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A RISK ANALYSIS AND MITIGATION FRAMEWORK TO REDUCE THE IMPACT OF ELECTRICITY DISRUPTION ON WATER SUPPLY: BASED ON A COST VS. BENEFIT ANALYSIS CASE STUDY

JC POTGIETER

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AND MITIGATION FRAMEWORK
TO REDUCE THE IMPACT OF ELECTRICITY
DISRUPTION ON WATER SUPPLY:
BASED ON A COST VS. BENEFIT
ANALYSIS CASE STUDY

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DISSERTATION SUMMARY

A RISK ANALYSIS AND MITIGATION FRAMEWORK TO REDUCE IMPACT OF ELECTRICITY DISRUPTION ON WATER SUPPLY: BASED ON A COST VS. BENEFIT ANALYSIS CASE STUDY

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Mitigating the impact of electricity disruptions on water supply was investigated as a case study on the City of Tshwane. The case study was done based on a Risk Analysis and Mitigation Framework of Integrated Water and Electricity Systems, or RAMFIWES. This study includes (1) analysing the risks associated with water supply interruptions due to electricity disruption events, (2) proposing institutional and design guidelines to mitigate the impact of electricity disruption events to the various parties involved (electricity suppliers, Water Service Providers and Water Service Authorities), (3)

estimating the cost of implementing various mitigating measures identified and (4) comparing this cost with the estimated economic benefit of ensuring uninterrupted water supply. Risk categories that were addressed are short-term disruptions of less than one day (for instance due to electrical maintenance with and estimated recurrence interval of 1 year), medium-term disruptions of up to a week (for example due to local distribution network failures as a result of vandalism or theft with an estimated recurrence interval of 20 years) and long-term electricity disruptions up to a month or even longer (for example due to a national blackout with a recurrence interval of 100 to 155 years). The direct economic benefit of ensuring uninterrupted water supply in the event of electricity disruption events were analysed through cost vs. benefit analyses. It was found that the direct benefit / cost ratio of supplying water during electricity disruption events is approximately 5.6 for wet-industries and 117 for other economic sectors in the City of Tshwane. The less easily quantifiable socio/political costs associated with longer duration wide area events are regarded to be much greater than the direct costs. The infrastructure required to ensure uninterrupted water supply during long-term electricity disruption events would result in an estimated increase of approximately 1% of the consumer's water tariff. It should further be noted that installing the infrastructure to mitigate long-term electricity disruption events will also in turn mitigate all shorter duration electricity disruption events'effects on water supply will also be mitigated.

ABSTRACT

Title:	A risk analysis and mitigation framework to reduce the impact of electricity disruption on water supply: based on a cost vs. benefit analysis case study
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Mitigating the impact of electricity disruptions on water supply was investigated as a case study on the City of Tshwane. The case study was approached through the development and application of a Risk Analysis and Mitigation Framework of Integrated Water and Electricity Systems, or RAMFIWES. Risks associated with water supply interruptions due to electricity disruption events were analysed; risk categories that were addressed are short-term disruptions of less than one day, medium-term disruptions of up to a week and long-term electricity disruptions up to a month or even longer. The direct economic benefit of ensuring uninterrupted water supply in the event of electricity disruption events were analysed through cost vs. benefit analyses. It was found that the direct benefit / cost ratio of supplying water during electricity disruption events is approximately 5.6 for wet-industries and 117 for other economic sectors in Tshwane. The less easily quantifiable socio/political costs associated with longer duration wide area events are regarded to be much greater than the direct costs. The infrastructure required to ensure uninterrupted water supply during electricity disruption events would result in an estimated increase of approximately 1% of the consumer's water tariff.

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LIST OF ABBREVIATIONS

AADD	-	Annual Average Daily Demand
AAPV	-	Average Annual Present Value
BRC	-	Board of Rand Water
CCP	-	Critical Control Point
CDC	-	Centre for Disease Control
CRA	-	Coarse Risk Analysis
CRC	-	Current Replacement Cost
CoT	-	City of Tshwane
CSIR	-	Council for Scientific and Industrial Research
DRMP	-	Disaster Risk Management Programme
DWS	-	Department of Water and Sanitation
EMP	-	Electro Magnetic Pulse
EPA	-	Environmental Protection Agency
Eskom	-	Electricity Supply Commission
ETA	-	Event Tree Analysis
FEMA	-	Federal Emergency Management Agency
FMEA	-	Failure Modes and Effect Analysis
FMECA	-	Failure Modes, Effects and Criticality Analysis
FRC	-	Future Replacement Cost
FTA	-	Fault Tree Analysis
GDP	-	Gross Domestic Product
GIS	-	Geographic Information System
HAZID	-	Hazard Identification
HAZOP	-	Hazard and Operability analysis
HCI	-	Hydraulic Criticality Index
MTTF	-	Mean Time To Failure
MTTR	-	Mean Time To Repair
NPV (PV)	-	Net Present Value (or Present Value)
NRW	-	Non-Revenue Water
PAHO	-	Pan American Health Organisation
PFD	-	Probability of Failure on Demand
PHA	-	Preliminary Hazard Analysis
QCRA	-	Quantitative Chemical Risk Assessment

QMRA	-	Quantitative Microbiological Risk Assessment
RAMFIWES	-	Risk Analysis and Mitigation Framework of Integrated Water and Electricity Systems
RBD	-	Reliability Block Diagram
RI	-	Recurrence Interval
RW	-	Rand Water
SANS	-	South African National Standard
SCADA	-	Supervisory Control and Data Acquisition
SIV	-	System Input Volume
THDB	-	Technau Hazard Data Base
UE	-	Undesired Event
UNISDR	-	United Nations International Strategy for Disaster Risk Reduction
WCDS	-	Water Conservation Demand Strategy
WRC	-	Water Research Commission
WSP	-	Water Service Provider
WSS	-	Water Supply Systems
WTW	-	Water Treatment Works
WWTW	-	Wastewater Treatment Works
W_2RAP	-	Wastewater Risk Abatement Plan

1 INTRODUCTION

1.1 BACKGROUND

The water supply sector is at the core of economic growth and social well-being. Water is indispensable to human survival. It is a quencher of thirst, a generator of power, a grower of crops and a basic natural resource for daily existence. Without water, there can be no power, no industry, no agriculture and no cities. Electricity disruptions can cause water supply interruptions which will have dire social and economic consequences for urban, densely populated areas (ADB, 2009).

Water and electricity are intrinsically linked: either one of the two can't be supplied without the other. This link is often referred to as the Energy-Water Nexus (Copeland and Carter, 2017). Electricity is used in the water sector for pumping, treatment of raw water, distribution of potable water, collection and treatment of wastewater, and water discharge.

Until recently in South Africa electricity supply used in the water sector was considered safe and the risk of electricity supply failure did not play a significant role in the design and operation of water supply and distribution systems.

Load shedding prompted the Water Research Commission of South Africa (WRC) in 2010 to conduct a high-level study of the effect of electricity disruptions, specifically load shedding, on water supply (Winter, 2011). Using the Winter (2011) study as background this study, also funded and initiated by the WRC[1], explores the implications in greater detail and takes account of new concerns that have arisen since 2011.

The major concerns include:

- Load shedding;
- Distribution failure; and
- A total or partial blackout.

Each occurrence has an array of possible causes, each with its own consequences. In particular, the consequences for potable water supply can be severe. This is especially true of much of the Gauteng water supply area, which straddles the continental divide, with most of the water

[1] WRC Project No. K5/2591: Mitigating the impact of electricity disruption on water supply.

supplied having to be pumped 200 km and raised through a pumping head of more than 300 m before it can be distributed to users.

The direct impacts of electricity supply failure include economic dislocation due to traffic congestion and disruption of businesses, health services problems, security risks and inconvenience and frustration of the public who have to use candles and torches, switch on generators or put up with cold or late meals. However, cutting off water supply can have explosive socio-political results, especially in the large poor section of the country's communities (where household water storage is negligible and transportation is limited and costly). The longer and more widespread the outage, the more inflammatory the situation could become.

The various risks posed by electricity disruption on water supply were assessed. These include:

- Short planned disruptions such as load shedding;
- Unplanned disruptions due to technical problems with a section of the grid; or
- Longer term disruptions due to, for instance, a part of the national grid being blacked out.

The concept of mitigating the impact that electricity disruptions can have on water supply is relatively new in South Africa. This is due to the fact that South Africa's electricity supply and distribution problems have only started to drastically affect the country in the last decade with nation-wide electricity load shedding being implemented sporadically since 2008 and reaching its most critical levels in 2015 (Goldberg, 2015). Although load shedding only causes short-term electricity disruption events, it was initiated as a result of a national shortage in electricity generation capacity in order to prevent a national blackout (which can occur if electricity demand is higher than supply). This highlights the risk of longer duration electricity disruption events in South Africa. During the peak load shedding period in 2015, energy analysts estimated that the probability of a national electricity blackout could have been as high as 50% (Fin24, 2015).

There are currently no frameworks, plans or guidelines which can guide the relevant authorities (electricity suppliers, Water Service Providers and Water Service Authorities) to mitigate the risks posed by electricity disruptions on water supply. A previous WRC study was done on mitigating various risks imposed on the wastewater sector and a Wastewater Risk Abatement Plan, or W_2RAP, was subsequently developed (van der Merwe-Botha and Manus, 2011). The need for a framework to mitigate risks imposed on the water sector due to electricity disruption event was identified. This need was addressed through the development of the Risk Analysis and Mitigation Framework of Integrated Water and Electricity Systems (RAMFIWES).

RAMFIWES was developed taking into consideration institutional arrangements currently in place to mitigate the impact of electricity disruptions on water supply; and evaluating these in terms of institutional arrangements, guidelines and strategies developed as part of similar studies. The outcome of the risk assessment and institutional arrangements' evaluation was also used to develop institutional and design guidelines for the various parties involved, including electricity suppliers, Water Service Providers (WSP) and Water Service Authorities (WSA). These proposed institutional and design guidelines were included as part of RAMFIWES.

The Tshwane case study was used to test the part of RAMFIWES that deals with Water Service Providers and Water Service Authorities. The framework was tested through various electricity disruption scenarios which simulated electricity interruptions and determined the impact on the water supply in the city. The disruption events ranged from short-term disruptions (less than one day) to long term disruptions (30 days). For each scenario, measures to ensure uninterrupted water supply were identified to mitigate the impact of the electricity disruption event. The costs of mitigating measures identified were compared to the economic benefit of ensuring uninterrupted water supply for each of the scenarios.

1.2 OBJECTIVES OF THE STUDY

The objectives of the study are listed below:

- Evaluate the risk to water supply posed by short-, medium- and long-term electricity supply disruption.
- Determine suitable institutional arrangements to mitigate impacts.
- Determine appropriate infrastructure design changes.
- Estimate the costs of mitigating measures.
- Determine whether it would be economically feasible to mitigate risks associated with water supply interruptions caused by electricity disruptions within the case study area (City of Tshwane).
- Develop a risk analysis and evaluation framework for mitigating the impact of electricity disruption on water supply.
- Test a component of the framework as part of the Tshwane case study.

1.3 SCOPE OF THE STUDY

The scope of the study is confined to the City of Tshwane, which is a significant portion of the strategic and vulnerable Rand Water (RW) supply area. Some 80% to 85% of Tshwane's water supply is derived from RW and Magalies Water; the rest being derived from own sources at Rietvlei Dam, Roodeplaat Dam and various dolomitic springs and wells.

The main limitations of the study include the following:

- Detailed information on Tshwane's electricity distribution infrastructure;
- Some detailed information on Tshwane's water and wastewater infrastructure (specifically pump stations within Tshwane); and
- Taking into consideration the interconnectedness of the various metropolitan areas in Gauteng in terms of bulk water supply from Water Service Providers (specifically Rand Water).
- Detailed information on hazards and hazardous events for the case study risk analysis.

These limitations are described in more detail in the Methodology (Section 3.1.4).

1.4 METHODOLOGY

This study which investigated mitigating the impact of electricity disruption on water supply formed part of a project funded by the Water Research Commission.

In order to guide electricity suppliers, Water Service Providers and Water Service Authorities on how to mitigate the risks imposed by electricity disruption events on water supply a framework (RAMFIWES) was necessary. RAMFIWES was developed taking into consideration the various authorities' institutional arrangements currently in place and relevant guideline from similar studies. As part of the framework developed, institutional and design guidelines were also recommended for electricity suppliers, Water Service Providers and Water Service Authorities.

RAMFIWES was tested on Tshwane as a case study. The approach followed for the case study is described below.

Background information on Tshwane's demographics, economic activity, and water and electricity infrastructure was obtained through consultation with water and electricity officials from Tshwane and from various readily available data sources (such as Tshwane's Integrated Development Plan and its annual financial reports) (CoT, 2015a; CoT, 2016).

Various theoretical electricity supply disruption scenarios that would result in water supply interruptions in Tshwane were identified and grouped according to their areal extent, duration and probability of occurrence. The risks identified were based on literature sources and various discussions with representatives from Eskom, Tshwane, and RW.

The impact of electricity disruption events on water supply were assessed by considering three different Tshwane supply areas ranging in size from a small residential area; one of Tshwane's six bulk water regions comprising mixed residential, commercial and industrial water uses; and the whole of Tshwane. For the study 1-day, 7-day and 30-day durations were examined for each size of the supply areas, giving a total of nine theoretical test case scenarios.

Mitigation options to sustain a minimum domestic water supply and protect most of the economic activity were identified and the cost of mitigation was estimated. The benefit of mitigation (due to continued economic activity) was compared to the cost as part of a cost vs. benefit analysis: the feasibility of mitigating the impact of electricity disruptions on water supply was based on the benefit to cost ratio and the increased water tariff that the consumer would end up paying.

1.5 ORGANISATION OF THE REPORT

The report consists of the following chapters and appendices:

- Chapter 1 serves as introduction to the report.
- Chapter 2 is a literature review which gives:
  a) An overview on risk assessment of water supply systems;
  b) A summary of institutional arrangements and guidelines from relevant studies which was reviewed and used to develop a framework to mitigate the impact of electricity disruptions on water supply; and
  c) Background on South Africa's electricity sector and an overview of South Africa's legislation governing the country's electricity and water sectors.
- Chapter 3 describes the methodology followed for the study.
- Chapter 4 contains the framework developed as part of this study to enable authorities to mitigate the impact of electricity disruptions on water supply (including the institutional and design guidelines proposed to mitigate risks).
- Chapter 5 gives relevant background information on (1) current institutional arrangements between Eskom, Rand Water and the Tshwane to deal with emergency

situations, (2) Tshwane's population, water demand, water and wastewater infrastructure and (3) the estimation of costs used in the case study's cost vs. benefit analysis.

- Chapter 6 summarises the case study risk analysis, the case study scenarios analysed and the case study cost vs. benefit analysis.
- Chapter 7 contains the conclusions and recommendations of the study.
- The list of references follows at the end of the report.

2 LITERATURE REVIEW

This chapter serves as a technical introduction to the study. The literature review covers the following aspects:

a) Risk assessment of the water sector;
b) Institutional arrangements, frameworks and strategies from comparable studies to mitigate risks and deal with disasters; and
c) Relevant background info on South Africa's electricity sector and legislation governing the electricity and water sectors.

a) Risk assessment of the water sector

(Section 2.1 to 2.7)

2.1 RISK ASSESSMENT INTRODUCTION

This section provides an overview of the main risk analysis methods for an electricity utility (Eskom), a Water Service Provider (WSP) and a Water Service Authority (WSA). The objective is to describe the tasks of a risk analysis, and to demonstrate the applicability and capabilities of the various methods, and thus support the implementation of a framework such as "Generic framework and methods for integrated risk management in water safety plans" (Rosén, Hokstad, Lindhe, Sklet and Røstum, 2007).

Risk analyses provide useful tools for management / decision makers to control the variety of hazards and hazardous events affecting a municipality or water utility; which could be:

- Failure of the treatment systems(s);
- Failure of the distribution network (leakages, pipe burst and pump failures);
- Failure of the wastewater treatment system(s); and
- Contamination / pollution of the raw water source.

Due to the wide range of technical, biological and human aspects of large water supply systems, the risk picture for water utilities is highly complex. What makes it even more complex is the fact that both water quantity and quality issues needs to be addressed.

A risk analysis is an important action to identify the hazards and hazardous events. A thorough knowledge is required of the water supply system as well as the electrical distribution system and the interconnectivity thereof.

According to Techneau (2009) a major problem in doing a risk analyses is the scarcity or lack of relevant data (for instance regarding failure events). Therefore, municipalities and water suppliers should compile their own databases and document undesired or hazardous events (including event causes and consequences); to be able to accurately estimate various failure probabilities (recurrence intervals). Generic data is sometimes insufficient to analyse risks of a municipality or water utility and relevant data may not be available. It would be useful if municipalities and water utilities apply a similar design of their databases and allow exchange of data with others.

2.2 DEFINITIONS

The following definitions of terms are applicable in this chapter (UNISDR, 2009; Tuhovčák & Ručka, 2007):

- **Hazard** is a source of potential harm or a situation with a potential of harm.
- **Hazardous agent** is for example a biological, chemical, physical or radiological agent that has the potential to cause harm.
- **Hazardous event** is an event which can trigger a hazard and cause harm.
- **Hazard identification** is the process of recognising that a hazard exists and defining its characteristics.
- **Risk** is a combination of the frequency, or probability, of occurrence and the consequences of a specified undesired event (IEC, 1995). For the purposes of the Water Supply Systems (WSS) risk analysis, we have accepted and developed this definition of risk and have expressed it as follows: R=P x C where R stands for the risk, P stands for probability of occurrence of undesired event and C stands for consequences of the event.
- **Recurrence interval (RI)** is the estimated time that will elapse for a time for a hazard or hazardous event to occur, for example the RI of an event with a yearly probability of occurrence of 0.1 is 10 years.
- **Risk analysis** is a systematic application of available information about the hazard identification and estimation of risk which individuals, society, assets and the environment are exposed to. The risk analysis comprises the task definition and definition of validity extension, hazard identification, and risk estimation. It is a structured process that analyses both probability and magnitude of consequences generated by specific activity, facility or system (IEC, 1995).
- **Risk estimation** is the process used to produce a measure of the level of risk being analysed. Risk estimation consists of the following steps; frequency analysis, consequence analysis, and their integration.

- **Risk evaluation** is the process in which judgements are made on the tolerability of the risk on the basis of risk analysis and taking into account factors such as socio-economic and environmental aspects.
- **Risk assessment** is the overall process of risk analysis and risk evaluation.
- **Risk management** is the systematic application of management policies, procedures and practices to the tasks of analysing, evaluating and controlling risk.
- **Undesired event (UE)** is a state when an element (system, part and product) loses its required property or ability to fulfil the required function in specific conditions. An undesired event is followed by undesired consequences.

2.3 GENERIC FRAMEWORK FOR INTEGRATED RISK MANAGEMENT

The risk management process is illustrated in **Figure 2-1**. This presents the generic framework for integrated risk management; this includes the following components (Techneau, 2009):

- Risk Analysis

In a risk analysis the various hazards / hazardous events imposed on a water supply system are identified and risks are estimated. Risk estimation is done, for instance, by determining the frequency of hazardous events and various consequences of these events.

- Risk Evaluation

Risk evaluation entails comparing risks identified with a set of risk acceptance / tolerability criteria that is defined for the specific water supply system (defined by the water utility or municipality). A decision can then be made on whether the risk is acceptable for the specific water supply system. Risk evaluation also includes conceptualising, considering and evaluating all possible risk reduction options and comparing their cost-effectiveness.

- Risk Reduction/Control

The most appropriate risk reduction options have to be determined and implemented to mitigate the risk (especially for risks that are above the risk acceptance / tolerability criteria). This also includes monitoring risks during operation of the utility.

Various activities are required in order to carry out a risk analysis, risk evaluation and risk control as listed in **Figure 2-1**.

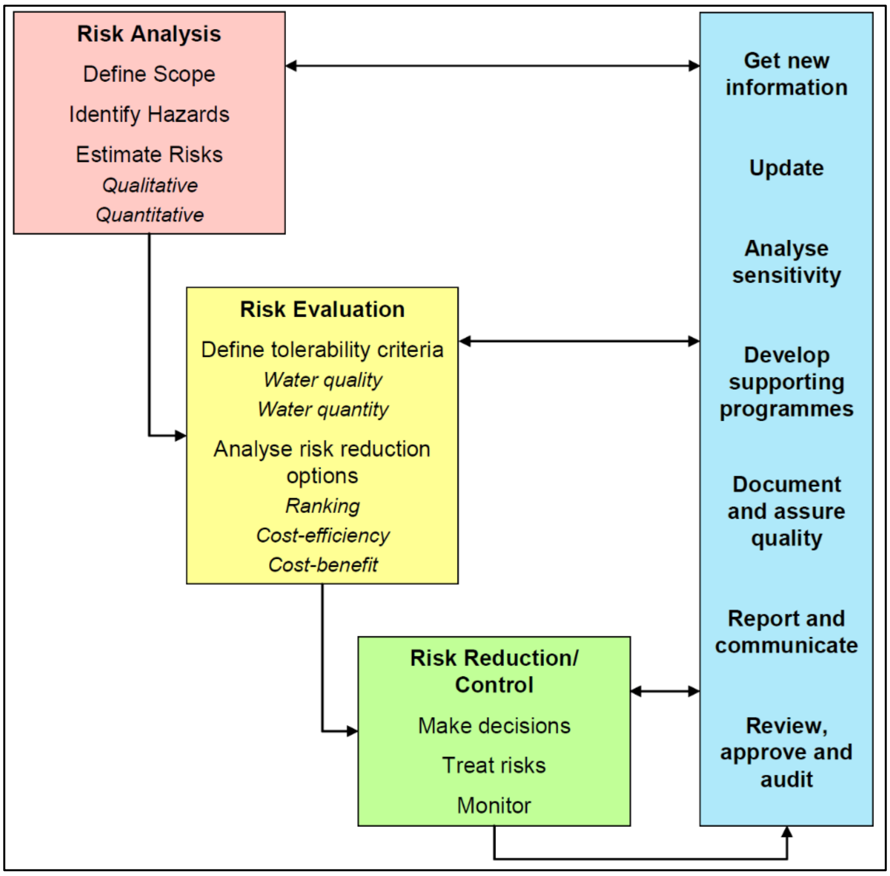

Figure 2-1: The main components of the generic framework for integrated risk management (Techneau, 2009).

The first component of the generic framework, risk analysis, includes the following three steps:

1. Defining the scope of the risk analysis

   A complete risk analysis will start by defining the scope of the analysis. For a water utility/municipality the objective of the analysis could be related to one or more of the following topics:

   - Water quality;
   - Water quantity (and availability);
   - Economy;
   - Environmental impact; and
   - Consumer trust.

   This component focuses on risk analysis related to water supply (raw water source to tap to wastewater effluent disposal). System definition/description and limitations of analysis are also given in this initial step.

2. Hazard identification

   The next step is the identification of all hazards and hazardous events. Methods to identify hazards and hazardous events include the use of checklists, hazard / hazardous event databases, past experience and expert judgements.

3. Risk estimation

   A number of methods exist for modelling and estimating frequency (or probability) and consequence of risks imposed on a water utility. The most appropriate risk estimation method should be identified based on the scope of the risk analysis. Important considerations include choosing the correct risk measurement method (quantitative, semi-quantitative or qualitative) and whether the whole water supply system should be considered or only a sub-system of it.

The second component of the generic framework is the evaluation of risks identified and analysed. Risk evaluation consists of two steps (Techneau, 2009):

1. Define risk tolerability criteria

   Risk tolerability, or acceptance, criteria for a water utility / municipality could be based on the same topics as identified as part of risk analysis, including: water quality, quantity, environment impact and consumer trust. For instance, if a water quality risk identified as part of the risk analysis is determined to fall within predefined risk tolerability criteria as part of the risk evaluation, the risk can be ignored during the rest of the risk assessment process and thus there will be no need to mitigate the risk.

2. Analyse risk reduction options

   This is applicable for each risk identified as part of the risk analysis that was not eliminated after evaluating the risk in terms of the defined risk tolerability criteria. All possible risk reduction options should be identified and compared in terms of either cost-efficiency or cost-benefit. The most appropriate risk reduction option would be the one which would effectively mitigate the risk at the lowest cost.

The third component of the generic framework is reduction and control of risks identified. This includes the implementation of the most appropriate risk reduction option identified in order to mitigate the risk. Furthermore, it includes continuous monitoring and improvement of the risk reduction measures implemented (Techneau, 2009).

2.3.1 Risk management programs

A Wastewater Risk Abatement Plan (W_2RAP guideline) to plan and manage towards safe and complying municipal wastewater collection and treatment in South Africa was compiled by the WRC (Van der Merwe-Botha & Manus, 2011).

A W_2RAP has three key components which are guided by health-based targets and overseen through surveillance of effluent released by wastewater treatment works (see **Figure 2-2**). These are:

- System assessment to determine whether the wastewater treatment as a whole can deliver effluent of a quality that meets health-based and environmental targets. This also includes the assessment of design criteria of new systems;
- Identifying control measures in a wastewater treatment system that will collectively control identified risks and ensure that the health-based and environmental targets are met. For each control measure identified, an appropriate means of operational monitoring should be defined that will ensure that any deviation from required performance is rapidly detected in a timely manner; and
- Management plans describing actions to be taken during normal operation or incident conditions and documenting the system assessment (including upgrade and improvement), monitoring and communication plans and supporting programmes.

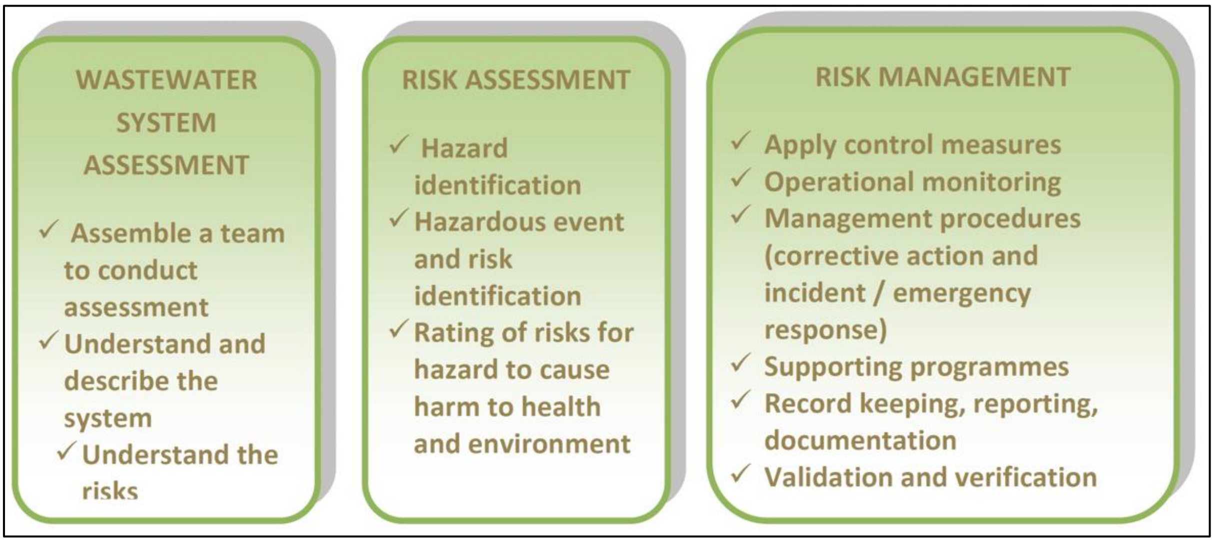

Figure 2-2: Three essential components of a W_2RAP (Van der Merwe-Botha & Manus, 2011).

In aiming to find a uniform approach in the manner in which risk assessments are conducted the key steps as followed in the W_2RAP procedure were also incorporated in the risk analysis of electricity disruptions on water supply. In RAMFIWES, which stands for Risk Analysis

Mitigation Framework of Integrated Water and Electricity Systems, the approach and steps followed are similar to that involved in developing a Wastewater Risk Abatement Plan (W_2RAP) shown in **Figure 2-3**.

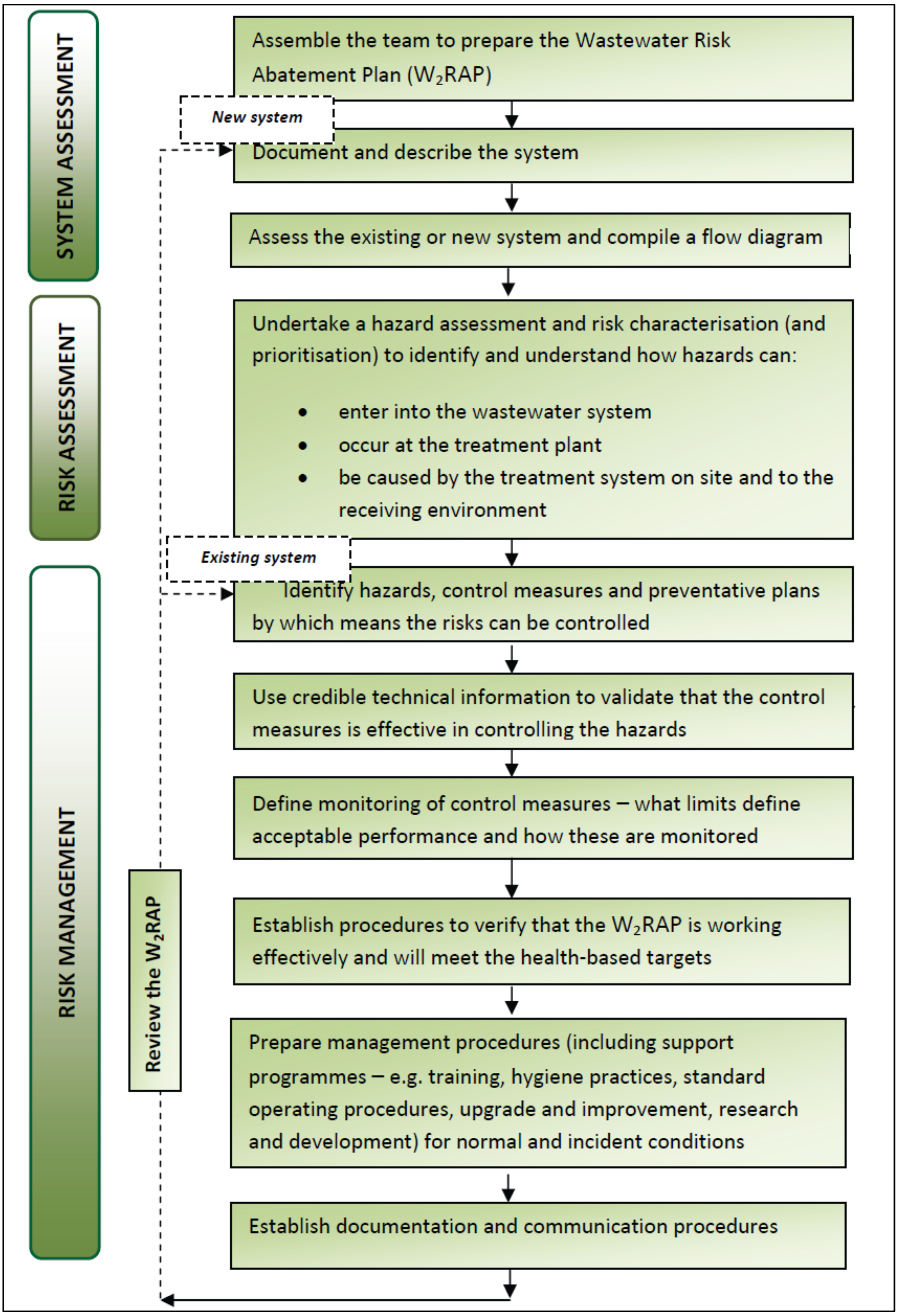

Figure 2-3: Overview of the key steps involved in developing a Wastewater Risk Abatement Plan (W_2RAP) (Van der Merwe-Botha & Manus, 2011).

2.4 RISK ANALYSIS OF WATER SUPPLY SYSTEMS

2.4.1 Introduction

This section describes the key components of the risk analysis process as well as the motivation for conducting a risk analysis. The process is described in detail specifically in the context of this study in Section 4.4 and includes the following steps (Tuhovčák & Ručka, 2007):

1. Defining the scope (this includes initiating the study, describing the system and assembling a team).
2. Identifying hazards and hazardous events.
3. Estimating the risks.

The risk analysis is a structured process which includes identifying both the probability of occurrence of an undesired event, and the extent of adverse consequences of the event. The following three questions need to be answered (Tuhovčák & Ručka, 2007):

1. What can go wrong? (Undesired events and hazard identification)
2. How likely is it? (Frequency analysis)
3. What are the consequences? (Consequence analysis)

Risk identification and risk estimation is uncommon in the WSS sector. The reason for this is that the risk of failure of water treatment and supply infrastructure has until recently been relatively low. Recent industry changes such as reducing costs whilst trying to keep improving on reliability, safety and efficient of systems has increased the risk of failure. New threats have also emerged such as electricity disruptions which now requires an evaluation of its potential impact.

2.4.2 Initiation and organisation of a complete risk analysis

A risk analysis should be started by a general objective on how to reduce the risk for the municipality or the water utility. Furthermore, a clear scope of the specific analysis should always be formulated.

When assembling the risk analysis team relevant stakeholders are to be identified, e.g. water utility owners, safety managers, electricity suppliers, consumers, municipalities, health authorities, etc. These decide whether any restrictions should be imposed on the work; for instance whether only a subsystem of the utility should be considered, or whether to include only specific types of hazardous events or risk reduction options. Critical stakeholders, for example, hospitals and schools, have to be identified and given special attention during the analysis.

As discussed below, in Section 2.4.3, initiating the risk analysis should be done by starting with an overview of the water supply system's overall risk situation. If the water utility or municipality is in a decision situation it should consider the following questions (Techneau, 2009):

- *What is the problem?*
- *What are the alternatives?*
- *Who is affected by the decision?*
- *Who is making the decision?*
- *Which aspects are considered when making the decision?*
- *What are the requirements, wishes and priorities of the various stakeholders?*

When risk analyses are utilised as decision support there are several ways to express (quantify) the various aspects of the risk. Thus if there are various benefits and losses (potential consequences) involved, the comparison of these benefits/losses may represent ethical problems, which must be handled by decision makers. One typical difficulty is how to quantify the value of human life.

Further, an analysis team must be selected; e.g. it must be decided who shall participate in the analysis work: risk analyst(s), various experts and generalists. The team should consist of water experts (operators, planners etc.), electricity experts/departments (generation, distribution, electricians etc.) and some outside specialists (e.g. researchers, consultants etc.) that may introduce new perspectives in the risk analysis process.

The working process must also be organised in a combination of meetings (with information gathering and evaluation) and analysis work. Thus the initial part of the analysis process is to organise and develop a plan for the work. In this respect it is important to stress the importance of having commitment from all professional categories of the municipality/water utility and electricity supplier in order to achieve real risk reductions as a result of the work.

2.4.3 Relevant decision situations for water utilities or municipalities

The scope of a risk analysis should describe the purpose of the analysis and the problems that initiated it. Some typical decision situations for municipalities or water utilities are listed, which could initiate risk analyses work including practical examples on this (Techneau, 2009).

- *An initial risk analyses is required before commissioning of a Water Treatment Works (WTW) or pump station, (or in the case of refurbishment or upgrading):*
  Although potable water supply is subjected to various risks, it is imperative to control risks on the most crucial areas first. Relevant objectives to initiate a risk analysis could simply be a need to:
  - Identify and prioritise all hazards and hazardous events (in order to control risk);
  - Estimate the risk (probability and consequence) to identify any need of additional Critical Control Points, (CCP); and
  - Evaluate cost/benefit of risk reduction options to achieve an acceptable risk.

  Examples of questions that could trigger risk analysis are:
  - What number of consumers will be affected if this WTW is unavailable to purify for a period of time due to an electricity disruption?
  - What is the make-up of the consumers that will be affected?
  - What effect will it have on water quality and health aspects?
  - Can a standby generator be a practical option to consider to reduce the risk?

- *Analyses carried out to "optimise" operational maintenance and emergency procedures:*
  The safe guarding, by implementing additional storage or bypasses at pump stations to enable areas to be supplied with water under gravity may be a long-term action for the municipality or water utility, and it may take some years before the required modification function is implemented. Thus, in the meantime:
  - How can the supply system be improved by optimising the present pipework configuration or interconnectivity of reservoir systems?
  - Which risks can be reduced by system optimisation?
  - How significant are periods with suboptimal performance?

- *Analysis triggered by a specific operational problem:*
  The municipality or water utility may have a hazard / hazardous event reporting system that gives support to the handling of specific problems. Such a system gives information on the acute actions applicable to the specific authority. It can also be designed to manage the need for improvements in order to avoid similar events in the future or to reduce their consequences. For example, it has been experienced that deviations related to a very rainy spring or summer in South Africa with subsequent higher occurrence of floods affects the water purification processes due to excessive

silt that needs to be removed. Any disruption of electricity then results in a situation where it is difficult to get the system filled again as the WTW is unable to run at higher capacities. The relevant questions are thus:

- What is the probability of such combinations of risks in the future?
- How can it be detected, monitored and mitigated, or how can the impact be reduced?

More generally, risk analyses could be triggered by problems like:

- Water supplied does not to comply with required quality standards (e.g. unacceptable level of some bacteria)
- Insufficient volume of water is supplied (to some group of users)
- Security problems
- Occurrence of an unwanted event (accident investigation)

- *Analyses to update initial risk analyses, in order to include possible new hazards:* A WTW operating plan could be designed for having a multi-barrier protection, while according to new knowledge formerly unknown microbial agents are pointed out as an important hazard. The recognition of new hazards can result in new risk reduction options. Relevant questions to initiate further analyses could be:
  - Are the barriers in the WTW sufficient for emerging microbial contamination?
  - How does the theft of the telemetry system's electricity supply (due to cable theft) impact on the reliability of supply?
  - What is the impact of climate change on the present treatment processes and what is the indirect impact on the electricity requirements?

- *Analysis to obtain acceptable risk with respect to supply, (major delivery failures):* Water suppliers may have acceptance criteria for supply interruptions taking into consideration the number of consumers affected and supply down-time. The risk of small scale (small area and short period) failures can be calculated from statistical or historical data, however, little information is available for the larger failures. Relevant questions to be asked are:
  - What is the limiting factor to achieve acceptable risk (raw water, treatment, the distribution system, or combination of all three)?
  - Are there any bottlenecks?

It is concluded that the above questions raised could be related to various infrastructure life cycle phases, (e.g. design or operational phase), and the questions can be related both to strategic and operational decisions.

2.4.4 System description

The first step of a risk assessment is to compile a system description / status assessment. This includes describing the functions each of the various subsystems. Each water supply system is unique and a description of the system is therefore an important part of a risk analysis. The specific hazard that is investigated is the impact of a disruption in electrical supply and thus a link between each water subsystem and its electrical dependence is very important. The description should include both illustrations (drawings) and written text. Examples of important documents are rules and regulations, standards, drawings, statistics, operating procedures (Techneau, 2009).

The system description should include information of the following six subsystems (if the whole water supply system is analysed) and its integration with the electrical supply system:

1. The catchment area and water source (groundwater and/or surface water).
2. Water treatment – and quality monitoring systems.
3. Distribution infrastructure (bulk and network), including pump stations and storage facilities.
4. Effluent disposal including wastewater conveyance (sewer pump stations) and wastewater treatment.
5. Electricity sources.
6. Electricity distribution system (including transmission lines and substations).

As an example **Figure 2-4** is an illustration of a water supply system from source to wastewater effluent disposal.

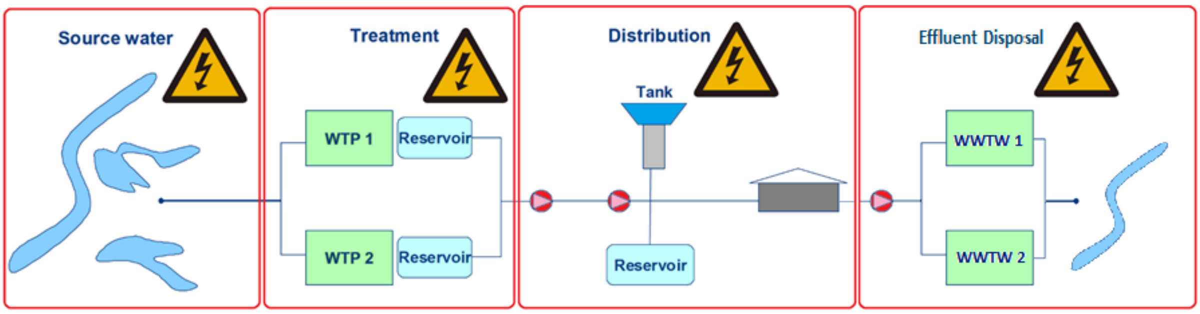

Figure 2-4: Illustration of water system flowchart, from source to effluent disposal.

The system description should summarise the system boundaries, the technical systems, operational conditions and the environment. For identification of hazards or hazardous events it will be necessary to identify important support systems, on which the water utility or municipality relies on for continuous supply (including power supply, availability of chemicals, electronic/SCADA systems, training and employment of personnel). The system description should also include other relevant information including the total number of consumers and the municipality's water demand.

The system description should illustrate a "normal operational situation", after the treatment process and control points have been decided. Thus specification of this normal operational situation is an important part of the system description. In particular, it should be specified which concentrations of various contaminants the treatment system is designed to handle.

Most risk analysis methods require a structured way in which the system is broken down into smaller subsystems. A common way is to break down the system into a hierarchical model based on how the system was designed. The model should be broken down into subsystems that are small enough to be accurately and easily analysed (i.e. splitting the system into subsystems like source, treatment, distribution and effluent disposal, as illustrated in **Figure 2-4**). Each subsystem can also be broken down further into modules, and each module into components, etc.

2.4.5 Identifying hazards and hazardous events

At each step of the hazard identification, it is important to ensure that adequate protection measures can be applied. Each step will thus be determined by the events that could lead to failure and have an impact on the water supply system, and the associated control measures for each hazard. Sources of hazards can be found in each step of the water treatment and supply system. An example of information useful for assessing a water treatment and supply system is listed in **Table 2-1**.

Table 2-1: Examples of information useful for assessing a water treatment and supply system.

Component	Information to consider in assessing component of system
Treatment (potable water & wastewater treatment)	% of area severed
	Type of network in place or to be installed
	Protection (e.g. covers, enclosures, access)
	Domestic component (existing and projected)
	Hydraulic loading
	Seasonal variations
	Peak flow factors
	Treatment history of equipment malfunctions
	Maintenance schedules and frequency
	List of suppliers for critical equipment and parts
	Treatment processes (including optional processes)
	Treatment chemicals used
	Treatment efficiencies (chemical, physical, microbiological)
	Electricity requirements for various treatment processes
	Equipment design
	Monitoring equipment and automation
	Availability of standby / spare equipment (mechanical, electrical)
Pump station	Pump head
	Pump type
	Availability of standby pump and motor sets
	Availability of backup power supply
	Peak flow
	Water type (raw, potable or sewerage)
Pipelines	Pipeline length
	Pipeline material
	Pipeline age
	Water conveyed (raw, potable or sewerage)
Storage	Reservoir size
	Reservoir type (ground level, elevated tower)
	Reservoir material (concrete or steel tank)
	Reservoir age

The impact of the hazard can be characterised by assessing the severity of the likely health and environmental outcome and probability of occurrence.

The next step of the risk analysis is to identify hazards or hazardous events, in all parts of the system (Tuhovčák & Ručka, 2007). In principle all types of unwanted events should be included although the focus in this risk analysis would be on the inter-relationship of electricity supply and water supply. The following hazards are typically considered:

- *Biological;*
- *Chemical;*

- *Radiological;*
- *Physical;*
- *Water availability (to consumers);*
- *Safety (safety to personnel, the environment and the public); and*
- *External damage (external damage to third parties, incl. liability).*

The pumping of water consumes the largest proportion of electricity supplied to the water sector (Petermann et al., 2011). In **Figure 2-5** the electricity dependencies of various elements which make up the water supply chain are illustrated (Mank, 2015).

Subsequently, not only drinking-water, but also wastewater transmission and treatment requires electricity (refer to **Figure 2-6**). According to Mank (2015) the wastewater treatment plants in Vienna, Austria, consumes around one percent of the total energy in Vienna.

Electricity disruptions may affect the water availability, quality and treatment. It may furthermore affect the communication between stakeholders to organize water provision as well as the communication with the population to provide assurance of and confidence in a quick repair of the problem. If this is not assured social upheaval and unrest are not unlikely.

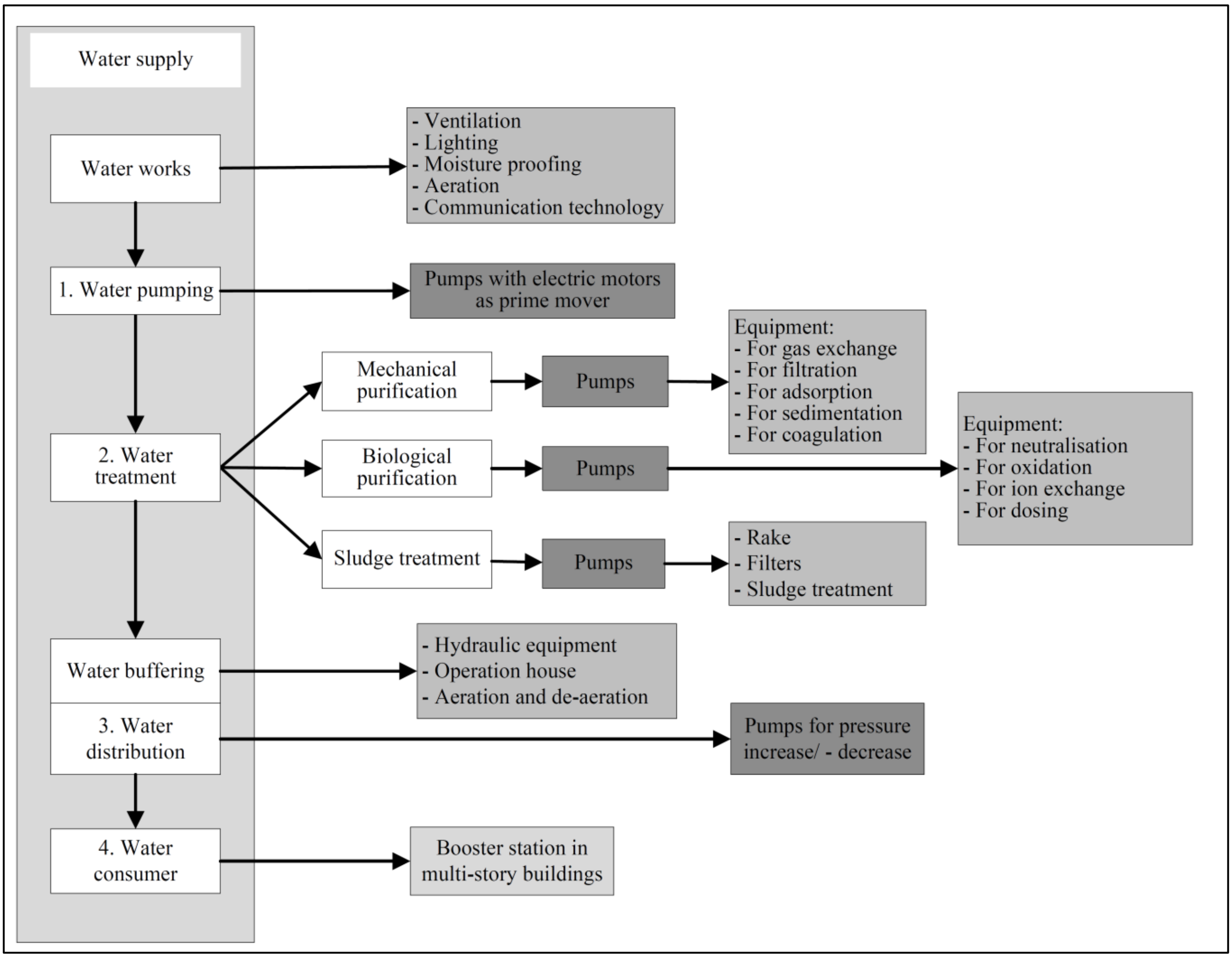

Figure 2-5: Technical elements in the water supply and the electricity dependency (electricity dependency: white: none; light grey: low; medium grey: medium; dark grey: high) (Mank, 2015).

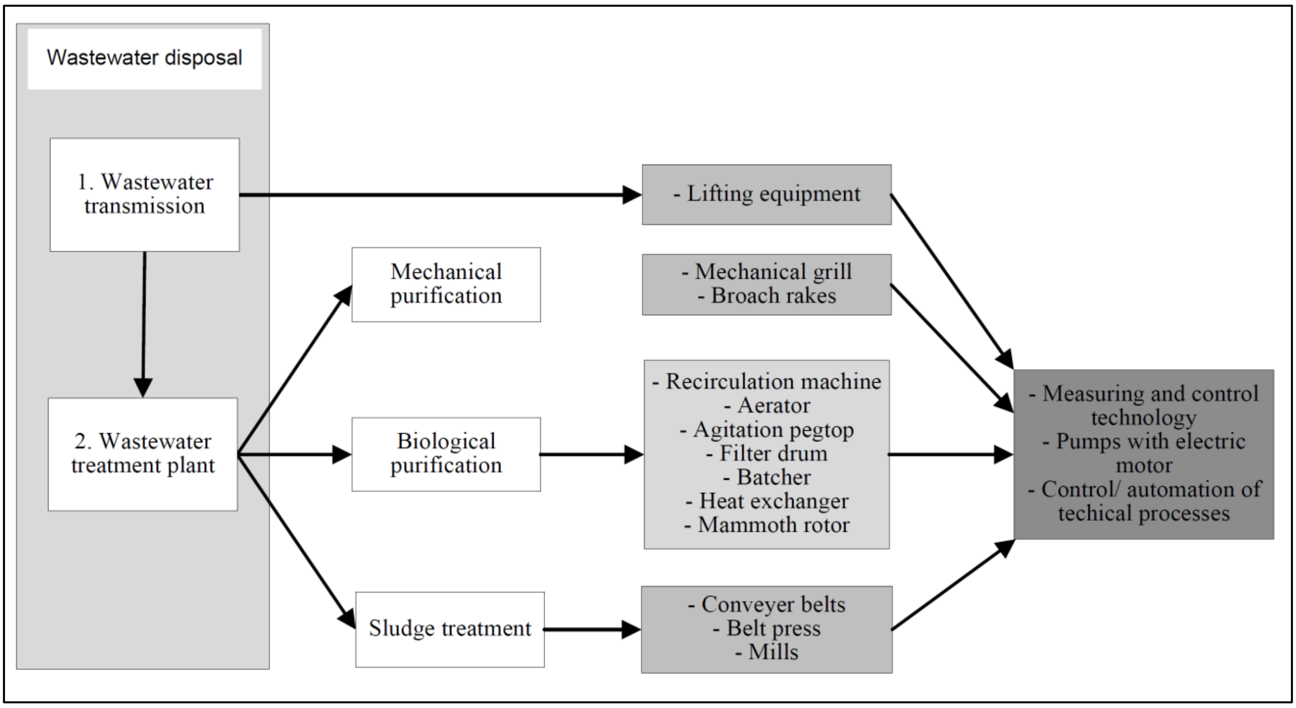

Figure 2-6: Wastewater disposal and its electrical dependency (electricity dependency: white: none; light grey: low; medium grey: medium; dark grey: high) (Mank, 2015).

2.4.6 Prioritising hazards for control

Effective risk management requires the identification of potential hazards, their sources and potential hazardous events and an assessment of the level of risk presented by each. Once potential hazards and their sources have been identified, the risk associated with each hazard or hazardous event should be compared for risk management priorities to be established and documented.

Although there are numerous hazards that can compromise water supply and treatment systems, not every hazard will require the same degree of attention.

The risk associated with each hazard or hazardous event may be described by identifying the likelihood of occurrence (e.g. certain, possible, rare) and evaluating the severity of consequences if the hazard occurred (e.g. insignificant, major, catastrophic). The aim should be to distinguish between important and less important hazards or hazardous events. The approach used typically involves a semi-quantitative matrix.

Different approaches for identifying hazardous events are discussed in Section 2.5.1.

2.4.7 Risk estimation

The risk estimation can be carried out at various levels of detail. An analysis of the hazardous events should include estimation of likelihood (probability) and consequence.

Often a semi-quantitative approach is chosen, just giving categories of likelihood and consequence. The combined likelihood-consequence categories could then be inserted in a risk matrix (refer to the example of risk matrix in **Figure 2-7**). As an example corresponding risk values ranking from very low (likelihood = rare; consequence = insignificant) to critical (likelihood = almost certain; consequence = catastrophic) can be indicated. This is just an example on how to rank the risks related to the various hazardous events. The categories (e.g. "catastrophic") can be defined in various ways as explained in Section 2.6.2.

	Likelihood				
Impact	**Rare**	**Unlikely**	**Possible**	**Likely**	**Almost certain**
Catastrophic	moderate	moderate	high	critical	critical
Major	low	moderate	moderate	high	critical
Moderate	low	moderate	moderate	moderate	high
Minor	very low	low	moderate	moderate	moderate
Insignificant	very low	very low	low	low	moderate

Figure 2-7: Example risk matrix (Rosén, Hokstad, Lindhe, Sklet and Røstum, 2007).

In more advanced analyses risk can be fully quantified although the input data to these quantifications are often rather uncertain, and the results involve considerable uncertainty. For such cases it is recommended to carry out a sensitivity analysis; i.e. calculating risk with various input values to demonstrate the range of "probable results".

It is not easy to draw a line between acceptable, tolerable and intolerable hazards and effects as also stated by Renn & Klinke (2015), because not one hazard is equal to another one or perceived in the same way by everybody or even by the same group of people. Risk tolerability highly depends on moral judgment and individual experiences influenced by the valuation of the infrastructure or resources that may be lost in case of an event, the weighing of costs for prevention and costs for response, and the foresight of the stakeholders (Renn & Klinke, 2015).

The risk matrix can be used in different variations and applications, depending on the priorities and approach taken by the municipality or water utility. The most important step is that risks are properly identified, so that it can be assessed for its likelihood and consequences. Risks in the collector system, such as pump station overflows and sewer blockages, are very real risks. Risk identification is therefore not a management prerogative; it must include the operational and maintenance staff closely involved in the day-to-day processes.

2.4.8 Risk analysis under uncertainty

According to Tuhovčák and Ručka (2007) a major problem with conducting a risk analysis is estimating the values of criticality (C), or consequence, and probability (P) under uncertainty. This is due to a lack of data, insufficient historical records and/or unreliable data, uncertainty of failure detection, uncertainty of employed methodology of risk analysis and proper interpretation, etc.

This problem can be solved by using frequency instead of mathematical probability of occurrence of a hazard or hazardous event, as well as by employing the Failure Mode and Effects Analysis (FMEA) and the Failure Mode, Effects and Criticality Analysis (FMECA) methodology. FMEA uses categorization of probability of occurrence, severity of consequences and all other potential inputs into categories (IEC, 2006).

For example, categories of frequency of occurrence may be as follows: rare – unlikely – moderate – likely – almost certain. The category is then represented by its point-score only, e.g. rare having a “1 rating” and almost certain having a “5 rating”.

Each analysed element can be assigned into one of the predetermined categories. This is done based on some chosen factors or indicators and based on limits of categories. Limits are set up by a water sector risk analysis expert (or experts) with sound knowledge of the system and experience on how it is operated. This is an effective approach especially in the situation where hard data is missing or unreliable and the analysis has to be based on “soft” data. A semi-qualitative model is constructed where experts’ qualitative information is very effectively used together with quantitative (statistical or empirical) hard data (Tuhovčák and Ručka, 2007).

The FMEA and FMECA are methods used to assign failures based on hazards or hazardous events which will have critical consequences and which will affect the system’s functionality. FMEA / FMECA is standardised by IEC 812 (IEC, 2006).

Both FMEA / FMECA can be used for risk analysis of technological system including WSS. The method for conducting FMEA / FMECA is described below (Tuhovčák and Ručka, 2007):

- The analysis starts with choosing the element from the lowest level for which enough information is available;
- Tables are created for describing different failure modes that may occur on each element of the level;
- The various system elements are assessed individually; and
- The consequence of the failure of each of the elements is considered as a failure mode when consequences of the failure are analysed at the next higher level.

In this way the analysis proceeds from a low level (simple level for which sufficient information is available) to more intricate levels. The result is the assignment of consequences of the failures with the specific failure modes at all required levels for the entire system (Tuhovčák and Ručka, 2007).

2.5 COARSE RISK ANALYSIS OF WATER SUPPLY SYSTEMS

The Coarse Risk Analysis (CRA) is a semi-quantitative risk analysis method. The scope of a CRA (including risk evaluation and control) generally consists of (Techneau, 2009):

1. Identify hazardous events in either the water supply system as a whole, or in a specific part. (Refer to Section 2.5.1)
2. Risk estimation, i.e. estimate the probability (frequency of occurrence) and consequence for each event. (Section 2.5.2)
3. Use risk matrices to summarise the risks, and compare to risk acceptance criteria.
4. Rank the various hazards / hazardous events based on the estimated risk.
5. Evaluate the need for implementing risk reduction options or more detailed analyses.

2.5.1 Identification of hazardous events

There are various approaches for the identification of hazardous events, e.g. using; brainstorming, experience from the past, checklists available in databases (examples of this is given in the following chapters) and hazard and operability analysis (HAZOP) (IEC, 1995).

There are various techniques for identification of hazards or hazardous events within a system. Hazard Identification (HAZID) is a collective term often used for such techniques.
A brief description of some of the methods is presented in this section (IEC, 1995).

- Brainstorming is a common problem solving method (idea generation in which members of a group contribute ideas spontaneously). The goal is to identify hazards or hazardous events in a water supply system. "What-if" scenario identification is an effective brainstorming approach.

- Relying on experience from the past, i.e. accident and reliability data, should also be used to point out problem areas and provide input data for frequency analysis (probability estimation). Historical experience and data is often used as input to the methods described in this section.

- A checklist comprises a list of specific items to identify typical types of hazards and potential disaster scenarios associated with a system. Checklists may vary widely in level of detail, are limited by their developers' knowledge and experience and should be viewed as documents that need to be updated continuously when necessary.

Experience from the past could be from the specific water utility or municipality (or similar entities), and should be provided by technical personnel of these entities. The total system could then be evaluated to record operational problems and concerns that the personnel experience. This method is comparable to brainstorming. One could also make use of statistics and historical event data that can be obtained from various data sources as described in Section 2.7.

A checklist is a simple, easy to use and a cost-effective way to identify typical hazards. Checklists can be applied at any life cycle stage of a water supply system. It can also be used to evaluate compliance with standards. The Techneau Hazard Database (Beuken, et al., 2008) comprises a comprehensive list of hazards and hazardous events that can serve as a checklist for water utilities and municipalities (see below).

Generic hazardous events can be evaluated by considering characteristics such as (IEC, 1995):

- Materials used or produced and their reactivity;
- Equipment used;
- The operating environment;
- Plant layout; and
- System components' integration, etc.

Given general or generic hazardous events identified, a more specific list may be developed for the various subsystems. An example of such a list and what is typically incorporated into such a list is given in **Table 2-2**.

Table 2-2: Specific list of hazardous events (Beuken, et al., 2008).

Hazardous Event	Cause	Vulnerable locality	Possible consequences
Section of electrical cable is stolen which supplies a potable water pump station	Criminal activity	Affected area directly linked to the supply from the specific pump station	- Interruption of water supply (short to medium period) - Increased risk in case of fire - Cost of replacement of section of cable (Maintenance team and actual costs) - Subsequent cost (refilling of supply pipelines, water storage reservoirs and distribution pipelines) - Loss in revenue to the water service provider and water service authority (No water sales during water supply interruption)

2.5.2 Identifying causes for hazards and their likelihood

Water or power outages are rarely the actual disaster, but are more likely to be effects of a disaster. For example, the natural disaster has a direct effect on the power supply and an indirect effect on the water system. Indirect effects are difficult to predict, seem unimaginable at the current point in time and yet can cause long lasting consequences to the population (Bissell, 2013). Causes, hazard and effects as described by Mank (2015) are depicted in **Figure 2-8**.

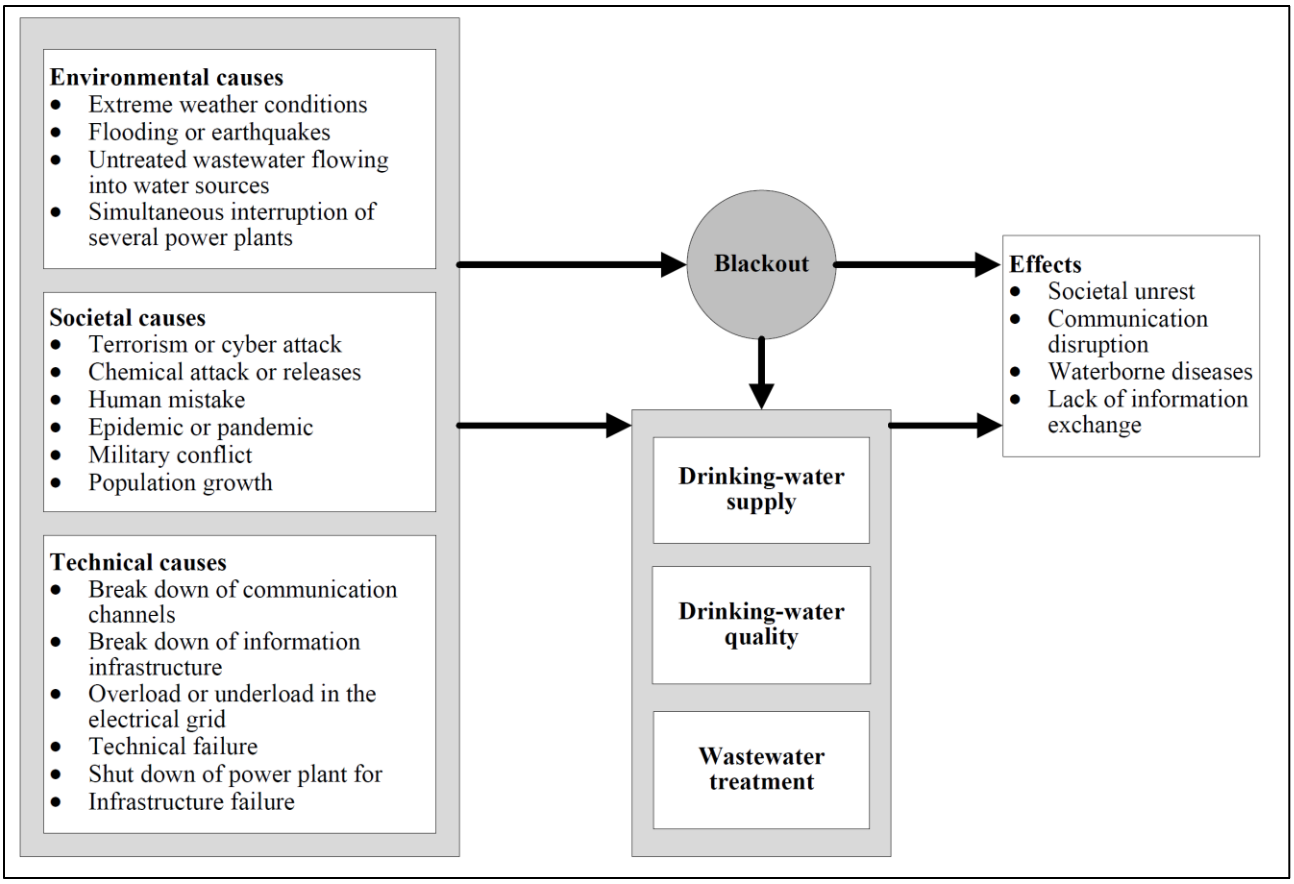

Figure 2-8: Causes, hazard and effects (Mank, 2015).

The Swiss ministry published a risk diagram contrasting each risk potential within the environmental, societal and technical causes (refer to **Figure 2-9**).

According to Hohl, et al. (2013) a power outage (blackout) has one of the highest probabilities and frequencies compared to other risks including heat, flooding and terrorist attacks, though the economic damage of a power outage is on average low compared, for example, to earthquakes or epidemics.

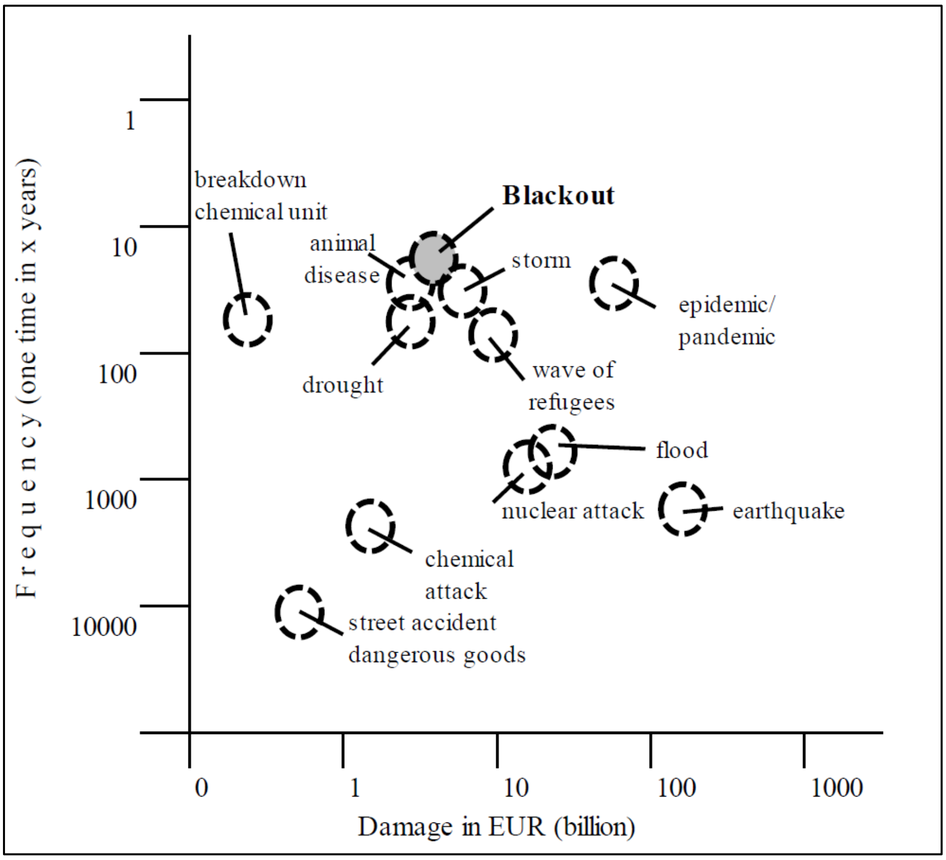

Figure 2-9: Risk diagram (Hohl, et al., 2013).

2.5.3 Impact assessment and options to mitigate the effects of a water and power outage

Table 2-3 gives a short overview and idea on the effects of a blackout, while additionally expressing severity, controls in place and actions planned (Mank, 2015). Indirect impacts such as (1) the halt of pressurized water due to a loss of pumping stations; (2) the loss of access to safe drinking-water; (3) a lack of water for sanitation and hygiene as a result of contamination; (4) the halt of wastewater treatment; and (5) a lack of preparatory measures in order to react to a water outage are more difficult to define and harder to estimate (Chang, et al., 2008).

Table 2-3: Impact assessment on the effects of a blackout (Mank, 2015).

Effects	Inherent assessment		Controls in place	Action planned
	Impact	Likelihood		
Halt of water pumps	Medium	Medium	Backup systems; gravitational flow	High-storage water tanks; self-efficient energy
Loss of access to drinking-water	High	Medium	Open-source water; bottled water	Water storage; Distribution of filters; public/ private partnerships
Lack of water for sanitation and hygiene	High	Low	Open source water	Water storage
Halt of wastewater treatment	Medium	High	Backup systems	Self-sufficient energy
Lack of preparatory measures	High	Medium	Brochures	Workshops, conferences, etc.
Halt of telecommunication	High	High	Backup generators; direct comm.	Distribution of leaflets; advanced planning
Distorted daily life	High	Medium	Communities; information	Strengthening resilience

The water sector is often indirectly affected either through a cascade of events leading up to the contamination of water or the leakage of a water pipe, or by threatening adequate healthcare in hospitals and hygiene at home (WHO, 2013). These are often unpredictable and complex consequences of direct hazards (Laugé et al., 2013). Effects are also influenced by the hour of the day, the day of the week, the season of the year and the current weather. While in summer a higher amount of electricity is needed for cooling, the same is the case for heating in winter. A blackout occurring over a small area quickly receives help from within the country as well as from neighbouring countries. The wider the area, the the more difficult it will be to build up the electrical flow again or to provide support (Hohl, et al., 2013).

Independent of the duration of the power and water outage, several mitigating options have been identified for the three sectors, water, electricity and fuel, and communication, and are combined in **Table 2-4** (Mank, 2015).

Table 2-4: Implementation options to mitigate the effects of a water and power outage (Mank, 2015).

Water	Electricity	Communication
Water sources: • pool water • rainwater • domestic water wells • artificial static water supply sources • open sources • hand-turned pumps • high-level water storage tanks • mobile water tanks • water from neighbouring cities • small water channels • bottled water **Water treatment:** • water filtration • silver chloride pills • UV light irradiation • Boiling • Distillation • Chlorination **Hygiene:** • mobile toilets • plastic bags • manholes in public places connected to the sewage system	**Emergency electricity provision:** • backup generators plus fuel • shared backup generators • rent backup generators • energy self-sufficient systems: photovoltaic panels, wind parks, sludge fermentation	**Internal communication:** • radio-relay systems • field wire • satellite communication systems with batteries, rechargeable batteries or solar panels • short wave radio gadgets with car batteries **External communication:** • alarm systems • radio broadcasting • flyers and brochures • personal communication • loudspeaker announcements **External communication places:** • city halls • fire brigade houses • municipality houses **Risk communication channels:** • news • specific events: change of the millennium • seminars, workshops • environmental and political actions • public incentives • platforms • books

2.5.4 Risk estimation in Coarse Risk Analysis (CRA)

It is a rather common situation that a municipality or a water utility wants to have a coarse overview of the main risks for its activities, in order to identify the most serious threats and then to correctly prioritise with respect to implementing risk reduction options.

In such a situation the municipality or water utility can carry out a Coarse Risk Analysis (CRA); this method is similar to the Preliminary Hazard Analysis (PHA). This type of analysis is also sometimes referred to as a Risk and Vulnerability analysis (Techneau, 2009).

These analyses are often carried out early in the development of a utility, or in the launching of a WSP implementation in an existing system. At that stage there is little information on design details and operating procedures, and the analysis can be a precursor to further studies. However, it is also used for analysing existing systems, or specific subsystem. The CRA can also be used to prepare emergency preparedness plans for water supply companies.

The main objective of the CRA is to identify hazardous events (as described above), the causes of the event, and to make a coarse evaluation of likelihoods (probabilities) and consequences of these events. The results are normally displayed in a list of hazardous events (in a worksheet form). Several variations of this form are used. One example of a worksheet used to document the results of the analysis are shown in **Table 2-5**. Each hazardous event, in this risk analysis any electricity disruption and its impact on water supply, is identified and inserted in the list and analysed (Techneau, 2009).

The risk estimation in a CRA usually restricts to presenting categories of probability and consequence. The probability categories are denoted e.g. P1–P5, and similarly consequence categories, C1-C5 (refer to **Table 2-5)**. These pairs of values are later inserted in the appropriate cell of the risk matrix. The consequences can be evaluated with respect to several "dimensions"; e. g. water quality, water quantity (supply) or reputation/economic loss.

Table 2-5: Example of a CRA- worksheet (adapted from Techneau (2009))

System: *Distribution*		**Operating mode:** *Normal operation*		**Analyst: WRC** **Date: 2016-10-18**			
Ref.	Hazard	Hazard event	Causes	Probability	Consequence	Preventative actions	Comments
1	Supply	Pumping station is offline	Cable theft	P2 [1]	C3 [2]	Improve security of electricity supply line	

Notes:

1) Probability category

2) Consequence category

According to the resulting risk-score of the various hazardous events in the risk matrix, the most serious hazardous events are identified. Risk reduction options to prevent the hazardous event or to neutralize its consequences are identified. The required efforts (in terms of costs, time, organization, training, etc.) and the reduction of risk of the various risk reduction options are roughly evaluated. Finally a priority list for risk reduction options (with deadlines) is formulated.

In summary, a CRA is a rather simple semi-quantitative risk analysis method. However, the CRA requires good information and knowledge about the system including surroundings. Hazard identification is usually based on some kind of expert judgement, e.g. using experience from the past, checklists, or a combination of these. If statistics about hazards are not available the CRA will rely on expert judgements to estimate the risk and define appropriate risk reduction options.

No detailed modelling and calculations are needed, and the analysis may be carried out by professionals with good system knowledge, but it does not require computational skills. Normally a CRA is not very time consuming. However, this depends on the size and complexity of the system to be analysed.

It should be noted that the score of the water utility's total risk is not provided by the CRA. The focus rather is on identifying serious hazards and hazardous events, and comparing these with respect to their contribution to risk.

2.5.5 Tools for risk analysis

Various tools have been developed for carrying out a risk analysis. Examples of tools developed in South Africa are the W_2RAP tool (Van der Merwe-Botha & Manus, 2011) see **Figure 2-10**, as well as the WATERRISK – Water Infrastructure Risk Assessment Tool (Jack, De Souza and Mackintosh, 2011), see **Figure 2-11**. The application of these tools provides uniformity in the water sector in South Africa.

Nelson Mandela Bay

WASTEWATER RISK ABATEMENT PLAN
LIST OF HAZARD EVENTS - WASTEWATER TREATMENT

Section	No	Hazard event	Risk assessed	Control measure in place	Last updated
Wastewater Treatment: **Fishwater Flats**	2.1	Flow exceeds design limits of WwTW	Yes	Yes	Nov-10
	2.2	Biological loading exceeds design limits of WwTW	Yes	Yes	Nov-10
	2.3	Blockages on pipelines or channels	Yes	Yes	Nov-10
	2.4	Power failures	Yes	Yes	Nov-10
	2.5	Mechanical failures/Inadequate redundancy on pumps	Yes	Yes	Nov-10
	2.6	Odour problems	Yes	Yes	Nov-10
	2.7	Failure of screening and/or screenings removal	Yes	Yes	Nov-10
	2.8	Failure of grit removal	Yes	Yes	Nov-10
	2.9	Failure on flow measurement equipment	Yes	Yes	Nov-10
	2.10	Overloading of the system due to inadequate flow balancing	Yes	Yes	Nov-10

Figure 2-10: Typical application of the risk tool to manage and track risk control measures in Nelson Mandela Bay (Van der Merwe-Botha & Manus, 2011).

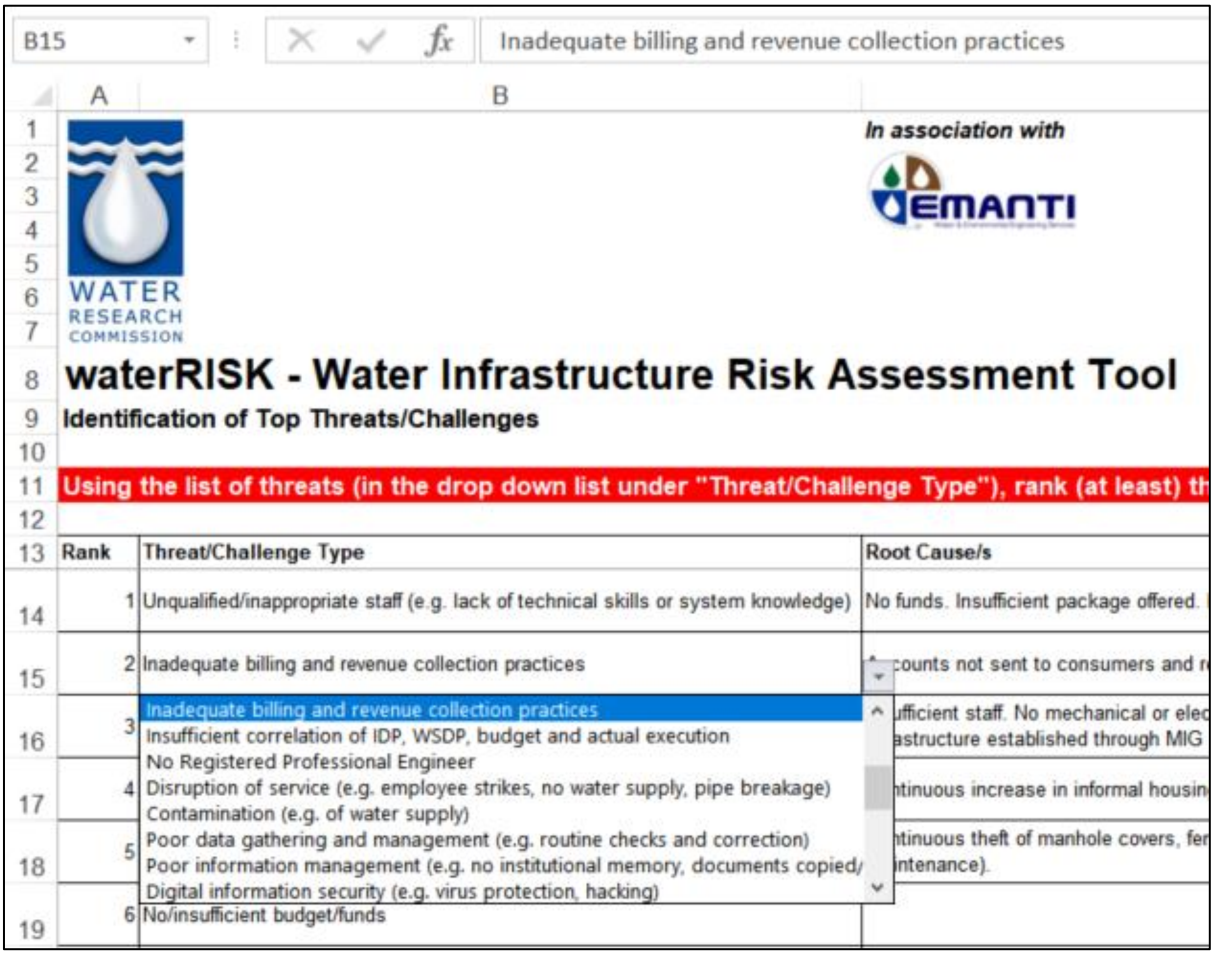

Figure 2-11: WATERRISK - Water Infrastructure Risk Assessment Tool (Jack, De Souza and Mackintosh, 2011).

A few examples of risk assessment tools for the water sector that have been developed international are given below:

- The Water Risk Filter Tool developed by the World Wide Fund for Nature: An online application for analysing the impact of various activities on water supply, to understand the potential risks and to obtain examples of risk mitigation options (WWF, 2018), see **Figure 2-12**;
- The Aqueduct™ tool developed by the World Resources Institute: A database of water risks presented on interactive global high-resolution maps (WRI, 2018), see **Figure 2-13**; and
- The Water Footprint Network's Water Footprint Assessment Tool: A free online application which provides information on how water is made available for human consumption and the impacts resulting from water use. It assists companies, governments, NGOs, investors and researchers to calculate and map the water

footprint, asses the sustainability of water use and to identify actions to improve sustainable use, efficiency and fair water use (Water Footprint Network, 2018).

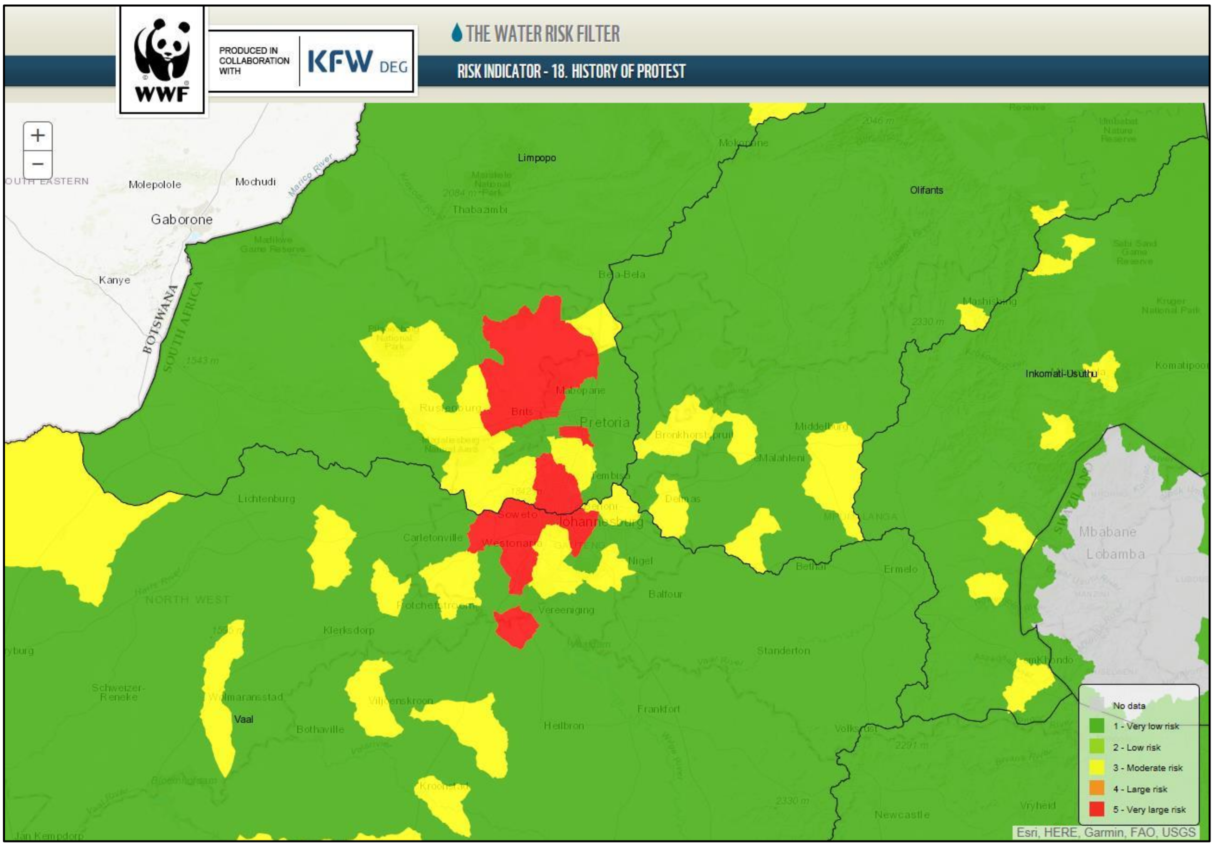

Figure 2-12: The Water Risk Filter - Map of Gauteng area indicating the risks related to the history of protests.

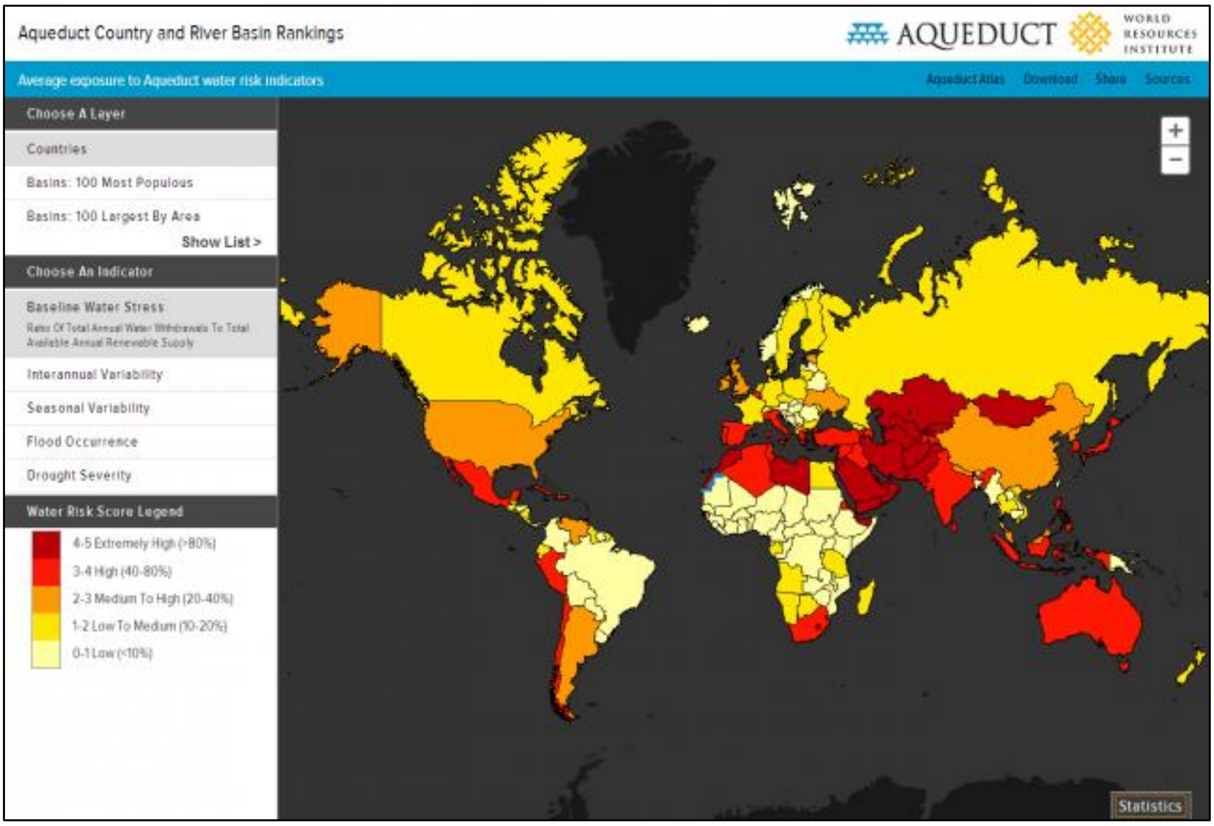

Figure 2-13: Aqueduct risk scores by country (WRI, 2018).

2.6 QUANTIFICATION OF RISK

Risk can be quantified in various ways, depending on which aspects of risk are considered. In this section the various methods to quantify or measuring risk are described.

2.6.1 The dimensions of risk and various methods to quantify risk

Risk can be defined as a combination of the consequence(s) of hazardous events and the probability (frequency) of the occurrence of these events. Risk is therefore generally expressed in terms of probabilities and consequences. The estimated risk of hazards / hazardous events can also be added to give an estimation of the total risk of a water supply system (Techneau, 2009).

Several types of potential consequences can be considered in a risk analysis of a water supply system. One refers to the various "dimensions" of risk, representing the different types of consequences, and each of these risk dimensions can be quantified.

For the end-user it is important that both the water quality be acceptable and the quantity be sufficient Risk analysis should therefore focus on the quality and quantity of water supply and how it is influenced by electricity disruptions, both aspects essential for the consumers' risk.

In order to quantify risk related to water quality, the complete water supply chain and to what degree it is dependent on electricity should be considered. Some examples of risk measures for water quality are (Techneau, 2009):

1. Probability of the water source being contaminated.
2. Probability of a treatment system failure, resulting in water of unacceptable quality entering the distribution network.
3. Probability that a consumer is supplied with water of unacceptable quality.
4. Mean number of consumers affected by drinking water of poor quality (due to a certain hazardous event, in this case an electricity disruption event).

Risk pertaining to water quality is not only measured in terms of the quality of water delivered to consumers (item 3 above), or as the health effects on the consumers (item 4). For a water supplier it is also necessary to estimate the risk of water source contamination or treatment system failure (items 1 and 2).

In Item 4 "Mean number of consumer getting adverse health effects" a quantification of risk is applied where probability and consequence are combined into one figure. Therefore a traditional definition of risk as the "mean loss", (probability x consequence) is applied.

When risk related to water quantity is calculated, it should be kept in mind that loss in terms of water quantity depends on (Techneau, 2009):

- frequency of water supply interruptions;
- interruption duration; and
- the number of consumers affected.

Even if water supply is not affected, the level of service can also be affected if the interruption results in network pressure which drops too low (for appliances to work). Therefore water pressure being excessively low is also a risk relating to water quantity, (just as excessively high water pressure is a hazard, potentially causing bursts and leakages).

As discussed in Techneau (2009) loss of water quality and loss of water quantity are the two most important "dimensions" of risk for a municipality or water utility. It should be noted that if analysis of water quality is restricted to include the effect on human health, then environmental impacts is another dimension of the risk. This risk can also be measured in various ways, e.g. in terms of frequency of polluting events and the exposure (e.g. number of affected species/animals).

In addition, the municipality or water utility can experience reputational damage (consumer trust), which is often more complex to measure. This can also have economic consequences.

Furthermore, commercial and industrial end-users and the municipality or water utility itself may experience economic losses, which are easily expressed in monetary units. Generally, it is possible to measure all losses (related both to water quality and quantity) in monetary units, and to give an overall measure of the total risk.

Finally, reference needs to be made to the societal risk, or indirect risks. This is the risk related to major events that cause the main functions of society to be at risk. Indirect risks are definitely relevant for key infrastructure such as water supply. Specific risk measures could also be developed to express these risks.

The measurement (quantification) of risk will be discussed in greater detail as part of the City of Tshwane Case study below. Some measures are "common", i.e. can be used for various dimensions of risk, and others are related to a specific dimension, as quality or quantity.

2.6.2 Qualitative versus quantitative expressions for risk

As stated above, risk is usually measured by severity of some unwanted consequence, C and the likelihood (i.e. probability, P, or frequency, f) that this consequence occurs.

Various types of consequences (losses) can be considered. Risks often need to be ranked in order to know which risks should be prioritised to be dealt with first. An overall measure of the risk is estimated as shown in the equation on the following page.

$$R = C \times P \qquad \text{(Equation 1)}$$

Where:

- R is the estimated risk;
- C is the consequence of the risk; and
- P is the probability of the risk.

This quantification can be time consuming. Also note that risk quantification expressed in 'detailed' numbers pretends an exactness that may not be the case because it has been derived from assumed probabilities or ranges of numbers described in the literature. Thus there is a danger of creating a false sense of precision of the result. However, it has the advantage of facilitating rational decision making, based on cost-benefit analysis and moderated by sensitivity analyses for the most important assumptions.

A ranking can also be carried out qualitatively, without specifying P- and C-values for each risk. One possibility is to apply paired ranking; i.e. comparing pairs of risks: each risk is compared to every other risk, specifying which of the two is greater (Techneau, 2009). This should give an explicit weighting, but again with the danger of giving a false sense of precision. The process could also be very time consuming and complicated due to the fact that "experts" are not always consistent (agreeing) in their evaluations of paired comparisons.

A common qualitative approach is to apply a classification of risk. Probabilities and consequences are divided into categories. For the probability category measures such as "rare" and "frequent/almost certain" are used. Consequences could be categorised as "insignificant" up to "catastrophic". These categories are a ranking of likelihood and consequences. The categories can also be defined by intervals, for instance, the probability category 'rare' could be defined as 'less than once a month'. Similarly, the consequence category 'small' with respect to health effects could be defined as 'at most 10 consumers with minor health effects', etc. In this case the term semi-quantitative approach is used (not fully quantitative but placed into pre-determined categories).

Based on categories for probability and consequence, a risk matrix can be made; for an example, based on water quality as described in the World Health Organisation's Guidelines for Drinking Water Quality (WHO, 2004), see **Figure 2-14**. In this figure risk categories are given (1-9) (note that this is an example). Also observe that the WHO definition of the likelihood (probability) category "Almost certain" equals "Once per day". In a risk analysis it is rather seldom to include events which are that frequent.

For the case study, a qualitative risk analysis procedure was followed. The reasoning behind this is described in Section 6.2.3 (Risk Estimation of the Case Study).

Likelihood	Severity of consequences: Insig-nificant	Minor	Moderate	Major	Cata-strophic
Almost certain	5	6	7	8	9
Likely	4	5	6	7	8
Moderately likely	3	4	5	6	7
Unlikely	2	3	4	5	6
Rare	1	2	3	4	5

Examples of definitions of likelihood (probability) and severity (consequence) categories that can be used in risk scoring

Item	Definition
Likelihood categories	
Almost certain	Once per day
Likely	Once per week
Moderately likely	Once per month
Unlikely	Once per year
Rare	Once every 5 years

Severity category	
Catastrophic	Mortality expected from consuming water
Major	Morbidity expected from consuming water
Moderate	Major aesthetic impact possibly resulting in use of alternative but unsafe water sources
Minor	Minor aesthetic impact possibly resulting in use of alternative but unsafe water sources
Insignificant	Not detectable impact

Figure 2-14: Example of a risk matrix and definitions of likelihood and severity categories to be used in risk scoring (Techneau, 2009).

2.6.3 Risk measures for loss of water quality

As described in Techneau (2009) when considering the total system, from source to tap to wastewater effluent disposal, there could be various quantifications related to loss of water quality, i.e. the measures could be related to:

1. Quality of source water, treatment technology and distribution network.
2. Health effects for consumers.
3. Effects on the consumers’ acceptability.
4. Effects on the distribution (bulk supply and pump stations) and equipment (e.g. corrosion)

A few examples are given below.

1. Quality of water source, treatment technology and distribution network

   The following are examples of risk measures:

   - Probability (frequency) of specific degrees of contaminations/pollution of the water source.
   - Probability of failure of specific treatment systems.
   - The probability of one litre of treated water containing a certain parasite.
   - Probability of pollution entering distribution network (if pipeline runs empty due to electricity failure and groundwater enters the system).

2. Health effects for municipal end-users

   The risk of polluted water to health can be characterised in a number of ways. For example one can give the risk per capita and in terms of the number of persons exposed. The risk per capita can be described by a probability distribution, and the measure could be given by the mean, the median etc. Some risk measures related to health effects for consumers are listed below:

   - Number of consumers affected by polluted drinking water that result in adverse health effects.
   - Frequency, f, of events resulting in at least N consumers being adversely affected; with say, N = 1000.

3. Effects on the consumers' acceptance of aesthetic water quality

   This may arise from taste, odour, colour or turbidity being noticeable (it can also increase economic risks and reputational damage). A few examples of risk measures are:

   - Probability that water supplied to consumer has unacceptable aesthetic quality.
   - Substandard Supply Minutes (SSM): the number of minutes an average consumer is supplied with inadequate potable water quality and / or quantity.

4. Effects on the distribution network and equipment

   Water quality could affect pumps and appliances due to water aggressiveness (by for example corrosion) or hardness. The risk measure should quantify this damage.

2.6.4 Risk measures for loss of water quantity (supply)

As described in Techneau (2009) the level of service of water supply in urban, well established, areas is generally quite high and in accordance with the relevant national or international standards. The probability of not supplying consumers is therefore relatively low in these areas.

Risk measures related to water quantity should take into consideration the number of effected consumers, the duration and the frequency that water supply is lost. It should also consider the consequences of the loss in water supply. For example, a measure of such a risk could be the average number of days that water supply was affected for all consumers. Another example is the frequency of water supply interruption for a given number of consumers (say 1000).

Loss of water quantity can be measured, for example, as (Techneau, 2009):

- *Probability (fraction of the time) that an arbitrary consumer is without water supply, (or supply is insufficient).*
- *Frequency of events resulting in failure to supply water to at least 1000 consumers.*
- *Volume of water missing (when supply is insufficient).*
- *Mean number of consumers affected by shortage (when supply is insufficient).*
- *Customer Minutes Loss (CML), i.e. the average number of minutes that drinking water is not delivered to an average consumer, and*
- *Level of service of water supply, i.e. when water supply is uninterrupted but supply can only be maintained at lower distribution network pressure.*

Generally, the fraction of time without water for an end-user (or a group of end-users) is an adequate measure for loss in water quantity. However, the risks posed by one prolonged water supply interruption event is not equal to the risks posed by a number of shorter duration events (even if the total water supply downtime of the shorter events is comparable to that of the single long duration disruption). For certain types of end-users (for example some industries); one short duration disruption event can have the same consequence of a long duration event if the event occurs during a critical phase of a time-sensitive manufacturing process. The same argument applies to residential end-users: the risks posed an event that affects 500 persons for 30 days (i.e. 15 000 consumer days) can be considered worse than 15 000 persons affected for 1 day (also 15 000 consumer days); even though both of the events will result in the same total water supply interruption duration.

Therefore, using the average unavailability of supply (for example in terms of consumer days) as a parameter to estimate the risk may not be adequate in all cases. Both the frequency and duration of interruptions should be taken into consideration when estimating the risk associated with loss in water quantity. There needs to be distinction between short duration and long duration water supply interruption events.

Loss in water quantity should be evaluated for both planned events (for example scheduled maintenance activities) and unplanned disruption events (for example electricity disruptions).

2.6.5 Risk measured in monetary units

Risks and risk reduction can be quantified in monetary units in order to:

1. Express all risks in a common unit; and
2. Enable economic analyses, e.g. cost-effectiveness or cost-benefit analyses, for choosing between various risk mitigation measures.

Economic valuation of marketable goods is usually done relatively easily. Economic valuation of non-marketable goods (for example the decreased risks to human health if adequate water supply ensured), is more problematic. Several studies (Freeman, 2003; EPA, 2000) provide detailed and extensive information on economic valuation methods of non-market goods.

Economic valuation of non-marketable goods is, to some extent controversial. Extensive research in the field of environmental economics has, however, resulted in a more uniform approach in terms of possibilities and limitation of economic valuation (for example, saving a statistical life and ecological improvement). In the water supply sector economic valuations can, as a result of recent improvements in the field, be used for numerous applications ranging from risk analysis to cost-effective asset management.

2.7 DATA FOR RISK ANALYSIS

2.7.1 Introduction

Available and accurate data is essential for achieving reliable results from a risk analysis. Data is needed for the system description, hazard identification risk estimation and risk reduction option identification and implementation as per the framework described in **Figure 2-1**. The level of detail of the required data depends on methods used for risk analysis, the required level of detail of the analysis and the need of accuracy of the results. Data requirements for a coarse qualitative risk analysis differ from the requirements for a detailed quantitative risk analysis.

Some relevant types of data are listed below (Techneau, 2009).

- *Technical data is required to understand the functions of the technical systems and to identify the barriers.*
- *Information about the specific layout of the system is essential to establish a system model and to gain an understanding of the system as a whole.*

- *Environmental and geographical data are necessary to identify possible hazards and to obtain an understanding of the environment where the water system is located. This information can allow evaluation of the dose and frequency of a contamination of the source, and to identify possible contamination points.*
- *Operational and maintenance data are needed to determine availability and reliability of components, subsystems or the entire system.*
- *Specific data about the reliability of barriers in the system is essential. The treatment systems will be of special importance.*
- *Knowledge about the effects of the identified hazard on consumers is also required.*
- *Guideline values and national standards.*
- *Knowledge about removal efficiencies.*

2.7.2 Data needs

The various types of data needed can be classified in three categories:

- Generic data:
  Data from external data (not from the water supply system investigated). It can relate to, for example, effectiveness or performance of various types of water treatment options or the effect that different types of pollutants have on humans.

- System data:
  Data describing the water supply system being evaluated (from source to tap to wastewater effluent disposal). Including raw water sources, plant and network layout, water treatment methods used, number of end-users and local conditions.

- Event data:
  Historically recorded data of hazards / hazardous events or system failures (sufficient monitoring of system components is necessary for accurate event data).

Some data needs for risk analysis are summarized in **Table 2-6**, following this categorisation.

Table 2-6: Data needed for risk analysis (adapted from Techneau, 2009).

Type of data	Use	Data sources
Generic data		
Data on health effects of various doses of various pollutants on humans:	Efficiency of treatment systems (i.e. level of	• WHO website • DWS website • Databases available on

Type of data	Use	Data sources
• Effectiveness of treatment systems for various types of contamination • Weights to be used in DALY calculations	contamination in source being unacceptable): • Calculations of risk	USEPA websites provide additional information (e.g. for health risk assessment).
System data		
Geographical data: • Layout of the catchment area and source • Possible hazards in the catchment area, water source and the distribution system • GIS data on hazards • Environmental data • Treatment systems • Water distribution network • Number and types of consumers connected to water utility • Volume of water consumed per consumer (per day)	System description is used throughout risk analysis to assess e.g.: • Hazards • Hazardous events • Treatment system reliability • Exposure and consequences to water quality and human health	Maps: • Water utility/plant data: o Technical drawings o Layout drawings o Asset databases o Maintenance systems • Municipality, water Utility (GIS maps, water distribution networks etc.) • Local knowledge • On-site inspection
Event data		
Failure data for various subsystems, (treatment systems / barriers): • Data on erroneous operation (human errors) • Events that have resulted in contaminated water • Preventive and corrective maintenance data	Reliability and failure rate of equipment and systems: • Type and frequency of hazardous events	• Failure data base of water utility • Maintenance system • Generic failure data bases • Vendor information (e.g. on failures) • Reporting system for hazardous/undesired events • Local knowledge, (e.g. Maintenance personnel)

2.7.3 Data sources

There are different sources that can be utilized to obtain data. These can be grouped in different categories (Rausand, 1991):

1. External data sources

External data sources can be used to test for reliability of technical components and systems and to obtain the effect different types of pollutants have on humans. In the case of component reliability this type of data source could supply valuable data because the operational time where failures are registered is often extensive. The effect that different pollutants have on humans is in most cases independent of local conditions, but the structure and sensitivity of the population supplied may be site specific (e.g. hospital or baby sanatorium connected to the network). It is important to consider the relevance of the data for the specific system in question before utilizing external data sources.

Similar systems or barriers might have different external conditions and maintenance which may affect the reliability (and effectiveness) of the barriers.

2. Internal data sources

   Internal data sources can be data monitored in a CMMS system (Computerized Maintenance Management System) or a SCADA (Supervisory Control And Data Acquisition) system, which can be important sources for reliable data.

3. Expert judgement and testing

   Expert judgment and testing can be from either internal or external sources. This is a good option where no reliable data is available. System testing can also be used in operation or in laboratories.

4. Literature and publications

   Risk databases such as the Techneau hazard database, the WHO website and the DWS website should be consulted. Literature and publications of pervious risk assessment studies should also be consulted, for example the WATERRISK tool developed in South Africa (Jack, De Souza and Mackintosh, 2011) and the Techneau Hazard Database that was developed by a global team (Beuken, et al., 2008).

Information about system reliability, defined by Rausand and Høyland (2004) is information about the failure/error modes and time to failure distributions for hardware, software and humans. The reliability of water supply systems (or sub-systems) is often not site specific. Therefore, it is possible to collect system reliability data from different sites into a common database. The following information can be included in such a database:

- Hazardous events;
- Components/equipment failure information (such as failure mode and repair time);

- Equipment inventory (asset registers), operational times, procedures, etc.; and
- Environmental and operational data relevant for the adequate functioning or cost-effective performance of the systems and sub-systems.

The following tasks are important when collecting data and developing a database:

- To make it easy to transfer data, the format of various databases needs to be kept as simple as possible and comparable;
- Encourage data (and database) sharing between various water supply entities (both locally and internationally); and
- To better utilise information contained in databases, it is necessary to continuously develop data analysis techniques.

A database developed following the guidelines above will ensure reliable analysis results and make the risk analysis less time consuming and costly.

b) Background on institutional arrangements, strategies and programmes

(Section 2.8)

2.8 INSTITUTIONAL ARRANGEMENTS, STRATEGIES AND PROGRAMMES

This section gives an overview of institutional arrangements that were developed in comparable studies and projects. These arrangements will be evaluated to determine the applicability of the various arrangements specifically on the effect of electricity disruptions on water supply.

2.8.1 International strategy for disaster risk reduction

The United Nations Office for Disaster Risk Reduction has developed the United Nations International Strategy for Disaster Reduction (UNISDR). The UNISDR seeks to enable communities to become resilient to the effects of natural, technological and environmental hazards, thereby reducing the risks that hazards pose to social and economic weaknesses within society (UNISDR, 2017).

The UNISDR has the following goals (UNISDR, 2017):

- To increase public awareness of risks that natural, technological and environmental hazards pose to society;
- To ensure commitment by public authorities to reduce risks to people, infrastructure and environmental resources;
- To engage public participation at levels of risk reduction implementation to create disaster-resistant communities; and
- To reduce the economic and social losses of disasters.

The UNISDR has published the Sendai Framework for Disaster Risk Reduction 2015-2030. The Sendai Framework seeks to achieve the following outcome (UNISDR, 2015):

"The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries."

In order to achieve the outcome above, the Sendai Framework proposes the following guiding principles:

1. It is the primary responsibility of States to reduce disaster risk;
2. It is the shared responsibility, under certain circumstances, between States (Government) and national authorities, sectors and stakeholders to reduce disaster risk;
3. To protect all persons and their assets whilst promoting and protecting all human rights;
4. To ensure engagement from all of society;
5. To ensure full engagements of all State institutions at national and local levels;
6. To empower local authorities and communities with resources, incentives and decision-making responsibilities as appropriate;
7. To ensure that decision making is inclusive and takes all risks into account using a multi-hazard approach;
8. To ensure coherence of disaster risk reduction and sustainable development across all sectors;
9. To take into account local characteristics of risks when determining measures to reduce risks;
10. To "Build Back Better" for preventing the creation of, and reducing existing, disaster risks;
11. To ensure effective global partnership and international cooperation in disaster risk reduction; and
12. To ensure sufficient support from developed countries is given to developing countries as per the specific needs of the developing countries.

Adoption of these guiding principles (where applicable) in the development of institutional arrangements to mitigate the effect of electricity disruptions on water supply systems can be a valuable way of ensuring that the arrangements identified are comprehensive and were developed with the right outcomes and objectives in mind.

2.8.2 Emergency and disaster preparedness plan development

Guidelines for effective response in case of a drinking water supply related disaster were developed as part of a study undertaken by the Pan American Health Organisation (PAHO) that forms part of the World Health Organisation (PAHO, 2002). This study focussed on all types of hazards that affects water supply and sewage systems, but includes valuable examples on the development of disaster mitigation plans. According to the study, disaster management consists of (PAHO, 2002):

"A coherent set of planning, organisation, control, evaluation, and training activities, involving all institutional, human and operational resources that should be developed and integrated into the agency or company."

The objective of emergency and disaster management is, firstly, to restore in the shortest time possible the water supply services most critical to society, secondly, to minimise the impact of emergency and disaster events on water supply and, thirdly, to ensure an effective response to the event to preserve the health of the population.

In the case of planning for electricity disruption events, these objectives can be written as follows:

- To mitigate the impact of electricity disruption events on water supply infrastructure, and
- To ensure effective response to guarantee that the available water supply is used optimally, to maintain sufficient water supply, water quality and public order.

According to the World Health Organisation (2007) emergency preparedness involves activities that aim at preventing, mitigating and preparing for emergencies. Furthermore, the criticality of a risk identified is proportional to the risk's hazard and system vulnerability compared to the level of preparedness, as shown in the equation below:

$$Risk = \frac{Hazard \times Vulnerability}{Level\ of\ Preparedness} \qquad \text{(Equation 2)}$$

Therefore, with effective preparation even risks with the highest hazard level and system vulnerability can be decreased to an acceptable. A very low level of preparedness (or none at all) can result in a situation where even small risks with relatively low hazard levels and system vulnerability are unmanageable and cause catastrophic disasters.

The development of disaster mitigation plans should be done through the following steps (PAHO, 2002):

1. Analysing and assessing the risk (likelihood and consequence) of identifiable events that could affect water supply systems,
2. Evaluating the effect of identified events on equipment and infrastructure in terms of vulnerability to be adversely affected by specific events,
3. Estimating the potential impact of events on various components of water supply systems,

4. Compiling and adopting mitigation measures to reduce equipment and infrastructure vulnerability and mitigating the potential impact of events, and
5. Programming emergency operations.

For the purpose of developing institutional arrangements, hazards (or electricity disruption events) should be classified into two categories:

- Sudden onset events such as a sudden failure of electricity generation infrastructure resulting in an electricity disruption event without warning (such as a blackout); or
- Gradual onset events such as a coal demand vs. supply deficit which results in decreased electricity generation capacity and in electricity disruption events with ample warning (such as load shedding).

2.8.3 Stages of a disaster cycle

The first step that should precede emergency action must be to reduce the probability of occurrence of the primary event(s) that cause it. In this regard Eskom has already put a number of initiatives in place. The requirements and dire consequences of disruption of water supply can lead to reappraisal of priorities, especially when higher order load shedding occurs and in the aftermath of a blackout when electrical supply is gradually reinstated. Excellent communication with all concerned (in this case Rand Water and Tshwane) is also required from the earliest onset of the incident to identify the nature and expected duration of the outage. Such communication needs to drill down quickly to plant, pump systems and operators.

This is essential to properly integrate available reservoir storage and water supply in the event of a long duration outage. Water that is wasted or ends up at the wrong end of the system during the first hours of an outage cannot be brought back to support the longer term deficit that will develop.

Emergency preparedness can be achieved by successfully designing a series of actions to prepare in advance for a disaster event and to implement the actions correctly after the disaster event occurs. **Figure 2-15** on the following page shows the different stages that effective disaster preparedness consists of. Identification and implementation of mitigation activities associated with every stage of the disaster cycle is very important, especially for the Warning and Response stage (PAHO, 2002).

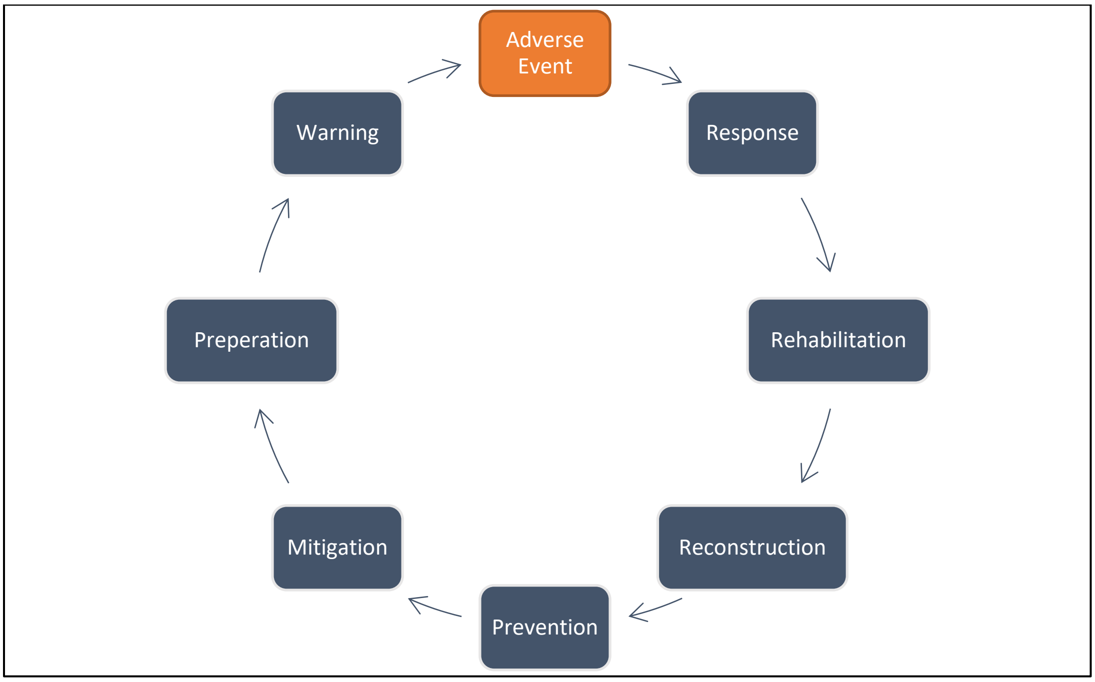

Figure 2-15: The disaster cycle (PAHO, 2002).

Prior to a disaster event, three sets of activities need to be developed:

- Prevention institutional arrangements (such as load shedding of critical loads);
- Mitigation institutional arrangements (such as early warning systems and ensuring sufficient storage capacity in reservoirs); and
- Preparedness institutional arrangements (such as disaster management plans).

Response activities after a disaster event has occurred include:

- Response (such as rapid implementation of water restrictions and public awareness communications);
- Rehabilitation (such as recommissioning of water supply zones that were affected by the electricity disruption event); and
- Reconstruction (required if an electricity disruption event results in damage to water infrastructure, including telemetry systems).

2.8.4 Design of a disaster prevention and response program

Over the last few decades, the way disasters are dealt globally have changed drastically (WHO, 2007). The emphasis of disaster management has moved from response and humanitarian relief activities to prioritising disaster mitigation strategies and planning for disasters before they occur.

A disaster prevention and response program should be developed based on the outcome of a complete risk analysis and should consist of (PAHO, 2002):

- National and institutional standards for emergency situations;
- Description of the water supply systems;
- Risk analysis outcomes;
- Prevention and mitigation measures (this report's objective);
- Emergency operation plans; and
- All relevant supporting documentation.

2.8.5 Identification of mitigation measures

Identification of disaster mitigation measures should be identified taking the following principles into consideration (FEMA, 2017):

- Preventive actions for all risks mitigation measures must be decided on at the local level;
- Private sector partnerships and participation are vital for effective risk mitigation; and
- Long-term efforts and investments in prevention measures are essential.

Based on the outcome of the risk analysis, the following aspects are important to keep in mind during the identification of mitigation measures (PAHO, 2002):

- The training needs of staff need to be defined,
- All strengths and weaknesses of the system and its various components must be identified,
- Mitigation measures must be developed for each of the hazards identified as part of the risk analysis,
- Specialised studies must be included in the development of mitigation measures if needed, and
- A financial assessment of the costs of mitigation measures needs to be done.

2.8.6 Components of disaster risk management programs

The following tools should be incorporated into disaster risk management programmes (FEMA, 2017):

- Hazard identification and mapping: this includes a database of all conceivable hazards and hazardous events in the specific area;

- Design and construction applications: This includes ensuring that building codes, architecture and design criteria of civil infrastructure are adhered to by all public and private infrastructure development schemes. This should be enforced by local authorities;
- Land use planning: This includes proper enforcement of land use planning criteria such as development population density controls, special land use permits and subdivision controls;
- Financial incentives: Community buy-in and public-private cooperation is critical for effective disaster risk reduction and mitigation. Financial incentives such as tax decreases can be an effective tool to encourage the community or private companies to assist local authorities with disaster risk reduction and mitigation; and
- Insurance: Insurance can be an effective tool to include as part of a disaster risk mitigation plan. Effective insurance planning is essentially saving enough funds to be able to deal with disasters when they occur without having to lend the funds after the disaster occurred. Insurance as a disaster risk mitigation tool requires detailed planning and understanding of hazards and hazardous events that may occur so that accurate cost-estimates of dealing with the disaster when it happens can be done.

A disaster risk management program is essentially made up of the following organisational components (PAHO, 2002):

a) The Institution or Agency Directors

The highest decision making body of the institution is responsible for establishing/adopting all policies, arrangements and strategies concerning emergencies and disasters.

b) A Central Emergency Committee

The chief role of the Central Emergency Committee is to ensure that water supply to the community is restored in the shortest possible time after a hazardous event and to prioritise and allocate available water resources.

c) A Disaster Office (or Disaster Unit)

The disaster office's responsibility is to carry out the institution's disaster prevention, mitigation and preparedness actions as required by the Central Emergency Committee.

d) A Situational Room

To ensure that a disaster management program can be implemented in a coordinated fashion, it is important to have a physical space available that is secure and contains all the required resources required to implement the disaster management program effectively. The Situational Room should be permanently available and should have the following items (among others):

- Backup electricity generators;
- Communication systems;
- All disaster management documentation;
- Operational control systems;
- Food and water;
- Keys to all infrastructure; and
- All relevant system information (e.g. water network map books and detailed system descriptions of water infrastructure components).

e) Field teams

Suitably equipped, mobile, qualified, authorised, drilled and motivated field teams with good communication with the Situation Room and having access to key installations (pumps, emergency generators, reservoirs and valves) are required. Such teams should be drawn largely from operating personnel.

f) The Declaration of States of Alert and Emergency

A state of alert is the period after an alert (or warning) is issued (i.e. when preparation for an electricity disruption event has been initialised) until the disaster event occurs (when the electricity disruption event occurs). There can be various alert levels associated with various risks, for example:

- Load shedding resulting from the electricity grid being under strain to supply the high demand during peak times can be defined as a low-risk alert level; and
- An imminent asteroid strike that will adversely affect the stability of the electricity grid and result in a blackout can be defined as a high-risk alert level.

It is important to note that a state of alert can only be declared for gradual onset hazardous events and not for sudden onset events.

A state of emergency is declared after a hazardous event has occurred (i.e. an electricity disruption event that results in water supply problems). If the hazardous event that results in a state of emergency was a sudden onset event, it is of cardinal importance that the disaster management plan is immediately implemented.

It should also be kept in mind that disaster management planning (or institutional arrangements) should be developed to address both the risks associated with gradual and sudden onset hazardous events.

2.8.7 Wastewater Risk Abatement Plan's approach to risk mitigation

The Wastewater Risk Abatement Plan (van der Merwe-Botha & Manus, 2011) was developed in South Africa to plan and manage towards safe and compliant municipal wastewater collection and treatment.

The W_2RAP contains relevant examples of risk mitigation control measures and possible preventative actions to mitigate risks. This section will briefly summarise the plan's outcomes in terms of risk mitigation control measures and preventative actions that can be adapted as institutional arrangements.

Control measures include all activities and systems that prevent, minimise or mitigate identified risks. Control measures should be defined for all hazardous events and associated risks. Control measures are made up of the following (van der Merwe-Botha & Manus, 2011):

- Standard operating procedures (SOPs);
- Contingency measures;
- Training; and
- Emergency procedures.

Risks were subdivided into two main risk categories (van der Merwe-Botha & Manus, 2011):

- Operational Risk Categories, including:
    - Design;
    - Operation;
    - Maintenance; and
    - Scientific.
- Infrastructure Risk Categories, including:
    - Collection system;
    - Treatment system;
    - Catchment system; and

- Administrative system.

Critical Control Points (CCPs) are defined based on identified hazards and the outcome of risk assessments. In the case of the W_2RAP guidelines, CCPs are points along the wastewater collection and treatment chain where monitoring and interventions can significantly impact the quality of wastewater. CCPs therefore enable the managing authority to isolate, mitigate and address problems as soon as they are identified (while the risks associated with the problems are still small) before the problems can escalate and pose higher risks (van der Merwe-Botha & Manus, 2011).

Examples of CCPs in wastewater treatment include (van der Merwe-Botha & Manus, 2011):

- Pump stations;
- Screens;
- Penstocks (sluice gates);
- Chlorine contact tank;
- Emergency pond overflows; and
- Security access points.

Examples of CCPs in water supply systems are given below:

- Raw water supply;
- Water purification works;
- Bulk water supply pump stations;
- Pressure reducing valves;
- Flow control valves;
- Reservoir inlet valves; and
- SCADA systems.

c) Relevant background on South Africa's electricity and water sectors

(Sections 2.9 to 2.11)

2.9 OVERVIEW OF SOUTH AFRICA'S ELECTRICITY SECTOR

This section gives an overview of South Africa's electricity sector. A comparison of South Africa's forecast electricity generation capacity and demand is made. The main challenges facing the electricity sector in South Africa are also summarised.

2.9.1 The Southern Africa Power Pool

South Africa forms part of the Southern Africa Power Pool (SAPP) along with Angola, Botswana, the DRC, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia and Zimbabwe (Pollet, et al., 2015). The SAPP's region is illustrated in **Figure 2-16** below.

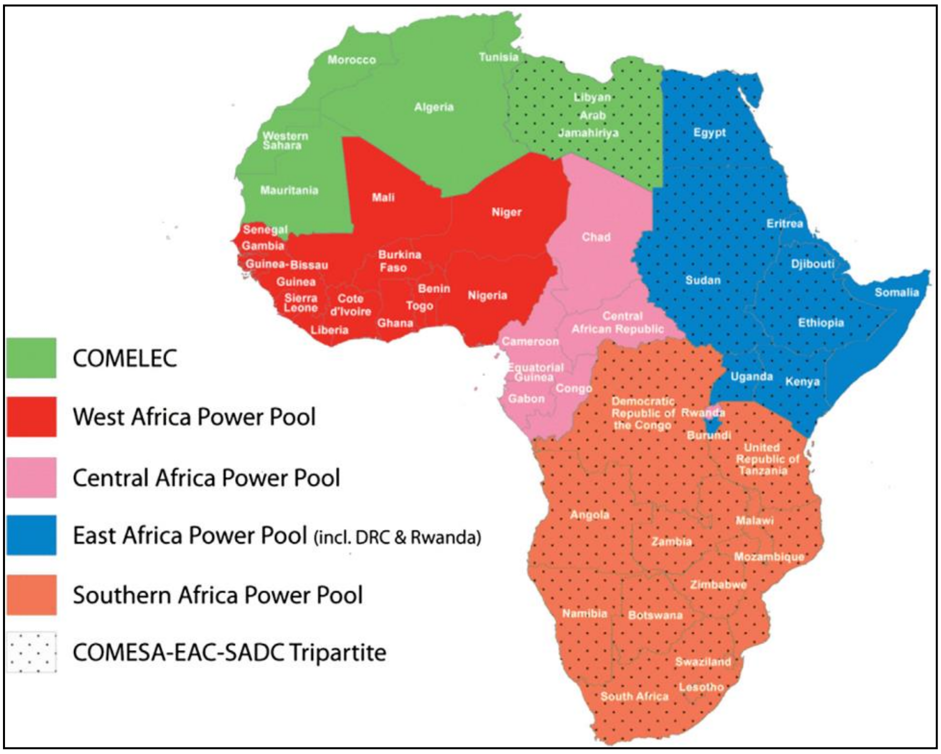

Figure 2-16: Africa's power pools (Pollet, et al., 2015).

Table 2-7 summarises the SAPP's annual power generation, consumption and peak generation capacity (The Infrastructure Consortium for Africa, 2011).

Table 2-7: Overview of the Southern Africa Power Pool (The Infrastructure Consortium for Africa, 2011).

Description	South Africa	SAPP	South Africa as percentage of SAPP Total
Annual power generation (GWh)	232 812	271 239	86%
Annual power consumption (GWh)	218 591	260 081	83%
Peak generation capacity (MW)	44 170	55 996	79%

A map of South Africa's power network is shown in **Figure 2-17**.

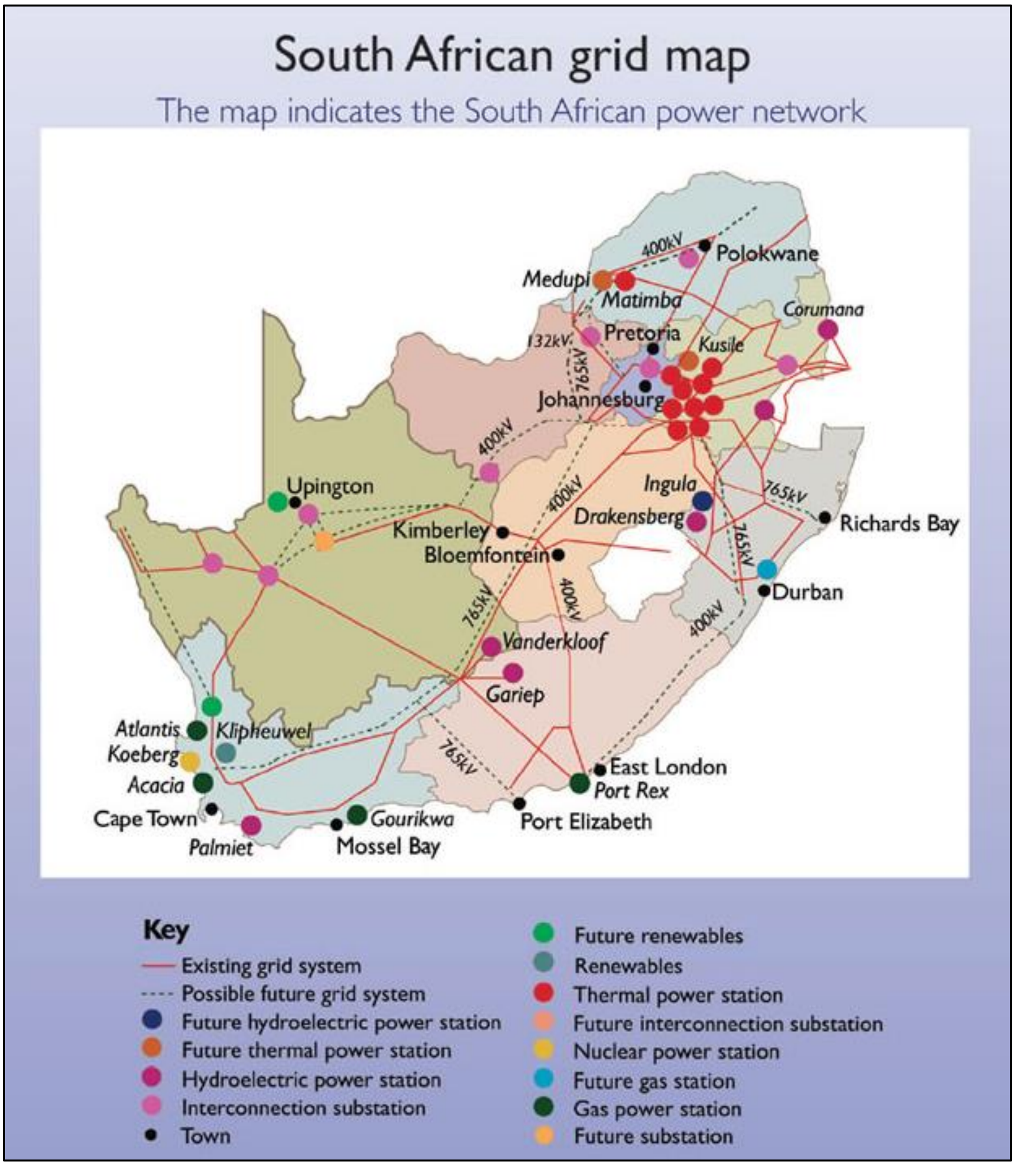

Figure 2-17: Map illustrating the South African power network (Eskom, 2012).

2.9.2 South Africa’s electricity generation capacity and demand

A comparison of South Africa's electricity generation capacity vs. the country’s electricity demand was done in terms of (a) annual electricity generation capacity vs. annual electricity demand and (b) peak electricity generation capacity vs. peak electricity demand. Both of these scenarios indicate specific risks and challenges to the reliability of South Africa's electricity supply.

a) Annual electricity generation capacity vs. annual electricity demand

According to Statistics South Africa (2016) there has been a decline in South Africa's electricity generation capacity from 2011. This can, however, be a result of the decrease in the country’s electricity demand due to the decrease in economic activity in South Africa from 2010 to 2016 (The World Bank, 2017).

The Council for Scientific and Industrial Research (CSIR, 2010) completed a report in which South Africa's annual electricity demand was forecast up to 2035. This forecast was done through statistical regression taking the historical electricity demand of South Africa's five main electricity consuming sectors into account. The following sectors were taken into account:

- The agricultural sector;
- The transport sector;
- The mining sector;
- The domestic sector; and
- The commerce and manufacturing sector.

Based on the separate evaluation of the various sectors’ electricity demand, the CSIR's forecast in terms of the country's total annual electricity demand is illustrated in **Figure 2-18**.

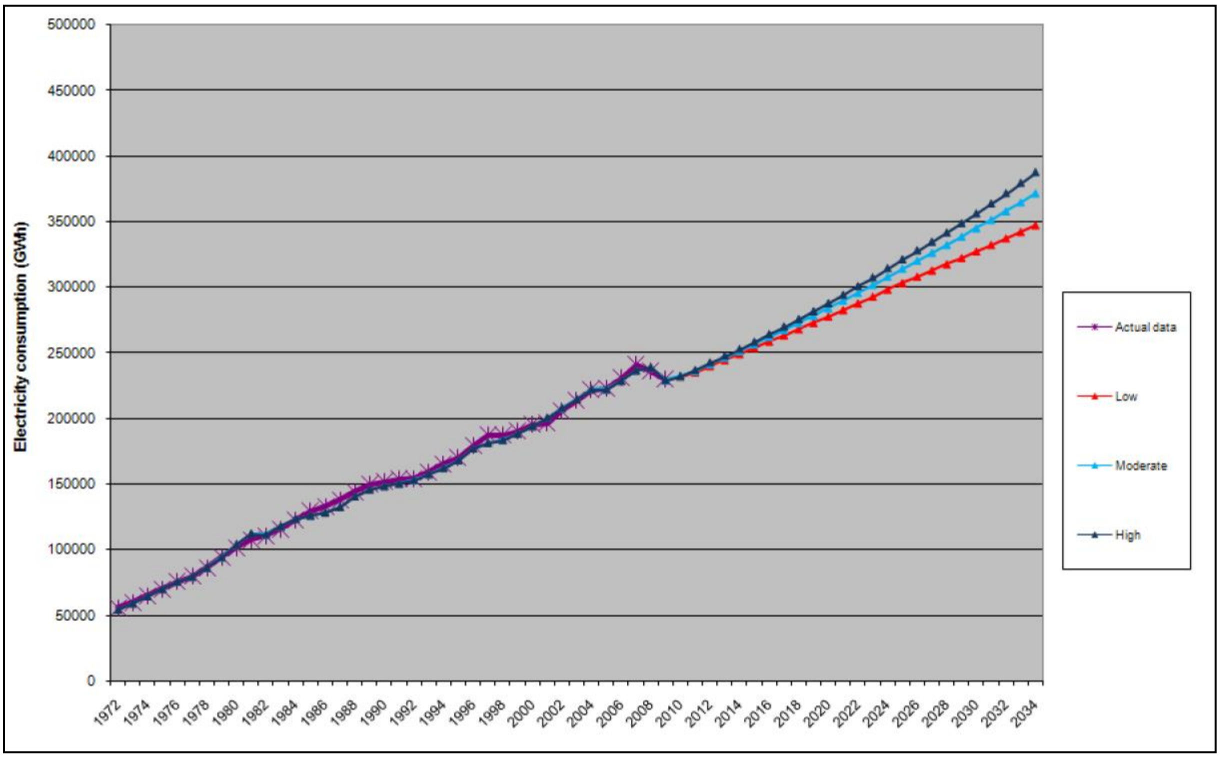

Figure 2-18: South Africa's total annual electricity demand forecast up to 2035 (CSIR, 2010).

As can be seen from the graph, apart from the decrease in South Africa's annual electricity demand (between 2006 and 2010), the total annual demand was forecast in 2010 to increase at more or less the same rate as the historical rate. It is assumed that the forecast done by the CSIR did not take into consideration the continuous decline in the country's economy up to 2016. It is, however, estimated that the country's annual electricity demand will return to a yearly growth pattern in line with the forecast once the country's economic decline ceases and economic growth resumes in the future.

b) Peak electricity generation capacity vs. peak electricity demand

A short-term (5 year) forecast of South Africa's peak electricity generation capacity from 2016 to 2021 was done by Eskom (2016). This forecast took into consideration the country's current infrastructure (including existing plants that will be decommissioned in the next five years) and future infrastructure that will be commissioned. Based on Eskom's forecast South Africa's current electricity generation capacity is approximately 49 000 MW (2017) and is expected to decline to approximately 48 000 in 2021 due to decommissioning of ageing infrastructure (Eskom, 2016).

Additional electricity generation capacity will be added as electricity plants currently under construction reaches completion and is commissioned, these include the Medupi - and Kusile coal power stations, the Ingula pumped storage scheme along with Independent Power Producers' (IPPs) plants. It is estimated that these electricity generation plants currently in construction will add approximately 4 500 MW by the end of 2017 and 18 500 MW by 2021 (Eskom, 2016).

Therefore, based on Eskom's forecasts the electricity generation capacity will be approximately 53 500 MW in 2017 and 67 500 MW by 2021.

Historically (between 1954 and 2000), Eskom has operated its infrastructure at a reserve margin of between 10% and 40%. During the electricity supply crises in 2006, the reserve margin was just 2.7% above the peak demand. For future planning purposes, Eskom plans to operate their infrastructure at a reserve margin of between 10% and 13% (Newbery and Eberhard, 2008). Applying this reserve margin (10%) to the forecast electricity generation capacity discussed above results in an adjusted electricity generation capacity of 48 150 MW in 2017 and 53 620 MW by 2021.

South Africa’s peak electricity demand for different electricity demand growth scenarios were forecast by Gibb in a recent study done for Eskom (Gibb (Pty) Ltd, 2015). The peak electricity demand for each of the growth scenarios are compared to the country’s estimated peak generation capacity in **Table 2-8** for the short-term period discussed above (i.e. for 2017 and 2021).

Table 2-8: South Africa's forecast peak electricity demand.

Year	Peak Electricity Demand Growth Scenario			Estimated Peak Generation Capacity (MW)
	Low (MW)	Moderate (MW)	High (MW)	
2017	45 000	48 000	51 500 *	48 150
2021	49 000	54 000 *	60 000 *	53 520

Note:

* Forecast peak electricity demand is higher than estimated peak generation capacity.

Additional issues in terms of future supply capacity is the planned decommissioning of a large portion of Eskom's base electricity supply infrastructure from 2025 onwards as illustrated in **Figure 2-19** (Mullins, 2011). If additional infrastructures apart from the plants currently in construction are not constructed to replace ageing infrastructure, South Africa's electricity supply vs. generation capacity issues will only get worse in the future.

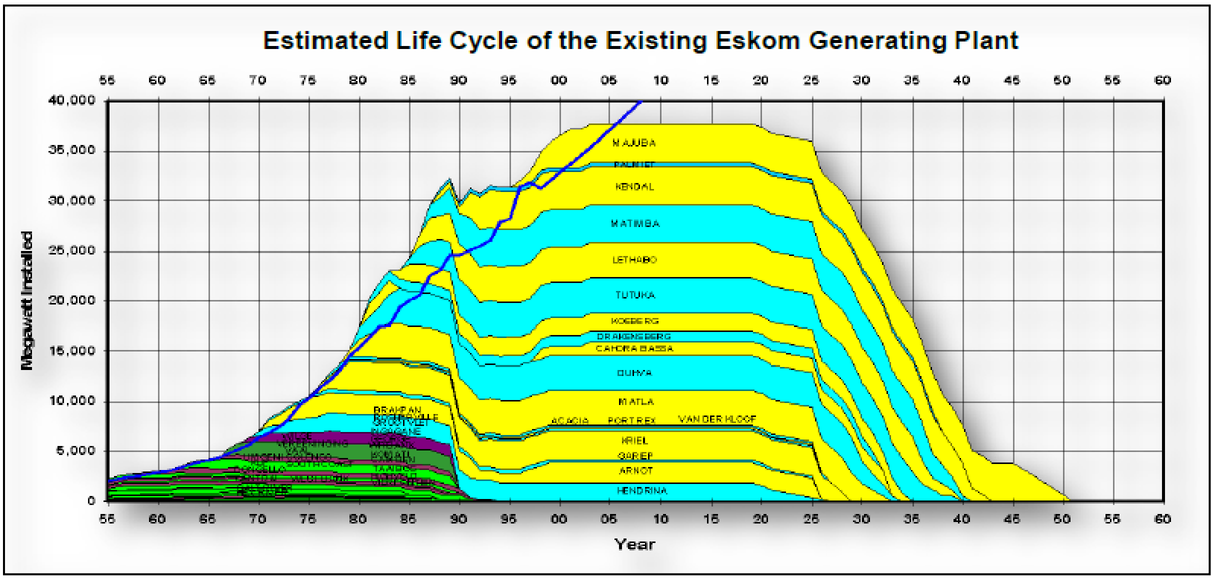

Figure 2-19: Estimated life cycle of existing Eskom electricity generation capacity (Mullins, 2011).

2.9.3 Challenges facing the energy sector in South Africa

According to Newbury and Eberhard (2008) the main challenges in the energy sector in South Africa are:

- Security of electricity supply has been compromised by the last few decade's underinvestment in electricity generation capacity, and that there is an urgent need for capacity expansion;
- Policy developers should ensure that Eskom's investments in new infrastructure are done with the lowest end-user cost in mind: State Owned Enterprises (SOEs) typically suffer from soft budget constraints and can rely on state funded bailouts or loans if funds are insufficient to undertake the new projects. Therefore SOEs typically do not cut costs or optimise their operations (this is crucial for similar companies in the private sector);
- Eskom is having trouble to maintain their existing infrastructure at required levels to operate adequately - recent blackouts were not only due to insufficient electricity generation capacity but also due to unplanned breakdowns and failures of existing electricity generation and distribution infrastructure;
- Financial principles of efficiency, cost-reflectivity and transparency need to be implemented by Eskom, although these principles are accepted by government and the regulator and incorporated into legislation, it has not been applied adequately to date;

- Apart from electricity generation capacity issues, transmission constraints are also becoming problematic due to ineffective and insufficient maintenance and inappropriate investment into new transmission infrastructure - this results in localised electricity disruption issues;
- Municipalities' electricity distribution infrastructure aren't being maintained and deteriorate at an unacceptable rate resulting in unnecessary costs - most municipalities (which owns almost half of electricity distribution infrastructure) are not suited for the management of electricity distribution infrastructure;
- Data used in the estimation of electrification planning probably overestimates the current number of households with access to electricity - this could mean that the future electricity demand growth will increase more rapidly than currently forecast; and
- Due to the relatively low capital, operational and maintenance costs of coal generating plants (compared to other alternatives like nuclear - and renewable electricity generating plants), South Africa's carbon emissions and air-pollutants will remain high and continue to grow in the future.

2.10 LEGISLATION GOVERNING THE ELECTRICITY SECTOR

This section gives an overview of applicable legislation governing the Electricity Sector in South Africa.

2.10.1 The Constitution of South Africa

The Constitution of South Africa gives municipalities the right and authority to control and supply electricity reticulation to its population (Newbery, et al., 2008).

2.10.2 The Eskom Conversion Act (2001)

The Eskom Conversion Act (South African Government, 2001) gives an outline of Eskom's status as a public company and that Eskom is subject to the Companies Act. It further clarifies that Eskom is 100% state owned, governed by a shareholder compact (the performance agreement between Eskom and the government of the country) and that Eskom is liable to pay dividends and taxes.

2.10.3 The National Energy Regulation Act

The National Energy Regulation Act was drawn up to establish a single regulator to regulate the electricity, petroleum pipeline and piped-gas industries in South Africa (South African Government, 2005). In the act it is stated that the main functions of the National Energy

Regulator are the same as the functions of the Electricity Control Board as set out in the Electricity Act of 1987. The Electricity Regulation Act of 2006, however, repeals and redefines the Electricity Act of 1987.

2.10.4 The Electricity Regulation Act

The functions of the National Electricity Regulator are defined in the Electricity Regulation Act. These functions include (South African Government, 2006):

- To regulate prices and tariffs;
- To deal with electricity licenses;
- To issue rules designed to implement the government's electricity policy framework, the integrated resource plan and the Electricity Regulation Act;
- To establish and manage monitoring and information systems and a national information system;
- To integrate the above-mentioned information systems with other relevant information systems; and
- To enforce performance and compliance.

2.10.5 The Local Government Municipal Systems Act

The Local Government Municipal Systems Act defines municipal administration of electricity distribution and electricity tariffs. The most notable objectives of the act in terms of electricity distribution include (South African Government, 2000):

- To ensure universal access to essential services;
- To provide for the manner in which municipalities perform their functions (i.e. service delivery);
- To establish the framework for municipalities' core processes of planning, performance management, resource mobilisation and organisational improvement; and
- To provide a framework for the provision of services and service delivery agreements.

2.10.6 Other legislation applicable

Other legislation that governs the electricity sector includes (Newbery, et al., 2008):

- The Public Finance Management Act of 1999 provides a framework for Eskom's responsibilities to government as a public company in terms of reporting and accounting;
- The Municipal Finance Management Act of 2003 defines the management of municipal electricity utilities;

- The National Nuclear Regulator Act of 1999 regulates nuclear safety issues;
- The National Environmental Management Act of 1998; and
- The Air Quality Act of 2004.

2.11 LEGISLATION GOVERNING THE WATER SECTOR

This section gives a brief overview of applicable legislation governing the water sector in South Africa. The primary focus of legislation is to ensure the provision of basic water and sanitation services to all (DWS, 2017a). This focus forms the basis of all post-apartheid water legislation in South Africa.

2.11.1 The Constitution of South Africa

Clause 1 of Section 27 of the Bill of Rights of South Africa's Constitution states that (South African Government, 2017):
"Everyone has the right to have access to sufficient food and water..."

Furthermore, Section 24 of the Bill of Rights of South Africa's Constitution states that (South African Government, 2017):
"Everyone has the right:

- to an environment that is not harmful to their health or well-being; and
- to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that:
  a) Prevent pollution and ecological degradation;
  b) Promote conservation; and
  c) Secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development."

2.11.2 The National Water Act

The Bill of Rights serves as the mandate for the National Water Act (NWA) which provides the framework for the protection, usage, development, conservation, management and control of water resources in South Africa. The applicable principles of the NWA with regards to this study are (South African Government, 1998a):

- "National government is the overall authority and ultimately responsible for the nation's water resources and their use, including the equitable allocation of water for beneficial use, the redistribution of water, and international water matters";

- "The ultimate aim of water resources management is to achieve the sustainable use of water for the benefit of all users"; and
- "All aspects of water resources need to be managed in an integrated way, and, where appropriate, management functions need to be delegated to a regional or catchment level to enable everyone to participate."

2.11.3 The Water Services Act

The Water Services Act's main objective is to guide municipalities in their role as water service authorities and to ensure that the interests of consumers are protected. Furthermore, it clarifies the role of all water service institutions, including: water service authorities (i.e. municipalities), water service providers and water boards (South African Government, 1997).

2.11.4 The Municipal Structure Act

The Municipal Structures Act describes how new municipalities are to be established. Municipalities in South Africa are subdivided into category A (metropolitan-), category B (local-) and category C (district municipalities). This act defines what powers and responsibilities each type of municipality has. Furthermore, it states that district municipalities (and metropolitan municipalities) are responsible for bulk water supply, bulk sewer treatment works and sewage disposal of significant portions of local municipalities. All further functions are local municipalities' responsibility (South African Government, 1998b).

2.11.5 The Municipal Structures Amendment Act

This act delegates the responsibility of all potable water, domestic sewerage and wastewater systems to district and metropolitan municipalities (categories A and C). This act therefore assigns the Water Services Authority function to these municipalities (South African Government, 2003).

3 METHODOLOGY

3.1 INTRODUCTION

3.1.1 Problem definition

The main focus of this study is to quantify the impact that electricity disruptions have on water supply. Although various electricity disruption events were evaluated as part of the risk analysis for the case study, the objective of this study was not to identify solutions to prohibit electricity disruption events from occurring. It goes without saying that if the problem of electricity disruptions can be addressed effectively, the need for water service entities to mitigate the impact of electricity disruption events will not exist.

It is, however, impossible for electricity suppliers to ensure that no electricity disruption events ever occur as various external hazardous events (e.g. solar flares, detonation of a nuclear warhead, lightning strikes, etc.) cannot be controlled. Electricity suppliers can only control and mitigate internal hazards and hazardous events.

The direct impact that an electricity disruption event will have on the water and wastewater sectors include water supply interruptions and wastewater spillages.

Water supply interruptions can have numerous adverse effects, including:

- Insufficient water available for domestic demands;
- Insufficient water available to fight fires throughout the city;
- Wet industries such as breweries and beverage plants will not be able to continue their operations;
- To a lesser extent other commercial sectors that do not require water to sustain their primary source of income will be affected;
- Critical public and private services such as the health care sector will not be able to continue operations; and
- Loss of revenue for the water service authority.

Prolonged wastewater spillages will result in pollution of water sources which will in turn result in environmental degradation and more advanced water treatment procedures required to treat raw water to potable standards downstream of the wastewater spillage area.

The indirect impacts of prolonged water supply interruptions due to electricity disruption include:

- Social unrest;
- Economic collapse of urban areas;
- Increased crime; and
- Civil war.

3.1.2 System constraints

Mitigating measures to ensure uninterrupted water supply during electricity disruption events took into consideration the following system constraints:

- Legal implications:
  It is the responsibility of the Water Service Authority as mandated by the Constitution of South Africa to ensure that the people residing within the Authority's area has access to clean water to sustain their basic human need for drinking, cooking and hygienic purposes.
- Level of service of water supply:
  Level of service in terms of water supply can be defined as "the extent to which water users' demand of potable water is met". For instance an absolute minimum level of service would be to only supply the minimum water to sustain basic human life as is mandated by the Constitution. A higher level of service can be to supply sufficient water to ensure uninterrupted economic and other necessary activities (health care, public administration, schools, law enforcement, etc.) within a city but not supplying sufficient water to meet all domestic water demands (for instance excluding potable water supply for domestic irrigation purposes, washing of vehicles, etc.). The highest level of service within South Africa's bulk water supply and distribution standards would typically be to ensure water supply is in line with the recommendations of the Guidelines for Human Settlement, Planning and Design (2005). The level of service of bulk water supply considered for the case study included minimum supply for the city's domestic water demand, reduced supply for the city's "other" water use (i.e. commercial water use) and supplying 50% of the city's industrial water requirements (including water losses). This is described in more detail in Section 6.5.
- The economy (affordability):
  Various measures to ensure uninterrupted water supply in the event of electricity disruptions exist. Affordability constraints define to which extent the level of service of water supply can be sustained (given that each person's basic human need for water has been addressed).

- The environment:
  The environmental effect of wastewater spillages due to electricity disruption events was also included as a risk which will need to be mitigated. It is difficult to quantify the environmental effect of an electricity disruption event due to wastewater spillages. This was only considered in terms of ensuring wastewater treatment works and wastewater pump stations within Tshwane remain operational.

3.1.3 Evaluation procedure

The part of RAMFIWES that deals with water (not focussing on the electricity related part of RAMFIWES) was applied on the Tshwane case study (RAMFIWES is discussed in more detail in Chapter 4).

Measuring the effectiveness of mitigation measures proposed to ensure uninterrupted water supply during electricity disruption events include the following:

- Comparing the economic benefit of uninterrupted water supply to the cost of mitigating measures required to do so. The cost benefit ratio of the mitigating measures proposed was used in this instance.
- A further measure of effectiveness on the mitigation measures proposed includes a high-level estimate of how much consumers' water tariffs would need to increase to pay for mitigating measures to be implemented.

3.1.4 Limitations of the study

The limitations of the study are described in more detail below:

a) Detailed information on Tshwane's electricity infrastructure:

Detailed information on Tshwane's electricity grid was not obtained. This includes information on the city's main electricity distribution lines, primary- and secondary substations and mini substations. This information, along with an in depth understanding of how the city's electricity network is operated could have been used to more accurately estimate the areas and durations of electricity disruptions used in the nine electricity disruption scenarios. Information received from the city's electricity department was limited to high-level electricity distribution system design and operation philosophy, as described in Section 5.2.11.

This limitation was overcame by arbitrarily selecting the electricity disruption event areas based on the city's water infrastructure supply zones. Since the cost vs. benefit analysis part of the case study scaled up the areas of each electricity disruption scenario, this would not affect the outcome of the cost vs. benefit analysis as all of the city's water infrastructure was considered (refer to Section 3.4.4 for the methodology followed on scale factors and to Section 6.5 for the cost vs. benefit analysis).

b) Detailed information on some of Tshwane's water infrastructure:
Detailed information on the city's internal bulk water supply and distribution pump stations as well as wastewater network pump stations was not included as part of the calculations in the case study' scenarios analysed and cost vs. benefit analysis.

Including these pump stations electricity requirements in the case study scenarios analyses and cost vs. benefit analysis would have resulted in an increased cost to mitigate the risks associated with water supply interruptions due to electricity disruptions. It is, however, estimated that these costs would be relatively small when compared to the total costs calculated and it would therefore not affect the outcome of the calculations. If the recommendations made in this study are implemented, detailed information on the city's water and wastewater pump stations will have to be incorporated.

c) Detailed economic information on the various economic sectors' water demand and spatial distribution:
High level information on the city's various economic sectors' water demand and contribution to the Gross Domestic Product were used in the case study scenarios analyses and cost vs. benefit analysis. More detailed information, specifically spatial distribution of the city's various economic sectors would result in a more accurate outcome for the cost vs. benefit analysis. This information could also be useful for prioritising areas which should be accommodated first in terms of the implementation of mitigation measure to ensure continuous water supply in the event of an electricity disruption.

d) Information on the interconnectedness between Water Service Authorities supplied by Rand Water:
Since Rand Water supplies the majority of Gauteng's potable water, it is important to consider the interconnectedness of the various Water Service Authorities supplied by Rand Water (e.g. between the City of Johannesburg and the City of Tshwane). This information will be crucial to plan emergency operations procedures of Rand Water if reduced water is supplied due to

decreased system capacities during an electricity disruption. This was not taken into consideration as part of the study.

e) Detailed hazards and hazardous events information to be used in the case study risk analysis: More detailed information on hazards and hazardous events that form part of the risk analysis will ensure increased accuracy of the risk estimation (for both the risk's consequence and probability). Compiling a more detailed list of hazards and hazardous events is a continuous process (as is the entire risk analysis) and needs to be updated as new data becomes available and more hazards and hazardous events are identified.

For this reason, there can be a discrepancy between the risks estimated as part of the case study risk analysis (refer to Section 6.2) and the actual risks. Risks identified and analysed can therefore either be over- or underestimated. As the risk analysis is continuously updated and improved this problem will become less critical (assuming the recommendation regarding the development of a Disaster Risk Mitigation Plan is implemented by the various parties involved).

3.2 CASE STUDY SCENARIOS ANALYSES

This section describes the process followed for the case study scenario analysis. Different types of theoretical electricity disruption events and their impact on water supply were analysed.

Electricity disruption scenarios investigated that may result in water supply interruptions are described in **Table 3-1**.

Table 3-1: Electricity disruption scenarios investigated.

Scenario	Area affected	Duration
Scenario 1	Small	Short-term
Scenario 2	Medium	Short-term
Scenario 3	Large	Short-term
Scenario 4	Small	Medium-term
Scenario 5	Medium	Medium-term
Scenario 6	Large	Medium-term
Scenario 7	Small	Long-term
Scenario 8	Medium	Long-term
Scenario 9	Large	Long-term

The size of affected areas investigated includes:

- Small areas - Only one reservoir / water tower's zone,
- Medium areas - One of Tshwane's bulk water supply regions
- Large areas - The entire City of Tshwane

The duration of electricity disruptions investigated includes:

- Short-term - Up to one day
- Medium-term - Up to one week
- Long-term - Up to one month

Mitigating the impact of the electricity disruption scenarios on water supply was approached following the steps described in **Table 3-2**:

Table 3-2: Steps followed for the electricity disruption scenarios analyses.

Step 1: Scenario description	Describe the scenario in terms of the electricity disruption event duration and area of effect.
Step 2: System description	Describe the electricity and water infrastructure and the number of end-users affected by the electricity disruption event.
Step 3: Risk analysis	Discuss the risks that result from the electricity disruption event.
Step 4: Risk mitigation options	Identify and describe risk mitigation options for the scenario.
Step 5: Cost estimate	Estimate the cost of risk mitigation and compare this cost with the estimated benefit of mitigation.
Step 6: Scenario conclusion	Summarise the scenario, identify shortcomings of the risk mitigation approach, and develop alternative solutions where necessary.

It should be noted that solutions identified to mitigate the effect of electricity disruption events on water supply are very similar for most of the electricity disruption scenarios in Section 6.4. The cost of implementing these solutions will therefore be shared between the various scenarios. This is not taken into consideration in the scenario analyses below but only in Section 6.5 that deals with the case study cost vs. benefit analysis.

Where obvious shortcomings in the theoretical solutions described in the scenario analyses below were identified, these shortcomings are highlighted and also addressed in Section 6.5.

3.3 COST VS. BENEFIT ANALYSIS

3.3.1 Introduction

The methodology followed in the cost vs. benefit analysis is summarised below.

In Section 6.5 the cost of mitigating the impact of electricity disruption events on water supply was compared to the benefit of ensuring uninterrupted water supply. The events that are dealt with have varying Recurrence Intervals (RIs) that can be longer or shorter than the estimated useful life of the required infrastructure. As a result of this it may be necessary to replace the infrastructure when it reaches its estimated useful life without having used it once as the electricity disruption event planned for, may not have occurred yet.

For instance, if backup electricity generation infrastructure with an estimated useful life of 30 years is installed to mitigate the impact of an electricity disruption event with a Recurrence

Interval (RI) of 155 years, the generator will have to be replaced on average approximately 5 times for every one time that the event will occur.

3.3.2 Estimated useful life of infrastructure

Infrastructure required to ensure uninterrupted water supply to the City of Tshwane (and sewerage treatment of its wastewater effluent) are backup electricity generators (mobile and permanent on-site) to power water treatment works, wastewater treatment works and water- and sewer pump stations.

These generators will consist mostly of mechanical and electrical equipment which typically has an estimated useful life of only 15 years (DPLG, 2009). However, since the backup generators will only be used infrequently it is estimated that these generators will last for 30 years provided that service and maintenance on the generators are carried out when required. It is assumed that a longer life than 15 years is feasible since the plant at any given elevated tower, pump station, WTW or WWTW will seldom be used, and then only for a short duration. In fact, this might make an even longer plant feasible.

3.3.3 Operational and maintenance costs of infrastructure

The operational and maintenance costs were also included as part of the cumulative future replacement cost of infrastructure.

Typical annual operational and maintenance costs of mechanical and electrical plant as a percentage of the Current Replacement Costs (CRC) of the plant are summarised in **Table 3-3**.

Table 3-3: Operational and maintenance costs of infrastructure (DPLG, 2009).

Plant type	Operational costs (% of CRC)	Maintenance costs (% of CRC)
Electrical plant	3	4.6
Mechanical plant	2	2.3

Backup electricity generation infrastructure consists of mechanical and electrical equipment. The combined annual operational and maintenance costs of electricity generators are estimated at 2.5% and 3.5% respectively of the CRC, or a total of 6% of the CRC per year.

However, in the case of permanent installations civil works with a much lower percentage maintenance cost have to be factored in. Moreover, it is important to recognise that the envisaged plant would be used only infrequently and then for only short durations during electricity outages. Hence much smaller maintenance cost percentages are envisaged. The annual maintenance cost for generators has therefore been estimated at a low 1% of the CRCs.

As described later in the report, operational costs have been estimated more directly from kWh and hence fuel usage.

3.4 ECONOMIC EVALUATION METHODS

3.4.1 Average annual present value of infrastructure

As stated above, the average annual cost of providing mitigating infrastructure is compared to the average annual benefit in order to determine whether it is economically justifiable (or feasible) to ensure uninterrupted water supply during an electricity disruption event.

As part of calculating the average annual cost of infrastructure the discount rate (i.e. the difference between the interest rate and the inflation rate) was also taken into consideration. The discount rate is used to calculate the estimated Future Replacement Cost (FRC) of an item in terms of its Present Value (PV) or Current Replacement Cost. In other words, if the interest rate (or return on investment) that the City of Tshwane (and therefore its citizens) can get on its investments is higher than the inflation rate, infrastructure will be relatively cheaper in the future than it currently is in terms of the PV. A discount rate of 3% was used in the calculation of the FRC of infrastructure in terms of its PV, as shown in the equation below.

$$FRC_{(PV)} = \frac{PV}{(1+DR)^n} \qquad \text{(Equation 4)}$$

Where:

- $FRC_{(PV)}$ is the Present Value of Future Replacement Cost of infrastructure
- PV is the Present Value,
- DR is the Discount Rate, and
- n is the number of years that are discounted.

The $FRC_{(PV)}$ is typically applicable for works that have shorter estimated useful lives than the expected RI of the risk that it will mitigate. The actual annual present value of the works required to mitigate risks is calculated using the equation below.

$$AAPV = \sum_{i=1}^{x} \frac{PV}{(1+DR)^{(x-1)\cdot n}} \qquad \text{(Equation 5)}$$

Where:

- $AAPV$ is the Average Annual Present Value of the infrastructure required, and
- X is the number of infrastructure replacements required during the Recurrence Interval (RI) of the risk mitigated.

X above is dependent on the difference between the estimated useful life of the infrastructure and the RI of the risk mitigated. For example, for infrastructure that has an expected useful life of 30 years which will be required to mitigate a risk with a RI of 150 years, the infrastructure will have to be procured at year 0 and replaced at years 30, 60, 90 and 120 (or 5 times in total during the estimated RI of the risk mitigated).

3.4.2 Net discount rate

An annual net discount rate (*DR* in Equation 5 in Section 3.4.1 above) of 3% has been assumed. This value is considered appropriate for a large entity like Tshwane, since the net discount rate should reflect the net rate (i.e. after inflation) that Tshwane can expect to earn on a similar investment if it did not invest in the generating plant.

3.4.3 Outlook period (analysis period)

The outlook period for the economic analyses, over which costs and benefits are compared has been taken as the RI of the power outage event being considered. Where necessary, the remaining value of capital works at the end of the outlook period has been credited before being discounted to a present value. A straight line depreciation of capital over the life of the works has been used for this purpose.

In instances when there are no direct economic benefits the outlook period has been set equal to the life of the capital works. This is applicable to Section 6.5.2 (Basic minimum domestic water supply) and Section 6.5.3 (Prevention of raw sewage spillage).

3.4.4 Scale factors

In the cases of scenarios covering power outages in small and medium sized areas, the costs have been scaled up to cover the whole of Tshwane. For example, the small area encompasses only one of Pretoria's elevated water towers, with a supply area AADD of 0.355 Mℓ/day. This has been scaled up to encompass all 38 such water towers in Tshwane, which have a combined AADD of 13 Mℓ/day, resulting in a cost scaling factor of 36.6.

3.4.5 Economic analysis carried out

For scenarios that do not have a direct benefit with which to compare costs, the economic analysis has been confined to calculating the levelised annual cost and to compare this with the volume of water normally supplied to all Tshwane consumers. This was done in order to calculate a unit cost per kℓ. This facilitates direct comparison with normal water accounts to place decision makers in a position to assess the implications.

In cases where direct estimates of the economic benefit can be made, a fuller economic assessment has been made to calculate the benefit to cost ratio and the present value net benefit.

Costs have been expressed as cents per kℓ of normal billed consumption for comparative purposes. For the purpose of this comparison, the unit tariff of water that the consumer usually pays is assumed to be R 10 per kℓ (Province of Gauteng, 2017).

4 RISK ANALYSIS AND MITIGATION FRAMEWORK

There are numerous guidelines, strategies and programmes which guide authorities on how a disaster risk mitigation plan can be developed. There are, however, no specific programmes that guide authorities on dealing with the risk posed by electricity disruptions on water supply. This highlights the need for the development of the Risk Analysis and Mitigation Framework of Integrated Water and Electricity Systems (RAMFIWES).

This chapter describes RAMFIWES developed as part of this study for electricity suppliers, Waster Service Providers and Water Service Authorities as part of the study. The framework developed also includes institutional and design guidelines for electricity suppliers, WSAs and WSPs to enable these authorities to plan accordingly to mitigate the impact of electricity disruption on water supply.

4.1 DEVELOPMENT OF RAMFIWES

This section briefly describes the rationale followed for the development of RAMFIWES. The objective of RAMFIWES is to assist, guide and enable the relevant authorities (electricity suppliers, WSPs and WSAs) to mitigate the risks posed by electricity disruption events on water supply.

The outline of the steps of RAMFIWES is illustrated in **Figure 4-1**.

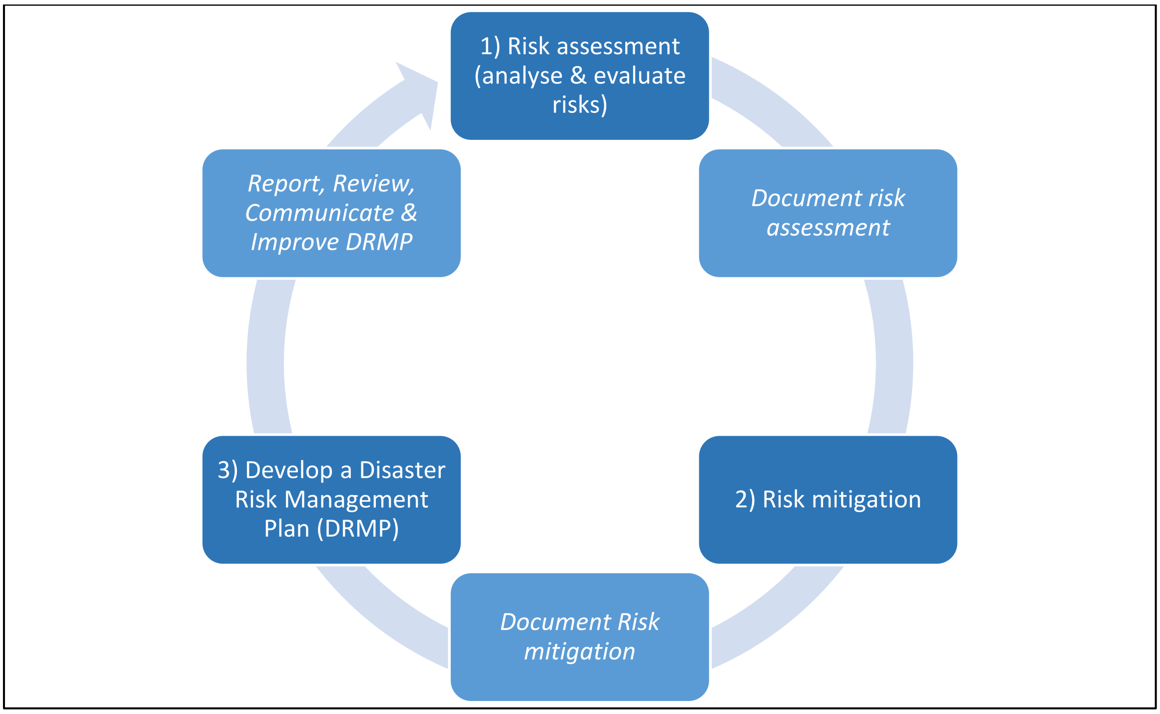

Figure 4-1: Diagram illustrating the development of RAMFIWES.

The steps of RAMFIWES are described below:

1. Risk assessment

   The risk assessment part of RAMFIWES includes the risk analysis and evaluation of the electricity and water systems. The risk assessment should be done based on the risk analysis and evaluation guidelines proposed as part of RAMFIWES (refer to Section 4.4).

   The most important part of RAMFIWES is to do a comprehensive risk analysis on the water and electricity supply system. The risk analysis will inform all subsequent steps of RAMFIWES: the accuracy of the risk analysis is critical for the effective mitigation of risks imposed on the water sector due to electricity disruption events. It is therefore necessary to continuously improve and further develop the risk analysis as updated relevant information becomes available. To ensure uniformity between various risk analyses for different WSAs or WSPs, it is recommended that an existing water risk analysis tool such as WaterRisk (Jack, De Souza and Mackintosh, 2011) is used.

   Quantifying electricity disruption hazards and hazardous events in terms of probability (or recurrence interval) and consequence (area of effect and duration) will be necessary as part of the risk analysis. This is due to the fact that the cost and economic benefit calculations will be based on quantified risks.

The second step of the risk assessment is to evaluate the risks identified as part of the risk analysis. Effective evaluation of risks identified will result in identifying of all possible risk reduction options which will guide the risk mitigation process.

2. Risk mitigation

   Risk mitigation follows the risk assessment. It includes gathering the necessary relevant data, doing a cost vs. benefit analysis on the risk mitigation options identified, making decisions and implementing those decisions.

   In order to have sufficient information to perform the cost vs. benefit analysis step, the WSA or WSP will need to obtain relevant technical data and economic data.

   Technical information includes:

   - The water demand of each economic sector within the city;
   - An overview of the water losses in the city;
   - An overview of the city's population;
   - Relevant water infrastructure information, including:
     - The city's supply and distribution pump stations;
     - The city's reservoirs and elevated water towers (including distribution zones);
     - The WTWs supplying the city;
     - The WWTWs treating the city's wastewater;
     - Wastewater network pump stations in the city;
   - Relevant electricity infrastructure information, including:
     - Main electricity sub stations that are connected to Eskom's grid;
     - The city's electricity distribution infrastructure (including internal sub stations); and
     - The electricity zones in the city.

   Economic information includes:

   - The various sectors' contribution to the city's economy;
   - Spatial distribution of the various economic sectors;
   - The portion of the various economic sectors that can continue with economic activity in the event of an electricity disruption event but which will be affected by water supply interruptions.

Costs for mitigating measures identified based on the outcome of the risk assessment should also be estimated as part of this step.

The cost vs. benefit analysis is necessary to determine the economic feasibility of the implementation of the risk mitigating measures identified as part of step two. This step will therefore determine whether the economic benefit of ensuring uninterrupted water supply during electricity disruption events would outweigh the cost. It also entails estimating the cost of the various mitigating measures to the city's consumers (water end-users). The cost vs. benefit analysis should be conducted as per the methodology described in Section 3.3.

It is important that this step also takes into consideration the absolute minimum mitigating measures that need to be implemented in accordance with South Africa's laws. The government authorities' obligations to South Africa's citizens' basic human right to water and an environment that is non-detrimental to their health, is here of specific relevance.

Therefore, if it is determined that it is not economically feasible to ensure uninterrupted water supply to the city's economic sectors during electricity disruption events, it will still be necessary to ensure that the absolute minimum domestic water demand can be met and to prevent wastewater spillages.

The risk analysis should identify electricity disruption hazards and hazardous events specifically applicable to the city's electricity sector. Since this was not the case with the City of Tshwane case study, theoretical electricity disruption scenarios were identified and used as part of the case study's risk analysis. It will therefore not necessarily be required to have theoretical electricity disruption scenarios in order to do the cost vs. benefit analysis. The cost vs. benefit analysis can be based on actual electricity disruption risks identified as part of the risk analysis.

Making decisions follows the completion of the cost vs. benefit analysis. The outcome of the cost vs. benefit analysis will give responsible decision makers of electricity suppliers, WSPs or WSAs adequate background information to decide whether the mitigating measures identified as part of step two should be implemented or not.

3. Development of a Disaster Risk Management Programme

   The final step is to develop a Disaster Risk Management Programme (DRMP). This programme should be based on the outcome of the risks assessment, mitigating measures identified and the decisions taken on whether to implement measures identified or not.

   If the electricity supplier, WSP or WSA already has a disaster programme in place, it should be updated taking into consideration specific risks posed by electricity disruption events on water supply.

   It should further be noted that risk management is dynamic process: risks will continuously change, technology to mitigate risks will continuously improve and better ideas to mitigate risks will continuously be developed. It is therefore important to review and redo the steps of RAMFIWES constantly as the water and electricity systems continuously change and develop.

4.2 OUTLINE OF RAMFIWES

Based on the steps described above, the outline of RAMFIWES is illustrated in **Figure 4-2**.

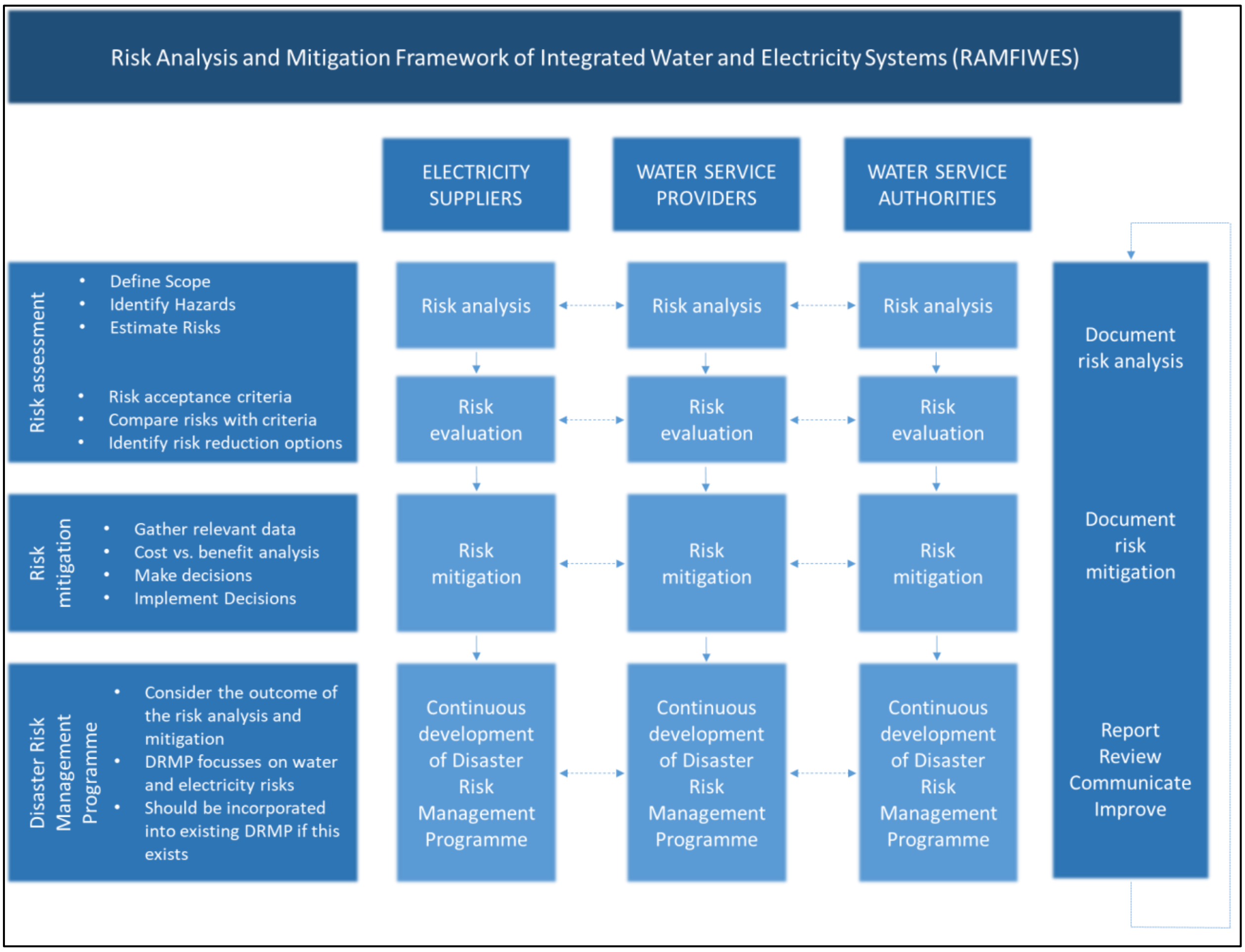

Figure 4-2: Outline of RAMFIWES.

Key concepts that the outline of RAMFIWES should portray to electricity suppliers, WSPs and WSAs include the following:

- The decisions that will be made by the authority using RAMFIWES should be based on the financial feasibility of implementing the measures identified to mitigate the various risks;
- Applying RAMFIWES will assist the authority to determine the absolute minimum measures to mitigate the impact of electricity disruption events on water supply;
- RAMFIWES is an integrated process that should be done with continuous and effective communication between electricity suppliers, WSPs and WSAs to effectively mitigate risks posed by electricity disruptions on water supply; and
- RAMFIWES is an ongoing process that should be reviewed and improved continuously.

4.3 DEVELOPMENT OF INSTITUTIONAL AND DESIGN GUIDELINES

In order to be able to develop and propose institutional and design guidelines it is important to understand how disaster events happen and what is necessary to mitigate the impacts of disaster events. This section briefly describes the rationale followed for the development of institutional and design guidelines to mitigate the impact of electricity disruption events on water supply.

4.3.1 Factors taken into consideration to develop institutional guidelines

This section highlights factors taken into consideration for the development of institutional and design guidelines.

Institutional arrangements and design guidelines are divided into two categories, namely preventative and reactive institutional arrangements. Preventative arrangements need to be in place and implemented before an electricity disruption event occurs. Reactive arrangements are implemented as soon as the authority (be it in the water or electricity sector) becomes aware of an electricity disruption event.

In terms of electricity supply, preventative arrangements are put in place to prohibit an electricity disruption event from occurring. These arrangements are either on the demand side (e.g. load shedding) or on the supply side.

Guidelines developed for Water Service Providers and Authorities are also based on the need for preventative and reactive arrangements:

- Preventative measures are put in place to ensure that all necessary precautions are in place if an electricity disruption event occurs.
- Reactive measures are put in place to minimise the effect of electricity disruptions on water supply given that a disruption is inevitable or has already occurred. These measures can be either pre-emptive or post-event based.

The institutional arrangements developed to mitigate the effect of electricity disruptions on water supply are defined based on the type of electricity disruption event that affects water supply. Electricity disruption events are categorised for appropriate planning as illustrated in **Figure 4-3**:

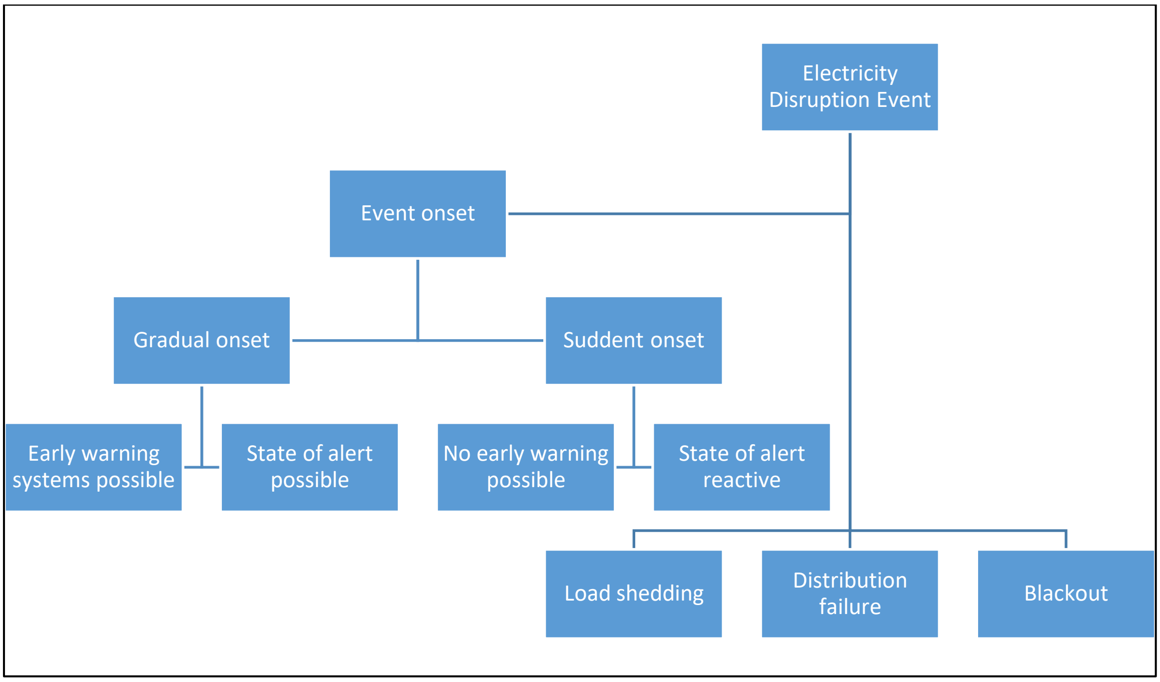

Figure 4-3: Electricity disruptions events that affect water supply.

Important components of a Disaster Risk Management Programme are summarised in **Figure 4-4**.

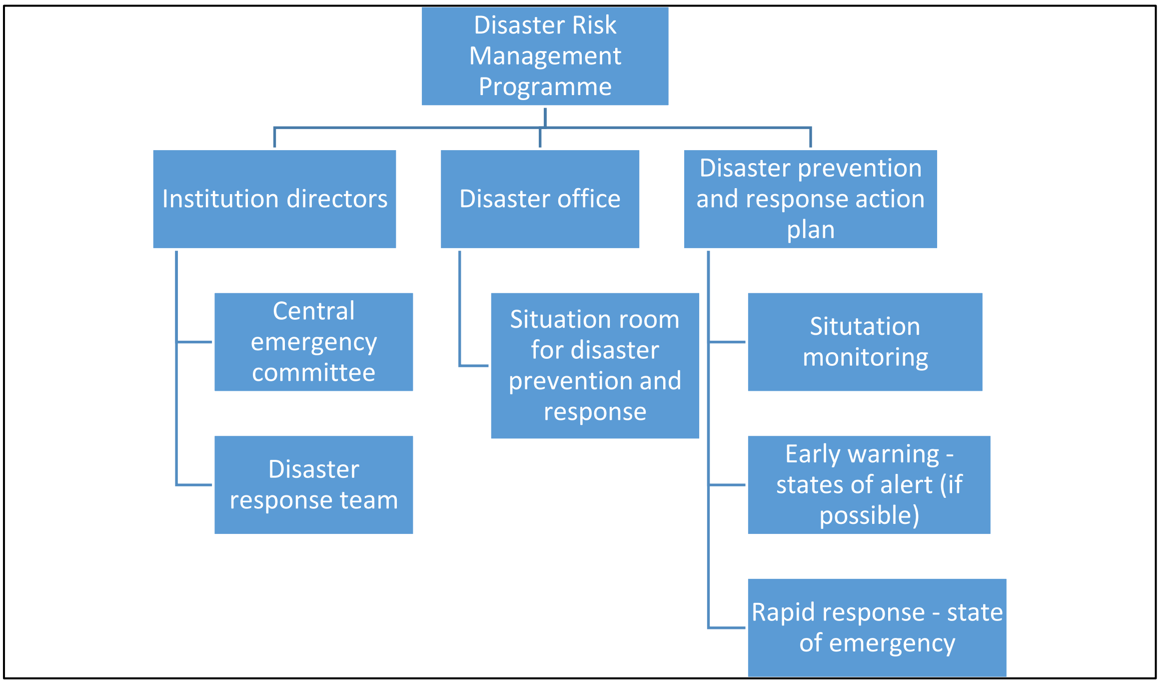

Figure 4-4: Disaster Risk Management Programme components.

Institutional arrangements to mitigate the effect of electricity disruptions on water supply proposed specifically for water service authorities are illustrated in **Figure 4-5**.

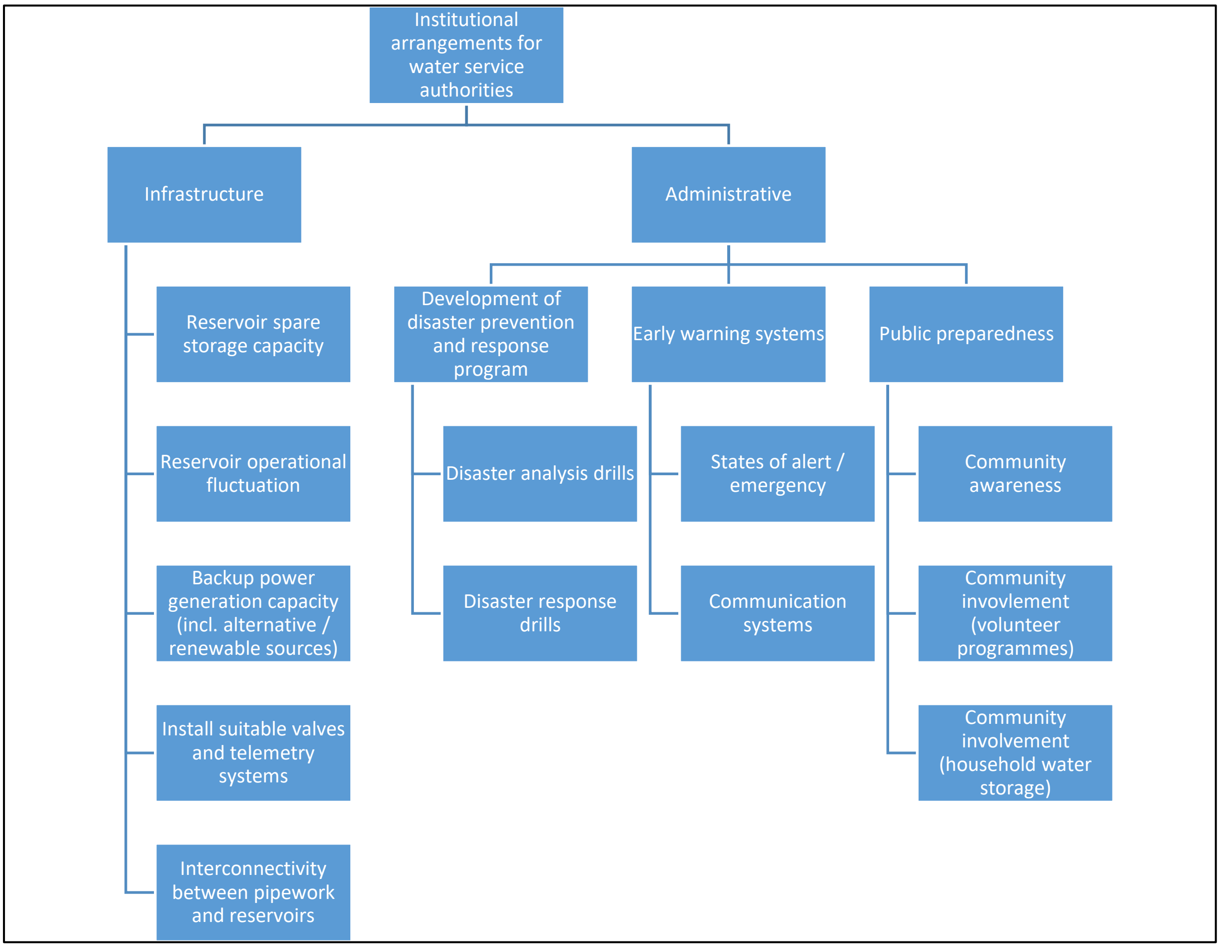

Figure 4-5: Institutional arrangements for water services authorities.

4.3.2 Structure of institutional guidelines proposed

Before any institutional and design guidelines proposed to the various parties involved can be implemented it is important to re-analyse and evaluate all risks posed by electricity disruption events on water supply. The first section of the institutional and design guidelines proposed is therefore guidelines on how a risk analysis and evaluation should be attempted (specifically defined in the context of the problem investigated).

Institutional guidelines for electricity suppliers (Eskom for the City of Tshwane Case Study), Water Service Providers and Water Service Authorities were divided into on managerial, administrative and operational changes that are to be made. Design guidelines for water service entities infrastructure changes need to be incorporated into the entities' water infrastructure.

Included as part of guidelines proposed for Water Service Providers and Authorities are the development of a Disaster Risk Management Programme. This programme should include all proposed guidelines made to water service entities.

4.4 RISK ASSESSMENT GUIDELINES

4.4.1 Introduction

This section describes the risk assessment (risk analysis and evaluation) processes and outlines steps to be taken to complete a risk analysis and evaluation. Risk analysis and evaluation guidelines are defined for the various institutions that form part of the electricity supply, water supply and water distribution sectors.

The components of a risk analysis are:

- Defining the scope and objective of the risk analysis
- Identification of hazards and hazardous events, and
- Estimation of risk (probabilities, consequences). Consequences with respect to both water quality and water quantity should be considered.

Risk evaluation follows risk analysis and includes defining risk acceptance / tolerability criteria in terms of water quantity and water quality. Through proper risk evaluation risks are distinguished between:

- Acceptable / tolerable risks which need not be addressed as part of the risk management process (i.e. these risks needn't be addressed as part of the institutional- and design guidelines), and
- Unacceptable / intolerable risks which need to be addressed as part of the risk management process (i.e. these risks are addressed by institutional- and design guidelines).

Risk analysis and evaluation forms part of the institutional guidelines proposed as part of RAMFIWES. Risk analysis and evaluation guidelines are specifically defined for the following institutions:

- Institutions responsible for electricity supply (i.e. Eskom in the City of Tshwane case study);

- Institutions responsible for bulk water supply: Water Service Providers (i.e. Rand Water, Magalies Water and the City of Tshwane[2] in the City of Tshwane case study); and
- Institutions responsible for water distribution: Water Service Authorities (i.e. the City of Tshwane in the case study).

Risk analysis guidelines are also further subdivided for three types of electricity disruption events that can affect water supply, including:

- Short-term electricity disruption events causing disruptions up to a few hours (e.g. load shedding),
- Medium-term electricity disruption events causing disruptions up to a few days (e.g. damage to a sub-station supplying electricity to a pump station), and
- Long-term electricity disruption events causing disruptions up to a few weeks (e.g. a local or national blackout as a result of a solar flare).

Table 4-1 summarises the risk assessment guidelines proposed.

Table 4-1: Summary of risk assessment guidelines

Risk analysis	a) Define scope
	b) Identify hazards & hazardous events
	c) Estimate risks
Risk evaluation	a) Define risk acceptance and tolerability criteria
	b) Compare risks with acceptance and tolerability criteria
	c) Identify risk reduction options

4.4.2 Risk analysis guidelines

This section summarises the main components of a generic risk analysis process and describes how each of these components should be approached specifically considering this study.

a) Defining the scope of a risk analysis

Table 4-2 summarises the steps of the risk analysis' scope definition and what needs to be taken into consideration specifically in the context of this study.

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[2] in a sense the City of Tshwane can also be seen as a Water Service Provider as they are also responsible for bulk water treatment and bulk water supply

Table 4-2: Special considerations to be included during scope definition of risk analysis.

Scope definition step	Description	Special considerations in terms of this study
a) Selection of the analysis team	Stakeholders to be included: • Eskom • Water Service Providers ○ Rand Water ○ Magalies Water ○ City of Tshwane • Water Service Authorities ○ City of Tshwane	Specific staff / parties to be included: • Managerial staff, • Technical staff (planning & design), • Operational staff, • External consultants (water and electricity sector experts) • External consultants (Risk analysis experts)
b) Define scope of the risk analysis	Objective of risk analysis	Identifying all conceivable electricity disruption events that could affect water supply.
	What should the risk analysis include	Include risks to water supply associated with all types of electricity disruptions events: • Short-term (e.g. load shedding) • Medium-term (e.g. distribution failure) • Long-term (e.g. blackout)
	Which dimensions of risk shall be treated?	In terms of water quantity: • Frequency of water supply interruptions (i.e. probability), • Duration of interruptions, • Number of consumers affected. In terms of water quality: • Probability of treatment system failure • Number of consumers affected
c) Describe the system to be analysed	Identify and describe all system components that form part of the scope of the risk analysis	Identify all system components that can cause electricity disruptions that will affect water supply. This should be done for all institutions involved and should consider the entire supply chain (from electricity generation to distribution and water source to discharge).

Scope definition step	Description	Special considerations in terms of this study
	List main functions of the systems identified	This should be done with the focus on how failure of the various systems identified will affect water.
	Define the boundaries of the system identified	Exclude all systems that cannot affect water supply.

b) Identify hazards and hazardous events

Table 4-3 summarises the steps of the hazard and hazardous events identification and what needs to be taken into consideration specifically in the context of this study.

Table 4-3: Special considerations to be included during identification of hazards and hazardous events.

Hazard identification step	Description	Special considerations in terms of this study
a) Collect available data on hazards & hazardous events	Generic data	• Databases such as Techneau Hazard Data Base (THDB) • Water Risk Water Infrastructure Risk Assessment Tool • Relevant previous research projects and reports that analysis team has worked on
	Site specific data	• Knowledge and experience of technical staff of all institutions • Knowledge and experience of operational staff of all institutions • Failure reports of various institutions' systems • Historical data of unplanned maintenance, breakdowns, system failures, etc.
b) Perform expert sessions to identify site specific hazards	Brainstorming and use of checklists	Think tank sessions between all institutions' staff (part of the risk analysis team) and other parties identified.

Hazard identification step	Description	Special considerations in terms of this study
and hazardous events		
c) Documentation of results	Compilation of a list of all hazards and hazardous events identified as part of the process	

c) Risk estimation

Table 4-4 summarises the steps of risk estimation and what needs to be taken into consideration specifically in the context of this study.

Table 4-4: Special considerations to be included as part of the risk estimation.

Risk estimation step	Description	Special considerations in terms of this study
a) Qualitative analysis	Identification of safety barriers	Includes electricity supply safety barriers, alternative municipal electricity supply routes, emergency generation facilities, water storage and gravity distribution.
b) Decide on risk analysis type	Risk analysis types: • Qualitative (semi-quantitative) - using a risk matrix[1] • Quantitative - data required for estimation of probabilities and consequences[2]	The decision regarding qualitative vs. quantitative depends on the data available. Since the water and electricity sectors generally both have good data capturing and storing systems quantitative analysis is possible for both of the sectors.
c) Perform risk estimation	Estimate the probability and consequence of all risks identified as part of the hazard or hazardous event identification step.	Focus should be on the consequence that the various hazards or hazardous events can have on water supply.

Risk estimation step	Description	Special considerations in terms of this study
d) Documentation of results	Compilation of a list of all risks assessed, including the risks' probability and consequence. This list should also priorities risks based on the risks' critically.	This includes short, medium term and long term electricity supply disruptions.

Notes on **Table 4-4**:

1 If a qualitative risk analysis is done a risk rating matrix should be used to determine the criticality of all risks identified.

2 If a quantitative risk analysis is done risks should be ranked based on how various risks identified compared with each other in terms of each risk’s estimated probability (recurrence interval) and duration.

4.4.3 Risk evaluation guidelines

This Section describes the risk evaluation process and gives guidelines on how risk evaluation should be approached in the context of this study. The risk evaluation process is made up of the following steps:

a) Defining risk acceptance and tolerability criteria

According to the United Nations Strategy for Disaster Risk Reduction (UNISDR, 2009) an acceptable or tolerable risk is defined as a level of potential loss that a society or community considers acceptable given prevalent social, economic, political, cultural, technical and environmental conditions.

In engineering terms, an acceptable or tolerable risk can also be defined as a hazard or hazardous event that will not adversely harm people, their property, services and systems given that nothing is done to mitigate the risk. This means that either the consequence of the risk is small enough not to cause any harm or that the probability of the risk is so small that the risk is almost entirely improbable.

In terms of this study risk acceptance and tolerability criteria are affected primarily by the duration of the electricity disruption event and the extent of the event (e.g. city-wide, province-wide or country-wide). The risk acceptance and tolerability criteria are defined in terms of the effect that abovementioned electricity disruptions will have on water supply, including:

- The direct effects that electricity disruptions can have on water supply, including:
  a) The number of end-users that will be affected by water supply interruptions due to electricity disruptions;
  b) The duration of water supply interruptions due to electricity disruptions; and
  c) Damage to water supply and distribution infrastructure due to the electricity disruption.
- The indirect effects that electricity disruptions can have on water supply, such as:
  a) Civil unrest due to water supply interruptions;
  b) Infrastructure already in place which mitigates the effect of electricity disruptions on water supply; and
  c) Loss in water quality due to electricity supply disruptions (for instance a sewer pump station that will overflow for a certain period of time causing deterioration of raw water quality).

The risk acceptance and tolerability criteria should be defined by the Water Service Provider(s) (Rand Water & Magalies Water for this study) working with the Water Service Authority (City of Tshwane for this study). This should be defined based on direct- and indirect effects of electricity disruptions on water supply as listed above.

However, the outcome of the risk assessment process can also be used to refine the risk acceptance criteria. Depending on the outcome of the risk assessment the following factors can affect the risk acceptance criteria:

- The number of risks identified with unacceptable consequences and probabilities (high priority or critical risks);
- The probability and consequence of risks identified;
- The resulting damage (monetary value) due to the hazard or hazardous event of each risk identified; and
- The cost to mitigate the risk identified.

For example, if the risk acceptance criteria are too stringent it may mean that all risks identified as part of the risk assessment will have to be dealt with regardless of the cost-benefit implications of dealing with each risk. If the risk acceptance criteria is too lenient it may mean that risks identified as critical risks or high priority risks can be left out and will not be dealt with as part of the risk reduction / control measures.

To summarise what needs to be considered as part of the risk acceptance and tolerability criteria definition:

1) Define generic risk acceptance and tolerability:
    - Risk acceptance and tolerability criteria should be defined by Water Service Authorities (City of Tshwane) and Water Service Providers (Rand Water and Magalies Water).
    - It should be based primarily on the duration and extent of electricity disruptions events:
        i. The risk acceptance criteria take into consideration the extent of the electricity disruption events (suburb-wide, city-wide, province-wide or country wide); and
        ii. It should also take into consideration the duration of electricity disruption events.
    - Defined in terms of the direct and indirect effects of electricity disruption on water supply:
        i. What is an acceptable number of end-users that can be affected in terms of water supply interruptions;
        ii. What is an acceptable duration that end-users can be affected by water supply interruptions;
        iii. What probability of civil unrest is acceptable;
        iv. What amount of damage to water supply and distribution infrastructure is acceptable;
        v. What infrastructure is already in place which can mitigate the effect of electricity disruptions on water supply; and
        vi. What level of loss in water quality due to electricity supply disruptions is acceptable?
2) Refine the risk acceptance and tolerability criteria based on the outcome of the risk assessment, based on the following factors:
    - The number of high priority or critical risks;
    - The resulting damage (monetary value) of each risk identified; and
    - The cost to mitigate the various risks identified.

b) Comparing of risks with acceptance or tolerability criteria

The next step is to compare the risks identified with the acceptance or tolerability criteria. This should be done in order to identify a list of risks to be mitigated by the various institutions involved.

This list should include the following information:

- All risks identified during risk assessment;
- The priority or criticality of each risk identified;
- Whether the risk is acceptable / tolerable or not; and
- If the risk is accepted / tolerated the reason for this.

The most important outcome of comparing the risks with acceptance or tolerability criteria is to ensure that the highest priority or most critical risks are dealt with first. Furthermore, it will ensure that dealing with acceptable / tolerable risks do not take up resources of the various institutions that should rather be used for dealing with more critical risks.

c) Risk reduction options

As part of the risk evaluation process, various risk reduction options can be identified as each risk is evaluated and compared with the risk acceptance and tolerability criteria. This should be done by identifying numerous possible solutions to mitigate each risk identified. The various solutions identified to mitigate each risk can then be compared in terms of a cost-benefit analysis to ensure the most effective solution is selected.

The risk reduction options proposed as part of the institutional and design guidelines are discussed in more detail in the following sections of this report.

4.5 GUIDELINES FOR ELECTRICITY SUPPLIERS

4.5.1 Introduction

This section defines institutional- and design guidelines for electricity suppliers which should be adopted in order to mitigate the effect of electricity disruptions on water supply.

The guidelines proposed for electricity suppliers to mitigate the impact of electricity disruption on water supply are generic and are therefore proposed for an arbitrary electricity supplier. The guidelines were, however, developed taking into consideration that currently in South Africa there is only one national electricity supplier; Eskom. The guidelines for electricity suppliers were therefore developed taking Eskom's current disaster management plan into account.

A brief background on how Eskom currently mitigates emergency situations that could lead to water supply interruptions is given as an introduction for the guidelines proposed for electricity suppliers.

Eskom already has a comprehensive disaster management system in place, centred on their control room. This system should be developed further to ensure that the requisite disaster response teams are ready and equipped to play their roles in the event of a major emergency that threatens the wider grid.

Eskom already has systems in place to alert Rand Water and municipal electricity departments. It is essential to ensure that such early warnings also alert all key managers and operating staff of a high-consequence hazardous event that will result in a long disruption requiring immediate action to preserve stored water resources, or of one that has just occurred. We cannot risk the "broken telephone" syndrome resulting from too many cascading links in the command chain. Actions have to be taken very rapidly. This is obviously a joint responsibility with the municipalities, but someone has to take the initiative.

The prioritisation of key water services also has to be built into Eskom's action list when power is restored after a regional or national blackout. It may be possible to bring in electrical supply to RW's purification works and main pump stations early on in the power station islanding process, bearing in mind that when the water supply is constrained both will be running constantly. Moreover, RW could give an undertaking to purify and pump water at a constant rate during the critical hours and days when the electricity output from the power station(s) is still relatively small and sensitive to variation in the loads of individual users.

4.5.2 Effect of electricity disruptions on water supply

In order to define the various institutional and design guidelines proposed for Eskom it is important to understand the effect of the different types of electricity disruptions on water supply. The effect of the different types of electricity disruption events are described below.

Short-term electricity disruption events are events that last only for a few hours and at most up to a day. These disruption events can either be planned or unplanned. Examples of planned short-term disruptions are load shedding or scheduled maintenance, refurbishment or upgrading of electricity infrastructure. Examples of unplanned short-term disruption events are Eskom sub-station power trips or local electricity distribution failures due to construction damage or theft of infrastructure.

a) Planned short-term electricity disruption

Load shedding a short-term electricity disruption that has been widely implemented in South Africa in the last decade. Due to this, Eskom's current arrangements to deal with high electricity peak demands are well documented and the process is strictly controlled.

Load shedding is an effective way to manage predictable electricity demand fluctuations, which includes daily peaks and seasonal fluctuation in power demand (winter peaks).

Load shedding related short-term electricity supply disruptions do not pose critical risks to the water sector. This is due to the fact that peak electricity demand periods in winter (the most probable load shedding times) do not correlate with peak water demand periods in summer. Average 7-day water demand during winter periods is at least one third less than average 7-day water demand during summer periods. Water treatment works therefore operate at only about 66% of their treatment capacity during winter low water demand periods.

The effect of a daily two to four hour load shedding period (or 8-16% of the day) on water treatment works and pumping systems should therefore not pose a problem in terms of supplying the required volume of water. This is, however, only true if water treatment works manages its water treatment schedule accordingly and if municipal reservoirs are kept at sufficient levels to ensure 48 hours of storage capacity. Moreover, larger municipalities have the ability to schedule load shedding in such a manner as to protect strategic water purification and pumping facilities. Guidelines on the operation of water treatment works and reservoirs are discussed in more details in the Sections below.

In some instances making this effective might require additional switching and cabling to limit the size of affected electrical supply zones. Where Eskom directly supplies a strategic installation (such as a major RW pump station) it may be necessary for them to limit the electricity supply zone area so as not to impede their load shedding options.

Essential interactions that have to be initiated by Eskom include minimisation of the need for load shedding, prevention of blackouts, effective communication with municipalities regarding contingency plan, advance warning of the onset of planned load shedding and the expected duration of such events. Other types of planned electricity disruption events can be dealt with in the same way as load shedding. These are included in the institutional arrangements discussed in Section 5.1.

Load shedding may, however, have to be implemented rapidly to deal with a sudden loss of electricity generating capacity or other systems faults.

b) Unplanned short-term electricity disruption events

Unanticipated load shedding initiated by Eskom's controllers or automatic control systems can be precipitated by sudden loss of generating capacity or other faults. If the event is big and rapid enough this may lead to regional or national blackouts.

Given that Water Service Providers and Authorities ensure that reservoirs are operated at the required levels, unplanned short-term electricity disruption events should also not present any unmanageable problems in terms of water supply. These events do, however, pose other risks on water supply and distribution infrastructure such as damage due to pressure surges resulting from pump trips. This is discussed in more detail in the design guidelines for Water Service Providers and Water Service Authorities in Sections 4.6.5 and 4.7.5 below.

c) Medium- to long-term disruptions' effect on water supply

Medium-term electricity disruption events are events that can last from a day up to a week. Long-term events can last from a week to a few months. These events can occur as a result of numerous reasons, including:

- Breakdown of electricity generation or distribution infrastructure;
- Theft of electricity infrastructure;
- Vandalism, terrorism, sabotage or war; or
- Natural disasters.

The effect that any of these events can have on electricity infrastructure depends greatly on the magnitude of the event itself, where the event occurs and whether there was time to implement precautionary measures before the event. This is typical information that will stem from the risk analysis and evaluation processes.

Eskom's current arrangements to respond to a blackout include:

- measures to prevent a black or cold start of power stations, such as islanding of power stations;
- the availability of two black start facilities in the case of a total blackout; and
- Eskom's Restoration Plan to prevent a failed black start.

Eskom's first priority in terms of its blackout recovery plan is currently to protect any power stations that remain in operation (or the stations that have been restored first). After successfully powering these stations' own needs, electricity is restored around the stations in small isolated circles that are increased gradually to ensure that the small grids are kept stable. Eskom's focus during this stage is to supply electricity to consumers with predictable and relatively constant demand patterns such as residential users.

Industries and the water sector, with varying and unpredictable electricity demand, are therefore not included in the early stages of Eskom's restoration plan to prevent a failed black start. Eskom therefore needs to include as part of their restoration plan, estimates of how long it would take to provide the Water Service Providers and authorities with electricity so that these entities can plan accordingly. The energy usage patterns of key water sector users during emergency conditions also need to be examined to determine if these can be prioritised for early return to service in Eskom's restoration plans. This may be possible, since during emergency conditions of severely restricted water supply, purification and pumping should be continuous (taking into consideration that demand will exceed supply and reservoirs will be at critically low levels and therefore have ample free storage at night time).

4.5.3 Summary of guidelines for electricity suppliers

Table 4-5 below summarises the guidelines proposed for electricity suppliers.

Table 4-5: Summary of guidelines for electricity suppliers.

Guidelines for electricity suppliers	
Institutional guidelines	a) Maintain internal controls to anticipate load shedding b) Maintain frequent communication with relevant authorities c) Put in place measures to decrease peak electricity demand d) Identify team to do risk assessment focussing on water supply interruptions e) Calculate the magnitude of electricity disruption events as soon as possible f) Ensure effective communication during electricity disruption events

	g) Give early warning of electricity disruption events h) For unplanned disruptions events: notify water service entities as soon as the electricity supplier becomes aware i) Make available information regarding the nature and expected duration of disruption events j) Develop and continuously improve a Disaster Risk Management Programme k) Minimise cable theft and formalise the scrap metal industry l) Guidelines specifically for short-term electricity disruption events m) Guidelines specifically for medium- to long-term electricity disruption events
Infrastructure guidelines	a) Ensure sufficient electricity generation capacity b) Prohibit vandalism, sabotage and terrorist attacks c) Prohibit cable theft d) Upgrade control facilities e) Upgrade switchgear f) Upgrade grid protection infrastructure

4.5.4 Institutional guidelines for electricity suppliers

Institutional guidelines proposed for electricity suppliers to mitigate the effect of short-term disruptions on water supply are listed below:

a) Maintain internal controls to anticipate load shedding

Maintain suitable internal controls to anticipate the need for planned load shedding to prevent a blackout. This is especially important now that the imminent threat of power shortages has receded and complacency could set in.

b) Maintain frequent communication with relevant authorities

Maintain frequent communication with Waster Service Authorities and Water Service Providers to ensure that they remain capable of implementing load shedding. This is particularly important from now onwards, since recent generating plant acquisitions should stave off the need for load shedding for long periods, during which complacency and/or loss of capacity within municipalities could occur.

c) Put in place measures to decrease peak electricity demand

Put in place measures to further decrease and manage the country's peak electricity demand, including:

- Promote optimised electricity usage focussing on sectors that can be expected to adapt their electricity demand patterns such as the water supply and distribution sector, the mining sector, the industrial and commercial sectors.
- Adjusting peak electricity usage tariffs upward for specific sectors that can adapt their demand patterns without affecting their normal operation (specifically the water supply and distribution sectors).

d) Identify team to do risk assessment focussing on water supply interruptions

Identify team from the electricity supplier to be part of the risk assessment and evaluation process specifically in terms of the effects that electricity disruptions can have on water supply.

e) Calculate the magnitude of electricity disruption events as soon as possible

That the electricity supplier, upon becoming aware of any electricity supply disruption event (or the chance of an event occurring), calculates the magnitude (expected duration and area affected) of the event.

f) Ensure effective communication during electricity disruption events

Maintain effective communication with Water Service Providers, Water Service Authorities, and government and ensure that all key managers and operating staff of water service entities are notified of electricity disruption events.

g) Give early warning of electricity disruption events

Give early warning to Water Service Providers and Water Service Authorities as far as possible in the case of planned or predicted disruptions to ensure that these entities can plan their operations and prepare accordingly.

h) For unplanned disruptions events: notify water service entities as soon as the electricity supplier becomes aware

That the electricity supplier notifies water service entities as soon as it becomes aware of any electricity disruption event that was not planned or predicted.

i) Make available information regarding the nature and expected duration of disruption events

As soon as possible inform Water Service Providers and Water Service Authorities of the nature and expected duration of disruption events so that they can ensure available reservoir storage and fuel and chemical reserves.

j) Develop and continuously improve a Disaster Risk Management Programme

Develop, evaluate and continuously improve the electricity supplier's Disaster Risk Management Plan. Ensure that disaster response teams are ready and equipped to play their roles in the event of a major emergency that threatens the wider electricity grid.

k) Minimise cable theft and formalise the scrap metal industry

Drive the adoption of new legislation which would formalise the scrap metal industry in order to minimise cable theft - a major cause of electricity disruptions in South Africa.

l) Guidelines specifically for short-term electricity disruption events:

- Keep water service entities updated of any changes in the planned load shedding schedules.
- Keep water service entities informed of the electricity supplier's planned maintenance, refurbishment and upgrading activities that my result in electricity disruptions.

m) Guidelines specifically for medium- to long-term electricity disruption events:

- Give water service entities detailed information and updates on how long it would take before electricity can be restored in the event of a blackout.
- Determine if it would be possible to revise its electricity restoration plan in the event of a blackout to prioritise electricity supply to water service entities, taking account of the heavily restricted water supply and hence anticipated uniform electricity usage pattern.

4.5.5 Infrastructure guidelines for electricity suppliers

Design guidelines proposed for electricity suppliers to mitigate the effect electricity disruptions on water supply are listed on the following pages:

a) Ensure sufficient electricity generation capacity

It goes without saying that Eskom should put measures in place to ensure that sufficient electricity generation capacity is planned and constructed for the country's future demand (not only taking into consideration the increase in electricity demand but also the predicted decrease in electricity generation capacity due to the decommissioning of older coal power stations that supply the country’s base-load).

b) Prohibit vandalism, sabotage and terrorist attacks

Ensure sufficient security measures are put in place at generation plants to prohibit vandalism, sabotage and terrorist attacks. This can be done by contracting in additional security services that can especially focus on high risk areas.

c) Prohibit cable theft

Put in place more security measures on electricity distribution infrastructure to prohibit cable theft. Furthermore, addressing the issue of illegal copper trading in the scrap metal industry is crucial to prohibiting cable theft.

d) Upgrade control facilities

Upgrade the central control room and other control facilities, if necessary, to ensure that this room will have the following:

- Ensure adequate power surge protection and disconnection options are incorporated;
- Backup power supply with emergency fuel storage;
- Backup communication facilities including radio communication in order to make communication with water service entities possible during blackouts; and
- A secure store room with maps, detailed drawings of all infrastructure and documentation on all emergency response plans.

e) Upgrade switchgear

Where necessary install switch gear, cabling and whatever is necessary to enable Eskom to prioritise electricity supply to critically important purification works and pump stations that are supplied directly by Eskom, in the event of a restart after a blackout.

f) Upgrade grid protection infrastructure

Install whatever is necessary to protect the grid and other equipment from damage due to direct currents induced by a high magnitude solar flare. Likewise, maintain any equipment required to provide advance warning of such an event and determine when it is safe to re-connect electricity distribution and generating plant. (It is understood that the ionosphere can remain affected for some time after the passage of an electro-magnetic pulse.)

4.6 GUIDELINES FOR WATER SERVICE PROVIDERS

4.6.1 Introduction

This section describes institutional and design guidelines proposed for Water Service Providers or bulk water suppliers to Water Service Authorities. For the City of Tshwane case study discussed later in the report, these guidelines are applicable to Rand Water, Magalies Water and also to the City of Tshwane where they treat and supply water to the city's population.

4.6.2 Summary of guidelines for Water Service Providers

The guidelines proposed for Water Service Providers are summarised in **Table 4-6**.

Table 4-6: Summary of guidelines for Water Service Providers.

Guidelines for Water Service Providers	
Operational and administrative guidelines	a) Ensure reservoirs are operated at correct levels b) Optimise reservoir storage c) Optimise water treatment works and bulk supply pipelines to ensure required reservoir operating levels d) Ensure adequate storage of chemicals, fuel and spares e) Rapid implementation of water restrictions f) Identify maintenance requirements of infrastructure that will negate effectiveness of mitigating measures taken g) Security measures to minimise risk of vandalism, theft, sabotage and terrorism h) Disaster Risk Management Programme implementation drills
Managerial guidelines	a) Develop a disaster risk management programme focussed on electricity supply disruptions b) Set up workshops with other institutions involved to ensure successful development of the disaster risk management programme c) Identify training needs of staff d) Review and correct current agreements between Water Service Providers and Water Service Authorities (municipalities) e) Establish community awareness programmes
Infrastructure guidelines	a) Provide sufficient reservoir storage capacity b) Provide backup power generation

	c) Provide storage facilities for chemicals, fuel and spares d) Design and construct emergency communication systems e) Design and construct an emergency / disaster office and situation room f) Provide the necessary valves to supply water during emergency situations g) Evaluate, design and construct water supply cross linkages h) Re-evaluate existing infrastructure in order to optimise future electricity consumption based on updated information available i) Optimising electricity demand of existing infrastructure j) Re-evaluate current security design criteria, adopt revised criteria and implement improved security criteria

4.6.3 Operational and administrative guidelines for Water Service Providers

The institutional guidelines discussed below are specifically applicable to operational and administrative staff.

a) Ensure reservoirs are operated at correct levels

Where Water Service Providers' reservoirs are used to directly supply water to municipalities' end-users, these reservoirs' minimum operational levels should be revised to ensure that at least the 48 hours of storage capacity is available. This should be based on the annual average daily demand of the distribution zone supplied by the reservoir.

b) Optimise reservoir storage

In view of the additional risk imposed by electricity supply, the required reservoir storage should be revised to ensure that a basic water supply can be maintained during prolonged emergency conditions. This optimisation should take account of emergency generating capacity.

c) Optimise water treatment works and bulk supply pipelines to ensure required reservoir operating levels

Evaluate the current operation of water treatment works, pump stations and bulk pipelines that supply to the Water Service Providers' reservoirs that directly supply the municipalities' customers with water. This is required in order to maintain the minimum required operating levels of reservoirs.

d) Ensure adequate storage of chemicals, fuel and spares

Adequate storage of chemicals, fuel and spares should be kept in stock in order to ensure continued water supply capabilities in the event that electricity disruption affects the availability of these materials. The minimum time to make provision for should be determined as part of the risk assessment and evaluation process. Materials stored on sites should also be sufficient to accommodate supply shortages following an electricity disruption event.

Adequate stock of chemicals required for maintaining the required levels of free available chlorine in reservoirs should also be ensured. This should take into consideration that the water in the reservoirs may be used sparingly in the event of an electricity disruption, which may affect the chemical demand of the water in the reservoir.

e) Rapid implementation of water restrictions

The rapid implementation of water restrictions is of cardinal importance in the event of a major electricity disruption event. Procedures should be put in place to ensure that this can be done across the whole Water Service Provider's supply chain (from raw water abstraction, to water treatment, to bulk water supply) as soon as possible in the event of an electricity disruption.

This implementation should include the necessary communication to Water Service Authorities and other Water Service Providers and it goes without saying that clear communication between Water Service Providers, Water Service Authorities and electricity suppliers is crucial to the effectiveness of these rapid water restrictions implementation measures.

Longer duration disruptions will necessitate increasingly more severe curtailment, optimised against the cost of emergency supply measures vs consequences of the disruption of the water supply. Close cooperation with Water Service Providers and electricity suppliers is essential to ensure understanding and agreement by all on the level of service and duration of electricity outage to be planned for.

f) Identify maintenance requirements of infrastructure that will negate effectiveness of mitigating measures taken

The operational staff should take responsibility for identifying infrastructure maintenance requirements and to make technical (planning) and managerial staff aware of such requirements. These maintenance issues include leaking pipelines, cathodic protection, flow meters, valves and reservoirs, faulty telemetry, pump faults, switchgear faults, etc.

Specific attention should be given to minimise water leaks from bulk water supply systems and a dedicated programme should be initiated (or continued if already in place) to accomplish this. Achievable goals should be set based on industry norms to measure the effectiveness of the leak detection / minimisation programme.

g) Security measures to minimise risk of vandalism, theft, sabotage and terrorism

The operational staff should be made aware of risks involved in terms of security threats so that the staff can be vigilant and able to address security issues (or report to technical or managerial staff) as they become aware of such issues.

h) Disaster risk management programme implementation drills

It is important that operational staff understand what is expected of them in the event of an electricity disruption. It is therefore proposed that the staff responsible for implementing mitigation measures as defined in the disaster risk management programme do drills and exercises. This should include drills on water restrictions, using backup power generation facilities, operation of the emergency control centre, communication stations and communicating effectively, etc.

These drills will also be effective for measuring and evaluating performance of the disaster risk management programme and to identify areas that this programme (or the staff responsible) still needs to improve on.

4.6.4 Managerial guidelines for Water Service Providers

The guidelines discussed below should be implemented by the Water Service Provider's management structure. The institutional changes required in the process of adopting these guidelines are, however, not only a management task but will involve technical (planning and design), operational and administrative staff.

a) Develop a disaster risk management programme focussed on electricity supply disruptions

A disaster risk management programme should be developed based on the outcomes of the risks assessment and evaluation process which focuses on risks that Water Service Providers and Water Service Authorities face due to the effect of electricity disruptions on water supply.

The requirements of the disaster risk management programme were discussed in more detail in Section 4.3.

Water Service Providers should liaise with one another and with the Water Service Authority during the development of these programmes. This is to ensure that the various institutions' disaster risk management programmes and objectives are integrated in order to prevent contradictory provisions in the programmes that would confuse Water Service Authorities affected by these programmes.

b) Set up workshops with other institutions involved to ensure successful development of the disaster risk management programme

Workshops need to be set up with Water Service Authorities and electricity suppliers to ensure the disaster risk management programme is developed with the correct information and agreed objectives from the various organisations. These workshops should be held on an ongoing basis as the disaster risk management programme is developed until the final adopted programme is accepted by all organisations involved.

Additional workshops should also be held specifically between the Water Service Providers and Water Service Authorities to ensure that the authorities (municipalities) understand (1) the implications of the Water Service Provider's disaster risk management programme and (2) the various measures the Water Service Provider will enforce to mitigate the effect of electricity disruptions on water supply.

Another outcome of these additional workshops is to ensure that the various Water Service Providers can come to an agreement on which areas will be supplied by each provider and the appropriate levels of curtailment in the case of electricity disruptions. This should be based on the capabilities of each Water Service Provider (based on an assessment of each Water Service Provider's infrastructure).

c) Identify training needs of staff

The managerial, technical (design staff), operational and administrative staff should be trained to better understand the risks associated with their organisation as a whole and the risks specifically due to the effect of electricity disruptions on water supply.

d) Review and correct current agreements between Water Service Providers and Water Service Authorities (municipalities)

This guideline is applicable in situations where reservoirs are used by multiple institutions. Current reservoir operating procedures between various entities are only defined for normal system operation and do not make provision for scenarios where water restrictions are implemented.

In terms of case study this is applicable to a reservoir that is owned by Johannesburg, supplied by Rand Water and distributes water to both Johannesburg and Tshwane. Normal operating procedures are defined for the reservoir in that the reservoir's outflows are metered and billed separately for each Water Service Authority. The procedures to follow in the case of water supply interruptions or water restrictions are, however, not defined.

These situations should be addressed by Water Service Authorities in order to define procedures to be followed in case of water supply interruptions or water restrictions. It is proposed that these situations be addressed in the form of a memorandum of understanding between the various entities and that information stemming from the development of such understandings be conveyed to technical and operational staff of all institutions involved.

It should also be ensured that shared reservoirs have sufficient storage capacity to accommodate the demand of all zones supplied from the reservoir (refer to Section 4.6.5 (a)).

e) Establish community awareness programmes

Community awareness programmes of Water Service Providers should summarise the capabilities and constraints of the organisations in a clear and understandable way so that the general public can appreciate the implications of risks and challenges that Water Service Providers face.

The Water Service Provider's community awareness programmes should summarise the capabilities and challenges that the organisation faces during normal operation and during emergency operations. These programmes should also clearly indicate what the Water Service Provider has done in preparation to mitigate various risks identified and specifically to mitigate the risks associated with the effect of electricity disruptions on water supply.

4.6.5 Infrastructure guidelines for Water Service Providers

This Section describes infrastructure guidelines proposed for Water Service Providers or Water Service Authorities responsible for bulk water treatment and supply. These guidelines are applicable to technical staff of the Water Service Provider responsible for planning, design, construction and maintenance of infrastructure.

a) Provide sufficient reservoir storage capacity

Where the Water Service Provider's reservoirs are used to provide storage capacity for municipal water distribution zones, it is required that these reservoirs have sufficient storage capacity.

For existing reservoirs that fit this description, it needs to be determined whether the reservoirs have sufficient capacity to provide 48 hours of spare storage capacity based on a the distribution zone's annual average daily demand, plus the storage required to meet the needs of the Water Service Provider (given that the reservoir is operated optimally as described in Section 4.6.3

point (a), (b) and (c)). If it is determined that the available storage capacity is insufficient, additional storage capacity should be made available through the design and construction of an additional reservoir / reservoirs.

For new reservoirs that fit this description, these reservoirs should be designed to have sufficient spare storage capacity to meet the above needs based on the distribution zone's future predicted annual average daily demand.

b) Provide backup power generation

Water Service Providers should provide backup power generation facilities at their water treatment works, pump stations, other parts of their infrastructure that require electricity during emergency operation (e.g. telemetry, SCADA and automatic valves) and auxiliary systems that will become effective in the case of electricity disruptions.

It is very important that the Water Service Provider in cooperation with the Water Service Authority determines the absolute minimum daily water supply volume required from each water treatment works if water restrictions are implemented in the event of electricity disruptions of differing duration. This should be calculated so that the Water Service Provider can determine the capacity of emergency power generation infrastructure that should be provided at each water treatment works.

Determination of the required backup power generation capacity should be based on the Water Service Provider's control methods (i.e. the use of automated valves, telemetry and SCADA systems). It is proposed that the Water Service Provider identifies which parts of its water supply system that normally operate automatically can be operated manually without electricity (such as reservoir control valves). This information should be used by the Water Service Provider to plan and design additional power generation or backup power facilities only where it is absolutely necessary.

c) Provide storage facilities for chemicals, fuel and spares

Storage facilities for chemicals, fuel and spares should be designed and constructed to ensure sufficient stock is available in the event that electricity disruptions affecting the supply of these stocks. The size of storage facilities should be sufficient to store enough stock for emergency works operation during the electricity disruption period as well as the recovery period after the disruption during which supplies still need to be accessed.

d) Design and construct emergency communication systems

Based on the communication requirements of the Water Service Provider's disaster risk management programme communication facilities should be designed and constructed. This is to ensure that effective communication can be maintained with all institutions (Eskom, Water Service Authorities and other affected parties) in the event of an electricity disruption.

The Water Service Provider's communication systems should also make provision for the communication requirements within the Water Service Provider's own emergency operations. These systems include: SCADA and telemetry information as essential elements in an emergency situation, communication between various sites such as water treatment works, pump stations, reservoirs and the central control room (emergency control room).

e) Design and construct an emergency / disaster office and situation room

To successfully implement its disaster risk management programme it is proposed that the Water Service Provider design and construct an emergency disaster office and situation room.

The Water Service Provider's existing control room can be upgraded for this purpose. It is recommended that the existing control room be evaluated in order to determine what is additionally required to meet the requirements of the emergency disaster office and situational room.

f) Provide the necessary valves to supply water during emergency situations

Based on the emergency operations procedures as defined in the Water Service Provider's disaster risk management programme the necessary valves and telemetry systems should be incorporated into the organisation's existing infrastructure. Most of the infrastructure required for emergency operations will probably already be in place as this is used for the metering and control of infrastructure (for billing of Water Service Authorities).

It is proposed that the existing infrastructure be evaluated to determine if the emergency operations procedures can be accommodated with current infrastructure and to determine what additional infrastructure is required for the implementation of the emergency operations procedures.

g) Evaluate, design and construct water supply cross linkages

It is recommended that the Water Service Provider determines the current capacity of existing cross linkages between various bulk water supply pump stations. This information should be compared with the minimum required volumes as determined in cooperation with the relevant Water Service Authorities.

If it is found that existing cross linkages do not have sufficient capacity, it is recommended that these be upgraded to supply the minimum required volumes.

h) Re-evaluate existing infrastructure in order to optimise future electricity consumption based on updated information available

The Water Service Provider should ensure that its water treatment and specifically its bulk water supply (i.e. pump stations) are operating effectively. It is proposed that current infrastructure's electricity consumption cost is compared to optimised infrastructure's electricity consumption cost (including the cost of upgrading current infrastructure).

If it is determined (through a life cycle cost analysis) that upgrading infrastructure is the most economical solution, the Water Service Provider should plan the necessary upgrades of its pipelines and pump stations. This will not only benefit the Water Service Provider in terms of minimising its assets' total life cycle cost but will also decrease future electricity demand.

i) Optimising electricity demand of existing infrastructure

To further reduce the electricity demand especially during peak electricity demand periods, the Water Service Provider should ensure that pump schedules are optimised in terms of electricity peak, standard and off-peak times.

This will not only reduce the electricity cost of pump stations but will also ensure that the Water Service Provider plays its role in minimising electricity consumption during peak electricity demand periods.

j) Re-evaluate current security design criteria, adopt revised criteria and implement improved security criteria

It is proposed that current security design criteria be reviewed based on the outcome of the risk assessment in terms of security threats. It is further proposed that revised security related design criteria be developed and adopted.

The current infrastructure should be evaluated based on the revised security related design criteria in order to ensure that risk related to vandalism, theft, sabotage and terrorism can effectively be mitigated.

4.7 GUIDELINES FOR WATER SERVICE AUTHORITIES

4.7.1 Introduction

This Section describes institutional- and design guidelines proposed for Water Service Authorities. For the case study, these guidelines are proposed for the City of Tshwane.

These guidelines specifically focus on the responsibilities of Water Service Authorities in the provision of adequate water storage and distribution infrastructure. Where Water Service Authorities also perform the role of Water Service Provider in that they treat and supply their own potable water the guidelines proposed for Water Service Providers specifically in terms of bulk water supply are also applicable to the Water Service Authority.

4.7.2 Summary of guidelines for Water Service Authorities

The guidelines proposed for Water Service Authorities are summarised in **Table 4-7**.

Table 4-7: Summary of guidelines for Water Service Authorities.

Guidelines for Water Service Authorities	
Operational and administrative guidelines	a) Ensure reservoirs are operated at correct levels b) Identify the nature and duration of electricity disruption event c) Optimise municipal reservoir storage d) Optimise electricity supply redundancy e) Rapid implementation of water restrictions f) Identify maintenance requirements of infrastructure that will negate effectiveness of mitigation measures taken g) Optimise the emergency power generation needs for waste water treatment works h) Security measures to minimise risk of vandalism, theft, sabotage and terrorism i) Disaster Risk Management Programme implementation drills
Managerial guidelines	a) Develop a disaster risk management programme focussed on electricity supply disruptions b) Set up workshops with other institutions involved to ensure successful development of the disaster risk management programme c) Identify training needs of staff d) Review and correct current agreements between Water Service Providers and Water Service Authorities (municipalities) e) Establish community awareness programmes f) Establish public communication strategies

Infrastructure guidelines	a) Provide sufficient reservoir storage capacity b) Provide backup power generation c) Provide electricity supply redundancy d) Provide storage facilities for chemicals, fuel and spares e) Design and construct emergency communication systems f) Design and construct an emergency / disaster office and situation room g) Provide the necessary valves to supply water during emergency situations h) Evaluate, design and construct water supply cross linkages i) Re-evaluate existing infrastructure in order to optimise future electricity consumption based on updated information available j) Optimising electricity demand of existing infrastructure k) Re-evaluate current security design criteria, adopt revised criteria and implement improved security criteria l) Initiate additional Water Conservation Demand Management projects m) Analyse the effect of electricity disruptions on water supply n) Provide emergency power generation needs for waste water treatment works

4.7.3 Operational and administrative guidelines for Water Service Authorities

The institutional guidelines discussed below are specifically applicable to operational and administrative staff.

a) Ensure reservoirs are operated at correct levels

The Water Service Authority's reservoirs' minimum operational levels should be revised to ensure that 48 hours of storage capacity is available. This should be based on the annual average daily demand of the distribution zone supplied by the reservoir.

b) Identify nature and duration of event

It is essential to rapidly identify the nature and expected duration of every electricity supply event that disrupts the provision of water services.

The first priority is to determine if the outage is due to a high risk large area and long duration event. This is essential information since it implies the need to implement water rationing and initiation of emergency water supply measures with immediate effect to conserve available storage in reservoirs. This requires excellent communication with Water Service Providers and with Eskom. It also requires pre-planned and well drilled emergency procedures. Such an event would also require fully manning the emergency control centre with the required managers and operators. A pre-prepared public awareness and co-operation campaign would also have to be set in motion.

If the event is less severe, communication with the Water Supply Authority's own electricity department would be required, to determine if the fault stems from the authority's own infrastructure, or an external source (in this case, Rand Water's pumping or purification systems, or an Eskom substation or power line).

Appropriate actions will stem from the extent and expected duration of the event.

It is also important to check with the Water Service Authorities water and electricity departments to determine if the sudden loss of electricity has resulted in pressure surges that may have damaged plant, such as pipelines and electrical distribution equipment.

c) Optimise municipal reservoir storage

In view of the additional risk imposed by electricity supply, the required reservoir storage should be revised to ensure that a basic water supply can be maintained during prolonged emergency conditions. This optimisation should take account of emergency generating capacity.

d) Optimise electricity supply redundancy

The City of Tshwane has two major external sources of electricity supply from Eskom, with little overlap between two large areas of supply. This increases the municipality's vulnerability. A means of supplying each of the two zones from either of the two major sub-stations would make it possible to implement a local form of rolling load-shedding in the event that either major sub-station is damaged. Without this there is the risk that half of the metro could be blacked out for an extensive period of time. Addressing this issue would be beneficial to all electricity users, not just the water sector.

Some other Water Service Authorities or municipalities might face similar hidden risks.

e) Rapid implementation of water restrictions

The rapid implementation of water restrictions is of cardinal importance in the event of a major electricity disruption event. Procedures should be put in place to ensure that this can be done across the whole Water Service Authority's supply chain (from reservoirs to distribution) as soon as possible in the event of an electricity disruption.

This implementation should include the necessary communication to Water Service Providers and other Water Service Authorities affected. It goes without saying that clear communication with Water Service Providers and Eskom is crucial to the effectiveness of these rapid water restrictions implementation measures.

Longer duration disruptions will necessitate increasingly more severe curtailment, optimised against the cost of emergency supply measures vs consequences of the disruption of the water supply. Close cooperation with Water Service Providers and Eskom is essential to ensure understanding and agreement by all on the level of service and duration of electricity outage to be planned for.

f) Identify maintenance requirements of infrastructure that will negate effectiveness of mitigating measures taken

The operational staff should take responsibility of identifying maintenance requirements of water distribution infrastructure and to make technical (planning) and managerial staff aware of such requirements. These maintenance issues include leaking pipelines, cathodic protection, flow meters, valves and reservoirs, faulty telemetry, pump faults, switchgear faults, etc.

Specific attention should be given to minimise water leaks in distribution systems and a dedicated programme should be initiated (or continued if already in place) to accomplish this. Achievable goals should be set, based on industry norms to measure the effectiveness of the leak detection / minimisation programme.

It goes without saying that all of these measures need to be in operation long (years) before a serious electricity disruption incident. This is important to limit the amount of water that needs to be provided and to increase the effectiveness and reduce the risk of mitigation measures, such as closing supply systems at night time.

g) Optimise the emergency power generation needs for waste water treatment works

Portable generators could be used to deal with electricity outages of relatively small extent. The locations where such equipment is stored and suitable transport facilities and fuel requirements also need to be considered. However, this will not suffice for wide area events such as regional or national blackouts. The viability of permanent generators with suitable fuel storage facilities can be considered.

Gas generators fed from own bio-sources could provide an attractive sustainable option, especially in instances when the benefit cost ratio is close to or exceeds unity. Such a plant need not be big enough to run the full capacity of the plant, seeing as during a high risk electricity outage event sewage return flow can be expected to decline in step with the heavily curtailed water supply.

The viability of solutions depends on the risk posed. Small works with little downstream water use might pose insignificant risk to warrant high priority intervention. During high risk electricity outages, prolonged loss of treated water supply poses a much bigger threat than pollution of rivers. Rivers also have natural self-cleansing properties with regard to biological pollution, especially when there are intervening reservoirs or long river reaches between source and abstraction point. The impact is greater for when sewage works are large relative to the natural water resource. The risk is also mitigated by the fact that abstraction of untreated river water for potable use is limited. Moreover, the emergency itself will reduce effluent flow rates.

Optimisation of emergency measures should therefore also include environmental impact assessments.

h) Security measures to minimise risk of vandalism, theft, sabotage and terrorism

The municipal operational staff should be made aware of risks involved in terms of security threats so that the staff can be vigilant and able to address security issues (or report to technical or managerial staff) as they become aware of such issues.

Support by way of motivation should be given to initiatives by Eskom, Water Service Providers, transport and telecom authorities and industrial users to curtail copper theft. In this regard municipalities should be primary role players since most of the cable theft takes place within their boundaries and causes frequent damage to municipal infrastructure. Champions should be sought to spearhead such initiatives, these can include special units such as the South African Police Service[3].

i) Disaster risk management programme implementation drills

It is important that municipal operational staff understand what is expected of them in the event of an electricity supply disruption. It is therefore proposed that the staff responsible for

[3] Although the tax payer will probably end up paying for this additional services by the South African Police Service, the savings in repairs, replacement of stolen copper and decrease in resulting costs to the economy due to less electricity outages will probably justify this additional cost (given that the assigned police unit does effectively fulfil their responsibility).

implementing mitigation measures as defined in the disaster risk management programme do drills and exercises. This should include drills on water restrictions, using backup power generation facilities, operation of the emergency control centre, communication stations and effective communication strategies.

These drills will also be effective for measuring and evaluating performance of the disaster risk management programme and to identify areas that this programme (or the staff responsible) still needs to improve on.

4.7.4 Managerial guidelines for Water Service Authorities

The guidelines discussed below should be implemented by the Water Service Authority's management structure. The institutional changes required in the process of adopting these guidelines are, however, not only a management task but will involve technical (planning and design), operational and administrative staff.

a) Develop a disaster risk management programme focussed on electricity supply disruptions

A disaster risk management programme should be developed based on the outcomes of the risks assessment and evaluation process which focuses on risks that Water Service Authorities face due to the effect of electricity disruptions on water supply.

The requirements of the disaster risk management programme were discussed in more detail in Section 4.3.

In the case of this project the City of Tshwane (the Water Service Authority) should liaise with other institutions involved such as Rand Water and Magalies Water (Water Service Providers) and Eskom during the development of this programme. This is to ensure integration of the various institutions' disaster risk management programmes and objectives in order to prevent contradictory provisions in the programmes that would confuse Water Service Authorities affected by these programmes.

b) Set up workshops with other institutions involved to ensure successful development of the disaster risk management programme

Workshops need to be set up with Water Service Providers and Eskom to ensure the disaster risk management programmes are developed with the correct information and agreed objectives from the various organisations. These workshops should be held on an ongoing basis as the disaster risk management programme is developed until the final adopted programme is accepted by all organisations involved.

Additional workshops should also be held specifically between the Water Service Authority and provider(s) to ensure that the Water Service Provider(s) (Rand Water and Magalies Water) understand the requirements of the Water Service Authority in terms of is minimum water supply requirements during the water restrictions.

Another outcome of these additional workshops is to ensure that the Water Service Authority is informed of the allocation of responsibility of each Water Service Provider, inclusive of the respective zone allocation and expected levels or curtailment.

c) Identify training needs of staff

The managerial, technical (design staff), operational and administrative staff should be trained to better understand the risks associated with their organisation as a whole and the specific risks resulting from electricity disruptions on water supply.

d) Review and correct current agreements between Water Service Providers and Water Service Authorities (municipalities)

This guideline is applicable in situations where reservoirs are used by multiple institutions. Current reservoir operating procedures between various entities are only defined for normal system operation and do not make provision for scenarios where water restrictions are implemented.

For the case study, this is applicable to a reservoir that is owned by the City of Johannesburg, supplied by Rand Water and which distributes water to both Johannesburg and Tshwane. Normal operating procedures are defined for the reservoir in that the reservoir's outflows are metered and billed separately for each Water Service Authority by Rand Water. The procedures to follow in the case of water supply interruptions or water restrictions are, however, not defined.

These situations should be addressed by Water Service Authorities in order to define procedures to be followed in case of water supply interruptions or water restrictions. It is proposed that these situations be addressed in the form of a memorandum of understanding between the various entities and that information stemming from the development of such understandings be conveyed to technical and operational staff of all institutions involved.

It should also be ensured that shared reservoirs have sufficient storage capacity to accommodate the demand of all zones supplied from the reservoir (refer to Section 6.2(a)). For the case study this is especially important to the City of Tshwane, which also requires negotiation with another Water Service Authority (the City of Johannesburg).

e) Establish community awareness programmes

Community awareness programmes of the Water Service Authority should summarise the capabilities and constraints of the organisation in a clear and understandable way so that the general public can appreciate the implications of risks and challenges faced by the Water Service Authority and the Water services Provider and the boundaries between the responsibilities of each.

The Water Service Authority's community awareness programmes should summarise the capabilities and challenges that the organisation faces during normal operation and during emergency operations respectively. These programmes should also clearly indicate what the Water Service Authority has done in preparation to mitigate various risks identified and specifically to mitigate the risks associated with the effect of electricity disruptions on water supply.

Volunteer programmes should also be included as part of the community awareness programme. Volunteer programmes will minimise the risk of community uprising in the event of an electricity disruption as the community will have a sense that they are (and will remain) part of the solution.

f) Establish public communication strategies

It is imperative to win the cooperation of the public in adhering to water rationing and to calm public reaction when they realise the gravity of the situation.

It is essential to keep the public informed of emergency situations so that they know where and when to get water, receive regular updates on how long the crisis/situation is expected to last, what progress has been made and receive assurances that the matter is under control. At the very earliest stages public co-operation in implementing and maintaining emergency water restrictions is required. Full and rapid use of radio, cell phone, telephone, TV, printed media, notices in public places and in streets and dissemination through municipal structures and NGOs will be valuable channels of communication. Municipal Call Centres need to be prepared to handle a massive influx of public enquiries and armed with suitable messages for high risk disruptions. Arrangements must be made ahead of time with media houses, Ward Committees and NGOs.

Key information required for dissemination during high risk incidents to be disseminated must be prepared ahead of time so that rapid deployment can take place. Community information structures for rapidly disseminating information should be prepared ahead of time.

Stocks of hand outs and posters need to be prepared ahead of time to cover high risk events since printing facilities are unlikely to have power supplies and few of their staff will be at work due to traffic and fuel problems and dealing with their own domestic problems.

4.7.5 Infrastructure guidelines for Water Service Authorities

This section describes design guidelines proposed for Water Service Authorities. These guidelines are applicable to technical personnel of the Water Service Authority that are responsible for planning, design, construction and maintenance of infrastructure.

a) Provide sufficient reservoir storage capacity

It needs to be determined whether the Water Service Authority's reservoirs have sufficient capacity to provide 48 hours of spare storage capacity based on a the distribution zone's AADD, plus the storage required to meet the needs of the Water Service Authority (given that the reservoir is operated optimally as described in Section 4.7.3 points (a), (b) and (c)). If it is determined that the available storage capacity is insufficient, additional storage capacity should be made available through the design and construction of an additional reservoir / reservoirs.

New reservoirs should be designed to have sufficient spare storage capacity to meet the above needs based on the distribution zone's future predicted annual average daily demand.

b) Provide backup power generation

Backup power generation capacity should be determined based on the Water Service Authority's control methods (i.e. the use of automated valves, telemetry and SCADA systems). It is proposed that the Water Service Authority identifies which parts of its water distribution system that normally operate automatically can be operated manually without electricity (such as reservoir control valves). This information should be used by the Water Service Authority to plan, design and provide additional power generation or backup power facilities only where it is absolutely necessary.

To prohibit long-term sewer spillages and contamination of raw water sources during electricity disruption events, backup power generation infrastructure should also be designed and constructed for the Water Service Authority's sewerage pump stations and wastewater treatment works.

c) Provide electricity supply redundancy

Depending on the outcome of recommendation 4.7.3(d), Water Service Authority or electricity supplier should design and construct the switchgear and transmission lines necessary to enable each of the two main substations to supply either of the two major supply area zones.

The rationale is given in Section 4.7.3(d).

d) Provide storage facilities for chemicals, fuel and spares

Storage facilities for chemicals, fuel and spares should be designed and constructed to ensure sufficient stock is available in the event that electricity disruptions affecting the supply of these stocks. The size of storage facilities should be sufficient to store enough stock for emergency works operation during the electricity disruption period as well as the recovery period after the disruption during which supplies still need to be accessed.

e) Design and construct emergency communication systems

Communication facilities should be designed and constructed based on the communication requirements of the Water Service Authority's disaster risk management programme. This is to ensure that effective communication can be maintained with all institutions (Eskom, Water Service Providers and other affected parties) in the event of an electricity disruption.

The Water Service Authority's communication systems should also make provision for the communication requirements within the Water Service Authority's own emergency operations. These systems include: SCADA and telemetry information as essential elements in an emergency situation, communication between various sites such as pump stations (potable and sewerage), reservoir sites, wastewater treatment works and the central control room (emergency control room).

f) Design and construct an emergency / disaster office and situation room

To successfully implement its disaster risk management programme it is proposed that the Water Service Authority design and construct an emergency disaster office and situation room.

If available, the Water Service Authority's existing control room can be upgraded for this purpose. It is recommended that the existing control room be evaluated in order to determine what is additionally required to meet the requirements of the emergency disaster office and situational room.

g) Provide the necessary valves to distribute water during emergency situations

Based on the emergency operations procedures as defined the Water Service Provider's disaster risk management programme the necessary valves and telemetry systems should be incorporated into the institution's existing infrastructure. Most of the infrastructure required for emergency operations will probably already be in place as this is used to manage its distribution zones.

It is proposed that the existing infrastructure be evaluated to determine if the emergency operations procedures can be accommodated with current infrastructure and in order to determine what additional infrastructure is required for the implementation of the emergency operations procedures.

h) Evaluate, design and construct water distribution cross linkages

It is recommended that the Water Service Authority determines the current capacity of existing cross linkages and connections between bulk reservoir distribution zones. This information should be compared with the minimum required volumes of each zone in order to determine whether reservoirs with surplus storage capacity can accommodate areas supplied by reservoirs with insufficient storage capacity.

This information is especially important for mitigating the effects of localised electricity supply disruptions on water supply. For example, water supply interruptions in isolated areas within the Water Service Authority's boundaries can be addressed from areas without interruptions.

i) Re-evaluate existing infrastructure in order to optimise future electricity consumption based on updated information available

The Water Service Authority should ensure that its internal supply pipelines (internal pump stations) are operating effectively. It is proposed that current infrastructure's electricity consumption cost is compared to optimise infrastructure's electricity consumption cost (including the cost of upgrading current infrastructure).

If it is determined (through a life cycle cost analysis) that upgrading of infrastructure is the most economical solution, the Water Service Authority should plan the necessary upgrades of its pipelines and pump stations. This will not only benefit the Water Service Authority in terms of minimising its assets' total life cycle cost but will also decrease future electricity demand.

j) Optimising electricity demand of existing infrastructure

To further reduce electricity demand especially during peak electricity demand periods, the Water Service Authority should ensure that pump schedules (of pump stations within the authority's boundaries) are optimised in terms of electricity peak, standard and off-peak times.

This will not only reduce the electricity cost of pump stations but will also ensure that the Water Service Authority plays its role in minimising electricity consumption during peak electricity demand periods.

k) Re-evaluate current security design criteria, adopt and implement revised criteria and implement revised security criteria

It is proposed that current security design criteria be reviewed based on the outcome of the risk assessment in terms of security threats. It is further proposed that revised security related design criteria be developed and adopted.

The current infrastructure should be evaluated based on the revised security related design criteria in order to ensure that risk related to vandalism, theft, sabotage and terrorism can effectively be mitigated.

l) Initiate additional Water Conservation Demand Management projects

Managing real water losses in Water Service Authorities is critical when water demand needs to be minimised especially when water restrictions are implemented.

It is therefore proposed that Water Service Authorities take drastic action to minimise water losses. This could only be achieved through effective implementation of Water Conservation and Demand Management projects.

m) Analyse the effect of electricity disruptions on water supply

It is proposed that the Water Service Authority analyse the effects of various electricity disruptions (distribution failures, regional- and national blackouts) to determine the theoretical effects of these disruptions on water supply.

n) Provide emergency power generation needs for waste water treatment works

As required, provide portable generators and storage facilities to deal with electricity outages of relatively small extent.

Where appropriate, design and build permanent standby generators with suitable fuel storage facilities, or biogas powered generators fed from waste water treatment works sludge digesters.

4.8 GUIDELINES FOR OTHER AFFECTED PARTIES

4.8.1 Guidelines for other institutions

It is proposed that Water Service Providers and Water Service Authorities identify other institutions that may be required to participate in mitigating the effects of electricity disruption on water supply.

These institutions include:

- Health services (both state and private);
- The South African National Defence Force;
- The South African Police Services;
- Public Organisations;
- Political Parties (to ensure stable social acceptance of the electricity disruption event and cooperation with mitigation steps taken);
- Communication centres;
- State and private radio stations, TV channels and printed media; and
- Other countries (to ensure regional disaster management strategies on a quid pro quo and solidarity basis/developments of a quid pro quo type of arrangement which will bind South Africa to assisting other countries if they are affected by disastrous events given that other countries will assist South Africa in return).

After electricity suppliers, Water Service Providers and Water Service Authorities have completed the development of their disaster risk management programmes; it is proposed that the above mentioned institutions be made aware of what the programmes consist of. This will provide these institutions with good information to be used for the development of their own risk management programmes if they deem it necessary.

4.8.2 Guidelines for the general public

It is of critical importance that the general public accepts and supports the various stakeholders' disaster risk management programmes. The public should be advised to make the necessary preparations for any event, regardless of the effectiveness of the implementation of the institutional disaster management program.

If this is implemented correctly, the following can be achieved:

- It will ensure that the public gains an understanding of the risks associated with electricity disruptions and the resultant water supply failures.
- It will give the public an appreciation of the scale of preparation work necessary to prepare adequately for such an event (given that the necessary institutional preparation is being done).
- It will increase the effectiveness of institutional arrangements made to mitigate the effect of electricity disruption on water supply (if the public took the necessary precautions as proposed, it is possible that they use emergency water stored for disaster events and will therefore not use the municipal water)[4]. Suitable household treatment of swimming pool water could serve a similar purpose. This would require that such households keep adequate stocks of chemicals needed to purify the water that they draw.

[4] This is, however, unlikely since the public will most probably deplete the stored municipal water before resorting to their own stored emergency water.

5 BACKGROUND INFORMATION FOR THE CASE STUDY

This chapter gives an overview of current institutional arrangements in place, the relevant background information on the Tshwane and summarises the estimated cost of infrastructure required to mitigate the risk that electricity disruption events imposes on water supply.

5.1 CURRENT INSTITUTIONAL ARRANGEMENTS

5.1.1 Introduction

Existing institutional arrangements between Eskom, Rand Water and Tshwane to mitigate the effect of electricity disruptions on water supply were examined and evaluated. These arrangements are summarised in this section.

Eskom, Rand Water and Tshwane's management approach and institutional capacity influences the impacts and extent of power failures and sustainability of water supply. In the following paragraphs' feedback is provided on discussions which were conducted with these organisations.

5.1.2 Eskom's preparedness

a) Background on Eskom's preparedness

Eskom has an operational plan in place to handle load shedding, the actions required to reduce the risk of widespread blackout and how such an occurrence would be handled. This section summarises information on Eskom's current institutional arrangements which deal with electricity disruption events based on information that was attained at the meeting (Koch and van Harte, 2016).

b) Load shedding

Load shedding comprises actions taken by Eskom to reduce power demand to manage imbalances between electricity demand and available electricity supply. This is particularly important since an imbalance between supply and demand could cause uncontrolled blackout of an entire region, or even the cascading blackout of the entire national grid. The ensuing need for a cold start could take several days to restore and has to be avoided at all costs due to the dire consequences.

Load shedding is invoked after the demand curtailments provided for in terms of agreements with certain major power users have been invoked, which allows curtailments of up to 10% of Eskom’s total power demand. Hence the general public only experiences load shedding after large power consumers have already faced much larger power curtailment. In effect the absolute level of curtailment to the large power users is often more severe than that experienced by the public through load shedding. This arrangement holds advantages for the industries involved since they get paid for not using part of their electricity (which is particularly advantageous under current constrained market conditions) and gain valuable warning. Two hours warning has to be given to these consumers so that they can bring miners to the surface, in the case of mines, or to finish a pour and empty their pot lines before they solidify, in the case of iron and steel works and aluminium smelters.

The main advantage for Eskom is being able to rely on this source of demand reduction before having to inconvenience much of the national population. Eskom is also able to manage such reductions themselves.

The first four stages of load shedding differ in that the application is out of the hands of Eskom and is essentially a voluntary action carried out by municipalities, which run a rotation system of rolling blackouts of different municipal electricity demand zones to achieve the desired reduction in power demand.

Municipalities are usually placed on alert for 15 minutes, followed by a final instruction 15 minutes before the actual commencement of load shedding to allow them time to make the necessary switch-overs. The major metros can achieve this quickly since they can control their substations from a central control centre. The notable exception is Ekurhuleni, which has to rely on manual switching that requires operators to physically drive out to every affected electricity supply zone to manually switch off the power supply. The same has to be done to switch power back on when the rolling blackout period for each block ends, and the supply to the next blocks of demand zones has to be switched off. The four commonly known levels of load shedding are as follows:

- Level 1: Power demand reduced by further 1000 MW (over and above the load shedding already applied to the large power users);
- Level 2: Power demand reduced by further 1000 MW;
- Level 3: Power demand reduced by further 1000 MW; and
- Level 4: Power demand reduced by further 1000 MW.

The above 1000 MW power reduction steps for each restriction level are approximate, since this is also related to the total power availability. Load shedding requires a municipality to cut off electricity supply to enough supply zones to meet its allocation. In nearly all instances these cut-off blocks are scheduled to last for 2 hours, although Johannesburg has chosen to implement 4 hour time blocks. Although Ekurhuleni would very much like to use 2 hour blocks, they are forced to adopt 3 hour blocks to accommodate their manual operating procedure (which already represents something of a traffic hazard from vehicles speeding to substations).

If the condition requiring the rolling blackout lasts longer than the block length, then power is restored to the affected zones and new zones are switched off according to a pre-planned roster. There is a long time gap between the scheduled Level 1 blocks. Successive curtailment levels of rolling blackout result in shortening the period of full supply to each block.

The roster carries on from where it left off when the next load shedding event occurs, thereby sharing the inconvenience equitably. To date it has not been necessary to advance beyond level 2 load shedding.

It was always recognised that circumstances could arise that require more levels of rolling blackout. Hence there are a further 4 levels of blackout (Levels 5 to 8), each adding another 1000 MW to the curtailment. While this is adequate to limit fairly predictable rises in diurnal peak power demand, it may not be rapid enough to deal with a sudden loss of generating capacity.

Until now load shedding has not imposed insurmountable problems for water supply. This is partially due to the biggest winter peak power demand periods not overlapping with summer peak water demand periods. Hence, a two to four hour cessation of pumping, combined with 48 hours of storage in municipal reservoirs, may not necessarily prevent the refilling of reservoirs sufficiently to inhibit meeting peak water demands. Even if the load shedding were to occur during hot dry summer conditions that do impair the ability to meet peak water demands, this need not represent a major water supply crisis, since the pumping failure would be temporary and there should still be sufficient water supply to satisfy industrial water requirements and the basic needs of domestic users. However, this presupposes correct management of the water supply system to prevent high lying areas from running dry while other areas continue to water gardens without restriction.

Moreover, larger metros have the ability to control which zones are switched off and can thereby to some extent protect national key points. However, smaller municipalities do not have this option, since the entire municipal area could comprise too few zones. Even in larger metros the number of national key points and sizing of zones might be too large to enable them to exclude every purification works, pump station, hospital, clinic and other national key point from load shedding.

Hence, after level 8 is exceeded, or before that if necessitated by a sudden drop in generating capacity, it could become necessary for Eskom to take over and implement rapid emergency measures to keep the grid stable and prevent a more damaging regional or national blackout. This could include a scenario where Eskom rapidly switches off the power supply to entire supply zones or even entire cities without warning.

Such emergency measures cross over a grey area between rolling blackout and regional or national blackout.

This could grow to the extent of having to black out entire regions, with other regions continuing to be supplied by designated power stations that are still operating. Eskom operators and automatic control systems have the authority to implement such actions as quickly as is required to stabilise the grid to prevent a total blackout.

c) Regional or national blackout

A regional or national blackout differs fundamentally from a rolling blackout in that it would require restarting some or all of the power stations. The most likely cause of a national blackout would be an unforeseen sequence of events that result in a cascading collapse of the transmission/generation system. This is a low likelihood, high impact incident. Such an incident can occur with very little or no warning. Restoration of the first loads would take several hours and that for the entire system could take multiple days or weeks, depending on the context.

In the worst case a national blackout would require a cold start of all thermal power stations. Since South Africa does not have adjacent power grids that can be relied upon to help, reliance has to be placed on a power source, such as hydro generators, that can produce enough power and sustain it long enough to run the auxiliary works to get the first thermal unit back in operation.

At present there are only two such power sources that can be relied upon to provide sufficient power and sustain it long enough to achieve this. Provided at least one of these two sources is operational, the first major generating unit can be brought back into operation. The power provided by this unit can then be used to start up adjacent stations, which can be synchronised to generators already in operation, and so on.

d) Blackout prevention

Eskom has established and regularly rehearses multiple layers of protection to prevent a blackout and to recover after various scenarios of incident as illustrated in **Figure 5-1**.

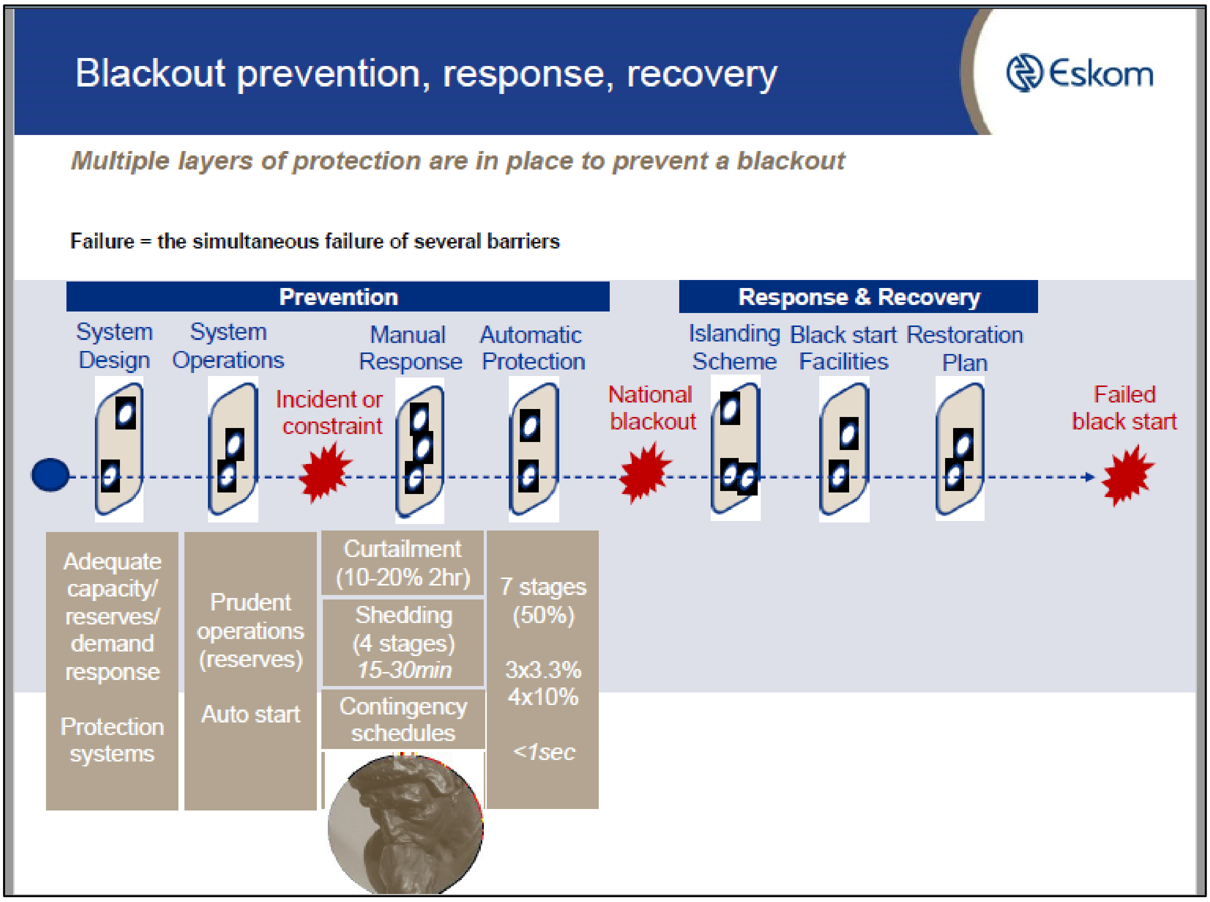

Figure 5-1: Blackout prevention, response and recovery barriers (Koch & van Harte, 2016).

The first two barriers represent normal operation.

The third Manual Response barrier includes curtailment of large industrial users and the first four stages of load shedding. After that Automatic Protection is set in motion, during which up to seven stages can be invoked automatically within less than a second to respond to a sudden loss of generating capacity. The first automatic stage typically occurs once per year, as illustrated in **Figure 5-2**.

It is important to note that the Manual Protection and Automatic Protection barriers are not necessarily preceded by Curtailment of large power users or load shedding. A sudden loss of generating capacity happens far too quickly and requires immediate response by Eskom themselves. Under such circumstances there might not even be enough time to issue warnings.

After these stages are exhausted a blackout occurs.

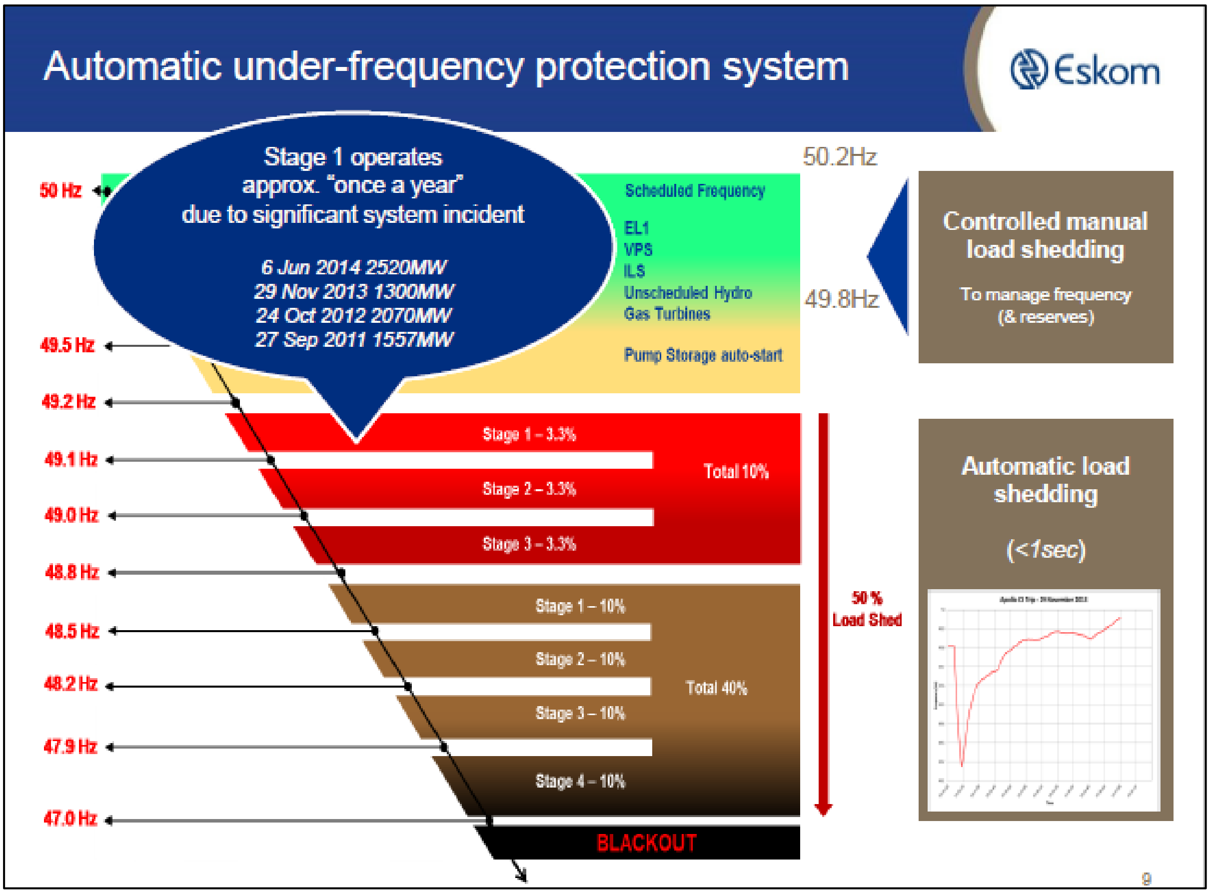

Figure 5-2: Automatic under-frequency protection system (Koch & van Harte, 2016).

e) Eskom response

Once a blackout occurs the emphasis shifts to rapid response and recovery in the shortest possible time.

Eskom has developed a system to rapidly respond to a sudden loss of part of its generating capacity, or exceedance of the capacity by rising peak power demands. This system has been well honed during the energy crisis that prevailed since 2007, making use of rolling blackouts to balance available supply with demand and keep the electricity supply system stable. Beyond the experience envelope of Phase 1 and 2 rolling blackouts and a similar extension to Phase 3 and 4 rolling blackouts, Eskom has procedures in place to allow operators to rapidly cut supply to entire macroscopic zones, if necessary.

If entire regions are blacked out, provision has been made for suitably equipped generating units with trained staff to operate as small independent “islands” (see **Figure 5-1**), essentially supplying their own requirements to keep their boilers hot and producing stream. This is important since restarting a coal-fired power station from a cold start can take over 16 hours. A cold start also carries greater risk than a warm start. The main risk of a cold start lies in obtaining an external power source large enough to run all the essential auxiliary plant (coal handling, water supply, etc.) for several hours until enough steam is made to drive the power station’s turbines so that the power station becomes self-sustaining.

Only two Black Start Facilities are available nationally to do this. If these are not available, then restarting South Africa’s power stations could take several months, since there are no adjacent power grids that can be drawn on to start up the power stations. Hence keeping power stations running as small independent islands is preferable to having them shut down entirely. There is the risk that successful islanding of some or all of the power stations may not be possible.

A warm start describes an intermediate condition where the boilers still retain some heat, meaning that a restart will not take as long as would be the case with a cold start. However, an external power source would still be required to run the ancillary works until enough steam is produced so that the turbines can be run. Hence, the sooner hot or warm power stations can be restarted the better.

Power stations that have been successfully islanded can then be used to build network “rings”, which can be expanded to incorporate more users and eventually be merged to supply larger regions and eventually the entire nation.

The final barrier is a well-planned and practiced Restoration Plan. It is essential to prevent a failed black start, since this would mean having to start again from scratch.

f) Duration of blackout

In the extreme case of a national blackout, it could take 14 days to bring all the generating units back on stream (provided that the cause of the blackout itself does not damage the grid or essential generating plants).

Restoring power to the Gauteng province in South Africa is considered a very high priority, since 12 million people inhabit the region and it is the economic hub of the nation. Eskom has considered two major possibilities in such an event to head off major social upheaval: (a) Evacuate Gauteng or (b) Restore the power as quickly as possible.

The first option has been rejected as impractical, leaving the only option to restore power as quickly as possible. This is extremely important for water suppliers to appreciate.

Interestingly, the restoration of power to national key points, such as water purification and pumping systems is not considered the first priority. The first priority is to protect the few power stations that remain in operation (or those that have been restored first), starting from small circles around each isolated station, primarily to supply the station's own operating needs in as stable a manner as possible. The supply areas would then be carefully increased, while continuously ensuring that the power supply is kept stable. During this process the first priority is actually domestic supply because this provides the most stable and predictable form of resistance, due to the presence of a large number of household heating units. This is an important requirement since the supply to many industries and national key points, such as pumping installations, is more variable and hence more likely to cause electrical instability and precipitate a secondary blackout when the power output is still low.

Once a large amount of more stable power is produced the variation in the water pumping power demand is small compared to the total and therefore less likely to cause a secondary blackout. Only then will national key points be prioritised. This too is an important factor affecting the length of time of power outages during which water will still have to be supplied.

It is thought that the systems and procedures introduced by Eskom can restore 50% of the power requirement of Gauteng within 2 to 3 days (provided at least one of the Black Start Facilities is operational). It is possible, however, that some key pumping installations and water works may not be included in this 50%. Eventually the growing islands of supply areas would merge as one station and zone is synchronised with another.

Getting the Sasol petrol from coal complex back into operation after a blackout could take 2 to 3 weeks, hence severe fuel shortages can be expected. This may affect fuel supplies to standby generators.

It must also be appreciated that events such as a solar flare, sabotage, computer virus attack or nuclear war (e.g. detonation of Electro Magnetic Pulse (EMP) devices) could lead to extensive damage to plant and infrastructure, which could extend the duration of the blackout considerably (unlike a solar storm, there would be little or no warning of an impending EMP).

Sabotage that affects the two Black Start generating facilities that Eskom relies on to initiate a cold start could result in a blackout running to several months due to the inability to supply enough power to restart the first generating unit.
Damage to generating plants, large transformers and transmission lines could also cause long delays in restoring the electricity supply to entire regions.

g) Consequences

As discussed earlier, the consequences of the disruption of electricity supply for water supply for any length of time are extremely serious.

h) Load shedding of critical loads

The National Code of Practice: Emergency Load Reduction and System Restoration Practices (SABS, 2010) specifically deals with how load reduction can be implemented. The various critical loads and the load scheduling applicability to these are listed in **Table 5-1**.

Table 5-1: National code of practice - Emergency load reduction and system restoration practices - load scheduling of critical loads (SABS, 2010).

Load	Scheduled for load shedding	Protocols before/during shedding	Comment
Airports	Yes	Yes / Yes	Airports require on-site backup supplies as a legal requirement
Rail (Commuter)	No	None	Where the power supply system allows for this
Rail (Long distance)	Yes	None	May be treated as curtailment loads where practicable
Traffic lights	Yes	None	The treatment of high, medium, and low impact traffic lights is addressed
Water (Power stations)	No	None	
Water (Industrial)	Yes	None	
Water (Agricultural)	Yes	None	May be temporarily removed if a state of disaster is declared.

Load	Scheduled for load shedding	Protocols before/during shedding	Comment
Water (Potable)	No*	None	* Bulk supply systems
Stadiums	Yes	No	May be temporarily removed in the event of a major event
Sewage	Yes*	None	* Unless the impact cannot be addressed
Refineries	No	None	May be treated as curtailment loads
Fuel pipe lines	No	None	
Coal mines	No*	None	* Only those mines that supply power stations
Education	Yes*	None	* Special arrangements may be made for temporary removal at critical times
Police	Yes	None	Adequate backup systems must be in place
Telecom's	Yes*	None	* See requirements related to data centres
Hospitals	Yes	Yes/Yes	
Clinics	Yes	None	
Data centres (National)	Yes	Yes*	* Hotline for customers should backup systems fail
Ports authorities	Yes	None	
Government Buildings	Yes*	None	* With the exception of the Union Buildings and National Parliament
Electricity Control Rooms	No	N/A*	* Control rooms are notified by default of load shedding as part of the load shedding process
NOTE: National key points in general are not by default considered critical loads. Application for temporary or permanent exemption needs to be made in terms of the criteria for critical loads.			

5.1.3 Rand Water's preparedness

a) Background on Rand Water's preparedness

The information summarised in this section were obtained through personal discussions by the WRC study's project team and Rand Water's staff (Mosai, 2016).

Rand Water is the largest bulk water utility in Africa and is one of the largest in the world, providing bulk potable water to more than 11 million people in Gauteng, parts of Mpumalanga, the Free State and North West – an area that stretches over 18 000 km².

Rand Water draws water from its catchments (described below) and purifies it for human consumption. The water is then supplied / sold to municipalities, mines and industries.

The municipalities, e.g. Johannesburg Water, City of Tshwane, in turn supply the water, at a cost, to the consumers or individual households.

Since 1974, the Tugela-Vaal scheme has fed water into the Vaal River to supplement its supply. This is done by inter-basin transfer of water from the Tugela River in KwaZulu-Natal. This means that water is released into the Vaal River system from the Sterkfontein Dam via the Nuwejaar Spruit and the Wilge River. The availability of water from the Tugela-Vaal system made it possible for Rand Water to maintain restricted, but adequate, water supplies to consumers during major droughts – from 1983 to 1987 and in 1995.

The Lesotho Highlands Water Project (LHWP) also transfers water to the Vaal Dam. This entire project comprises six dams and three pumping stations. It diverts the flow of the Senqu River via tunnels through the Maluti Mountains, channelling the water to the Eastern Free State, and then on to the Vaal Dam.

The first phase of the LHWP was completed in 1998 and is designed to meet the demand for water in Gauteng up to the year 2020.

Rand Water operates a pipeline network some 3 056 km long, two big combined pumping and purification stations (at Vereeniging and Zuikerbosch), four booster pumping stations (Zwartkopjes, Palmiet, Mapleton and Eikenhof) and a number of enclosed reservoirs as shown in **Figure 5-3**. Two thirds of the value of this infrastructure, estimated to be worth about R30 billion, lies in the pipelines.

Rand Water abstracts water from the Vaal Dam and treats it at the Vereeniging and Zuikerbosch Purification and Primary Pumping Stations and then pumps it at a head of approximately 180 to 360 metres to the main Booster Pumping Station, Zwartkopjes and its three satellite Booster Pumping Stations, Palmiet, Eikenhof and Mapleton.

Each Booster Pumping Station then elevates the water a further 180 to 360 meters to reservoirs in and around Johannesburg. From these areas the water flows under gravity and is re-pumped at distribution stations to the extreme boundaries of the supply area.

The water is supplied through approximately 3 056 km of pipeline into 58 reservoirs. The core product is then delivered in bulk from the reservoirs to Rand Water’s customers: three metropolitan councils, 15 municipalities, the Royal Bafokeng administration, 45 mines and approximately 771 industries and direct consumers.

In the case of evaluating the supply for the City of Tshwane supply area, it is clear that the more important systems are the Zuikerbosch Purification and Primary Pumping Stations and the Palmiet and Mapleton Pump stations. Although there are some cross connections which could feed water from the Vereeniging treatment facility.

Rand Water's preparedness to deal with the effect of electricity disruptions on water supply is handled by a specialised unit referred to as Business Continuity. This division focuses on Rand Water’s continuous supply and various eventualities which could impact on its main function (it looks at water quality and quantity).

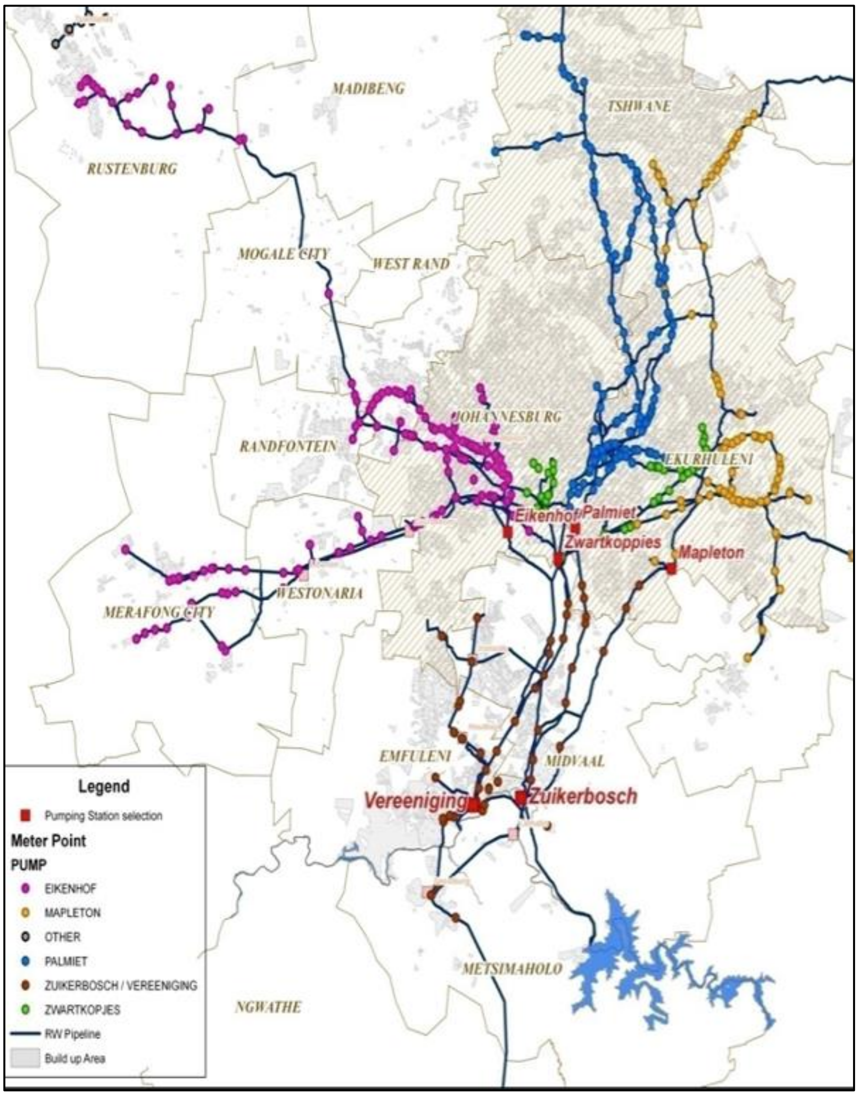

Figure 5-3: Rand Water bulk supply system layout (Mail and Guradian, 2014).

In March every year, Rand Water's management identifies and reviews major risks that the company will prioritise in the new financial year beginning in July. This is done through the process of risk assessment. Risks identified through this risk management process are prioritised based on probability and severity of the risk.

These risks are discussed and the responsibilities related to them get assigned to people that are most suited to manage them in terms of expertise and areas of responsibility. Mitigating strategies are designed and committed upon. The Risk Register is then taken through governance structures for approval. These structures include the Corporate Risk Committee and Portfolio Integrating Committee.

After approval by the Board of Rand Water (BRC), Management reports to the BRC on progress on the mitigation of risks in a meeting that is held quarterly. Thereafter, the Risk Report as well as any emerging or materialising risk is also discussed at the board meeting.

In the latest Rand Water Annual Report (Rand Water, 2016) twenty four risks were identified to have the potential of hindering achievement of Rand Water objectives in the period under review. A Strategic Risk Review Workshop was held, facilitated by an independent service provider and the following Top Ten Strategic Risks emanated from that process (see **Table 5-2**).

Table 5-2: The Rand Water top ten risk centres (Rand Water, 2016).

Risk number	Risk name
1	Availability, reliability, reliance and quality of electricity supply, critical spares and chemicals
2	Encroachment over pipeline, servitudes and properties
3	Non-revenue water in the Rand Water and municipal systems
4	Capacity to supply sufficient volumes / inability to supply potable water to clients
5	Failure to supply quality potable water
6	Business Continuity
7	Extended area of service and products
8	Credit Risk
9	Supply Chain Management / process
10	Health and Safety

Discussions with Rand Water indicated that policies are in place to deal with interruptions. These policies are however not just specifically focussed on electricity interruptions but cover basically all potential impacts on meeting RW's objective of supplying potable water. All the various failure scenarios or potential risk scenarios are, however, not identified in detail.

b) How can the impact be measured?

The focus of this study is on identifying and mitigating the risk to water supply posed by a disruption of electricity supply. Electrical power supply is important within the total water supply and distribution environment.

Power supply failures have different causes, such as power generation plant failures, distribution system faults, substation failures, blown transformers, faulty fuses, faulty breakers, lightning storms, natural disasters, etc.

The electricity utility industry commonly uses the Institute of Electrical and Electronics Engineering (IEEE) reliability indices to track and benchmark power supply reliability. The IEEE Standard 1366-2003 defines reliability indices to foster uniformity in the development of electricity distribution reporting practices by utilities (Eto, et al., 2008).

The recently completed NRS 048-8 specification provides the requirements for reporting the network interruption performance of high voltage and extra high voltage networks in the South African Electricity Supply Industry. The aim of the specification is to evaluate and track the overall performance of South African electricity supply systems (Chatterton, et al., 2009).

The two most frequently used indices are the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI) (Bollen, et al., 2006; Chatterton, et al., 2009; Jadrijev, et al., 2009). The SAIDI index gives information about the average time that supply to customers is interrupted during a period of one year, and it is commonly referred to as the customer minutes of interruption. The SAIFI index gives information about the average frequency of sustained interruptions per customer. Both these indices are normally reported over a time period of one year for a particular area.

c) Power Supply Reliability Measures

The characterisation of electricity supply performance is based upon the determination of the number of interruptions per year, as well as the sum of the duration of all interruptions during one year (Bollen et al., 2006). Network operators use different definitions to express power supply reliability.

Reliability of power supply is commonly measured making use of indices, such as amongst others, the SAIDI and SAIFI indices as defined by the Institute of Electrical and Electronics Engineering (IEEE).

To provide more detailed insight into the reliability of power supply of a bulk water supply utility, data collected by Rand Water from seven of its pump stations was obtained. Rand Water uses the term “trip” to define any failure of a pump unit to operate (irrespective of the cause).

Trips, in turn, are divided into internal and external trips (Fredericks, et al. 2007):

- An internal trip is caused by failure of direct components of the pump or motor (mechanical, electrical or structurally related). An internal trip can be overcome by utilising a standby pump unit; and
- An external trip is associated with failure of power supply to the pump station itself. As stated before, power supply failures have different causes, such as power generation plant failures, distribution system faults, substation failures, blown transformers, faulty fuses, faulty breakers, cable theft, lightning storms, natural disasters, etc.

As such, the reliability of supply considers their combined effect. In the event of an external trip, none of the duty and standby pump units affected will be operational.

The power supply failure data (external trips only) for seven of Rand Water's large pump stations (Mbula, 2008) were analysed and the results are summarised in **Table 5-3**. For strategic reasons, the names of the pump stations are omitted.

Over all the pump stations the average number of external trips was 11.4 per year, and the average duration of the external trips was 96 minutes. More recent failures resulted in longer durations which would increase the average outage.

Table 5-3: Rand Water distribution pump station power failure statistics (Mbula, 2008).

Pump station	External trip statistics				
	Year	Number of failure events	Minimum failure duration (minutes)	Average failure duration (minutes)	Maximum failure duration (minutes)
A	2005	15	7	113	767
	2006	37	2	110	1190
	2007	16	8	99	452
	Average	23	2	108	1190
B	2005	4	20	111	282
	2006	7	12	207	900
	2007	14	19	136	606
	Average	8	12	152	900
C	2005	13	1	88	475
	2006	9	1	126	855
	2007	5	15	55	95
	Average	9	1	94	855
D	2006	3	1	60	150
	2007	3	65	534	940
	Average	3	1	297	940
E	2005	11	2	80	190
	2006	11	15	54	108
	2007	19	1	63	248
	Average	14	1	65	248
F	2005	11	1	85	475
	2006	13	1	112	876
	2007	23	1	18	145
	Average	16	1	60	846
G	2005	3	30	78	135
	2006	6	25	34	60
	2007	5	20	84	180
	Average	5	20	62	180
All combined		**11,4**		**96**	

Nel and Haarhoff (2011) showed how the SAIDI and SAIFI indices can be used to determine the power supply availability, the power supply probability of failure, as well as the frequency of power supply failures at a point.

Data was obtained from a number of sources and used to benchmark the probable extent of power supply reliability. The probability of failure of power supply varied, but generally fell within a range of less than approximately 8.3 hours per year in developed countries. In South Africa, a developing country, the probability of failure of power supply is of the order of approximately 50 hours per year (Nel and Haarhoff, 2011). It should be noted that this average was affected by load shedding experienced since 2007.

The reliability of power supply from seven of Rand Water's (South Africa) pump stations was obtained and analysed, and it was noted that:

- The results suggest that the average number of power failure incidents was 11.4 per year and the lognormal distribution with base e and $\mu = 2.20$ and $\sigma = 0.70$ provided a good fit to the power failure incidents cumulative distribution function.
- The average duration of the power failures was 1.6 hours and the lognormal distribution with base e and $\mu = -0.61$ and $\sigma = 1.54$ provided a good fit to the power failure duration cumulative distribution function.
- A previous study on the duration of large-scale power failures in the USA also found the lognormal distribution to provide a good fit.
- The Rand Water pump station power failure data analysis for all pump stations combined suggests a probability of power failure of approximately 18 hours of non-supply per year, which is better than the South African national average of approximately 50 hours as reported by Nel and Haarhof (2011). The lower failure rate experienced by Rand Water might be due to a possible higher level of service related to power supply reliability provided to critical services authorities in South Africa.

5.1.4 Tshwane's preparedness

Tshwane's preparedness to deal with the effect of electricity disruptions on water supply is limited. The city has never performed a risk assessment that focusses on the risks posed by water supply interruptions and historically dealt with water supply disruptions situations as they occur. The city has a detailed Geographic Information System (GIS) which includes detail on the water, wastewater and electricity infrastructure.

A layout of Tshwane's bulk water distribution pipelines and reservoirs is illustrated in **Figure 5-4** (Loots, et al., 2014). This layout that was drawn using the city's IMQS system (a system which contains GIS-based information on the city's electricity, water and wastewater infrastructure).

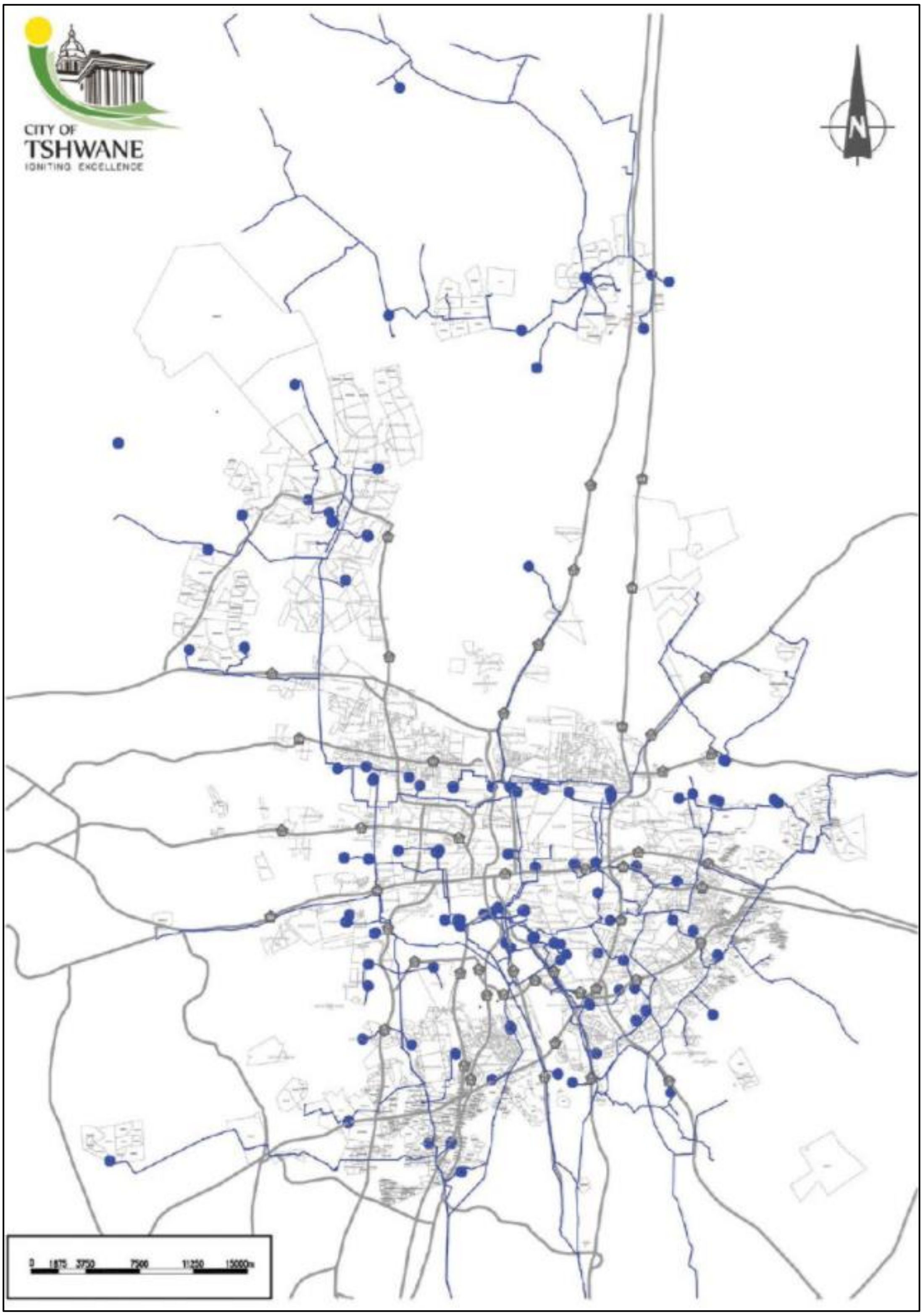

Figure 5-4: Layout of Tshwane's reservoirs and bulk distribution pipelines (Loots, et al., 2014).

When the influence of energy disruption on water supply is considered within the City of Tshwane, the design criteria need to be highlighted first followed by an assessment of how the status of the supply network and operational philosophy enhance the assured water supply. A summary of the design criteria which should be in place are:

- Demand in relation to the storage facility;
- What elevation needs to be overcome to get the water in the storage facility to be able to distribute under gravity;
- Interconnectivity of the water supply network;
- Interconnectivity of the electricity network;
- Interdependency identification of water and electricity; and
- Efficient use of the energy to deliver water to the storage facilities.

The City of Tshwane (now including Metsweding) receives Bulk water from Rand Water, Magalies Water and own sources including boreholes, water purification plants and fountains. Water is then distributed through a large water system that includes 166 reservoirs, 38 water towers and 10 677 km of pipelines of various diameter (GLS Consulting, 2017).

5.1.5 Institutional arrangements between key role players

The current institutional arrangements between Eskom, Rand Water and the City of Tshwane are extremely limited. The information obtained from the various role players seems to indicate that the various entities operate in silos. There are further complexities with Rand Water also being dependent on other entities such as Johannesburg's City Power and Ekurhuleni Municipality to maintain an uninterrupted power supply.

Although Rand Water and Eskom communicate in keeping the power supply to the critically important water purifications plants and pump stations uninterrupted the arrangements with other institutions are much less concrete.

5.2 BACKGROUND ON THE CITY OF TSHWANE

5.2.1 Introduction

In order to estimate the number of people whose water supply will be affected by an electricity disruption event it is necessary to know the city's population, its number of households, the city's water demand and the city's available water storage capacity as well as the co-dependence of the water and electricity networks.

Furthermore, the city's economic information is used to quantify the economic effect of water supply interruptions due to electricity disruptions. Some background on the city's economy is therefore also given.

According to the City of Tshwane's Integrated Development Plan for the period 2016 to 2021 the city had a population of 3 152 162 in 2015 (CoT, 2016). There are approximately 911 550 households in the City of Tshwane. Therefore the number of inhabitants per household in the City of Tshwane is approximately 3.5.

The City of Tshwane plays an important economic role in South Africa and Africa. The city accounts for approximately 28% of Gauteng's Gross Domestic Product (GDP) output and 10% of South Africa's GDP output. Furthermore, it is estimated that approximately 2% of Africa's GDP output can be attributed to the City of Tshwane. Gauteng's GDP in 2014 was R 720 billion and the City of Tshwane's 2014 GDP was R 202 billion (Tshwane Economic Development Agency, 2015).

Comparing this to the city's population indicate the importance of the City of Tshwane in terms of its economy into perspective, as is summarised in **Table 5-4**.

Table 5-4: The importance of the City of Tshwane's economy in South Africa and Africa (Statistics South Africa, 2016).

Comparison area	Tshwane contribution towards GDP	Percentage of total population
Gauteng	28%	23%
South Africa	10%	6%
Africa	2%	0.3%

The most important economic sectors in Tshwane are government-, social- and personal services sector followed by the finance- and business services sector. The city's various sectors' contribution to its economy is illustrated in **Figure 5-5**.

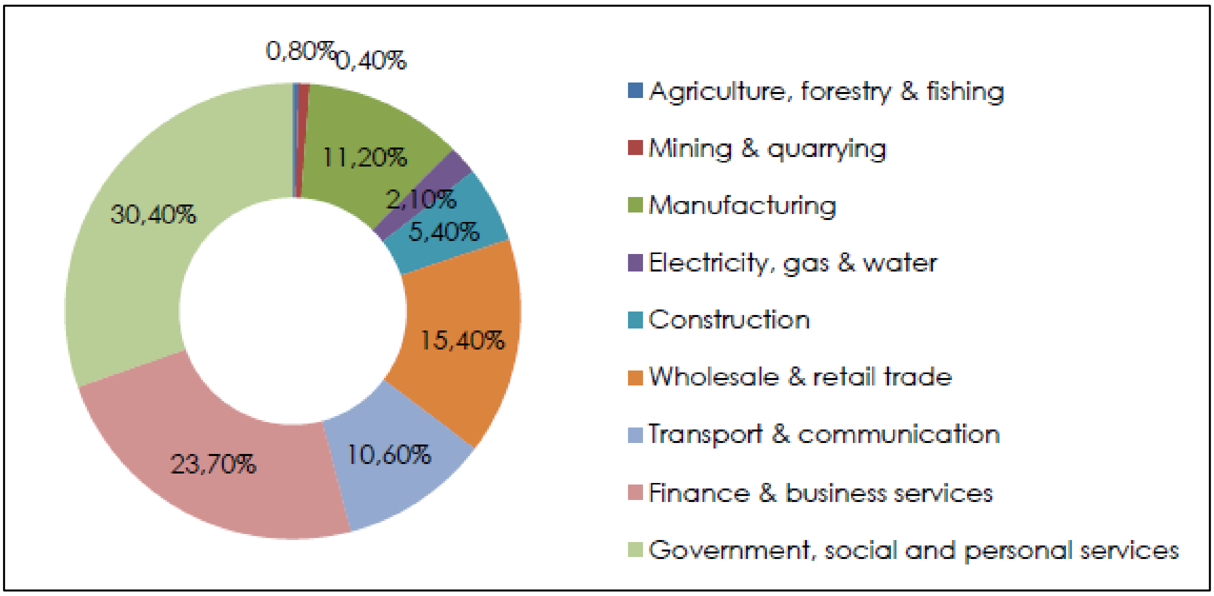

Figure 5-5: City of Tshwane's various sectors' contribution to its economy (Tshwane Economic Development Agency, 2015).

Although all of the sectors listed in **Figure 5-5** will be affected if water supply is interrupted as a result of an electricity disruption event, only a few sectors will be affected in such a way that their day to day economic activities can't continue. The effect that water supply interruptions will have on the various sectors' economic activity is summarised in **Table 5-5**.

Table 5-5: Effect of potable water supply interruptions on various sectors' economic activity.

Sector	Will sector's economic activity be affected?	Comment
Government, social and personal services	No	Social services including hospitals, clinics and the fire brigade won't be able to continue with their work if water supply is interrupted. Water is less important to these services in terms of economic activity and more important in terms of the service being delivered.
Finance and business services	No	
Wholesale and retail trade	No	

Sector	Will sector's economic activity be affected?	Comment
Manufacturing	Yes	Only if the specific industry requires potable water from the City of Tshwane (specifically wet industries).
Transport and communication	No	
Construction	Yes	Only if the construction activity requires potable water to continue construction (i.e. concrete mixing batch plants wetting soil for optimum compaction, dust control).
Electricity, gas and water	Yes	This sector is intrinsically linked to the topic of this case study (i.e. these industries will be the reason for the electricity disruption event or won't be able to supply water due to the disruption event).
Agriculture, forestry and fishing	No	The agriculture and forestry industries typically use raw water for their activities.
Mining and quarrying	No	Mining and quarrying activities will typically use raw water.

It should be noted that if an electricity disruption event affects a sector in such a way that its economic activities can't continue, the fact that it will not have water will not have any further economic effect on the sector's economic activity. The economic effect of water supply interruptions therefore only comes into play when economic activity can't continue as a result of the water supply interruption and the industry is not affected by the electricity disruption event[5].

5.2.2 The City of Tshwane's water demand

The City of Tshwane's current Average Annual Daily Demand (AADD) is approximately 843 Mℓ/day according to the latest City of Tshwane Bulk Water Supply Systems' Master Plan

[5] An example of this is where the industry has made provision for backup power generation facilities in the event of an electricity disruption but cannot continue with its day to day activities due to water supply interruptions also resulting from the electricity disruption event.

(GLS Consulting, 2017). According to the City of Tshwane's Annual Report for the 2014/2015 financial year (CoT, 2015a) the city's water demand by each sector is given in **Table 5-6**.

Table 5-6: City of Tshwane water use by sector (City of Tshwane, 2015a).

Sector	Agriculture	Forestry	Industrial	Domestic	Unaccounted for Water Losses	To neighbouring municipalities	Other
Percentage of water use	0%	0%	4.6%	53.2%	22.0%	7%	13.2%

Assuming that unaccounted for water losses are distributed evenly between Industrial, Domestic and Other water uses, the city's water demand per sector in Tshwane is therefore summarised in **Table 5-7** below.

Table 5-7: City of Tshwane water use by sector - simplified (City of Tshwane, 2015a).

Sector	Industrial	Domestic	Other*	Total
Percentage of water use	6.5%	75.0%	18.6%	**100%**
AADD per sector including losses (Mℓ/day)	55	632	157	**843**
AADD per sector excluding losses (Mℓ/day)**	42	487	121	**650**

Notes:

* It is assumed that "Other" water use includes commercial, municipal, government, education, health services and the construction sectors' water use.

** The city's total water losses of 193 Mℓ/day (refer to **Section 5.2.8**) are excluded for each sector's water demand as water losses are dealt with separately in some calculations in Section 6.5.

It is important to keep in mind that the city's water demand varies based on numerous variables, including:

- The day of the week;
- The season;
- The temperature; and
- The climate (i.e. precipitation / sunshine).

The 7-day peak demand in summer can typically be 1.5 times the AADD (CSIR, 2005). Winter off-peak periods' 7-day minimum demand can be as low as 0.65 of the AADD based on the outcome of a recent study done for the Mangaung Metropolitan Municipality in which 10-year's daily water demand in Bloemfontein was analysed (Bigen Africa, 2016a).

It should further be noted that an area's AADD is not an accurate measure of water demand if drastic water restrictions are imposed. Especially taking into consideration that if people are made aware of possible water supply interruptions they will probably disregard calls to use water sparingly and try to fill up all empty baths, sinks and bottles that they have to ensure that they have water for the first couple of days of the water supply interruption. What is even worse is that people will probably also continue to irrigate their gardens and fill their swimming pools (because they won't be able to do that once the taps run dry). Therefore, if water restrictions are not implemented and controlled effectively, it can result in water demand spikes.

a) CoT's Domestic water use

The current daily household water demand is on average 693 ℓ/household taking into account the city's current AADD and the fact that 75% of the city's AADD is for domestic use. Based on the city's population and its AADD the daily water demand per person is on average 200 ℓ/person.

Typical domestic water use in South Africa is illustrated in **Figure 5-6** below (Price, 2009). As can be seen, outdoor use of water (irrigation and swimming pools) generally makes up a quarter of total water demand in a residential area.

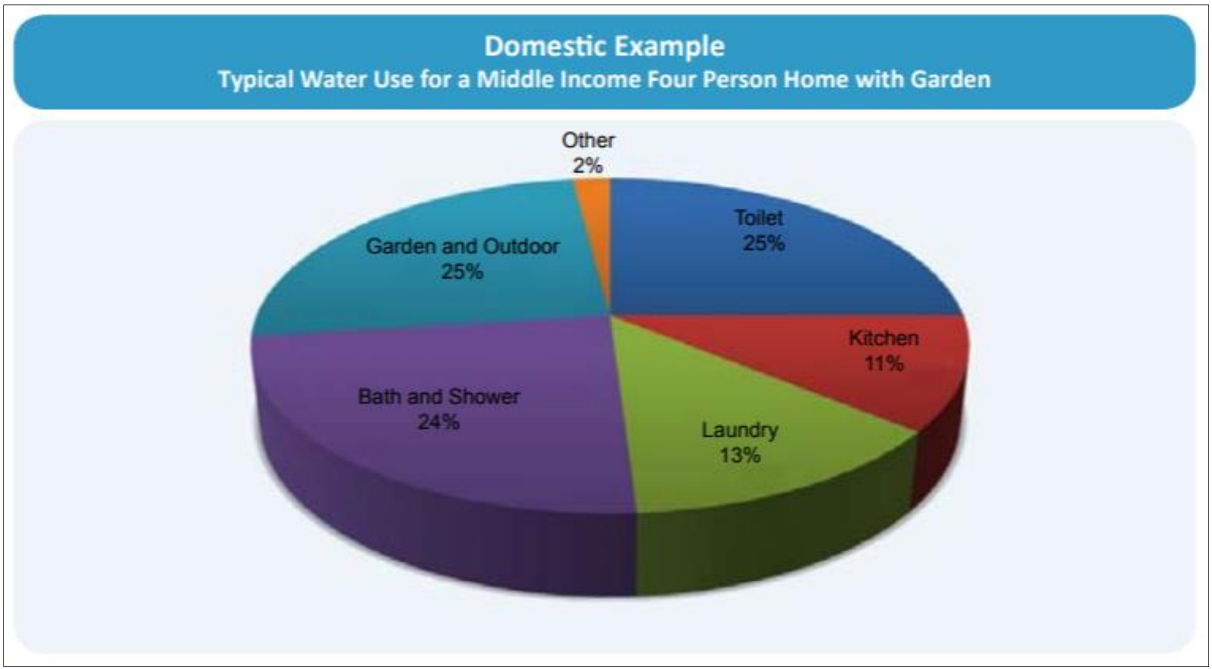

Figure 5-6: Typical domestic water use breakdown (Price, 2009).

b) Industrial water use and its impact on the economy

The city of Tshwane's industrial water demand is 55 Mℓ/day. Industries are classified as either dry- or wet-industries. Wet-industries require water as part of their production processes and will therefore be economically affected if water supply is interrupted.

As summarised in Section 5.2.1, the City of Tshwane's sectors that will be economically affected by water supply interruptions include Manufacturing and Construction. These industries account for 16.6% of the city's GDP of R 202 billion, or R 33.5 billion.

The industries that account for approximately 80% of the City of Tshwane's industrial water use include brewery, recycling, beverages, textile, and food manufacturing and canning industries. The proportional water use of these industries is illustrated in **Figure 5-7**.

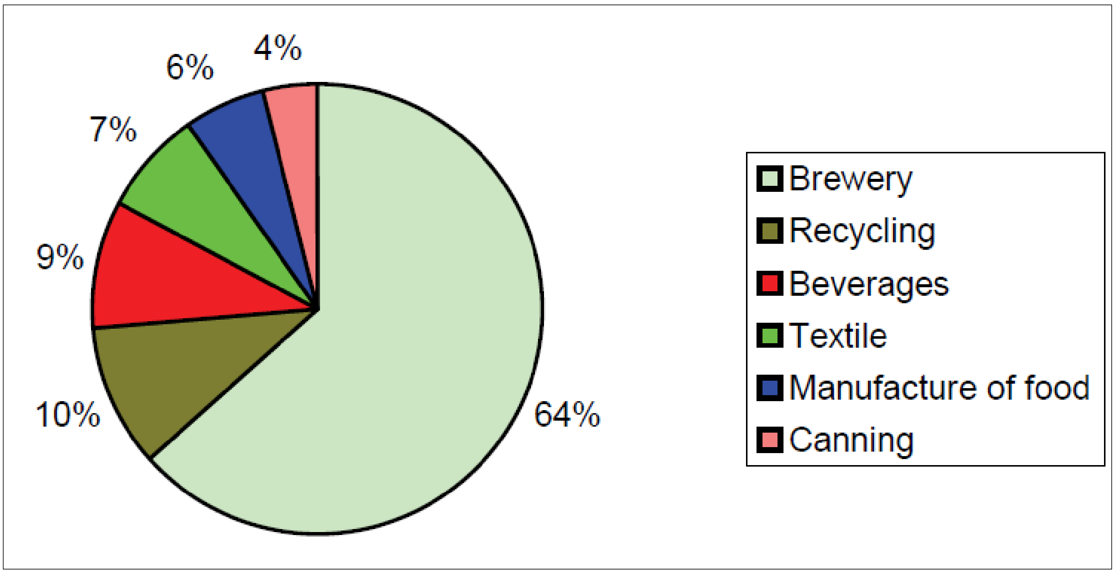

Figure 5-7: Top 80% water use industries in the City of Tshwane (Cloete, et al., 2010).

No additional information of the city's distribution between wet- and dry-industries could be obtained and further research on this field will be required. For the purpose of this study it is assumed that the 50% of the manufacturing sector (i.e. industrial water users) will be economically affected by water supply interruptions and that the part of the construction sector that will be economically affected by water supply interruptions is negligible. This is discussed in more detail in Section 6.5.4.

As discussed earlier, the manufacturing sector accounts for 11.2% of the city's economy, or R 22.6 billion per year. The worst case economic impact of water supply interruptions on the city's industrial sector will therefore be R 62 million per day of water supply interruption. For the purpose of this case study it is assumed that wet-industries are evenly distributed in the City of Tshwane for larger areas analysed as part of the Electricity Disruption Scenarios in Chapter 5 of this report.

This is only a rough estimate of the economic impact of water supply interruptions on the city's wet-industries and as stated above further research on this topic will be required in order to determine:

- Detailed water demand data of Tshwane's industrial sector, specifically the water demand of the city's wet- and dry-industries;
- The economic contribution of the city's industrial sector, specifically in terms of wet- and dry industries;

- Spatial distribution of the city’s industrial sector’s wet- and dry-industries – this information will be useful to identify areas where most wet-industries are located in order to accommodate these industries during water supply interruptions; and
- Data indicating how many of the city’s industries have backup power supply / generation facilities in place to continue operations in the event of electricity disruption events (specifically for wet-industries).

This additional information will be required to more accurately determine the economic impact of water supply interruptions due to electricity disruption events in the City of Tshwane.

c) “Other” water use

As stated above “other” water use includes commercial, municipal, government, education, health services and the construction sectors’ water use.

In a situation where water supply is interrupted due to an electricity disruption event, it will be crucial for these water-use sectors to decrease their water demand. The water demand of these sectors can be divided up into critical water demands and non-critical water demands.

Critical water demands include water for health services, water for the police and army to be able to perform their function, water for firefighting and water for laboratories and scientific research institutes that require it for their continued operation.

Non-critical water demands include water for commercial areas, retail areas and water for governmental and municipal use. This will typically be water for washing of floors and windows and water for irrigation. There will, however, be a minimum water demand for these sectors to continue with daily operations – if possible this minimum water demand for these sectors should still be supplied.

Detailed information on “other” water use sectors’ critical and non-critical water demand will be required in order to determine the minimum water demand for these users. This needs to be addressed in future studies. For the purpose of this study it is estimated that “other” water use can be decreased by 75% whilst ensuring critical water demands can still be supplied.

5.2.3 Emergency water supply

Emergency household water storage is a possible mitigation measure that can assist authorities greatly if a hazardous event results in water supply failures. There are various guidelines on the minimum volume of water that should be stored at a household for emergency use.

The Centre for Disease Control and Prevention (CDC) has guidelines for emergency water supply in case a disaster strikes. This emergency water supply is based on an absolute minimum daily water supply for drinking, cooking and basic hygiene. These are summarised in three steps (Centre for Disease Control and Prevention, 2016):

1) Determining how much water a household requires:

The volume of water to be stored for emergency use should be calculated as follows:

- A bare minimum of 4 ℓ of water per person per day for at least 3 days for drinking purposes (i.e. 12 ℓ per person);
- Water for cooking and personal hygiene; and
- Water for household pets.

It should be kept in mind that children, pregnant women, sick people and people living in hot climates will need more water.

2) Gather and store the emergency water supply:

Emergency water can be either pre-packaged bottled water (the safest option) or filled water containers. The following containers should be avoided:

- Containers that have held any poisonous substance;
- Containers that can break easily;
- Containers without a tight seal;
- Containers that can be hard to clean; and
- Containers that are made of plastics that can break down over time.

Stored emergency water should be replaced every 6 months.

3) Stay healthy and safe:

Some additional precautions highlighted by the CDC include:

- Stay hydrated (never drink less than the prescribed minimum volume of water to ration it - it will end in dehydration),

- Only drink clean water (if emergency stored water is finished, take steps to ensure that additional water obtained is as clean as possible before drinking it), and
- Protect the household (shut-off the household's erf connection valve to ensure that unsafe water cannot enter the home).

In terms of South Africa's proposed minimum water requirements as per the Council for Scientific and Industrial Development (CSIR), the minimum water requirement is 25 ℓ per person per day (CSIR, 2005).

These minimum water requirements proposed are set to sustain basic human life. However, it does not take into consideration additional water requirements to sustain economic, administrative, public health and safety activities in urban area’s industrial and commercial areas.

5.2.4 The City of Tshwane’s minimum water demand for household use

As was discussed in the above section the recommended minimum daily water supply is 25 ℓ per person per day (CSIR, 2005).

Based on this recommended minimum, the City of Tshwane with its population of about 3.2 million will require 80 Mℓ/day of potable water if all citizens are supplied with the recommended minimum. Supplying only this recommended minimum water to the city’s community would decrease the city’s demand by more than 90%. This decreased demand does not, however, take into account real water losses in the system (this is discussed in more detail in Section 5.2.8).

Supplying only the above minimum domestic water demand into the CoT will still result in a high risk for civil unrest and guaranteed economic loss due to water interruptions to wet industries and the city’s other economic sectors. Therefore, a basic minimum water supply during electricity disruption events that takes into consideration the cost vs. benefits of ensuring uninterrupted water supply is defined in Section 6.5.2.

5.2.5 The City of Tshwane’s water storage capacity

The City of Tshwane has 166 water storage reservoirs and ground level tanks with an average volume of approximately 11 Mℓ and a combined total volume of approximately 1877 Mℓ (GLS Consulting, 2017). Furthermore, the city has 38 elevated water storage towers with an average volume of approximately 342 kℓ and a combined total water storage volume of approximately 13 Mℓ (CoT, 2015b).

The total available (spare) water storage capacity of the city is an important parameter when developing alternative solutions in dealing with the effect of electricity disruptions on water supply.

The available water storage capacity is estimated for the City of Tshwane based on the assumptions made as discussed below.

The Guidelines for Human Settlement, Planning and Design (CSIR, 2005) recommends that reservoirs' water storage volume makes provision for the following as is illustrated in **Figure 5-8** below:

- The reservoir's fluctuation volume: storage volume to accommodate diurnal peak demands combined with summer peak demands – this is required to ensure that the reservoir level doesn't drop below the 2xAADD storage capacity as part of daily fluctuations;
- Two times the reservoir zone's AADD[6]; and
- Additional storage volume to accommodate fire water storage in accordance with the national standard SANS 10090 (SABS, 2003): Community Protection Against Fire.

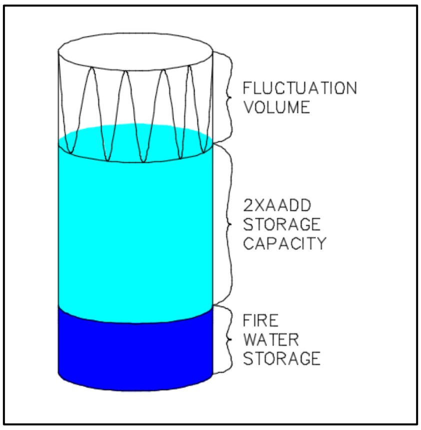

Figure 5-8: Reservoir sizing guidelines.

[6] This can be reduced to 1 day's AADD if the reservoir can be filled from multiple sources which will reduce the risk of water supply interruptions. This is, however not the case for the City of Tshwane's water sources as the bulk of its potable water is supplied from Rand Water. The possibility that all sources are dependent on electricity has also not been taken into account.

As stipulated in SANS 10090 (SABS, 2003) the fire water storage requirement is based on the fire risk category of the zone supplied by the reservoir. The fire water storage required in reservoirs for the various fire risk categories is summarised in **Table 5-8**.

Table 5-8: Fire water storage required (SABS, 2003).

Risk category	Flow required (ℓ/min)	Duration required (hours)	Fire water storage required (kℓ)
A	13000	4	3120
B	9000	4	2160
C	6000	2	720
D1	1900	2	228
D2	2850	2	342
D3	3800	2	456
D4	5700	2	684

The various fire risk categories are summarised in **Table 5-9**.

Table 5-9: Fire risk categories (SABS, 2003).

Fire risk categories	
A	Non-residential buildings having divisions not greater than 5000 m²
B	Non-residential buildings having divisions not greater than 2500 m²
C	Non-residential buildings not greater than 1250 m²
D1	Houses > 30 m
D2	Houses 10.1 to 30 m apart
D3	Houses 3- 10 m apart
D4	Houses < 3 m apart
E	As determined by risk assessment – to be defined by fire department

In order to determine the city's available water storage the following assumptions are made:

- Water storage reservoirs have an operational fluctuation volume of 10%[7];
- Elevated storage towers have an operational fluctuation volume of 20%[7];
- Operational rules to ensure that water levels in reservoirs and towers are adhered to and reservoirs and towers are only operated within their fluctuation volume;
- Reservoirs have a dead storage volume of 1%[7];
- Elevated towers have no dead storage volume;
- Water storage for fire water requirements is in terms of fire risk category C which equates to 720 kℓ of water storage per reservoir for fire water requirements; and

[7] Based on the percentage of the total reservoir and elevated tank storage volume.

- No provision for fire water storage is made in elevated towers since elevated towers are usually constructed next to / close to reservoirs from which they are supplied via pumps (i.e. it is assumed that towers zones' fire water storage required is also stored in the reservoirs from which they are supplied)[8].

Based on the assumptions above, the City of Tshwane's current AADD and the current number and volume of reservoirs and elevated towers, the city theoretically has approximately 1561 Mℓ or 1 day and 20 hours' worth of available water storage (assuming that reservoirs' fire water storage is not included as available storage capacity).

If reservoirs' fire water is also included as part of available water storage, the city has approximately 1681 Mℓ or 2 days' worth of available water storage. The risk of this approach is that if the municipal supply fails there will be no fire water available at hydrants to fill up fire engines' tanks in case of a fire.

The available water storage estimated above is for the City of Tshwane as a whole and does not compare specific reservoirs and/or towers with the zone(s) supplied from them. The outcome of a detailed comparison between each reservoir and tower and the zone(s) supplied from them will indicate that some reservoirs have a surplus (i.e. more than two days' AADD stored as available storage capacity) and others a shortage.

The exercise of comparing the city's total available water storage capacity with its demand gives a good indication of the period that water will be available in the event of an electricity disruption.

5.2.6 The city's water pipelines

The City of Tshwane has 10 505 km of bulk and distribution pipelines. The total volume of water in the city's water pipelines equates to approximately 456 Mℓ. In a critical water supply interruption situation, this volume of water can also be utilised to ensure citizens are supplied with water (GLS Consulting, 2017).

This will only be possible if the water can be accessed at local low points in the distribution network. Furthermore, emptying the city's bulk and distribution pipelines will mean that

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[8] This means that in order to be able to supply the elevated towers zones' minimum fire flow requirements during electricity disruption events backup power generation facilities are required at the pumps supplying the elevated towers.

polluted groundwater can infiltrate the water network if the city's pipelines are empty and the ground water table is above the pipelines. This will result in a water quality risk when water supply is resumed after the electricity disruption event.

5.2.7 Pump Stations in the City of Tshwane

There are 102 active pump stations in the city (GLS Consulting, 2017). Functions of the pump stations include (not including the functions of sewer pump stations):

- Raw water abstraction;
- Water treatment;
- Bulk water supply from the city's water treatment works;
- Distribution pump stations within the city;
- Network booster pump stations;
- Pump stations to fill elevated water towers; and
- Boreholes.

In order to gauge the importance of each of these pump stations in the event of an electricity disruption event, the following information will be crucial:

- The area supplied from the pump station;
- The power requirements of each pump station;
- The number of households served (or population served); and
- The primary function of each pump station (i.e. the level of service provided by each pump station[9]).

The abovementioned information is important in order to prioritise pump stations to be provided with backup power generation in case an electricity disruption affects the pump station. This information was not available at the time of this case study and will therefore have to be included in future studies.

5.2.8 Water losses in the City of Tshwane

This section gives an overview of the City of Tshwane's Water Conservation Demand Strategy (WCDS) and real water losses. Real water losses are the physical loses of water from a

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[9] It will be a lower priority to provide backup power generation to a network booster pump station ensuring municipal pressures in the network are maintained during peak demand periods than to provide backup power generation to a pump station filling reservoirs.

distribution system. Real losses increase the production and distribution costs of potable water and increase the stress on raw water resources (AWWA, 2017).

The city has a potable water System Input Volume (SIV) of 342 million m³ per annum (937 Mℓ/day). Non-Revenue Water (NRW) makes up approximately 25.7% of the SIV. Real losses account for 80% of the city's NRW and equates to 70 million m³ per annum (193 Mℓ/day) (COT, 2015b). Note that the System Input Volume of 937 Mℓ/day is not in line with the city's AADD of 843 Mℓ/day used in this report (referred to in **Section 5.2.2**). This discrepancy is briefly explained as follows:

Approximately 7% of the city's water is exported to neighbouring municipalities (or 66 Mℓ/day). The remaining part of the city's SIV is 870 Mℓ/day (this is 2015's data), referred to as the "WCDS AADD". Assuming a 1.5% water demand growth rate per annum the city's water 2017 WCDS AADD would have been 896 Mℓ/day. This is 6% higher than the "CoT AADD" of 843 Mℓ/day. The reason for the discrepancy is most probably due to the source of the data used for the AADD determination:

- The data source used for WCDS AADD determination is typically monthly bulk water sales invoices from Water Service Providers (WSPs) supplying water to the city (including bulk water supply from the city's own sources). Even accurately calibrated bulk flow meter readings can be out by a few percent. (If the meters are old and not maintained this can be even more).

- The data source used to determine the CoT AADD is GLS' Swift software, which statistically analyses the city's water users' monthly water demand to determine the theoretical AADD of the users. For users that are not billed monthly, the theoretical AADD of the water demand is calculated separately in accordance with provisions made in the Guidelines for Human Settlement, Planning and Design.

- Although either of the two AADDs listed above (the WCDS AADD of 896 Mℓ/day and the CoT AADD of 843 Mℓ/day) can be correct, the discrepancy between the two (of 6%) is deemed negligible and the CoT AADD was used for calculations in the report.

A problem with real water losses is that the losses will typically stay constant or increase if water demand drops due to the implementation of water restrictions due to the following reasons:

- The water level of reservoirs and elevated water towers will rise to the full storage level as demand decreases; and
- As demand decreases friction and secondary pressures losses in the distribution network will decrease and the subsequent physical losses will increase.

The result of this is that distribution zones' pressures will tend to increase towards the zones' static pressures and therefore increase the real water losses through leaks.

Losses will only start to decrease once the pressure in the system falls due to emptying reservoirs and water towers.

The City of Tshwane's current real loss volume as a percentage of its AADD is 23%. If 50% water restrictions are imposed effectively, the real loss volume as a percentage of the city's AADD will increase to ±46%. This means that if 50% water restrictions are imposed as a measure to mitigate the impact of electricity disruptions on water supply, approximately half of the water stored in the city's reservoirs and towers will be lost through real losses (i.e. leaks, connection losses, evaporation, etc.).

The city's total available water storage volume estimation described earlier of 1561 Mℓ/day and the average daily real water losses of 193 Mℓ/day are important parameters to keep in mind when identifying and developing measures to mitigate the impact of electricity disruptions on water supply.

It is imperative that the city (and the country) reduces its real water loss as there are numerous advantages to this, including:

- Less raw water used;
- Less energy consumed across the water sector (from raw water abstraction, treatment, distribution, wastewater treatment to discharge);
- A lower water bill for municipalities whilst keeping water sales revenue unchanged; and
- More effective water-use curtailment if water restrictions are imposed (important in this study).

To put the real loss in the city (at 23%) into perspective in terms of what can be achieved, real water losses in Israel is estimated at 10% nationwide (Kaye, 2017) whilst the real water loss rate in Dubai is 8.26% (Khaleej Times, 2017). Tshwane has the lowest real water losses of all metropolitan municipalities in South Africa (City of Tshwane, 2015). The national average real water losses is 25.4% (Mckenzie, et al., 2012).

5.2.9 The City of Tshwane's bulk water supply

The City of Tshwane is supplied with potable water from Rand Water, Magalies Water, its own sources and a few small-scale private suppliers.

The majority of the city's water is supplied from Rand Water. Approximately 81% of the city's water is supplied from Rand Water (±76%) and Magalies Water (±5%) (City of Tshwane, 2015). Rand Water therefore supplies an average of 641 Mℓ/day to the City of Tshwane based on the city's current AADD.

Magalies Water has three WTWs supplying water to the City of Tshwane (among others) including (Magalies Water, 2015):

- Klipdrift WTW (18 Mℓ/day);
- Cullinan WTW (16 Mℓ/day); and
- Wallmannsthal WTW (12 Mℓ/day).

Magalies Water's water treatment works supplying the City of Tshwane therefore has a total treatment capacity of 46 Mℓ/day.

The City of Tshwane has four large water treatment works, namely (GLS Consulting, 2017):

- Rietvlei WTW (40 Mℓ/day);
- Roodeplaat WTW (90 Mℓ/day);
- Temba WTW (60 Mℓ/day); and
- Bronkhorstspruit WTW (54 Mℓ/day).

The bulk water supply pipelines, bulk water supply from WSPs and the City of Tshwane's water treatment works are shown below in **Figure 5-9** (CoT, 2015c).

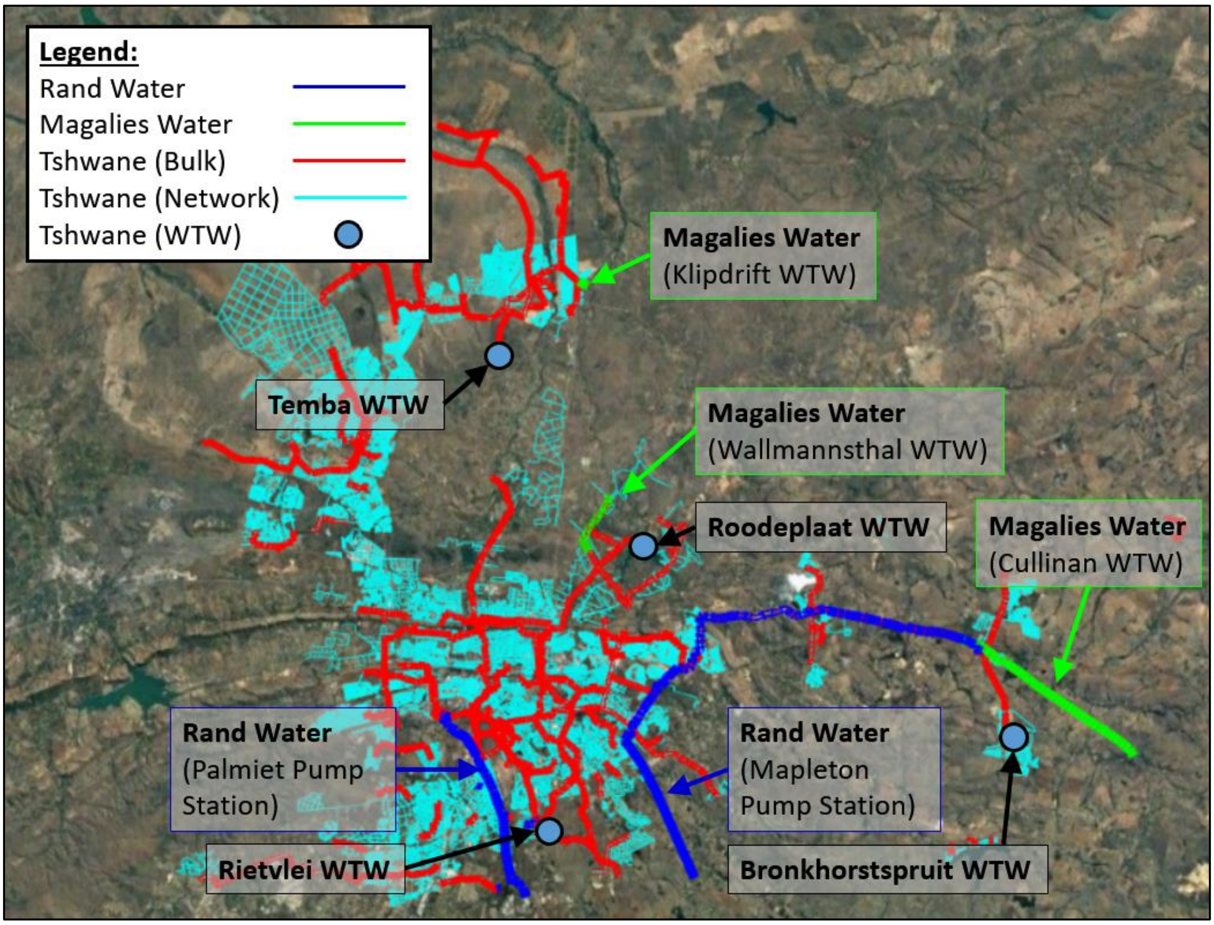

Figure 5-9: Location of the City of Tshwane's water treatment works.

There are also a few smaller water treatment works within the city's urban edge supplying approximately 1 Mℓ/day in total to the city's inhabitants. These water treatment works include the Kungwini Country Estate WTW, the Bronkhorstbaai WTW, the Summerplace WTW and the Aqua Vista WTW (GLS Consulting, 2017).

5.2.10 The City of Tshwane's wastewater treatment works

According to the Department of Water Affairs (now Department of Water and Sanitation) Masterplan for Gauteng Waste Water Treatment Works (DWS, 2017b; DWS, 2017c; DWS, 2014) the City of Tshwane has a total of 27 wastewater treatment works. The capacity of these wastewater treatment works is summarised below:

- The works have a total wet weather capacity of 1593 Mℓ/day; and
- The total biological capacity of the works is 692 Mℓ/day.

A summary of the City of Tshwane’s 10 largest wastewater treatment works is given below, these wastewater treatment works account for 86% of the city’s total wastewater treatment capacity (Department of Water Affairs, 2014):

1. Babelegi WWTW (2.3 Mℓ/day);
2. Temba (Klipdrift) WWTW (12.5 Mℓ/day),;
3. Rietgat WWTW (20 Mℓ/day);
4. Klipgat WWTW (55 Mℓ/day);
5. Sandspruit WWTW (20 Mℓ/day);
6. Rooiwal WWTW (220 Mℓ/day);
7. Zeekoegat WWTW (30 Mℓ/day);
8. Baviaanspoort WWTW (60 Mℓ/day);
9. Daspoort WWTW (55 Mℓ/day); and
10. Sunderland Ridge WWTW (95 Mℓ/day).

The locations of the City of Tshwane’s 10 largest wastewater treatment works are indicated in **Figure 5-10** (CoT, 2015c).

Figure 5-10: City of Tshwane's 10 largest wastewater treatment works (CoT, 2015c).

In terms of emergency storage capacity at wastewater treatment works a general rule of thumb is that 4-6 hours of emergency storage (attenuation) facilities are included as part of wastewater treatment works design (Slabbert, 2017). Furthermore, wastewater treatment works typically have standby generators on site although these generators are not normally big enough for the plant to continue operating at its design capacity. As part of the case study it is assumed that the City of Tshwane's wastewater treatment works have 6 hours of emergency storage capacity and no standby generators on site.

5.2.11 Eskom and the City of Tshwane's protection against electricity disruption

Information on Tshwane's internal electricity distribution infrastructure was obtained through a meeting with Tshwane's Divisional Head: Energy and Electricity. The information received was limited to a high-level overview of Tshwane's electricity supply and design standards.

Approximately 95% of Tshwane's electricity is supplied from Eskom. Electricity is supplied into the city via 7 infeed substations. Tshwane has two coal power stations that supply approximately 5% of the city's electricity, the Pretoria West – and Rooiwal Power Station (Maswanganyi, 2017).

The infeed substations are listed below (infeed voltage included in brackets) (CoT, 2011):

- Kwagga Station (275kV);
- Nyala Station (275kV);
- Rietvlei Station (132kV);
- Buffel Station (132kV);
- Mabopane Station (33kV);
- Hartebeespoort Station (33kV); and
- Hammanskraal (11kV).

The location of the infeed substations and the two power stations are illustrated on **Figure 5-11**.

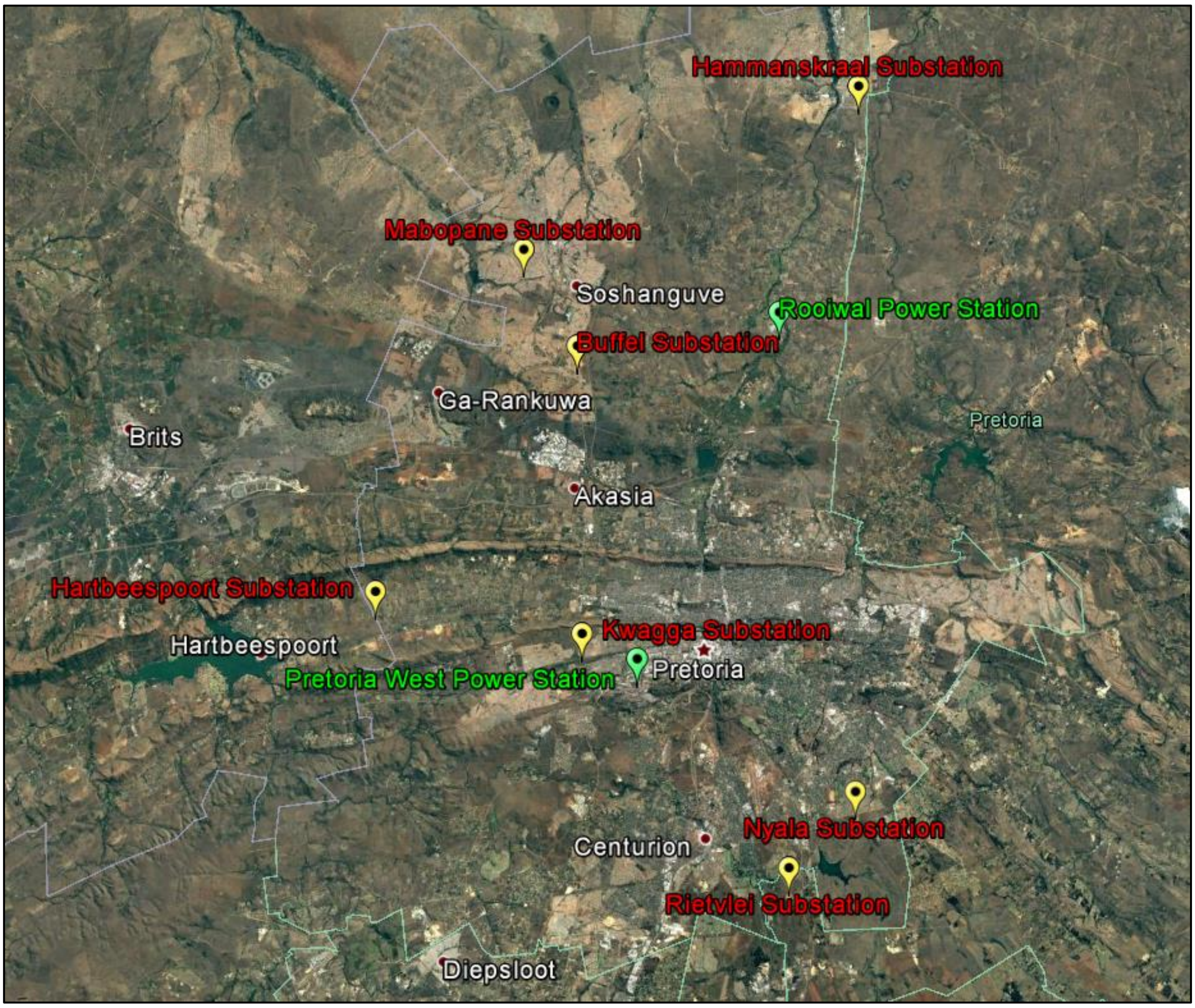

Figure 5-11: Locality map of Tshwane's infeed substations and power stations (CoT, 2011).

Approximately 50% of the city's electricity is supplied via the Kwagga Substation and 35% is supplied via the Nyala Substation. The remaining 10% supplied from infeed substations are supplied from the other 5 infeed stations (Maswanganyi, 2017).

If electricity supply to either the Kwagga or Nyala infeed stations is disrupted the city will not be able to maintain power supply to any of its industrial, commercial or domestic users. This is due to the fact that current load shedding protocols only allow for a maximum electricity demand load shedding of 30%. Therefore there will be a city-wide electricity disruption (blackout) if electricity supply to either of these two infeed stations is disrupted. To mitigate this risk, there are two Eskom electricity supply transmission lines (from two different points on the Eskom grid) that connect to these infeed substations.

At the main infeed substations the electricity supplied from Eskom is transformed from 275 kV to 132 kV (infeed substation with infeed voltages of 132 kV or higher). The electricity is then transformed from 132 kV to 11 kV at primary substations. Finally, the electricity is transformed from 11 kV to 380 V at satellite substations from which most domestic, commercial and industrial electricity connections are made.

Tshwane’s standard of bulk electricity distribution infrastructure is described below:

- Houses and most industries are electrified via a single electricity distribution line; therefore, if there is a fault on the transmission line (e.g. theft, power trip, vandalism or transmission line damage) there will be a electricity disruption to the area supplied;
- All of the city’s water and wastewater infrastructure that are dependent on electricity (e.g. pump stations, water- and wastewater treatment works) is electrified via radial ring transmission lines; if there is a transmission fault on the one side of the radial supply to the water or wastewater infrastructure the site can still be electrified from the other side of the radial transmission line (therefore at least one redundant electricity transmission line is always available in case of a transmission fault),
- Regional and national key points are always electrified with at least two redundant electricity transmission lines (i.e. there are always three functional transmission lines that electrify regional and national key points).

The current arrangements in place between Eskom and Tshwane to prevent damage to electricity infrastructure if an electricity disruption event occurs will have to be investigated in more detail as part of future studies. More detailed evaluation of Tshwane’s electricity distribution network will result in the identification of specific electricity disruption risks in the city. If this information is incorporated into the risk assessment; theoretical electricity disruption scenarios as were used for the Tshwane case study will not be necessary.

5.3 ESTIMATING THE COST OF INFRASTRUCTURE REQUIRED

This section summarises the cost of infrastructure required in order to mitigate the impact of electricity disruption on water supply.

5.3.1 Electricity requirements of water infrastructure

The electricity consumption range for the South African water supply chain is summarised in **Table 5-10** (Swartz, et al., 2013).

Table 5-10: Electricity consumption range for the South African water supply chain (Swartz, et al., 2013).

Process	Electricity consumption range (kWh/Mℓ)	
	Minimum	Maximum
Raw water abstraction	0	100
Water treatment	150	650
Water distribution	0	350
Water reticulation	0	350
Wastewater treatment	200	1800

It is estimated that the City of Tshwane's water treatment works require 600 kWh/Mℓ for raw water abstraction, water treatment and water distribution (supply into the city)[10]. This will however have to be determined individually for every water treatment works supplying the city.

Water supplied to the City of Tshwane from Rand Water's Vereeniging WTW and booster pump station is pumped a maximum head (static and friction head) of 319m from the Zuikerbosch Pump Station over the Witwatersrand Escarpment to the Vlakfontein Reservoir. CoT's minimum water demand of 423 Mℓ/day requires additional water supply (apart from its own WTWs' capacity of 244 Mℓ/day) from Rand Water if a City-wide electricity disruption event causes water supply interruptions. The minimum water supply in such an event is approximately 179 Mℓ/day (refer to Section 5.2.3).

Assuming a pump efficiency of 75%, supplying 179 Mℓ/day to CoT from Rand Water at a total head of 319 m will require 8.64 MW of power. Although the total head that water is pumped will be less than the maximum head of 319 m if supply volumes are decreased due to lower system friction and secondary losses, the conservative value of 8.6 MW is used for the cost-benefit analysis in Chapter 6.5. Assuming a 24 hour per day pumping time water supply from the Zuikerbosch WTW will therefore consume 1153 kWh/Mℓ.

Since raw water gravitates from the Vaal Dam to the Zuikerbosch WTW supplying Tshwane, raw water abstraction from Vaal Dam uses no electricity.

The purification cost for Rand Water's WTWs supplying Tshwane is estimated at the minimum value of 150 kWh/Mℓ for the electricity consumption range stated in **Table 5-10**. This minimum value is used as the raw water quality in the Vaal Dam and is considerably better than

[10] Total energy use is based on a breakdown of 50 kWh/Mℓ for raw water abstraction, 400 kWh/Mℓ for treatment and 150 kWh/Mℓ for water distribution.

that of the City of Tshwane's own sources. Furthermore, due to the size of the Zuikerbosch WTW (with a treatment capacity of 3200 Mℓ/day), water treatment will use considerably less electricity per unit of water treated than other smaller WTWs in South Africa due to the economies of scale of a very large WTW. The total electricity consumption for water supplied from Rand Water (i.e. treatment and supply) therefore equates to 1303 kWh/Mℓ.

More detailed wastewater treatment works electricity consumption rates (in kWh/Mℓ) are given for various types of wastewater treatment works in South Africa in **Figure 5-12** below (Scheepers & van der Merwe-Botha, 2013).

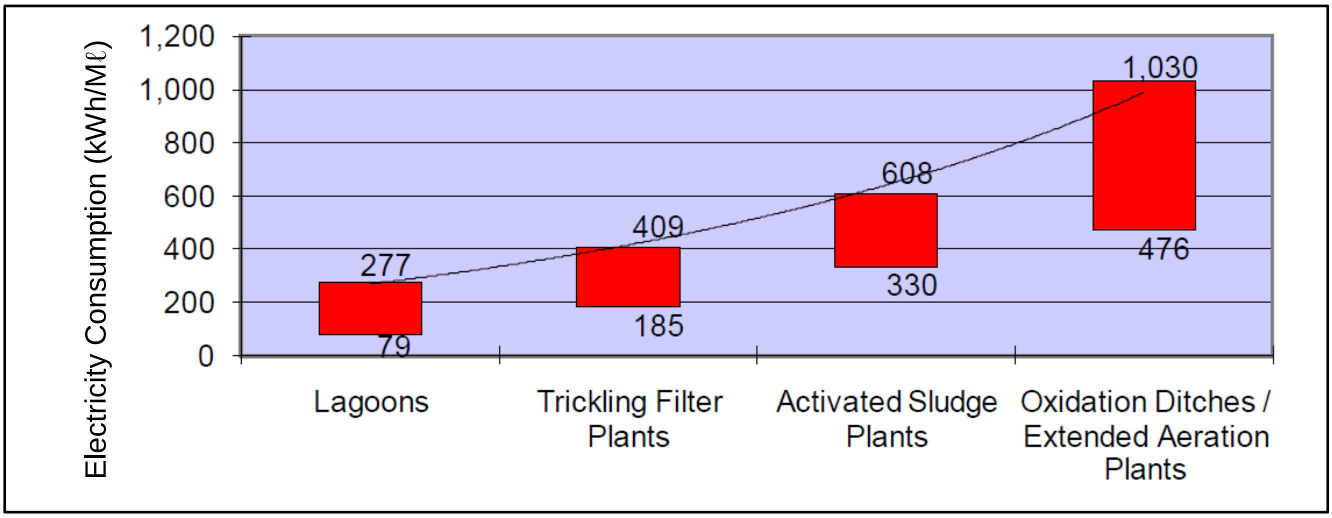

Figure 5-12: Electricity consumption rates for various types of wastewater treatment works (Scheepers & van der Merwe-Botha, 2013).

It is assumed that all wastewater treatment works in Tshwane have electricity consumption rates comparable to that of Activated Sludge Plants for the purpose of this Case Study. It was assumed that the city's wastewater treatment works require 500 kWh/Mℓ for backup power generation - this needs to be confirmed from Tshwane for each of its wastewater treatment works in future studies if the recommendations in this study are implemented.

According to Musvoto & Ikumi (2016) the average annual flow recorded in 2014 at the Zeekoegat WWTW was 67.6 Mℓ/day (24.7 thousand Mℓ during 2014). The total electricity consumption during 2014 at the plant was approximately 11,2 thousand kWh. Therefore, the electricity consumption at the Zeekoegat WWTW was 455 kWh/Mℓ. The value used for the calculations of the case study scenarios analyses and cost vs. benefit analysis (500kWh/Mℓ) was therefore left unchanged as it is conservative and leaves some room for error if some of the other WWTWs use more than the assumed 500 kWh/Mℓ.

The total estimated electricity consumption for water treatment, supply, distribution and wastewater treatment in Tshwane equates to roughly 1400 kWh/Mℓ. This was calculated taking the following into consideration:

- Tshwane's reduced water demand during electricity disruption events of 423 Mℓ/day;
- The weighted average for electricity consumption for water supplied from Tshwane's own sources (244 Mℓ/day at 600 kWh/Mℓ) and Rand Water's treatment plants (179 Mℓ/day at 1303 kWh/Mℓ) was calculated to be roughly 900 kWh/Mℓ; and
- The assumed wastewater treatment electricity consumption value of 500 kWh/Mℓ.

Tshwane's electricity consumption for the water supply (900 kWh/Mℓ) and the water cycle as a whole for (1400 kWh/Mℓ) was compared to electricity consumption values for other cities determined as part of comparable studies. This was done to gauge the accuracy of the value used in the case study.

The electricity consumption for Tshwane's water supply based on the reduced water supply volume (423 Mℓ/day) was compared to other cities' water supply electricity consumption (Lam, Kenway & Lant, 2017). This comparison is illustrated in **Figure 5-13**. The electricity consumption of Tshwane is relatively high (at 900 kWh/Mℓ), this is probably due to the high pumping head of water supplied to Tshwane from Rand Water. The electricity consumption value of Tshwane's water supply is, however, assumed to be within an acceptable range compared to other cities and was therefore used in calculations of the case study scenarios analysed and the cost vs. benefit analysis.

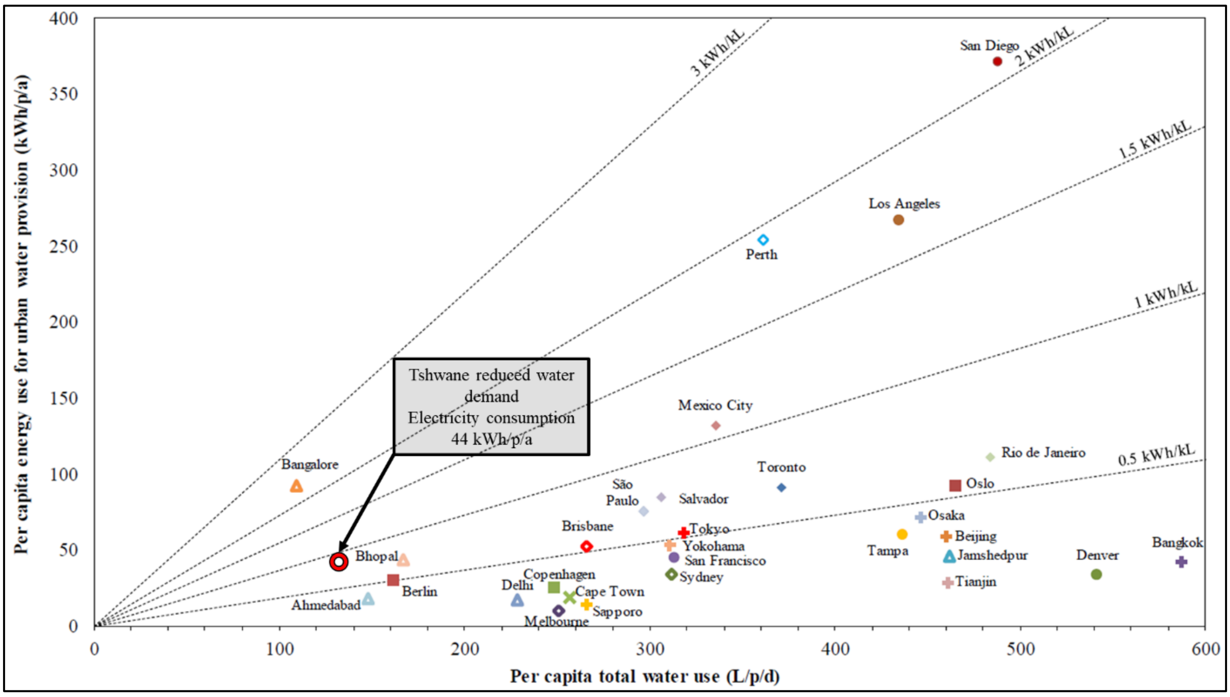

Figure 5-13: Tshwane's water supply electricity consumption compared to 30 large cities (Lam, Kenway & Lant, 2017).

The electricity consumption range for the total water cycle was determined for the following urban areas by Plappaly and Lienhard (2012):

- The water cycle in Ontario consumes between 1410 kWh/Mℓ and 2420 kWh/Mℓ of electricity;
- California’s electricity consumption for its water cycle ranges from 668 kWh/Mℓ to 1508 kWh/Mℓ; and
- The electricity consumption of the water cycle of metropolitan areas in Australia is between 890 kWh/Mℓ and 2350 kWh/Mℓ.

The electricity consumption for Tshwane’s water cycle as a whole is comparable to the values determined as part of comparable studies.

5.3.2 Backup power generation

Backup power generation is one way to mitigate the impact of electricity disruptions on water supply. It is required throughout the water sector, from water treatment works and distribution to wastewater treatment.

For the purpose of determining the cost of backup power generation capacity, only the cost of diesel backup power generators were considered and used for the cost vs. benefit analysis.

However, various other backup power supply options could prove more feasible for certain applications such as solar power or backup battery power supply systems. Further investigation into backup power supply options to mitigate the impact of electricity disruptions on water supply may conclude that, for various applications, different types of backup power supply may be the most cost effective. For example, providing solar panels with backup battery systems could prove more cost effective at elevated water tower pump stations considering that the pump supplying these reservoirs typically do not use too much power (e.g. less than 50kW at certain sites).

Considering that alternative power supply options can be used as a primary power source if designed and installed correctly, makes alternative power supply options even more attractive. The cost effectiveness of various backup power supply options should be considered at the preliminary design stage of designing backup power generation for various applications.

The cost of backup power generation is based on two factors. Firstly, the cost of generation infrastructure (the capital cost) which is based on the diesel generator's capacity and secondly, the operational cost of the generator when it is in use (mostly diesel).

Based on a study by Foster and Steinbuks (2009) the cost of generation capacity for generators smaller than 1 MW was approximately US$ 600 per kW in 2005. Based on the United States historical inflation rates the cost of generation capacity in Net Present Value (NPV) is US$ 753 per kW (CoinNews Media Group LLC, 2015).

The cost of backup power generators with a capacity of less than 1 MW in Rand (NPV) based on the current Rand / US$ exchange rate of R 12.97/$ (24 July 2017) is therefore R 9 766.41 per kW.

The cost of backup power generators listed above (R 9 766.41 per kW) was compared to more up to date prices from a South African electricity generator supplier (New Way Power (Pty) Ltd, 2017). Based on the updated prices received the cost of supply and installation of a backup power generator in South Africa is approximately R 6 710 per kW[11]. This cost is probably lower than the cost from the Foster and Steinbuks (2009) study due to technological advances in the electricity generation sector in the past 8 years since the Foster and Steinbuks study was completed.

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[11] Including installation and electrical engineering consulting fees.

The more conservative cost of backup electricity generators as determined from the Foster and Steinbuks (2009) study was, however, used in the calculations of the case study scenarios analyses and cost vs. benefit analysis. As will be seen in the outcome of the cost vs. benefit analysis in Section 6.5, this does not affect the outcome of the cost vs. benefit analysis.

The operating cost of generators is based on the fuel efficiency of generators. The fuel efficiency of generators smaller than 1 MW is approximately 0.45 ℓ/kWh. Based on the current diesel price of R 10.98/ℓ (AASA, 2017) the operational cost of standby electricity generators is therefore approximately R 4.94 per kWh.

The cost of permanent on site backup power generation (a) and mobile backup power generation (b) is summarised below.

a) Permanent on-site backup power generation

On-site (permanent) backup power generators can be installed at critical pump stations in Tshwane or at the pump stations of Water Service Providers (Rand Water and Magalies Water) supplying potable water to the city.

Backup power generators will also be required at sewer pump stations in the city's sewer network and at pump stations supplying elevated water towers with water from larger ground level reservoirs.

The cost of on-site backup power generators for water distribution was assumed to be R 9'766 per kW of generation capacity as discussed above.

On-site backup power generation capacity for water distribution is calculated based on the following equation:

$$P = \frac{pgHQ}{n} \qquad \text{(Equation 3)}$$

Where:

- P is the hydraulic power required (in kW);
- p is the density of water (assumed as 1000 kg/m³);
- g is gravitational acceleration (assumed as 9.81 m/s²);
- H is the differential head that the water is pumped (m);

- Q is the flow required (m³/s); and
- n is the pump efficiency (assumed as 75%).

Permanent on-site backup power generators will require servicing and maintenance, for instance:

- Generators will have to be serviced annually;
- Fuel in the generators' tanks will have to be changed every six months if the generators were not in use; and
- The generators will have to be started up every two weeks (or in accordance with their manufacturers recommendation) to ensure continuous operation.

Installing permanent on-site backup power generators will therefore also place an administrative burden on the municipality's technical division. The servicing and maintenance of the generators will also have a yearly financial implication.

b) Mobile backup power generation

Mobile backup power generators can be an effective tool to mitigate the impact of isolated electricity disruption events on water supply. It may be worthwhile to purchase mobile generators based on the budget available to ensure water can be distributed to the city's reservoirs and elevated towers in the event of an electricity disruption event.

The cost of a 250 kVA (200kW) generator is R 366 000 (Maverick Generators, 2017) and a 5 ton flatbed truck to transport the generator to various sites is R 548 000 (Isuzu Trucks, 2017). The total cost of backup mobile generator sets equates to R 914 000.

Mobile backup power generators will require the same service and maintenance as permanent (on-site) backup power generators. However, since these generators are mobile, it will be easier to service and maintain these generators as all mobile generators can be serviced at a central location.

5.3.3 Additional potable water storage capacity

Additional storage capacity will be required in all cases where reservoirs and elevated water towers' available storage capacity is insufficient to supply 2 days' AADD for this study. This is due to the fact that for large-area electricity disruption events, it is assumed that water supply to all water treatment works supplying Tshwane will be affected, emphasising the need for at least 48 hours of available water storage at AADD.

The cost of new reservoirs is based on the values used in the latest City of Tshwane's Water System Master Plan and is illustrated in **Figure 5-14** (GLS Consulting, 2017).

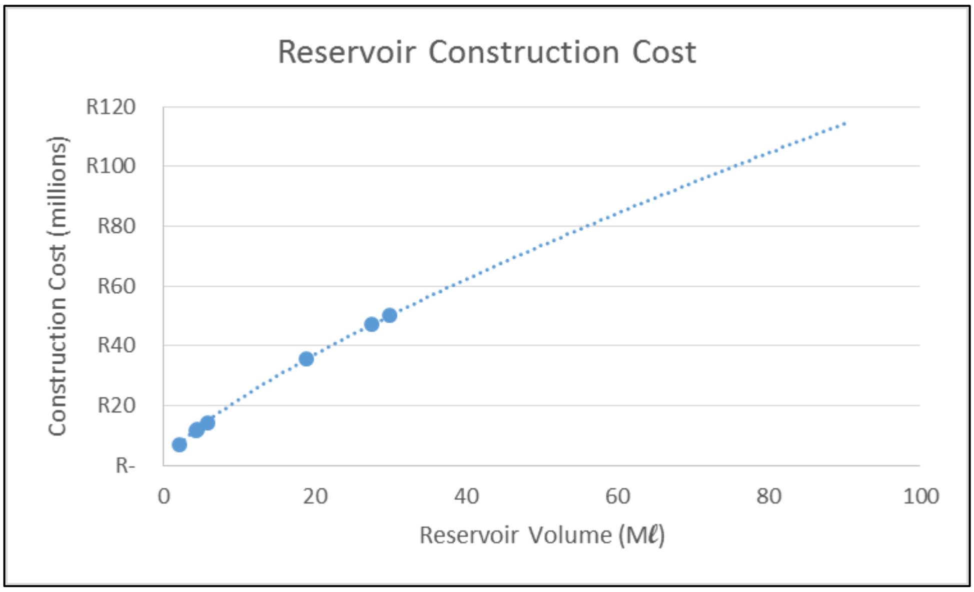

Figure 5-14: New reservoirs construction cost (GLS Consulting, 2017).

It is estimated that the construction cost of elevated water towers costs R 5 million per Mℓ. This is based on the construction cost of elevated towers recently constructed (Bigen Africa, 2016b).

5.3.4 Additional emergency storage capacity for wastewater

Temporary storage capacity for wastewater to prevent spillages at municipal pump stations is an alternative to on-site backup power generation. Especially if the electricity disruption event planned for is of a short-duration (less than one day). Emergency wastewater storage capacity comprises open dams that are typically concrete lined. These concrete-lined dams cost approximately R 490 000 per Mℓ. This is unit cost is based on the following rates:

- Excavation and spoiling of excavated material rate of R 300 per m^3; and
- Steel mesh-reinforced concrete rate of R 2500 per m^3.

The restriction in terms of emergency storage capacity for wastewater is generally available land. For instance, a medium sized wastewater treatment works such as the Baviaanspoort WWTW with a capacity of 60 Mℓ/day will require an emergency storage pond with a floor area of approximately 40 000 m² (200 m x 200 m x 1.5 m deep) for only one day's emergency storage capacity. It will therefore probably not be possible to provide emergency wastewater storage capacity for electricity disruption events longer than a day (especially considering that open space is generally not available at existing wastewater treatment works).

5.3.5 New pipelines

The cost of additional water conveyance infrastructure was derived from the Guidelines for Infrastructure Asset Management in Local Government for 2006 to 2009 (DPLG, 2009). These guidelines were developed in accordance with best practice asset management standards as depicted in the International Infrastructure Asset Management Manual (NAMS & IPWEA, 2011). The rates from the DPLG (2009) were verified using more up to date steel pipeline construction cost estimates based on recently completed water pipeline construction projects (Bigen Africa, 2014).

The cost of installing new steel pipelines is illustrated in **Figure 5-15** (DPLG, 2009; Bigen Africa, 2014)[12].

12 The Guideline's 2005 costs were escalated in line with South Africa's historical inflation rate to get the construction cost of new steel pipelines in NPV.

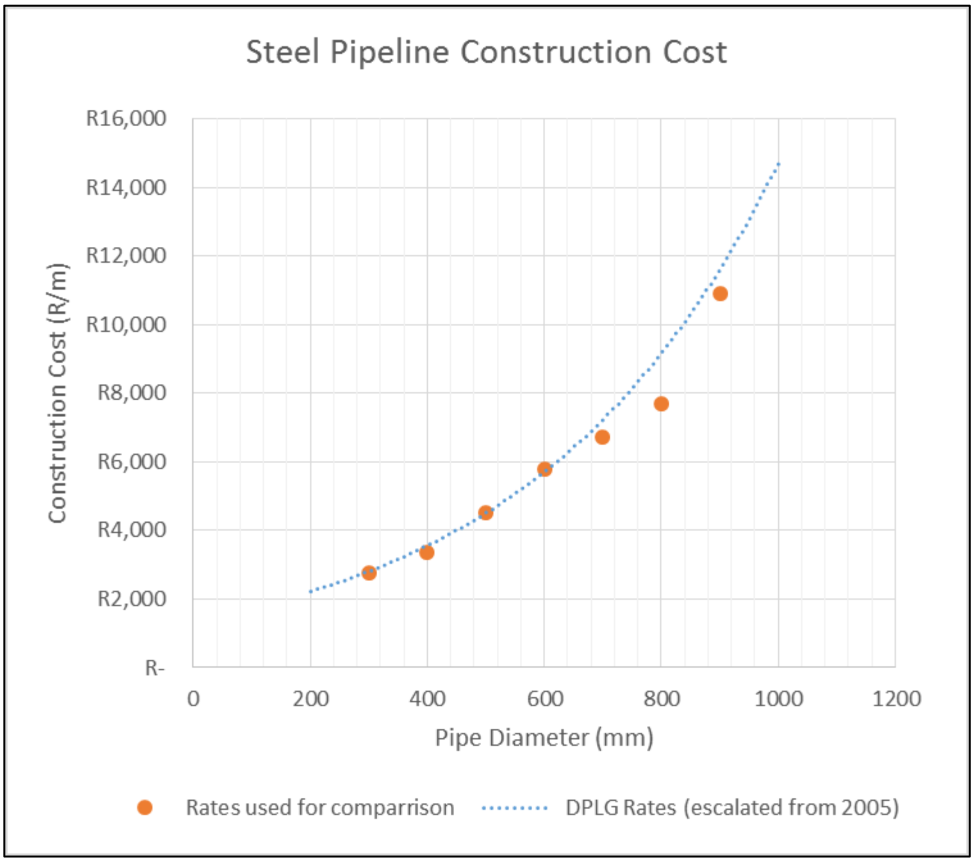

Figure 5-15: New steel pipelines construction cost (DPLG, 2009; Bigen Africa, 2014).

5.3.6 Cost of water tankers

In order to be able to ensure continuous supply of potable water to the community during water supply interruptions caused by electricity disruptions, it will be necessary to have water tankers available on stand-by.

The cost of a second-hand 16 000 ℓ water tanker is R 600 000 (Truck & Trailer, 2017). The cost of a new water tanker is estimated at R 1 million.

5.3.7 Summary of costs

The estimated costs of various types of infrastructure used for the case study's cost vs. benefit analysis is summarised in **Table 5-11**.

Table 5-11: Summary of costs for various types of infrastructure required.

Type of infrastructure	Cost	Comment
Permanent backup power generation	R 9 766.41 per kW	Assumed that the price of backup power generation will increase with the size of the generator (i.e. no economies of scale assumed)
Operational costs of standby generators	R 4.94 per kWh	
Mobile backup power generator	R 914 000	For a 250 kVA (200kW) generator
Additional potable water storage	R 1.9 million per Mℓ	Varies slightly due to economies of scale
Elevated water towers	R 5 million per Mℓ	
Emergency storage for WWTW	R 0.49 million per Mℓ	
New pipelines	Varies	Varies for different pipe diameters.
Cost of water tankers	R 1 million	16 000 ℓ water tanker

6 TESTING RAMFIWES – CITY OF TSWHANE CASE STUDY

6.1 TESTING RAMFIWES AND OUTLINE OF CASE STUDY

The part of RAMFIWES that was tested on the Tshwane case study is illustrated in **Figure 6-1**. Only the part of RAMFIWES that deals with Water Service Providers and Water Service Authorities' risk analaysis, evaluation and mitigation could be tested.

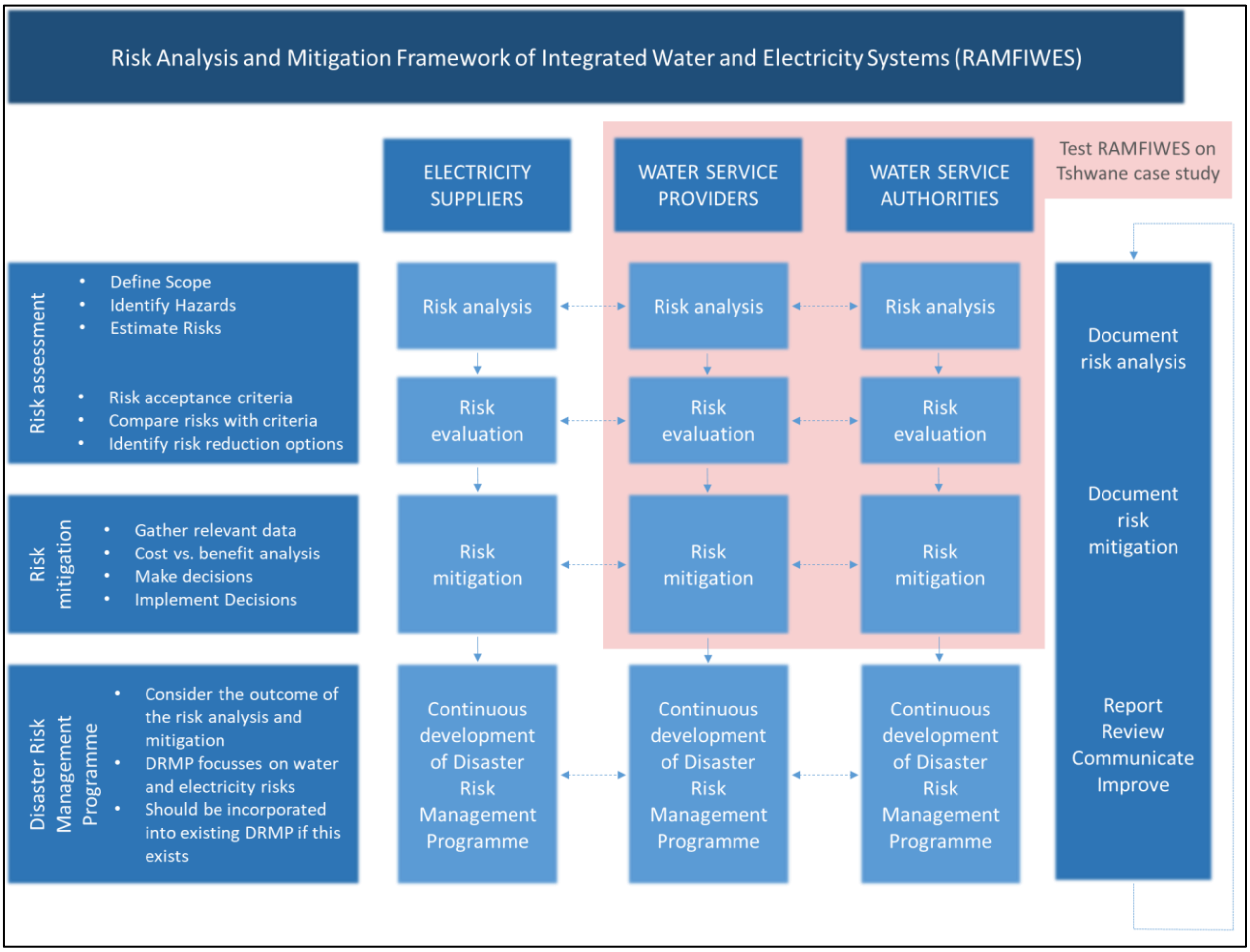

Figure 6-1: Testing RAMFIWES on the City of Tshwane case study.

6.2 CASE STUDY RISK ANALYSIS

This section describes the risk analysis and evaluation done as part of the Tshwane Case Study. The framework developed and discussed earlier in this report (RAMFIWES) was used to conduct the risk analysis and evaluation.

The risk analysis and evaluation steps are summarised in **Figure 6-2** and is in line with the risk assessment guidelines developed as part of RAMFIWES.

Risk analysis

- Defining the scope and objective of the risk analysis
- Identifying hazards and hazardous events,
- Estimating the probability and consequences of identified hazards and hazardous events.

Risk evaluation

- Defining risk acceptance criteria
- Distinguishing between acceptable risks and unacceptable risks
- Prioritising risks to be mitigated

Figure 6-2: Risk analysis and evaluation conducted as part of the case study.

6.2.1 Scope of the risk analysis

The first step of the risk analysis is to define the scope of the risk analysis. This risk analysis was conducted by the study team of the WRC project, although the inputs of the various stakeholders at the project's feedback meetings were taken into consideration as part of the Case Study risk analysis.

The scope of the risk analysis is described below and was defined by determining the objective of the risk analysis (a), specifying what the analysis included (b) and which dimensions of risks were analysed (c).

a) The objective of the risk analysis

The objective of the risk analysis is to identify, analyse and evaluate all conceivable risks resulting from electricity disruption events that impact water supply to the City of Tshwane's consumers.

b) The risk analysis included the following:

Risks to water supply and/ or water quality associated with all types of electricity disruption events:

- Short-term (e.g. load shedding);
- Medium-term (e.g. distribution failure); and
- Long-term (e.g. blackout).

c) The following dimensions of risks were analysed:

In terms of water quantity:

- Frequency of water supply interruptions (i.e. probability);
- Duration of interruptions; and
- Number of consumers affected.

In terms of water quality:

- Probability of treatment system failure; and
- Number of consumers affected.

Table 6-1 describes the components of the system that were analysed. The system described below is limited to components that form part of the scope of the risk analysis, including:

- System components that have an effect on electricity disruptions (i.e. electricity infrastructure); and
- System components that are affected by electricity disruptions (i.e. water infrastructure and water end-users).

Table 6-1: System components that form part of the risk analysis.

Component	Sub-component	Function	Boundaries of the system identified
Electricity generation infrastructure	Resources to generate electricity	Required for electricity generation	Generation infrastructure supplying the City of Tshwane (CoT): Eskom
	Power stations	Electricity generation	
Electricity distribution infrastructure	Bulk distribution networks	Electricity distribution	Distribution infrastructure supplying the CoT: Eskom
	Distribution stations	Electricity distribution	
	Sub stations	Electricity distribution	

Component	Sub-component	Function	Boundaries of the system identified
	Control Room	Control and Monitoring	
Electricity distribution infrastructure within CoT	Distribution networks	Electricity distribution	Electricity distribution infrastructure within CoT: CoT Electricity Department
	Sub-stations	Electricity distribution	
	Control room	Electricity distribution	
Water Treatment Works	Raw water abstraction	Required for water treatment	WTWs supplying the CoT: Rand Water, Magalies Water and CoT's WTWs
	Water treatment	Water Treatment	
	Bulk water supply pump stations	Water supply into CoT	
	Bulk water supply pipelines	Water supply into CoT	
Water supply and distribution infrastructure	Reservoirs	Provides additional storage capacity for water in case of water supply interruptions	Rand Water's and CoT's reservoirs providing storage capacity to the CoT
	Water distribution pipelines	Water distribution within CoT	CoT's water distribution pipelines
	Water distribution pump stations	Water distribution within CoT	Pump stations distributing water in CoT's
Water end-users		Residential, commercial and industrial end-users of water in the City of Tshwane	Population of approximately 3.1 million (±911 500 households) (City of Tshwane, 2016).
Wastewater	Sewer pump stations	Conveys sewerage to WWTWs	CoT's sewer pump stations
	WWTW	Treats sewerage to required quality	CoT's WWTWs

6.2.2 Identifying hazards and hazardous events

This section describes hazards and hazardous events associated with short-, medium- and long-term electricity disruptions. Risks emanating from hazards and hazardous events identified are also described.

Table 6-2 describes hazards / hazardous events emanating from short-term electricity supply disruptions (i.e. disruptions less than one day long).

Table 6-2: Hazards / hazardous events emanating from short-term electricity disruptions.

Hazard / hazardous event	Hazard / hazardous event description	Risks associated with hazard / hazardous event
Load shedding	Low frequency load shedding	• Water supply to reservoirs interrupted < 1 day • Water supply to pressure towers interrupted < 1 day • High lying areas supplied by booster pump systems without water • WTWs without backup power cannot continue to operate • Pump stations without backup power cannot continue to operate • WWTWs without backup power cannot continue to operate (wastewater spills) • Wastewater pump stations without backup power generation cannot continue to operate (wastewater spills) • If adequate warning is not given this can result in damage to water infrastructure (water hammer, pump trips, etc.) • Affected population without water < 1 day
	High frequency load shedding	
Planned activities resulting in electricity disruptions	Planned maintenance	
	Scheduled upgrading, refurbishment or construction activities	
Unplanned activities resulting in electricity disruptions	Unplanned maintenance (e.g. theft, vandalism, breakdowns)	
	Substation power trips (e.g. due to varying electricity demand)	

Table 6-3 describes hazards / hazardous events emanating from medium-term electricity supply disruptions (i.e. disruptions longer than one day and up to a week).

Table 6-3: Hazards / hazardous events emanating from medium-term electricity disruptions.

<table>
<tr><th>Hazard / hazardous event</th><th>Hazard / hazardous event description</th><th>Risks associated with hazard / hazardous event</th></tr>
<tr><td rowspan="2">Distribution failures</td><td>Breakdown of electricity generation infrastructure</td><td rowspan="7">• Water supply to reservoirs interrupted up to 7 days
• Water supply to pressure towers interrupted up to 7 days
• High lying areas supplied by booster pump systems without water
• WTWs without backup power cannot continue to operate
• WTWs without sufficient chemicals stored cannot continue to operate
• Pump stations without (or with insufficient) backup power cannot continue to operate
• WWTWs without backup power cannot continue to operate (wastewater spills)
• Wastewater pump stations without backup power generation cannot continue to operate (wastewater spills)
• If adequate warning is not given this can result in damage to water infrastructure (water hammer, pump trips, etc.)
• Affected population without water for up to 7 days (important to note is that a 7 day event not mitigated effectively can have severe long-term effects as the result of the intangible risks associated with water supply interruptions)
• Protest action & civil unrest
• Hospitals without water
• Fire brigades without water</td></tr>
<tr><td>Breakdown of electricity distribution infrastructure</td></tr>
<tr><td rowspan="2">Blackouts</td><td>Successful pre-blackout preparation and successful islanding of electricity infrastructure (warm start within a few days)</td></tr>
<tr><td>Unsuccessful pre-blackout preparation and islanding of electricity infrastructure but with minimal infrastructure damage (cold start within 7 days)</td></tr>
<tr><td>Criminal activities</td><td>Theft, vandalism, terrorism, sabotage or war</td></tr>
<tr><td rowspan="2">Natural disasters</td><td rowspan="2">Lightning strikes, earthquakes, floods</td></tr>
<tr></tr>
</table>

Table 6-4 describes hazards / hazardous events emanating from long-term electricity supply disruptions (i.e. disruptions longer than a week).

Table 6-4: Hazards / hazardous events emanating from long-term electricity disruptions.

<table>
<tr><th>Hazard / hazardous event</th><th>Hazard / hazardous event description</th><th>Risks associated with hazard / hazardous event</th></tr>
<tr><td rowspan="2">Distribution failures</td><td>Breakdown of electricity generation infrastructure</td><td rowspan="7">Water supply to reservoirs interrupted longer than 7 days
Water supply to pressure towers interrupted longer than 7 days
High lying areas supplied by booster pump systems without water
WTWs without backup power cannot continue to operate
WTWs without sufficient chemicals stored cannot continue to operate
Pump stations without (or with insufficient) backup power cannot continue to operate
WWTWs without backup power cannot continue to operate (wastewater spills)
Wastewater pump stations without backup power generation cannot continue to operate (wastewater spills)
If adequate warning is not given it can result in damage to water infrastructure (water hammer, pump trips, etc.)
Affected population without water for longer than 7 days
Protest action & civil unrest
Hospitals without water
Fire brigades without water
All other emergency services without water</td></tr>
<tr><td>Breakdown of electricity distribution infrastructure</td></tr>
<tr><td rowspan="3">Blackouts</td><td>Unsuccessful pre-blackout preparation and islanding of electricity infrastructure but with minimal infrastructure damage (cold start not possible within 7 days)</td></tr>
<tr><td>Unsuccessful pre-blackout preparation and islanding of electricity infrastructure with serious infrastructure damage (cold start not possible within a few weeks)</td></tr>
<tr><td>Cold start facilities damaged (cold start could take up to a few months)</td></tr>
<tr><td>Criminal activities</td><td>Theft, vandalism, terrorism, sabotage or war</td></tr>
<tr><td>Natural disasters</td><td>Earthquakes, floods, solar flairs</td></tr>
</table>

6.2.3 Risk estimation

For the estimation of risks as part of the case study a quantitative risk estimation approach was followed rather than a qualitative approach. This is due to the fact that cost vs. benefit calculations made as part of the case study took into consideration the actual estimated duration and recurrence intervals of risks identified. A qualitative risk analysis approach would not have been as suitable for the case study's risk analysis for the following reasons:

- The duration and recurrence interval of risks identified would not necessarily have been estimated in detail as they could only be ranked against each other based on the risk assessor's perception; and
- Due to the fact that risks are only ranked against each other, it places less emphasis on accurately estimating the duration and recurrence intervals of the risks.

As was emphasized in the Literature Review (Chapter 2) and in the description of the study's limitations (Section 3.1.4), obtaining the necessary data on hazards and hazardous events is crucial to accurate risk estimation. For the risk estimation (i.e. quantification of risks' probabilities, or recurrence intervals, and consequences) it was necessary to make some informed assumptions due to the limited data available (Herold, 2017).

Table 6-5 summarises the risk estimation on risks identified as part of the hazard / hazardous events identification process.

Table 6-5: Estimation of risks identified (for CoT).

Event	Extent	Duration	RI (years)	Consequences
Load Shedding				
Low frequency load shedding	Gauteng municipalities	2-4 hours	<1 to 5	RW and Tshwane reservoir storage sufficient: low-cost
Higher frequency load shedding	Gauteng municipalities	2-4 hours	10	Low-medium cost
Distribution Failure				
Affecting RW pumps	One major booster pump station (About 20% of Tshwane's supply)	1 day	10	Low cost
		5 day	20	Low-medium cost
		10 day	40	Medium cost

	Two major booster stations or Vereeniging main station. (About 40% of Tshwane's supply)	1 day	20	Low-medium cost
		5 day	40	Medium-high cost
		10 day	80	High cost
	Three booster stations or Zuikerbosch main station (About 60% Tshwane's supply)	1 day	30	Medium cost
		5 day	60	High cost
		10 day	120	Very high cost
Affecting Tshwane	Local substations	1 day	5	Low cost
		7 day	20	Severity depends on gravity supply from RW and other own sources: Low-medium cost
		30 day	50	Low-medium cost
	One main substation (High lying areas that cannot be supplied by gravity by RW	1 day	20	Low cost
		7 day	50	High cost
		30 day	100	Very high cost & major civil unrest
Blackout				
Islanding successful, no serious damage to infrastructure (Operating failure)	To get Gauteng back up (longer for rest of country)	2 day	38	Medium-high cost & civil unrest
Islanding unsuccessful, no serious damage to infrastructure (As above, operator strike or lower intensity solar flare with adequate warning)	Cold start (longer recovery time)	7 day	55	High cost & serious civil unrest

Infrastructure damage (High magnitude solar flare with inadequate warning, computer attack, etc.)	Longer recovery time	7 days	50	Extremely high cost, loss of life & socio-political collapse
Cold start facilities damaged (High magnitude solar flare without warning, sabotage, high altitude EMP device, natural disaster.)	Much longer recovery	>30 days	155	Extremely high cost

Notes:

1. It is difficult to isolate the economic damage due to failure to supply water to industries and commercial users since in most instances the loss of electrical supply will also shut them down. In Tshwane's case, however, disruption of RW's supply due to electrical distribution failure would not affect Tshwane's electricity supply, in which case the entire economic cost would be attributable to the disruption of the water supply. Similarly an electricity disruption in CoT may not necessarily affect the water supply (it will depend on the location and area of the disruption event).

2. At the higher durations of electrical supply disruption the economic cost is superseded by the direct threat to human life and the ensuing civil unrest. This is particularly the case in heavily populated poor communities bereft of water storage (in swimming pools, etc.) and where residents lack the financial resources to exploit alternative resources. In this regard a major blackout of any length of time could lead to violent protest. Civil unrest arising from a major disruption of the water supply due to prolonged electrical distribution failure to even a single major metro such as Tshwane could spill over into wider national civil unrest.

3. Recurrence intervals for types of blackout have been estimated as per the rationale given in **Table 6-6**.

Table 6-6: Estimated recurrence intervals associated with blackout events.

Event	Dura-tion	Cause	Rationale	RI (yrs)
1. Islanding successful, no serious damage to infrastructure. (Operating failure, Executive order)	2 day	1.1 Operating failure	An operating failure is considered unlikely due to Eskom's status as a single utility with unique experience related to the long period of rolling blackouts. Assume a 1:100 year RI and assume that successful islanding has a ⅔ probability of occurrence. (Hence unsuccessful islanding can be expected to have a ⅓ probability – Cause 2.1.) Assume no significant infrastructure damage to most of Eskom's fleet.	150
		1.2 Executive order	A politically motivated executive order to Eskom control management preventing them from implementing high level rolling blackouts is the surest method of precipitating a national blackout. This risk has receded somewhat due to the recently installed generating capacity but could recur due to financial melt-down or a resurgence of the economy. This risk of political pressure has increased due to increasing political instability and reaction thereto by voters during by-elections.	50
		Combined risk		38
2. Islanding unsuccessful, no serious damage to infrastructure. (Operating failure, operator strike, High magnitude solar storm with adequate warning, sabotage, biological attack.)	5 day	2.1 Operating failure	See above (Cause 1.1). An RI of double that of a 1 day event has been estimated.	300
		2.2 Operator strike lasting more than 18 hours	There is a high level of loyalty amongst the operators and there has never been such a strike. Hence a relatively low risk has been assigned.	200
		2.3 High magnitude solar storm with adequate warning	The Carrington solar flare of 1859 was the most severe on record. The manual telegraph had only been invented 20 years earlier and hence transmission lines were short (reducing the effect of induced currents). Had this occurred presently the effects would have been much more severe. Two similar events that would have produced severe damage to modern communications and electricity supply systems occurred in 1882 and 1921. Hence 3 such events have occurred over the last 157 years, placing it as approximately a 1:52 (say 1:50) year event. (As recently as 2003 a solar flare of similar magnitude to	75

Event	Dura-tion	Cause	Rationale	RI (yrs)
			the Carrigngton occurred, but fortunately it was on the opposite hemisphere of the sun. This could be regarded as a 50:50 miss, but since it missed the earth it has not been included in the statistics. A number of smaller magnitude events affecting smaller regions have also been recorded, but it is difficult to estimate the probability of occurrence over South Africa and the likely consequences.) The electromagnetic pulse from such a flare travels slower than the speed of light and takes about 18 hours to reach the earth's ionosphere. Observation satellites placed in deep space are unaffected since there are no ions that can be aligned to form a strong direct current. The circuitry in the satellites is also too short to form an induced current strong enough to affect them. Hence earth observers have 18 hours of warning. Eskom monitors transmissions and should therefore have enough warning to isolate transformers and generating plants. However, ions in the upper atmosphere will be aligned to form very strong electrical fields that will persist for days after the solar flare has passed. This will mean having to keep Eskom's infrastructure shut down for a few days, creating a nation-wide blackout for a few days. This shut-down should limit damage, although strong induced currents in the long transmission lines could cause damage. It is also possible that advance warning systems or their monitoring by Eskom could fail. Protection systems are also designed to handle alternating current and may not offer sufficient protection against strong induced direct current. Hence damage to electrical infrastructure may still occur. Telecommunication systems will be particularly prone to serious damage due to induced currents in long cables. This could also affect electricity supply and telemetry systems used in water supply systems.	

Event	Dura-tion	Cause	Rationale	RI (yrs)
			The assumption has been made that there is likely to be adequate warning and a ⅔ probability of not incurring serious infrastructure damage. Hence the recurrence interval for insignificant infrastructure damage would be 1:75 year.	
		2.4 Sabotage	Sabotage would cause a sudden drop in either electricity supply or load. However, it would probably require multiple simultaneous attacks to cause a national blackout. It is unlikely that it would be successful. The biggest risk appears to be an attack on Eskom's control centre, which is not inconceivable if a fanatical terrorist group is involved. The current threat level appears to be low, but it cannot be disregarded since political unrest might escalate. It would also require only a small group of determined fanatics. A RI of 1:500 years has been assumed.	500
		2.5 Biological attack	The Swiss ministry (Hohl et al, 2013) estimates the RI of an epidemic / Pandemic at about 1:55. The probability of such an event affecting Eskom's specialist operating staff is very low. However, the risk of a terrorist group specifically targeting this small group of specialist staff with a virulent biological agent is higher. Infecting just one staff member would suffice, seeing as they would rapidly infect other members of their group working together in a secure confined space. Then again, this would depend on motive, which in the case of South Africa might be quite low. Hence a relatively low RI of 1:500 has been chosen.	500
		Combined risk		39
3. Infrastructure damage (High magnitude solar storm, Cyber-attack, Asteroid strike)	10-15 days	3.1 High magnitude solar storm with significant infrastructure damage	See discussion on Cause 2.3. It is important to recognise that such an event would have extensive world-wide impact. Hence major transformers or generating units would be difficult to source, since the first priority of overseas suppliers would be to replace vital infrastructure in their own countries.	200

Event	Dura-tion	Cause	Rationale	RI (yrs)
		3.2 Cyber attack	A cyber-attack aimed at South Africa can be expected to damage infrastructure since it would occur without warning and would be malicious and therefore deliberately aimed at doing the greatest possible damage. Although difficult to quantify because of the secrecy involved the risk keeps increasing due to the large and escalating number of new computer viruses introduced every day, together with the determined efforts of well-resourced national military establishments and the increasing sophistication of terrorist organisations. In time the risk to Eskom could be increased by the trend towards renewables and the concomitant move towards a smart grid to allow rapid switching of power sources to account for frequent sudden shifts in generation output from intermittent solar and wind sources. Such computer based systems are more vulnerable to cyber-attack. The RI for present conditions has been set quite low for the current at 1:200.	200
		3.3 Asteroid strike	The 1908 asteroid explosion over Siberia that devastated an area with a radius of 30 km is estimated to have been a 1:100 RI event. However, the surface area of the earth is $3.25x10^{12}$ km^2 , which means that the RI of such a strike hitting a sensitive target such as Megawatt Park or the heart of the power generating area (say about 20 000 km^2) in the Mpumalanga Highveld is minute.	$1.6x\ 10^{10}$
		Combined risk		100
4. Black start facilities damaged (High magnitude solar	Months	4.1 High magnitude solar storm	See discussion on Causes 2.3, 3.1 and 4.1. The combined RI for all 3 duration events comes to 1:50 year (see discussion on Cause 2.3). A lower probability has been assigned to a solar storm causing damage to South Africa's two black start generating facilities due to the 18 hours warning that should be	300

Event	Dura-tion	Cause	Rationale	RI (yrs)
storm, high altitude EMP device.)			available. (Although long power lines and municipal infrastructure might still be at risk. Communications systems will be extremely vulnerable.)	
		4.2 High altitude EMP	Detonation of one or more high altitude nuclear devices would have a similar effect to a high magnitude solar storm. This is not a theory, devices magnitudes of power smaller than current hydrogen bombs were tested twice as long ago as 1952, once by the USA over the central Pacific Ocean and once by Russia over a remote part of Siberia. The first destroyed one-third of all satellites in low orbit (affected by the ionosphere) and caused electrical damage 1450 km away in Hawaii. The second fused 570 km of telephone cable, shut down 1000 km of buried cable and burned down a power plant. Such an event aimed at inflicting damage to an enemy's communication and electricity systems would be a prime target for one or two hydrogen bombs in the event of a nuclear conflict. It would also be an attractive target for a small rogue state, such as North Korea. It is important to observe that an EMP (Electro Magnetic Pulse) device would affect a very wide target area, as well as setting off a mirror image pulse on the other side of the earth. Hence South Africa is unlikely to be immune. The effects will also last some time (a few days) due to the persistence of the magnetic field induced in the ionosphere. Unlike a solar flare, there is no warning of an EMP detonation. Hence extensive damage to electrical infrastructure can be expected. It is likely that such damage will include equipment at SA's two cold start facilities. Seeing that an EMP is within the grasp of even small nations, and perhaps even well-funded terrorist groups, and the target need not be South Africa or even in the southern hemisphere, the probability must be higher than that of a nuclear attack on	400

Event	Dura-tion	Cause	Rationale	RI (yrs)
			SA. Hence a probability four times higher than that of a direct nuclear attack on SA has been adopted.	
		4.3 Nuclear war	The risk diagram published by Hohl, et al. (2013) gives the RI for nuclear attack on Switzerland as about 1:800 years. Although Switzerland is a low risk target, it is located in Europe, which is at greater risk and attacks on neighbouring countries would inevitably affect Switzerland as well. Being located in the southern hemisphere, which is devoid of nuclear weapons, South Africa should be at lower risk. However, South Africa did once possess nuclear weapons and therefore has proven capability to do it again. It is therefore possible that one or more nuclear nations might have an ICBM with multiple re-entry vehicles targeted on South Africa. (After all, there are tens of thousands of hydrogen bombs that are still operational, presenting foreign powers with a lack of viable targets. Even conventional armies of nations remote from the northern hemisphere that would escape unscathed after a devastating nuclear exchange between super powers must present as a threat to nations that know that their military capability would be seriously weakened after such an exchange. Hence we cannot assume that the risk to South Africa is negligible.) A RI of twice the estimated RI of Switzerland is therefore assumed.	1600
		Combined risk		155

6.3 CASE STUDY RISK EVALUATION

6.3.1 Defining risk acceptance and tolerability criteria

Risk acceptance criteria should be defined by the City of Tshwane (as the Water Service Authority) working with Rand Water and Magalies Water (as the Water Service Providers).

It is important that risk acceptance criteria be defined taking current infrastructure into consideration as existing electricity - and water infrastructure already has a certain level of mitigation built into the system.

This is illustrated in the following examples:

- Current reservoir storage capacity design standards specify between one and two days' available storage capacity in reservoirs based on the reservoir supply zone's Annual Average Daily Demand.
- Most wastewater pump stations that convey sewerage to WWTWs for treatment will already have backup power generation facilities and / or emergency storage capacity for wastewater if an electricity disruption event or a pump failure occurs.
- In terms of bulk water supply into the City of Tshwane from Rand Water, supply will still be possible even if some of the booster pump stations supplying the City of Tshwane with water are affected by electricity disruption events. Even if all of Rand Water's infrastructure is down due to electricity disruptions, the city may also still be supplied from its own sources and from Magalies Water (depending on the extent of the electricity disruption event).

Risk acceptance criteria are discussed in more detail below:

a) Extent of electricity disruption events

The extent of the electricity disruption event influences the number of water users that are affected by water supply interruptions. Given that the City of Tshwane has a certain number (unknown) of water tankers that can deliver potable water to affected areas; a certain degree of risk in terms of the extent of electricity disruptions is acceptable. In other words, the number of water users that can be supplied with water in the event of an electricity disruption utilising the city's current water tanker fleet will determine the acceptable risk in terms of the extent of electricity disruptions.

Furthermore, the location of an area with water supply interruptions due to electricity disruptions is also important. It may be more problematic to address high–lying areas that are supplied from booster pump stations or elevated pressure towers than lower areas supplied from larger ground level elevation reservoirs.

b) Duration of electricity disruption events

Reservoirs in the City of Tshwane should theoretically have sufficient storage capacity to accommodate the demand of the specific reservoir zones for a period of two days based on the AADD of the zone. Therefore, electricity disruptions of up to two days should not pose too much of a risk provided that reservoirs are kept at the required levels and that reservoirs are sized in accordance with the zone demands.

Risk in terms of water supply interruptions due to electricity disruptions that last less than two days can therefore be accepted as the existing infrastructure should accommodate this[13]. (Provided water restrictions are imposed early enough, especially in hot weather.)

c) The probability of civil unrest during an electricity disruption event

If an electricity disruption event results in water supply interruptions of middle- to higher income residential areas, there will be a lower chance of civil unrest than if the event interrupted water supply to lower income areas. The reason for this is that medium- to higher income citizens will probably be better equipped to get water during emergencies. The area that is affected by water supply interruptions due to an electricity disruption event will therefore affect the probability of civil unrest.

Furthermore, the emotional status of the city's population (especially the lower-income fraction) can also have an effect on whether an electricity disruption induced water supply interruption results in civil unrest. For instance, if the general mood of the city's population is not in agreement with the current status of the country, the province or the city, civil unrest will occur more rapidly than if the population's general mood is content.

d) Existing infrastructure's resilience to damage due to electricity disruptions

Water pipelines and pump stations are designed to accommodate the effect of electricity disruptions on the infrastructure. These effects include pressure surges (water hammer) in pipelines, pump trips and failure of electronically actuated valves to open / close. Old, deteriorated pipelines or pipelines that were not designed according to the maximum surge pressures of a system, can be damaged by these effects.

As it is probable that all of the City of Tshwane's water infrastructure have already been (and will in future be) subjected to the effects of electricity disruptions; it can be assumed that most of the existing water infrastructure will not be damaged due to electricity disruptions. Therefore the effect of electricity disruptions on water infrastructure can be seen as an acceptable risk (apart from specific areas with old, deteriorated or poorly designed infrastructure).

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[13] This is only applicable to areas that are supplied from reservoirs via gravity.

e) The probability that an electricity disruption event will result in water quality issues

Water treatment works may have sufficient backup power generation capacity and stored chemicals used for treatment to continue treating water in the event of an electricity disruption. In this case, an electricity disruption event will not result in water quality issues in terms of water supply.

Wastewater treatment works and pump stations can also have sufficient backup power generation and / or emergency storage facilities to ensure that raw sewerage is not spilled resulting in pollution and environmental degradation in the event of electricity disruptions.

However, if an electricity disruption occurs over an extended period, or if there are insufficient measures in place (e.g. emergency storage, backup power, chemical storage for water treatment, etc.); electricity disruption events can adversely affect water quality.

Therefore, acceptable risks in terms of the impact of electricity disruption on water quality occur where the existing infrastructure can accommodate electricity disruption events. This in turn is affected by the duration of the event.

6.3.2 Distinguishing between acceptable and unacceptable risks

Risks that are defined as acceptable given the risk acceptance and tolerability criteria listed above are described below:

- Load shedding and other short-term duration events: Assuming that the city's reservoirs are kept at sufficient water levels (and that the city's operational rules for its reservoirs are adhered to) electricity disruption events do not pose significant risks[14]; and
- Risks that affect small areas can be dealt with more effectively than risks that affect larger areas as the city's emergency response teams will be able to focus all of its attention to the risk affecting the small area.

Unacceptable risks are listed below:

- All risks identified that have electricity disruption durations longer than what the city's water reservoirs and towers can supply;

[14] This is a practical example of Equation 2 in Section 2.8.2: Tshwane's current level of preparedness (reservoir water storage volume available) results in the risks related to short-term electricity disruption events being acceptable.

- All electricity disruption events that will result in adverse economic effects for Tshwane if not mitigated; and
- All risks that can have a detrimental effect on the health or wellbeing of Tshwane's citizens.

Unacceptable risks are therefore medium- to long-term electricity disruption events. This is due to the fact that the city's reservoirs should have sufficient capacity to ensure at least one day's water supply. The feasibility of mitigating the unacceptable risks above will be determined through the case study cost vs. benefit analysis.

If the outcome of the cost vs. benefit analysis indicates that mitigating the risks initially defined as unacceptable is not feasible; then these risks should, in fact, be considered as an acceptable risks. This is explained through the following example: if a risk identified will result in an economic loss for Tshwane of R 10 million, the risk can easily be considered as an unacceptable risk by decision makers at Tshwane based on the face value of the economic loss (i.e. the apparent impact of the economic loss). However, if it is concluded that mitigating the risk will cost Tshwane R 20 million it will be clear for decision makers that the cost outweighs the benefit. This will therefore mean that this risk is, in fact, an acceptable risk.

Identifying risks as acceptable or unacceptable is therefore an iterative process that needs to go hand in hand with a cost vs. benefit analysis to aid decision makers in deciding on whether to mitigate a risk or not.

Some risks will have to be mitigated regardless of the cost vs. benefit feasibility of the risk (for example risks that endanger Tshwane's citizens). The indirect cost (e.g. loss of human life, loss of infrastructure, civil war, etc.) of a risk can therefore cause it to be unacceptable regardless of the cost of mitigation.

6.3.3 Prioritising risks to be mitigated

A few examples of factors that affect risk prioritisation are listed below:

- Risks resulting from electricity disruption events that affect large areas are prioritised higher than risks that affect smaller areas.
- Risks that have the most adverse effect on the city's economy are prioritised higher than other risks that do not affect the city's economy.
- Risks that have more potential to endanger Tshwane's citizens are prioritised higher than risks that do not pose any threat to the city's citizens.

Based on the factors above, it is necessary to prioritise the most critical, unacceptable, risks to be mitigated first. As will be seen from the electricity disruption scenarios analysed later in this chapter, mitigating the most critical risks will result in all less-critical risks also being mitigated.

6.4 CASE STUDY ELECTRICITY DISRUPTION SCENARIOS

6.4.1 Introduction

In this section each of the nine electricity disruption scenarios as per the methodology described Section 3.2 are analysed.

6.4.2 Scenario 1 (Short-term disruption, small area)

Step 1: Scenario Description

Scenario 1 entails a small-sized area affected by a short-term electricity disruption event where an elevated storage tower cannot be filled via a pump station from a reservoir due to an electricity disruption. **Figure 6-3** gives and illustration of the tower, the reservoir from where the tower is supplied and the tower's distribution zone.

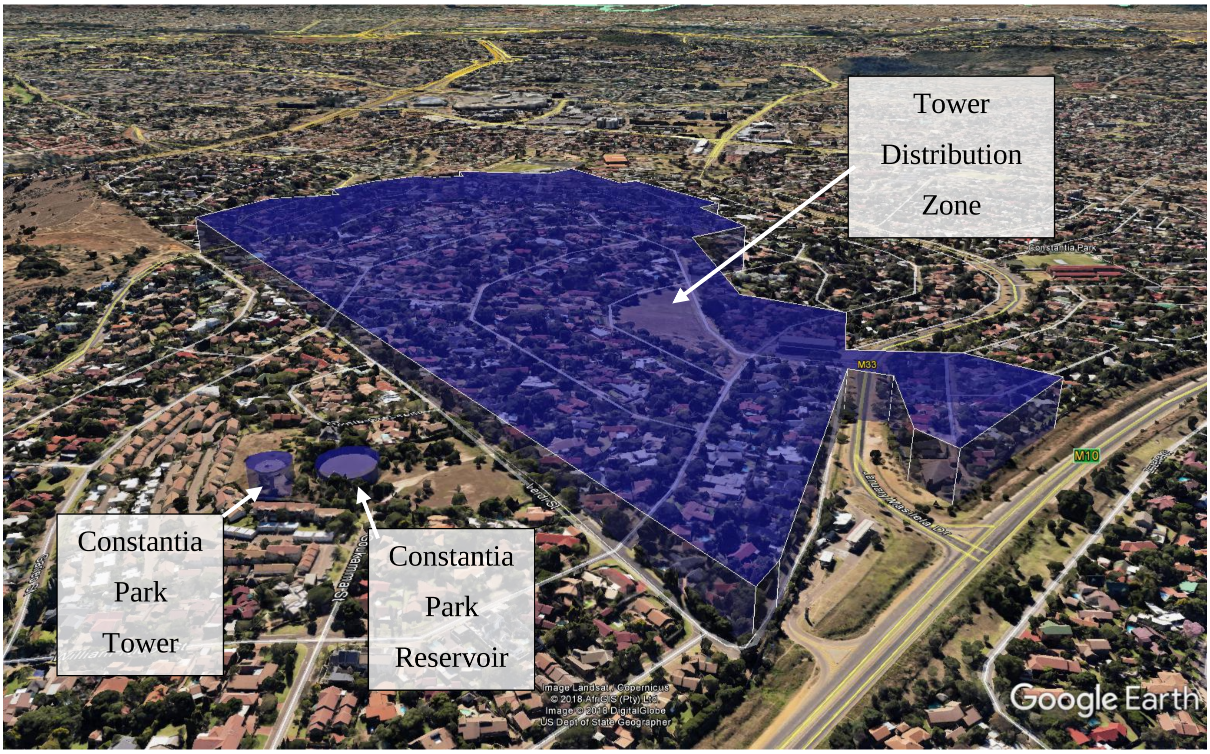

Figure 6-3: Constantia Park Tower, reservoir and tower distribution zone.

The water supply to the Constantia Park Tower is interrupted due to an electricity disruption. The duration is less than one day. The area affected by Scenario 1 is shown in red in **Figure 6-4**. The Constantia Park Tower is also indicated in red.

Step 2: System Description

The system affected consists of the Constantia Park Tower, the pumps filling the tower and its distribution zone consisting of approximately 140 houses (i.e. ± 490 people).

The demand (AADD) of this area is 355 kℓ/day and the volume of the tower supplying this area is estimated at 370 kℓ. The available spare capacity that should be available in the tower given that its operating rules are adhered to is therefore ±300 kℓ.

Step 3: Risk analysis

Risks associated with this event are as per **Table 6-2**: water supply to towers interrupted for less than one day.

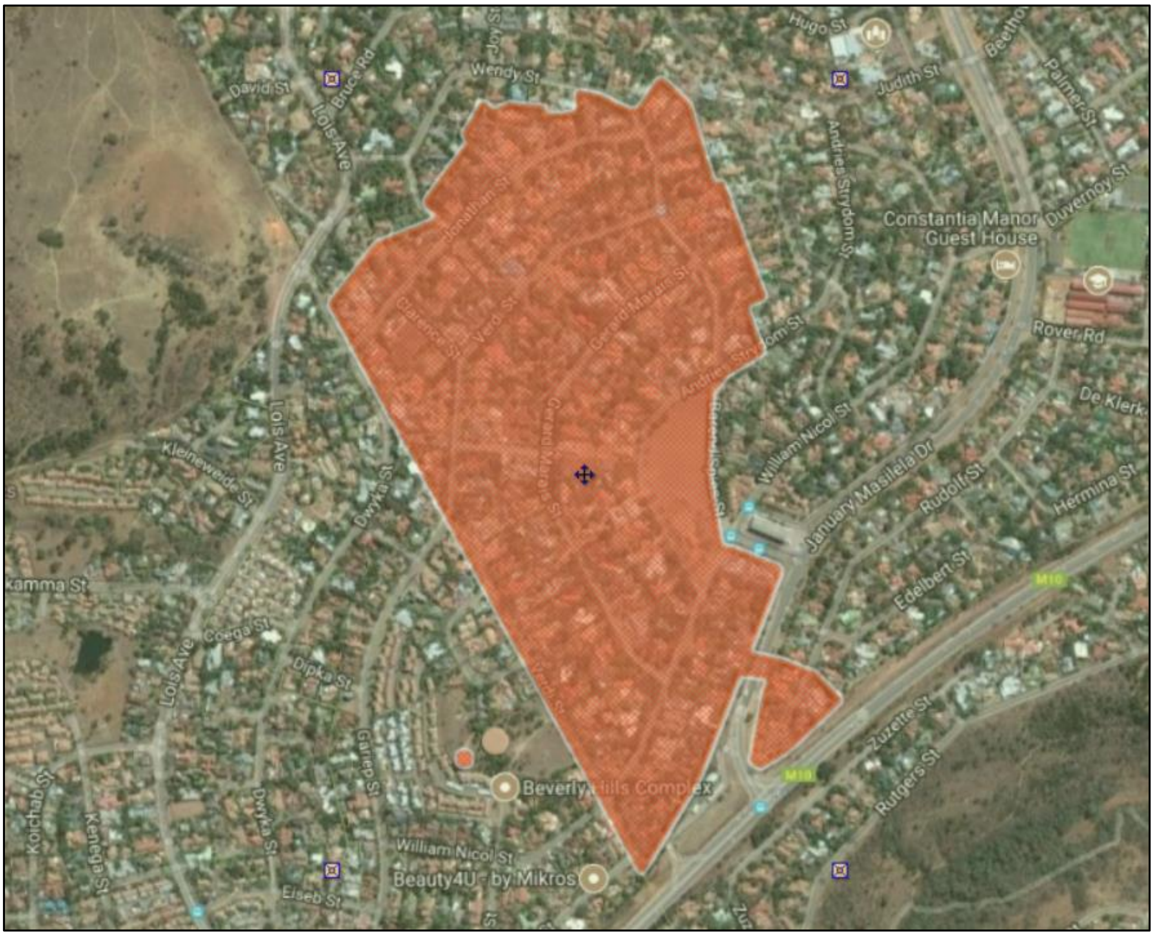

Figure 6-4: Scenario 1 area affected – Constantia Park Tower distribution zone.

Since the water tower almost has sufficient available storage capacity to accommodate the developments AADD for one day, water supply will at most be interrupted for only a few hours. There is therefore no health risk to the affected community that can arise due to water supply interruptions. There is, however, a risk that if the tower empties, the water distribution network will also empty which can result in polluted groundwater infiltrating the network.

The area affected by this scenario is on a hill which means that sewerage will definitely gravitate from the area and there is therefore no risk in terms of environmental pollution due to sewerage overflows at sewer network pump stations.

Step 4 : Risk mitigation options

Since the tower's available storage capacity is not sufficient to accommodate the zone's AADD water demand for one day, alternative solutions have to be identified.

Solutions identified are discussed below:

a) The do-nothing approach

Depending on the season, temperature and climate the do-nothing approach can be suitable for short-term water supply interruptions due to electricity disruptions. This is especially suitable, considering that a few hours of water supply interruptions will almost certainly not be detrimental to human health, except where excessive pipe leakage is present. Residents must be alerted of this danger and the precautionary measure of avoiding potable consumption until the potentially polluted slug of water has been consumed by other uses. This should be backed up by good disinfection, although this can only be relied upon to partially overtake the tail of the polluted slug of water.

b) Water restrictions

Informing the affected community of the situation and imposing water restriction for the day (especially prohibiting watering of gardens) will decrease the area's water demand to ensure that the available water storage in the tower is sufficient. This will in turn ensure that water supply is not interrupted during the electricity disruption.

There are numerous problems associated with imposing water restrictions effectively on end-users, especially if this needs to be done within a short warning period. There should therefore be a detailed plan and consumer buy-in to ensure water restrictions are imposed effectively.

c) Flushing the distribution network

If the suburb's water storage volume was depleted as a result of the electricity disruption event it may be possible that polluted groundwater infiltrated the water distribution network. It will therefore be necessary to flush the water in the distribution network to ensure the polluted water is not used by the affected community.

Step 5: Cost estimate

There will not be a cost implication for either solution (a) or (b) above in terms of infrastructure. There might be administrative costs involved for solution (b), however, these costs will be minimal and will form part of the municipality's day to day expenses.

If solution (c) is required, it will have a cost implication in terms of potable water losses. It will, however, not have a capital (i.e. infrastructure) cost implication.

Step 6: Scenario 1 conclusion

Conclusions drawn from Scenario 1:

- Small-scale and short-term electricity disruptions (i.e. less than one day) will typically not pose any major risks to the community,
- The impact of these electricity disruptions on water supply should be relatively simple to deal with,
- It should not have a cost implication in terms of additional infrastructure required, and
- Since this is a small, purely residential area a water supply interruption event will not have a significant economic impact on the city.

6.4.3 Scenario 2 (Short-term disruption, medium area)

Step 1: Scenario Description

Scenario 2 is a medium-sized area affected by a short-term electricity disruption event where Rietvlei WTW cannot supply water.

The water supply from the Rietvlei WTW is interrupted due to an electricity disruption. The Rietvlei WTW is shown in **Figure 6-5**.

Figure 6-5: Location and aerial view of the Rietvlei WTW.

The duration of the electricity disruption is less than one day. The area affected by Scenario 2 is shown in red in **Figure 6-6**.

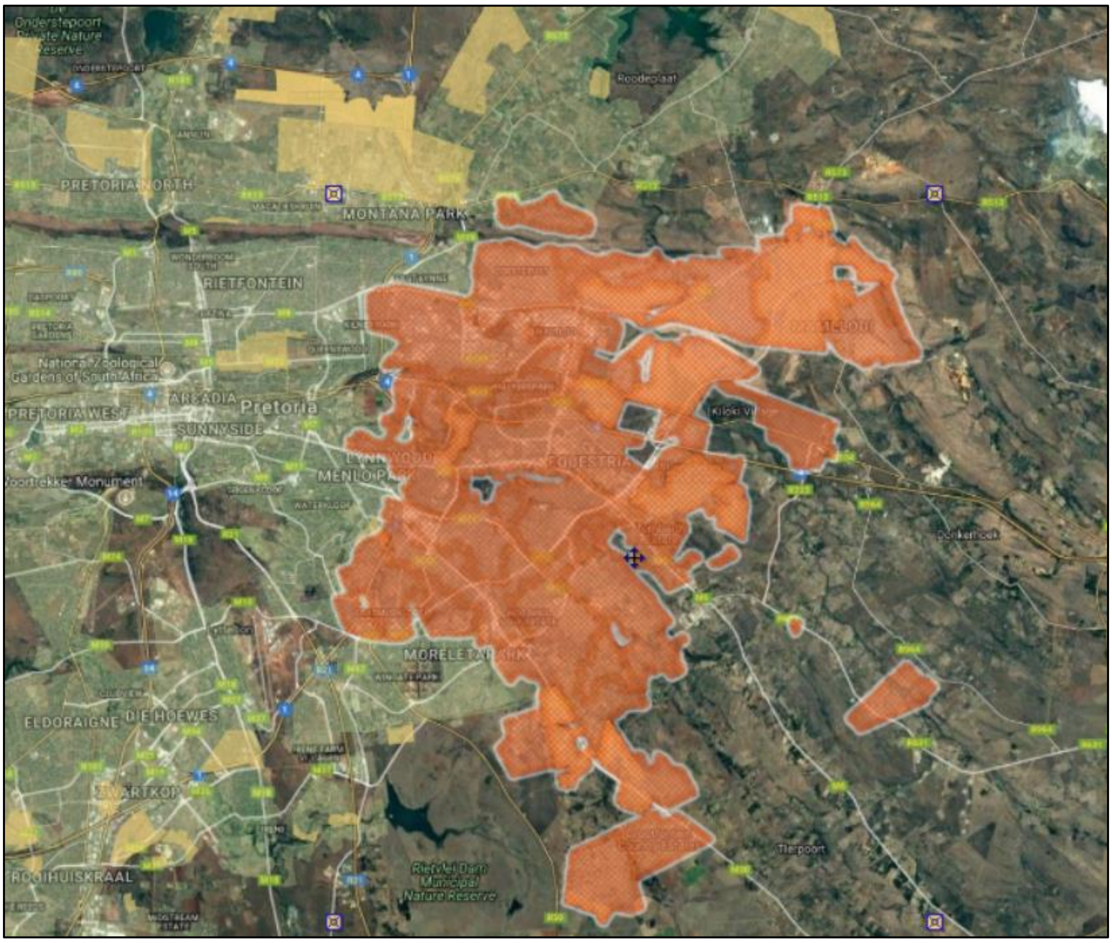

Figure 6-6: Scenario 2 area affected - City of Tshwane bulk supply Region 6.

Step 2: System Description

This area is supplied from the Rand Water Bronberg Reservoir, the Rietvlei Dam WTW and from the Magalies Water's Wallmannsthal WTW.

The AADD of this bulk water supply region is 159.9 Mℓ/day. The total volume of reservoirs and elevated water tower supplying water to this area is 403.2 Mℓ. The total available water storage in reservoirs and towers in Bulk Supply Region 6 is 394.3 Mℓ based on the assumptions made in Section 5.2.5.

This area consists of 173 thousand households and a population of approximately 600 thousand people. The domestic water demand of this area is 120 Mℓ/day[15]. As stated in Section 5.2.2 b), it is assumed that the city's wet-industries are uniformly distributed in the city for larger areas analysed. The industrial water demand of this area is therefore estimated as 10 Mℓ/day[8]. The water demand of other sectors is 30 Mℓ/day[8].

It is assumed that the electricity disruption event affecting this area results in the Rietvlei Dam WTW not being able to supply water. As stated in Section 5.2.9 the Rietvlei WTW has a capacity of 40 Mℓ/day.

There are four elevated water towers in the City of Tshwane's Bulk Water Supply Region 6. The demands of these towers are summarised in **Table 6-7**.

Table 6-7: Elevated water towers in Bulk Region 6.

Tower name	Zone AADD (kℓ/day)	Number of households	Population served
Constantia Park Tower (Scenario 1 & 4)	355	140	490
Erasmusrand Tower	1116	440	1540
Grootfontein Tower	496	196	686
Murrayfield Tower	90	35	123

[15] These water demands include real losses as it was obtained from the theoretical model (which includes losses).

It is assumed that the electricity disruption event affecting this area results in the Rietvlei Dam WTW not being able to supply water. As stated in Section 5.2.9 the Rietvlei WTW has a capacity of 40 Mℓ/day.

Wastewater treatment works in this area include the Zeekoegat WWTW (30 Mℓ/day) and the Baviaanspoort WWTW (60 Mℓ/day).

Step 3: Risk analysis

Possible risks associated with this event are as described in **Table 6-2**. The most critical risks include:

- Wastewater spillages;
- Sections of Bulk Water Supply Region 6 where specific reservoirs or towers do not have sufficient available storage capacity to accommodate the zones' demand can run out of water; and
- Economic loss due to water supply interruptions to wet-industries.

Such a large area will almost certainly include small home industries that would be disrupted for want of water supply. This has not been investigated in this project.

The total available storage capacity in this area is more than two days' AADD of the region. The existing water storage infrastructure has sufficient capacity to ensure continuous water supply during the electricity disruption. However, in view of the size of the area involved and the initial lack of prior knowledge of how long the power outage will last, it would be prudent to take immediate action to preserve stored water and commence emergency pumping into the elevated water towers to protect continued water supply to high lying areas.

The various potable water pump stations within the region also need to be examined to identify what other backup generating capacity is required to ensure continuation of service.

Unexpected glitches can greatly prolong the repair time for small electricity outages, which presents greater uncertainty when more complex repairs to bigger, harder to source plant are required. (As a case in point: In September 2014, when a large transformer supplying power to one of RW's four major booster pump stations failed. When the standby transformer was switch on it exploded and it would have taken two weeks to provide an alternative power supply. Thus on the first day it looked like a 2-week loss of a quarter of RW's supply. Fortunately the next day it was possible to repair the original transformer, reducing it to a 1-

day outage. But it was essential to assume that the outage would be of longer duration and to operate the system accordingly, which was the logical course of action at the time.)

Wastewater spillages resulting from the electricity disruption events and wastewater treatment works overflowing will have negative environmental effects. This will need to be addressed through the installation of backup power generation capacity.

Since this area has sufficient storage to accommodate the area's water demand for the duration of the electricity disruption event, water supply to wet-industries and other significant generators of GNP will not be interrupted. There should therefore not be an economic impact due to interrupted water supply.

Step 4 : Risk mitigation options

The following risk mitigation options were identified:

a) The do-nothing approach

During the day when the power is out raw sewage will continue to enter WWTWs. It is assumed that the raw sewage inflow rate for a short duration event like this will remain the same as for normal operation. The ensuing overflow of untreated sewage would pose environmental and health risks for informal users. Moreover, it risks overloading the biological capacity of downstream water treatment works, thereby imperilling domestic users.

After a region-wide power outage has occurred the erstwhile relatively low risk would have been transformed into a present certainty, at which point the much higher subservient risk of the outage lasting longer than a day would come into play. This high knock-on risk cannot be ignored by operators, managers and planners. Hence the risk posed by the do-nothing option would not be tenable.

b) Addressing wastewater treatment works' backup power generation requirements.

The Zeekoegat - and Baviaanspoort WWTWs have a total capacity of 90 Mℓ/day. Based on the assumed electricity consumption rate of 500 kWh/Mℓ and assuming the WWTWs will have a constant electricity demand throughout the day the two WWTWs will require backup power generation capacity of approximately 1875 kW. The total energy consumption of the two WWTWs for the duration of the disruption will be 45 MWh.

c) Addressing wastewater through additional emergency storage capacity

If wastewater inflows into the two wastewater treatment works are not addressed through the installation of backup power generation capacity, it will have to be addressed through additional emergency storage capacity. Approximately 68 Mℓ of additional emergency storage capacity to accommodate the wastewater inflow at the Zeekoegat – and Baviaanspoort WWTWs will be required (assuming there are already 6 hours of emergency storage capacity on site).

d) Water restrictions

Based on the fact that total available storage capacity in reservoirs being more than the Bulk Water supply Region's AADD, water restrictions are theoretically not necessary to prohibit water supply interruptions. However, water restrictions will ensure that less of the available water storage is used ensuring that reservoir levels are kept as high as possible in case the electricity disruption event lasts longer than anticipated.

Furthermore, water restrictions may also result in lower sewerage flows entering the wastewater treatment works that will also be affected by the electricity disruption, which will result in lower electricity consumption and in lower fuel consumption.

e) Addressing the area's fire risk

Provision is made in the SANS 10090 (2003) standard for a municipality's water division to inform the city's fire brigade if a situation arises where certain fire hydrants in an isolated area cannot be used for filling fire engines due to water supply interruptions to the area. The fire brigade will therefore have to be notified accordingly to ensure that they do not use fire hydrants in the affected area to fill fire engines' tanks in the case of a fire. This is only applicable as a mitigation option for small areas (e.g. area supplied from elevated towers).

f) Additional storage capacity

Additional storage capacity is required in order to ensure that the towers' volume is at least sufficient to be able to supply 2 days' AADD as is recommended in the Red Book (Council for Scientific and Industrial Research, 2005). Therefore, approximately 400 kℓ of additional storage capacity will have to be constructed. The additional storage capacity will, however, not be sufficient to prohibit water supply interruptions during the 7-day electricity disruption event.

g) Water tankers

If backup power generation is not available on site, water tankers will have to be deployed to the affected area to ensure that the community in the affected area has access to potable water.

Based on the estimate that 140 households and 490 people will be affected by the electricity disruption this means that 12 250 litres of water will have to be delivered per day in order to meet the required 25 litres per person per day as recommended in the Red Book (Council for Scientific and Industrial Research, 2005).

Therefore, one 15 kl water tanker daily should be sufficient to supply this area with water during the electricity disruption event. If it is assumed that it will take 30 seconds to fill up a 25 litre water container and that the 490 water containers will need to be filled up, it will take approximately 4 hours per day to fill the affected community's water containers. However, this is an ideal that assumes that the residents have any such large water containers and additional clean containers in which to store water. It is likely then that many more trips would be required to collect the household water quota. Moreover, residents are unlikely to be available at the same time. Hence considerably longer vehicle standing time can be expected.

A water delivery schedule will therefore have to be developed and communicated clearly to the community.

h) Backup power generator on-site

A backup power generator on site will ensure that the water tower's water level can be maintained through normal operation of the pumps supplying the main reservoir. Assuming that the water is pumped 7 m from the ground level main reservoir into the tower a 5 kW on-site generator will be able to provide sufficient power generation capacity on site to ensure an unchanged level of service for this tower (including providing the minimum fire flow requirements in the tower's distribution zone).

i) Mobile backup power generator

If the city has mobile backup power generators available and there are no on-site backup power generation facilities, it can be used to provide electricity to the pumps affected by the electricity disruption. If mobile backup power generators are to be used it should be kept in mind that pump station's electrical systems will probably have to be upgraded to accommodate external power supply (power connection points, surge protection, etc.).

j) Bypass the tower

Another option is to bypass the tower completely if possible and supply the affected area with potable water from the reservoir from which water is usually pumped to the elevated tower. If the pipework required to do this is not already in place, it should be relatively simple and quick to do so. It is estimated that approximately 50 m of 200 mm diameter pipe will be required.

Although static pressures will be very low (in the order of 5 m head at the highest houses supplied from the tower), the affected community will still be able to get water from their taps. The affected community members will therefore be supplied at a lowered level of service for the duration of the electricity disruption event but will continue to have access to water from their municipal connections.

k) Water restrictions

As this electricity disruption will result in the affected community not having water or having very little water it will be of upmost importance to effectively implement water restrictions to ensure that all affected community members will have access to potable water.

If the option of bypassing the tower is chosen, it is important to extend the area of water restrictions to include the larger main reservoir's distribution zone.

Step 5: Cost estimate

a) Waste water treatment

The capital cost of the backup electricity generation infrastructure needed to prevent untreated sewage spills is approximately R 18 million. The two wastewater treatment works will consume 20 thousand litres of diesel to ensure continuous operation (at a cost of R 222 000). This does not include the cost of fuel storage and transport.

The cost of additional emergency storage capacity at the two wastewater treatment works will be approximately R 33.2 million. This is higher than the cost of backup electricity generation capacity.

b) Supply to high lying areas

The cost of providing on-site backup power generators at the elevated towers is the cheapest option to ensure uninterrupted water supply to the affected areas during the electricity disruption events. This is estimated at R 199 000.

c) Water treatment

It is not necessary to consider the cost of backup power generation for the Rietvlei WTW because for this option RW would continue to meet 76% of Tshwane's water supply, which is more than adequate to meet basic domestic, industrial and other contributors to Tshwane's GDP.

The costs are summarised in **Table 6-8.**

Table 6-8: Summary of costs for Scenario 2: 1-day power outage, medium area.

Description	**Cost (million R)**		**Benefit**
	Capital	Operating	(million R)
WWTW power supply	18.31	6.67	-
Elevated water tower power supply	0.19	0.07	-
Total	18.50	6.74	-

Step 6: Scenario 2 conclusion

Conclusions drawn from Scenario 2:

- Based on the available information it doesn't appear that potable water supply will be interrupted in the event of an electricity disruption that is shorter than one day.
- Backup power generation to ensure wastewater treatment works can continue operating and to mitigate the environmental impact of electricity disruption will cost approximately R 18.2 million.
- For some time the duration of the power outage will be unknown and hence the precautionary measure of switching on emergency generators to supply water towers

will be required. The capital cost of the emergency generators is estimated at R 0.20 million.

- Appropriate power supply backup measures also have to be evaluated for potable water supply pumps within the region (and the remaining five regions of Tshwane).

6.4.4 Scenario 3 (Short-term disruption, large area)

Step 1: Scenario Description

Scenario 3 is a large area affected by a short-term electricity disruption where it is assumed that the entire City of Tshwane does not have electricity and all water treatment works supplying the city are affected by the electricity disruption event.

The water supply to the entire Tshwane area is affected by Scenario 3, the entire Tshwane water distribution network is therefore affected, as shown in red in **Figure 6-7**. It is assumed that this electricity disruption event also causes electricity disruptions to Rand Water and Magalies Water's water treatment works.

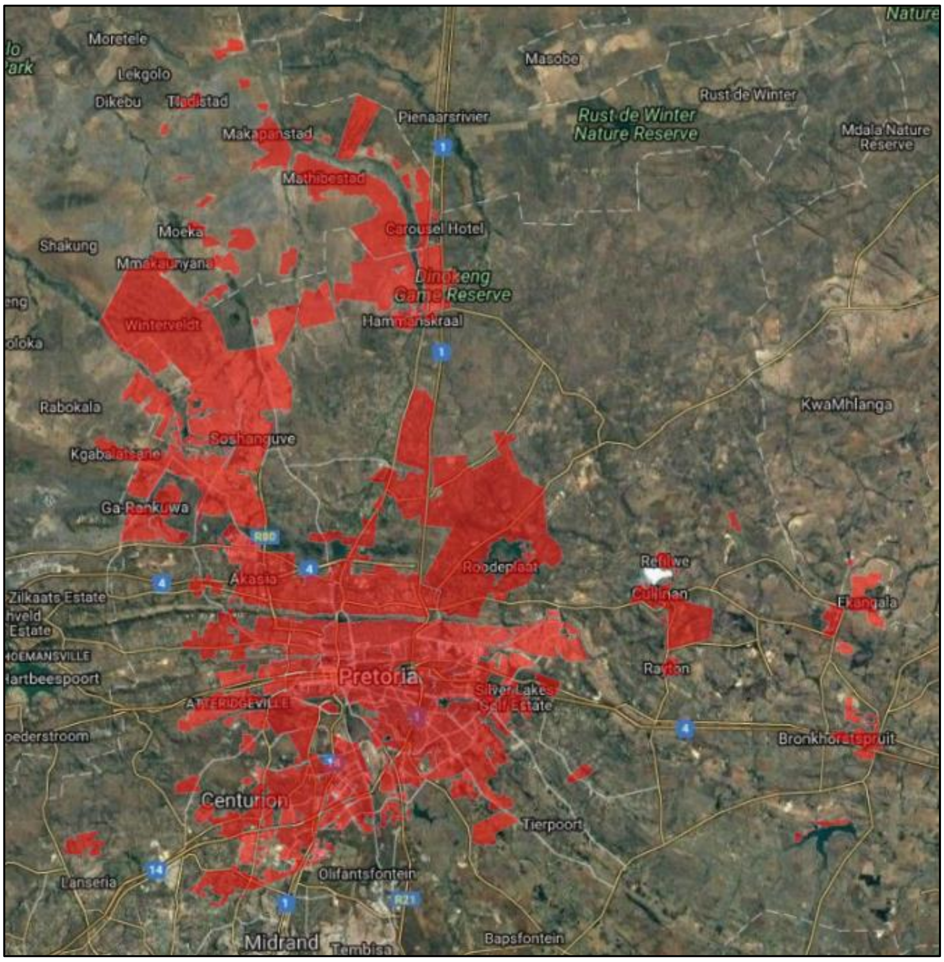

Figure 6-7: Scenario 3 area affected – City of Tshwane's water distribution network.

Step 2: System Description

It is assumed that the entire City of Tshwane water and sewer systems are affected by an electricity disruption.

It is further assumed that water delivery from RW will not be affected. The reasoning here is that restoration of city-wide power within only one day implies an event that cannot be attributable to a regional or national blackout or serious damage to infrastructure. Hence this scenario is analogous to Scenario 2, but on a larger scale.
All pump systems supplying elevated storage towers will be affected, together with all network booster pump systems.

No water will be supplied into the city from any water treatment works.

The total wastewater treatment works capacity that will be offline is approximately 584 Mℓ/day (refer to Section 5.2.10).

Step 3: Risk analysis

Risks associated with this event are as described in **Table 6-2**. The most critical risks include:

- Wastewater spillages at the city's wastewater treatment works and wastewater pump stations,
- All reservoirs and elevated storage towers that do not have sufficient available storage capacity to accommodate at least one day's water demand will cause water supply interruptions, and
- Economic loss due to water supply interruptions to wet-industries.

The total available reservoir and elevated water tower storage capacity in the City of Tshwane is equal to approximately 1 day and 20 hours' worth of water storage based on the city's AADD. Therefore, only isolated areas where reservoirs or elevated water towers have insufficient capacity will have water supply interruptions.

Wastewater spillages resulting from the electricity disruption event and wastewater treatment works overflowing would have negative environmental effects and endanger downstream domestic water use. These impacts need to be addressed.

Step 4 : Risk mitigation options

The following risk mitigation options were identified:

a) The do-nothing approach

As was stated for Scenario 2, the do-nothing approach will only be suitable in terms of water supply. Addressing the backup power generation requirements will be required to mitigate negative environmental impacts of wastewater spillages.

b) Addressing wastewater treatment works' backup power generation requirements

The City of Tshwane's wastewater treatment works have a total treatment capacity of 584 Mℓ/day. Therefore, the wastewater treatment works will require a combined backup power generation capacity of 12.2 MW and 292 MWh of energy will be consumed during the 24 hour period. The energy requirement is a little conservative since curtailing the water demand should result in a corresponding reduction in sewage discharge. However, for the first part of the day sewage will continue to flow at its normal rate. Accordingly the generating capacity has to be able to handle the full treatment capacity.

c) Addressing wastewater through additional emergency storage capacity

If wastewater inflow into the city's wastewater treatment works is not addressed through the installation of backup power generation capacity, it will have to be addressed through additional emergency storage capacity. Approximately 438 Mℓ of additional emergency storage capacity to accommodate the wastewater inflow into the city's wastewater treatment works will be required (assuming there are already 6 hours of emergency storage capacity on site).

d) Supply to high lying areas

The power and one-day energy requirements for standby generators at Tshwane's 38 elevated water towers are estimated at 0.19 MW and 4.56 MWh respectively.

e) Water restrictions

Same as Section 6.4.3 Step 4 (d).

Step 5: Cost estimate

The capital cost of the backup electricity generation infrastructure for wastewater treatment works is approximately R 119 million. The city's wastewater treatment works will consume 131 400 litres of diesel to ensure continuous operation (at a cost of R 1.4 million).

The capital cost of increasing emergency storage capacity at the city's wastewater treatment works will amount to R 215 million. It will therefore be cheaper to install backup electricity generation infrastructure at the city's wastewater treatment works.

The costs are summarised in **Table 6-9**.

Table 6-9: Summary of costs for Scenario 3: 1-day power outage, large area.

Description	**Cost (million R)**		**Benefit**
	Capital	Operating	(million R)
WWTW power supply	119.15	1.44	-
Elevated water tower power supply	1.86	0.02	-
Total	121.01	1.46	-

Step 6: Scenario 3 conclusion

Conclusions drawn from Scenario 3:

- Based on the available information it does not appear that potable water supply will be interrupted in the event of an electricity disruption event that is shorter than one day,
- Isolated cases of water supply interruptions can occur where reservoirs or water towers do not have sufficient available storage capacity to accommodate the zonal water demand for one day,
- The cost of precautionary backup power generation requirement at elevated water towers is estimated as R 18.8 million, and
- Backup power generation to ensure wastewater treatment works can continue operating and to mitigate the environmental impact of electricity disruption will cost approximately R 120.6 million.

6.4.5 Scenario 4 (Medium-term disruption, small area)

Step 1: Scenario Description

Scenario 4 is a small-sized area affected by a medium-term electricity disruption event where an elevated storage tower cannot be filled via a pump station from a reservoir due to an electricity disruption. It is assumed that this disruption will last 7 days.

Refer to **Figure 6-4** for an indication of the tower's water distribution zone.

Step 2: System Description

The system affected consists of the Constantia Park Tower, the pumps filling the tower and its distribution zone consisting of approximately 140 houses (i.e. ± 490 people).

The demand (AADD) of this area is 355 kℓ/day and the volume of the tower supplying this area is estimated at 370 kℓ. The available spare capacity that should therefore be available in the tower given that its operating rules are adhered to is therefore ±300 kℓ.

Step 3: Risk analysis

Risks associated with this event are as per **Table 6-3**: water supply to towers interrupted for up to a week.

Since the water tower only has sufficient available storage capacity to accommodate the area's AADD for one day, water supply to the tower's zone will be interrupted for more than 6 days if the tower is not supplied during the electricity disruption event.

There is an additional risk that the zone supplied by the tower does not have sufficient storage capacity to supply the required minimum fire water requirements. However, since the area is small this should not pose a problem, especially if the fire department is kept up to date on the situation.

Step 4 : Risk mitigation options

The water tower's available water storage capacity is only sufficient to supply approximately one day's water to its zone.

Options to mitigate the impact of the electricity disruption on this tower's water supply are discussed on the following pages.

a) Do-nothing approach

This will not be a feasible solution as the result of this will be that the inhabitants of the zones supplied by the water tower will not have water for up to six days.

b) Addressing the area’s fire risk

Provision is made in the SANS 10090 (2003) standard for a municipality’s water division to inform the city’s fire brigade if a situation arises where certain fire hydrants in an isolated area cannot be used for filling fire engines due to water supply interruptions to the area. The fire brigade will therefore have to be notified accordingly to ensure that they do not use fire hydrants in the affected area to fill fire engines’ tanks in the case of a fire. This is only an applicable mitigation option for small areas (e.g. area supplied from elevated towers).

c) Additional storage capacity

Additional storage capacity is required in order to ensure that the volume of the tower is at least sufficient to be able to supply 2 days’ AADD as is recommended in the Red Book (Council for Scientific and Industrial Research, 2005). Therefore, approximately 400kℓ of additional storage capacity will have to be constructed. The additional storage capacity will, however, not be sufficient to prohibit water supply interruptions during the 7-day electricity disruption event.

d) Water tankers

If backup power generation is not available on site, water tankers will have to be deployed to the affected area to ensure that the community in the affected area has access to potable water.

Based on the estimate that 140 households and 490 people will be affected by the electricity disruption ,12 250 litres of water will have to be delivered per day in order to meet the required 25 litres per person per day as recommended in the Red Book (Council for Scientific and Industrial Research, 2005).

Therefore, one 15 kl water tanker daily should be sufficient to supply this area with water during the electricity disruption event. If it is assumed that it will take 30 seconds to fill up a 25 litre water container and that 490 water containers will need to be filled up, it will take approximately 4 hours per day to fill the affected community’s water containers. However, this is an ideal that assumes that the residents have any such large water containers and additional clean containers in which to store water. It is likely then that many more trips would be required to collect the household water quota. Moreover, residents are unlikely to be available at the same time. Hence considerably longer vehicle standing time can be expected.

A water delivery schedule will therefore have to be developed and communicated clearly to the community.

e) Backup power generator on-site

A backup power generator on site will ensure that the water tower's water level can be maintained through normal operation of the pumps supplying the main reservoir. Assuming that the water is pumped 7m from the ground level main reservoir into the tower a 5 kW on-site generator will be able to provide sufficient power generation capacity on site to ensure an unchanged level of service for this tower (including providing the minimum fire flow requirements in the tower's distribution zone). Running the on-site 5 kW generator for 20 hours per day (the assumed pumping time per day) for the 7-day period will consume 700 kWh of electricity and the diesel generator will use 315 ℓ of diesel.

f) Mobile backup power generator

If the city has mobile backup power generators available and there are no on-site backup power generation facilities, it can be used to provide electricity to the pumps affected by the electricity disruption. If mobile backup power generators are to be used it should be kept in mind that the pump station's electrical systems will probably have to be upgraded to accommodate external power supply (power connection points, surge protection, etc.).

g) Bypass the tower

Another option is to bypass the tower completely if possible and supply the affected area with potable water from the reservoir from which water is usually pumped to the elevated tower. If the pipework required to do this is not already in place, it should be relatively simple and quick to do so. It is estimated that approximately 50m of 200mm diameter pipe will be required.

Although static pressures will be very low (in the order of 5m head at the highest houses supplied from the tower), the affected community will still be able to get water from their taps. The affected community members will therefore be supplied at a lowered level of service for the duration of the electricity disruption event but will continue to have access to water from their municipal connections.

h) Water restrictions

Since this electricity disruption will result in the affected community not having water or having very little water it will be of upmost importance to effectively implement water restrictions to ensure that all affected community members will have access to potable water.

If the option of bypassing the tower is chosen, it is important to extend the area of water restrictions to include the larger main reservoir's distribution zone.

Step 5: Cost estimate

The cost of mitigating measures identified and discussed above is summarised as follows:

- Additional storage capacity required to ensure that this tower has sufficient available storage capacity for at least 2 days' AADD will cost R 2 million;
- A water tanker to supply this area will cost approximately R 1 million to purchase, although it could be shared amongst a number of communities for small isolated events;
- An on-site backup power generator will cost approximately R 50 000, with a diesel cost for the 7-day period of R 3 485;
- A mobile backup power generator that can supply power to the pump station filling the water tower will cost approximately R 914 000, although it could be shared between communities; and
- Bypassing the tower will cost approximately R 100 000.

Comparing the various options above it can be seen that the least costly option to mitigate the risk and to ensure continuous water supply (whilst ensuring an unchanged level of service) to this small area would be to provide an on-site power generator to power the pumps that fill the tower.

Bypassing the tower will lower the level of service to the end-users and will be more expensive in this instance in terms of capital cost. There will, however, be less ongoing operational and maintenance cost on the civil infrastructure (bypassing pipework) than the electrical infrastructure.

The average cost of supplying water to the affected community is:

- R 17 per person per day at an unchanged level of service (permanent on-site backup power generator)
- R 310 per person per day at an unchanged level of service (mobile backup power generator), and
- R 34 per person per day at a lowered level of service (bypassing the reservoir).

The costs are summarised in **Table 6-10**.

Table 6-10: Summary of costs for Scenario 4: 7-day power outage, small area.

Description	Cost (million R)		Benefit
	Capital	Operating	(million R)
Elevated water tower power supply	0.05	0.004	-
Total	0.05	0.004	-

Step 6: Scenario 4 conclusion

The following conclusions are drawn from this scenario:

- Water restrictions will again be key to ensure that all community members will be supplied with water;
- That installing on-site backup power generators will be the lowest cost option to ensure uninterrupted water supply; and
- If water supply via water tankers had been the least costly option, it would have been unlikely that the affected community members would have had enough 25 litre water containers (at least 4 per household) – members of the community will therefore have to be provided with (or be advised to purchase) water containers in case of emergency.

6.4.6 Scenario 5 (Medium-term disruption, medium area)

Step 1: Scenario Description

Scenario 5 is a medium-sized area affected by a medium-term electricity disruption event where Rietvlei WTW cannot supply water.

The water supply from the Rietvlei WTW is interrupted due to an electricity disruption. The duration of the electricity disruption will last 7 days. The area affected by Scenario 5 is shown in red below in **Figure 6-6**.

Step 2: System Description

The system is the same as that for Scenario 2 and is described in Section 5.3.2.

Step 3: Risk analysis

It is important to recognise that since this scenario leaves the other five regions of Tshwane in operation, the electricity outage cannot be due to a national blackout. Since the primary cause of the power outage would have to be local, due for instance to failure of a major sub-station, it is likely that the operation of Tshwane's Rietvlei WTW as well as the Magalies Water supply to Region 6 would also be out of commission. However, 76% of Tshwane's water supply is provided by RW and this source would be unaffected by the Region 6 power outage. RW's supply is by gravity and can reach virtually anywhere in Tshwane without recourse to additional pumping, although at a reduced level of service. Moreover, by diverting a small portion of RW's supply from other regions to Region 6, even more than 76% of Region 6's demand could be met with little impact on other regions.

The total available storage capacity in this area is more than two days' AADD of the region. This, together with the continued supply of most of the region's water demand from RW should ensure that the reduction in supply will be less noticeable.

Hence backup power for the water treatment works that are affected by electricity disruptions (the Rietvlei and MW WTWs) will not be required.

Possible risks associated with this event are as described in **Table 6-3**. The most critical risks include:

- Bulk water supply to the area affected (supply from the Rietvlei WTW and from Magalies Water will be interrupted, the RW supply will remain fully operational);
- Water supply to reservoirs and elevated towers filled from pump stations in the affected area will be interrupted; and
- Wastewater spillages.

Wastewater spillages resulting from the electricity disruption events and wastewater treatment works overflowing will have negative environmental effects. This will need to be addressed through the installation of backup power generation capacity (discussed below in Risk Mitigation Options).

This limited water supply interruption should not have any economic impact on wet industries or other users contributing to the GDP of the region. Action will be required to supply residents of high lying areas normally supplied from elevated water towers.

Step 4 : Risk mitigation options

The following risk mitigation options were identified:

a) The do-nothing approach

This will not be an option for this scenario due to the size of the affected area and the duration of the electricity disruption event.

b) Wastewater treatment works' backup power generation requirements

As for Scenario 2, permanent backup generating capacity is the favoured solution for the Zeekoegat - and Baviaanspoort WWTWs, with an estimated power generation requirement of 1875 kW. The assumption is made that the WWTWs would need to deliver at their full capacity for the first day and that for the remaining 6 days operating costs would be at 35% of capacity, due to the reduction in water supply available to users. The total energy consumption of the two WWTWs for the 7 day duration of the disruption will be 140 MWh.

c) Backup power generation for the water treatment works

Backup power generation at the Rietvlei Dam WTW is not necessary for this Scenario since RW can supply 76% of Tshwane's water requirements.

d) Dealing with elevated towers distribution zones' demand

The water supply interruptions to the four water towers' distribution zones can be mitigated through any of the following options:

- Bypassing the towers:
  This option will lower the level of service to the community for the duration of the event. It will cost approximately R 100 thousand per tower in pipework and there will not be a significant operational and maintenance cost due to this option.

- Providing mobile backup power generation to the towers:
  This option will entail four mobile generators deployed to the four towers' pump stations. This option will cost R 4 million based on the estimated cost of mobile generators.

- Providing mobile backup power generation to the towers:
  This option will entail four mobile generators deployed to the four towers' pump stations. This option will cost R 4 million based on the estimated cost of mobile generators.

- Providing permanent backup power generation:
  This option will entail the installation of four permanent power generators to the four sites. The power required for each of these generators is summarised in **Table 6-11**.

Table 6-11: Summary of permanent on-site power generation required for Scenario 5.

Tower name	Zone AADD (kℓ/day)	Peak demand (m^3/s)	Power required (kW)	Generator cost
Constantia Park Tower (Scenario 1 & 4)	355	0.048	4.4	R43 000
Erasmusrand Tower	1116	0.083	7.6	R75 000
Grootfontein Tower	496	0.055	5.0	R49 000
Murrayfield Tower	90	0.036	3.3	R32 000
			Total	R199 000

- Water tankers deployed to the towers zones': There are 811 households, or approximately 2900 people, supplied from the four towers. The volume required (at 25 ℓ per person) and time for one 16000 ℓ water tanker to distribute water to the affected community (at 30s per person) are summarised in **Table 6-12**.

Table 6-12: Water tanker volume required and distribution time for Scenario 5.

Tower name	Population served	Volume required (kl)	Water distribution time
Constantia Park Tower (Scenario 1 & 4)	490	12250	4 hours
Erasmusrand Tower	1540	38500	13 hours+
Grootfontein Tower	686	17150	6 hours
Murrayfield Tower	123	615	1 hour

e) Pump Stations in Bulk Region 6

There are 18 pump stations in Bulk Region 6 (including the four that supply the elevated towers discussed above). Critical pump stations in this area that are responsible for filling reservoirs will have to be supplied with backup power generation facilities.

There are three bulk pump stations in Bulk Region 6. Information on the pump sizes and power required for the pump stations is not available and will have to form part of future studies.

f) Water restrictions

Since this electricity disruption event will affect water supply to almost 600 thousand people. It will be worthwhile to impose water restrictions not only on the affected area's community but also on the adjacent Bulk Regions to ensure uninterrupted water supply.

Step 5: Cost estimate

The cost of mitigating measures identified and discussed above is summarised as follows:

a) Costs to mitigate risks

The cost of mitigating risks identified for Scenario 5 through the various options identified is briefly discussed below.

The capital cost of backup power generation facilities at the affected wastewater treatment works is R 18 million. The two wastewater treatment works will consume 142 thousand litres of diesel over the period of the event, which will amount to R 1.6 million.

Alternatively, emergency storage dams for the wastewater inflow during the electricity disruption event would cost R 309 million.

The capital cost of backup power generation facilities at the Rietvlei WTW would be roughly R 10 million. The water treatment works would consume 76 thousand litres of diesel which will amount to R 830 thousand. However, this should not be required for this scenario since the gravity supply from RW should be able to reach all but the high lying areas supplied from water towers.

The cost of providing on-site backup power generators at the elevated towers is the cheapest option to ensure uninterrupted water supply to the affected areas during the electricity disruption events. This is estimated at R 199 thousand.

Since no detailed information is available for the bulk pump stations in Bulk Region 6, the cost of providing backup power generation facilities at these pump stations cannot be determined.

b) Costs vs. benefit: Supplying water to industrial areas

Industrial and “other” consumers do not appear to be at risk for this scenario. The costs are summarised in **Table 6-13**.

Table 6-13: Summary of costs for Scenario 5: 7-day power outage, medium area.

Description	**Cost (million R)**		**Benefit**
	Capital	Operating	(million R)
WWTW power supply	18.31	0.69	-
Elevated water tower power supply	0.19	0.02	-
Total	18.50	0.71	-

Step 6: Scenario conclusion

The following conclusions are drawn from this scenario:

- Water restrictions will again be key to ensure that all community members will be supplied with water;

- Providing permanent on-site backup power generation at wastewater treatment works will be cheaper than providing emergency storage capacity;
- Providing emergency storage capacity for wastewater inflow at wastewater treatment works during medium- and long-term electricity disruptions will probably not be feasible due to the size and cost of emergency storage dams; and
- The city's wastewater infrastructure's backup power generation requirements in terms of fuel will need to be prioritised in order to ensure that fuel will be available for these works to continue.

6.4.7 Scenario 6 (Medium-term disruption, large area)

Step 1: Scenario Description

Scenario 6 is a large area affected by a medium-term electricity disruption where it is assumed that the entire City of Tshwane does not have electricity and all water treatment works supplying the city are affected by the electricity disruption event.

A city-wide medium duration event such as this would almost certainly be associated with a national blackout that would also affect RW and MW.

The area affected by Scenario 6 is shown in red in **Figure 6-7**.

The objective of this scenario is to analyse the cost vs. benefit of medium- to long-term electricity disruptions that will interrupt water supply into the City. It is a high level cost vs. benefit analysis taking the city's industries, other economically active water sectors and the city's domestic minimum water requirements into account. This scenario also investigates how much of the city's minimum water demand can be met from its own sources.

Evaluation of the implications of supplying water to high lying areas is not dealt with in this section since they have already been covered by Scenario 3.

Step 2: System Description

It is assumed that the City of Tshwane's entire water system would be affected by this electricity disruption, requiring drastic curtailment of domestic (including all bulk-, booster- and elevated tower pump stations), industrial and all other sectors contributing to the economy. Waste water treatment works would also be affected.

Normal power supply to all water treatment works supplying water into the city will be affected by the electricity disruption event (including supply from Rand Water and Magalies Water). Since Tshwane's local sources are the cheapest to treat and distribute, it is assumed that the first recourse of the city will be to supply water to its citizens from its own water treatment works.

The following priorities for minimum water supply are considered:

- Meet the basic minimum water demand of domestic users;
- Prevent spillage of untreated sewage; and
- Sustain as many of Tshwane's GDP-generating activities as possible.

Each of these priorities is discussed below:

a) Minimum domestic water supply

Meeting the basic minimum domestic water supply is the non-negotiable first priority.

Ideally supply to domestic water users could be reduced to the baseline minimum of 25 ℓ per capita per day, which is considered sufficient to sustain human requirements and permit those gainfully employed to continue to participate in the economy (provided that their employers have sufficient backup generation facilities to run their operations and that they can find transport).

This is acceptable for small isolated areas being supplied by road tankers, where few residents would have the opportunity (or time to queue twice) to withdraw more than their allocated 25 ℓ per capita per day. However, supplying the 3.15 million residents of Tshwane by this means would require no less than 5254 road tankers. Travelling at 60 km per hour, this would require a convoy 305 km long! Moreover they would all have to converge at a few local water treatment works and queue up for a substantial period of time to fill their 15 kl tanks. A fleet that size comprised even of second-hand tankers would cost Tshwane R 3.2 billion (even if there were that many second hand tankers available to be bought), only to sit idle for years, along with many of their drivers, waiting for such an emergency to occur. The time delay involved in filling all these tankers at a few supply points at one end and eking out their water to residents at the other end would also be absurdly time consuming. The many hours spent by all of Tshwane's residents queuing up to collect their ration would also be prohibitively disruptive to economic production. Clearly this solution is hopelessly impractical and costly.

By far the cheapest and most practical solution is to make use of the existing developed pipelines, pumping systems and distribution networks that have been invested in over many decades with the express purpose of delivering potable water to all of Tshwane's residents. However, there are challenges to accomplishing this.

The problem is that it is impossible to supply all residents with 25 ℓ per capita per day without giving upstream consumers served by the same network the opportunity to withdraw considerably more than their quota. The half year delay in achieving anything like the comparatively modest 15% restriction called for during 2016, together with the failure of Cape Town residents to reduce water demand below 90 ℓ to meet extremely severe prolonged drought conditions, renders voluntary attainment of a 25 ℓ per capita per day goal within only 7 days an impossible dream. Fortunately, during the drastic conditions being addressed in this option, physical constriction of water supply at source and limitation of times of supply to limited hours would go a long way to achieving the minimum target. However, this would only partially solve the problem of users located nearer to the supply source unconsciously withdrawing more than their allocation and consequently leaving downstream users with nothing at all, which is clearly unacceptable.

In view of the above practical difficulties the assumption has been made that assuring a minimum supply of 25 ℓ per capita per day to all residents will require Tshwane having to supply twice this amount, i.e. a total of 158 Mℓ/day.

Further research is required to refine this estimate, determine the best ways to achieve it and how the additional extra water requirement can be reduced.

Achievement of the basic minimum supply to all would also require standby pumps to lift water from ground level reservoirs to elevated towers. This would require pumping an average of 0.34 Mℓ/day to each of the 38 elevated towers throughout Tshwane.

b) Waste water treatment

Tshwane's waste water treatment works have a combined capacity of 584 Mℓ/day. This is assumed to define the required standby power requirement, since initially raw sewage will continue to flow into the WWTWs at this rate, while there is no power supply to run the works.

The rate at which this flow declines due to the reduction in water supply combined with the storage available at the WWTWs might allow this upper limit of the power requirement to be reduced. However, it must be appreciated that the emergency storage at WWTWs is meant to cater for wet weather sewage flow and that such conditions might prevail at onset of the power outage. Moreover, the water stored in municipal reservoirs and in the reticulation pipework could sustain normal operation of toilets, laundry, washing and showering for some time before sewer discharges decline in response to reduced water supply. Refinement of this assumption requires further investigation.

The assumption has been made that the energy requirement would be based on the full average WWTW flow of 584 Mℓ/day for the first day, and decline to 207 Mℓ/day for the remaining 6 days. (This is based on the ratios of the real water demands after and before the reduction in demand is achieved. This is calculated as the restricted overall water demand less the real loss divided by unrestricted water demand less the real loss, i.e. (423-193)/(843-193)•584 = 207 Mℓ/day)

The electricity disruption event will also affect the city's sewer pump stations, and the energy requirements for this will have to be examined in further studies.

c) Industrial water use

The supply to the city's industrial users is assumed to be kept unchanged at 42 Mℓ/day since the dominant wet industries need most of their supply to facilitate continued operation,

It should be possible to reduce this requirement by separating essential wet industry use from non-critical activities such as vehicle and floor washing and wasteful water losses in bathrooms and kitchens. These refinements also require further investigation.

d) Water use by other economic sectors

The assumption is made that the supply to "other" (commercial, governmental, etc.) water use sectors can be reduced by 75% (i.e. to 30 Mℓ/day), which is assumed to be the minimum required to keep dry industries and commercial operations functional. (This assumption will have to be confirmed by more detailed investigation.)

e) Real water losses

Real water loses have been allowed to grow to a large proportion of supply (193 Mℓ/day) and this water loss will not diminish when the supply is reduced. If anything it will increase, since the friction head of the pipes will drop resulting in a rise in pressure close to the full static head of the mostly gravity fed system.

Clearly the water supply needed to meet minimum water requirements can be substantially reduced by addressing water leaks. However, it must be recognised that the dire need to reduce water demand by 15% through leak reduction has been known for decades, during which the real water loss increased, rather than decreased. It would therefore be most unwise to assume that an as yet unachieved water loss reduction can be relied upon to meet the minimum water supply target. Until such time that there is clear evidence that the physical water losses have been reduced to more manageable levels, the assumption has to be made that the current real water losses have to be curtailed in full.

For the purposes of this study the assumption has been made that the real water loss will remain constant at 193 Mℓ/day (2015 demand year). Further study is required to refine this assumption.

It must be stressed that under conditions of severe water restriction this wastage would comprise much more than double the total basic water requirement for domestic user of 79 Mℓ/day (based on 25 ℓ per capita per day). This emphasises the urgent need to curtail water losses, which even under normal operating conditions offers considerable economic benefit for Tshwane anyway. In addition, excessive water losses are seriously degrading water security due to the extra demand on our scarce water resources. Temporarily redressing the ensuing scarcity of developed resource at source (very difficult to achieve in a water scarce interior region) is also unnecessarily increasing water tariffs, which is also counterproductive for Tshwane and all other water users.

For this scenario the city's minimum water demand would be reduced to the following:

- Domestic: 158 Mℓ/day
- Industrial: 42 Mℓ/day
- Other water sectors: 30 Mℓ/day
- Losses: 193 Mℓ/day

Based on the above assumptions the city's total water demand could therefore be decreased to a minimum of 423 Mℓ/day whilst meeting basic requirements for human consumption and critical services and continuing 75% of GPD-generating activities. This is equivalent to 73 ℓ per person per day.

Step 3: Risk analysis

Risks associated with this event are as discussed in **Table 6-3**. The most crucial of these risks include:

- Water supply into the city being interrupted for 7 days;
- Reservoirs and elevated storage towers will not be supplied with water if they are filled from pump stations in the city with insufficient backup power;
- Wastewater spillages at the city's wastewater treatment works and wastewater pump stations; and
- Economic loss due to water supply interruptions to wet-industries and other economic sectors.

The city's industries account for R 22.6 billion per year of the city's GDP (R 61.9 million per day). If all industries cannot continue to function as a result of a water supply interruption due to an electricity disruption event, the economic loss of the event will therefore be R 433 million for the 7 day period (this is the worst case economic loss and includes all industries).

It is reasonable to assume that the "other" water use sector produces the remaining R 179.4 billion of Tshwane's GDP. (A small part of this is contributed by small home industries, but this is expected to be immaterial to the calculation.) Hence this sector contributes a very substantial R 3 438 million over a 7-day period. In fact the "other" water use sector is 1.8 times more efficient at generating GDP per unit of water consumption than the manufacturing sector. This provides a telling indication of the economic importance of the services sectors.

However, not all industries and other economically active sectors will have sufficient generating capacity to sustain full production, or will not have enough fuel reserves to keep operating for 7 days. This would reduce economic activity in any event, thereby reducing the benefit attributable to maintaining an adequate water supply. Accordingly the assumption has been made that the daily economic benefit would be reduced by 25% to R 46.4 million and R 368.4 million for industrial and "other" sectors respectively.

While the domestic users are not shown as directly generating significantly to the GDP, they do provide the entire work force to the sectors that do. Hence it must be concluded that if domestic users do not receive their basic minimum water requirement, the ensuing distress would cause all economic activity to cease. This is because the workforce would be fully engrossed in finding water to satisfy their needs.

The City of Tshwane's water treatment works have a total treatment capacity of 244 Mℓ/day. The minimum water demand is 230 Mℓ/day and the daily real water loss is 193 Mℓ/day. If the real water losses cannot be reduced the total minimum water demand (including losses) will be 423 Mℓ/day. Hence 179 Mℓ/day would have to be obtained from external Water Services Providers (i.e. RW and MW). The risk in terms of the city's water treatment capacity is that the city's real water losses are so high that the minimum water demand cannot be met from its own sources if losses are not reduced.

Step 4 : Risk mitigation options

The following risk mitigation options were identified:

a) Providing backup power generation at the city's waste water treatment works

Based on a WWTW AADD of 584 Mℓ/day, the backup power requirement to prevent raw water spillage during the first day of the power outage is estimated at 12.2 MW,

The WWTWs are assumed to run at capacity for the first day, requiring an energy consumption of 293 MWh, declining to 35% of capacity for the remaining 6 days, requiring a further 616 MWh, giving a total for the 7-day outage of 908 MWh.

b) Providing backup power generation at the city's water treatment works

The city's four water treatment works with a combined treatment capacity of 244 Mℓ/day will require 6.1 MW of backup power generation capacity and will consume 1025 MWh of electricity over the 7 day period.

c) Providing backup power generation to supply water from water boards

Since a 7-day Tshwane-wide outage will almost certainly be associated with a national blackout, it can be assumed that external water boards supplying Tshwane will also be affected. It is reasonable to expect water boards, which after all are Tshwane's paid Water Services Providers, to make provision for emergency water supply during such serious electricity supply outages. It is also reasonable to expect that Tshwane will pay its fair share of the cost of such provision. (This will happen automatically through bulk water tariffs.)

A conservative estimate of the standby power requirement is based on obtaining the entire 179 Mℓ/day additional water requirement from Rand Water. Where appropriate some of the emergency supply from Water Boards would be obtained from Magalies Water. Determining the optimal proportions from RW and MW would require an in-depth examination of pumping heads, treatment costs and pipeline constraints for individual supply zones, which is beyond the scope of this study.

The total pumping head from the Zuikerbosch water treatment works to the top of the Witwatersrand via the Mapleton booster pump station through a 600 Mℓ/d pipeline is estimated at 319 m. This would require 8.65 MW of installed capacity to pump 179 Mℓ/d. Further generating capacity of about 1.12 MW, based on the minimum unit requirement given in **Table 5-10**). Hence the total standby power requirement comes to 9.77 MW.

There is no energy requirement to deliver raw water from Vaal Dam to the head of the Zuikerbosch water treatment works since this is delivered by gravity via the Zuikerbosch canal.

d) Providing backup power generation for the city’s pump stations

The city’s bulk-, booster- and elevated tower pump stations will have to be provided with backup power generation capacity. Based on 38 water towers each requiring a 5 kW pump, this amounts to 0.19 MW.

Pump stations that are required to ensure uninterrupted water supply at an acceptable level of service to industrial water users should be the specific focus of further studies.

e) Water restrictions

Effectively restricting water use for domestic and “other” economic sectors will be very essential to ensure uninterrupted water supply to the entire city and sufficient supply to the industrial sector.

f) Addressing the city’s water losses

The city’s real water losses of 193 Mℓ/day is seriously inflating (by 84%) the standby power generation required to meet minimum water demands in time of emergency. It also means that the city’s own water treatment works will not be able to supply the city’s minimum water demand from its own sources and 179 Mℓ/day (an extra 78% of the minimum supply to users) has to be supplied from distant and more expensive external sources. It is therefore imperative that the city's water losses be addressed.

One way to minimise water losses in the city's distribution network will be to close reservoir outlet valves (to residential areas) for most of the day and only opening up the reservoirs' outlet valves for a brief period or, in other words, apply "water shedding" (similar to electricity "load shedding"). This may also be an effective way to reduce the risk of the community using more water that their minimum daily allowance of 25 ℓ per person per day.

It should, however, be kept in mind that water losses will still occur during the periods that reservoir outlet valves are open. There are a few other problems with this solution:

- The City of Tshwane has 204 reservoirs and elevated towers – coordinating reservoir outlet valves opening and closing times will be very difficult and time consuming.
- There is a risk of damaging reservoir valves (especially older valves) which can result in increased water losses during a time of water supply interruptions or in the valve being stuck in the open or closed position.
- The pipe network at reservoirs and elevated towers is often complex which would further complicate closing and opening reservoir outlet valves.
- There is the danger of air locks forming as pipes empty during times when the valves are closed, leading to pipe damage when the water supply is switched back on.
- If the municipality's "disaster mitigation plan" (i.e. water shedding) is not communicated clearly and effectively with the community before a disaster situation strikes, it may result in protest and civil unrest. Water restrictions will only work effectively if public buy-in and acceptance of mitigating options are achieved. The public has to be convinced that the mitigation options opted for by the municipality are (1) put in place by the municipality in the public's best interest, (2) not occurring unnecessarily as the result of negligence by any of the parties involved (e.g. Eskom, CoT or Rand Water) and (3) that the implementation of the mitigating options are the only way to ensure continued economic activity in the CoT.

Step 5: Cost estimate

a) Providing backup power generation at the city's waste water treatment works

The capital cost of providing generators to run Tshwane's WWTWs is estimated at R 119.2 million, with a 7-day energy cost of R 4.48 million, assuming full flow for the first day and the flow reduced to 35% for the remaining 6 days.

b) Providing backup power generation at the city's water treatment works

Providing backup power generation for the city's water treatment works to operate at full capacity will cost approximately R 59.6million. Over the 7 day period the cost of energy consumption is estimated at R 5.06 million,

c) Providing backup power generation to supply water from water boards

A backup power generating plant for water treated and pumped by Rand Water would cost a further R 65.3 million with 7-day fuel cost of R 5.6 million.

d) Providing backup power generation for the city's pump stations

The capital cost of providing generators to pump water into elevated towers is estimated at R 0.19 million, with a 7-day energy cost of R 0.16 million.

The city's distribution pump stations will also require backup power generation to ensure the minimum water demand is met – the cost of this will have to be determined as part of future studies.

The different cost and benefit components are summarised in **Table 6-14**.

Table 6-14: Summary of costs for Scenario 6: 7-day power outage, large area.

Description	**Cost (million R)**		**Benefit**
	Capital	Operating	(million R)
WWTW standby power supply	119.15	4.48	-
WTW standby power supply	59.58	5.06	-
Water boards standby power supply	95.42	8.11	-
Elevated water tower power supply	1.86	0.16	-
Manufacturing industries	-	-	216.6
Other sectors	-	-	2 578.6
Total	276.00	17.81	2 795.2

e) Apportionment of potable water supply costs

Comparing the cost and benefits of supplying economically active water sectors requires splitting the costs of the components shown in **Table 5-9** differently. The costs of supplying water to all types of potable water use, including water losses, are inextricably intertwined.

Hence the potable water costs (i.e. supply from Tshwane's own WTWs plus supply by water boards) have been apportioned to each type of water use according to its portion of the total minimum water supply. In the case of the minimum domestic supply, the costs associated with standby power supply to elevated tanks have been added to the apportioned total for this water use. This information is carried forward to the economic analyses discussed in Section 6.

The apportioned capital and operating costs is given in **Table 6-15**.

Table 6-15: Summary of apportioned potable water supply costs for Scenario 6: 7-day power outage, large area.

Water supply	Supply (Mℓ/day)	Cost (million R)		Benefit
		Capital	Operating	(million R)
Domestic	290.6	108.33	9.206	-
Industrial	77.2	28.30	2.405	216.6
Other sectors	55.2	20.22	1.718	2 578.6
TOTAL	423.0	156.85	13.329	2 795.2

The costs for preventing untreated water spillages remains as per the first row of **Table 6-14**.

Step 6: Scenario conclusion

The following conclusions can be drawn from the Scenario 6 analysis:

- Minimising the city's real water losses will be key to minimising the cost of uninterrupted water supply to the city during an electricity disruption event;
- Effective water restrictions will be necessary to ensure all of the city's inhabitants have sufficient water and that industrial water demands can be met,;
- The provision of backup power generation for the city's water treatment works, WWTWs, elevated towers and external water boards is the most cost-effective means of ensuring an adequate minimum water supply to users and residents;
- This scenario carries a very high benefit, suggesting that the most economical option for the city will be to ensure uninterrupted supply to the city's wet industries and a minimum viable supply to the "Other" economic sectors; and
- It should be possible to restrict the supply to wet industries by prohibiting non-essential water uses, such as for vehicle and floor washing and garden watering. Further investigation is required to determine the degree of restriction that can be achieved for major industries.

6.4.8 Scenario 7 (Long-term disruption, small area)

Scenarios 7, 8 and 9 are similar in every way to Scenarios 4, 5 and 6, except that they are for longer 30-day periods of power outage. Hence the power requirements are identical and the operating costs and the benefits are scaled-up from 7 to 30 days. The estimated costs for scenario 7 are given in **Table 6-16**.

Table 6-16: Summary of costs for Scenario 7: 30-day power outage, small area.

Description	Cost (million R)		Benefit
	Capital	Operating	(million R)
Elevated towers	0.05	0.02	-
Total	0.05	0.02	-

6.4.9 Scenario 8 (Long-term disruption, medium area)

Scenario 8 covers the same medium area used in Scenario 5, except that the period of electricity failure is longer, at 30 days. The costs are summarised in **Table 6-17**.

Table 6-17: Summary of costs for Scenario 8: 30-day power outage, medium area.

Description	Cost (million R)		Benefit
	Capital	Operating	(million R)
WWTW standby power supply	119.15	16.13	-
WTW standby power supply	59.56	21.70	-
RW standby power supply	95.42	34.75	
Elevated water tower power supply	1.86	0.68	
Manufacturing industries	-	-	928.1
Other sectors	-	-	11 051.3
Total	276.00	73.25	11 979.4

6.4.10 Scenario 9 (Long-term disruption, large area)

Scenario 9 covers the same large area used in Scenario 6, except that the period of electricity failure is longer, at 30 days. The costs are summarised in **Table 6-18**.

Table 6-18: Summary of costs for Scenario 7: 30-day power outage, large area.

Description	Cost (million R)		Benefit
	Capital	Operating	(million R)
WWTW standby power supply	119.15	16.13	-
WTW standby power supply	59.58	21.70	-
RW standby power supply	95.42	34.75	
Elevated water tower power supply	1.86	0.68	
Manufacturing industries	-	-	928.1
Other sectors	-	-	11 051.3
Total	276.00	73.25	11 979.4

The capital and operating costs for potable water supply apportioned to different water use sectors is given in **Table 6-19**.

Table 6-19: Summary of apportioned potable water supply costs for Scenario 9: 30-day power outage, large area.

Water supply	Supply (Mℓ/day)	Cost (million R)		Benefit
		Capital	Operating	(million R)
Domestic	290.6	108.33	39.45	-
Industrial	77.2	28.30	10.31	928.1
Other sectors	55.2	20.22	7.36	11 051.3
TOTAL	423.0	156.85	57.12	11 979.4

6.5 CASE STUDY COST-BENEFIT ANALYSIS

6.5.1 Introduction

This section compares the cost of ensuring uninterrupted water supply during electricity disruption events to the economic and other benefits of uninterrupted water supply. The average annual cost and benefit was determined through comparing the probability of each electricity disruption event type (load shedding, distribution failure and blackout) to the cost and benefit of mitigating the effect of the electricity disruption event.

The costs that will result from an electricity disruption event that causes water supply interruptions can be either direct or indirect.

Direct costs are the total economic impact of water supply interruptions due to electricity disruption events. These costs are due to interrupted economic activity of the City of Tshwane. The direct costs are relatively simple to estimate based on the City of Tshwane's available economic information. The bulk of this section deals with direct costs.

The following were considered for the cost-benefit analysis:

- The city's water demand;
- The city's water supply;
- The city's wastewater treatment;
- The type, probability and duration of electricity disruption events; and
- The direct and indirect cost of the electricity disruption event.

Backup power generation is required to meet the minimum requirements for the following water uses:

- Basic minimum supply for domestic water use;
- Prevention of spillage of untreated sewage; and
- Sustaining GDP-producing activities.

The direct economic benefit of meeting the first two minimum requirements cannot be assessed. In these two instances the emphasis must rather be placed on meeting these requirements by the most efficient means. Section 6.5.2 provides an initial assessment of this.

In the case of the last bulleted requirement, a definite benefit can be attributed and compared with the cost of achieving it.

Table 6-20 summarises the risks estimated for hazardous events described in **Table 6-5** and **Table 6-6** in the case study risk analysis (Section 6.2) which have been reconciled with the electricity disruption scenarios given in **Table 3-1** (Section 3.2)**.**

Table 6-20: Estimation of recurrence intervals for each scenario.

Scenario	Event	Cause	Extent	Dur. (day)	RI (Yr)
1	Local substation	Maintenance, old equipment, cable theft	Small	1	5
4	Local substation	As above	Small	7	20
7	Local substation	As above	Small	30	50
2	1 main sub-station	As above	Medium	1	20
5	1 main sub-station	As above	Medium	7	50
8	1 main sub-station	As above	Medium	30	100
3	Regional blackout, islanding successful, no serious damage	Operating error	Large	1	38
6a	Blackout, no islanding, failed cold start, limited damage	As above, operator strike, lower intensity solar flare	Large	7	44
6b	Blackout, no islanding, infrastructure damage	High intensity solar flare with inadequate warning, computer attack, etc.	Large	7	100
6	As above	As above	Large	7	30*
9	Blackout, no islanding, Black Start facilities damaged	High intensity solar flare with inadequate warning, sabotage, attack on control centre and/or operating staff, high altitude EMP device, war, natural disaster	Large	30	155

Notes:

* The combined RI of Scenarios 6a and 6b calculated as $(1/44+1/100)^{-1}$.

6.5.2 Basic minimum domestic water supply

Meeting the basic minimum water requirement of residents is considered to be a non-negotiable cost. Put plainly it is the bottom line minimum supply level underlying the normal service delivery target of the municipality. The cost, in terms of both human suffering and economic collapse is simply too massive to ignore.

Failure to meet the minimum water requirement will mean massive human distress, leading to the disintegration of the municipality and social anarchy. It would also mean the total cessation of all economic activity, since all sectors contributing to the generation of Tshwane's GDP would be deprived of their workforce, from top management right through to unskilled labourers. If this massive disruption results in violent protest that leads to (which is highly likely under current conditions) the loss of economic activity could persist for much longer than the duration of the power outage. Hence responsible municipal managers dare not ignore the risk and cannot escape the responsibility to take reasonable action to prevent its occurrence.

Due to the fact the securing a minimum domestic water supply is not negotiable, it is inappropriate to attempt to justify it by means of a benefit-cost analysis. If providing a comfortable (normal) water supply is an important municipal target, then meeting the basic minimum supply requirement for residents a much greater imperative.

As discussed in Section 5.2.4, a basic minimum domestic supply of 25 ℓ per capita per day has been used. However, achievement of this is assumed to require a supply at the top end of the distribution system of twice this amount to account for users higher up the system being able (even unconsciously) to abstract well above their quota, which would leave downstream residents with no water at all.

Pumping water into elevated towers is considered to be part of the cost of meeting the basic minimum domestic water supply.

The capital, annual capital maintenance and operating costs for the standby power generation plant required to meet the basic water demand have been derived from the summary tables of Sections 6.4.2 to 6.4.10.

The cost requirements for each scenario are shown in **Table 6-21**.

Table 6-21: Cost requirements for minimum domestic supply.

Scenario No.	Scenario Description	RI (Yr)	Capital (mill. R)	Mainten-ance (mill. R)	Opera-tion (mill. R)	3% NDR* Ann. Cost (mill. R)	3% NDR* Δ billing+ (c/kl)
1	Small, 1 day	5	0.00	0.00	0.00	0.00	0.00
2	Medium, 1 day	20	1.86	0.02	0.02	0.12	0.05
3	Large, 1 day	38	1.86	0.02	0.02	0.11	0.05
4	Small, 7 day	20	1.86	0.02	0.16	0.13	0.06
5	Medium, 7 day	50	1.86	0.02	0.16	0.12	0.05
6	Large, 7 day	30	108.33	1.08	9.21	6.98	3.05
7	Small, 30 day	50	1.86	0.02	0.68	0.13	0.06
8	Medium, 30 day	100	1.86	0.02	0.68	0.12	0.05
9	Large, 30 day	155	108.33	1.08	39.45	6.88	3.01

Note: * Net discount rate.
+ Required increase in normal billing to customers based on average supply to paying customers of 626 Mℓ/day.

The additional charge to be borne by water users paying for their services would come to 3 c/kℓ, which amounts to an increase of less than 0.3%. This is a small price to pay to protect against the social and political consequences of a national blackout.

There is a strong likelihood of violent social upheaval inherent in a national blackout. Moreover, such an event also has a high probability of occurrence (1:30 year RI for a 7-day outage and 1:155 year RI for a 30-day outage, giving a combined RI of 1:25 years). That represents a 4% probability of occurrence in any one year and nearly a one in five chance of occurrence within the term of office of a politician. The minimal economic cost of protecting society against such a calamity pales into insignificance against such an enormous risk, which has an almost incalculable associated cost and high probability of occurrence.

When interpreting **Table 6-21**, it is noteworthy that if a larger event (such as a national blackout) is catered for, then the same capital equipment will serve to meet the generating requirements for all smaller events. Hence the capital and maintenance costs should not be repeated for any of the lesser events. All that needs to be added for smaller events is the event operating cost divided by the event recurrence interval, which gives the probable average annual operating cost.

For example, if a decision is taken to make provision for a large event of 7 or 30 day duration, then the capital investment of R 108.3 million, with an annual maintenance cost of R 1.08 million would suffice for all eventualities. The operating cost would then depend on the sum of the expected annual fuel spend. Hence, in this instance the probable annual operating cost for all 9 scenarios comes to R0.67 million.

6.5.3 Prevention of raw sewage spillage

Standby power generation to prevent the spillage of up to 584 Mℓ/day of raw sewage is considered necessary to protect the natural environment and to prohibit biological overloading of downstream water treatment works and informal users.

The direct economic benefit is difficult to assess. For example, it is difficult to determine the recovery period of river biota recover after such an event. The impact on downstream WTWs is heavily dependent on their distance from the location of the raw sewage overflow since biological and viral matter decays in rivers. The presence of intervening dams also plays a major role in the decay process. Informal use is a major concern, but is difficult to quantify and can be expected to diminish as the already high proportion of domestic users receiving a treated potable water supply increases.

During the more acute emergencies discussed in this report, meeting basic minimum water supply will be by far the most important consideration. Hence meeting this expense must take precedence over all else. Subsequently, the desirability of preventing sewage overflows will have to be weighed against its affordability by competent decision makers supported by expertise in aspects such as heath, river ecology, water quality modelling, water treatment and economics.

The capital, annual capital maintenance and operating costs for the standby power generation plant required to meet the basic water demand have been derived from the summary tables of Sections 6.4.2 to 6.4.10.

The cost requirements for each scenario are shown in **Table 6-22**.

Table 6-22: Cost requirements for preventing sewage overflow.

Scenario No.	Scenario Description	RI (Yr)	Capital (mill. R)	Maintenance (mill. R)	Operation (mill. R)	3% NDR* Ann. cost (mill. R)	3% NDR* Δ billing+ (c/kl)
1	Small, 1 day	1	0.00	0.00	0.00	0.00	-
2	Medium, 1 day	10	119.15	1.19	1.45	8.38	3.93
3	Large, 1 day	19	119.15	1.19	1.45	7.85	3.68
4	Small, 7 day	10	0.00	0.00	0.00	0.00	-
5	Medium, 7 day	30	119.15	1.19	4.48	7.42	3.48
6	Large, 7 day	25	119.15	1.19	4.48	7.67	3.60
7	Small, 30 day	50	0.00	0.00	0.00	0.00	-
8	Medium, 30 day	100	119.15	1.19	16.13	7.45	3.49
9	Large, 30 day	155	119.15	1.19	16.13	7.38	3.46

Note: * Net discount rate.
+ Required increase in normal billing to customers based on 584 Mℓ/day sewage effluent discharge.

If a decision is taken to institute the R 119.2 million capital investments in power generation plant to prevent raw sewage overflows, then all 9 scenarios would be covered. Taking account of the RI and the fuel (operating) cost of each scenario, combined probable operating cost for all 9 scenarios comes to R0.81 million.

A cost-effective means of preventing raw sewage overflows during times of power outage would be to install gas engines using biogas derived from digesters at municipal WWTWs. It is understood that the installation at the Johannesburg's Northern WWTW is competitive with the cost of Eskom supply. Hence switching to gas engines could actually be beneficial, thereby turning a cost into a benefit.

6.5.4 Maintaining industrial activity

R 22.6 billion of Tshwane's GDP is derived from the manufacturing sector, much of which is from wet industries.

The standby power generation required to maintain 50% of Tshwane's industrial output in the face of different durations of blackout has been estimated. In this instance the data required to estimate the direct economic benefit is available, facilitating comparison between costs and benefits.

The capital, annual capital maintenance and operating costs for the standby power generation plant required to maintain 50% of the GDP output of industries during blackouts are summarised in Sections 6.4.2 to 6.4.10.

Since RW supplies 76% of Tshwane's water supply, the industrial water supply is only threatened by an event that shuts down power supply to both Tshwane and RW. Since wet industries are highly dependent on water supply, process utilisation would be the dominant water use and there is little flexibility to reduce demand. Hence the simplified assumption has been made that the full industrial water demand would have to be met. However, it is unrealistic to expect that even after providing the full water supply that industrial activity will not be constrained by labour stay-aways and late arrivals due to transport difficulties. Also, some users may not have enough power generating capacity to maintain full operation. Accordingly the assumption has been made that only 50% of industrial output could be maintained.

The most feasible cause for a disruption of this areal extent and duration would be a national blackout, i.e., Scenarios 3, 6, or 9. Moreover, in view of the available reservoir storage such an event would have to persist for longer than one day. This rules out Scenario 3, leaving Scenarios 6 and 9.

The cost requirements for each scenario are shown in **Table 6-23**.

Table 6-23: Costs and benefits of maintaining 50% of industrial output.

Scenario		RI	Capital	Mainten-ance	Opera-tion	Benefit /event	3% net discount rate annual				
							Benefit	Cost	B-C	B/C ratio	Δ billing+
No.	Description	Yr	mill. R	mill. R	mill. R	mill. R	mill. R	mill. R	mill. R	-	c/kl
6	Large, 7 day	30	28.30	0.28	2.41	216.60	7.22	1.81	5.41	4.00	0.79
9	Large, 30 day	155	28.30	0.28	10.31	928.10	5.99	2.30	3.70	2.61	1.01
Combined			28.30	0.28	-	-	13.21	2.38	10.93	5.55	1.04

Note: + Required increase in normal billing to customers.

The combined cost is included in **Table 6-23**Table 6-23, along with the benefit, which is the sum of the benefits for scenarios 6 and 9. Combing the scenarios has the effect of significantly increasing the net benefit and the benefit/cost ratio. The combined increase in the cost per kl of water supplied to paying water users comes to 1.04 c/kl, which is less than 0.1% of the normal water charge. Since the capital works will have to be paid off over a shorter period than used in the longer discounting period used to make valid comparisons, the actual change in the billing will be greater than 1.04 c/kl while the capital is being paid off, but thereafter for the rest of the life of the works the capital redemption cost will drop to zero. Nevertheless, the increase in the billing will remain very small.

The benefit/cost ratio of 5.6 is very attractive.

Moreover, aside from the economic advantage, maintaining the employment of labours working in this sector would hold the advantage sustaining their families.

Good communication with employees long before such an event happens could assist in increasing the proportion of the wet industries that can keep operating. Adequate transport arrangements to get employees to work could make a big difference. Some industries may also be in a position provide additional backup, or to make use of alternative technologies to reduce their dependence on external electricity supply,

The provision of a basic minimum water supply to all domestic users is essential, since otherwise at best absenteeism due to people desperately looking for water will shut down all economic activity. Massive civil unrest and violence would also ensue, with possible much worse long term consequences.

6.5.5 Maintaining other sectors' economic activity

R 179.4 billion of Tshwane's GDP is attributable to other sectors, such as finances, commerce and other services that for most of the time are impervious to restrictions in water supply. However, below a critical level the work force of these enterprises will be affected, resulting in absenteeism and impairment of production. It is reasonable to assume that this point will be reached once domestic water supply falls below a basic minimum requirement.

Standby power generation requirements have been estimated to maintain 75% of Tshwane's industrial output in the event of large area blackout scenarios. Use has been made of readily available data to estimate the direct economic benefit.

The capital, annual capital maintenance and operating costs for the standby power generation plant required to maintain 75% of the GDP output of other economic sectors (excluding industries) during blackouts are summarised in Sections 6.4.2 to 6.4.10.

For the same reasons as discussed above, water supply to these sectors would only be disrupted by a wide area power blackout affecting both Tshwane and RW. It is assumed that water supply to these sectors, for which water is not a part of their product stream, can be reduced by 75% before serious human impact affects business. These sectors are less dependent on labourers and their wealthier employees would be better able to overcome transport difficulties. Moreover the electricity requirements to sustain core operations are more easily met by standby generators, many of which would already be in place after the long sequence of rolling blackouts. Hence the assumption has been made that 75% of the GDP-generating activities of these sectors could be maintained.

The cost requirements for each scenario are shown in **Table 6-24**.

Table 6-24: Costs and benefits of maintaining 75% other sectors' output.

Scenario		RI	Capital	Mainten-ance	Opera-tion	Benefit /event	3% net discount rate annual				
							Benefit	Cost	B-C	B/C	Δ billing+
No	Description	Yr	mill. R	mill. R	mill. R	mill. R	mill. R	mill. R	mill. R	ratio	c/kl
6	Large, 7 day	30	20.22	0.20	1.72	2578.6	85.95	1.29	84.66	66.6	0.56
9	Large, 30 day	155	20.22	0.20	7.36	11051.3	71.30	1.28	70.02	55.6	0.56
Combined			20.22	0.20	-	-	157.25	1.340	155.91	117.4	0.59

Note: + Required increase in normal billing to customers.

The combined cost and benefit for scenarios 6 and 9 is included in **Table 6-24**. The combined increase in the cost per kl of water supplied to paying water users comes to 0.59 c/kl, which represents a negligible increase that is well below 0.05% of the normal water charge.

The benefit/cost ratio of 117 and the annual net benefit of R 156 million are both substantial, indicating that the small cost of protecting the other sectors of the economy is well worth the investment.

The large disparity between the benefits derived from these economic sectors, compared with those of the wet industries is immediately apparent. Moreover, at only 30 Mℓ/day (25% of normal demand), the estimated minimum water requirement to sustain these activities is frugal.

In terms of minimum water use these sectors contribute 17 times the economic contribution per unit of water used. Under normal circumstances this comparison is immaterial and the disparity in the overall economic contribution much smaller. But when water supply is severely constrained it is a much more important consideration. It is therefore considered extremely important to provide enough emergency water supply to sustain these sectors.

Underpinning this is the imperative to ensure a basic minimum water supply to domestic users. Without this the fabric of society will collapse, and with it all economic activity.

6.5.6 Sensitivity analysis of cost-benefit analysis outcome

The input parameters used for financial calculations can generally vary to a certain degree based on the assumptions made as part of the financial analysis (these parameter include, for example the discount rate, unit cost of infrastructure or the economic benefit due resulting from mitigating a risk). Given the assumptions made as part of this study a simple sensitivity analysis was done to ensure the robustness of the results.

The overall average increase in potable water costs, taking account of the proportions of water supplied to each of the previously discussed three broad groupings (domestic, industrial and other economic sectors) comes to 5.0 c/kℓ, or 0.5% of normal paid billing. This is the estimated cost to secure a minimum basic water supply to domestic users, sustain 50% of industrial economic output and 75% of the output of other economically active sectors.

The associated overall annual cost for all three user groupings (domestic, industrial and other sectors) is estimated at R 11.0 million, yielding an annual benefit of R 170.46 million. Hence the annual net benefit comes to R 159.45 million, with an extremely high benefit / cost ratio of 15.5.

The very high benefit / cost ratio indicates rare resilience against variations in the estimates of cost and benefit. For example, even if the cost estimate were to be doubled, the annual net benefit would remain substantial at R 148.4 million and the benefit / cost ratio would still be exceptional at 7.7.

Alternatively, if the benefit were to be halved, the net benefit would be reduced to R 74.2 million but remain a significant profit on investment. The benefit / cost ratio would remain exceptional at 7.7.

If the cost were to double and the benefit halved, the net benefit would reduce to R 71.8 million but remain a substantial profit on investment. The benefit / cost ratio of 3.9 would still remain very attractive.

6.5.7 Indirect costs of electricity disruption events

Indirect costs include all other costs that can be related to the water supply interruption. The indirect costs are not so simple to estimate although it is expected that they will probably be more than the direct costs. For instance, if an electricity disruption event that causes water supply interruptions triggers major city-wide (or nation-wide) civil unrest, it can result in the following indirect costs:

- Halt all economic activity during and after the water supply interruption;
- Loss of infrastructure;
- Economic vulnerability due to global uncertainty in South Africa's economy;
- Loss of human life; and
- Result in violent regime change or civil war.

Violent regime change might shut down Tshwane's economy for a longer period of time, resulting in an economic cost equal to its entire GDP of R 202 billion, with the attendant risk of an annual cost of R 1.3 billion for a 155 year RI event.

Quantifying the indirect costs resulting from an electricity disruption event which causes water supply interruptions should be addressed as part of future studies.

7 CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSION

The following was achieved through this study:

- Risks posed by electricity disruption events were evaluated for short-, medium- and long-term disruption events.

- Institutional arrangements were proposed which would enable the relevant institutions (electricity suppliers, Water Service Providers and Water Service Authorities) to mitigate the impact of electricity disruptions on water supply.

- Infrastructure design changes to mitigate risks posed by electricity disruptions were proposed in the form of design guidelines developed for the relevant institutions.

- The cost of implementing mitigating measures identified was estimated.

- The feasibility of mitigating risks posed by electricity disruption events on water supply were determined by comparing the estimated costs of mitigating risks to the economic benefits of mitigating risks.

- The Risk Analysis and Mitigation Framework of Integrated Water and Electricity Systems was developed to guide authorities on how to mitigate the impact of electricity disruption on water supply.

- A component of RAMFIWES was tested as on the City of Tshwane.

The following conclusions are drawn from the Case Study's review of the City of Tshwane's water infrastructure and the outcome of the scenario analyses:

- For short-term electricity disruption events: It is crucial to ensure (firstly) that reservoirs and elevated towers are large enough to be able to supply at least 2 days' AADD, and (secondly) that reservoirs and towers' operating rules are adhered to in order to ensure that water levels are maintained within the fluctuation volume of the reservoirs / towers.

- For medium- to long-term electricity disruption events: It is concluded that the volume of water stored in the city’s reservoirs and elevated water towers as a measure to mitigate risks posed by electricity disruptions is less important for medium- to long-term disruptions. This is due to the fact that the volume of water stored in the city’s reservoirs and elevated towers will almost certainly run out during medium- to long-term electricity disruption events if water supply cannot be ensured (regardless of the volume of reservoirs and towers).

- Backup power generators (both mobile and permanent) will require ongoing servicing and maintenance – this will have to be incorporated into the city’s water department’s operational and maintenance schedules.

- Alternative energy sources (such as solar panels or batteries) should be considered as part of further investigations if it is decided to provide backup power to mitigate the risk of electricity disruptions on water supply – this will have to be investigated in separate cost-comparisons between various backup power supply options during the preliminary design stage of designing backup power generators.

- Providing emergency storage capacity for sewerage inflow in wastewater treatment works is more expensive than providing backup power generation at wastewater treatment works and emergency storage will not be practical for medium- to long-term duration electricity disruption events.

- The supply and delivery of fuel to the city’s water- and sewer pump stations and its water- and wastewater treatment works will have to be planned (and secured via a contract or formal arrangement) to ensure fuel gets delivered in the event of an electricity disruption event.

- The City of Tshwane will, in addressing medium- to long-term electricity disruption events, mitigate all risks associated with short-term electricity disruption events, which means that the capital cost of mitigating medium- to long-term risks will also address the short-term risks.

- The economic benefit of ensuring that water supply to the city’s industries and other economic sectors far outweigh the cost of providing water to these industries.

- Water restrictions implementation and end-user buy-in will be critical to ensure that water supply to the city is not interrupted in the event of an electricity disruption event – the most effective way to restrict water use to domestic and commercial users during electricity disruption events will probably be to close reservoir and elevated tank outlet pipes and only opening the pipes at certain times of day (after getting community buy-in).

- Public buy-in and acceptance of all other water supply mitigation options opted for by the City of Tshwane will be crucial to avoid intangible risks associated with water supply interruptions (such as wide-spread civil unrest, loss of human life, economic meltdown and civil war). The public has to believe that the mitigations opted for are firstly, put in place by the municipality in the public's best interest, secondly, not occurring unnecessarily as the result of negligence by any of the parties involved (e.g. Eskom, CoT or Rand Water) and thirdly, that the implementation of the mitigating options are the only way to ensure continued economic activity in the CoT.

- The benefits of ensuring uninterrupted minimum water supply greatly outweigh the costs of ensuring uninterrupted water supply purely from a direct economic costs-benefit analysis perspective.

- The benefit / cost ratio of supplying water during electricity disruption events is approximately 5.6 for wet-industries and 117 for other economic sectors in the CoT.

- The infrastructure required to ensure uninterrupted water supply during electricity disruption events would result in an estimated increase of approximately 1% of the consumer's water tariff.

- The intangible risks associated with prolonged water supply interruptions (socio-economic impacts) will probably be of greater concern than economic inactivity due to water supply interruptions.

- Reducing the risk of damage to Eskom's power generating facilities and distribution network during a blackout is highly desirable.

- Biogas power generation at waste water treatment works can reduce, if not eliminate, the costs associated with standby power generation plant required to prevent sewage overflows.

- The Risk Analysis Mitigation Framework of Integrated Water and Electricity Systems, or RAMFIWES, was developed based on the approach followed for this study. RAMFIWES proposes a structured approach which can be used to mitigate the impact of electricity disruption on water supply.

As part of the case study various shortcomings of current available data were identified. The following additional information will be required to be able to plan ways to mitigate the effects of electricity disruption on the City of Tshwane's water supply in detail:

- Water demand and other relevant data for the City of Tshwane's industries, including:
  - The economic output of individual wet- and dry-industries,
  - The water demand of wet- and dry-industries,
  - The spatial distribution of the city's wet- and dry industries, and
  - Information on the current level of preparation of wet-industries to continue operations during electricity disruption events.

- Water demand of other critical services in the City of Tshwane including health services, water for the security forces, water for firefighting and water for other critical services such as laboratories and scientific research institutes.

- More detailed information on the City of Tshwane's water and sewer pump stations to be able to better determine the cost of mitigating the effect of electricity disruptions on water supply.

- The actual electricity demand of each of the City of Tshwane's water treatment works and wastewater treatment works will be required to accurately determine the size of backup generators and fuel storage required on site.

- The actual electricity demand of each of the Water Service Providers' water treatment works supply Tshwane will be required to accurately determine the size of backup generators and fuel storage required on site.

- A study to quantify the indirect costs (socio-economic effect) associated with water supply interruptions due to electricity disruption events.

- A study to determine whether economic sectors other than wet-industries will be directly affected if water supply is decreased in the event of electricity disruption and if so, to what extent economic activity will be affected.

- A study to determine the current measures in place by the City of Tshwane and Eskom to protect electricity infrastructure if an electricity disruption event occurs. Future additional requirements should also be included.

7.2 RECOMMENDATIONS

In terms of the risk analysis, the following institutional and design guidelines are proposed:

- That the various stakeholders identified as part of this study (Eskom, Water Service Providers and Authorities) conduct a comprehensive risk assessment based on the framework proposed in this report.

- That the stakeholders develop a disaster risk management programme to mitigate the impact of electricity disruptions on water supply (or review it if it is already in place).

- That the stakeholders engage with each other on a regular basis to ensure communication is effective and to further reduce the risk of not being ill-prepared for an electricity event.

- That the various stakeholders review their current institutional arrangement and infrastructure status to determine whether it is in line with the proposals made in this report.

In terms of the outcome of the cost vs. benefit analysis of the case study the following is recommended:

- That the City of Tshwane put in place measures to mitigate the impact of electricity disruptions as the outcome of the case study indicates that the economic benefit of mitigating risks substantially outweigh the costs.

- That studies to further investigate and quantify the indirect impacts of electricity disruptions on water supply is conducted.

- That the Risk Analysis Mitigation Framework of Integrated Water and Electricity Systems, or RAMFIWES, be implemented by Water Service Providers and Water Service Authorities, in collaboration with Eskom, in order to effectively mitigate the risks posed by electricity disruption events on the water supply.

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