THE APPLICATION OF ECOTOXICITY AND ACTIVITY SYSTEM ANALYSIS OF SALT MANAGEMENT TO WATER RESOURCE PROTECTION AND USE: SECTOR-SPECIFIC GUIDELINES FOR AGRICULTURE, MINING AND MUNICIPAL WASTEWATER

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

BACKGROUND

Freshwater salinisation in South Africa is on an increasing trajectory with elevated levels of sulphate, sodium and chloride ions in many of the country's rivers, causing increased electrical conductivity and changes in ion composition. The problem of freshwater salinisation is intractable and desalinisation, though an effective treatment technique, it is expensive in terms of cost and energy consumption. Therefore, preventative or precautionary management options through the application of appropriate workable and innovative researched methods are not only desirable but also necessary. Again, there is a call for a new paradigm in water research in South Africa whereby science and social science methods are effectively combined to ensure proper management of water resources. The notion of combining the know-how of science and technology with knowledge from all stakeholders is one of the surest ways of managing the threat of freshwater salinisation. In this regard, this project investigated ways of effectively managing salinity risk to water resources by combining traditional science methods with those of social sciences in order to develop water quality guidelines (WQGs) and management practices for salinity. The project combined ecotoxicological and Cultural History Activity Theory (CHAT) research techniques in the light of new trends in water research.

AIMS

The following were the aims of the project:

1. To develop saltwater quality guidelines for the protection of freshwater resources from salinisation due to agriculture, mining and wastewater effluents.
2. To develop a salt management practice using the approach of CHAT.

METHODOLOGY

Short term and long term lethal exposure tests were conducted with indigenous South African aquatic organisms belonging to different taxonomic groupings. Ecotoxicological experiments were conducted by exposing different species of organisms to either NaCl, Na_2SO_4 and wastewater effluents in separate experiments. Static non-renewal experimental methods were employed for short-term lethal tests (≤ 96 h), and static renewal for long-term lethal tests (> 96 h ≤ 21 d). The mortality results were used to estimate the lethal concentration (LCx) values. The LCx values from these experiments, those from a salt database hosted by the Institute for Water Research (IWR) and those from literature search, were used to develop risk-based WQGs using the species sensitivity distribution (SSD) approach. Similarly, for the Social Science approach, a survey of water quality management activities with emphasis on salts using field questionnaire was carried out in the Kat River Valley. The questionnaires, which consisted of mainly structured questions but also a few unstructured questions, were administered to farmers who were engaged in either subsistence (small scale) or commercial (large scale) farming activities. The aim of the survey was to gather data about farming activities in the Kat River Valley and how these activities impact the river's water quality, especially salinity.

RESULTS AND DISCUSSION

Different median protective concentrations (PC) with their lower and upper predicted intervals were estimated for different proportions of the population against exposure to NaCl, Na_2SO_4 and wastewater effluents. The median protective concentrations of 95% of the population (PC95) values of distributions together with their lower and upper predicted intervals are used as the WQGs. The PC95 value is the mean guideline, while the lower-upper predicted values represent acceptable limits, i.e. acceptable or tolerable risks. Beyond these, risks are unacceptable. CHAT analysis showed that activity systems of both large and small-scale farmers seem to have minimum impact on Kat River's water salinity compared to small-scale livestock farming activity system. This is due to the fact that large-scale farmers need to satisfy export conditions of their produce so they adhere to strict standards so their activity system tend to decrease salinity; most small-scale crop farmers do not depend on the Kat River for irrigation, so their activity system tend to decrease salinity; livestock feeding and drinking approaches employed by most small-scale livestock farmers tend to increase salinity. These outcomes were used to develop good salinity management practices.

CONCLUSIONS

In this study, risked-based WQGs were developed for the protection of freshwater resources against salinity due to agriculture (NaCl), mining (Na_2SO_4) and wastewater treatments works (wastewater effluent). It is hoped that these WQGs for NaCl, Na_2SO_4 and wastewater effluent would provide some means of protection to the different ecological integrity classes of South African Ecological Reserves. Very importantly, the mutual learning and co-creation of knowledge by both research team and communities resulted in the development of a strategy to control the anthropogenic impact of salinity. Thus, using the CHAT model has ensured the development of a tool that can be used to analyse anthropogenic activities and their impacts in a catchment system and propose appropriate management options.

RECOMMENDATIONS

The following recommendations are made:

1 A future study to model climate change effect on the concentration of salts in the country's rivers.
2 A research project to characterise the major ions, and therefore major salts, found in domestic wastewater effluents.

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ACRONYMS & ABBREVIATIONS

AF	Assessment factor
AMD	Acid mine drainage
CHAT	CHAT Cultural History Activity Theory
CMA	Catchment Management Agency
DAFF	Department of Agriculture, Forestry and Fisheries
DWA	Department of Water Affairs
DWR	Developmental Work Research
DWS	Department of Water and Sanitation
ECLs	Environmental concern levels
EL	Expansive learning
ERA	Environmental risk assessment
ESLs	Environmentally safe levels
FPEF	Fresh Produce Exporters' Forum
GDP	Gross Domestic Product
HCp	Hazardous concentration
HR	High reliability
IPCC	Intergovernmental Panel on Climate Change
ITRC	International Training and Research Centre
IWR	Institute of Water Research
IWRM	Integrated Water Resources Management
KRV	Kat River Valley
LCx	Lethal concentrations
LR	Low reliability
MR	Moderate reliability
NCMP	National Chemical Monitoring Programme
NWA	National Water Act
QSAR	Quantitative structure-activity relationship
R&D	Research and development
RQOs	Resource Quality Objectives
SETAC	Society of Environmental Toxicology and Chemistry
SOPs	Standard operating procedures
SSD	Species sensitivity distribution

TDS	Total dissolved solids
TIMS	Toxicologically important major salts
TVs	Trigger values
UCEWQ	Unilever Centre for Environmental Water Quality
USEPA	United States Environmental Protection Agency
WQ	Water quality
WQGs	Water quality guidelines
WQM	Water quality management
WRC	Water Research Commission
WWTWs	Wastewater Treatment Works
WWAP	World Water Assessment Programme

GLOSSARY

Acid mine drainage (AMD): Acidic water that originates from sulphur-based substances from mines, especially, coal mines.

Climate change: A change in the statistical distribution of weather patterns when that change lasts for an extended period of time.

Cultural History Activity Theory (CHAT): A theoretical framework which helps to analyse and understand the relationship between the human mind (what people think and feel) and activity (what people do).

Developmental Work Research (DWR): A methodology for simultaneous research and innovation in workplace settings, developed by Yryö Engeström.

Ecological Reserve: The water quality and quantity, pattern of flow and physical habitat necessary to ensure good ecosystem health as identified by a resource classification procedure.

Ecological risk assessment (ERA): Evaluation of the likelihood that adverse ecological effects may occur or are occurring as a result of one or more stressors.

Ecotoxicology: A multidisciplinary field that studies the effects of toxic chemicals on biological organisms at all levels of biological organisation.

Expansive learning (EL): It is initiated when some individuals involved in a collective activity take the action of transforming an activity system through a reconceptualisation of the object and the motive of activity embracing a radically wider horizon of possibilities than in the previous mode of activity (Yryö Engeström). It is a part of activity theory and can be considered as a kind of design methodology (developmental research) that aims at change.

Freshwater salinisation: The phenomenon of freshwater resources becoming saline due to the impact of increasing salinity. Primary or natural salinisation occurs naturally and influenced by factors such as geology and climate while secondary salinisation is caused by anthropogenic activities such as industrial, mining, wastewater treatment works (WWTWs) and agriculture.

Hazardous concentration (HCp): The concentration at which a certain percentage (p) of all species is assumed to be affected in an SSD model.

LC50: The median lethal concentration or concentration that kills 50% of the population in an exposure test

Lethal concentration (LCx): The concentration of a chemical that kills certain percent (x) of the population in an exposure test.

Long-term lethal test: An exposure test that that exceeds 96 h (in this study) and the endpoint is mortality.

Maucha diagram: A graphical representation of the major cations and anions in a chemical sample.

National Chemical Monitoring Programme (NCMP): Provides data and information on the surface inorganic chemical water quality of the country's water resources.

Protective concentrations (PCx): An experimentally estimated concentration deemed necessary to protect certain proportion (x) of the population.

Salinity: The total concentration of dissolved inorganic ions in water or soil measured either as total dissolved solids (TDS, in mg/L) or electrical conductivity (EC, in mS/m).

Short-term lethal test: An exposure test that that does not exceed 96 h (in this study) and the endpoint is mortality.

Species-sensitivity distribution (SSD): The cumulative probability distribution of a toxicity measurements of a chemical obtained from single-species bioassays of various species that can be used to estimate the ecotoxicological impacts of that chemical.

Taxonomic groupings: The major groups that organism used in bioassays belong to. Organisms used in this test belong to the following 5 taxonomic groupings included insects, molluscs, crustaceans, fish and plants.

Trigger values (TVs): Protective concentration values that indicate risk of an impact if exceeded and normally result in (i.e. “trigger”) some form of management action, which may include further investigation, remediation and/or implementation of strategies.

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CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

Salinity has been defined as the total concentration of dissolved inorganic ions in water or soil, measured either as total dissolved solids (TDS, in mg/l) or electrical conductivity (EC in mS/m) (Palmer et al., 2004a; Cañedo-Argüelles et al., 2013). Although salinity is an essential component of natural waters, its level of concentration can be used as an indication of the water quality. Salinisation is a process that increases the salinity or concentration of total dissolved solids (TDS) in inland waters (Hart et al., 1991; Palmer et al., 1996; Williams, 1999). Depending on origin, it may be classified as primary or secondary salinisation. Salinity increases that originate from natural sources are regarded as primary salinisation while those arising from anthropogenic practices are called secondary salinisation (Hart et al., 1991; Palmer et al., 1996; Williams, 1999; Williams, 2001; Cañedo-Argüelles et al., 2013). Primary or natural salinisation occurs naturally in soil and water, influenced by geology and climate of the area. These factors play a role in increasing salt content of freshwater resources (Lerotholi et al., 2004). There are also aquatic ecosystems that are naturally saline, including salt pans, salt marshes, salt lakes and lagoons. Some of these ecosystems are formed by the accumulation of salts in closed basins from rainwater or leached down from terrestrial sources at rates unaffected by anthropogenic practices (Williams, 2001; Cañedo-Argüelles et al., 2013). Secondary salinisation is caused by anthropogenic activities such as industrial, mining, wastewater treatment works (WWTWs) and agriculture. In fact, most freshwater salinisation is a result of various inter-related sources mainly attributed to secondary than natural. The mobilisation of salts stored in the soil profile and/or groundwater brought about by anthropogenic activities, particularly land-use disturbances, including land clearing and irrigation, cause significant salinity levels (Marshall & Bailey, 2004). As the water table approaches the soil surface, water evaporates and leaves the salts behind which causes land salinisation or salty groundwater. This water may also move laterally or vertically towards watercourses and thereby increase the salinity of rivers and wetlands, which can affect organisms adversely (Williams, 2001; Marshall & Bailey, 2004; Thayalakumaran et al., 2007). Secondary salinisation can have a significant negative impact on biological, chemical and physical components of freshwater, especially because salts do no degrade naturally.

This notwithstanding, the instream concentrations of salts can be diluted and their potential effects reduced. However, in semi-arid regions where rainfall is minimal and evaporation often higher than rainfall, the implication is that risk of adverse effects of salinity on aquatic organisms is higher in arid and semi-arid regions than regions with plenteous rainfall (MEA, 2005). It is therefore important that salinity is properly managed in semi-arid regions such as South Africa.

South Africa experiences low annual rainfall and high evapotranspiration compared to other countries in sub- Sahara Africa (Mzezewa, 2010). This condition has been made worse in the last few years, especially in 2015-2016, whereby the country experienced an extreme drought condition. This has led to reducing water quantity in most of the country's rivers and reservoirs (e.g. dams), resulting in increased concentrations of total dissolved solids in freshwater resources. Although the drought situation is attributed to the El Nino weather phenomenon, which is a natural occurrence, anthropogenic activities such as mining, agriculture and discharges from Wastewater Treatment Works (WWTWs) are exacerbating the situation by increasing salinity levels of freshwater resources. For example, ageing WWTW plants are not able to remove all the pollutants, which end up discharged with the final effluent to receiving freshwater resources (Vogel, 2009); mine effluent such as acid mine drainage (AMD) contains high loads of salts, which end up discharged with the final effluent to receiving freshwater resources (Adler et al., 2007); and agricultural activities are responsible for increasing salinity of freshwater resources through non-point source pollution, as well as by removing and replacing of natural plants with agricultural crops and using fertilisers and pesticides that contain chemical ions.

In South Africa, freshwater salinisation poses a threat to water resource protection as well as the productive economic use of the resource. It is therefore important that innovative approaches are employed to effectively manage the salinity risk. Combining the know-how from science and technology with knowledge from all stakeholders is one of the surest ways of managing the threat of freshwater salinisation. There is a call for a new paradigm in water research in South Africa whereby science and social science methods are effectively combined to ensure proper management of water resource. Therefore, in this project, Cultural History Activity Theory (CHAT) (Jonassen and Rohrer-Murphy, 1999; Engestrom, 2000; Roth and Lee, 2007), a social science method was applied to analyse activities of salt management and to engage with salinity managers so as to effectively apply knowledge about the ecotoxicity of salts. This innovative approach holds promise for the effective management of salinity risks.

1.2 PROJECT AIMS

The aim of this project was to develop water quality guidelines for saline water as resource quality objectives (RQOs) for the protection of freshwater resources from salinisation due to agriculture, mining and wastewater effluents, as well as to develop a salt management practice using the approach of CHAT. In order to achieve this aim, the following specific objectives have been set for the project:

- To conduct short-term and long-term lethal ecotoxicological tests using selected representative salts and organisms.
- To develop risk-based salinity guidelines using species sensitivity distribution
- To use the resultant risk-based salinity guidelines as a basis for setting resource objectives.
- To assess the current risk posed by freshwater salinisation in South Africa.
- To analyse salt management activities in agriculture facility and proposed a new management practice using CHAT.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter focuses primarily on the literature review with respect to the phenomenon of freshwater salinisation at the global and national levels; how freshwater salinisation interacts with subjects of national importance such as climate change, water-energy-food nexus and wetlands. A model linking these interactions was developed at the end of the review. Also literature review was done on the tools for protection of freshwater resources, focusing on guidelines and management practices, with particular attention to wastewater, agricultural, mining and industrial facilities, drawing on international and national literature.

2.2 OVERVIEW OF GLOBAL FRESHWATER SALINISATION

The extent of freshwater salinisation in many parts of the world is also well documented (Williams, 1999; Kefford, 2007; Holland et al., 2011; Cañedo-Argüelles et al., 2013; Kunz et al., 2013). By 1991, an estimated 950 million hectares of land were already affected by salt globally (Hart et al., 1991), with worldwide climatic variation predicted to increase salinity concentrations in many parts of the world (Williams, 1999). The danger of this environmental catastrophe is that in arid areas, where precipitation range between 25 mm and 500 mm per annum, anthropogenic salinisation exacerbates the threat (Slaughter, 2005). Australia has for long described freshwater salinisation as a serious single greatest threat facing its environment (Hart et al., 1991; Palmer et al., 2004b; Marshall & Bailey, 2004; Dunlop et al., 2007; Horrigan et al., 2007). However, although natural salinity levels occurring in freshwater bodies depend on the geographical location, it is known that anthropogenic threats may not necessarily be different from one location to another (Slaughter, 2005). In addition, the geographical patterns of ionic dominance occurrence in rivers of some regions (e.g. Southern Africa) tend to classify the inland water systems based on major ion chemistry (Slaughter, 2005). In worst case scenarios, some freshwater bodies have changed to saline basins due to salt inflows in drainage water from surrounding agricultural lands (Williams, 1999).

2.3 FRESHWATER SALINISATION IN SOUTH AFRICA

South Africa experiences lower reliability of rainfall and a decrease in annual precipitation about 450 mm per annum, which both contribute to salinisation (Palmer et al., 1996; Holland et al., 2011). The demand for food by the increasing population has led to rapid industrial and agricultural developments, which has resulted in increased freshwater inorganic salts (Holland et al., 2011). Coupled with irrigation return flows, the increase in inorganic salts are a major threat to freshwater resources and soils (Palmer et al., 2004a). Most freshwater catchment areas in South Africa are widely known to contain significant natural water chemistry variations. Furthermore, increased salinisation in South Africa is burgeoned by geological formations of the area, mining, agricultural and industrial activities, while high rates of evapotranspiration and sewage effluents also exacerbate the problem (Palmer et al., 2004b; Muschal, 2006; Manders et al., 2009; McCarthy & Pretorius, 2009; Holland et al., 2011).

The effects arising from geological explorations, industrial and mining developments, and urbanisation tend to leave visual fingerprints on the total ionic composition of surface waters (Silberbauer, 2010). To visualise the ionic trends or occurrences of inorganic salt compositions in various regions of South African freshwater bodies, it is best to illustrate the various scenarios using some symbols such as the Maucha diagrams. Maucha ionic diagrams act as an important tool for comparing water chemistry types and summarise the ratios of the main ions present in a water sample (Van Niekerk et al., 2014). Furthermore, the total area for the anions on the left of a Maucha diagram balances that for the cations on the right (Van Niekerk et al., 2014). The Maucha diagram has been used to depict freshwater salinisation in South Africa for many years and it can be used to show a salt pattern and ionic distributions for rivers. Also, Maucha diagrams are powerful means for suggesting where links between land use, surface water and groundwater chemistry may occur (Silberbauer, 2010). In essence, the indicator ions show the effect of anthropogenic practices on general surface water chemistry. For example, the presence of sulphates suggests a mining activity (usually coal), while the occurrence of sodium chloride is mostly a sign of sewage effluent or agricultural activities. In this case, it is easy for one to just look at the Maucha diagram spikes to determine water chemistry available at a particular sampling site.

Some studies have characterised the presence of salts in various South African rivers based on the type of activity associated with such freshwater ecosystems. The Olifants River located in the north-eastern part of South Africa has characterised by sulphate salinisation due to predominant agricultural, industrial and mining activities in the catchment areas; while the Breede River in the Western Cape is known to be driven by agricultural salinisation, i.e. sodium chloride (Scherman et al., 2003a, 2003b). The dilute waters in Gauteng and KwaZulu-Natal are dominated by calcium carbonate while salt sodium chloride is predominant in inland waters (Slaughter, 2005). Sodium chloride is associated with inland water bodies subject to high degree of evaporation while sulphates form some proportions of the salts found in inland waters naturally (Slaughter, 2005). Slaughter (2005) reported that water resources in regions of the Northern Cape in South Africa tend to be usually saline while some rivers near Port Elizabeth contain moderate salinity levels. There are also mountain streams with low salinity flowing from mountain regions of Lesotho, the Northern Cape, eastern Gauteng and KwaZulu-Natal. In addition, Mpumalanga's Crocodile River water quality faces salinity increase due to the effluents discharged mainly from anthropogenic activities (Deksissa et al., 2004). All these indicate that secondary salinisation is widespread in South Africa despite costly remediation and prevention measures (Palmer et al., 2004a).

2.3.1 Increase trajectory of freshwater salinisation in South Africa

A recent Department of Water Affairs report (DWA, 2011) identified freshwater salinisation as a major water issue at the national scale and linked the observed phenomenon to elevated levels of sulphate, sodium and chloride, which pose a risk to industrial water supply and aquatic health. The report (DWA, 2011), in terms of salinity compliance, indicated that 30% of the monitoring sites had unacceptably high levels of salts (>85 mS/m), and 25% within the tolerable range (50-85 mS/m). This general review currently puts freshwater salinisation as one of the country's major water quality problems. This needs urgent attention since salinisation is intractable and expensive to treat. Desalinisation, removal of salts from water in order to make the quality good for the intended purpose, is an energy-intensive process. Therefore, municipal wastewater, agriculture, mining and other industry contribution of freshwater salinisation need to be prevented. This then requires accurate guideline for salts, as well as better ways of managing salts and saline effluents from municipal wastewater, agriculture, mining, and industrial activities.

This gap is what the project seeks to address by assessing the current risk posed by salinisation in South Africa, further developing and applying salt-ecotoxicity data, and vitally integrated these into management using CHAT (Cultural Historical Activity Theory)-based salinity management practices specific to municipal wastewater, agriculture, mining and industry using toxicologically important major salts (TIMSs). CHAT is a research tool for investigating human activities, such as water resource management in a systematic manner that enables learning and empowerments of individuals in their workplaces. It can be used for catalysing change in water resource management.

Although freshwater salinisation is on an increasing trajectory in South Africa, research in toxic effects of salts on the resource has remained almost static for about a decade (studies by Palmer and others in 2004/2005 remain last of substantive publications). Conversely, salt research among the international scientific community has been on the increase in recent years. For example, studies in Australia have been on the increase resulting in numerous publications in recent times (Horrigan et al., 2007; Dunlop et al., 2008; Hickey et al., 2008; Kefford et al., 2007, 2011, 2012). Furthermore, the Society of Environmental Toxicology and Chemistry (SETAC) has a Global Advisory Group on Freshwater Salinisation, which spearheads research into the regulation of salt concentration in freshwaters. Therefore, this project seeks to contribute to the global research of preventing or minimising freshwater salinisation as well as ensuring that South Africa plays a major role in salt research in Africa.

2.3.2 Salt guidelines for the Ecological Reserve

Serious water quality deterioration of South Africa's surface waters due to over a century of mining, industrial activities, and domestic water use became apparent in the early 1970s, necessitating the implementation of The National Chemical Monitoring Programme (NCMP) to provide data and information on the surface inorganic chemical water quality of the country's water resources. The NCMP focused on routine measurement of electrical conductivity, total dissolved solids and component major ions at many sites. Salinisation emerged as a major concern, with mining and industry causing increased electrical conductivity and changes in ion composition, commonly with higher sulphate concentrations. Although the NCMP continued for decades, it was only at the beginning of the 1990s that meaningful research began on the subject with studies from foremost researchers including Flugel (1991) and, Du Plessis and Van Veelen (1991).

The years that follow, Unilever Centre for Environmental Water Quality (UCEWQ) and the Institute for Water Research (IWR) of Rhodes University started intensive research into salinisation countrywide, conducting studies in almost all major rivers in the country. These studies, mainly funded by Water Research Commission (WRC) and with other funding agencies, resulted in numerous publication including Palmer et al. (1996), Goetsch and Palmer (1997), Palmer and Scherman (2000), Zokufa et al. (2001), Palmer et al. (2002), Scherman et al. (2002) and Palmer et al. (2004). These various studies formed the basis for a salinity-based process for assessing water quality in ecological Reserve determinations.

The ecological Reserve, defined as water quality and quantity, the pattern of flow and physical habitat necessary to ensure an agreed level of ecosystem health as identified by a resource classification procedure, is aimed at fulfilling the sustainability principle of the National Water

Act (NWA) (No. 36 of 1998). The NWA was based on the principles of equity, sustainability and efficiency. Equity is ensured by access to benefits from water resource use through social, economic, environmental and developments, while sustainability is ensured by resource protection to promote long-term use (NWRS2, 2013). The basis for resource protection is the ecological Reserve.

When work started for the ecological Reserve in early the 2000s, a guideline for salt was that it should not vary from the natural by more than 15%. However, work in the Olifants River showed that variation of more than 15% does not affect river health, making it difficult to know when saltly is toxic. It was the UCEWQ that first reported that different salts have different toxicity, using NaCl and Na_2SO_4 as model salts for agricultural and mining, respectively (Scherman et al., 2003). NaCl was chosen as a model for agriculture-related salinisation because Na^+ and Cl^- ions were dominant in samples collected from receiving rivers, while Na_2SO_4 chosen as a model for mining-related salinisation because of elevated SO_4^{2-} ions in receiving rivers of mining effluents. The studies with these salts and with other toxicological important major salts including $MgSO_4$, $CaSO_4$ and saline effluents led to the development of a national salinity database based on ecotoxicology (Palmer et al., 2004).

2.4 FRESHWATER SALINISATION AND CLIMATE CHANGE

According to the 5th Intergovernmental Panel on Climate Change (IPCC) report released in 2014, climate-related risks to freshwater ecosystems will continue to increase if greenhouse gas concentrations in the atmosphere continue to rise (Jiménez Cisneros et al., 2014). Under future climate change scenarios, reduced rainfall is projected to reduce available surface water and groundwater, and increase periods of drought. This will increase human competition for water and potentially reduce the amount of water available for aquatic ecosystems, potentially threaten biodiversity and functioning of these systems. The report suggested that these climate-related changes will be prominent in dry subtropical regions, particularly semi-arid regions, like southern Africa. A similar recent study by Jeppesen et al. (2015) suggested that freshwater ecosystems in a semi-arid climate and Mediterranean climate zones are projected to be particularly affected by climate-induced droughts in the future. South Africa, as a semi-arid country, needs to take every possible measure to curb the increase of greenhouse gas gases as a country and on the African continent. There is evidence that low water levels result in high salinity, with its associated reduced biodiversity and ecosystem functioning (Aladin et al., 2009). It has been suggested that the impact of increasing salinity on freshwater ecosystems may override all other impacts by environmental factors such as temperature or eutrophication (Jeppesen et al., 2009).

2.4.1 Effects of climate change on freshwater resources of South Africa

As stated earlier, South Africa is a semi-arid, water-stressed country so management of water pollution is of paramount concern (DWAF, 2004). The climate varies from desert and semi-desert in the west, to sub-humid along the eastern coastal area. The average annual rainfall is 450 mm, well, below the world's average of 860 mm per annum, while evaporation is comparatively high (DWAF, 2004). As a result, South African rivers have a low streamflow compared to other rivers in the sub-region. For example, the average annual streamflow of all the rivers in South Africa is about 49 000 million cubic metres, which is less than half the annual flow of the Zambezi River to the north. The Orange River carries only 10 percent of the volume of water flowing down the Zambezi River and one percent of that in the Congo River. The Limpopo, Inkomati, Pongola and Orange Rivers, which together drain 60 percent of the country's land area and contribute 40 percent of its total river flow, are shared with other southern Africa countries. Furthermore, only about 20 percent of groundwater in major aquifers can be used on a large scale, due to the hard nature of South African rocks (DWAF, 2004). All these factors limit water availability in South Africa. This means that dilution, which is the most common and cheapest pollution management approach, can only be used to a limited extent before it impacts negatively on other water uses and users.

The hydrology of South Africa has a high-risk climate with a low conversion of rainfall to run-off and very high year-to-year variability (e.g. a 10% change in rainfall can result in up to a 20-30% change in run-off). In addition, run-off response to rainfall is non-linear, with a larger proportion of rainfall being converted to run-off when a catchment is wetter, either because a region is in a high rainfall zone or because the soil water content is high as a result of previous rainfall (Dallas and Rivers-Moore, 2014). Climate change projections suggest that many freshwater ecosystems in the southern Africa regions, including South Africa will experience high salinity by mimicking the situation in the Murray-Darling Basin in Australia, which is expected to increase by 13-19% by 2050. In fact, many river systems, for example, the Berg River in the Western Cape, have high levels of salinity (Dallas and Rivers-Moore, 2014).

2.4.2 Effects of climate change on water levels in aquatic ecosystems of South Africa

Generally, reduced rainfall as a result of climate change and increased water abstraction for human use two main factors responsible for decreasing water levels in aquatic systems around the world. These factors are often related since reduced rainfall is likely to increase the demand for water abstraction, as communities look to use scarce water resources for their economic activities (Yano et al., 2007; Diaz et al., 2007). However, it can be difficult to disentangle the effects of increased salinity from the effects of reduced lake levels, as both are caused by reduced rainfall and water abstraction. For example, reduced water levels caused by human water abstraction can also lead to high salinity of freshwater ecosystems. For example, the Aral Sea between Kazakhstan and Uzbekistan has shrunk by more than 50% since Soviet irrigation projects were constructed in the 1960s and have high salinity levels that have resulted in huge reductions in biodiversity (Aladin et al., 2009).

There is a broad trend that changes in water levels and salinity had significant effects on the lake ecosystems, nutrient dynamics, nutrient concentrations and water quality. Water level reduction often results in higher nutrient concentrations, higher phytoplankton biomass and lower water transparency in both shallow and deep lakes and reservoirs. Similarly, increases in salinity often alter the community composition of phytoplankton, zooplankton, macrophytes and fish, consequently decreasing the biomass and diversity of each of these organism groups (Jeppesen et al., 2009).

Nutrient concentrations in lakes generally rise when the water level drops because although there is less nutrient loading from runoff of fertiliser and waste from surrounding towns and fields, the nutrients already in the shrinking lake are likely to be concentrated. In many cases, this can lead to eutrophication, where high nutrient concentrations, especially of phosphates, cause plants and algae bloom, blocking light and causing hypoxia (low dissolved oxygen levels in the water), which can kill or harm other aquatic animals, and make the water unsafe to drink or bathe in. Shallower lakes or lowered lake levels due to abstraction with increased water temperatures might experience blooms of cyanobacteria, especially of toxin-producing species such as Microcystis. It should be noted that more variable and extreme climatic conditions may lead to sporadically extreme nutrient loading, for example when heavy rain causes flooding and the erosion of river banks and overflows of wastewater and sewage pipes.

2.4.3 Effect of climate change on sea level rise and freshwater salinisation

Another effect of global climate change is the gradual sea level rise. The global mean sea level has risen about 20 cm, just as the global air temperature has also increased by about 0.5-0.6°C by the turn of the last millennium (Liu and Liu, 2014). According to USEPA (1999), sea level rise estimates for the year 2025 range from 5 to 21 inches above current sea level, while estimates of the rise by 2100 range from 2 to 11 feet. Jeppesen et al. (2009) reported that under future climate change scenarios, rising sea levels will continue to increase salinisation of freshwater ecosystems. The rise in sea level can cause saline water intrusion upstream into estuaries and rivers, thereby threatening freshwater habitat and drinking-water supplies. Salinity intrusion into inland waters could cause shifts in salt-sensitive habitats and affect the distribution of flora and fauna. Many flora and fauna are found in coastal environments because of the interaction of seasonal pulses of freshwater and constant fluctuation of tides that nurture several distinct ecosystems (Stabenau et al., 2011). Unfortunately, sea level rise due to climate change is causing freshwater salinisation thereby placing these distinct ecosystems are in danger. Salinity intrusion of inland waters may also cause their quality to become unsuitable for certain uses, such as agricultural, industrial and drinking purposes. Therefore, the determination of the salinity distribution along inland waters is a major interest for water managers in estuaries and coastal regions. Furthermore, the evaluation of transport time scales is highly related to the water quality and ecological health of different aquatic systems (Liu and Liu, 2014).

Liu and Liu (2014) established a three-dimensional hydrodynamic model to simulate salinity distributions and transport time scales in the Wu River estuary of central Taiwan. The model was calibrated and verified using tidal amplitudes and phases, time-series water surface elevation and salinity distributions in 2011. The validated model was then applied to calculate the salinity distribution, flushing time and residence time in response to a sea level rise of 38.27 cm. The results showed that the flushing time for high flow under the present condition was lower compared to the sea level rise scenario and that the flushing time for low flow under the present condition was higher compared to the sea level rise scenario.

The residence time for the present condition and the sea level rise scenario was between 10.51 and 34.23 hours and between 17.11 and 38.92 hours, respectively. The simulated results showed that the residence time of the Wu River estuary will increase when the sea level rises. The distance of salinity intrusion in the Wu River estuary will increase and move further upstream when the sea level rises, resulting in the limited availability of water of suitable quality for municipal and industrial uses.

The United States Environmental Protection Agency (USEPA) and the Delaware River Basin Commission examined implications of greenhouse warming for salinity control in the Delaware estuary. The study focused on the implications of future scenarios of a 21-inch rise in global sea level expected by 2050, which would imply a rise of 2.4 feet in the Delaware estuary; a 7-foot global rise by 2100, which would imply an 8.2-foot rise in the Delaware estuary. Increase in the estuary salinity and the possible increase in salinity of the Potomac-Raritan-Magothy aquifer system were also estimated (USEPA, 1999). The results revealed that sea level rise could substantially increase the salinity of the Delaware estuary in the next century. Also, the accelerated sea level rise could cause excessive salinity concentrations at Philadelphia's Torresdale intake and threaten the New Jersey aquifers recharged by the Delaware River if no countermeasures are taken.

2.4.4 Climate change in relation to the water-energy-food nexus

The global freshwater systems are under threat from many anthropogenic activities such as urbanisation, industrialisation, agriculture and mining, with the largest water-use sector being irrigated agriculture, which is affected by changes in water availability and irrigation water demand, both of which are caused by climate change (Figure 2.1). Higher temperatures and more variable rainfall tend to increase water demand per unit of irrigated area unless total rainfall increases sufficiently in compensation.

However, water demand to produce a given amount of food, feed or fibre will increase less (or decrease more) than demand per unit of irrigated area, as crop water productivity increases due to higher carbon dioxide concentrations (Döll et al., 2015).

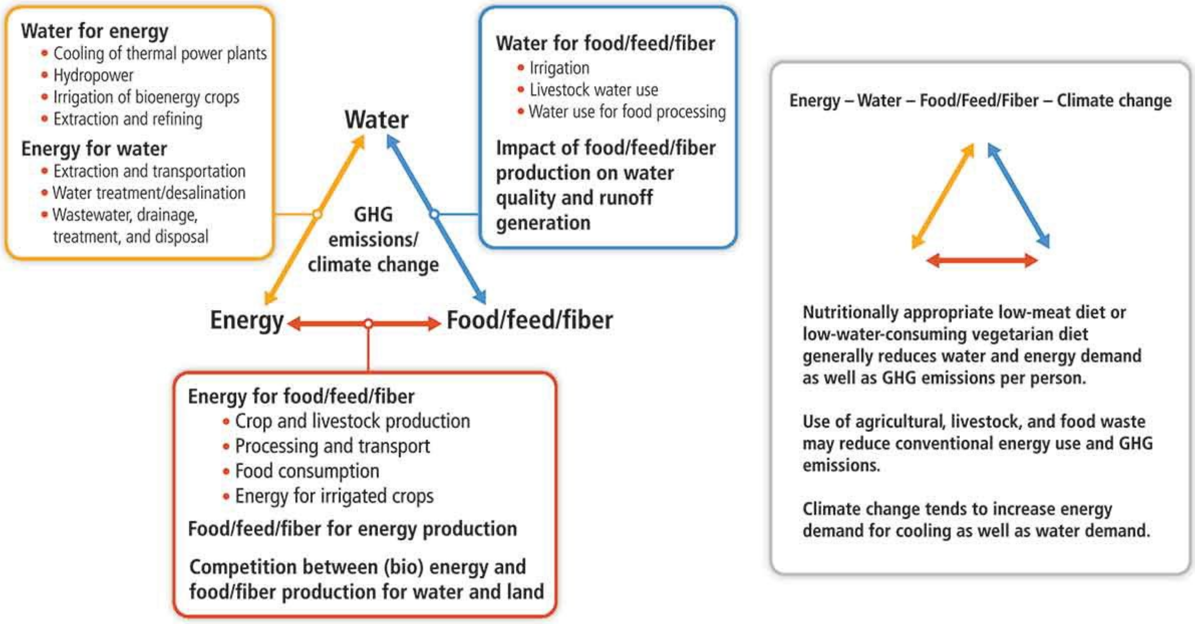

Figure 2.1: The water-energy-food nexus as related to climate change. The interlinkages of supply/demand, quantity and quality of water, energy and food/feed/fibre with changing climatic conditions have implications for both adaptation and mitigation strategies in water management too (from Arent et al., 2014).

Many modernisation processes have been undertaken in many of these areas (e.g. irrigation) around the world in recent years, with improving water use efficiency is the main objective, but simultaneously to reduce the influence of pollution, drought and to promote water conservation. Although the primary aim is to improve water use efficiency, these modernisation processes come with some side effects. Rodríguez-Díaz et al. (2011) reported that many irrigation districts have either been modernised or are currently being improved in southern Spain. However, as part of the modernisation process, some unexpected side effects have been observed. They stated that although the amount of water diverted for irrigation to farms has been considerably reduced due to improved practices, consumptive use has increased, mainly due to a change in crop rotations. The costs for operation and system maintenance have dramatically risen to about 400% as the energy for pumping pressurized systems is much higher now compared to gravity fed systems used previously.

A regional analysis in ten Southern Spain irrigation districts of the relationship between energy requirements and irrigation water applied showed that to apply an average depth of 2590 m^3 ha, the energy required was estimated to be 1000 kWh/ha. They concluded that a new approach is needed that involves effective management of both water and energy resources in the studied modernised systems.

Recent international research has highlighted the need to optimise both water and energy efficiency. For example, the California Energy Commission (CEC) launched the “Agricultural Peak Load Demand Program” with the main objective of reducing peaks in energy consumption in irrigation districts (ITRC, 2005); Moreno et al. (2009) focused on the improvement of energy efficiency at pumping stations and the determination of optimal pump curves; Pulido Calvo et al. (2003) developed a pump selection algorithm for reducing energy costs in irrigation districts, while Vieira and Ramos (2009) introduced a water turbine in the network in order to use any excess available hydraulic energy.

2.5 EFFECT OF FRESHWATER SALINISATION ON AQUATIC BIOTA

Reduced water levels have an enormous effect on the water quality of aquatic ecosystems. For example, reduced rainfall will cause increases in salinity as solutes in the water become more concentrated. A small increase in water salinity can result in a significant biodiversity loss, altering the ecosystem functions. This is because higher salinity levels put the cells of many organisms under osmotic stress, whereby the concentration of solutes in the surrounding water body affects the manner water gets in and out of an organism’s cells. Jeppesen et al. (2009) suggested that salinity is the most important factor in determining the ecology of Mediterranean lakes. They reported that *Daphnia spp.* has a low salinity tolerance (although it is higher in some Mediterranean species), while fish are least tolerant to salinity in their juvenile stages, potentially inhibiting the reproduction of existing populations. In this regard, salt-averse fish species may be replaced by salt-tolerant species such as the three- and ten-spined stickleback in highly saline lakes. Macrophyte diversity may also decrease, due to difficulties in plant germination, and the success of a small number of salt-tolerant species. Freshwater bodies vary in terms of their mineral constituent ratios and diversity (Berezina, 2003). Various groups of invertebrates manifest different requirements for the contents of main cations in water. However, although salinity is a naturally occurring constituent of freshwater (Cañedo-Argüelles et al., 2013; Hickey et al., 2008), the excessive or insufficient contents of a certain component of total dissolved solids may harm life activities of individual species, which potentially limit their distribution pattern, growth and reproduction in an ecosystem (Berezina, 2003; Nielsen et al., 2003; Miranda et al., 2010).

Aquatic organisms react adversely to salinisation increases, although the effects on individual species are poorly understood (Holland et al., 2011). Thus, a number of salinisation effects on aquatic ecosystems have been reported in various studies (Hart et al., 1991; Berezina, 2003; Palmer et al., 2004b; Slaughter et al., 2008; Holland et al., 2011; Cañedo-Argüelles et al., 2013). A study by Dallas and Day (2004) reported adverse effects on receiving waters from urban runoff to include physical effects such as flooding, erosion and sedimentation; physicochemical effects such as elevated temperatures, dissolved oxygen depletion, nutrient enrichment, toxicity; and biological effects like reduced biodiversity. Increased salinities can also lead to a proliferation of exotic freshwater species, decrease of some species richness, affect osmoregulation of aquatic organisms (whereby inhibiting the uptake of oxygen), and promote habitat loss (Slaughter, 2005; Slaughter et al., 2008; Holland et al., 2011). Salinity has also economic implications for the water users in situations where the affected rivers provide the only long-term and reliable water sources as it renders water useless for most purposes such as drinking and industrial uses. Despite abundant information of salinity effects in literature, there are still significant and increasing salinity challenges, uncertainties and knowledge gaps to fully understand effects on different species, organisms or communities in an ecosystem. Céspedes et al. (2013) study noted that water salinity and ionic composition are among the main environmental variables that confine the important niches of aquatic species, and thus, physiological tolerance to these factors constitute a crucial part of the evolution, ecology and biogeography of aquatic organisms.

Griffin and Palmer (2014) report on the status trends of the water quality in the Olifants River noted that the upper catchment water quality is heavily impacted but improves with distance downstream of the upper reaches catchment due to several land uses. Similarly, a study by Mgaba (2014) on macroinvertebrate assemblages in Bloukrans River of the Eastern Cape

Province in South Africa also revealed deteriorating water quality in the upper reaches of the river − attributed to different land uses in the catchment area.

Generally, it is widely known that pollution levels deteriorate in the downstream reaches of water bodies. As for salinity in South Africa, however, it poses grave concerns on the ecological significance of various existing species in a particular water body which may negatively affect various ecosystem functions; and current study aims to address these potential risks.

2.6 EFFECT OF FRESHWATER SALINISATION ON WETLAND ECOSYSTEMS

Ecosystems as well as the biota that inhabit them have a natural variation in their tolerance to salinity, with rivers, riverbanks, wetlands, and vegetation in lower parts of the landscape being the most likely to be affected by increased salinity. High salinity has an adverse impact on most plants because they find it becomes more difficult for plants to extract water from the soil as salinity increases. This creates an imbalance of plant nutrients in the soil, which results in some salts becoming toxic to certain plants and waterlog. Waterlogging causes poor soil aeration and therefore, lack of sufficient plant oxygen. The immediate effects of high salinity on plants that are not adapted to salt include leaf drop, leaf burn, stunted growth, poor seed germination and tree death. High salinity also affects the health of the vegetation communities as fewer young plants survive to adulthood to replace the previous generation. Furthermore, the composition of vegetation communities may also change as salt tolerant plants become dominant in salt-affected areas.

However, there are some plants called halophytes that are able to grow in high saline habitats like semi-deserts, mangrove swamps, marshes and sloughs and seashores. Halophytes have two types of salt resistance strategies: salt tolerance strategy that involves physiological and biochemical adaptations for maintaining protoplasmic viability as cells accumulate electrolytes; salt avoidance strategy that involves structural with physiological adaptations to minimize salt concentrations of the cells or physiological exclusion by root membranes. Another classification of halophytes is excretives (or excluders) and succulents (includers). Excretives have glandular cells capable of secreting excess salts from plant organs, while succulents use an increase in water content within large vacuoles to minimize salt toxicity.

Salt is a natural component of the Australian landscape in which a number of biota have adapted inhabiting rivers and wetlands. According to Nielsen et al. (2003), periods of low flow have resulted in the concentration of salts in wetlands and riverine pools under natural flow conditions. The organisms of these systems survive these salinities by tolerance or avoidance.

They suggested that freshwater ecosystems in Australia are now becoming increasingly threatened by salinity because of rising saline groundwater and modification of the water regime reducing the frequency of high-flow (flushing) events, resulting in an accumulation of salt. They also reported that available data point to the fact that aquatic biota in these systems will be adversely affected as salinity exceeds 1000 mg/L (1500 EC).

Climate change can impact salt marshes in a number of ways, including through sea-level rise, by sea walls preventing marsh vegetation from migrating upward and inland (Erwin, 2009). However, evidence studies have shown that sea-level rise does not necessarily lead to loss of marsh vegetation because some marshes may accrete vertically and maintain their elevation with respect to sea-level where the supply of sediment is sufficient.

Conversely, organogenic marshes and those in areas where sediment-limiting areas may be more prone to coastal squeeze if some extreme predictions of accelerated rates of sea level rise are realized (Erwin, 2009). Increasing temperature and decreasing rainfall due to climate change may affect tidal marshes drastically. For example, increased temperature may interact with other stressors to damage coastal marshes as occurred in the Mississippi Delta where large areas of salt marsh were stressed and dying during the spring to fall period of 2000. This observation was attributed to the combined effects strong La Nina event, which resulted in sustained low water levels, prolonged and extreme drought, and high air temperatures. These combined factors raised soil salinities to stressful and, consequently, toxic levels (Erwin, 2009).

Climate change models projects higher water temperatures, increased precipitation intensity, and longer periods of low flows, exacerbating freshwater salinisation and many forms of water pollution such as sediments, nutrients, dissolved organic carbon, pathogens, pesticides, and thermal pollution. The current state of water quality of many South African rivers and wetlands coupled with climatic drivers impose so much stress on these ecosystems (Dallas and Rivers-Moore, 2014). Furthermore, much of South Africa is projected to have increases in annual stream flows by 20-30%, regardless of flow variability, duration and timing, except the southwestern Cape, which will have reduced stream flows especially in the wet years. They suggested a likelihood of streamflow reduction that would result in perenniality (rivers) or permanence of inundation (wetlands), with perennial rivers becoming non-perennial and permanent wetlands becoming seasonal or temporary (Dallas and Rivers-Moore, 2014).

2.7 MANAGEMENT OF FRESHWATER SALINISATION

2.7.1 Water management and policy for low water and high salinity

It is imperative that water resource management plan or policy for aquatic ecosystems in semi-arid regions takes into account future climate change scenarios and increased human demands for water in the future if such tools are to manage, conserve and potentially restore these ecosystems adequately. Integrated water resource management (IWRM) may be employed, emphasising on the reshaping of planning processes, coordination of land and water use, recognising the interrelatedness of water quality and quantity, sustainable use of surface water and groundwater, and the protection and restoration of natural systems and inland water storage. The IWRM approach include promoting sustainable water use, such as water pricing and water use prioritisation; control over-abstraction of surface and groundwater; implementation of water safety technologies; efficient water usage and conservation technologies; reduction of water loss and water-friendly farming; and increasing the storage capacity of water in the drainage basin through reforestation and controlled drainage.

2.7.2 Countermeasures against salinity intrusion of inland waters

Both natural processes and human interventions can counter salinity intrusion of inland waters due to climate change. High capacity reservoirs could offset salinity increases. According to USEPA (1999), salinity increases resulting from a one-foot rise in sea level expected in the next forty years would require increased reservoir capacity of at least 110 thousand acre-feet. It has also been suggested that possible shifts in precipitation resulting from the greenhouse warming could overwhelm salinity increases caused by sea level rise and that most coastal areas will experience a 10 percent increase in precipitation. Again, soil deposition events from periodic hurricane storm surges have increased the elevation of coastal embankments in the past (Whelan et al., 2009; Davis et al., 2004). While these deposition events are expected to provide a measure of resistance to rising sea level, they are also a source of saltwater inundation. Increases in freshwater flow through restoration efforts may offset increases in soil salinity in the coastal habitats.

2.8 CONCLUSION

This literature review shows the current state of freshwater resources in South Africa and around the globe and the impact of increased salinity on these resources. It is evident that climate change is affecting the flow regimes and volumes of freshwater bodies. The decrease in water flow and quality implies less volume for dilution, and therefore increases concentrations of pollutants, including salts, downstream of discharge points.

Increase salinity has economic implications for the water users as it renders water useless for most purposes such as drinking and industrial uses. Increasing salinity also poses grave threats to the ecological significance of various freshwater ecosystems, including the existing biota, which may result in biodiversity loss. It may also impact negatively the various ecosystem services and functions. Thus, the current study aims to address these potential risks.

CHAPTER 3: ECOTOXICITY TESTS OF SELECTED SALTS AND WASTERWATER TO FRESHWATER MACROINVERTEBRATES

3.1 INTRODUCTION

The development of the South African salinity ecotoxicity database focussed on using NaCl as a model for agriculturally-related salinisation because of the dominance of Na+ and Cl- ions found in water bodies that predominantly drains these species. Similarly, Na_2SO_4 was used as model for mining related salinisation because of elevated SO_4^{2-} ions found in water bodies that predominantly drains these species (Palmer et al., 2004). Unlike agriculture and mining, the major constituents of ions found in wastewater have not been properly described. Therefore, the aim of this chapter was to generate ecotoxicity data for NaCl (representing salinisation due to agriculture), Na_2SO_4 (representing salinisation due to mining) and wastewater treatment works (WWTW) effluent (representing salinisation due to wastewater). This aim was achieved by exposing selected indigenous South African freshwater organisms of different taxonomic groupings to the two test salts and WWTW effluent using short-term (96 h) and long-term (240 h) exposure methods. The resultant lethality data obtained were used to calculate lethal concentration values, including LC1, LC10, LC50, LC90 and LC99), which were in turn used to derive risk-based salinity guidelines using the species sensitivity distribution (SSD) technique in chapter 4.

3.2 MATERIALS AND METHODS

3.2.1 Aquatic organisms used in the toxicity tests

Short term and long term lethal, Roundup® exposure tests were conducted with different aquatic organisms belonging to different South African taxonomic groups. These include insects (*Adenophlebia auriculata*, *Afronurus barnardi*, *Afronurus peringueyi*, *Afroptilum sudafricanum*, *Baetis harrisoni*, *Euthraulus elegans*, *Tricorythus discolour* and *Tricorythus tinctus*), molluscs (*Burnupia stenochorias*), and crustaceans (*Caridina nilotica* and *Daphnia pulex*).

These organisms were collected from either unimpacted sites in the Palmiet or Balfour Rivers in the Eastern Cape Province, South Africa, or obtained from laboratory cultures maintained in laboratories of Unilever Centre for Environmental Water Quality (UCEWQ) (Institute for Water Research, Rhodes University, Eastern Cape Province, South Africa). The species, common names, taxonomic group, and collection source are recorded in Table 3.1. All field-collected species were acclimated to laboratory conditions for a minimum of 24 hours before exposure.

Table 3.1*:* Characteristics of South African species in laboratory toxicity tests with different concentrations of NaCl and Na_2SO_4

Scientific Name	**Common name**	**Taxonomic grouping**	**Source**
Adenophlebia auriculata	Mayfly	Insect	Palmiet River
Afronurus barnardi	Mayfly	Insect	Palmiet River
Afronurus peringueyi	Mayfly	Insect	Palmiet River
Afroptilum sudafricanum	Mayfly	Insect	Palmiet River
Baetis harrisoni	Mayfly	Insect	Palmiet River
Burnupia stenochorias	Limpet	Mollusc	Balfour River
Caridina nilotica	Shrimp	Crustacean	Lab cultured
Daphnia pulex	Water flea	Crustacean	Lab cultured
Euthraulus elegans	Mayfly	Insect	Palmiet River
Tricorythus discolour	Mayfly	Insect	Palmiet River
Tricorythus tinctus	Mayfly	Insect	Palmiet River

3.2.2 Exposure tests of aquatic organisms

Static non-renewal experimental methods were employed for acute tests (short-term lethal tests) (≤ 96 h), and static renewal for chronic tests (long-term lethal tests) (> 96 h ≤ 21 d). Based on a prior range-finding tests, 10 different tested concentrations (0.625, 0.25, 0.5, 1, 2, 4, 8, 16, 32 and 64 g/L) were selected and used for both lethal and sub-lethal tests. All exposure tests involved water-only controls. For all animal exposure tests, each concentration contained 10 organisms and was replicated three times. Dead organisms were recorded twice daily and removed from experimental vessels. Animals were not fed during short-term exposure periods but were fed with TetraMin tropical flakes to satiation twice a day during the long-term experimental period.

Experiments were conducted under a 12-hour light: 12-hour dark artificial light regime using Biolux fluorescent tubes in a temperature-controlled room of temperature 25.00°C (± 0.05) in

600 mL glass beakers for the macro-invertebrates and 20 L glass tanks for fish exposure tests. The experimental chambers were provided with aeration. Water quality parameters, including hydrogen ion concentration (pH), dissolved oxygen (DO), electrical conductivity (EC) and temperature were measured in all concentrations at the beginning and just after change of solution.

Mortality was evaluated in different ways for the different species. Generally, animals were deemed dead when they become immobile and unresponsive (i.e. they did not respond to any form of repeated tactile stimulation with the aid of a plastic pipette after about 10 seconds under a stereo-microscope (van Wijngaarden *et al.*, 2010)), decolourised or degenerated. The mortality score endpoints were used to calculate the lethal concentrations at which specific percentage of animals died (LCx). Mortality of organisms in controls was less than 10% for all exposure tests.

3.2.3 Statistical analyses

Probit statistical software version 1.5 (USEPA, 1990) was used to estimate the LC50 values and their 95% confidence limits. One-way analysis of variance (ANOVA) followed by Tukey multiple comparison post hoc tests were used to compare mean LC50 values of all taxonomic groups. Statistics were performed using Statistica Version 9 and all statistical decisions were made at alpha = 0.05 *a priori*.

3.3 RESULTS

3.3.1 Water quality parameters

The overall mean water quality parameters for NaCl and Na_2SO_4 toxicity tests were as follows: control pH ranged from 6.8 to 8.5, DO from 5.8 to 6.0 mg/L, EC from 0.8 to 0.9 mS/cm and temperature from 23.0 to 24.5 °C. The ranges of these water quality parameters for the treatment groups were not significantly different from those of the control and were all within the acclimated conditions of the culture maintained in the laboratory.

3.3.2 Short-term laboratory toxicity tests

Mortality results of the short-term toxicity tests for NaCl and Na_2SO_4 were used to estimate lethal concentrations, which are presented in Tables 3.2 and 3.3, respectively. ANOVA of macroinvertebrates acute LC50 values for NaCl showed a significant difference between at least two taxonomic groups ($p < 001$). A pairwise Tukey multiple comparison tests at the 0.05 significance level revealed that the LC50 values of *Tricorythus tinctus, Baetis harrisoni,* *Daphnia pulex* and *Burnupia stenochorias* were not significantly different, but significantly different from *Caridina nilotica* and *Euthraulus elegans*.

Table 3.2: Mean LC50 values with upper and lower limits for different organisms exposed to NaCl for 96 h

Organism	**Mean LC50 (mg/L)**	**Lower limit (mg/L)**	**Upper limit (mg/L)**
Tricorythus tinctus	1846.16	142.02	12163.08
Baetis harrisoni	2353.13	287.77	3237.85
Daphnia pulex	2882.76	2325.70	3508.96
Burnupia stenochorias	4289.83	3956.06	4698.84
Caridina nilotica	6542.87	5550.32	7479.54
Euthraulus elegans	8084.41	7074.67	9306.07

Table 3.3: Mean LC50 values with upper and lower limits for different organisms exposed to Na_2SO_4 for 96 h

Organism	**Mean LC50 (mg/L)**	**Lower limit (mg/L)**	**Upper limit (mg/L)**
Daphnia pulex	2025.68	1122.41	5439.62
Tricorythus tinctus	2166.83	939.14	3400.96
Baetis harrisoni	2988.77	43.36	6862.25
Afroptilum sudafricanum	3267.01	2870.04	3617.73
Tricorythus discolor	3499.52	172.45	4335.60
Burnupia stenochorias	5089.97	4703.68	5555.12
Caridina nilotica	5157.66	4021.72	6220.60
Afronurus barnardi	5878.41	4920.91	6897.59
Adenophlebia auriculata	8240.58	7664.24	8620.67

3.3.3 Long-term laboratory toxicity tests

Similarly, mortality results of the long-term toxicity tests for NaCl and Na_2SO_4 were used to estimate lethal concentrations, which are presented in Tables 3.4 and 3.5, respectively. ANOVA of macroinvertebrates chronic LC50 values for NaCl showed no significant difference between any of the taxonomic groups ($p = 0.98$). However, ANOVA of macroinvertebrates chronic LC50 values for Na_2SO_4 showed a significant difference between at least two taxonomic groups ($p = 0.02$). A pairwise Tukey multiple comparison tests at the 0.05

significance level revealed that the LC50 values of *Tricorythus tinctus* and *Tricorythus discolor* were not significantly different, just as the LC50 values of *Tricorythus discolor* and *Caridina nilotica* were not significantly different. Nevertheless, the LC50 values of *Tricorythus discolor* and *Caridina nilotica* were significantly different.

Table 3.4: Mean LC50 values with upper and lower limits for different organisms exposed to NaCl for 240 h

Organism	**Mean LC50 (mg/L)**	**Lower limit (mg/L)**	**Upper limit (mg/L)**
Tricorythus tinctus	2384.50	799.23	3337.99
Tricorythus discolor	3389.24	885.24	5147.58
Afronurus barnardi	4124.57	3131.38	6321.81
Baetis harrisoni	4646.03	3552.95	6033.29
Afronurus peringueyi	4732.61	3392.40	4868.91
Euthraulus elegans	5329.47	3724.32	11462.62
Adenophlebia auriculata	5859.13	4279.26	8082.29
Caridina nilotica	7014.00	6385.52	7664.49

Table 3.5: Mean LC50 values with upper and lower limits for different organisms exposed to Na_2SO_4 for 240 h

Organism	**Mean LC50 (mg/L)**	**Lower limit (mg/L)**	**Upper limit (mg/L)**
Tricorythus tinctus	1197.45	950.86	1608.23
Tricorythus discolor	2680.12	2275.56	3155.90
Caridina nilotica	3603.59	3085.07	3970.67

3.3.4 Comparison of NaCl and Na_2SO_4 toxicities to the test organisms

For 96 h acute toxicity test, the test organisms were found to be significantly more sensitive to NaCl than Na_2SO_4 ($p < 0.05$), whereby the mean 96 h LC50 values registered for both salts were 3851.94 mg/L and 8522.08 mg/L for NaCl and Na_2SO_4, respectively. However, for 240 h chronic toxicity test, the test organisms were found to be significantly more sensitive to Na_2SO_4 than NaCl ($p < 0.05$), whereby the mean 240 h LC50 values recorded for both salts were 3027.71 mg/L and 5488.77 mg/L for Na_2SO_4 and NaCl, respectively.

3.4 DISCUSSION

This study has shown that both NaCl and Na_2SO_4 can pose adverse effects to the aquatic macroinvertebrates, whether the exposure was acute or chronic. From the above results of the comparison of NaCl and Na_2SO_4 toxicities to the test organisms, very interesting phenomenon can be observed. The organisms became more tolerance (i.e. less sensitive) to NaCl as time increased, which was evidenced in the LC50 value increasing from 3851.94 mg/L at 96 h to 5488.77 mg/L at 240 h.

On the contrary, organisms exposed to Na_2SO_4 became less tolerance (i.e. more sensitive) to the salt as time increased, resulting in decreasing LC50 values from 5488.77 mg/L at 96 h to 3027.71 mg/L at 240 h. This interesting phenomenon seems to suggest that Na_2SO_4 may persist in the environment and have an accumulating effect upon exposure to aquatic macroinvertebrates. However, opposite to this phenomenon may be the case for NaCl exposure to the aquatic macroinvertebrates.

Many ions are found in nature but very little is known about their effects on aquatic organisms (Dallas and Day, 2004). Studies have shown that many South African rivers are at risk of salinity (Slaughter, 2005; Holland et al., 2011). The Olifants River in Mpumalanga and the Breed River in the Western Cape have been reported to contain high levels of sulphates and chlorides respectively due to predominant agricultural, industrial and mining activities in the catchment areas (Scherman et al., 2003; Holland et al., 2011). Some studies have argued that excessive contents of a certain component of salinity may harm life activities of individual species, thereby potentially limiting their distribution pattern, growth and reproduction in an ecosystem (Berezina, 2003; Miranda et al., 2010). The current study has shown that both NaCl and Na_2SO_4 toxicity adversely affected all the tested organisms. Although few results exist on effects of these two salts on the tested organisms, a couple of studies have been reported to show that macroinvertebrates are susceptible to such salts.

In South Africa, when work started for the Ecological Reserve in early the 2000s, a guideline for salt was that it should not vary from the natural by more than 15%. However, work in the Olifants River showed that variation of more than 15% does not affect river health, making it difficult to know when saltly is toxic. It should be noted that chronic background toxicity, below acute toxicity, is toxic to organisms in the longer term, and that many freshwater salinisation in South Africa is on an increasing trajectory. A recent Department of Water Affairs report (DWA, 2011) identified freshwater salinisation as a major water issue at the national scale, and linked the observed phenomenon to elevated levels of sulphate, sodium and chloride, which pose a risk to industrial water supply and aquatic health.

Through various work done by the UCEWQ, the first reported toxicity of different salts was recorded, using NaCl and Na_2SO_4 as model salts for agricultural and mining, respectively (Scherman et al., 2003). NaCl was chosen as a model for agriculture-related salinisation because Na^+ and Cl^- ions were dominant in samples collected from receiving rivers, while Na_2SO_4 chosen as a model for mining-related salinisation because of elevated $SO4^{2-}$ ions in receiving rivers of mining effluents. Unfortunately, the situation has not changed; these two areas (agriculture and mining) continue to be the major anthropogenic sources of freshwater salinisation in South Africa as shown by the results of this study.

3.5 CONCLUSION

It has been argued that salts become toxic to the aquatic biota when they exceed natural concentrations (Kefford et al., 2002). In order to manage the effects of increasing freshwater salinisation, it is important to measure the responses of freshwater organisms to changes in salinity, which can appropriately be done in laboratory experiments. The outcome of laboratory studies can provide a causal link between a particular salinity and the measured responses. This assertion is backed by recent laboratory experiments whereby high salinities have been reported to adversely affect freshwater macroinvertebrates (Holland et al., 2011; Kefford et al., 2003, 2005, 2006; Mensah et. al., 2015).

Therefore, the findings of these study could be applied to derive guidelines for the protection of freshwater macroinvertebrates. The findings of this current study could also contribute to data for validation and refinement of the existing inconsistencies in South African Ecological Reserve boundaries for salts. This is part of this project: to develop risk-based salinity guidelines using species sensitivity distribution and to use the resultant risk-based salinity guidelines as a basis for setting resource objectives for resource protection.

CHAPTER 4: DEVELOPMENT OF RISK-BASED SALINITY GUIDELINES

4.1 INTRODUCTION

Environmental risk assessment (ERA) is the process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors (Claassen et al., 2001). The species sensitivity distribution (SSD) technique is one of the tools used in ERA as well as deriving water quality guidelines (USEPA, 1998; CCME, 2007; Posthuma and de Zwart, 2014). In this chapter, the SSD approach was applied to develop risk-based salinity guidelines using the lethal concentrations values obtained from the short-term and long-term lethal ecotoxicological tests reported in the previous chapter (chapter 3). Lethal concentrations were also extracted from the salinity database hosted by the Unilever Centre for Environmental Water Quality (UCEWQ), Institute of Water Research (IWR), Rhodes University. Thus, risk-based salinity guidelines were developed for involving exposing organisms of different taxonomic groupings to the salts NaCl, Na_2SO_4 and WWTW effluent, representing salinisation due to agriculture, mining and wastewater, respectively. In this thesis, SSDs are used to estimate protective concentrations for NaCl and Na_2SO_4. The findings could be used to design appropriate freshwater monitoring programs that are aligned with the protection of water resources as stipulated in the National Water Act (Act No. 36 of 1998).

4.1.1 Species sensitivity distribution (SSD)

A single-species battery assay is used in aquatic ecotoxicology as a predictive effect assessment tool to assess the effect mechanisms (mode of actions) of toxicants. However, extrapolation of results obtained from single-species test batteries to ecosystems is often over-simplified because important aspects of community ecology are not considered (Schmitt-Jansena *et al.*, 2008). Such over-simplification of the ecosystem may include the following:

- Ecosystem assemblages of species usually cover a wide range of different species sensitivities, but only one or a few aquatic test species are used in ecotoxicological or regulatory testing.
- Different species in a community interact through competition for food and space, but this is not the case in single-species bioassays.

- Important functional groups may be under-represented or completely left out in a single-species test battery assay since such an assessment does not consider the community structure of the ecosystem.
- Ecosystem functions are not considered in single-species test batteries assay since assessment strategies are restricted to the species level (Schmitt-Jansena *et al.*, 2008).

Therefore, to achieve a better ecological risk assessment of toxicants, with higher ecological relevance, it is worthwhile integrating theoretical ecology in aquatic ecotoxicology (Schmitt-Jansena, 2008). This can be done by integrating ecological, chemical, analytical and ecotoxicological tools. The role of basic ecology is to derive the mechanistic understanding of ecosystem structure, function and regulation, while aquatic ecotoxicology is used to support regulatory decisions by providing scientifically sound methods to derive environmental quality criteria or to identify and assess relevant contamination in aquatic ecosystems. Therefore, a strong base of theoretical ecology is necessary to develop ecotoxicological measurement tools that are scientifically sound. Such tools will enhance ecological relevance in assessment strategies and reduce uncertainty in the extrapolation process (Schmitt-Jansena *et al.*, 2008). Traditionally, dose-response data from single-species toxicity tests were used in ecological risk assessment processes to protect populations, communities, and ecosystems (Newman *et al.*, 2000). This seems to create incongruity, as extrapolations of results to these entities from single-species are often oversimplified (Schmitt-Jansena *et al.*, 2008). Kooijman (1987) proposed an evaluation of species-sensitivity distribution (SSD) to resolve the difference between individual-based data and the complex biological entities addressed in ecological risk assessment. The SSD method is now considered a useful tool in aquatic ecotoxicology for predictive effect assessments of toxicants.

The SSD is based on the principle that living things have inherent biological differences. These differences create diversities in behaviour, geographical distribution, life history, morphology, physiology and taxonomy. This means different species will respond differently to a given toxicant concentration because they have different sensitivities. This variation in species sensitivities can be described by a statistical distribution or empirical function, which gives rise to SSDs (Posthuma *et al.*, 2002).

The main hypothesis of the SSD approach states that the sensitivities of a set of species can be described by a “distribution”, often a parametric distribution such as normal, triangular or logistic; or nonparametric distribution, such as resampling. Available data from ecotoxicological studies are used as a sample from this “distribution” to estimate the SSD parameters. Specific percentile from the empirical distribution is then used to estimate a safe concentration expected to protect most species of interest. This safe concentration is then used to set an environmental water quality (EWQ) guideline (Posthuma *et al*., 2002). Based on the above treatise, SSD may be defined as the representation of species-sensitivity variation to a toxicant by a statistical or empirical distribution function of responses for a sample of species.

Application of SSD in ecological risk assessment involves combining data from single-species toxicity tests to predict concentrations affecting only a certain percentage of species in a community (Newman *et al*., 2000). For instance, the median lethal concentration (LC50), no-observed-effect concentration (NOEC) or lowest-observed-effect concentration (LOEC) values from single-species data for many species are separately fitted to a distribution such as the lognormal or log-logistic. A hazardous concentration (HCp), at which a certain percentage (p) of all species is assumed to be affected, is then identified from the resulting distribution of species sensitivities. The most conservative form of this approach uses the lower 95% tolerance limit of the estimated percentage to ensure that the specified level of protection is achieved (Newman *et al*., 2000). The SSD or extrapolation methods are not only being incorporated into ecological risk assessments but also into recommendations for pesticide registration and regulation (Newman *et al*., 2000). Application of the SSD method demands assumptions in order to ensure derivation of reliable water quality criteria. Chapman *et al*. (1996) and Newman *et al*. (2000) stated these assumptions include the following:

- The LC50, EC50 and NOEC derived from single-species toxicity tests have very significant deficiencies as measures of effect on field populations and communities. Thus, the SSD, which is a secondary metric based on such compromised primary metrics, possesses the same deficiencies.

- The extrapolation of the single-species toxicity test measures of effect to field populations and communities may suspiciously result in species loss, which may be acceptable or not. Proponents of the SSD methods are of the view that the loss is acceptable and has no intrinsic value since communities harbour enough redundancy to allow for some loss. Those who oppose the redundant species hypothesis combine the rivet popper hypothesis with the argument that it is better when faced with uncertainty in ecological risk assessment, to adopt a conservative stance. The rivet popper hypothesis states that “community integrity is reduced by each loss of a species” and contends that ecosystem productivity, stability, sustainability, and nutrient retention decrease as species diversity decreases.

- Species-sensitivity distribution methods could downplay the importance of maintaining dominant and keystone species, as well as influencing species interactions if they are not performed with careful thought.

- Single species toxicity tests are often biased toward mortality data and the use of standard test species that are amenable to laboratory culture and manipulation, even though sub-lethal effects and non-standard test species, respectively, may be at least as important in determining local population extinction. Nevertheless, these deficiencies are shared by other risk assessment applications of ecotoxicological data, including SSD.

- Many data sets plotted alongside values predicted from the assumption of a specific distribution may not be valid, as they show clear deviations from the assumed lognormal distribution. The basic assumption of a uni-modal distribution is even more uncertain since SSD uses pooled data from different taxonomic groups. In order to reduce the size of this problem, specific taxonomic groups were used in the SSD procedure in the present study, but the ambiguity associated with selecting the lognormal distribution still remains.

- Assessment of questions about adequate sample size and representativeness of the community is difficult for most applications. Most discussions in this regard centre on pragmatic issues of producing an acceptable number of observations for regulatory agencies. Most studies fail either to report confidence limits along with estimates of HCp, to calculate minimal sample sizes, or to discuss the extent of the dataset in relation to the community at risk.

Two of the above issues, namely ambiguity in selecting a specific distribution, and estimation of the adequate number of species needed to estimate HCp precisely, are partly answered by bootstrap estimation. Firstly, bootstrap estimation decreases the intricacy of selecting an appropriate distribution since calculations do not require an explicit distribution. The only prerequisite is a random sample of species sensitivities from a set of possible species sensitivities. Secondly, bootstrap methods can be used to assess the number of approximate species needed to minimise variation around the HCp estimate (Newman *et al*., 2000).

In this study, the SSD approach was used to derive water quality guidelines (WQGs) for NaCl and Na_2SO_4, using data from single species toxicity tests conducted with South African aquatic organisms.

4.1.1.1 Measures for estimating the SSD

The measure normally used to generate SSDs is the no observed effect concentration (NOEC). However, this practice has received widespread criticism from authors including Chapman *et al*. (1996), Fox (2008), Newman (2008), Warne and van Dam (2008), Landis and Chapman (2011), Jager (2012), and van Dam *et al*. (2012). The authors opined that the NOEC is associated with a number of deficiencies. These deficiencies include the fact that (a) it is one of the test concentrations (b) the procedure by which it is determined "rewards bad experiments" (c) it cannot be determined in some cases (d) its size is a function of the choice of statistical test and level of significance, and therefore (e) definite conclusions cannot be made based on it. In order to eliminate the problems associated with using NOEC data to generate SSDs, other measures such as lower LEC/EC values including LC/EC 1, 5, 10 and 20 have been proposed as alternatives (Fox, 2008). In this study, these proposed lower LC/EC values were used to generate SSDs for long-term protection of aquatic life, while short-term WQGs were derived using LE(C) 50 values.

4.1.2 Development of protocol for derivation of water quality guidelines

Warne et al. (2004) developed a protocol for the development of South African water quality guidelines (WQGs), using the Australian and New Zealand framework (ANZECC and ARMCANZ, 2000) extensively as a reference. This was due to the fact that the ANZECC and ARMCANZ (2000):

- Aims at achieving sustainable use of water resources by protecting and enhancing their quality while maintaining economic and social development, which is in line with National Water Act (Act 36 of 1998) of South Africa.

- Incorporates the most recent advances in ecotoxicology, ecology, statistics and ecological risk assessment in deriving water quality guidelines (WQG). Although currently under revision, it is widely acknowledged as being the most sophisticated set of water quality guidelines in the world (Warne, 2001).

- Uses the species sensitivity distribution (SSD) method in preference to assessment factors (AF) (Warne, 2001). The SSD is advantageous to AF because it selects the statistical distribution that best fits the toxicity data from a family of distributions rather than trying to apply a single distribution.

- Acknowledges that the national water quality guidelines may not be applied blindly to all freshwater aquatic ecosystems and encourages site-specific assessments in addition to providing a series of risk-based decision trees to support and guide site-specific investigations (Warne, 2001).

- Specifically addresses the toxicity of mixtures, which are not included in any other known framework for the development of guidelines (Warne, 2001).

In this study, the Australian and New Zealand framework (ANZECC and ARMCANZ, 2000), United States (USEPA, 2005), Canada (CCME, 2007) together with those of South Africa (Warne et al., 2004) were used as reference documents to develop a water quality derivation protocol for the various salts. This was used to derive salinity guidelines that could be used for water resource management. Water quality guidelines are perceived as environmentally safe levels (ESLs) that would provide adequate protection to aquatic life (Warne, 2001).

The ANZECC and ARMCANZ (2000) and Warne *et al*. (2004) frameworks referred to the ESLs as trigger values (TVs), which may be derived using an SSD in preference to AF approach. Therefore, TVs and SSDs are briefly discussed as applied in this study to derive WQGs for NaCl and Na_2SO_4.

4.1.3 Trigger values

Trigger values (TVs) are protective concentration values used to manage chemical substances in the environment for the protection of aquatic life. Trigger values indicate risk of an impact if exceeded and normally result in (i.e. “trigger”) some form of management action, which may include further investigation, remediation and/or implementation of strategies (Warne *et al*., 2004). There are three grades of hierarchical TVs, namely high reliability (HR), moderate reliability (MR) and low reliability (LR). The LR TV is further divided into interim (LR (interim) TV) and environmental concern level (LR (ECL) TV), depending on the quality of data. Warne *et al*. (2004) suggested that derivation of HR TV should always be the target if there is adequate and suitable toxicity data. However, if data to derive HR TV are inadequate, then the hierarchy is descended until the available data meet the minimum requirements for a particular grade of TV (Warne *et al*., 2004).

A TV may be determined using either the assessment factor (AF) approach, which involves dividing the most sensitive toxicity value by an assessment factor (usually 10, 100 or 1000) (Warne, 2001), or the species sensitivity distribution (SSD) approach, which involves fitting a statistical distribution to toxicity data of a number of species in order to estimate the concentration that should protect any chosen percentage of species (Warne *et al*., 2004). The SSD is the preferred approach, but AF is used where data are constrained (ANZECC and ARMCANZ, 2000; USEPA, 2005; Warne *et al*., 2004; CCME, 2007). The data requirements for using the SSD approach in determining trigger values are presented in Tables 4.1 and 4.2. In the current study, a number of South African aquatic organisms belonging to five different taxonomic groups were used to derive a high-reliability trigger value for protecting aquatic life from exposure to the excess salts.

Table 4.1: Minimum data required by the statistical distribution approach for the three grades of trigger values (after Warne et al., 2004)

Level of trigger value	Minimum data requirement
HR	Requires chronic NOEC toxicity data for at least five species that belong to at least four different taxonomic groups
MR	Requires acute toxicity data (i.e. LC50 or EC50) for at least five species that belong to at least four taxonomic groups
LR (interim) for non-polar chemicals only	Requires nineteen estimates of chronic toxicity derived by QSARs

Table 4.2: Types of taxonomically different organisms and major subdivisions to which they belong (after Warne et al., 2004)

Major subdivisions of organisms	Types of organisms that are considered as being taxonomically different
Fish	Fish
Invertebrates	Crustaceans, insects, molluscs, annelids, echinoderms, rotifers, hydra
Plants	Green algae, blue algae, red algae, macrophytes
Others	Blue-green algae (cyanobacteria), amphibians, protozoans, coral, fungi and others

4.2 METHODOLOGY

4.2.1 Data from single-species toxicity tests, UCEWQ database and literature search

Single-species short-term and long-term ecotoxicity tests were conducted (in chapter 3) whereby different South African freshwater aquatic organisms belonging to five different taxonomic groupings were exposed to two salts. The five taxonomic groupings included insects, molluscs, crustaceans, fish and plants, while the two salts to which the organisms were exposed to were NaCl, Na_2SO_4 and wastewater effluents. The exposed organisms were collected from either the Swartkops or Balfour Rivers in the Eastern Cape Province, or were obtained from laboratory cultures maintained in laboratories of Unilever Centre for Environmental Water Quality (UCEWQ), Institute for Water Research, Rhodes University, Eastern Cape Province. Algae toxicity tests were conducted using commercial algaltoxkit bought from a local supplier.

The details of how the various tests were actually conducted had already been presented in chapter 3. Short-term and long-term lethal and effective concentrations values (LCx and ECx) for NaCl, Na_2SO_4 and wastewater effluents from these tests, as well as data extracted from the UCEWQ salt toxicity database and literature search, are presented in Tables 4.3-4.7. The short-term data consisted of LC50 values for tests of durations not more than 96 h, while the long-term data consisted of LC1-20 values for test durations of mostly 240 h. These data were used to generate SSD curves for organisms representing the five taxonomic groupings and their responses to NaCl, Na_2SO_4 and wastewater effluents.

Table 4.3: Short-term LC50 values of NaCl for different freshwater species used to generate SSDs

Scientific name	**Taxonomic grouping**	**Test duration (h)**	**LC/EC**	**Conc (g/L)**	**LCL (g/L)**	**UCL (g/L)**
Tricorythus tinctus	Insect	96	50	1.689	0.067	14.935
Euthraulus elegans	Insect	96	50	7.625	6.560	8.979
Baetis harrisoni	Insect	96	50	1.569	0.000	2.972
Caridina nilotica	Crustacean	48	50	5.979	4.823	7.059
Caridina nilotica	Crustacean	48	50	5.955	5.100	6.752
Caridina nilotica	Crustacean	48	50	4.450	3.709	5.196
Caridina nilotica	Crustacean	48	50	5.487	4.528	6.446
Caridina nilotica	Crustacean	96	50	8.568	7.546	9.483
Oligoneuriopsis lawrencei	Insect	96	50	4.815	4.300	5.244
Plea pullula	Insect	96	50	0.008	-	-
Daphnia pulex	Crustacean	48	50	1.911	0.426	4.490

Scientific name	**Taxonomic grouping**	**Test duration (h)**	**LC/EC**	**Conc (g/L)**	**LCL (g/L)**	**UCL (g/L)**
Daphnia pulex	Crustacean	48	50	2.400	2.255	2.538
Daphnia pulex	Crustacean	48	50	2.926	2.868	2.989
Daphnia pulex	Crustacean	24	50	3.827	3.670	3.979
Daphnia pulex	Crustacean	48	50	2.975	2.896	3.060
Daphnia pulex	Crustacean	24	50	3.569	3.388	3.744
Daphnia pulex	Crustacean	24	50	4.072	3.936	4.203
Daphnia pulex	Crustacean	48	50	3.696	-	-
Chlorella sorokiniana	Plant	96	50	0.240	-	-
Chlorella protothecoides	Plant	96	50	1.690	-	-
Chlorella vulgaris	Plant	96	50	1.370	-	-
Pseudokirchneriella subcapitata	Plant	96	50	0.540	-	-

Table 4.4: Long-term LC1-20 values of NaCl for different freshwater species used to generate SSDs

Scientific name	**Taxonomic grouping**	**Test duration (h)**	**LC/EC**	**Conc (g/L)**	**LCL (g/L)**	**UCL (g/L)**
Caridina nilotica	Crustacean	240	1	0.244	0.181	0.290
Euthraulus elegans	Insect	240	1	0.583	0.286	0.868
Afronurus peringueyi	Insect	240	1	1.314	0.841	1.709
Afronurus peringueyi	Insect	240	1	2.430	1.538	2.957
Tricorythus discolor	Insect	240	1	1.958	1.195	2.378
Tricorythus discolor	Insect	240	1	0.427	0.072	0.875
Euthraulus elegans	Insect	240	1	1.265	0.198	2.128
Tricorythus tinctus	Insect	240	1	0.323	0.007	0.618
Adenophlebia auriculata	Insect	240	1	1.703	0.391	2.747
Adenophlebia auriculata	Insect	240	1	0.286	2.143	3.386
Baetis harrisoni	Insect	240	1	2.007	0.473	2.746
Baetis harrisoni	Insect	240	1	2.394	1.789	2.760
Afronurus peringueyi	Insect	240	1	0.255	0.138	0.385
Euthraulus elegans	Insect	240	1	2.716	0.809	3.672
Euthraulus elegans	Insect	240	1	0.175	0.000	0.614
Tricorythus discolor	Insect	240	1	0.817	0.118	1.390
Afronurus barnardi	Insect	240	1	1.427	0.854	1.846
Euthraulus elegans	Insect	240	1	1.830	0.459	2.812
Euthraulus elegans	Insect	240	1	0.431	0.064	0.881
Tricorythus discolor	Insect	240	1	1.977	1.068	2.417
Afronurus barnardi	Insect	168	1	1.564	0.694	2.121
Tricorythus discolor	Insect	168	1	0.667	0.068	1.214
Tricorythus discolor	Insect	168	1	0.087	0.009	0.241
Euthraulus elegans	Insect	168	1	3.253	1.648	4.181
Euthraulus elegans	Insect	240	1	2.053	1.071	2.760
Tricorythus discolor	Insect	240	1	1.283	0.024	2.138

Scientific name	**Taxonomic grouping**	**Test duration (h)**	**LC/EC**	**Conc (g/L)**	**LCL (g/L)**	**UCL (g/L)**
Tricorythus discolor	Insect	216	1	0.103	-	-
Tricorythus discolor	Insect	240	1	0.058	-	-
Tricorythus discolor	Insect	240	1	0.098	-	-
Euthraulus elegans	Insect	240	1	0.963	-	-
Caridina nilotica	Crustacean	240	5	2.480	2.370	2.540
Chlorella sorokiniana	Plant	96	20	0.120	-	-
Chlorella protothecoides	Plant	96	20	0.590	-	-
Chlorella vulgaris	Plant	96	20	0.520	-	-
Pseudokirchneriella subcapitata	Plant	96	20	0.150	-	-

Table 4.5: Short-term LC50 values of Na_2SO_4 for different freshwater species used to generate SSDs

Scientific name	**Taxonomic grouping**	**Test duration (h)**	**LC/EC**	**Conc (g/L)**	**LCL (g/L)**	**UCL (g/L)**
Tricorythus discolor	Insect	96	50	2.722	1.014	4.306
Tricorythus discolor	Insect	96	50	2.584	0.758	4.382
Tricorythus tinctus	Insect	96	50	2.757	1.875	4.409
Afroptilum sudafricanum	Insect	96	50	3.096	1.952	4.087
Adenophlebia auriculata	Insect	96	50	10.379	9.940	10.808
Adenophlebia auriculata	Insect	96	50	6.363	5.994	6.695
Afroptilum sudafricanum	Insect	96	50	2.755	2.588	2.942
Adenophlebia auriculata	Insect	96	50	8.073	7.583	8.550
Tricorythus discolor	Insect	96	50	9.400	8.233	12.180
Afronurus barnardi	Insect	96	50	5.924	4.840	7.129
Caridina nilotica	Crustacea	48	50	5.989	4.874	7.181
Caridina nilotica	Crustacea	48	50	7.002	4.710	9.024
Caridina nilotica	Crustacea	48	50	5.734	5.084	6.614
Caridina nilotica	Crustacea	48	50	5.477	4.840	6.007
Caridina nilotica	Crustacea	96	50	6.820	5.615	7.886
Plea pullula	Insect	96	50	0.009	0.007	0.012
Adenophlebia auriculata	Insect	96	50	7.736	-	-
Euthraulus elegans	Insect	96	50	10.165	-	-
Daphnia pulex	Crustacea	48	50	0.610	0.056	10.360
Daphnia pulex	Crustacea	48	50	3.446	2.671	4.428
Daphnia pulex	Crustacea	48	50	2.565	1.218	15.874
Daphnia pulex	Crustacea	48	50	3.269	2.801	3.749
Caridina nilotica	Crustacea	96	50	2.052	1.587	2.516
Adenophlebia auriculata	Insect	96	50	6.439	3.594	9.283
Burnupia stenochorias	Mollusc	96	50	1.491	1.267	1.715
Oreochromis mossambicus	Fish	96	50	4.385	3.697	5.074

Scientific name	Taxonomic grouping	Test duration (h)	LC/EC	Conc (g/L)	LCL (g/L)	UCL (g/L)
Pseudokirchneriella subcapitata	Plant	48	50	3.802	-	-
Chlorella sorokiniana	Plant	96	50	2.350	-	-
Chlorella protothecoides	Plant	96	50	2.330	-	-
Chlorella vulgaris	Plant	96	50	2.310	-	-
Pseudokirchneriella subcapitata	Plant	96	50	0.350	-	-

Table 4.6: Long-term LC1-20 values of Na_2SO_4 for different freshwater species used to generate SSDs

Scientific name	Taxonomic grouping	Test duration (h)	LC/EC	Conc (g/L)	LCL (g/L)	UCL (g/L)
Caridina nilotica	Crustacean	240	1	0.173	0.107	0.246
Caridina nilotica	Crustacean	240	1	0.966	0.586	1.301
Caridina nilotica	Crustacean	240	1	1.800	0.775	2.445
Tricorythus tinctus	Insect	240	1	0.122	0.061	0.179
Tricorythus discolor	Insect	252	1	0.796	0.422	1.058
Tricorythus discolor	Insect	252	1	0.641	0.303	0.901
Tricorythus tinctus	Insect	288	1	0.137	0.074	0.197
Tricorythus discolor	Insect	252	1	0.342	-	-
Caridina nilotica	Crustacean	240	10	0.339	0.217	0.462
Adenophlebia auriculata	Insect	240	10	0.027	0.030	0.086
Burnupia stenochorias	Mollusc	240	10	0.334	0.273	0.394
Oreochromis mossambicus	Fish	240	10	1.893	1.220	2.565
Pseudokirchneriella subcapitata	Plant	96	10	1.002	-	-
Chlorella sorokiniana	Plant	96	20	0.760	-	-
Chlorella protothecoides	Plant	96	20	0.420	-	-
Chlorella vulgaris	Plant	96	20	0.400	-	-
Pseudokirchneriella subcapitata	Plant	96	20	0.160	-	-

Table 4.7: Short-term LC50 and corresponding toxic unit values of wastewater effluent for different freshwater species used to generate SSDs

Organism	Taxonomic grouping	LC50	Toxicity units (100/LC50)
Melanoides tuberculata	Mollusc	11.4	8.8
Ceriodaphnia dubia	Crustacea	40.0	2.5
Poecillia reticulata	Fish	19.0	5.3
Daphnia magna	Crustacea	32.0	3.1
Selenastrum capricornutum	Plant	14.0	7.1
Caridina nilotica	Crustacea	51.2	2.0
Stonefly	Insect	3.6	27.8

4.2.2 Generation of species sensitivity distributions curves for NaCl, Na_2SO_4 and wastewater effluent

Species sensitivity distributions (SSDs) were constructed using the Species Sensitivity Distribution Generator, a tool used to create custom SSDs (Posthuma et al., 2002; USEPA, 2005). The SSD generator fits a commonly applied distribution, the log-probit (i.e. linearized log-normal) to data for concentrations at which different species exhibit a standard response to a stressor (Posthuma et al., 2002; USEPA, 2005). The 95% protective concentrations (PC95) of NaCl, Na_2SO_4 and wastewater effluent were calculated from the SSDs and used to derive water quality guidelines for their respective sectors.

4.3 RESULTS

4.3.1 Generation of SSD curves and protective concentrations for NaCl

The NaCl LC/EC values from the single-species test results and UCEWQ database were used to generate species sensitivity distribution (SSD) curves using the SSD Generator. SSD curves were generated for South African freshwater aquatic organisms based on 48-96 hour short-term LC50 (Figure 4.1) and 168-240 long-term LC1-20 values (Figure 4.2) values. The model's goodness of fit in terms of R^2 was 0.803 and 0.972 for short-term and long-term analysis, respectively. Protective concentrations for different proportions of the population against NaCl were also estimated for short-term (Table 4.8) and long-term (Table 4.9) exposures, respectively.

Table 4.8: Probit estimation of protective concentrations for different proportions of the population against short-term exposure to NaCl

Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.355	-1.501	0.277	-0.537	-2.465	0.032	0.290	0.003
0.1	3.718	-1.157	0.251	-0.239	-2.075	0.070	0.576	0.008
0.2	4.158	-0.740	0.228	0.135	-1.615	0.182	1.363	0.024
0.4	4.747	-0.183	0.212	0.661	-1.026	0.657	4.583	0.094
0.5	5.000	0.057	0.210	0.898	-0.783	1.141	7.908	0.165
0.7	5.524	0.554	0.217	1.408	-0.300	3.584	25.609	0.502
0.8	5.842	0.855	0.228	1.730	-0.020	7.162	53.661	0.956
0.9	6.282	1.272	0.251	2.190	0.354	18.704	154.704	2.261
0.95	6.645	1.616	0.277	2.580	0.652	41.327	380.485	4.489

Table 4.9: Probit estimation of protective concentrations for different proportions of the population against long-term exposure to NaCl

Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.355	-0.877	0.006	-0.735	-1.018	0.133	0.184	0.096
0.1	3.718	-0.737	0.006	-0.601	-0.873	0.183	0.251	0.134
0.2	4.158	-0.567	0.005	-0.436	-0.699	0.271	0.366	0.200
0.4	4.747	-0.341	0.005	-0.214	-0.469	0.456	0.612	0.340
0.5	5.000	-0.244	0.005	-0.116	-0.371	0.571	0.765	0.426
0.7	5.524	-0.042	0.005	0.087	-0.171	0.908	1.221	0.675
0.8	5.842	0.080	0.005	0.211	-0.051	1.203	1.627	0.889
0.9	6.282	0.249	0.006	0.386	0.113	1.776	2.430	1.298
0.95	6.645	0.389	0.006	0.531	0.248	2.450	3.394	1.769

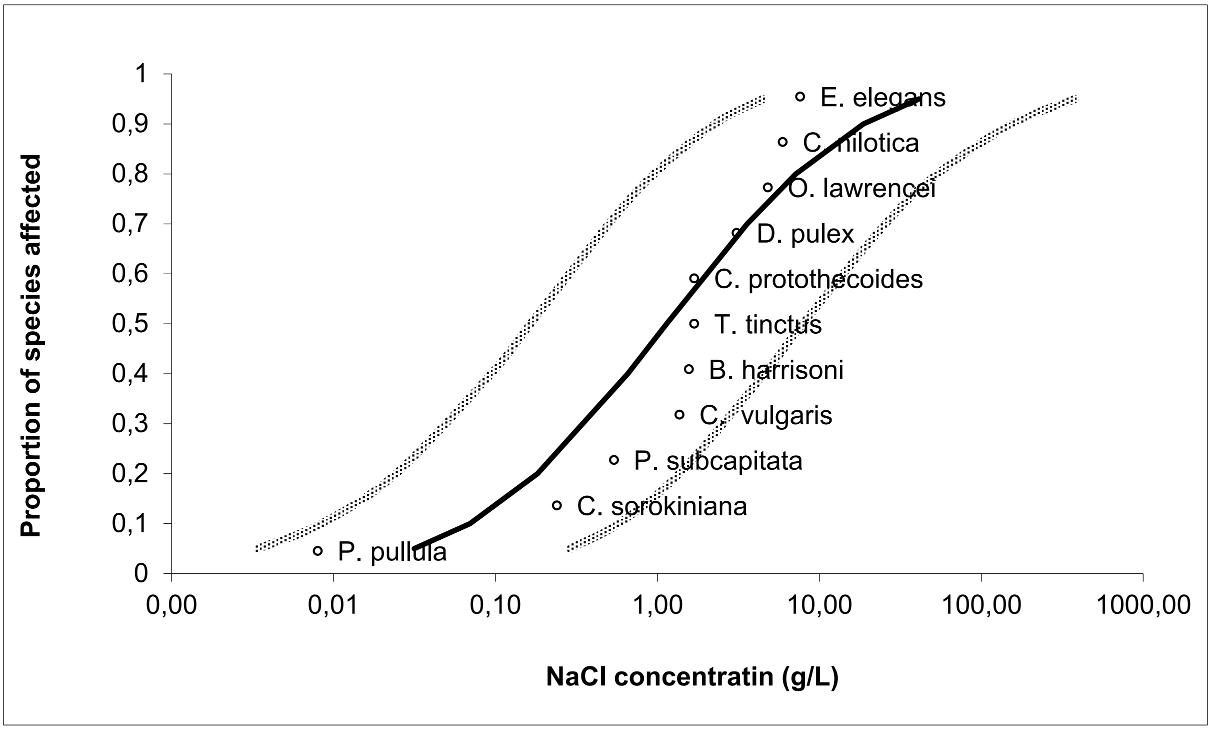

Figure 4.1: Species sensitivity distribution (SSD) curve of freshwater aquatic organisms from based on short-term 48-96 hour LC50 values for NaCl

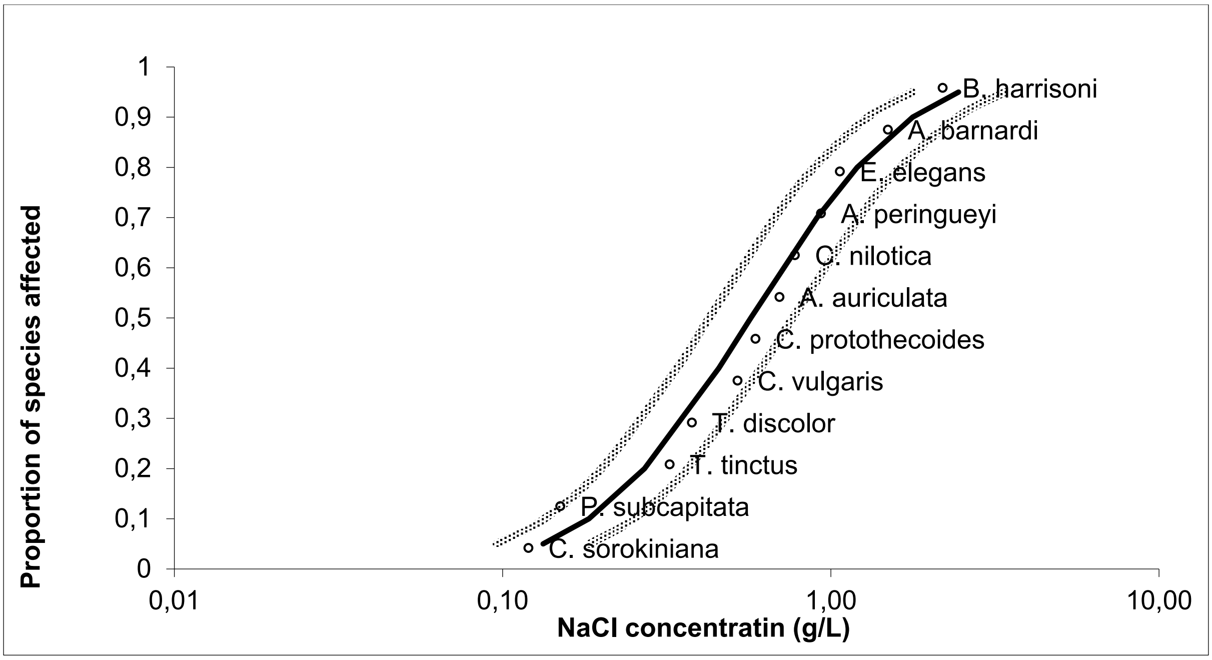

Figure 4.2: Species sensitivity distribution (SSD) curve of freshwater aquatic organisms from based on short-term 168-240 hour LC1-20 values for NaCl

4.3.2 Generation of species sensitivity distributions curves for Na_2SO_4

The Na_2SO_4 LC/EC values from the single-species test results and UCEWQ database were used to generate species sensitivity distribution (SSD) curves using the SSD Generator. SSD curves were generated for South African freshwater aquatic organisms based on 48-96 hour short-term LC50 (Figure 4.3) and 240-288 long-term LC1-20 values (Figure 4.4) values. The model's goodness of fit in terms of R2 was 0.620 and 0.856 for short-term and long-term analysis, respectively. Protective concentrations for different proportions of the population against Na_2SO_4 were also estimated for short-term (Table 4.10) and long-term (Table 4.11) exposures, respectively.

Table 4.10: Probit estimation of protective concentrations for different proportions of the population against short-term exposure to Na_2SO_4

Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.355	-1.152	0.459	0.048	-2.352	0.071	1.117	0.004
0.1	3.718	-0.822	0.418	0.323	-1.966	0.151	2.103	0.011
0.2	4.158	-0.422	0.382	0.672	-1.516	0.378	4.695	0.030
0.4	4.747	0.112	0.357	1.170	-0.945	1.295	14.776	0.113
0.5	5.000	0.342	0.354	1.396	-0.712	2.199	24.887	0.194
0.7	5.524	0.819	0.365	1.888	-0.251	6.585	77.277	0.561
0.8	5.842	1.107	0.382	2.201	0.013	12.784	158.696	1.030
0.9	6.282	1.506	0.418	2.651	0.362	32.082	447.661	2.299
0.95	6.645	1.836	0.459	3.036	0.636	68.588	1086.773	4.329

Table 4.11: Probit estimation of protective concentrations for different proportions of the population against long-term exposure to Na_2SO_4

Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.355	-1.328	0.066	-0.849	-1.808	0.047	0.142	0.016
0.1	3.718	-1.133	0.060	-0.677	-1.589	0.074	0.210	0.026
0.2	4.158	-0.897	0.054	-0.463	-1.331	0.127	0.344	0.047
0.4	4.747	-0.581	0.051	-0.163	-0.999	0.262	0.687	0.100
0.5	5.000	-0.445	0.050	-0.029	-0.861	0.359	0.936	0.138
0.7	5.524	-0.163	0.052	0.260	-0.586	0.687	1.820	0.259
0.8	5.842	0.007	0.054	0.441	-0.427	1.017	2.760	0.374
0.9	6.282	0.243	0.060	0.699	-0.212	1.752	5.002	0.613
0.95	6.645	0.439	0.066	0.918	-0.041	2.745	8.279	0.910

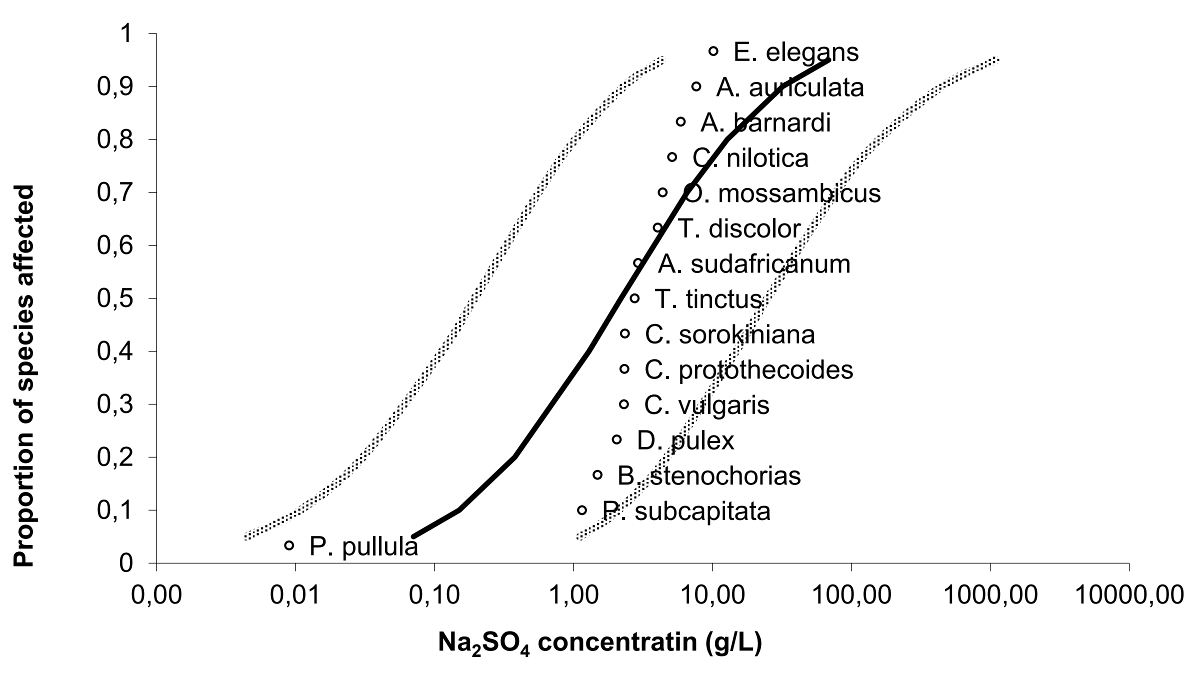

Figure 4.3: Species sensitivity distribution (SSD) curve of freshwater aquatic organisms from based on short-term 48-96 hour LC50 values for Na_2SO_4

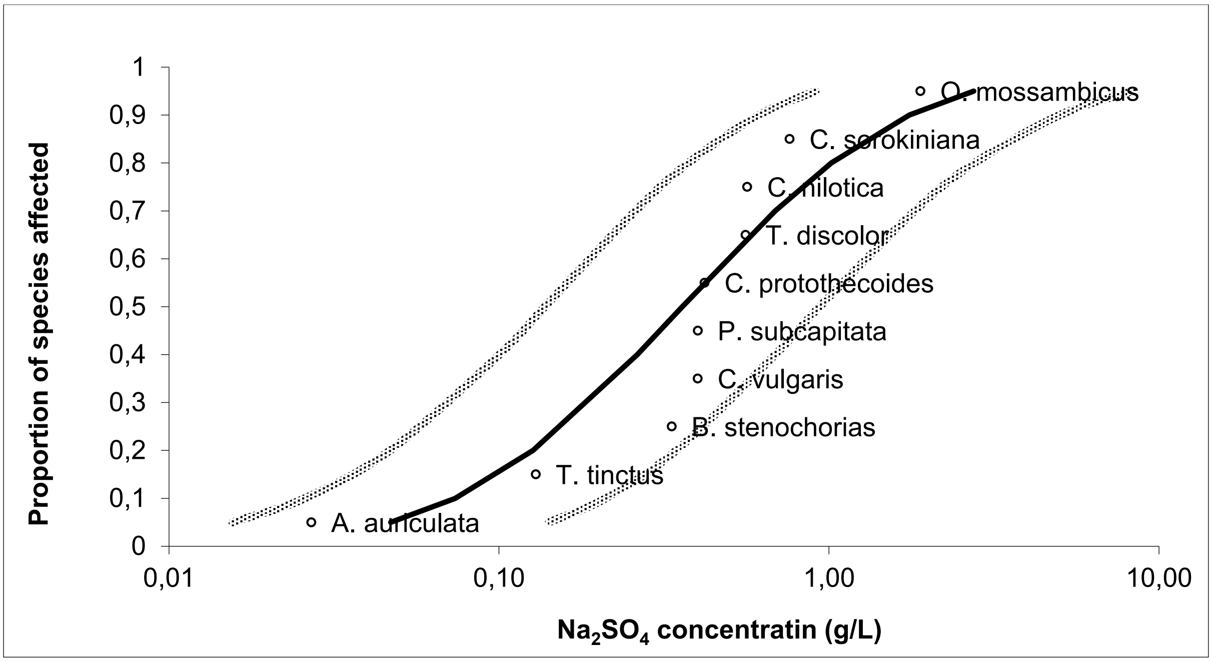

Figure 4.4: Species sensitivity distribution (SSD) curve of freshwater aquatic organisms from based on short-term 240-280 hour LC1-20 values for Na_2SO_4

4.3.3 Generation of species sensitivity distributions curves for wastewater effluent

The wastewater effluent LC/EC values from the single-species test results and literature search were converted to toxic units and used to generate species sensitivity distribution (SSD) curves using the SSD Generator. SSD curves were generated for South African freshwater aquatic organisms based on 48-96 hour short-term LC50 (Figure 4.5). Long-term SSDs were generated based on extrapolated results from the short-term results. The model's goodness of fit in terms of R^2 was 0.905 for short-term. Protective concentrations for different proportions of the population against wastewater effluent were also estimated for short-term (Table 4.12).

Table 4.12: Probit estimation of protective concentrations for different proportions of the population against short-term exposure to wastewater effluent

Proportion	Probit	Log Central Tendency	SSQ	Log Upper PI	Log Lower PI	Central Tendency	Upper PI	Lower PI
0.05	3.355	0.004	0.029	0.335	-0.327	1.009	2.161	0.471
0.1	3.718	0.155	0.026	0.467	-0.157	1.428	2.929	0.696
0.2	4.158	0.337	0.023	0.632	0.043	2.174	4.282	1.103
0.4	4.747	0.581	0.021	0.863	0.299	3.813	7.295	1.993
0.5	5.000	0.686	0.021	0.967	0.406	4.857	9.264	2.546
0.7	5.524	0.904	0.022	1.190	0.618	8.014	15.483	4.149
0.8	5.842	1.035	0.023	1.330	0.741	10.851	21.376	5.508
0.9	6.282	1.218	0.026	1.530	0.906	16.518	33.876	8.054
0.95	6.645	1.369	0.029	1.699	1.038	23.371	50.046	10.914

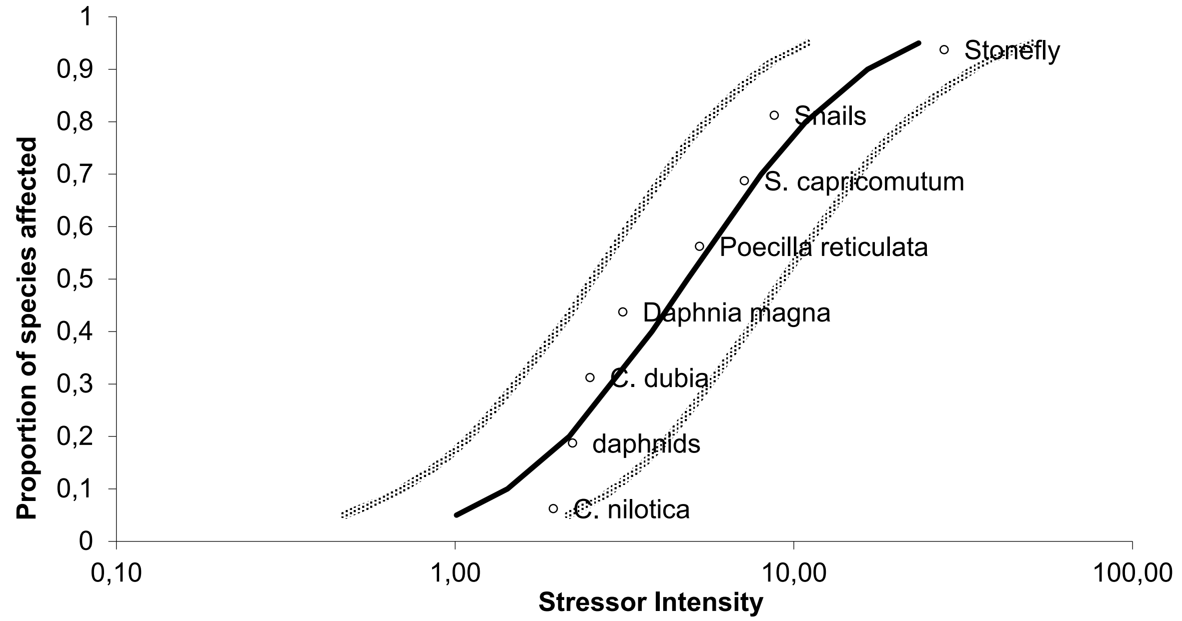

Figure 4.5: Species sensitivity distribution (SSD) curve of freshwater aquatic organisms based on short-term 24-96 hour TU values for wastewater

4.4 DISCUSSION

4.4.1 Species sensitivity distribution (SSD) curves for South African aquatic species

Species sensitivity distribution (SSD) curves provide a relatively quick, qualitative, visual comparison of toxicity data and the protective concentrations for different proportions of the population. SSDs from this study provided an estimate of species representing five taxonomic groupings affected by NaCl and Na_2SO_4. Positions of species on different parts of the SSD curve reflects the distribution patterns of the taxonomic groups that these species represent.

For short-term exposure to NaCl, the SSD curve (Figure 4.1) revealed *P. pullala* (an insect) to be the most sensitive appearing at the tail-end of the curve. However, the aquatic plants seemed more sensitive than all other taxonomic groupings as *C. sorokiniana*, *P. subcapitata* and *C. vulgaris* were found at the far-left tail-end of the curve. In contrast *E. elegans* and *O. lawrencei* (insects) as well *C. nilotica* and *D. pulex* (crustaceans) appeared at the right tail-end of the curve, suggesting their insensitivity to NaCl.

The sensitivities of most insects, especially those belonging to the order Ephemeroptera, seem to fall within the same range in the middle of the curve. This analysis shows that most plants of the population under consideration are very sensitive to NaCl, while crustaceans and aquatic insects seem to tolerate the salt.

For long-term exposure to NaCl, the SSD curve (Figure 4.2) revealed *C. sorokiniana* and *P. subcapitata* (aquatic plants) very sensitive as they appeared at the far-left tail-end, while most insects including *B. harrisoni, A. barnardi, E. elegans and A. peringueyi* seemed less sensitive as they appeared at the far-right tail-end of the curve. *C. nilotica* (crustacean), *A. auriculata* (insect), *C. protothecoides* and *C. vulgaris* (plants) all seem to show similar sensitivity to NaCl as they appeared in the middle of the curve. This analysis of long-term exposure of the population under consideration shows that the aquatic plants are still sensitive to NaCl but they become less sensitive with time.

For short-term exposure to Na_2SO_4, the SSD curve (Figure 4.3) showed revealed *P. pullala* (an insect) to be the most sensitive appearing at the tail-end of the curve, just like for NaCl. Again, just like for NaCl, *P. subcapitata* (aquatic plant) seemed very sensitive as it was found at the far-left tail-end of the curve. The sensitivities of *C. sorokiniana*, *C. protothecoides*, *C. vulgaris* (plants), *D. pulex* (crustacean), *T. tinctus, A. sudafricanum, T. discolor* (insects) and

O. mossambicus all seemed similar, lying in the middle. Once again just as for NaCl, *E. elegans* and *A. Auriculata, A. barnardi* (insects) and *C. nilotica* (crustacean) appeared at the right tail-end of the curve, suggesting their insensitivity to NaCl. This analysis shows that most plants of the population under consideration are very sensitive to NaCl, while crustaceans and aquatic insects seem to tolerate the salt.

For long-term exposure to Na_2SO_4, the SSD curve (Figure 4.4) showed *A. Auriculata* and T*. tinctus* (insects) to be the most sensitive as they appeared at the far-left tail-end of the curve, while O*. mossambicus* was located at the far-right tail-end, indicating it was less sensitive. The sensitivities of *B. stenochorias* (mollusc), *C. sorokiniana*, *C. protothecoides*, *P. subcapitata*, *C. vulgaris* (plants), *T. discolor* (insect) and *C. nilotica* (crustacean) seemed to lie in the middle. For the population under consideration, this analysis suggests that the aquatic plants sensitivity to Na_2SO_4 is between some sensitive Ephemeropterans and fish.

Many wastewater treatment works (WWTWs) apply chlorination to kill pathogenic microbes. This process introduces large amounts of chlorine into the receiving water, which ultimately increase salinity of the receiving system. This results in an ecological hazard that would last for a short period of time. For this reason and lack of long-term toxicity data for wastewater effluent, only short-term guidelines were developed in this study for wastewater effects.

Also, ecological hazard may arise from the fact that WWTWs most often receive effluent from different sources, including domestic and industrial, of which the treatment is not be adequate to eliminate all pathogenic microbes (DWAF, 2003). Since wastewater is a complex chemical mixture, using chemical-specific limits to control it in itself is limiting. Therefore, is appropriate develop guideline limits based on whole effluent toxicity (WET) test, which directly assesses the environmental toxicity hazard and the risk such hazard poses to the aquatic biota. The Totale Effluent Milieuhygiene (TEM) methodology, also known as Whole Effluent Environmental Risk (WEER), developed in the Netherlands has been suggested as a tool that could be used to directly measure the potential toxic effect of complex wastewater. The test is based on selecting a set of parameters derived from the potential effects of discharges, rather than from the discharges themselves, and using one or more tests to measure each parameter (e.g., oxygen depletion, acute and chronic toxicity, mutagenicity, endocrine impairment and persistence potential).

4.4.2 Estimation of water quality guidelines for NaCl, Na_2SO_4 and wastewater effluent

In this study, the method used to derive the water quality guidelines (WQGs) for NaCl and NaSO4 follows that of ANZECC and ARMCANZ (2000), Warne et al. (2004), USEPA (2005) and CCME (2007). However, the CCME (2007) provides separate guidance for both short-term and long-term exposures. This is very important since the use of one common guideline to address both short-term and long-term exposure effects have not been successful in many of the above countries, including South Africa. Therefore, separate preliminary South African water quality guidelines were derived for short-term and long-term exposure to NaCl and Na_2SO_4.

The objective of the short-term WQG is to protect most species from death during severe but transient events such as inappropriate application, improper disposal, and spill events. Inappropriate application or improper disposal includes spraying under worst conditions of heavy rainfall, or in severe wind, and not following label instructions. Thus, the short-term WQG is intended to protect most species in the aquatic environment during unfortunate and catastrophic events, but not indefinitely.

Conversely, the objective of long-term WQGs is to protect all aquatic species and life stages against adverse effects during chronic exposure. Chronic exposure of aquatic organisms to a pesticide may result from gradual release from soil or sediment, gradual entry through groundwater or runoff, a repeated application within the same localised region, and long-range transport events.

4.5 CONCLUSION

Based on the estimation of protective concentrations for different proportions of the population against exposure to NaCl, Na_2SO_4 and wastewater, preliminary short-term and long-term South African water quality guidelines are presented in Table 4.13 and Table 4.14, respectively. Central tendency represents the median PC95 value, while predicted interval refers to the boundaries within which the PC95 value is located. The central tendencies of distributions together with lower and upper predicted intervals are used as guidelines. The central tendency is the mean guideline (i.e. PC95 value) and the lower-upper predicted values represent acceptable limits, i.e. acceptable or tolerable risks. Beyond these, risks are unacceptable.

Table 4.13: Short-term guidelines for NaCl, Na_2SO_4 and wastewater effluent for protection of aquatic life resulting from SSD 0.05 proportion (5th percentile)

Salt	**Central tendency**	**Lower predicted interval**	**Upper predicted interval**
NaCl (g/L)	0.032	0.290	0.003
Na_2SO_4 (g/L)	0.071	1.117	0.004
Wastewater effluent (Toxic Units)	1.009	0.471	2.161

Table 4.14: long-term guidelines for NaCl and NaSO4 for protection of aquatic life resulting from SSD 0.05 proportion (5th percentile)

Salt	**Central tendency**	**Lower predicted interval**	**Upper predicted interval**
NaCl (g/L)	0.133	0.184	0.096
Na_2SO_4 (g/L)	0.047	0.142	0.016

As stated from the beginning, these are preliminary guidelines and their ratification depends on the national department of Water and Sanitation. However, the final guidelines for both NaCl and Na_2SO_4 are related to the different recommended protection levels to equate them to the various ecological integrity classes of the ecological Reserve of South Africa (Warne et al., 2004). This is presented in Chapter 6 of this report.

CHAPTER 5: ANALYSIS OF SALINE WATER MANAGEMENT PRACTICES USING CULTURAL HISTORICAL THEORY

5.1 INTRODUCTION

There is a new trend (or an emerging a paradigm shift) in water research to effectively combine the traditional approaches of the natural sciences with social sciences methods. This innovative approach is very promising to the development of new management practices of water resources. Thus, in this project, the Cultural Historical Activity Theory (CHAT), a social science action research method was applied for the effective management of water salinity risks as perceived by the triad process of environmental water quality management study involving water physicochemistry, biomonitoring and ecotoxicology. The CHAT theory (Jonassen and Rohrer-Murphy, 1999; Engestrom, 2000; Roth and Lee, 2007), which is based on a methodology called Developmental Work Research (DWR), provides a process framework for expansive learning (EL). The DWR is a change-oriented and innovation-centred methodology, which draws on the strengths of joint analysis and concrete transformation of current practices. In this chapter, the activities of farmers and wastewater treatment works in the Kat River Valley (KRV), Eastern Cape, and their impact on Kat River's salinity were analysed using the CHAT methodology. Although the focus is on salinity as a water quality parameter, other parameters have been included in some cases since it was not easy to totally delink salinity from other water quality variables (in fact, this is actually what the study found).

5.1.1 Cultural Historical Activities Theory (CHAT)

Traditionally and before 1994, management of South African water resources is based on scientific approaches with little or no input from other disciplines. However, this has been changing in recent years, whereby the National Department of Water and Sanitation (DWS) as well the Water Research Commission (WRC) incorporating other disciplines in the management of water resources. The main aim of incorporating aspects of social science aspect into this study is to understand how activities of farmers impact on Kat River's water salinity and how to manage that. Cultural Historical Activity Theory (CHAT) has been proposed as a framework that can be used by natural science researchers with little background in the social sciences to study the activities of people on a common item.

Thus, the CHAT framework was employed in this study to investigate how past and current agriculture practices in the Kat River catchment may have contributed to the river's current salinity and how to manage the river's salinity going forward.

Activity Theory places emphasis on both history and development of ideas and the role of humans. As noted by Kuhn (1972), for any discipline to survive and increase in value, it must allow changes in practice and theory. The idea of CHAT was originally proposed in 1920 by the Russian scholar Vygotsky (Vygotsky, 1978; Yamagata-Lynch, 2010). Kuutti (1995) defined CHAT as "a philosophical and cross-disciplinary framework for studying different forms of human practices as developmental processes, with both individual and social levels interlinked at the same time". This framework is not only useful for the analysis of human activities but also applicable to analysing multiple points of views, intentions, traditions, interests and expected results.

CHAT is a framework that focuses on linking gaps between development stage of humans and historical state of activities (Wenger, 1998), and has three conceptual generational models: first, second and third generations (Engeström, 1987, 2001; Edwards, 2007). The first generation consists of basics Vygotskian mediation that links subject, object and tool. Vygotsky described the interplay of the tool, subject and object as an idea of mediation (Figure 5.1). With respect to activity system, subject refers to an individual or group of people who participate in an activity that leads to achieving an object; object refers to a mental or physical product that the subject intends to achieve. It represents the goal and essence of the activity; a tool is any device or and implement used to carry out a particular task. Tools shape thoughts and actions of people. It includes culture, mental models or physical object.

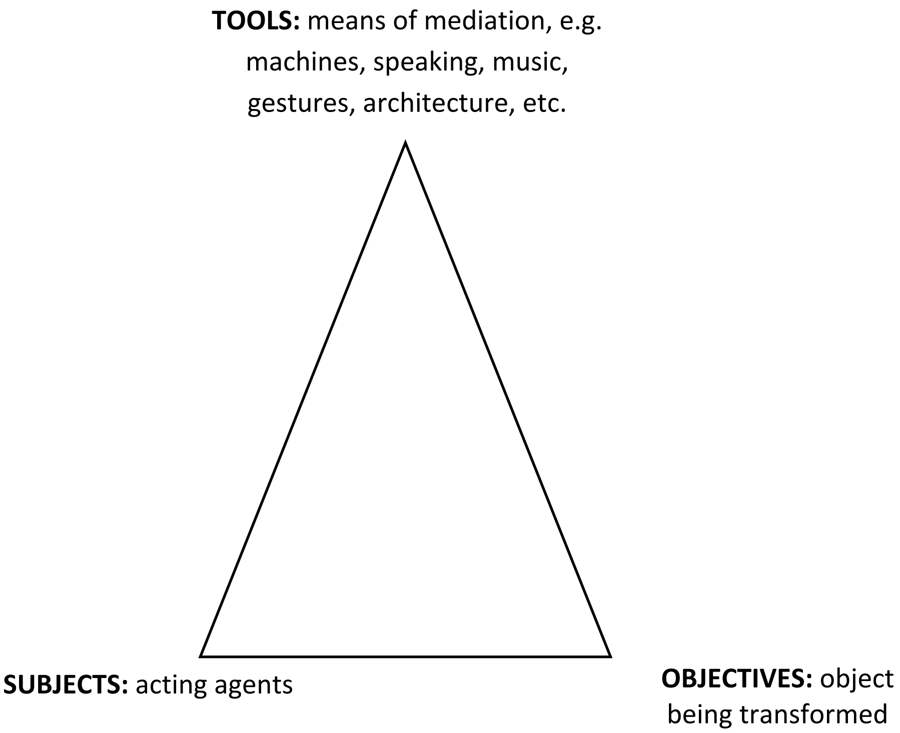

Figure 5.1: First Generation CHAT (basic mediation triad)

The second generation of CHAT shows further developments of the Vygotskian model by Engeström by postulating that because humans do not live in isolation, their activities are influenced by rules, other people and the community at large (Figure 5.2). In this sense, community refers to the environments within which an activity is carried out or influence is felt; rules refers to standards, guidelines or principles for conducting an activity, and could be formal or informal, explicit or implicit; division of labour refers to the explicit and implicit organisation of the community involved in an activity.

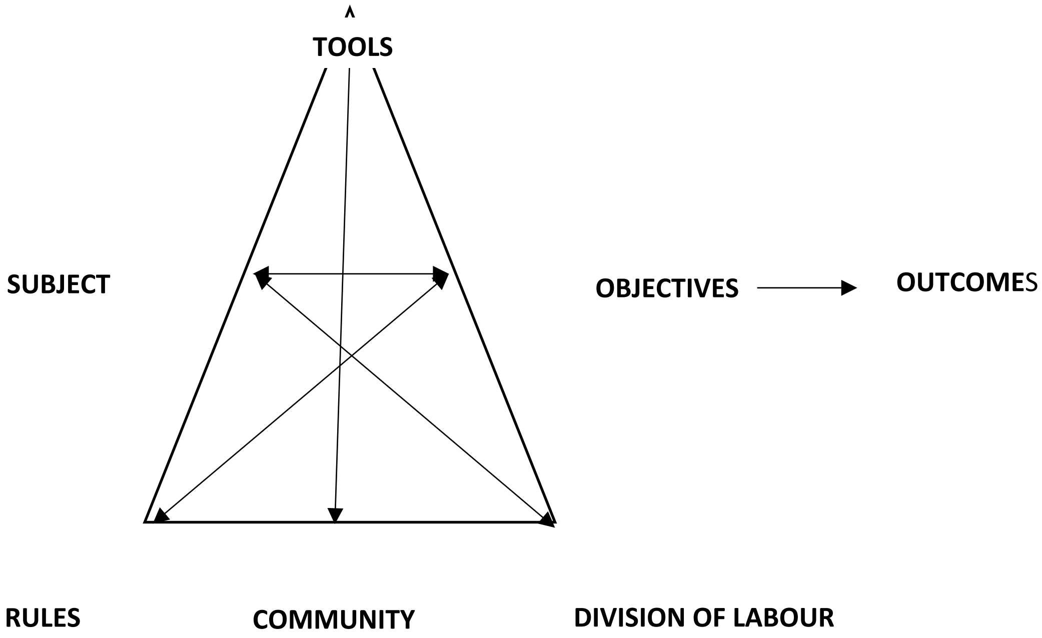

Figure 5.2: Second Generation CHAT

Engeström further argued that different human activities at the second generation CHAT model may impact on each other in the third generation CHAT (Figure 5.3). Thus, the third generation CHAT exists where there is some interaction between 2 second generation activities (e.g. interaction between farming and mining activities) (Figure 5.3).

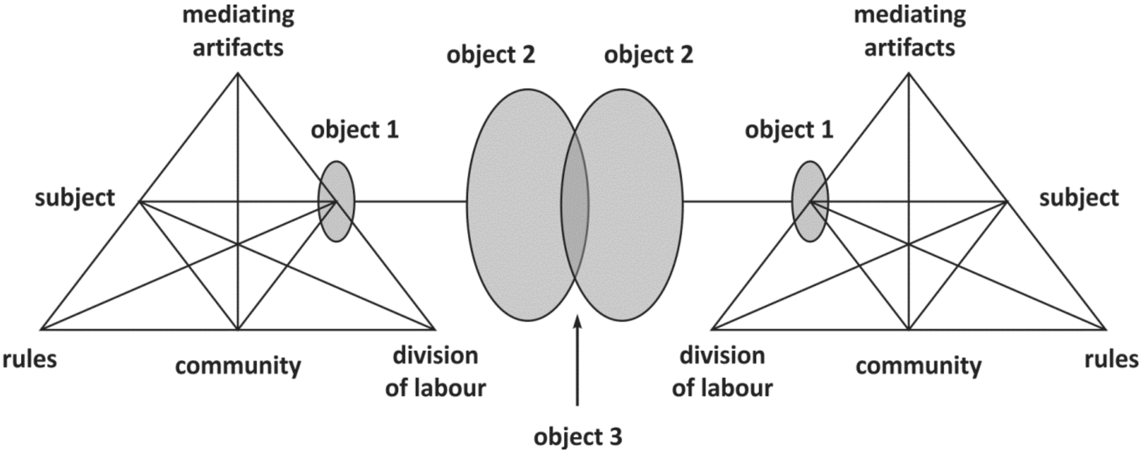

Figure 5.3: Two interacting activity systems as minimal model for the third generation of activity theory (Engeström, 2001)

Currently, in South Africa, a new paradigm for water resource management that recognises and takes account of the inherent complexity of water-related systems has been proposed. CHAT is one of the many methodological frameworks suggested under this new paradigm, and its application is subject to the following assumptions: (Sahula, 2015).

- Understanding how activity systems are currently functioning by analysing the different components of an activity system, highlighting where contradictions and gaps are found.
- Understanding of an activity as situated in a cultural-historical context.
- Developing and simulating learning environments based on an understanding of learning as emerging from an activity, where diverse stakeholder groups get to review their practice within a particular activity.
- Ongoing monitoring and evaluation of practice by reflecting on how a change in practice influences the different components of the activity and whether this leads to reaching an agreed outcome of the activity.

In this study, the second generational CHAT model was used to investigate agriculture activities in the Kat River catchment water salinity and its management.

5.1.2 Values and beliefs system for farmers

The agricultural sector is so vital to South Africa's economy because it creates employment opportunities for the poor and contributes about 2.2% of the Gross Domestic Product (GDP). However, the agricultural sector is the largest consumer of freshwater on a global basis and a major cause of degradation of surface and groundwater resources through erosion and chemical runoff (WWAP, 2009). In South Africa, water is one of the limiting factors of agricultural production. Due to water scarcity, some farmers have shifted to non-agriculture ventures, causing a decline in farming production. In many cases, this has led job losses and greatly affected the economic and social well-being majority of the country's rural folk who mainly work in the agriculture sector.

Farming in South Africa is either practised on commercial (large scale) or subsistence (small scale) basis. These two types of farmers have their own consciences, unique personal value systems and worlds views based on their own experiences, moral values and characters (Schoon and Te Grotenhuis, 2000). For example, South Africa has limited fertile land for agriculture. Farmers have to use fertilizers to increase and maintain soil fertility.

Most commercial farmers use agro-chemicals such as fertilizers and pesticides to increase productivity, while most subsistence farmers consider using such agro-chemicals violation of the laws of nature. Such farmers use practices such as crop rotation to increase soil organic matter and nutrients, as well as removing invasive vegetation and replacing with indigenous vegetation (Schoon and Te Grotenhuis, 2000). Nevertheless, these two types of farmers may not always differ in their values and belief systems. They sometimes actually found common ground on many issues, and two of these are discussed here. 1) Both commercial and subsistence farmers believe that family members have to take over the business to ensure its continuation in the family. 2) They consider it a great value to be an independent entrepreneur and making their own decisions about their farming practices. Nevertheless, some farmers are willing to co-operate with environmental regulators if their own independence is respected (Schoon and Rita Te Grotenhuis, 2000).

According Department of Water and Sanitation (DWS), farmers have to leave, at least, 30-40-meter buffer zones of natural vegetation between cultivated land and river, and about 25-75-meter buffer zones between wetland and cultivated land. They have to ensure efficient irrigation techniques that take into account soil type, crop type, and soil water status and weather condition. Also, they need to register as water users with the DWS. Nonetheless, many large and small-scale farmers hardly comply with these regulations.

5.2 METHODOLOGY

5.2.1 Data collection: interviews on cultural historical activity system

The aim of the current study was to gather data about farming activities in the Kat River Valley and how these activities impact the river's water quality, especially salinity. To achieve this aim, a questionnaire was prepared and administered to farmers who were engaged in either subsistence (small scale) or commercial (large scale) farming activities. Forty (40) small-scale farmers (25 crop farmers and 15 livestock farmers), as well as 8 commercial farmers (all citrus farmers), were interviewed. The questionnaire consisted of mainly structured questions but also a few unstructured questions.

The structured questions were closed-ended and required the respondent to choose from a predetermined set of responses or scale points. This reduced the amount of thinking, effort and time required by respondents and the response process was faster. This was very helpful because the majority of respondents did not have much time because the study occurred during a very busy harvesting season. The questionnaire is presented in this report as Appendix 1.

5.2.2 Ethical considerations

The principle of voluntary participation requires that people are not coerced into participating in research. Closely related to the notion of voluntary participation is the requirement of informed consent, which means that prospective research participants are fully informed about the procedures and risks involved in research and must give their consent to participate. Participants in this study were inform of the purpose of the study and their concerns were sought as shown as shown in the introduction of the question (Appendix 1). The principle of anonymity was also adhered to in this study as participants were not required to write their names on the questionnaires (Appendix 1). The researchers guaranteed participants' confidentiality as they were assured that identifying information will not be made available to anyone who is not directly involved in the study and that the outcome shall be made available to them (the participants). Participants were informed of their right to voluntary participation and that they have the right not to answer any question they do not want and were allowed to withdraw from the research at any point.

5.2.3 Data analysis

This study adopted descriptive research design in order to describe the observations and outcomes with respect to the issue or problem under study. Data collected using the questionnaires were subjected to an interpretation process using an analytical tool presented in Table 5.1 below. The analytical tool contains all six components of the second generation activity system, with each component having some diagnostic open-ended questions relevant to translating the activity system in relation to water quality and salinity management practices being examined in the study.

Table 5.1: Analytical Tool used to analyse data collected using the questionnaires (adapted and modified from Sahula, 2015)

Component of Activity System	**Analytical questions**
Subject	• Who is or should be involved in WQM? • What are their roles? • Do subjects have sufficient skills to use the available tools effectively in support of WQM? (This includes the questions of literacy and language proficiency – including technical language proficiency). • Are they the relevant people (*qualified, knowledgeable, skilled, well informed, focused, etc.*)?
Tools	• What tools are in place and being used to support WQM? • Are the tools in use well suited to WQM? • In what ways are the tools in use constraining or influencing WQM? • What other tools, knowledge and skills could be needed for the work? • Are these readily available? Can they be sourced? From where? How and by who?
Rules	• What socio-historical norms and rules govern WQM • What are the formal rules (manuals, standard operating procedures, etc.) that promote or constrain WQM? • What are the informal rules (cultural, experience) that promote or constrain WQM? • What other structures or systems must be applied to influence WQM? • What other implicit (subtle) events and circumstances influence WQM?
Objectives	• What is your objective for working towards achieving good water WQM? • Do you work voluntarily or are compelled to achieve your WQM objectives? • How do other water users around you view and value the goals of WQM?
Division of Labour	• Who does what, who should do what in WQM? • Who does what in the organization in relation to WQM? • Is this necessary or merely a division of labour? • In what ways does the division of labour promote or constrain WQM? • Is it necessary to share the work of WQM in a different way? Why and how?
Community of Practice	• Who else is involved or should be involved and how in WQM? • How does your location in the system affect you and how do you affect it? • How do conflicts in your locality or community affect interactions?

5.3 RESULTS

The results of the interview questions on water quality and salinity management activity system in the Kat River catchment are presented below. First, the results are presented in the activity system diagrams, followed by a description of the various components. Results are presented for large-scale (commercial) crop farming (Figure 5.4), small-scale (subsistence) crop farming (Figure 5.5), and small-scale livestock farming (Figure 5.6).

5.3.1 Large-scale (commercial) crop farming

All the commercial farmers are involved in citrus farming. The main **subjects** of the commercial farming activity system are the grower association members, and employees and managers of the citrus processing factories. The growers produce citrus and sell them to the processing factories that process them mainly for export but also for the local market. The processing factories too have their own farm but buy the products from the growers as well. There are two processing factories in the Kat River Valley (KRV): Riverside Farms and Eden Agric. These are well-established farms with all the necessary machinery for production, processing and marketing. The growers are mainly emerging farmers who are largely supported by the two big farms. The **objective** of these subjects is to produce quality citrus, especially for export. Therefore, they ensure that they will always have good water quality and the salinity within acceptable limits. The established farmers help the growers in this respect so that they will achieve their **outcome** of good water quality. For example, to ensure that production is not impacted by water quality, including salinity, farmers have been advised to spray excess pesticides or fertilisers to wind brakes to avoid polluting the soil and ultimately runoff into the river. The **tools** used by the commercial farmers in order to achieve their objectives include physical machinery and equipment such as planters, plough, irrigation systems, sprayer and harvesters. There are also processing infrastructures and transportation machinery including trucks. Soft-tools used by the commercial farmers include water abstraction permits and administration & marketing plans. The activity system of commercial farmers adheres to strict **rules** to meet export requirements. The **community of practice** of these citrus farmers is very much interactive in that they have to constantly meet to review their activities. The growers association constantly get advice from the established farmers as well as extension officers. Inputs and expectations of the foreign buyers are major drivers that seem to keep the farmers on their toes. The commercial farming of citrus in the KRV is a serious business and the entire stakeholders share in the **division of labour** to ensure production of quality products (Figure 5.4).

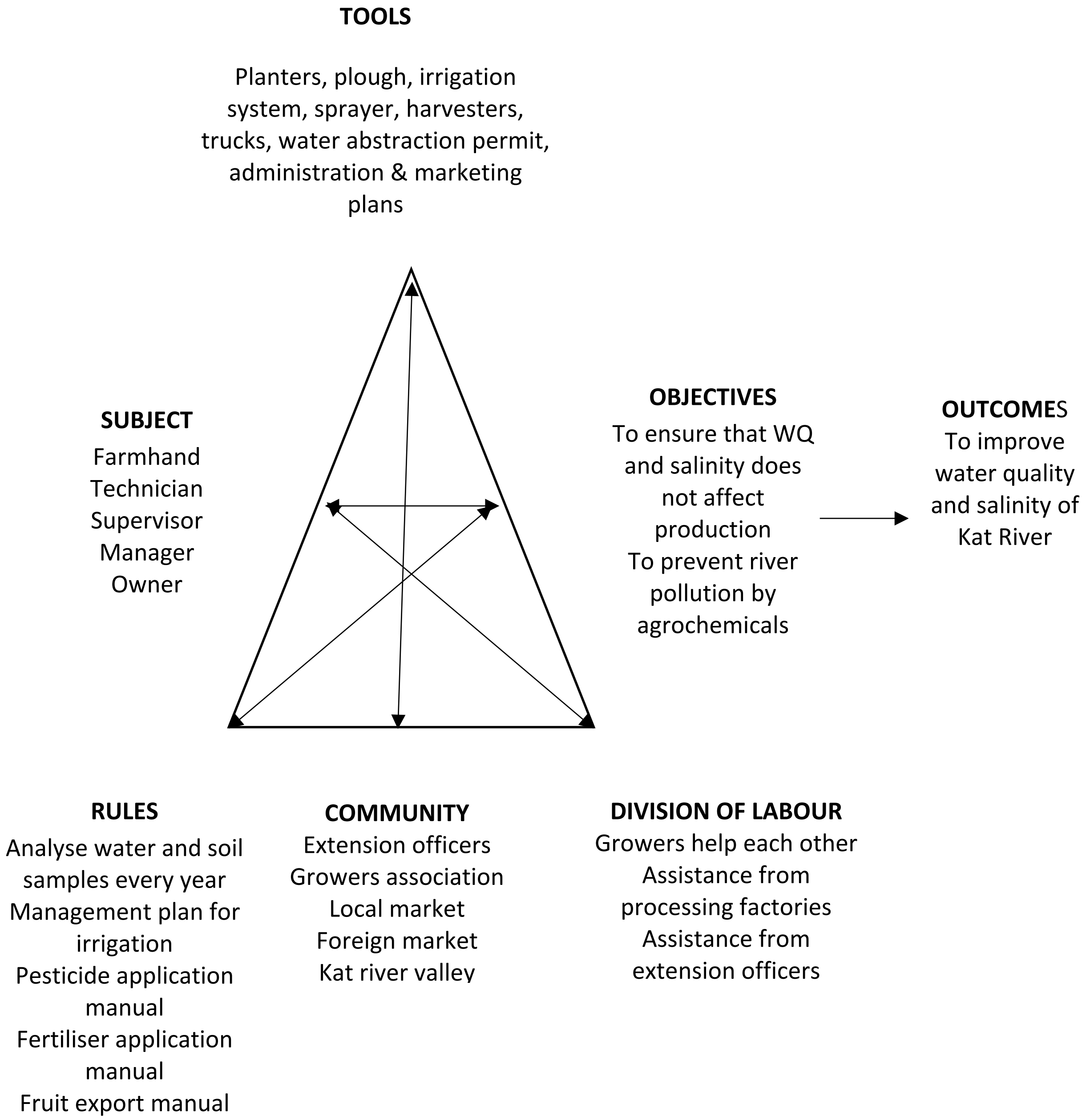

Figure 5.4: Large-scale citrus farming activity system in the Kat River Valley

5.3.2 Small-scale (subsistence) crop farming

The **subjects** of small-scale crop farming activity system that responded to the questionnaire were mainly residents of the various rural areas of Kat river valley (KRV). Crops grown by these farmers include pumpkins, butternuts, maize and hay for cattle feed. These crops are mainly sold to the local markets, although the produce also ensures availability of food to farmers and their families. To achieve their **objective** of getting income and food from this activity system, most of these small-scale farmers pay attention to water quality and not necessarily salinity. However, some farmers take measures to specifically ensure that the **outcome** of their activity is not affected by high salinity as this may impact negatively on the farm produce. These farmers used **tools** ranging from simple ones such as spade, hand fork, watering can, rake, hoe and machete, to heavy duty and not-so-simple tools such as tractor, water pump, sprinkler, plough, discs and planter. The activity system of small scales farmers is guided by both formal and informal **rules**, but unlike commercial farmers, small-scale farmers do not have strict rules. Formal rules include procedures and regulation for fertiliser and pesticides application which are mostly done according to the manufacturer's instructions. Farm corporative and the local market within KRV all form part of the **community** involves in the activity system of these small-scale farmers. For the **division of labour**, farmers get help from extension officers, other farmers and even family members in some cases (Figure 5.5).

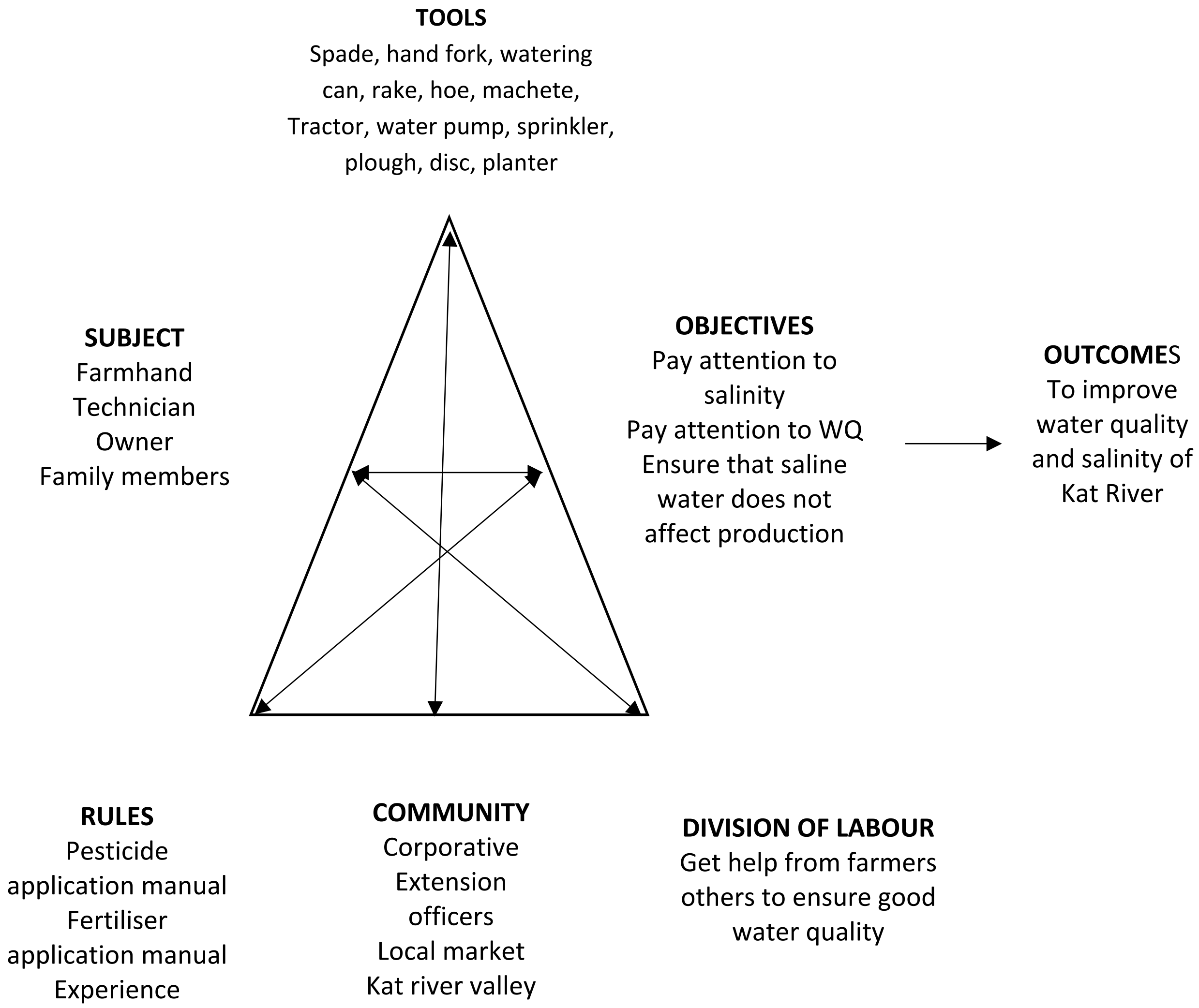

Figure 5.5: Small-scale crop farming activity system in the Kat River Valley

5.3.3 Small-scale livestock farming

The **Subjects** of small-scale livestock farming activity system that responded to the questionnaire were mainly residents of the various rural areas of Kat river valley (KRV). The livestock kept by the various farmers were mainly cattle and sheep. The livestock is mainly sold to the local market. The **objective** of this activity system is to rear animals with good quality of meat and dairy products. Thus, the farmers' activity system is geared towards achieving keeping healthy livestock as an **outcome** dependent on good water quality. **Tools** used in the small-scale livestock farming activity system include access to pasture, dipping, dosing and antibiotics. The **rules** used are protocols for applying dosing and antibiotics (formal) and experience (informal), among others. The pastures and river in the **community** support this activity system, while extension officers and other farmers and family members provide means of **labour division** (Figure 5.6).

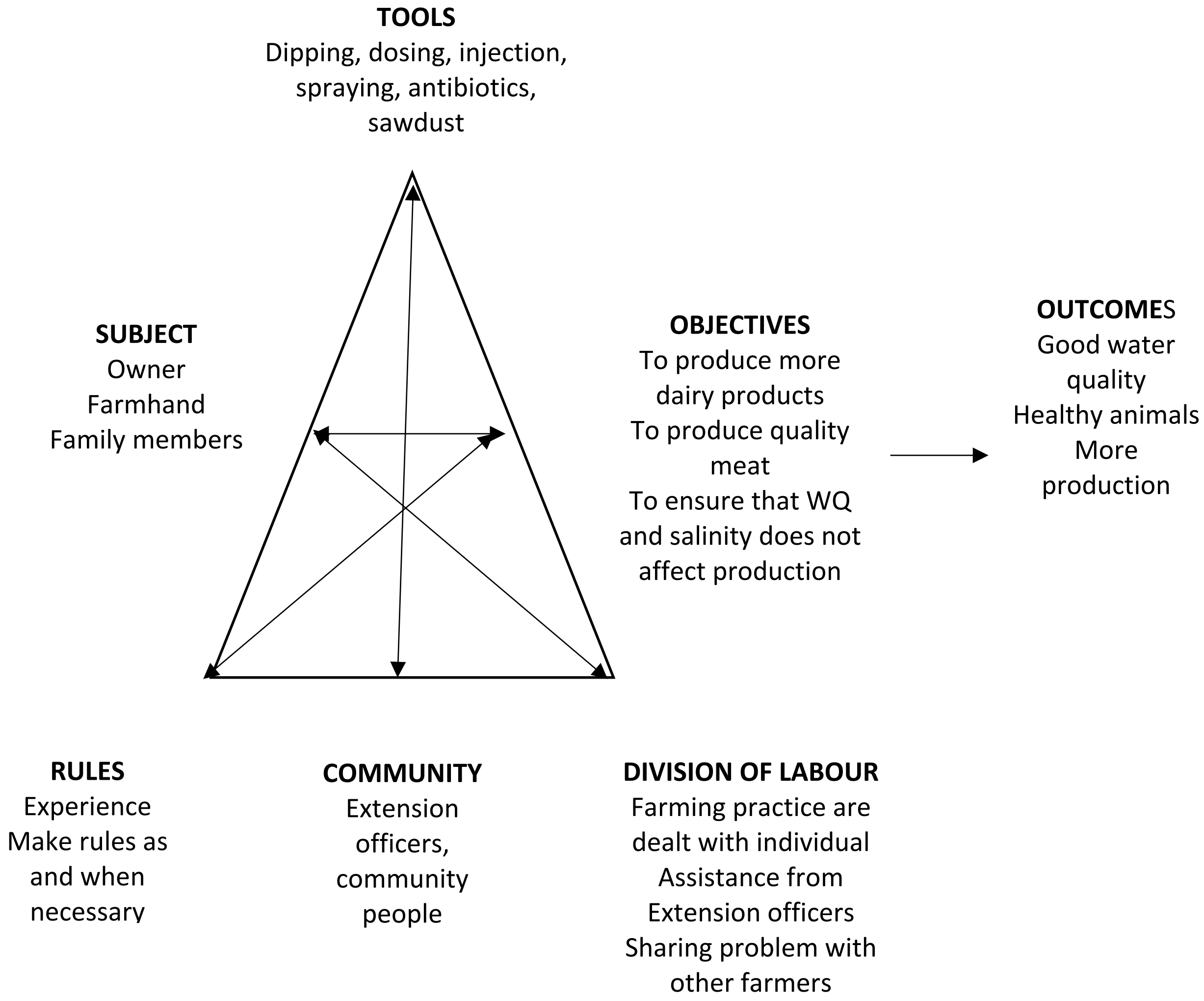

Figure 5.6: Small-scale livestock farming activity system in the Kat River Valley

5.4 DISCUSSION

5.4.1 CHAT analysis activity systems in the Kat River Valley

5.4.1.1 Large-scale (commercial) crop farming

In this study, the activity systems of both large and small-scale farmers in the Kat River Valley and its impact on the river water quality, especially salinity, were analysed using CHAT. The large-scale farming activity system analysed was citrus farming; the produce is mainly for export. The large-scale farming activity system seems to contribute less to water quality deterioration and by extension, increasing salinity, of the Kat River. The motivation for this seems to come from the requirement for export of citrus in particular and fresh fruits in general. According to the Fresh Fruit Export Directory, 2016 edition, released by the Fresh Produce Exporters' Forum (FPEF, 2016), South Africa is the largest fresh fruit exporter (by volume) in the Southern Hemisphere. South Africa exports 2.7 million tonnes of fresh fruit each year, which accounts for about 50% of the country's annual agricultural exports. Also, South Africa is the second largest exporter of citrus fruit, and together with the export of pome fruit, stone fruit, table grapes, subtropical fruit and exotic fruit to 92 destination-countries, generated about $1.7 billion for the country's economy. The country exports citrus to China, Japan, South Korea, Iran, European Union (EU) and the United States of America (USA) (DAFF, 2010).

Therefore, the motivation to produce the highest quality of farm produce for export has ensured that commercial farmers approach to farming activity system does not deteriorate or pollute both soil and water. The commercial citrus farmers adhere to strict rules and regulations including standard operating manuals so that they meet international standards as the majority of the citrus are for export. For example, they are required to do soil and water, as well as pesticides residue in fruit analyses to ensure that they citrus they export is of the highest quality. Thus, they do soils and water analysis once a year and pesticides residue analysis every harvest. The farmers, therefore, stick strictly to standard operating procedures, with little or no room for informal rules except, probably, regular norms and values associated with the farming activities. This motivation to produce high-quality fresh fruits to satisfy export demands with 'unintended outcome' may be seen as a 'contradiction' as suggested by Engeström (1999).

Engeström (1999) intimated that a contradiction could be a 'motive force of change and development' that has the capacity to modify both subject and environment through mediated activity, which could ultimately cause evolution in the activity system. Commercial farming activity system in the KRV has a motive force of change of enduring good water quality including salinity, and this mediated through execution of farming approaches that meet export standards and requirement.

5.4.1.2 Small-scale (subsistence) crop farming

Analysis of small-scale crop farming interview results did not suggest any meaningful impact of Kat River's water quality, including salinity by the farming activity system. This could be attributed to the fact that most of these farmers do not rely on the Kat River for irrigation of their crops. They rely on rainwater and storage water in 'earthly dams' (i.e. dams constructed from dugouts in the earth). This notwithstanding, a few of the small-scale crop farmers depend on the Kat River for irrigation of their crops. Activity system of such farmers may impact on the water quality, including salinity of the Kat River since they do not follow strict procedures and protocols as do large-scale farmers.

5.4.1.3 Small-scale (subsistence) livestock farming

Unlike the small-scale crop farming activity system that had little impact on Kat River's water quality, analysis of small-scale livestock farming interview results did suggest meaningful impact. This may be due to the inherent nature of how the activity occurs. As mentioned in the results, livestock depends on pasture for their feed. This mode of feeding clears the land off vegetation and exposes the topsoil, which is easily washed into the river during rainfall, resulting in water pollution including high salinity. Also, most farmers send their livestock to the river for drinking. This practice does not only result in animals muddling the river water but they also defecate into the river. The droppings of these animals tend to increase nutrients and salts levels, posing risks to both humans and the environment.

5.4.2 Activities likely to contribute to increasing salinity of the Kat River based on CHAT analysis activity systems in the Kat River Valley

During the Cultural Historical Activity Theory (CHAT) analysis of activity system in the Kat River Valley (KRV) as reported in Deliverable 5 of this project, it was revealed that the primary objective of commercial farmers is to produce quality citrus, especially for export. Therefore, they ensure that they will always have good water quality and the salinity within acceptable limits. The established farmers help the emerging farmers and growers in this respect by offering advice so that the produce (from emerging farmers and growers) will be of the expected quality. For instance, to ensure that water quality and salinity does not affect production, growers have been advised to spray excess pesticides or fertilisers to wind brakes to avoid polluting the soil and ultimately runoff into the river. This tends to favour improvement of water quality and salinity of Kat River. Furthermore, activities such as the analyses of water and soil samples, as well as sticking to the standard operating procedures (SOPs) for irrigation, pesticide application, fertiliser application, harvesting and export ensure better management of salinity.

Similarly, the primary objective of small scaled crop farmers, according to the CHAT analysis, is to get income and food from their activities. Therefore, most of these farmers pay attention to water quality and not necessarily salinity, while some take measures to specifically ensure that the outcome of their activities is not negatively impacted by high salinity.

For livestock farming, which is mostly on a small-scale, the CHAT analysis revealed that the primary objective of this activity system is to rear animals with good quality of meat and dairy products. Thus, the farmers' activity system is geared towards achieving keeping healthy livestock as an outcome dependent on good water quality, including salinity.

As stated above, the primary objectives of the various farming activities in the KRV are aimed at achieving good water quality, including a reduction in salinity. However, the CHAT analysis revealed that all the farming activities, as well as the activity Fort Beaufort Wastewater Treatment Works, add to the salinity levels of the Kat River. These activities that are likely to cause increase salinity of the Kat River include fertiliser application, land clearing and burning, irrigation, farming close to/in the buffer zone, livestock grazing and Fort Beaufort Wastewater Treatment Works.

5.4.2.1 Application of fertilizers

In the KRV, fertilisers are applied in farming activities to increase productivity. However, some portion of fertilisers inevitably washes into waterways as nonpoint source runoff along with eroded sediments. Thus, the nitrogen, potassium and phosphate in fertilisers find their way into the rivers. This can cause eutrophication, whereby nitrogen feeds an algal bloom, but when the short-lived algae die, decomposing bacteria then consume most of the available oxygen, suffocating aquatic life and causing "dead zones" that kill aquatic life. The entering of potassium and phosphates into the river also increases river salinity.

5.4.2.2 Land clearing and burning

Although land clearing and burning is known to directly kill millions of birds and other animals by destroying their habitat, shelter and food sources, leading to the extinction of species, it is also regarded as a major cause of salinity as removal of native vegetation ensures that rain moves down to the water table, causing it to rise and forcing the soil salt to the surface. This situation is almost impossible to reverse and ruins not only the native life but devastates the agricultural value of the land. Land clearing directly leads to the degradation of fertile farmland causing millions of dollars of lost production and negatively affecting farmers and rural communities. Furthermore, the ashes from burning are washed by runoff into waterbodies, increasing salinity.

5.4.2.3 Irrigation

Irrigation salinity is the rise in saline groundwater and the associated build-up of salt in the soil surface in irrigated areas. Inefficient irrigation or applying more water than what the plants can use results in excess water getting leaked past the root zone to groundwater (recharge). This excess water can cause a rise in the water table under irrigation areas, which allows evaporation to occur resulting in salt concentrates at the surface and, in some cases, the ground becoming waterlogged. Irrigation salinity will be made worse where the water that is being applied to the irrigated area is derived from already salty rivers. Thus, although the current study did not include irrigation salinity, it is recommended that future research should focus on that because of the extensive irrigation occurring at the KRV and reported high salinity in some sites during field sampling for river water.

5.4.2.4 Farming close to/in buffer zones

In land-use planning, buffer zones have been used to protect natural resources and limit the impact of one land-use on another. Thus, aquatic buffer zones are designed to act as a barrier between human activities and sensitive water resources thereby protecting them from adverse negative impacts (Macfarlane et al., 2014). It was observed during data collection in the KRV that the buffer zone to the river is non-existent or has been encroached. This situation made it impossible to prevent pollution of the river quality with excess salt from farming activities. For example, crops were seen grown close to the river and livestock was frequently seen grazing very on the river back while standing in the river. A fenced or a protected area in a form of a buffer zone would have made it impossible for such encroachment.

5.4.2.5 Livestock grazing

Although livestock farming is beneficial to farmers and economy of the KRV, it has also proven to be detrimental to the landscape in many cases. For example, topsoil exposure due to overgrazing enhances soil salinity due to the increase in evaporation and the consequent rise of salts to the surface. Soil salinity gets washed into rivers in runoff, thereby increasing the salinity of the river water. It is worthy of note that the direction and extent of the responses to grazing are greatly variable along an elevation gradient (Di Bella et al., 2014).

As elevation decreases, exposure of topsoil, and therefore soil salinity also increases. In the KRV, livestock normally grazes over lowlands or decreased elevation, exposing a greater area of topsoil thereby increasing soil and consequently river salinity. Furthermore, livestock feeding habit caused simultaneous pulse increase in river turbidity and salinity during the sampling period. This seems to suggest a positive correlation between these two water quality factors, which require further investigations.

5.4.2.6 Wastewater Treatment Works

Sewage discharges into freshwater systems are a major component of pollution, negatively impacting water quality parameters such increasing dissolved solids, resulting in high electrical conductivity (EC) and increasing nutrient loads of the water bodies, promoting toxic algal blooms and leading to a destabilised aquatic ecosystem. This situation could be worsened in instances whereby the treatment facility is not efficient enough to adequately treat sewage before discharge or sewage flowing from burst pipes into the water body. This was the situation observed at the Fort Beaufort WWTW facility during the field survey, water sampling and biomonitoring. The Fort Beaufort sampling site and its downstream constantly recorded high salinity and turbidity values. It was observed that sheep and goats would have just muddied the waters by their feeding habits. This creates a situation of episodic pulse, ensuring constant circulation of dissolved suspended solids in the water column, resulting in high salinity and turbidity. This argument is supported by the fact both salinity and turbidity downstream this site were lower throughout the sampling period.

5.4.3 Management of Kat River water salinity based on CHAT analysis of farming and wastewater treatment activity systems in the Kat River Valley

5.4.3.1 What to do to manage salinity in the Kat River Valley

Salinity is the result of biophysical changes to the aquatic ecosystem and landscape. Therefore, effective management of salinity requires putting an end to or reversing some of those changes or factors that cause them. This will require major adaptation of our current patterns of land use. Table 5.2 presents a summary of the anthropogenic activities in the Kat River Valley (KRV) that give rise to increasing salinity and possible control measures. Summary of CHAT analysis of practices that could be employed to manage salinity problems due to farming and wastewater treatment activities systems in the KRV include:

- Leave, at least, 30-40-meter buffer zones of natural vegetation between cultivated land and river, and about 25-75-meter buffer zones between wetland and cultivated land.

- Ensure efficient irrigation techniques that take into account soil type, crop type, and soil water status and weather condition. Test for salinity in non-municipal (river, well and pond) irrigation water.

- Co-operating with environmental regulators and registration as water users with the Depart of Water and Sanitation.

- Crop rotation to increase soil organic matter and nutrients.

- Removing invasive vegetation and replacing with indigenous vegetation. Some invasive alien species are known to absorb much water, which leaves the soil very salty.

- Retaining native vegetation: allowing native forest or perennial vegetation to revegetate natural and limiting future clearing of native vegetation.

- Existing vegetation can be enhanced and/or fenced to control grazing. Buffer strips and livestock fencing may be used to reduce sediment input to the Kat River.

- Stabilise area against erosion and setting a high priority on maintaining vegetative cover.

Table 5.2: Identified salinity-increasing anthropogenic activities in the Kat River catchment and possible control measures based on the outcome of awareness creation and training workshop

Anthropogenic Activity	Mechanism of contributing to increasing salinity	Effects of increasing salinity	Control of increasing salinity
Fertilizer application	Portion of fertilisers get wash into the river as nonpoint source runoff, spray drift Nitrogen, potassium and phosphate in fertilisers find their way into the river	Increasing nutrient loads (nitrogen), leading to eutrophication Increasing salinity (potassium and phosphate)	Use manufacturer's manual Periodic soil and water analysis Take note of windy and flooding conditions before application Plough against the slope Use organic manure

Anthropogenic Activity	**Mechanism of contributing to increasing salinity**	**Effects of increasing salinity**	**Control of increasing salinity**
Land clearing and burning	Removal of native vegetation ensures that rain moves down to the water table, causing it to rise and forcing the soil salt to the surface Some alien species absorb much water, leaving the soil very salty	Ashes from burning get to soil, soil become salty, runoff carries salts into river, leading to increasing salinity Ruins native plant life Devastates agricultural value of the land	Replace invasive alien vegetation with indigenous ones and Limit future clearing of native vegetation Remove alien vegetation Overstock for grazing instead of burning
Irrigation	Inefficient irrigation or applying more water than what the plants can use Excess water gets leaked past the root zone to groundwater (recharge) Rise in saline groundwater and salts build-up on the soil surface, which is made worse by evaporation and already saline water	Soil becomes salty, runoff carries salts into river, leading to increasing salinity Devastates agricultural value of the land	Use efficient irrigation techniques (e.g. drip irrigation) Test for salinity of irrigation water regularly Construct holding dam
Encroachment of buffer zones	Aquatic buffer zones are designed to act as a barrier between human activities and sensitive water resources thereby protecting them from adverse negative impacts Crops grown close to makes it easy for fertilisers and ashes from burning to enter the river Animals drink and feed directly from the river,	Impossible to prevent activities that will lead to excess salt Erosion of topsoil makes easy runoff of minerals into river, leading to increasing salinity Sediment turn over release sank minerals, leading to increasing salinity	Leave, at least, 30-40 m buffer zones of natural vegetation between cultivated land and river Fencing of buffer zones Enforcement of laws by chiefs, CMFs, municipalities Construction of dams and water points for livestock Government must work with the communities

Anthropogenic Activity	**Mechanism of contributing to increasing salinity**	**Effects of increasing salinity**	**Control of increasing salinity**
	which exposes the topsoil and increases turbidity		There should be specific places where one could get to the river
Livestock grazing	Overgrazing enhances exposes the topsoil and increase in evaporation resulting in rising of salts to the surface Livestock feeding habit causes simultaneous pulse increase in river turbidity and salinity	Soil becomes salty, runoff carries salts into river, leading to increasing salinity Sediment turn over release sank minerals, leading to increasing salinity	Set high priority on maintaining vegetative cover and stabilise area against erosion Rotational grazing Fencing to prevent getting to the river Government and communities may employ rangers to prevent getting to the river
Wastewater treatment works	Inefficient and inadequate sewage treatment before discharge Sewage flowing from burst pipes into the river	High electrical conductivity, leading to increasing salinity Increasing nutrient loads, leading to eutrophication	Use modern and efficient technology Regular test to ensure meeting discharge standards Community members must report leaks and bursts to their leaders who will in turn report to the appropriate authority

5.4.3.2 Integrated management framework for salinity in the Kat River Valley

In the preceding section, some specific actions to take in order to ensure effective management of salinity in the KRV were enumerated. However, recognition is given to the view that the best way to manage salinity is to adopt an integrated management framework that best addresses ownership needs, type and extent of salinity, and the available options. Developing such a framework for a catchment should take into consideration investigating the processes and extent of salinity, and then developing a plan which incorporates whole-of-catchment processes and whole-of-farm activities (DNRE, 2011). The appropriateness of such salinity management actions for individual catchments is important because all catchments differ in terms of geology, soil types, rainfall, runoff, recharge rates and the extent of salinisation. Also, environmental features such as wetlands and vegetation, as well as socio-economic parameters make catchments different from each other. Thus, effective catchment salinity management requires a fundamental understanding of processes and activity systems in the catchment. This is the approach adopted in this study whereby scientific and social-economic investigations of the processes and local factors that contribute to salinity in the KRV were scientific and social-economic investigated in the entire catchment. For the scientific investigations, field tests were carried on Kat River's salts levels and effects of these salts on the aquatic biota (macroinvertebrates and diatoms), while socio-economic investigations focused on farming activities on the river's salinity. More importantly, the integrated management framework should ensure that there is partnership across management scales from local, through municipal, to provincial and national levels (DNRE, 2000). The responsibilities across these different management scales may include the following:

National Department: Key management issues include national leadership to develop coordinated and integrated approaches to public investment across jurisdictions; leading the development of better management principles, tools and systems; improving the knowledge base through strategic research and development (R&D); articulating, disseminating, demonstrating and refining best-practice approaches; improving incentives, especially in areas such as taxation measures; and ensuring the wider South African community is well informed about the issues. The government contributes primarily to activities which produce public benefits. Therefore, the National Department may agree to contribute towards salinity management activities that provide private benefits, where the cumulative uptake of these activities provides significant public benefit and Government support is required to facilitate this uptake. Before Government will contribute to any salinity management activity, the activity must be technically sound and the economic benefits must justify the costs.

Provincial Governments: Key management issues include the provision of research and technical support services; establishment of legislative frameworks; articulating, disseminating, demonstrating and refining best-practice approaches; pursuing the development of better management principles, tools and systems, e.g. market-based measures; implementing national and nationwide strategies; and establishing effective catchment/regional institutional arrangements.

Local Government: Relevant to natural resource management including cooperation with the catchment management agency; facilitating local people involvement; statutory water use planning; local support to community salinity management groups; and provision of local incentives.

Local Community: Community based KRV salinity management program participating in decision making on resource management options; partnering CMAs to provide a strong framework for community participation in implementing sustainable management practices of the resource; participating in monitoring natural resource issues; community education to ensure awareness salinity issues; and upholding the duty of care to protect the water resource.

5.5 CONCLUSION

In this chapter, the CHAT model was used to analyse agricultural and wastewater works activity systems and their impact on river water salinity in the Kat River Valley (KRV). The analysis showed that activity systems of both large and small-scale farmers seem to have minimum impact on Kat River's water salinity compared to small-scale livestock farming activity system. This is due to following reasons: large-scale farmers need to satisfy export conditions of their produce so adhere to strict standards so their activity system tend to decrease salinity; most small-scale crop farmers do not depend on the Kat River for irrigation so their activity system tend to decrease salinity; livestock feeding and drinking approaches employed by most small-scale livestock farmers tend to increase salinity.

The study also showed that decision making is crucial for salinity management. To decide on any management option means making the best decision between competing objectives, such as environmental and economic objectives. It is important to consider a cost-benefit analysis when evaluating management options. Important considerations should include the costs of managing the current degraded situation, remediation strategies, and reclamation of sites along the course of the Kat River affected by high salinity.

It is also crucial to assess the long-long term benefit if some management strategies may adversely affect the livelihood of farmers. At the same time, early implementation of management options will avert future salinity problems that may negatively impact the livelihood of people in the KRV catchment. In order to ensure effective management of salinity in the KRV catchment, the management strategies enumerated should be institutionalised in the decision-making process across all scales, i.e. national, provincial, local government and community levels. While it is acknowledged that everyone in the salinity management decision-making process will play their role effectively, the final decision of ensuring that Kat River's water salinity does not impact negatively on livelihood in the KRV catchment rest upon the individual farmers.

CHAPTER 6: GENERAL CONLUSION

6.1 IMPLEMENTATION OF OUTCOMES AND APPLICATION THEREOF

6.1.1 The developed salinity guidelines and the ecological class categories

South Africa has different Ecological Reserve categories and each category needs different levels of protection. Warne *et al*. (2004) recommended different levels of protection to equate the various Ecological Reserve categories for toxicants (Table 6.1). These recommendations are applied in this study to relate the derived WQGs trigger values to Reserve categories of South Africa. The SSD Generator calculates PC values as point estimates together with their corresponding lower and upper 95% confidence limits (interval estimates) (Posthuma *et al*., 2002; USEPA, 2005). The levels of PC percentages used in this study were based on the default output of the SSD Generator (i.e. the first four in decreasing order. Table 6.2-6.6 present NaCl, Na_2SO_4 and wastewater effluent guidelines for different levels of protection recommended for the different ecological integrity classes of South African Ecological Reserves.

Table 6.1: Recommended protection levels to equate the various ecological integrity classes of the ecological Reserve of South Africa (after Warne et al., 2004)

Alternate class description for ecological integrity		Level of protection
Excellent (natural)	A	PC > 95
Good	B	PC > 90
	C	
Fair		PC > 80
	D	
Poor	E	PC < 80

Table 6.2: Short-term NaCl WQG values associated with different levels of ecological integrity classes

Alternate class description for ecological integrity		Level of protection	Guideline value with 95% confidence limits (g/L)
Excellent (natural)	A	PC95	0.032 (0.003-0.290)
Good	B	PC90	0.070 (0.008-0.576)
	C		
Fair		PC80	0.182 (0.024-1.363)
	D		
Poor	E	PC60	0.657 (0.094-4.583)

Table 6.3: Long-term NaCl WQG values associated with different levels of ecological integrity classes

Alternate class description for ecological integrity		Level of protection	Guideline value with 95% confidence limits (g/L)
Excellent (natural)	A	PC95	0.133 (0.096-0.184)
Good	B	PC90	0.183 (0.134-0.251)
	C		
Fair		PC80	0.271 (0.200-0.366)
	D		
Poor	E	PC60	0.456 (0.340-0.612)

Table 6.4: Short-term Na_2SO_4 WQG values associated with different levels of ecological integrity classes

Alternate class description for ecological integrity		Level of protection	Guideline value with 95% confidence limits (g/L)
Excellent (natural)	A	PC95	0.071 (0.004-1.117)
Good	B	PC90	0.151 (0.011-2.103)
	C		
Fair		PC80	0.378 (0.030-4.695)
	D		
Poor	E	PC60	0.113 (1.295-14.776)

Table 6.5: Long-term Na_2SO_4 WQG values associated with different levels of ecological integrity classes

<table>
<tr><th colspan="2">Alternate class description for ecological integrity</th><th>Level of protection</th><th>Guideline value with 95% confidence limits (g/L)</th></tr>
<tr><td>Excellent (natural)</td><td>A</td><td>PC95</td><td>0.047 (0.016-0.142)</td></tr>
<tr><td rowspan="2">Good</td><td>B</td><td rowspan="2">PC90</td><td rowspan="2">0.074 (0.026-0.210)</td></tr>
<tr><td rowspan="2">C</td></tr>
<tr><td rowspan="2">Fair</td><td rowspan="2">PC80</td><td rowspan="2">0.127 (0.047-0.344)</td></tr>
<tr><td>D</td></tr>
<tr><td>Poor</td><td>E</td><td>PC60</td><td>0.262 (0.100-0.687)</td></tr>
</table>

Table 6.6: Short-term wastewater WQG values associated with different levels of ecological integrity classes

<table>
<tr><th colspan="2">Alternate class description for ecological integrity</th><th>Level of protection</th><th>Guideline value with 95% confidence limits (toxic units)</th></tr>
<tr><td>Excellent (natural)</td><td>A</td><td>PC95</td><td>1.009 (0.471-2.161)</td></tr>
<tr><td rowspan="2">Good</td><td>B</td><td rowspan="2">PC90</td><td rowspan="2">1.428 (0.696-2.929)</td></tr>
<tr><td rowspan="2">C</td></tr>
<tr><td rowspan="2">Fair</td><td rowspan="2">PC80</td><td rowspan="2">2.174 (1.103-4.282)</td></tr>
<tr><td>D</td></tr>
<tr><td>Poor</td><td>E</td><td>PC60</td><td>3.813 (1.993-7.295)</td></tr>
</table>

The short-term wastewater WQG values could also be aligned to the toxicity and wastewater effluent classification system by Persoone et al. (2003) as shown in Table 6.7.

Table 6.7: Hazard classification system for wastes discharged into the aquatic environment

Toxic unit	Toxicity	Classification
< 0.4 TU	No acute toxicity	Class I
0.4-1 TU	Slight acute toxicity	Class II
1-10 TU	Acute toxicity	Class III
10-100 TU	High acute toxicity	Class IV
>100 TU	Very high acutely toxicity	Class V

6.1.2 Salinity management practices

As part of this project, feedback session, awareness creation and training workshop were organised with communities involved in this research. The engagement provided research and experiential learning opportunities for both the research team (which included students) and the communities. The research team ensured that a genuine partnership was developed with the communities so that research/academic goals (learning and awareness creation) and community goals (capacity-building for change and improvement) are beneficial to both. Thus, the research team did not see itself as the only experts. Instead, there was a reciprocal exchange of information with mutual respect for the expertise and knowledge that both research team and communities brought to the table. This resulted in mutual learning and co-creation of knowledge, as evidenced in the development of a strategy to control the anthropogenic impact of salinity in the Kat River catchment. The research team see the mutual learning and co-creation of knowledge approach as a means of implementation transformation research, which has gained increasing attention as means of studying socio-ecological systems in recent years. Furthermore, the mutual learning and co-creation of knowledge by both research team and communities resulted in the development of a strategy to control the anthropogenic impact of salinity in the Kat River catchment. This strategy has been designed and developed into a brochure, which is attached as Appendix 2**.** In this context, the CHAT model has proven its suitability as a tool to analyse anthropogenic activities and their impacts in a catchment system and propose appropriate management options.

6.1.3 Impact on climate change

The outcomes of this project have strong links to two of the WRCs lighthouses, namely: Climate Change and Water-Energy-Food Security. South Africa is a water-stressed country with high evapotranspiration rate and low mean annual rainfall below the global average. Furthermore, various climate change models are showing a continuous rise in temperature. In fact, it is expected that South Africa will have 3 degrees Celsius rise in mean temperature by the end of this century. Thus, it is expected that these adverse climatic conditions may lead to increased river salinity. The literature review on the effect of temperature rise due to global climate change on freshwater salinisation together with the guidelines and management practices that have been developed in this project will ensure effective management of climate change impact on South Africa's freshwater resources.

6.1.4 Impact on water-energy-food nexus

In terms of the water-energy-food security nexus, it is important to note that farm crops generally do not grow well under saline water and soil conditions. This is crucial because many effluents from municipal wastewater, agricultural and mining facilities are used directly for irrigation of farmlands or are discharged into rivers, which then get abstracted and used for irrigation. One way of dealing with this problem is by removing salts from saline water (i.e. desalinisation) to render it useful for its intended purpose. However, the desalinisation process is energy intensive, needing a large amount of electricity. Therefore, the outcomes of this project will go a long way to establish a well-balanced relationship between the water-energy-food security nexus by implementing the developed guidelines and management practices in the three water use catchments (i.e. municipal wastewater treatment works, mining and agriculture).

6.2 RECOMMENDATIONS

Based on this study outcome, the research team recommend:

- Modelling of climate change effect on the the concentration of salts in the country's rivers for future study.

- A research project to characterise the major ions, and therefore major salts, found in domestic wastewater effluents.

6.3 CAPACITY BUILDING, PUBLICATIONS AND CONFERENCES

6.3.1 Capacity building

This project supported 2 MSc students and 1 PhD students, all supervised by the project leader, Dr PK Mensah. Ms Yvonne Chiliboyi graduated in April 2017 with an MSc in Water Resource Science; Ms Ntombekhaya Mgaba is almost done with her MSc thesis and at the point of submission for examination; Mr Emmanuel Vellemu, submitted his PhD thesis for examination in October 2017 and he would likely graduate in April 2018.

6.3.2 Publications

1. Mensah, P.K., Mgaba, N., Griffin N., Odume, N.O. and Palmer, C.G. (2017). Development of a procedure for determining the mixing ratios in ecotoxicological experiments and its application in binary salt mixture experiments. *Ecotoxicology*, 26, 1011-1017.

2. Vellemu, E., Mensah, P.K., Odume, O.N. and Griffin, N. (2017). Sensitivity of the mayfly *Adenophlebia auriculata* (Ephemeroptera: Leptophlebiidae) to $MgSO_4$ and Na_2SO_4. *Physics and Chemistry of the Earth*, 100, 81-85.
3. Vellemu, E., Mensah, P.K., Odume, O.N. and Griffin, N. (2017). Using a risk-based approach for derivation of water quality guidelines for sulphate. *Mine Water and the Environment*. doi: 10.1007/s10230-017-0480-2.

4. Vellemu, E., Mensah, P.K., Odume, O.N. and Griffin, N. (2017). The derivation of water quality guidelines for acid mine drainage using a risk-based approach. Manuscript submitted for publication in the African Journal of Aquatic Science.

6.3.3 Conferences

1. Mgaba, N. 2017. Evaluation of salinity risks to the river ecosystem in relation to irrigation practices and domestic wastewater discharge in the Kat River. A paper presented at the 8th International Young Water Professionals Conference. Cape Town Convention Centre, Cape Town, South Africa. December 2017.

2. Mgaba, N. 2016. Impact of agriculture activities on salinity of the Kat River. A paper presented at the Southern Africa Society of Aquatic Scientists (SASAqS) Conference. Kruger National Park, Skukuza, South Africa. June 2016.

3. Mensah, P.K. 2016. Use of the indigenous freshwater shrimp Caridina nilotica as a standard test organism for ecotoxicological studies in South Africa. A paper presented at the Southern Africa Society of Aquatic Scientists (SASAqS) Conference. Kruger National Park, Skukuza, South Africa. June 2016.

4. Mensah, P.K., Mgaba, N., Griffin, N., Odume, O.N., Palmer, C.G., 2015. Development of a Procedure for Mixture Ecotoxicological Experiments and it application for Binary Salt Mixture Experiments. A paper presented at the 7th Society of Environmental Toxicology and Chemistry (SETAC) Africa Conference. Langebaan, South Africa. October 2015.

5. Vellemu EC, Mensah PK, and Palmer CG (2015) Tolerance of juvenile and adult freshwater shrimps (Caridina nilotica) to MgSO4 and Na2SO4. Paper presented at the Society of Environmental Toxicology and Chemistry (SETAC) Europe 25th Annual Meeting in Barcelona, Catalonia, Spain. May 2015.

6. Vellemu EC, Mensah PK, and Palmer CG (2015) Sensitivity of the mayfly nymph (Adenophlebiide auricurata) Leptophlebiidae to MgSO4 and Na2SO4. Paper presented at the 16th WaterNet/ WARFSA/GWP-SA Symposium in Le Meridien Ile Maurice hotel, Mauritius, October 2015.

7. Vellemu EC (2015) Fighting Elephants, Suffering Grass: Towards a clumsy solution to solving acid mine drainage in South Africa. Poster presented at the 4th YWP ZA Biennial and 1st African Young Water Professionals (YWP) Conference in Pretoria, South Africa, 16-18 November 2015.

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APPENDICES

Appendix 1: Cultural Historical Activity System Interview Questions

This interview is part of a project by the Water Research Commission (WRC) of South Africa. The aim is to gather data about farming activities with respect to water quality, especially salinity, in the Kat River. The outcome will help design a framework for the management of salinity in the Kat River. The interview is strictly anonymous and respondents are welcome to decline answering questions they do not want to answer.

Question 1: Subject

i. How did you end up in this job?
   A. Family business
   B. Passion
   C. Field of training
   D. Available job
   E. Other……………………………………………………………………………………

ii. Do you look forward to coming to work every morning?
   A. Yes
   B. No

iii. Is it easy or is it quite difficult?
   A. Easy
   B. Difficult

iv. How long has your organisation been here?
   A. Less than 1 year
   B. 1-5
   C. 6-10
   D. 11-15
   E. More than 15 years

v. How are things going for the organisation now?
   A. Very good
   B. Good
   C. Satisfactory
   D. Fair
   E. Not good

vi. Do you understand what is meant by the term “water quality”
   A. Yes
   B. No

vii. Do you understand what is meant by the term “Salinity”?
   A. Yes
   B. No

viii. Do you check for water quality or salinity in the work you do?
   A. Yes
   B. No
   C. If yes, how?...

Question 2: Objective

i. What are your duties for the work you do?
   A. Farmhand
   B. Herdsman
   C. Technician
   D. Supervisor/Manager
   E. Owner
   F. Other………………………………………………………………………………

ii. What is the expected outcome of the work you do?
   A. To sell to the local market
   B. To export
   C. To have good income
   D. Other………………………………………………………………………………

iii. Do you pay attention to water quality in the work you do?

A. Yes
B. No

iv. Do you pay attention to salinity in the work you do?

A. Yes
B. No

v. Are you aware that some farming activities such as irrigation, fertiliser and pesticide applications produce excess salts that could affect the soil and water salinity?

A. Yes
B. No

vi. How do you ensure that salinity (water quality) does not affect production?

A. Making farrows to control irrigated water getting to the crops
B. Control application of fertiliser
C. Control of application of pesticides
D. Analysis of water samples (for major ions)
E. Other…………………………………………………………………………………

vii. Have you ever experienced any salinity problem in your work?

A. Yes
B. No
C. If yes, how did it affect your goals?...

viii. Do you have any measures in place to deal with increase salinity?

A. Yes
B. No
C. If yes, how?..

Question 3: Tools

i. What are the tools you have available to do your job?

…………………………………………………………………………………………

ii. Which of these tools work well for you, and which would you like to change to ensure decrease salinity?
   A. Work well…………………………………………………………………………
   B. Do not work well……………………………………………………………………

iii. What is the basic production processes?
   ……………………………………………………………………………………………

iv. Do you have any procedures, protocols and paper work to check salinity?
   A. Yes
   B. No
   C. If yes, what are they?...

v. Which of these changes would you make in the in the production process or the treatment processes to decrease salinity?
   A. Measure salinity periodically
   B. Proper application of fertilisers and pesticides
   C. Analysis of soil and water samples
   D. Keeping to the proper procedures and guidelines
   E. Other………………………………………………………………………………

Question 4: Sharing the tasks

i. Do you work alone or with a team?
   A. Alone
   B. Team

ii. What do you or the team members need to do to achieve decrease salinity?
   A. Measure salinity periodically
   B. Proper application of fertilisers and pesticides
   C. Analysis of soil and water samples
   D. Keeping to the proper procedures and guidelines
   E. Other…………………………………………………………………………………

iii. Does your work ensure achieving good water quality?
   A. Yes
   B. No

iv. Do you get help from others to do your job to ensure good water quality or decrease salinity?
   A. Yes
   B. No

Question 5: Community of practice, or peers

i. Do you have other workers, association or professional bodies that you meet with or have discussions with outside your workplace to enable you to improve upon your work?
   A. Yes
   B. No

ii. Do you have access to a trade or professional publications or magazines to enable you to improve upon your work?
   A. Yes
   B. No

iii. In your meeting with your fellow workers, association members or professionals, do you discuss water quality (e.g. salinity) as a major topic?
   A. Yes
   B. No

iv. Are you concerned about the state of water quality of the Kat River?
   A. Yes
   B. No
   C. If yes, what do you think could be done about it?

…………………………………………………………………………………………………..

Question 6: The rules of the game

i. Do you have formal rules, regulations or procedures to ensure good water quality, especially salinity, for the work you are doing?
   A. Yes
   B. No
   C. If yes, where do they come from?...

ii. If yes to (i) above, do you think aspects of the formal rules, regulations or procedures need to change to ensure good water quality, especially salinity?

   A. Yes
   B. No
   C. If yes, which aspects?……………………………………………………………

iii. Do you have informal rules, regulations or procedures that ensure the job actually gets done?

   A. Yes
   B. No
   C. If yes, state what these are…………………………………………………………

Question 7: The past and the future in the present

i. Were there important turning points you remember about your organisation’s handling of water quality, especially salinity, concerning the water resource you use (i.e. Kat River)?

   A. Yes
   B. No
   C. If yes, what were they?..

ii. What are your concerns about the future of water quality in Kat River?

   A. Less water for irrigation
   B. Less water for livestock
   C. Poor water quality (e.g. salinity) will make water not useable
   D. All of the above

iii. How long do you think you would continue operating if it depends on the water quality of the water resource you use (i.e. Kat River)?

   A. 5-10 years
   B. 10-20 years
   C. More than 20 years
   D. Other…………………………………………………………………………

iv. What do you think the future of water quality of the Kat River looks like?

A. Very good
B. Good
C. Satisfactory
D. Fair
E. Not good

v. How do you think this research can contribute to achieving good water quality of the Kat River?

……

Concluding comments

Thank you very much for your time and co-operation.

We will be feeding back the results of this interview and our analysis to you at a later date.

Appendix 2: A strategy to control anthropogenic impact of salinity in the Kat River catchment

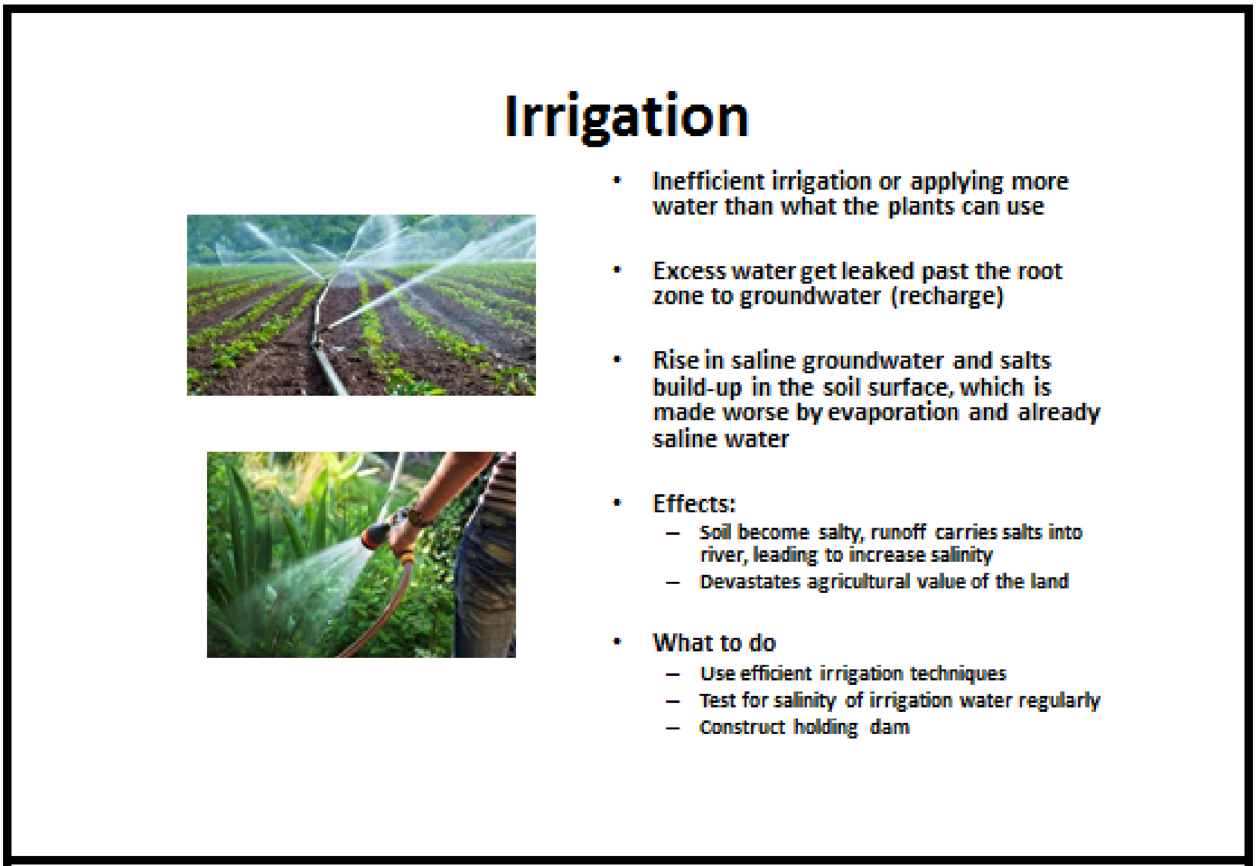
Salinity-increasing anthropogenic activities in the Kat River catchment and control measures

Fertilizer application

- Portion of fertilisers get wash into the river as nonpoint source runoff, spray drift
- Nitrogen, potassium and phosphate in fertilisers find their way into the river
- Effects
  - Increasing nutrient loads (nitrogen), leading to eutrophication
  - Increase salinity (potassium and phosphate)
- What to do
  - Use manufacturer's manual
  - Periodic soil and water analysis
  - Take note of windy and flooding conditions before application
  - Plough against the slope
  - Use organic manure

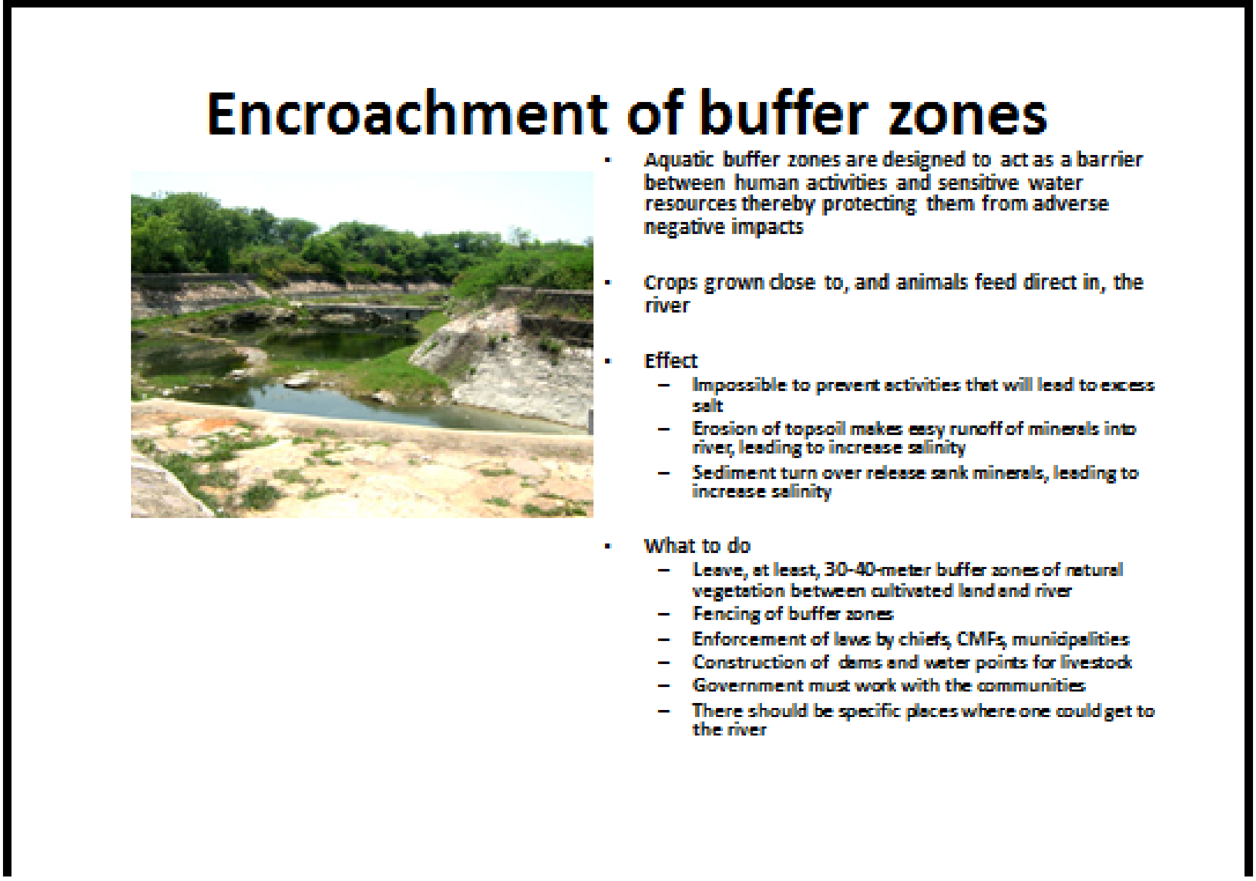
Land clearing and burning

- Removal of native vegetation ensures that rain moves down to the water table, causing it to rise and forcing the soil salt to the surface
- Some alien species absorb much water, leaving the soil very salty
- Effects
  - Ashes from burning get to soil, soil become salty, runoff carries salts into river, leading to increase salinity
  - Ruins native plant life
  - devastates agricultural value of the land
- What to do
  - Replace alien vegetation with indigenous ones
  - Limit future clearing of native vegetation
  - Remove alien vegetation
  - Overstock for grazing instead of burning



Irrigation

- Inefficient irrigation or applying more water than what the plants can use
- Excess water get leaked past the root zone to groundwater (recharge)
- Rise in saline groundwater and salts build-up in the soil surface, which is made worse by evaporation and already saline water
- Effects:
  - Soil become salty, runoff carries salts into river, leading to increase salinity
  - Devastates agricultural value of the land
- What to do
  - Use efficient irrigation techniques
  - Test for salinity of irrigation water regularly
  - Construct holding dam



Encroachment of buffer zones

- Aquatic buffer zones are designed to act as a barrier between human activities and sensitive water resources thereby protecting them from adverse negative impacts
- Crops grown close to, and animals feed direct in, the river
- Effect
  - Impossible to prevent activities that will lead to excess salt
  - Erosion of topsoil makes easy runoff of minerals into river, leading to increase salinity
  - Sediment turn over release sank minerals, leading to increase salinity
- What to do
  - Leave, at least, 30-40-meter buffer zones of natural vegetation between cultivated land and river
  - Fencing of buffer zones
  - Enforcement of laws by chiefs, CMFs, municipalities
  - Construction of dams and water points for livestock
  - Government must work with the communities
  - There should be specific places where one could get to the river

Livestock grazing

- Overgrazing enhances exposes the topsoil and increase in evaporation resulting in rise of salts to the surface
- Livestock feeding habit causes simultaneous pulse increase in river turbidity and salinity
- Effects
  - Soil become salty, runoff carries salts into river, leading to increase salinity
  - Sediment turn over release sank minerals, leading to increase salinity
- What to do
  - Set high priority on maintaining vegetative cover and stabilise area against erosion
  - Rotational grazing
  - Fencing to prevent getting to the river
  - Government and communities may employ rangers to prevent getting to the river

Wastewater treatment works

- Inefficient and inadequate sewage treatment before discharge
- Sewages flowing from burst pipes into the river
- Effects
  - High electrical conductivity, leading to increase salinity
  - Increasing nutrient loads, leading to eutrophication
- What to do
  - Use modern and efficient technology
  - Regular test to ensure meeting discharge standards
  - Community members must report leaks and bursts to their leaders who will in turn report to the appropriate authority