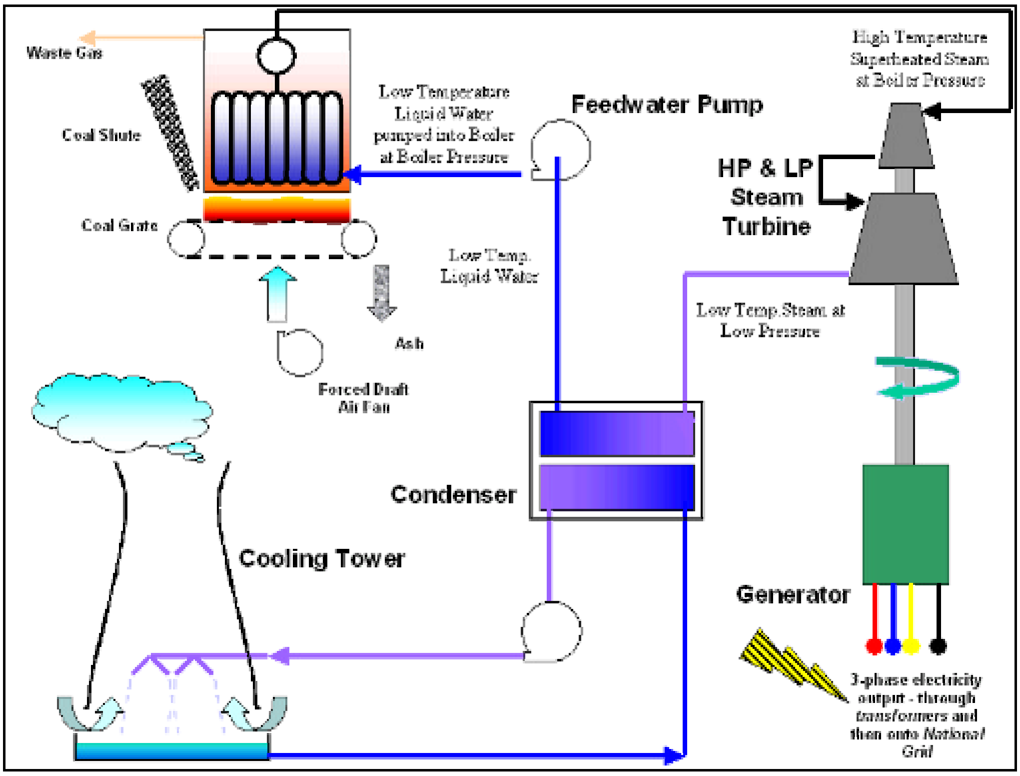

FIGURE 1 : The two main loops of a power generating process

2.2 Types of Power Generating processes

Power generation processes can basically be divided into four major types. The principle of steam generation (as described above) is the same for all types, but the fuel source and type of steam generator differ. Types of power generation processes include

- Coal Fired Processes
- Nuclear Processes
- Hydro-Electric Processes and
- Gas Turbine Processes.

As shown in Figure 2, approximately 90% of power generated in South Africa is generated by means of coal-fired processes. This results from the fact that coal is one of the most abundant sources of energy in South Africa, and that coal mining in South Africa is relatively cheap compared to the rest of the world (in Europe costs are almost four times higher).

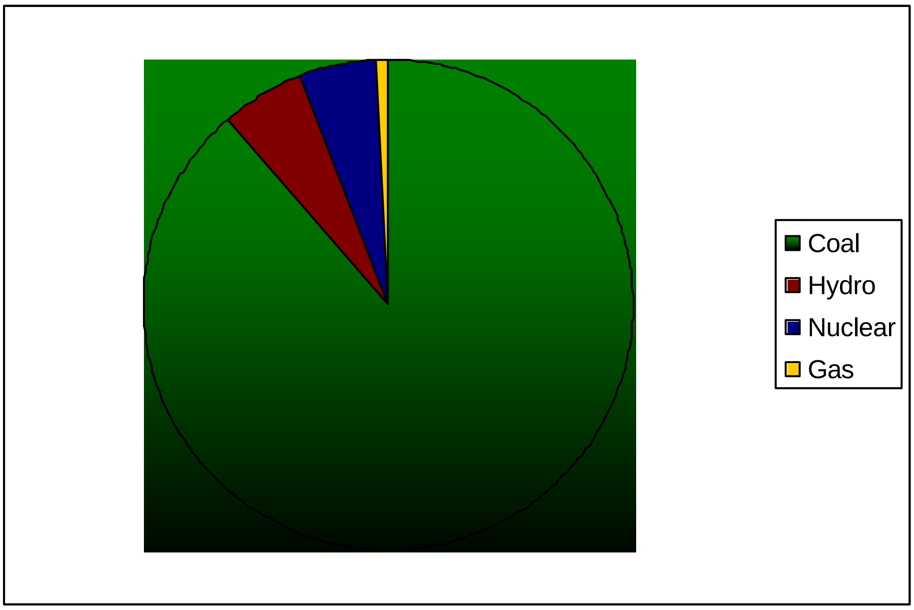

FIGURE 2 : South African Power Generation Mix

2.2.1 Coal Fired Power Generating Process

Although electricity cannot be stored or harnessed from nature directly, electrical energy can be extracted from a fuel source such as coal, oil or natural gas. Coal Fired Power Stations are also referred to as Fossil fuel or Thermal power stations.

Internationally, as well as in South Africa, coal is currently the most widely used primary fuel, accounting for approximately 36% of the world's electricity production. South Africa is the fifth largest coal producing country in the world, exporting 25% of production. Of the remainder, 53% of the coal produced is used for electricity generation.

Coal is transported from the stockyard via storage silos to boiler bunkers by means of conveyor belts. From the boiler bunkers, it is fed to mills where it is pulverized to form dust, which is then blown through boiler burners into a furnace. In the furnace, it burns at a temperature of approximately 1300°C. A heated air stream for combustion purposes is forced by the pressure of a forced fan or sucked by an induced daft fan, to move through the boiler. The chemical energy of the fuel is converted to heat energy, which is then taken up by the boiler feed water to produce steam.

Fly ash and course ash are produced during the combustion process. Course ash falls to the bottom of the boiler and into a submerged scraper convoy trough. The course ash is removed from ash hoppers by means of ash extractors. Ash is damped by means of water sprays and discharged onto belt conveyors. The slurry is either fed to ash dams, where ash settles down and water are recycled (a*sh water cycle*), or it is conveyed to ash bunkers where surplus moisture is drained off prior to discharge into railway trucks or vehicles for disposal.

The air stream however, contains the combustion by-products (sulphur, carbon dioxide, etc.) and fly ash, which are small coal particles that did not burn completely. The fly ash is separated from the flue gases in scrubbers, which may be electrostatic precipitators, bag filters or cyclones. Cleaned flue gases pass to the atmosphere through chimneystacks.

The boiler feed water in the tubing that forms the boiler walls absorbs heat produced by burning the coal. The water is converted to steam at a high temperature and pressure.

The steam produced pass through superheaters to high-pressure steam turbines. Exhaust steam is returned to the boiler re-heaters and then channelled to the intermediate-pressure turbine and low-pressure turbines. Modern steam turbines usually have high pressure and low pressure turbines to improve the efficiency of the energy transfer from steam energy to mechanical energy. The rotating shafts of the steam turbines are coupled to electrical generators. The electricity passes from the generator stator windings to a transformer. The speed at which the steam turbine is operated is very important, as this determines the electrical frequency, for example in South Africa we use 50 Hz.

Figure 3 shows the machine hall of a 2000 MW coal fired power station, which has four 500 MW steam turbine and generator sets.

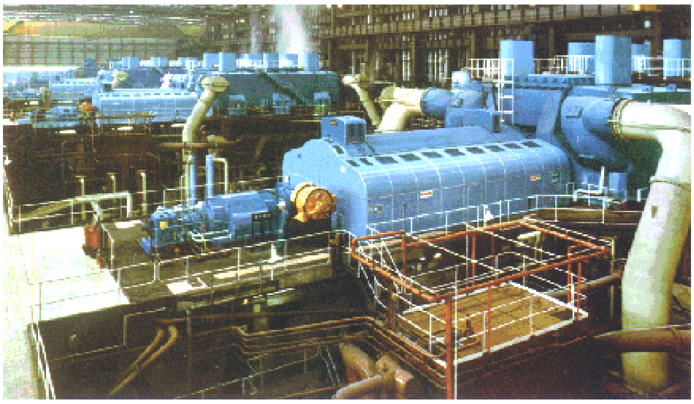

FIGURE 3 : Steam turbines of a 2000 MW coal fired power station

Spent steam is condensed and pumped via feed heaters and de-aerators to the boiler feed pumps and then back to the boiler to repeat the cycle. This water cycle between the boiler and condenser is called the *Demineralisation water cycle.* The condenser in which spent steam is condensed is essentially a heat exchanger operated at near vacuum conditions on the steam turbine side. On the other side of the condenser, chilled water cooled in a cooling tower is pumped by a re-circulating pump into the condenser to remove the latent heat of the low-pressure steam, and allow the steam to phase change back into liquid water. The water cycle between the condenser and cooling towers are called the *Cooling water cycle.*

The cooling fluid is normally raw water, such as river water or sea water. This fluid does not mix with or contaminate the demineralised water used for steam production. At most Municipal power generating plants, treated sewage effluent is used for cooling purposes. Eskom power plants mainly use river water or recycled sewage effluent (to supplement raw water).

Coal Fired Processes make use of two different types of cooling processes, namely

- Wet Cooling and

In wet cooling towers, cooling water circulated through the condenser is sprayed through nozzles into an upward moving air stream in a tower at a height of approximately 13 m. Figure 4 shows wet cooling towers at the Eskom Lethabo and Duvha power stations. The updraught of air through the cooling tower is due to convection. The heat is absorbed by the air and dissipated into the atmosphere. However, water vapour in the form of mist is also lost to the atmosphere. Approximately 80% of the water consumed at wet-cooled power plants is lost due to evaporation from the cooling towers.

FIGURE 4 : Wet cooling towers at the Lethabo and Duvha Power Stations

- Direct / Indirect Dry cooling

Dry cooling units utilises a system whereby the water used for steam generation is passed through radiators installed in the cooling towers. The advantage of dry cooling is that water losses due to evaporation in wet cooling towers are reduced, resulting in a reduction of total amount of water consumed by the power station. However, the disadvantage of using dry-cooled systems is a loss in overall efficiency, which may impact on emissions produced.

There are two basic dry-cooling systems:

- Indirect dry-cooling,
  where heat is conducted from the water to the metal surface of the radiator and from there to the atmospheric air. The air remains dry since the water is in a closed circuit and evaporation is thus minimised.
- Direct dry-cooling (air-cooled condenser),
  where steam from the turbine is directed into a radiator type heat exchanger. The steam's heat is transferred to the metal surface of the finned tube. Air to cool the fins is drawn across the heat exchanger either by natural convection or electrically driven fans.

Figure 5 shows the largest direct dry-cooled station in the world, the Eskom Matimba Power station as well as the largest indirect dry-cooled power station in the world, the Eskom Kendal Power Station.

FIGURE 5 : The Matimba and Kendal Power Stations using the direct and indirect dry-cooled technology respectively.

A schematic diagram of the coal-fired power generation process is shown in Figure 6. The red lines indicate the demineralisation water cycle and the blue lines indicate the cooling water cycle.

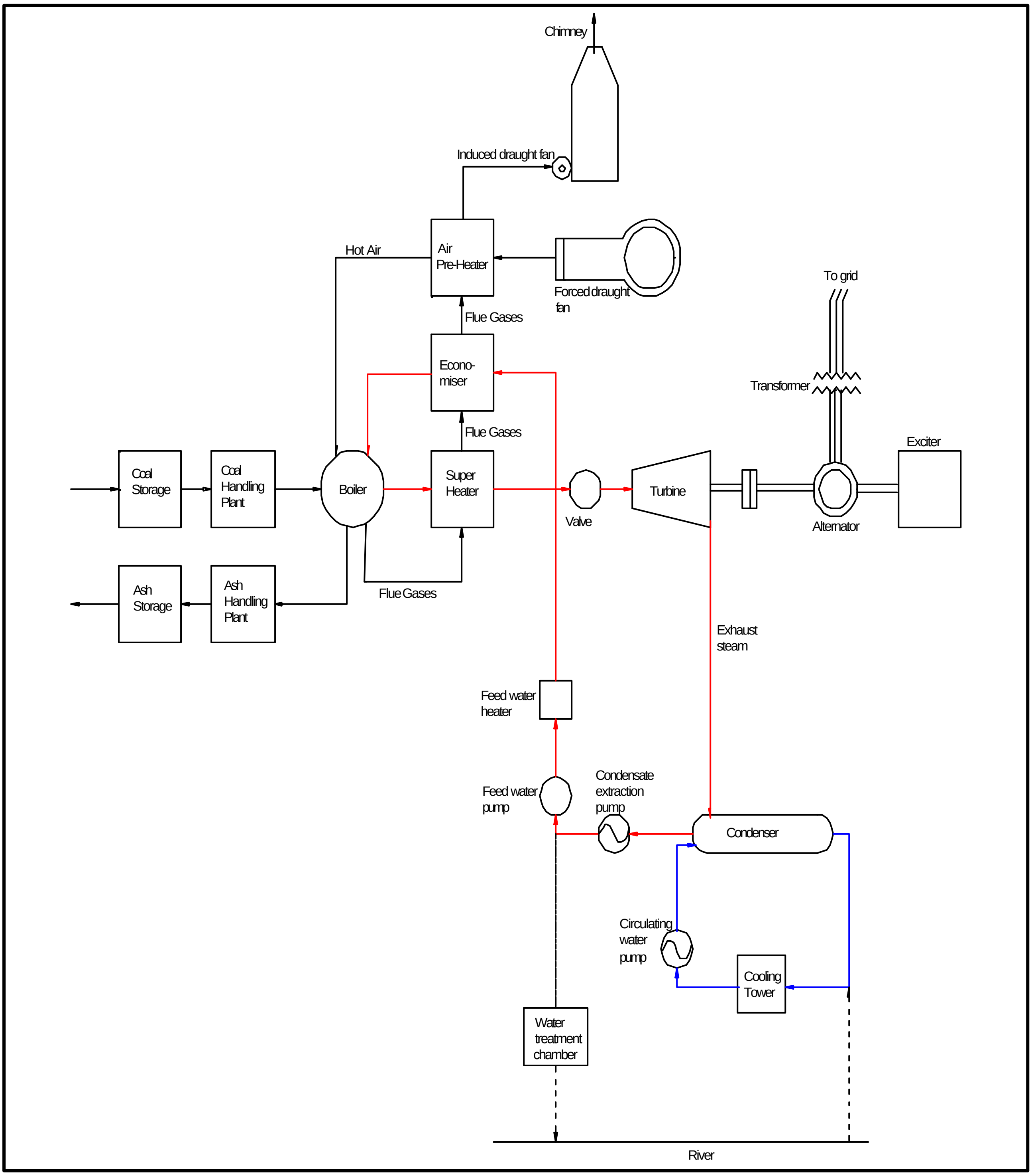

FIGURE 6 : Schematic diagram of the coal-fired power generation process

2.2.2 Nuclear Power Generating Process

In nuclear plants, the natural decay of uranium is used to provide the heat energy required to transform water to steam. Heavy elements such as Uranium (U^{235}) or Thorium (Th^{232}) are subjected to nuclear fission (splitting if atoms) in reactors. The fission process generates heat energy, which is transferred to the primary coolant. The primary coolant consists of purified water, which is kept at a high pressure to prevent it from boiling. Powerful pumps are used to circulate this pressurised water from the reactor vessel through tubes in the steam generator, back to the nuclear reactor vessel. This water circuit is called the *primary circuit.*

The heat energy of the water in the tubes, is used to convert a separate water stream to steam in the steam generator. Similar to coal-fired plants, the steam is used to drive turbines which turn the generators to generate electricity. The steam cycle is called the *secondary circuit.* There is no contact between the water in the primary and secondary steam circuits.

Once the steam has driven the turbines, it flows to condensers where a third water system, *the tertiary circuit*, is used to cool and condense steam back to water, which is circulated back to the steam generator. There is also no contact between the third water system and the primary or secondary circuits. All three water systems are completely closed and separated from each other.

Figure 7 shows a schematic diagram of the nuclear power generating process. The red lines indicate the primary circuit, the blue line the secondary water circuit and the green line the tertiary water circuit.

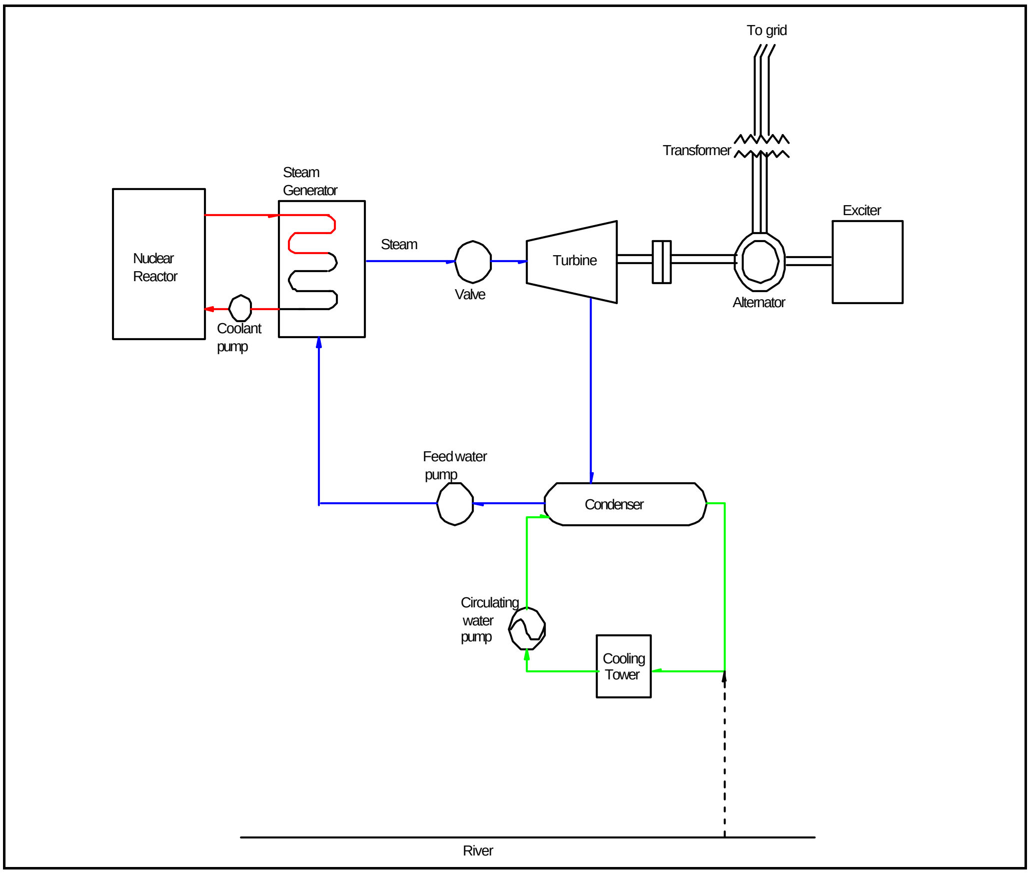

FIGURE 7 : Schematic diagram of the nuclear power generating process

2.2.3 Hydro-Electric Power Generating Process and Pumped Storage Schemes

In conventional Hydro-electric schemes, the potential energy of water stored in a dam is converted into electrical energy.

Water is conveyed through pressure tunnels to a hydraulic turbine. As the water runs through the turbine, it drives a generator coupled to it. Energy generated is fed into the transmission lines that link up to the national grid. Once the water has run through the turbines, it is discharged below the power station to run back into the river and continues its course.

In contrast with hydro-electric schemes, pumped storage schemes does not use the water only once. Whereas a conventional hydro-electric power station creates energy from potential energy stored in water in a dam, the pumped storage scheme first uses energy to pump water into an elevated dam from which it can be released to generate energy when it is needed.

A pumped storage scheme consists of a lower and an upper reservoir with a power station between the two. During periods of low demand, it uses energy to pump water from the lower to the upper reservoir. During periods of emergency or peak demands, this water can then be allowed to run back into the lower reservoir through the turbines to generate electricity.

Pumped storage schemes and hydro-electric power generation plants thus serve as emergency- or peaking power stations that can start generating power within minutes and provide energy for limited periods of time.

Figure 8 shows a schematic diagram of the hydro-electric generating process.

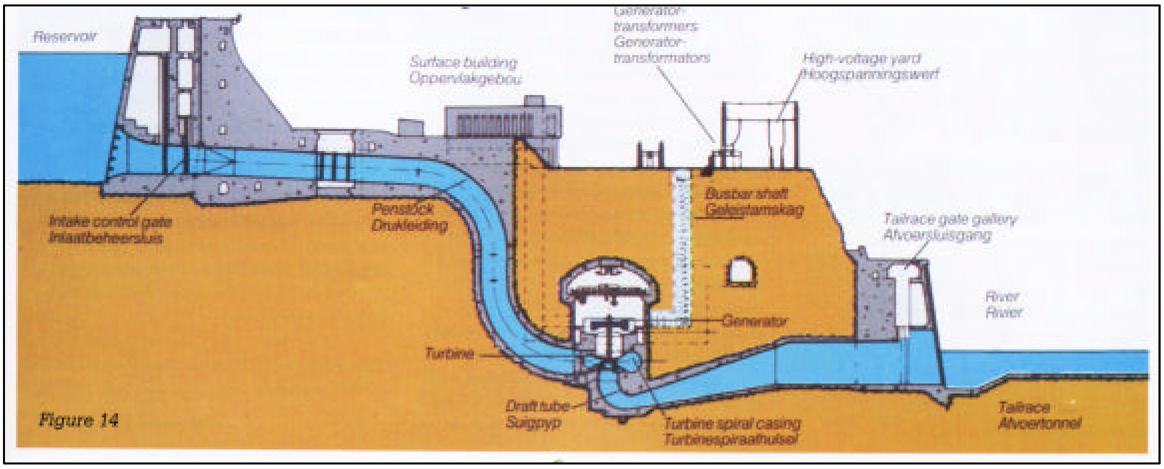

FIGURE 8 : Schematic diagram of the hydro-electric power gene rating process

2.2.4 Gas Turbine Power Generating Process

A Gas Turbine plant employs a gas turbine as the prime mover for the generation of electrical energy. The working fluid for this plant is compressed air which is heated in a combustion chamber either by means of burning fuel or using air heaters. Air at a high pressure and temperature is passed to a gas turbine which in turn drives the alternator converting mechanical energy into electrical energy.

Figure 9 shows a schematic diagram of the gas turbine power generating process. Water is not used in this type of power generating process.

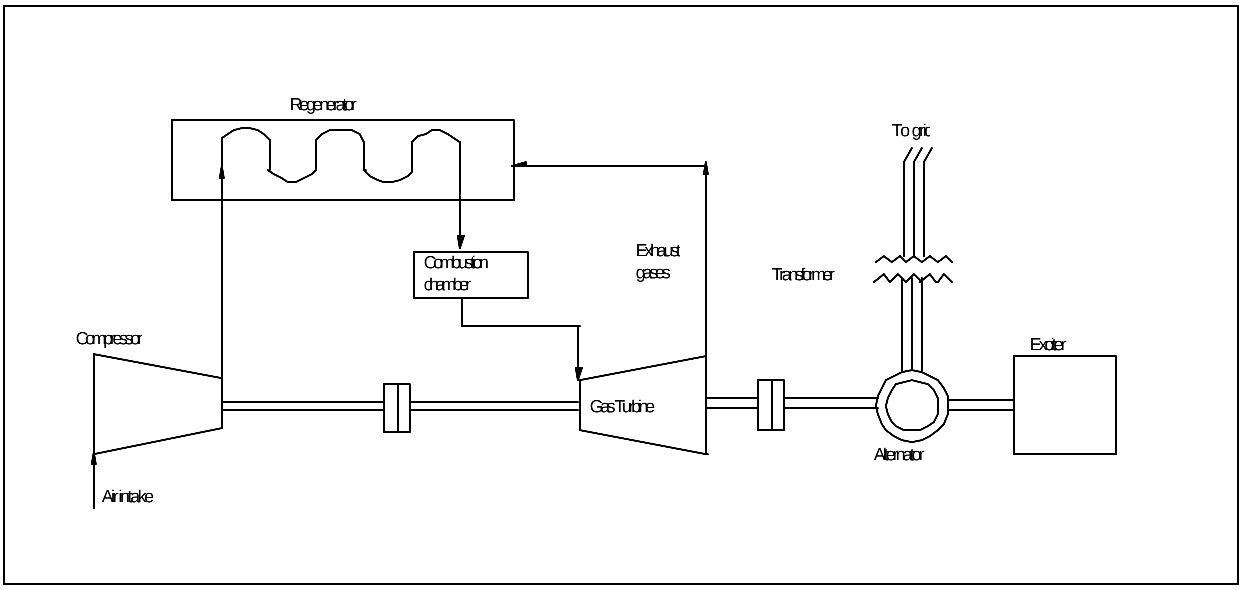

FIGURE 9 : Schematic diagram of the gas turbine power generating process

3. WATER USAGE IN POWER GENERATING PLANTS

Since pumped storage and hydro-electric schemes have non-consumptive water use (it only uses the energy contained in running water), and no water is required for power production in gas turbine plants, water usage will only be considered for coal-fired and nuclear power generating processes.

3.1 Raw Water Sources

Water consumed in power generating plants are supplied by various sources :

- Natural Water Sources

Natural water sources used in power generating plants include Rain water, River water and Sea water. Sea water is only used at the Koeberg Power Station.

- Municipal Water Sources

At various municipal power stations, municipal water or treated effluent from municipal sewage plants are being used. At several Eskom plants, treated sewage effluent from the plant self is recycled and used to supplement raw water used for cooling or irrigation purposes.

3.2 Pre-treatment of Raw Water

At most power stations utilizing raw water from rivers, water is pumped to reservoirs for storage. From the reservoirs, water is pumped to raw water clarifiers in which solid particles and dissolved impurities are being removed by means of a precipitation process (coagulation and flocculation). Flocculants and lime treatment are used. At some power stations water is filtered in pressurised sand filters (after clarification) before distribution to the main water loops.

3.3 Water Distribution

3.3.1 Coal Fired Power Generating Process

The overall raw water intake at coal-fired power generating plants are distributed as shown in Figure 10 below :

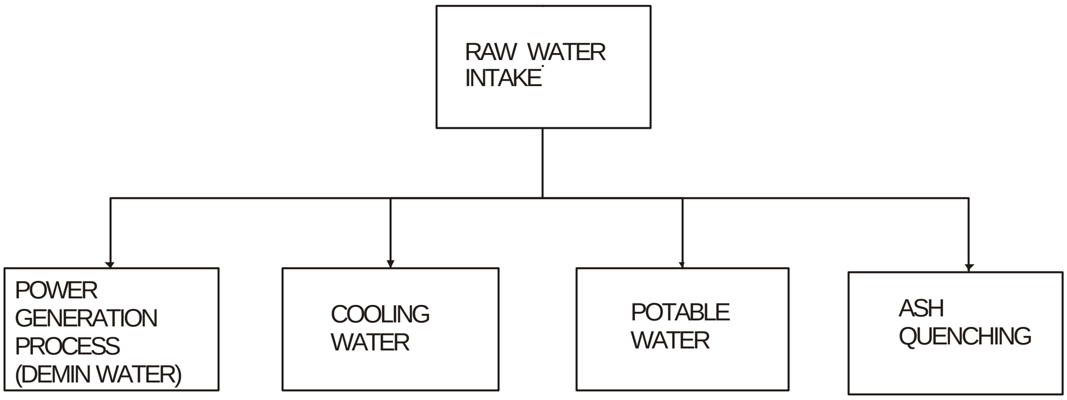

FIGURE 10 : Water Distribution : Coal-Fired Power Generating Processes

Four main water cycles have been identified in Coal Fired Power Generating Plants :

3.3.1.1 Demineralization Water Cycle

Boilers require clean and soft water for longer life and better efficiency. Water from the pressurised sand filters are further demineralised in demineralisation (demin) plants. These plants use ion-exchange processes consisting of three separate demin trains, namely the anion, cation and mixed bed system. The water produced only contains residual impurities of a few parts per billion. The demineralised water produced are used as feedwater to the boilers for steam production. Steam is used to drive turbines whereafter spent steam is condensed in condensers and returned to the boilers by the feedwater pumps. The cycle is described in more detail in section 2.2.1.

3.3.1.2 Cooling Water Cycle

Raw water from the reservoirs are fed directly to the cooling system. The cooling system is described in section 2.2.1. The water used in cooling towers are recirculated and does not mix with or contaminate the demineralised water used for power generating purposes. Biodispersant is added to cooling water at some power stations to prevent the growth of algae.

3.3.1.3 Potable Water Cycle

A small percentage of water from the sand filters is chlorinated to produce potable water for the power station as well as other third parties.

3.3.1.4 Ash Water Cycle

The ash generated after burning coal in the boilers is removed by mixing it with water to form a slurry and removing it with sludge pumps to ash dams. In the ash dams the ash settles down and water is withdrawn for recycling. The water is returned to the station for reuse to convey ash to the ash dams.

3.3.2 Nuclear Power Generating Process

There is only one nuclear power generating plant in South Africa, the Koeberg Power Station, which is situated in the Western Cape.

This specific Nuclear Power Generating plant operate on three separate water systems, namely the

- Primary System
- Secondary System and
- Tertiary System

as described in more detail in section 2.2.2.

3.3.2.1 Primary System

In the primary water system, water is used to remove heat from the nuclear reactor and carry this heat to the steam generators. The water is recirculated to the reactor by means of a pump. The primary system is a closed system.

3.3.2.2 Secondary System

The secondary water system is also a closed system. Water is used in the steam generator for steam production, which drives the turbines and generator for electricity production. The steam leaving the turbine is condensed and circulated back to the steam generator.

3.3.2.3 Tertiary system

The tertiary system is used in the condensers. The cooling water system for the condensers uses seawater to cool the steam in the condensers. Once it has cooled the steam down, it is returned to the sea.

The fact that the 3 systems are separate is important. It indicates that the water in the nuclear reactor, which is radioactive but is in a closed system, does not come into contact with the other two systems and therefore does not contaminate the water in these systems.

Apart from these systems, there is also potable water, which is used for domestic purposes. This water is discharged to the municipal sewer.

3.4 Effluent Produced

All Eskom plants operate on a policy of Zero Liquid Effluent Discharge, i.e. no polluted water is allowed to leave the site under any conditions.

The water control system is designed specifically for treatment and reuse of water and all the liquid effluents produced, including treated sewage and accumulated storm water. All effluents produced are collected and stored in dams on the power station site. This water is then re-used for functions that can accept lower quality water. In this way the amount of wastewater recycled is maximised and the quantity of raw water required is minimised.

The wastewater dams used by power stations are managed carefully in terms of the water quality and water level to minimise the impact of any spillage into the natural environment. The only way in which water mostly leaves the confines of the station is by evaporation from the cooling towers.

In contrast with Eskom power stations, municipal power stations make use of *once through systems* utilizing municipal water as water source. After usage, most water is disposed off to the municipal sewer. At the Kelvin Power Station, effluent from the demineralisation water cycle as well as treated cooling water are partially recycled and used for ashing and dust control purposes.

The Rooiwal Power Station implemented a closed cycle in 2002. Cooling water, condensate from the demineralisation cycle and return water from ash dams are treated and re-used, similar to the water control systems in Eskom plants.

3.4.1 Coal Fired Power Generating Process

Effluents produced at coal-fired power generating plants include

- sandfilter backwash
- raw water clarifier sludge
- cooling water blowdown and side streams
- cooling water sludge and
- spent ion-exchange regenerants.

Clarifier sludge and spent ion-exchange regenerants together contain all the dissolved solids and chemicals introduced into the power station. These effluents are mainly used for fly-ash conditioning.

Dissolved salts present in the make-up raw water to cooling towers as well as the daily accumulation of salts and solids in the circulating water are concentrated as a result of evaporation from the cooling towers. These salts must be eliminated from the system to prevent scale build-up and its associated problems. To reduce the build-up of salts in the cooling water cycle, a side stream is regularly drawn of the cooling water circuit.

This cooling water side stream, as well as station effluents recycled from the dirty drains storage dam and bottom-ash quenching water from the boiler are sent to clarifiers for treatment. Water is treated with lime and soda ash resulting in the precipitation of solids. The clarifier overflow returns to the cooling towers as make-up water.

A process flow sheet of water use and recycling is shown in Appendix A.

3.4.2 Nuclear Power Generating Process

Effluents produced by nuclear plants include

- sewage Effluent
- treated Radiological Effluent
- conventional Liquid Effluent and
- cooling water.

All effluent is discharged to the sea.

4. SUMMARY OF SURVEY RESULTS

4.1 Raw Water

The Mean Raw Water Intake / unit sent out (RWI) gives a good indication of the water efficiency of a power generating process. Raw water intake and qualities obtained during the survey are presented in the tables below.

4.1.1 Coal-Fired Power Generating Plants

The water intake for coal-fired power plants is summarized in Table 2 below. Data was gathered for ten Eskom coal-fired plants and two municipal plants. The Bloemfontein Power Station as well as the Athlone Power station was found to be non-operational at the time of this study. These stations are at present only re-fired in winter times. The Pretoria West Power Station was not willing to co-operate in this research project.

TABLE 2 : Mean Raw Water Intake / Power generated (l/kWh) for Coal-Fired Processes

	RAW WATER INTAKE / UNIT SENT OUT (l / kWh)		WATER RECEIVED (Ml / month)	
	WET-COOLED	DRY-COOLED	WET-COOLED	DRY-COOLED
Eskom Power stations River Water	1.70 - 2.20	0.08 -0.10	1500 – 4000*	220 - 260
Other Power stations : Treated Sewage Water : Municipal Water:	1.80 - 6.49		557.55 -646.63 11.15 - 67.38	

* Depends on the units generated in a particular station. Normally a wet cooled station using 1500 Ml/month would be operating at a low load factor.

Water received by most Eskom coal-fired power generating plants comes from nearby rivers, including the Vaal, Usutu and Komati Water Systems as well as the Slang river and Mongol River. A diagram depicting the water supply schemes to the Power Stations in Mpumalanga is attached in Appendix B.

Water received by municipal plants includes

- treated sewage water from nearby sewage works which are used for cooling purposes,
- rain water and
- municipal water sources which are used for domestic purposes as well as primary energy demands.

4.1.2 Nuclear Power Generating Plants

Water received by the nuclear power generating plant in the Western Cape comes from three different sources, including :

- Municipal Water

Water received from the municipality are used for domestic, horticultural and primary energy demands.

- Borehole Water and

Borehole water is primarily used for primary energy production.

- Seawater

Seawater is only used for cooling purposes and is afterwards returned to the ocean.

The raw water intake for this nuclear power plant is summarized in Table 3 below.

TABLE 3 : Mean Raw Water Intake/Power generated (l/kWh) for Nuclear Processes

WATER SOURCE	AVERAGE CONSUMPTION (l / KWH)	WATER RECEIVED Ml / MONTH
Municipal Water	0.073 - 0.090	55.97 – 105.54
Borehole Water	0.000 - 0.005	0.00 - 1.35
Sea Water (used only at the Koeberg Power Station)	0.185 - 0.211	175.78 - 178.58
Total	0.258 – 0.306	**231.752 – 284.12**

4.1.3 Raw water Quality

The chemical composition of raw water received by coal-fired power generating plants is given in Table 4. The raw water quality for nuclear plants was not available.

TABLE 4: Quality of Raw Water received : Coal Fired Power Generating Plants.

	Turbidity (NTU)	pH	Conductivity (µS/cm)	p-Alk (mg/kg)	M-Alk (mg/kg)	Total Hardness (mg/kg)	Ca Hardness (mg/kg)	Mg Hardness (mg/kg)	Na (mg/kg)
River water	0.71 -50.84	6.65 – 8.29	80 - 290	0.00 - 1.00	6 - 103	29 - 115	16 - 70	6.07 - 58	3.9 - 18
Municipal water	Not available	7.8 – 8.9	210 - 267	0 – 20	33 - 88	74 - 164	46 - 108	12 - 88	Not available
Sewage water	Not available	6 - 8.4	481 - 647	0	42 - 104	98 - 194	65 – 170	28 - 105	Not available

	K (mg/kg)	Cl (mg/kg)	SO_4 (mg/kg)	SiO_2 (mg/kg)	Fe ppm	Mn ppm	F Ppm	Zn ppm	NO_3 ppm
River water	0.29 - 4.6	2.0 - 14	2.4 - 27.7	0.98 -32.30	0.18 - 0.43	0.01 - 0.02	0.08 - 3.49	0.01 – 0.37	0.51 - 3.49
Municipal water	Not available	2 - 13	Not available	Not available	Not available	Not available	Not available	Not available	Not available
Sewage water	Not available	27 - 86	Not available	Not available	Not available	Not available	Not available	Not available	Not available

4.2 Water distribution

4.2.1 Coal Fired Power Generating Plants

The distribution of raw water to the main four water systems as discussed in section 3.3.1 for coal-fired plants is shown in Table 5.

TABLE 5: Water Distribution : Coal Fired Power Generating Plants

	% OF RAW WATER WATER		
	WET COOLING		DRY COOLING
WATER CYCLE	ESKOM	MUNICIPAL	
Demineralized Water Cycle	< 5%	3 - 12 %	< 5%
Cooling Water Cycle	80 - 90%	63 - 85%	Negilible
Potable Water Cycle	5 - 10%	3 - 10%	90%
Ashing Water Cycle	1 -10 %	5 - 20%	< 5%

4.2.2 Nuclear Power Generating Plants

The distribution of raw water to the three water systems as discussed in section 3.3.2 for nuclear plants is shown in Table 6.

TABLE 6: Water Distribution : Nuclear Power Generating Plants

SUB-SYSTEM	% OF RAW WATER USED
Primary System + Secondary System (Demineralized water)	24% - 33%
Tertiary System (Cooling)	67% - 76%
Third parties	0.3 - 0.5%

4.2.3 Quality of Cooling, Potable, Sewage and Ash Water

The quality of water for cooling, potable and ashing water systems as well as sewage effluent in municipal and Eskom coal-fired plants are given in tables 7,8,9 and 10. Note that Tables 7 and 9 present Eskom cooling water standards and Eskom potable water standards. The standards imply that Eskom plants are supposed to operate within these. Occasionally, plants may operate outside these limits for various reasons and those situations are rectified accordingly.

TABLE 7 : Quality of Cooling Water : Wet-cooled Coal Fired processes

	CaH ppm as $CaCO_3$	Cl ppm	Fe ppm	K ppm	K_{25} µS/cm	Phosphate as PO_4 ppm	M-Alk ppm as $CaCO_3$	Na ppm
ESKOM*	200 - 500	< 400	No specified	Not specified	< 4000	< 0.5	80 – 120	< 500
MUNICIPAL	Not Available	64.0 – 256.0	Not Available	Not Available	69.0 – 256.0	Not Available	Not Available	Not Available

	PAlk ppm as $CaCO_3$	pH @ 25ºC	SiO_2 ppm	SiO_2xMgH ppm	SO_4 ppm	$CaCO_3$ Precipitation potential ppm	Turbidity (NTU)	Zn ppm
ESKOM*	< 7.5	8.1 – 8.6	< 150**	< 25 000	< 1000	< 30***	< 100	Not specified
MUNICIPAL	Not Available	8.26 – 8.75	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available

*Eskom Cooling Water Standard : Wet-cooled Coal Fired processes operated within the standard
** Subject to limitation of MgHxSiO_2
*** with crystal modifier $CaCO_3$ precipitation potential < 45 ppm

TABLE 8 ; Quality of Ash Water

	CaH ppm as $CaCO_3$	Cl ppm	K ppm	K_{25} µS/cm	M-alk ppm as $CaCO_3$	MgH ppm as $CaCO_3$	Na ppm
ESKOM	36.3 – 868.5	34.7 – 251.0	18.3 – 96.5	1647.6 – 3263.8	212.9 – 660.5	6.3 - 25	78.4 – 287.5

	PAlk ppm as $CaCO_3$	pH	SiO_2 ppm	SO_4 ppm	TH ppm as $CaCO_3$	Turbidity (NTU)
ESKOM	64.7 – 632.3	10 - 12	2.3 – 7.3	380.0 – 519.6	61.3 – 879.4	0.42 – 17.4

TABLE 9 : Quality of Potable Water

	CaH ppm as $CaCO_3$	pH	Turbidity (NTU)	K ppm
ESKOM*	1.08 – 31.43	> 7.5	< 1	Not specified
MUNICIPAL	Not available	8.9-9.3	Not available	Not available

	K_{25} µS/cm	MgH ppm as $CaCO_3$	Na ppm
ESKOM*	< 700	< 70	< 100
MUNICIPAL	220	Not available	Not available

* Eskom Potable Water Standard

TABLE 10 : Quality of Sewage Effluent

	COD ppm	Free Cl_2 ppm	pH	SO_4 ppm as P
ESKOM*	31.3 – 74.9	0.1 – 2.2	6.7 – 9.0	0.6 – 10.1
MUNICIPAL	67	Not Available	7.2	Not available

	K_{25} µS/cm	M-alk ppm as $CaCO_3$	Turbidity (NTU)	NO_3 ppm as N
ESKOM*	32.2 – 725.3	72.5 – 101.8	5.6 – 14.5	0.4 – 15.5
MUNICIPAL	130	Not available	Not available	Not available

4.3 Effluent produced

4.3.1 Coal-Fired Power Generating Plants

A summary of effluents produced at coal-fired power generating plants is given in Table 11.

TABLE 11 : Water to Waste : Coal-Fired Processes

	COAL FIRED PLANTS (l/kWh)	**MUNICIPAL (l/kWh)**
TOWER EVAPORATION	1.6 (40-115 Ml/day)	2.52
WATER DISCHARGE TO WASTE	0.049	1.92
WATER RECLAIMED TO ASH SYSTEM	0.049	0

4.3.2 Nuclear Power Generating Plants

A summary of effluents produced at nuclear power generating plants is given in Table 12.

Table 12 : Water to Waste : Nuclear Processes

EFFLUENT TYPE	AMOUNT (Ml / MONTH)
SEWAGE PLANT EFFLUENT	1.2
TREATED RADIOLOGICAL WASTE	1.6
CONVENTIONAL LIQUID EFFLUENT	89.443

5. DISCUSSION

Results show that the main functions of water in the power generating industry include

- Steam Generation and Heating
- Cooling
- Wet cleaning
- Ash disposal (wet ashing systems)
- Dust suppression
- Regenerants and other chemical make-up dilution and
- Irrigation.

The quality of the water required for these various functions differ. Some functions, such as the steam generation process, need water of a high quality (pureness) to ensure efficient and reliable operation of the systems and equipment. Other functions, such as the cooling processes, can use water of a lower quality.

The raw water intake/unit sent out (RWI) for the power generating industry in South Africa depends largely on the technology employed at the various power stations.

Results show that dry-cooled coal fired power stations have the lowest RWI (0.09 l/kWh) compared to other plants (1.95 l/kWh for wet-cooled coal fired power plants and 0.073 l/kWh for nuclear power generating plants). It was found that evaporation from cooling towers account for the large proportion (65-80%) of the RWI for wet-cooled systems.

These losses are reduced significantly by applying the dry-cooled technology, resulting in an overall reduction of the total amount of water consumed. At present, the total dry-cooled installed capacity in South Africa is 10 477 MW which is approximately 33% of the total capacity for coal fired stations. It is estimated that an average water saving of 7.2 million cubic meters per month is achieved by the total production of dry cooled power plants. However, it also results in a loss of generation capacity in the order of 8% and an increase in capital as well as operating costs.

Apart from evaporative losses in power generating plants, effluent volumes generated are small compared to the raw water intake. It is possible to recycle most water and thus minimise effluent generated. However, most municipal plants still utilise once-through systems with only partial recycling resulting in the use of large volumes of raw water. Results indicated a significant difference in the RWI for wet-cooled power plants with water recycling (1.95 l/kWh) compared to wet-cooled power plants using once-through systems (6.5 l/kWh).

Results also show that wet ashing systems uses much more water than dry ashing. The difference between wet ashing and dry ashing is that in wet ashing, water is used to convey ash from the boiler to the ash dam in pipelines. In dry ashing, ash is conveyed on conveyor belts with minimum water just to dampen the ash to suppress dust. It is estimated that dry-ash removal systems could result in water savings of approximately 60 Ml per month per station.

Eskom has undertaken several projects over the last few years resulting in a significant decrease in overall water consumption (figure 11). Sufficient data could not be gathered to determine the improvement in the case of power stations operated by municipalities and public private partnerships.

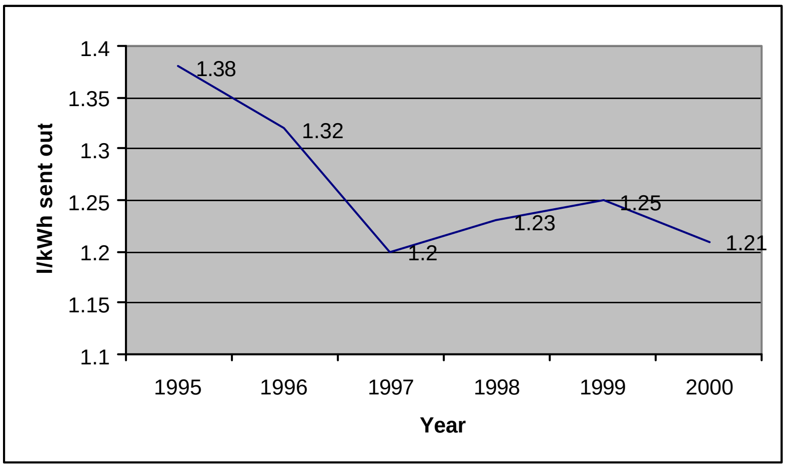

FIGURE 11 : Improvement in raw specific water consumption per kilowatt hour electricity generated for Eskom Power Generating Plants (including wet-cooled, dry-cooled, nuclear and non-consumptive peaking stations)

The Rooiwal Power station implemented recycling of cooling water as from 2002.

There is a significant difference in raw water quality for power plants, which results from the use of mainly river water at Eskom plants and treated sewage water at municipal plants. Pre-treatment of water is necessary to improve boiler life and efficiency. The three main types of impurities monitored and treated include oxygen, hardness (Calcium and Magnesium) and alkalinity. Oxygen must be removed since it oxidizes steels to rust. Oxygen-related corrosion is particularly dangerous since it can be localized in the form of pits that penetrate the metal of the boiler.

Similar to oxygen, the presence of hardness ions also hinders boiler operation. As water is heated in the boiler, the solubility of calcium and magnesium ions decreases, allowing them to precipitate on boiler surfaces, causing scaling which hinders steam-generation efficiency. To remove hardness, water is softened by adding lime.

Alkalinity refers to bicarbonate and carbonate anions which decompose in the boiler to form carbon dioxide. When steam condenses, the carbon dioxide dissolves in the water to form carbonic acid, which can be corrosive. Alkalinity is therefore removed in the demineralisation pre-treatment system.

The main components monitored in cooling water is dissolved impurities and salts. Due to evaporation of large amounts of water from cooling towers, dissolved salts and impurities are concentrated in the remaining cooling water. It is of utmost importance to control the concentrations of these salts and impurities to prevent scaling, corrosion and erosion. To reduce the build-up of salts, a side stream is regularly drawn of the cooling water circuit and treated with lime and soda ash to precipitate solids. The treated water returns to the cooling towers as make-up water. Allowable levels of impurities in cooling water are shown in Table 13 .

TABLE 13 : Allowable levels of impurities in cooling water

PARAMETER	ALLOWABLE LEVEL
pH @ 25ºC	8 – 8.7
Turbidity	< 100
P-Alk (as mg/l CaCO3)	< 15
M-Alk (as mg/l CaCO3)	80 – 180
Sulphates (as mg/l SO4)	< 1000

At present, several power stations investigate the use of desalination plants to recover and treat mining effluent, with the aim of using this recycled mine water to supplement raw water. This would result in a further reduction in RWI. Research on this topic is still undergoing development but has successfully been implemented at the Lethabo and Tutuka Eskom Power Stations. Water savings in power generating plants will not only benefit providers, but assist greatly in preserving South Africa’s limited water sources. It is therefore important to use this precious resource more efficiently and research aiming towards water savings should be ongoing.

6. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that

- Water is definitely a major resource required to generate electricity in South Africa, especially in coal-fired power generation plants.

- The raw water intake per kW electricity generated is largely influenced by

  - the type of cooling process utilized (wet-cooling / dry cooling or a combination) in coal-fired plants
  - the type of ashing system used, wet or dry, and
  - whether cooling water is recycled or once-through systems are used.

- Dry cooled coal fired power stations have the lowest RWI.

- Wet ashing uses much more water than dry ashing.

- Recycling of cooling water results in significant water savings.

- It is not realistic to set specific targets for RWI for the Power Generation Industry as a whole since the RWI is influenced by the technology employed at each power station. However, a maximum RWI of 2.5 l/kWh at wet-cooled power stations and 0.8 l/kWh at dry-cooled power stations is achievable.

In order to utilize water intake more efficiently, it is recommended that

- all power generation plants co-operate with the department of Water Affairs and Forestry to develop and implement suitable water management plans, if not yet in place;

- methods of reducing water use and minimizing wastages must be identified and implemented;

- methods of water recirculation in municipal plants be investigated and implemented;

- an appropriate system for the monitoring of water use and construction of a monthly water balance be implemented at *municipal power stations*;

- environmental issues such as biological monitoring of cooling water be addressed;

- operating personnel be informed about the importance of water conservation and be involved in a water management programme and

- opportunities for reducing RWI and improving the efficiency of water use be identified and acted upon.

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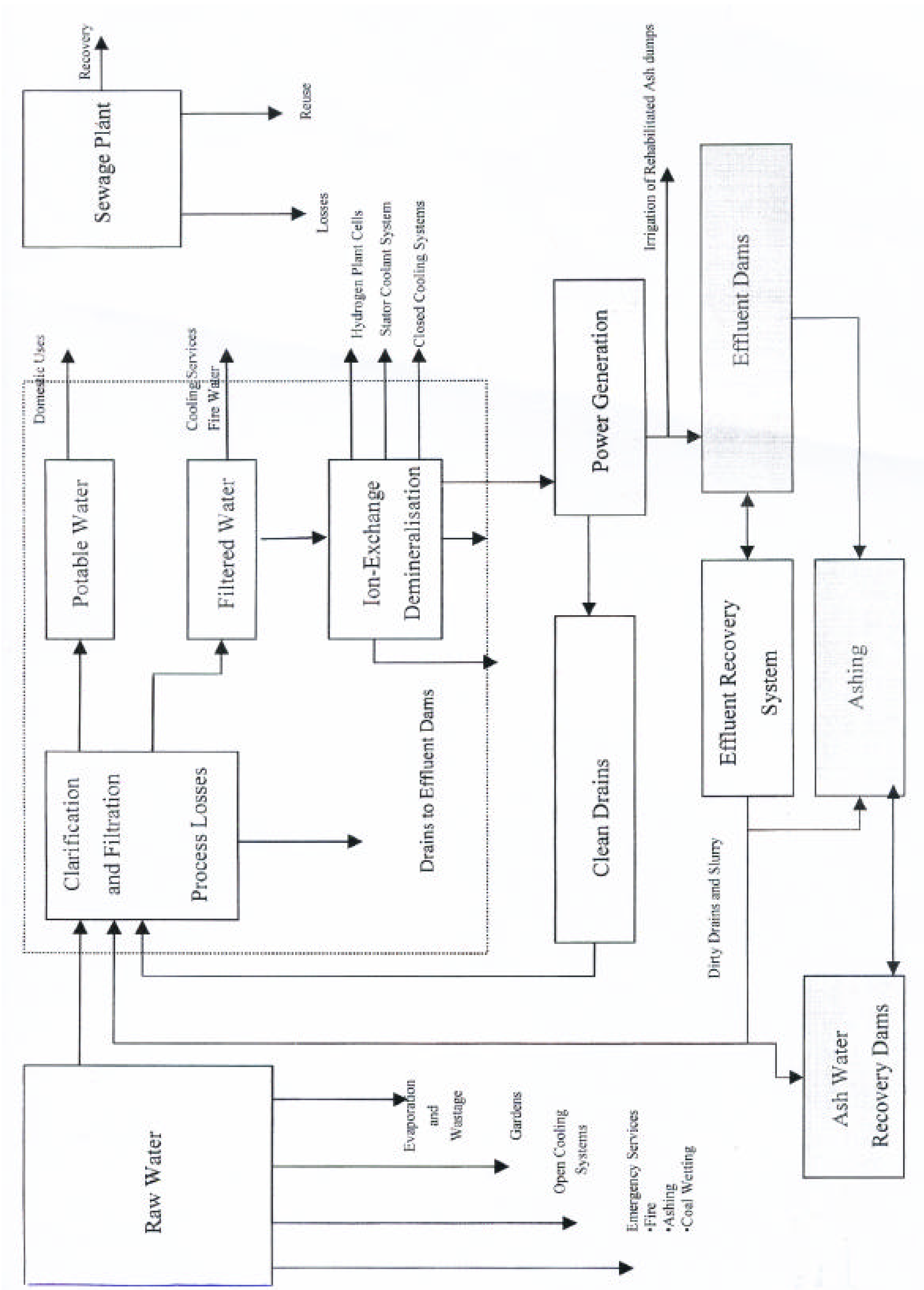
APPENDIX A : RAW WATER DISTRIBUTION



APPENDIX B : WATER SUPPLY SCHEME IN MPUMALANGA