EXPLORING THE DEVELOPMENT OF AN INTEGRATED, PARTICIPATIVE, WATER QUALITY MANAGEMENT PROCESS FOR THE CROCODILE RIVER CATCHMENT, FOCUSING ON THE SUGAR INDUSTRY

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This thesis is submitted in fulfilment of the requirements for the degree of Master of Science Degree, Water Resource Science at Rhodes University

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ABSTRACT

Water quality deterioration is reaching crisis proportions in South Africa. Many South African catchments are over-allocated, and decreasing volumes of source water mean increasing concentrations of pollutants. The Crocodile River Catchment in the Mpumalanga province in South Africa was identified through previous research, as a catchment faced with deteriorating source water quality for water users in the catchment. Poor source water quality has become a sufficiently acute concern for the stakeholders in this catchment to co-operate in developing a process that assists with compliance control of their water use and waste disposal to reduce costs, decrease industrial risks as water quality compliance increases, and improve source water quality.

The sugar industry is downstream within the Crocodile River Catchment, and is affected by the activities of all upstream water users; the industry is thus dependent on the stakeholders upstream participating in the effective management of the resource. However, the sugar industry is also located just before the confluence of the Crocodile River and Komati River upstream of the Mozambique border, and thus the water quality of the sugar industry effluent will affect the quality of the water that flows into Mozambique. The sugar industry is on the opposite river bank to the Kruger National Park, which has high water resource protection goals. Therefore, the sugar industry has a national role to play in the management of water resources in the Crocodile River Catchment.

This study provides a focused view of the role of the sugar industry in the development of a co-operative, integrated water quality management process (IWQMP) in the Crocodile River Catchment. In order to address the objectives of this study, this research drew from an understanding of the social processes that influence water management practices within the sugar industry as well as social processes that influence the role of the Inkomati-Usuthu Catchment Management Agency as the main governing institution in water resource management in the Inkomati Water Management Area. The study also drew from an understanding of scientific knowledge in terms of a water chemistry which describes the upstream and downstream water quality impacts related to the sugar industry.

The water quality analysis for the Lower Crocodile River Catchment shows a decline in water quality in terms of Total Dissolved Solids (TDS) loads when moving from below Mbombela to

the Mozambique border. The major sources of TDS in the Lower Crocodile River are point source dominated, which may be attributed to the extensive mining, industrial and municipal activities that occur across the catchment.

When observing Total Alkalinity (TAL) and pH values from below Mbombela to the furthest monitoring point, there is deterioration in the quality of the water in the Lower Crocodile River, with the Kaap River contributing a negative effect that is diluted by the Crocodile main stem. The Hectorspruit Waste Water Treatment Works (WWTWs) (located in the Lower Crocodile River Catchment) contributes high concentrations of TDS and TAL into the Crocodile River.

Total Inorganic Nitrogen and Soluble Reactive Phosphorus concentrations decrease in the lower reaches of the Crocodile River compared with the river below Mbombela, which can be attributed to the extensive sugar cane plantations located in the Lower Crocodile River Catchment acting as an “agricultural wetland” that serves a function of bioremediation resulting in large scale absorption of nutrients. This is an interesting result as earlier assumptions were that fertiliser application would result in an overall increase in nutrient loads and concentrations.

Biomonitoring data show no substantial change in aquatic health in the Lower Crocodile River Catchment. For a catchment that has an extensive agricultural land use in terms of sugarcane and citrus production, the Crocodile River is unexpectedly not in a toxic state in terms of aquatic health. This is a positive result and it suggests that pesticide use is strictly controlled in the sugar and citrus industry in the Crocodile River Catchment. For long term sustainability, it is essential for the sugar industry to maintain (and possibly improve) this pesticide management.

The social component of this study aimed to provide an analysis of the management practices of the sugar mill as well as examining agricultural practices in the sugar cane fields in relation to water quality management through the use of Cultural Historical Activity System Theory (CHAT). This component showed that there are contradictions within the sugar industry activity system that are considered to be areas of “tension” that can be loosened or focused on to improve the contribution the sugar industry can make to the IWQMP. Surfacing contradictions within the sugar industry activity system and the Inkomati-

Usuthu Catchment Management Agency activity systems highlighted areas of potential for learning and change.

While an understanding of biophysical processes through scientific knowledge is critical in water management decision making, it is evident that an understanding of other actors, institutions and networks that inform water quality management decision-making also plays a significant role. The notion of improving the role of scientific or biophysical knowledge in contributing to socio-ecologically robust knowledge co-creation, decisions and actions towards resolving water quality problems is emphasised. Specifically, moving towards improving interactions between scientists and other actors (water users in the Crocodile Catchment in this case), so that scientific practices become more orientated towards societal platforms where water quality management is tackled to enable improved water quality management practices. Therefore, linking the social and biophysical components in this study provides a holistic understanding of how the sugar industry can contribute to the development of an IWQMP for the Crocodile River catchment.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASPT	Average Score per Taxon
AWARD	Association for Water and Rural Development
BOD	Biological Oxygen Demand
BMWP	Biological Monitoring Working Party
CEO	Chief Executive Officer
CHAT	Cultural Historical Activity Theory
CMA	Catchment Management Agency
COD	Chemical Oxygen Demand
COO	Chief Operating Officer
CMS	Catchment Management Strategy
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
EEC	Effective Electrical Conductivity
EIAs	Environmental Impact Assessments
EMPRs	Environmental Management Programmes
FAS	Fertilizer Advisory Service
FDCs	Flow Duration Curves
FRAI	Fish Response Assessment Index
GIS	Geographical Information System
GWP	Global Water Partnership
ICMA	Inkomati Catchment Management Agency
IIMA	Interim IncoMaputo Agreement

IUCMA	Inkomati-Usuthu Catchment Management Agency
IWQMP	Integrated Water Quality Management Process
IWRM	Integrated Water Resource Management
LDCs	Load Duration Curves
LIMS	Laboratory Information Monitoring System
MAP	Mean Annual Precipitation
MIRAI	Macro-Invertebrate Response Assessment Index
NDP	National Development Plan
NOSA	National Occupational Safety Association
NRF-THRIP	National Research Foundation-The technology and Human Resources for Industry Programme
NWA	National Water Act
NWP	National Water Policy
NWRS	National Water Resource Strategy
PES	Present Ecological Status
PP	Particulate Phosphorus
RDM	Resource Directed Measures
RHP	River Health Programme
RQOs	Resource Quality Objectives
RSA	Republic of South Africa
RSC	Residual Sodium Carbonate
RWQOs	Resource Water Quality Objectives
SACU	Southern African Customs Union
SAM	Strategic Adaptive Management
SANPARKS	South African National Parks
SAR	Sodium Absorption Ratio

SASA	South African Sugar Association
SASRI	South African Sugarcane Research Institute
SASS	South African Scoring System
SES	Social Ecological System
SIP	Session Initiating Protocol
SP	Soluble Phosphorus
SQ	Subquatenary
SQR	Subquatenary River
SRP	Soluble Reactive Phosphorus
SUP	Soluble Unreactive Phosphorus
SUSFARMS	Sustainable Sugarcane Farm Management System
TDS	Total Dissolved Solids
TIN	Total Inorganic Nitrogen
TP	Total Phosphorus
TSB	Transvaal Suiker Beperk
TSS	Total Suspended Solids
TWQR	Target Water Quality Range
WARMS	Water Authorisation and Registration Management System
WMAs	Water Management Areas
WMI	Water Management Institution
WMS	Water Management System
WQSAM	Simple Water Quality and Quantity Integration Model
WWF	World Wildlife Fund
WWTWs	Waste Water Treatment Works
WUAs	Water User Associations

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DEDICATION

This work is dedicated to the loving memory of my late brother Siyanela "Bushy" Gwentshe

Memories are all we have left. You will always be a part of our lives. Gone but never forgotten

24 April 1982- 4 August 2013

DECLARATION

The following thesis has not been submitted to any university other than Rhodes University, Grahamstown, South Africa. The work presented here is that of the author except the data interpreted in Chapter 6. This data is part of Mr D.H.C. Retief's MSc Research (Retief, 2014).

CHAPTER 1

1.1 General Introduction

Water is one of the most fundamental of all natural resources because it is vital for life and the quality of life, to the environment, food production, hygiene, industry and the generation of energy. The availability of affordable water can also be a limiting factor for economic growth and social development, especially where it is a scarce resource (DWAF, 2004a). There is an increasing understanding both nationally and internationally that water resources can be effectively managed only if their multisectoral (natural, economic, social and political) nature is fully considered (Global Water Partneship Technical Commitee, 2009).

Rapidly growing human populations have exerted immense pressure on the world's natural resources, particularly freshwater resources. Human impacts have resulted in the degradation of these resources, especially the world's rivers and wetlands (Kingsford, 2011). Human use of freshwater resources and degradation of freshwater quality have now reached a point where shortages of safe water limit food production, ecosystem function and result in non-efficient systems of urban water supply (Jury and Vaux, 2007). Poor people are often most severely affected by increasing water scarcity and poor water quality as they are often directly dependent on freshwater ecosystems for their subsistence, relying on the goods and services provided by local freshwater ecosystems (Bordalo and Savva-Bordalo, 2007). Many water managers across the world are faced with the challenge of not being able to provide reliable and affordable freshwater supplies (Poff *et al*., 2010).

1.2 Water Quality Management in South Africa

Freshwater resources in South Africa are scarce and under immense pressure due to population growth, increased demand for agriculture, industry and socio-economic development (Davies and Day, 1998; King and Harrison, 2011). Rivers are the main source of freshwater in South Africa and the country depends on surface water resources for industrial, urban and irrigation water requirements (DWAF, 2004b). However, freshwater systems in South Africa are adversely affected by water abstraction and pollution (Dallas *et al*., 1994; Davies and Day, 1998; Palmer *et al*., 2004). Although human activities affect both the quantity and the quality of water resources, much of the emphasis of water resource management in South Africa pre-1994 has been on providing efficient adequate water quantity for a limited group of people with access to land (Dallas *et al.*, 1994; Davies and Day, 1998; DWAF, 2004a).

However, rivers and other water resources are often used to dispose of waste, thus affecting the quality of the water resource as well (Davies and Day, 1998; Dallas and Day 2004). It has thus become important to not manage water quantity and quality in isolation as both influence the assimilative capacity of the water resource which affects the amount of water available to users. Assimilative capacity is described as the ability of the water resource to absorb a certain level of pollution and remain serviceable (DWAF, 2004a). This concept has also been expanded to include the ability of water resources to absorb wastes that are more complex than simple organics without being degraded (Cairns Jr., 1999).

Leandri (2008) emphasises that the level of assimilative capacity of a natural system is not constant and it depends on either the current amount of pollution present or the amount of flow within the system to provide dilution. Deksissa *et al.* (2004) add that because the dilution capacity of a water resource is reduced due to high levels of water abstraction from upstream, water quality in downstream reaches is often considerably affected. In the past when human populations were much lower than present, waste volumes were low and simple (with few complex compounds such as endocrine disrupters) with limited concerns about how appropriate it is to use rivers for disposal. However, due to increased human populations it became evident that the assimilative capacity of rivers can be exceeded, resulting in degradation of water resources (Leandri, 2008). Reduced flows also results in increased sedimentation impacts as well as increased concentration of total dissolved solids downstream. This concept applies to both surface water as well as groundwater (Deksissa *et al.*, 2004).

There are a number of processes that influence the quality of surface water which can either be natural or human induced (Palmer *et al.*, 2004). These processes include erosion, diffused discharges from irrigated farmlands, industrial waste and sewage discharges, domestic and urban runoff (Dallas and Day, 2004). Pollutants from these processes enter water resources from point and non-point sources. Point sources are described as the identifiable points where waste is discharged into the water resource through pipes or drains. On the other hand, non-point sources refer to pollution that takes place in a wider area, mostly associated with specific land use practices such as agriculture (Rand, 1995; Davies and Day, 1998).

According to Görgen *et al.* (2003), it has been recognised that non-point source pollution plays a significant role in deteriorating water quality, especially with regards to increased nutrient and sediment levels. Agriculture has been identified as a major contributor of non-point pollution and the associated water quality concerns include salinization (contributed by irrigation return flows and leaching through cultivated dry-land), sedimentation of water courses (through erosion), eutrophication (through fertilizer leaching and nutrient wash-off from nearby human settlements), pathogens (from intensive animal farming and poor sanitization on farms), pesticides (through the application of pesticides, insecticides and herbicides on farms) and heavy metals (Görgens *et al*., 2003: 1). It is therefore important to address non-point source contributions to manage catchment water quality.

According to King and Harrison (2011: 14), the trends in population growth, increasing demands of water, resulting water resource development and consequent ecosystem degradation are a global concern, however adapting and managing water resources effectively depends on each country. South Africa has made considerable strides in acknowledging the interactions that exist between hydrological flows, ecosystem functions, economic growth and human well-being and this is evident in the development of the water policy and legislation in South Africa (Lorentzen, 2009).

1.3 Water policy and legislation in South Africa

1.3.1 National Water Act pre-1994 ad post-1994

In South Africa prior to 1994, water was governed in a way that was discriminatory and favoured the minority with access to land (de Coning and Sherwill, 2004). The 1956 Water Act gave the right to use water to people who owned land and they had private rights (also termed riparian rights) to groundwater, or water from streams and rivers on or next to their land. This meant that people who did not own land did not have access to water on privately owned land. The Water Act of 1956 focused on water provision for agriculture; hence water was given to landowners, for example farmers (DWAF, 1998).

The previous Act also focused on water supply (through development of dams), water pollution control and not on conservation, protection and management of water demand.

Due to increasing competition for the use of water resources, sustainability of water resources became a priority, but this was only included in South Africa's legislation when the National Water Act (No. 36) of 1998 was passed. The commitment to sustainable utilization of water resources in the National Water Act (No. 36 of 1998) implies the willingness to balance the short-term needs for water use with the need to protect water resource for sustained long-term use (DWAF, 1996a).

It is stated in the Bill of Rights contained in the Republic of South Africa's Constitution (Act 108 of 1996), in Section 27 (1) (b), that all South Africans have the right to an environment that is not harmful to their health and wellbeing, as well as an environment that is protected for the benefit of both present and future generations. The Government therefore has the responsibility to ensure that sufficient water is available to maintain the integrity and function of ecological water resources, as well as ensuring that water conservation and sustainability, economic and social development is achieved through the prevention of water pollution (DWAF, 2004b). The National Water Act (No. 36) of 1998 also aims to ensure that water access is no longer a discriminatory process but that water use is a public trust and water belongs to everyone in South Africa. This is based on the principle that the distribution of water should be fair and equal (DWAF, 1998).

The National Water Policy (NWP) (DWAF, 1997: 19) has three fundamental objectives for managing South Africa's water resources:

- To achieve equitable access to water, that is, equity of access to water services, to the use of water resources, and to benefits from the use of water resources.
- To achieve sustainable use of water by making progressive adjustments to water use with the objective of achieving a balance between water availability and water requirements, as well as implementation of water resource protection.
- To achieve efficient and effective water use for optimum economic and social development.

The objective of environmentally sustainable water use is to balance water resource use with water resource protection such that the resources are not degraded beyond recovery.

The purpose of the National Water Act (NWA, Act No. 36 of 1998: 9) is to ensure that South Africa's water resources are "protected, used, developed, conserved, managed and controlled” in ways that make it possible to meet basic humans needs and requirements for aquatic ecosystems in the present and for future generations. Through the development of this new act, water resource protection became a priority in water resource management, and is now focused on ecosystems and biological diversity. The NWP also established priorities, which stipulate how water would be allocated, where water for basic human needs is the first priority, environmental requirements (also described as the ecological Reserve) being the second priority and then international obligations and all the other water uses of water are considered for allocation. The quantity and quality of water required to satisfy the first two priorities (basic human needs and environmental requirements) is termed the Reserve (King and Harrison, 2011).

The ecological Reserve is defined as the quantity and quality of water necessary to protect aquatic ecosystems, in order to ensure ecological sustainability while still allowing use of the resource (Scherman *et al*., 2003). Worldwide, many scientists have been involved in the development of methods that will help in the determination of the ecological Reserve and this process includes stakeholder participation to prioritise and set ecological requirements before other pressing needs (Palmer, 1999; DWAF, 2004a). The National Water Act (NWA) and National Water Policy (NWP) support the management of South Africa’s water resources through the implementation of the National Water Resource Strategy (NWRS) (DWAF, 2004b; DWA, 2013). The success of water resource management therefore depends on the co-operation of all domains of government as well as the integrated involvement of all water users and organisations (NWA, Act No. 36 of 1998).

1.3.2 National Water Resource Strategy

The National Water Resource Strategy (NWRS) provides the framework that sets out policies, strategies, objectives, plans, guidelines, procedures and institutional arrangements for the protection, use, development, conservation, management and control of water resources for the whole country (DWAF, 2004a; DWA, 2013). It also provides the framework within which water can be managed at a regional and catchment level in defined water management areas (DWAF, 2003). According to NWA (Section 6) the purpose of the NWRS (DWAF, 2004a; DWA, 2013) is to:

I. Facilitate the proper management of the nation’s water resources
II. Provide a framework for the protection, use, development, conservation, management and control of water resources for the country as a whole
III. Provide a framework within which water will be managed at regional or catchment level, in defined water management areas
IV. Provide information about all aspects of water resource management
V. Identity water-related development opportunities and constraints.

The first edition of the NWRS was published in 2004. It was a comprehensive strategy that described the fundamentals of integrated water resource management and presented a clear perspective of the water situation in South Africa with critical actions required (DWA, 2013: 1). However, since the NWA was established in 1998 and the first NWRS was published in 2004 the country has evolved and a National Development Plan (NDP) was published in 2011 that seeks to eliminate poverty and reduce inequality by 2030. In order for the NDP to be implemented effectively by 2030 the NWRS must respond to it by outlining the strategy for managing South Africa’s water resources. The second NWRS that was published in 2013 as a revision of the first NWRS after a consultation process, outlines the role of water in the economy of the country and seeks to address concerns about socio-economic growth which may be restricted if water scarcity, resource quality and other water management issues are not resolved (DWA, 2013: 3).

King and Harrison (2011) highlight the importance of effective water management institutions such as catchment management agencies to meet the requirements of the NWA. The Water Management Institutions (WMI) Guide (DWA, 2004c) outlines the different water management institutions, how they should be established, and their overall functions. There are three tiers of management, which are distributed as following:

- First Tier: ensures the overall effective management of water resources in the country. This tier consists of the Minister of Water Affairs and the Department of Water Affairs (DWA) and these officials are responsible for establishing the National Water Resource Strategy. The main focus of this tier is national policy, regulatory framework for water resource management and ensuring that other institutions are effectively fulfilling their responsibilities (DWAF, 2004c). This tier operates at the national scale.

- The second tier: Catchment Management Agency (CMA) which is responsible for the establishment of catchment management strategies (CMS) for each of the 9 water management areas. The key factor in CMAs is public participation, cooperative governance and coordination of activities within management (DWA, 2004c).
- The third tier: Water User Associations (WUAs) are co-operative associations of individual water users who wish to undertake water-related activities for their mutual benefit. This tier is governed by a management committee. WUAs operate at local level scale and deal with local water related activities and this provides a mechanism through which the catchment management strategy of that water management area can be implemented at local level. Merrey *et al*. (2001) outline how important the local level implementation of IWRM is in terms of poverty alleviation and food security to improve the livelihoods of people and also to ensure sustainable and equitable use of water resources especially in developing countries such as those in sub-Saharan Africa.

1.3.3 Catchment Management Strategy

South Africa is currently divided into 9 Water Management areas (WMAs) which allows water resource management to be delegated from national government to catchment level (King and Harrison, 2011). This is achieved through the establishment of Catchment Management Agencies (CMAs) in each WMA. Each CMA develops a Catchment Management Strategy (CMS) for the protection, use, development, management, conservation and control of water resources within each WMA (DWAF, 2004a; DWA, 2013). In the process of CMS development, the CMA has to ensure that the CMS is in agreement with the NWRS and the CMA has to ensure that co-operation and agreement to water-related issues is reached among relevant stakeholders. The CMS includes a water allocation plan that sets out the principles of allocating water to existing as well as prospective water users ensuring that it takes account of all issues related to protection, use, development, conservation, management and control of water resources (NWA, Act No. 36 of 1998). A CMS has been developed for the Inkomati CMA, which relates to the study area of this thesis (ICMA, 2004).

The Department of Water Affairs (now referred to as Department of Water and Sanitation: DWS) is working towards eventually handing over particular water resource management functions to CMAs, but until CMAs are fully established and operational, DWS regional offices continue to manage water resources in judicial areas (NWA, Act No. 36 of 1998).

1.4 The Crocodile River Catchment as a complex social-ecological system

Natural resource managers in the past approached resource management from a single domain perspective. For example, understanding biophysical aspects of wetland processes is good, but might not be sufficient for successful rehabilitation if the links of the aquatic processes to the surrounding terrestrial landscape as well as the socio-political context are not taken into account. The link between biophysical and socio-economic processes has also been given inadequate consideration (Pollard *et al*., 2008). Palmer *et al.* (2012) add that there is evident failure within water resource management because of this disconnect in our understanding which has resulted in the deterioration of water quality.

To rectify this problem, several initiatives are in progress in South Africa to establish Integrated Water Resource Management (IWRM) frameworks to improve sustainability and promote equitable use. The concept of IWRM was established following an international consensus reached in international conferences on water and environmental issues in Dublin and Rio de Janeiro held in 1992, and then imported into SA water policy (Global Water Partnership, 2000). During the Dublin and Rio conferences, all governments that were participating agreed on four Dublin principles that form the core of IWRM, these principles are listed below (Funke *et al*., 2007: 1239):

1. Freshwater is a finite and valuable resource, essential to sustain life, development and the environment.
2. Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
3. Women play a central part in the provision, management and safeguarding of water.
4. Water has an economic value in all its competing uses and should be recognised as an economic good.

The Dublin principles aim to promote changes in the concepts and practices that are considered to be fundamental for improved water resources management and these principles have found support in the international community as the guiding principles for IWRM (Global Water Partnership, 2000).

The IWRM framework is applied in SA to achieve integration in water resources management in the country. In order to reach the balance of understanding ecological and social-economic processing of a catchment, it has to be viewed as an integrated social-ecological system (SES) (Pollard *et al*., 2008). According to Pollard and du Toit (2008) and Berkes *et al*. (2008) the social and ecological systems that make up a catchment are complex in their own right and are made even more complex as they interact. These interactions can include surface and groundwater links; link between water quantity and quality; runoff from land; infiltration and evaporation; demand, supply and discharge; as well as the link between land use and water.

Complex systems are described as systems that possess the following characteristics: non-linearity, uncertainty, multi-scale as well as cross-scale interactions, self-organisation and feedback loops between its components (Pollard *et al*., 2008). Pollard and du Toit (2008) add that catchments consist of linked social and ecological systems and water does not only have an ecological view but also socio-economic, political and institutional aspects that have to be managed. Under this view, it is important to see social-ecological systems holistically and understand that they vary in time and space which determines how they function and adapt to changes. Past management approaches have failed to deal with the complex and changing social-ecological systems, emphasising the need for integrated approaches that have been included in integrated resource management (IWRM). South Africa's NWA and associated policies reflect an incorporation of a holistic approach with a system understanding to strike a balance between the use of resources for livelihoods and protection of resources for the future, while promoting social equity, environmental sustainability and economic efficiency (DWAF, 2004b).

The Crocodile River Catchment is a complex social-ecological system with various interactions between hydrological flows, ecosystem functions, economic growth and human well-being that need to be understood in order to achieve effective and efficient management of the Crocodile River.

1.5 Motivation of the study

The Crocodile River Catchment in the Mpumalanga Province in South Africa is faced with the deterioration of source water quality for water users in the catchment. Water quality comprises many variables, and it is often difficult to identify pollution culprits and to enforce compliance. However low water quality is becoming a sufficiently acute concern for the stakeholders in this catchment and thus, the need to co-operate to develop a process that assist with achieving compliance in terms of their water use and waste disposal has been recognised. This will reduce the costs of enforcement, and industrial risks will decrease as water quality compliance increases, and therefore the source water quality will improve.

Businesses in the Crocodile catchment are facing direct risks and costs to profitability. These risks and current costs include the following: low source water quality escalates the costs of in-house treatment for mining, sugar milling, water boards, beverage and paper manufacturers (Deksissa *et al*., 2003). It also reduces the productivity of sugar cane and citrus crops and this is a risk to the export quality of citrus and sugar. Industries also face risks associated with non-compliance such as fines or costly litigation. Affected industries in the Crocodile River Catchment include water boards, water user associations, mines, forestry, pulp and paper manufacturing and sugar mills. Each of these industries perceive their medium to long term business viability to be at risk because of low water quality (Palmer *et al.,* 2012).

It is only as each of a set of water users finds itself impacted by others, and experiences the consequences of inadequate and inefficient regulation that the potential for co-operation and self-regulation emerges. According to Palmer *et al.* (2012), such a point has been reached in the Crocodile River catchment; however, to be cost effective, an integrated, systems and complexity-based approach is necessary, together with excellent technology, facilitation and engagement. With so many water quality “users” in this catchment, a viable solution is for stakeholders to co-operate with each other and with the regulators to set their own management processes and to collectively hold each other to account. This saves on litigation costs, and if the trajectory of water quality deterioration can be halted and turned around, tangible savings can be delivered including increased economic viability in the long term.

Another important motivation for cooperation in improving the water quality is that the confluence of the Crocodile and the Komati River lies just upstream of the Mozambique border at Ressano Garcia where the river is then known as the Incomati River. The Crocodile River is one of the numerous rivers that contribute to transboundary flows. South Africa, Mozambique and Swaziland signed the Interim IncoMaputo Agreement (IIMA) for co-operation on the protection and sustainable use of Incomati and Maputo watercourses. The agreement sets limitations on water use in each basin with specific target flows that need to be maintained to ensure that river ecology is sustained and that the water quality meets a certain standard (Table 1.5.1 and 1.5.2) (ICMA, 2004). The agreement also serves to promote cooperation between the countries and to ensure the protection and sustainable utilisation of the shared water resources (Lorentzen, 2009; du Toit *et al.*, 2012). The agreement as shown in Table 1.5.1 highlights that South Africa should ensure a minimum cross-border flow of 2.6 m^3/s at Ressano Garcia for environmental purposes as well as 29 Mm^3/a for irrigation and 1 Mm^3/a for domestic purposes (TPTC, 2002). According to Lorentzen (2009), South Africa has occasionally failed to achieve this commitment and this has led to conflicts with Mozambique.

Table 1.5.1: Target Interim IncoMaputo Agreement ecological flows at key points in the Inkomati WMA (ICMA, 2004).

River	**Key Point**	**Interim Target Instream Flow**	
		Mean (Mm^3/a)	**Minimum (m^3/s)**
Sabie	**Lower Sabie**	200	0.6
Crocodile	**Tenbosch**	245	1.2
Komati	**Diepgezet** **Mananga** **Lebombo**	190 200 42	0.6 0.9 1.0
Incomati	**Ressano Garcia**	290	2.6

The agreement also includes a resolution on water quality management goals that is developed through the exchange of and access of information and data among the countries, as well as a framework for capacity building within the countries as shown in

Table 1.5.2 below (TPTC, 2002). The resolution describes the water quality management goals that each country needs to conform to which include the following (TPTC, 2002):

i. ensure that existing aquatic ecosystems are protected;
ii. allow for abstraction for use in the production of drinking water after appropriate treatment;
iii. prevent significant adverse transboundary impacts;
iv. prevent deterioration of the water quality of the watercourses;
v. be guided in general by water quality guideline values for the specific water use sectors;
vi. at least conform to the values set for the parameters indicated in Table 1.5.2.

Table 1.5.2: Short Term Water Quality Guidelines (TPTC, 2002).

PROPERTY, CONSTITUENT PARAMETER	GENERAL IDENTIFICATION[a]	UNIT	CONCENTRATION OR VALUE[b]	SAMPLING FREQUENCY
Colour	4	mg/l Pt-Co	15	As required
Odour	4	Dilution factor	3	As required
Turbidity	4	NTU	5	Quarterly
pH	1,4	Units	6.5 – 8.5	Quarterly
Conductivity (electrical)	1,4	mS/m[c]	150	Quarterly
Ammonia (NH_4)	1,4	mg/l[d]	1.0	Quarterly
Biochemical Oxygen Demand (BOD)		mg/l	<5	Quarterly
Chemical Oxygen Demand (COD)	1,4	mg/l	10	Quarterly
Chloride	1,4	mg/l	250	Quarterly
Dissolved Oxygen (DO)	1	% sat	>75	Quarterly
Fluoride	1,3,4	mg/l	0.75	Quarterly
Nitrate (as NO_3)	1,2	mg/l	50	Quarterly
Potassium		mg/l	50	Quarterly
Sodium		mg/l	200	Quarterly
Total phosphate	1,4	mg/l	2.0	Quarterly
Sulphate	1,2,4	mg/l	250	Quarterly
Total coliforms	1,2	No/100 ml	10 000	Monthly
Faecal coliforms	1,2	No/100ml	2 000	Monthly
Faecal streptococci	1,2	No/100ml	1 000	Monthly
***Vibrio cholerae* (non agglutinable)**	3	No/1 000ml	Number to be communicated within 1 year	As required
Copper	1	mg/l	0.02	Quarterly
Iron	1,2	mg/l	Value to be communicated within 1 year	Quarterly
Manganese	1,2,4	mg/l	0.3	Quarterly
Pesticides	3,4		Qualitative	Quarterly

Legend for Table 1.5.2

a: 1: General indicators of water quality

2: Commonly present and may lead to health problems

3: Less frequently detected at levels of real concern

4: Present at concentrations of environmental or economic concern

b: stated values refer to 75 percentiles

c: milli-Siemens per metre

d: milligrams per litre

Thus, South Africa has the responsibility to ensure that the water that flows to Mozambique is of a particular quality and quantity as the Crocodile River is an international water course that is shared by the two countries (Pollard and du Toit, 2011a). It is thus essential to consider the Crocodile River Catchment as a complex Social Ecological Systems (SES) to be able to unravel water quality issues with biophysical and socio-economic links within the catchment.

The aim of this study is to provide a focused view of the development of a co-operative, integrated water quality management process in the Crocodile River Catchment. The sugar industry is downstream within the Crocodile River Catchment and is affected by the activities of upstream water users, and it is thus, dependent on the stakeholders upstream participating in the effective management of the resource. On the other hand, the sugar industry is also located just before the confluence of the Crocodile River and Komati River upstream of the Mozambique border, thus the water quality of effluent from the sugar industry will affect the quality of the water that flows into Mozambique.

This study will examine how the technical processes of the sugar industry can be modified to improve the water quality of the Crocodile River using biophysical data to monitor the areas that need focus as well as the outcome of Cultural Historical Activity System analysis (Engeström, 2001) to build relationships with the other water users in the catchment, thus improving upstream-downstream negotiation.

This research contributes to a larger project with the aim of building a co-operative, implemented and integrated water quality management process (IWQMP) in the Crocodile

River Catchment. The larger project aims to bring together industries in the Crocodile River Catchment with local government and water service providers with the focus of seeking collaboration to improve water quality in the Crocodile River to save industries and local government treatment costs as well as to contribute to human and environmental health.

This study contributes to the larger project by providing a focused view of the role the sugar industry can play in contributing to the development of an IWQMP for the Crocodile River Catchment.

1.6 Sugar Industry in South Africa and the Crocodile River Catchment

1.6.1 Profile of the South African Sugar Industry

The South African Sugar Industry is described as one of the world’s leading cost-competitive producers of high quality sugar (SASA, 2012). The industry is diverse, producing raw and refined sugar, syrups, specialised sugars and a range of by-products as well as co-products for both local and export markets from 15 mills. The mills are supplied with sugar cane grown by approximately 29,130 registered sugar canes growers farming in KwaZulu-Natal, Mpumalanga and the Eastern Cape Province (Maloa, 2001; SASA, 2012).

There are currently 14 sugar milling companies that are located in South Africa. They include: Illovo Sugar (owns four mills), Tongaat Hulett Sugar (four mills), TSB sugar (owns three mills), Gledhow Sugar (one mill), UCL Company (one mill) and Umfolozi Sugar (one mill) (SASA, 2012). Only two of these mills are located in Mpumalanga province, with the rest located in KwaZulu-Natal. This study will focus on the TSB Malelane Mill that is located in the study area in the Crocodile River Catchment.

The South African Sugar Industry is governed by the South African Sugar Association on behalf of the South African Cane Growers’ Association and the South African Sugar Millers’ Association (SASA, 2012). The South African Sugar Association is an organisation that is not controlled by the government, and its administration and industrial activities are financed through the proceeds from local sales and exports of sugar. Figure 1.6.1 below is a schematic diagram of the organisational structure of the South African Sugar Industry.

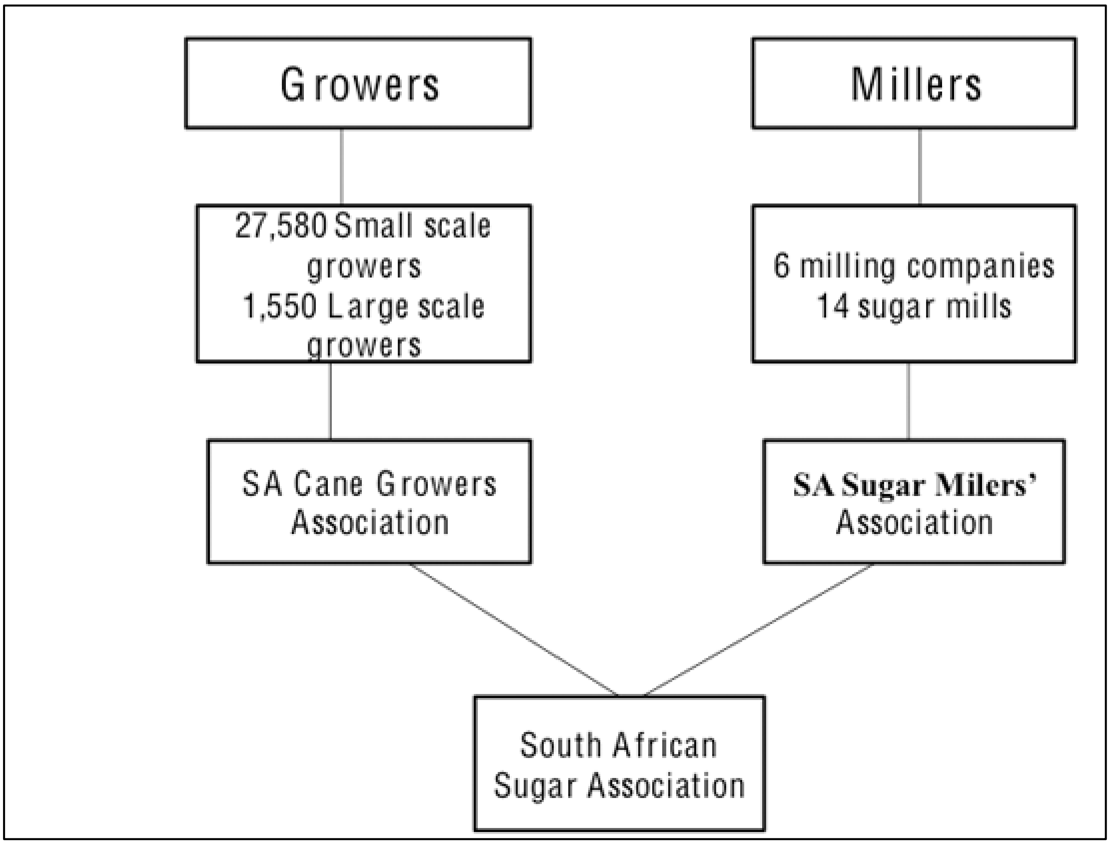


Figure 1.6.1: Organisational structure of the South African Sugar Industry (Source: Global Agricultural Information network, 2011).

According to SASA (2002), the industry produces an average of 2.2 Mtons of sugar per season and 75% of this is marketed in the Southern African Customs Union (SACU), the remainder is exported to markets in Africa, Asia and USA. SASA (2002) adds that there is a unique relationship that exists between the agricultural sector (sugar cane growers) in the sugar industry and industrial sugar production, in that sugar cane is a bulky commodity that cannot be traded. It is thus crucial that once it is harvested from the sugar cane fields, it is processed rapidly to preserve the sucrose that is available in the cane. This has resulted in sugar mills to be located very close to the sugar cane supply and the financial viability of sugar cane production is dependent on the sustainability of sugar cane supply in each mill.

1.6.2 TSB Company Profile

TSB (Transvaal Suiker Beperk) Sugar RSA limited is a company owned by REMGRO which is a subsidiary of TSB Sugar Holdings limited. The company's head office is located in Malelane, approximately 60 km east of Nelspruit (TSB RSA Sugar, 2000). The company's mills are located in Malelane, Pongola and Komatipoort; of these three mills, two have refineries, a packaging plant, sugar estates, cane and sugar transport and an animal feed division (SASA, 2012). TSB's core function or business activity is the production of refined sugar that is marketed nationally under the Selati sugar brand (TSB RSA Sugar, 2000). However this study will focus on the mill at Malelane as it is located within the Crocodile River Catchment and abstracts water from the Crocodile River.

According to VWG Consulting (2007), the Malelane Mill was built in 1967 and is the older of the two TSB mills. It produces approximately 267 000 tons of raw sugar per annum and it has a refinery that processes its own raw sugar as well as raw sugar from the Komati Mill. The refinery processes sugar all year round whereas the sugar plantations have growing and harvesting periods. The refinery produces 330 000 tons of refined sugar per annum, 88 000 tons of which is exported. The Malelane Mill abstracts raw/source water from the Crocodile River, at a point just upstream of the Crocodile River Bridge entrance to the Kruger National Park. Water use patterns of the mill are influenced by the seasonality of the crushing process which depends on the availability and storage of sugar cane. VWG Consulting (2007) adds that the mill also has a water treatment works that treats a portion of the source water to potable water and distributes potable as well as source water to other users.

Sugar cane harvesting and processing occurs over a 9 month period annually, during harvesting, the sugar cane is burnt in the fields to remove the leaves. After manual harvesting it is loaded onto trucks and transported to the mill, each truck load is weighed before the cane is processed and the cane must be processed within two days of harvesting to avoid bacterial fermentation and loss of sucrose. The Malelane mill has the following water intensive processes:

I. Juice extraction, clarification and evaporation
II. Raw sugar boiling
III. Decolourisation
IV. Refined sugar boiling

Figure 1.6.2.1 below is a flow diagram that shows the sugar manufacturing process. The sugar cane is transported from sugar plantations owned by the sugar mill as well as from the individually owned sugar plantations. When it arrives at the sugar mill it goes a preparation phase where it is washed and crushed.

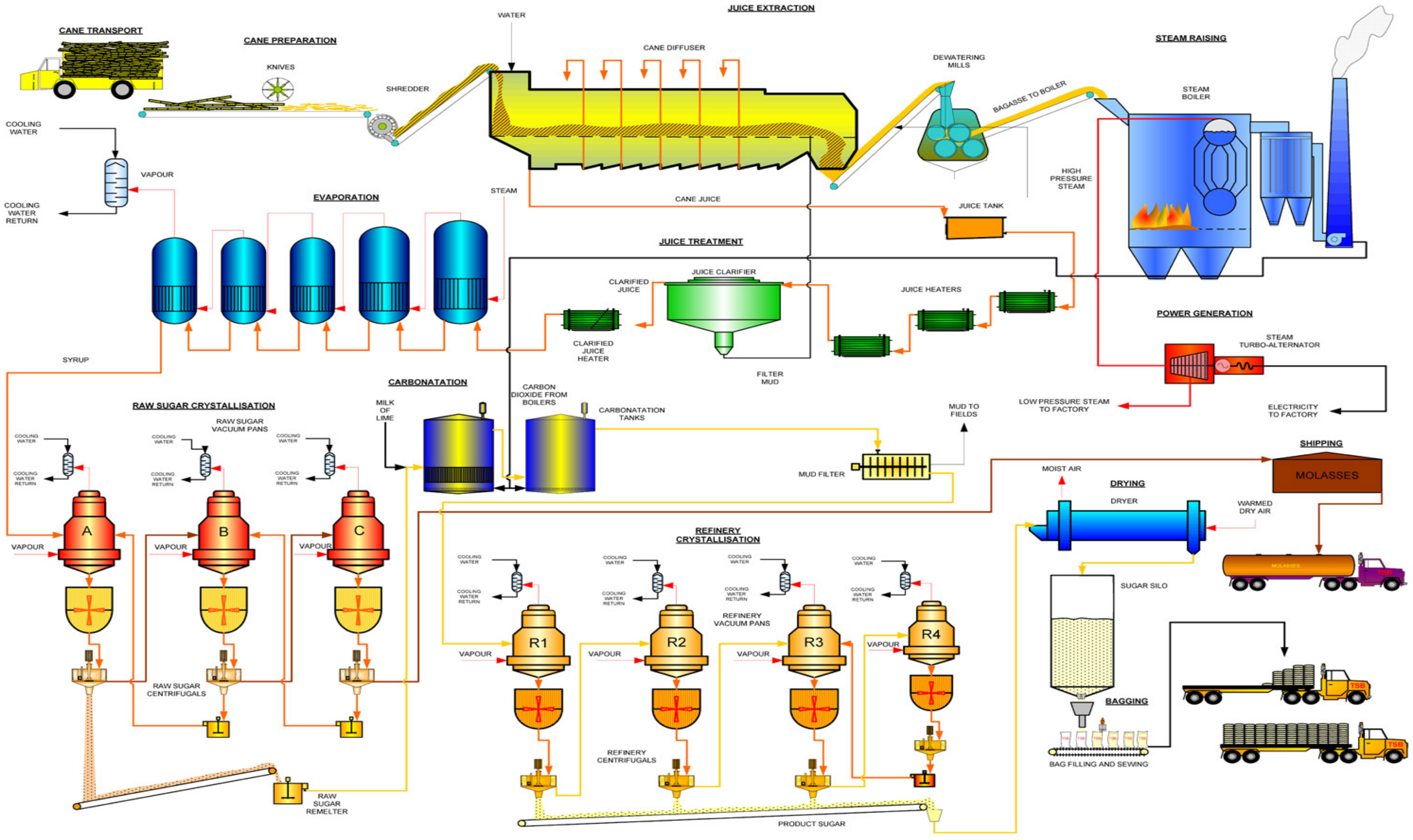


Figure 1.6.2.1: Sugar Manufacturing Process (Source: http://www.tsb.co.za//manufacturing_process.cfm#.UkLUIYaAr7M).

From here it goes through a juice extraction process (at this phase sucrose is extracted from the sugar cane and the fibrous material known as bagasse that is left is dewatered and fed into the steam production process) , clarification and evaporation. At this point, a clear sucrose juice is produced, which goes through the raw sugar boiling and crystallisation, and finally into drying and packing. The process described above is TSB specific.

Figure 1.6.2.2 below shows a schematic diagram (showing where water is used) of the sugar manufacturing process at the TSB Mill including water use. According to VWG Consulting (2007) the mill abstracts water from the Crocodile River through pump station into a water treatment plant. Raw water is also abstracted by other users from the TSB pump station as indicated in Figure 1.6.2.2. Potable water is also distributed to various water users. The treated water is used as cooling water during various phases of sugar manufacturing; the warm water is pumped into the cooling towers and can be recycled back into the mill. Any excess warm water is pumped into the spray dams to reduce temperature, and then it is released into a holding dam for further cooling before it is released back into the Crocodile River through Stingspruit channel. This water is not contaminated. Effluent produced from sugar manufacturing and effluent produced during animal feed production at Molatek (an animal feed factory) is pumped into two effluent dams/settling ponds to eliminate suspended solids. These effluent dams are desluged and the sludge/mud is deposited into the TSB landfill.

The bagasse (fibrous mass that remains after sucrose has been extracted from sugar cane) produced as a by-product of sugar production is used to produce animal feed at Molatek and some is deposited into the boilers to produce electricity. Ash that forms as a precipitate during electricity production is washed out of the boilers and the ash water is pumped into four ash dams for settling suspended sediments and to decrease Chemical Oxygen Demand (COD) concentration. Ash sludge scraped off the ash dams is deposited into the TSB landfill. The effluent water (10%) is mixed with the ash water (90%) and pumped to the TSB sugar cane field for irrigation.

According to Lorentzen (2009), the sugar industry generates water demand in the Crocodile River Catchment through the irrigation of sugar cane and as input into the sugar manufacturing process. Additionally, sugar cane is an extremely water-intensive crop (it requires a rainfall of between 1 100 and 1 500 mm during the period of vegetative growth, followed by a dry-off period for ripening; DAFF, 2012) and in the Crocodile River Catchment region, natural rainfall is supplemented by irrigation for sugar cane crops and water is scarce. It is important to understand how the sugar industry in the Crocodile River catchment can be involved in ensuring that water resources are used effectively and efficiently in the catchment.

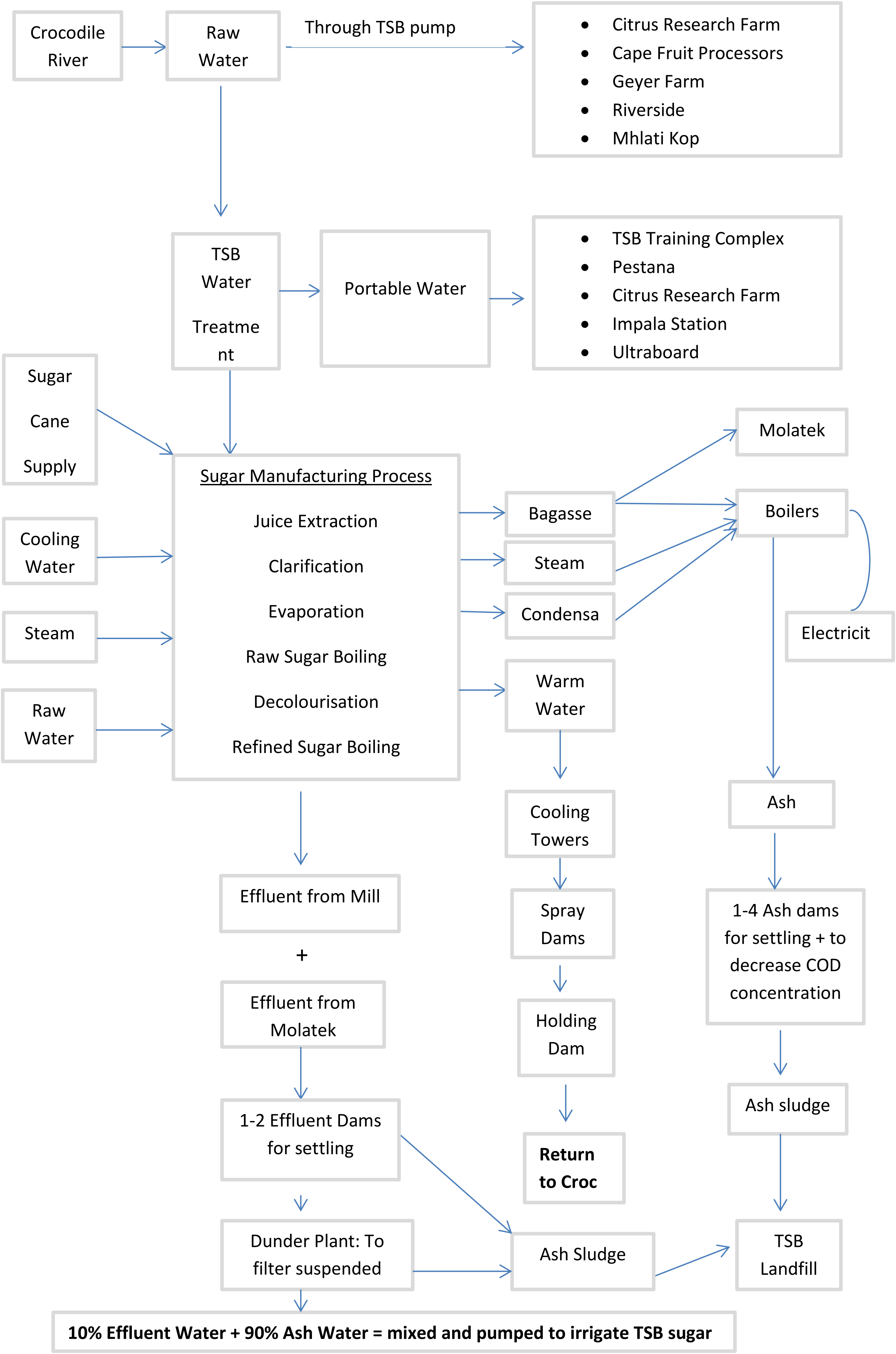


Figure 1.6.2.2: Summary of Sugar Manufacturing at TSB Mill showing water use. Source: Modified from VWG Consulting (2007)

1.7 Aim and objectives

1.7.1 Aim

This study aims to critically explore the role of the sugar industry in the development of an integrated, participative, water quality management process for the Crocodile River Catchment, focusing on the sugar industry. The research question that this study seeks to answer is: how can the sugar industry contribute to the development of an Integrated Water Quality Management Process for the Crocodile River Catchment to secure their source water quality needs? The aim of this study is to therefore contribute a focused view of one of the stakeholders involved in developing the integrated water quality management process for the Crocodile River Catchment.

1.7.2 Objectives

I. To analyse the management practices of the sugar mill and agricultural practices of the sugar cane fields.

II. To identify the contradictions within the sugar industry in relation to the development of an integrated water quality management process for the Crocodile River Catchment

III. To identify the contradictions between the sugar industry activity system and the activity system of Inkomati Catchment Management Agency activity system in relation to the development of an IWQMP for the Crocodile River Catchment.

IV. To identify water quality needs for the sugar industry (sugar cane growers and the sugar mills).

V. To identify water quality impacts of the sugar industry (sugar cane growers and the sugar mills).

VI. To explore the contribution the sugar industry can make to a catchment-wide collaborative Integrated Water Quality Management Process to secure their water quality needs.

1.7.3 Specific research questions

In order to achieve objectives two and three listed above, the following specific research questions were addressed:

a) ***What are the management practices of the sugar industry in the Crocodile River Catchment (sugar mill and agricultural practices of the sugarcane fields) in relation to water quality management?***
b) ***What are the contradictions (see Chapter 3, Section 3.1.5 for explanation of using this term) within the sugar industry in relation to the development of an IWQMP for the Crocodile River Catchment?***
c) ***What are the contradictions between the sugar industry activity system and the activity system of Inkomati-Usuthu Catchment Management Agency activity system in relation to the development of an IWQMP for the Crocodile River Catchments?***

1.8 Structure of the thesis

The thesis is made up of seven chapters:

CHAPTER 1: the general introduction and background on water policy, legislation, water quality management, and the sugar industry in South Africa, motivation of the study, as well as the aim and objectives of the study.

CHAPTER 2: a description of the study area.

CHAPTER 3: the conceptual framework for this thesis.

CHAPTER 4: a description of the methods that are used in the study.

CHAPTER 5: the Sugar Industry Water Quality Management Analysis (sugar mill and agricultural practices of the sugarcane fields) in relation to water quality management in the Crocodile River Catchment.

CHAPTER 6: presents the Sugar Industry in relation to the water quality system of the Crocodile River Catchment: A description of the disaggregation of water chemistry monitoring data in the perspective of the water quality impact on the sugar industry and the impact of the sugar industry on the in-stream water quality of the river below the industry.

CHAPTER 7: the concluding discussion, highlighting the progress towards the development of an IWQMP for the Crocodile River Catchment, the contributions and limitations of this study and the way forward.

CHAPTER 2

Study Area

2.1 Ecological Background

The Crocodile River Catchment is located in the Mpumalanga Province of South Africa (Figure 2.1). It occupies 1.2% (an area of about 10 450 km^2) of the total land area of the country and rises at an altitude 2000 m above sea level in the Steenkampsberg Mountains near Dullstroom (Deksissa *et al.*, 2004; DWAF, 2009a; Roux and Selepe, 2014). The catchment is a sub-catchment of the Inkomati Water Management Area. The Crocodile River is approximately 326 km in length, flowing from west to east past Elandshoek and Nelspruit running along the Kruger National Park border until it confluences with the Komati River at Komatipoort, and flows into Mozambique (DWAF, 2009a). The significant tributaries of the Crocodile River include Lunsklip, Elands, Houtbosloop, Stads, Nels, Gladde, White, Kaap, Nsikazi and Mbyamiti (ICMA, 2004). The significant dams in the Crocodile River Catchment include Kwena Dam that augments supply for the entire Crocodile River, Ngodwana Dam on the Elands River, Witklip Dam in the Nels catchment and Klipkoppie, Longmere and Primkop Dams on White River (ICMA, 2004)(Figure 2.1.1).

The river flows from sharply defined cliff slopes on the eastern edge of the escarpment (upper catchment) and levels out into the Kwena Dam basin (Roux *et al.*, 1999) . The river winds along the valleys of Schoemanskloof down to the Montrose Falls until it reaches the confluence with Elands River. As the river flows from Montrose falls until it reaches Nelspruit, it is slightly incised into a broad, flat valley and further downstream it has steep sided river banks that are covered by riparian vegetation and reeds. The gradient of the river then flattens downstream from the confluence with Kaap River until it reaches its confluence with Komati River at Komatipoort. In this area the river forms meanders that are incised into a wide sandy river bed with some segments where the river flows through numerous bedrock channels (Deksissa *et al*., 2004; Roux *et al*., 1999). The Crocodile River is described as a slow flowing river with mainly dolerite intrusions and basaltic lava bedrock or sandy pools, about 45 m wide with a low gradient (Roux and Selepe, 2014).

2.1.1 Rainfall and runoff

The Inkomati Water Management Area as a whole has rainfall that is influenced by the topography of the area and as a result the majority of the rainfall occurs in the mountainous region and provides most of the surface runoff (west and central areas) (ICMA, 2004) . This influences the management and operation of the rivers in the Water Management Area as most of the water demand is in the low-lying area below this high rainfall area. In the South African context, the Crocodile River Catchment is characterised as a relatively high rainfall sub-catchment with Mean Annual Precipitation (MAP) ranging from 1200 mm in the mountainous western regions to 600 mm in the lower areas of the catchment. Overall, the catchment receives an average MAP of 800 mm, with a greater proportion of this rainfall received during the warm summer months of November to April (Deksissa *et al*., 2004).

Surface runoff in the Crocodile catchment follows the same pattern as rainfall which causes the downstream water users to be extremely dependent on the flow in the river. This means that effective management of upstream water users and runoff from upstream is essential. The Mean Annual Runoff from the catchment is estimated at 1 137 Mm^3/a (ICMA, 2004).

2.1.2 Geology and soils

According to Mussá *et al*. (2014) geology of the Crocodile River Catchment (Figure 2.1.2 and Figure 2.1.3) is complex with approximately 60% of the middle and lower regions of the 4catchment characterised by mainly granites and gneiss. The south area of the catchment is characterised by sedimentary rocks such as arenite and volcanic rocks (mainly lavas) of the Barberton sequence. ICMA (2008) adds that the Barberton sequence results in soil development consisting of potentially expansive clays and the important minerals that are found in this sequence including gold and magnesite associated with mining activity. The other minerals found in this sequence include asbestos, barites, iron, mercury, nickel and copper. Mussá *et al*. (2014) add that the western region of the catchment is characterised by a complex assemblage of sedimentary rocks such as arenite and shale, volcanic (mainly andesite) and dolomitic rocks of the Transvaal sequence. While the eastern region of the catchment is characterised by a small area of sedimentary rocks such as shale and volcanic rocks such as basalt and rhyolite of the Karoo sequence.

The soils that form from the basaltic rocks can be up to 3m thick and consist of active black clay in some parts while the soil that forms from the rhyolite rocks is generally siltier and less active (ICMA, 2008).

According to DWAF (2003) the soil types that occur in the Crocodile River Catchment follow the pattern of the geology of the catchment with the western region with moderately deep clayey loam soil that has an undulating relief. Most of the central region of the catchment is characterised by moderate to deep clayey loam soil with a steep relief while the eastern region has mostly moderately deep clayey soils with an undulating relief. In general, the bulk part of the catchment consists of moderately deep sandy loam soil with undulating relief.

2.1.3 Land Use

The Crocodile River Catchment is dominated by the following land use practices (Figure 2.1.4) agricultural activities (which include pasture, dry land or irrigated cultivation), irrigation, forestry, mining, industry and rural and urban settlements. According to ICMA (2004), the catchment lies in the lowveld which has a warm-subtropical climate conducive for growing frost-sensitive crops and tropical fruit such as bananas, mangoes, pawpaws, avocados and macadamia nuts. Sugar cane and citrus fruit production also occurs in the eastern parts of the catchment. The sugar cane grown in this area is supplied and processed in the TSB Malelane Sugar Mill.

Forestry is also dominant in the catchment with large pine and eucalyptus plantations in the mountainous areas (high rainfall areas), which supply the wood, pulp and paper industry such as SAPPI Ngondwana (one of the largest paper mills in the country) situated 40 km west of Nelspruit. According to DWAF (2004a), irrigated agriculture and forestry are the most dominant land use activities in terms of water use, with an estimated 42 300 ha of irrigated land and an estimated 1,775 km^2 of forest in the catchment. Agriculture accounts for approximately 59% of water use in the catchment, whilst forestry reduces the runoff from the catchment by an estimated 157 Mm^3/a (ICMA, 2004). According to Pollard and du Toit (2011a), the water requirements in the Crocodile River Catchment exceed the available resource and the catchment is considered highly stressed (Table 2.1.4).

Besides the important contribution the Crocodile catchment makes in terms of agriculture, the river also forms the southern boundary of the world renowned Kruger National Park (KNP), which is the most prominent of all the conservation areas in the Inkomati Water Management Area that attracts tourists and adds to the biodiversity richness of the area. KNP covers approximately 2 million hectares and is home to diverse life forms such as fish and amphibians that depend on the water resource for habitat, food, reproduction and migration, as well as other life forms that depend on the water resource in other ways (DWAF, 2004).

According to ICMA (2004), mining is limited in the Crocodile River Catchment, located in the east part of the catchment and it is mainly dominated by manganese, chrome, as well as localised sand mining in some areas that is not properly managed at the moment. The main industrial water uses in the catchment include paper and pulp production, sugar milling, timber saw mills, ferrochrome smelting, manganese extraction or manganese oxide production and other industries that are linked to municipal water use (such as steel, chemical and food production). The major industrial water users are the paper and pulp production and sugar milling.

Table 2.1.4: Water availability, demand and water balance of the Crocodile River Catchment including the Reserve estimates (based on the preliminary estimate for 2008) (DWAF, 2009b).

Availability/Use	Crocodile River Catchment
Availability	**555 M m^3/a**
Current use (excluding the Reserve)	632.3 M m^3/a
Allocated use with Reserve	
Cross Border	51 M m^3/a
Reserve	205 M m^3/a
Domestic	73 M m^3/a
Industry/Mining	27 M m^3/a
Irrigation	482 M m^3/a
Strategic	0 M m^3/a
Total demand with Reserve	**837 M m^3/a**
Afforestation	158 M m^3/a
Alien Vegetation	32 M m^3/a
Balance currently	**-77.3 M m^3/a**
Balance with Reserve	**-282 M m^3/a**

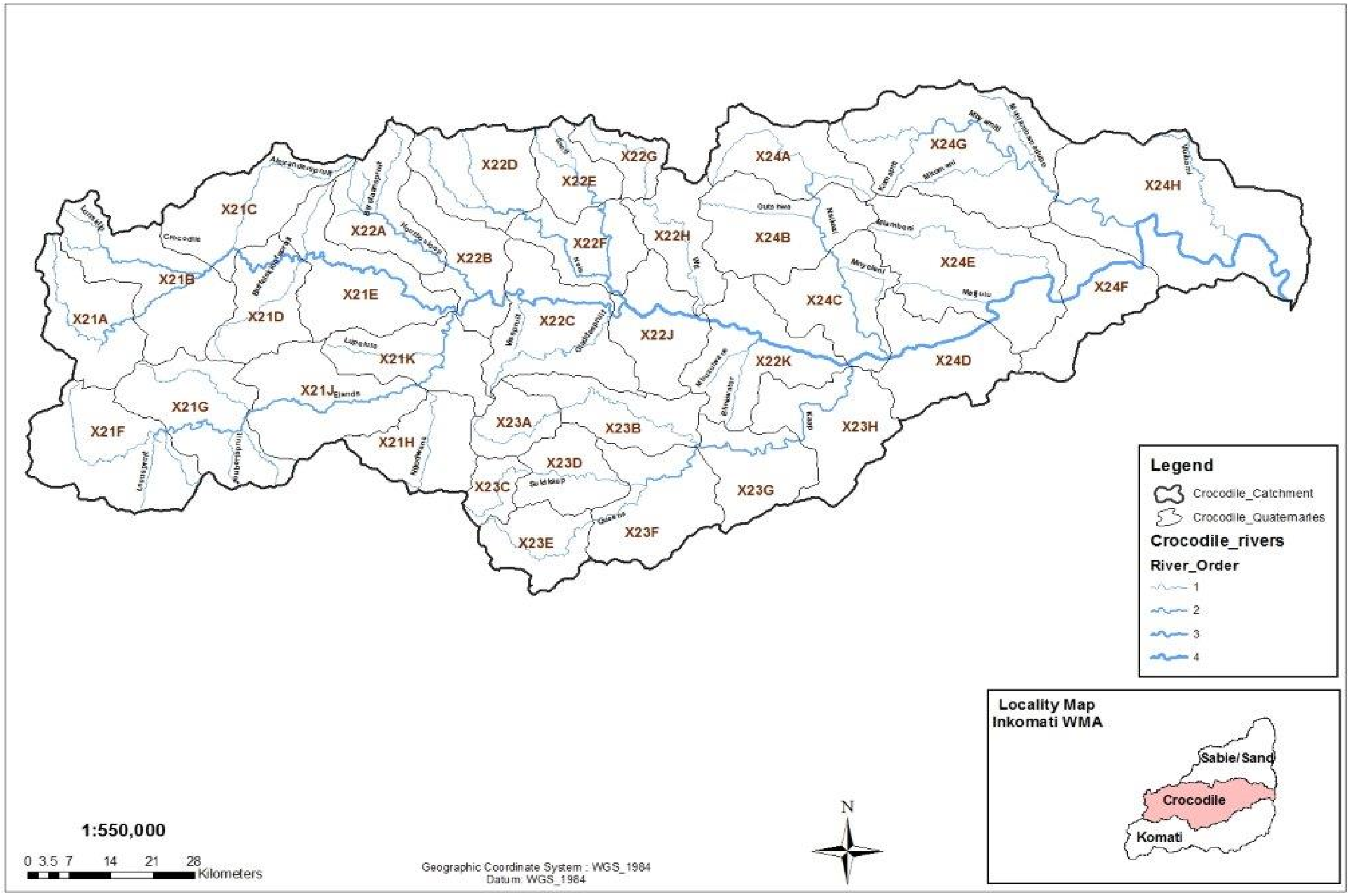


Figure 2.1.1: Dams and the rivers of the Crocodile River Catchment in South Africa (created using ESRI (2011) ArcGIS Desktop: Release 10.1. Redlands, CA).

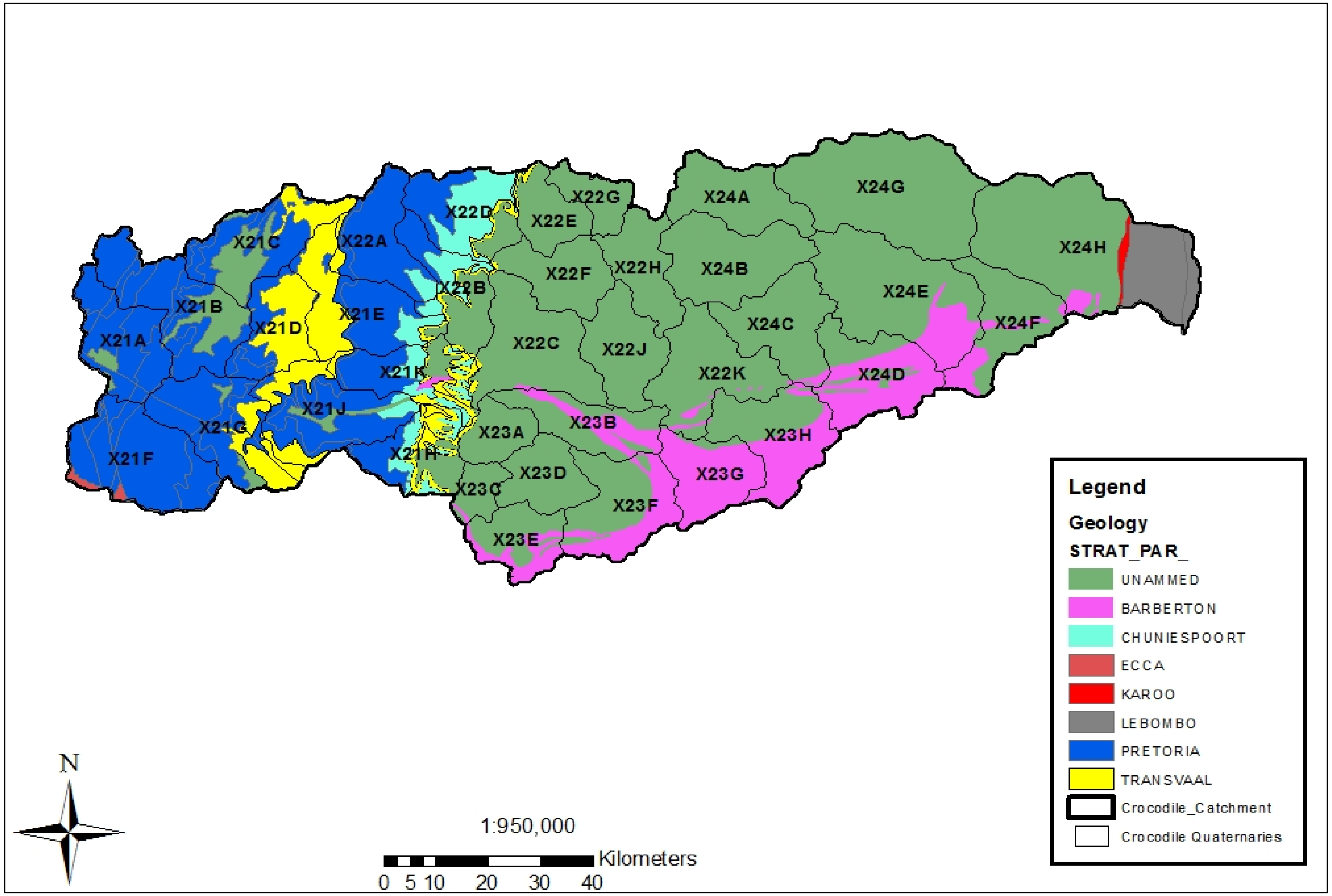


Figure 2.1.2: Geology of the Crocodile River Catchment, South Africa (created using ESRI (2011) ArcGIS Desktop: Release 10.1. Redlands,CA).

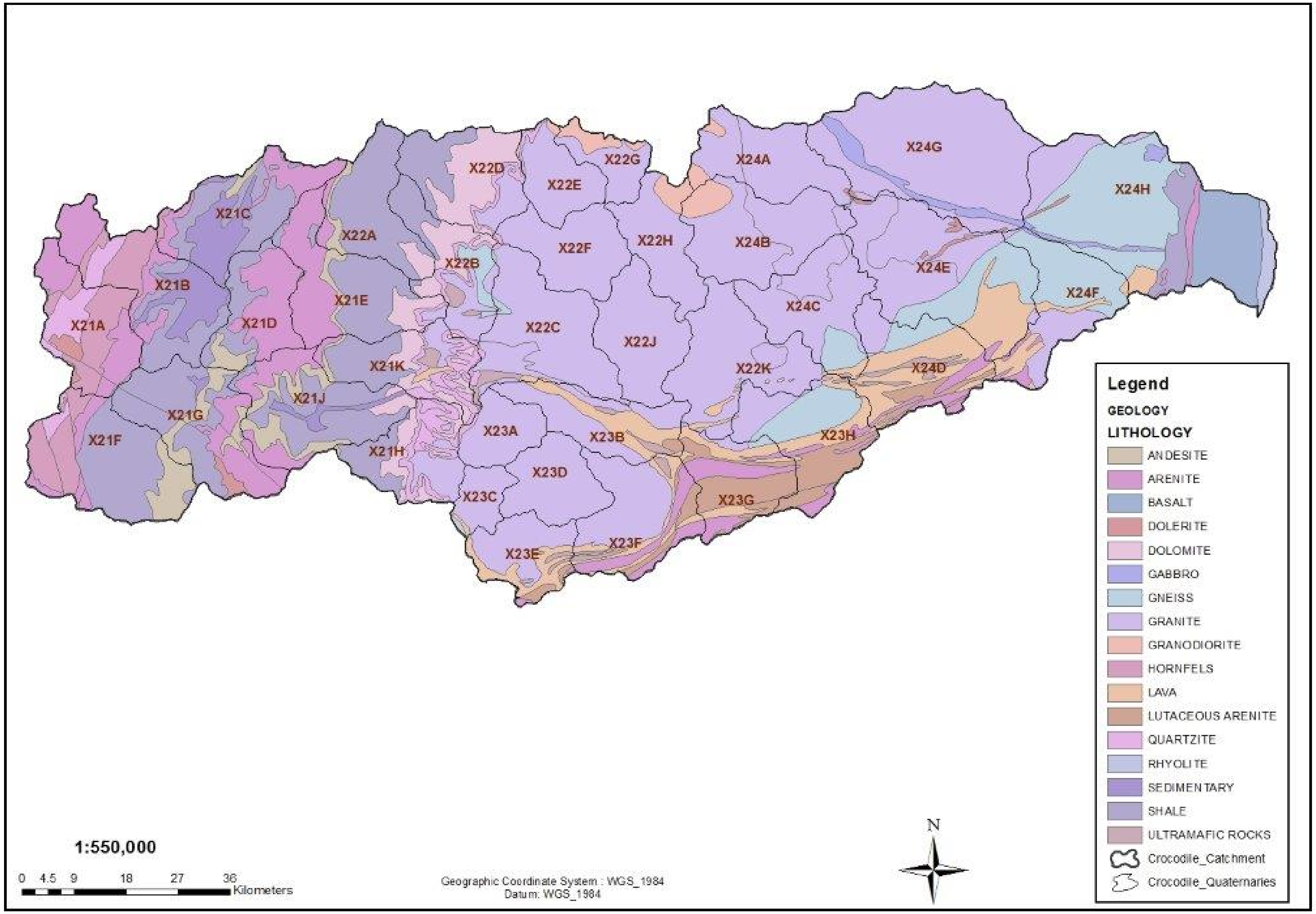


Figure 2.1.3: Dominant lithology of the Crocodile River Catchment, South Africa (created using ESRI (2011) ArcGIS Desktop: Release 10.1. Redlands,CA).

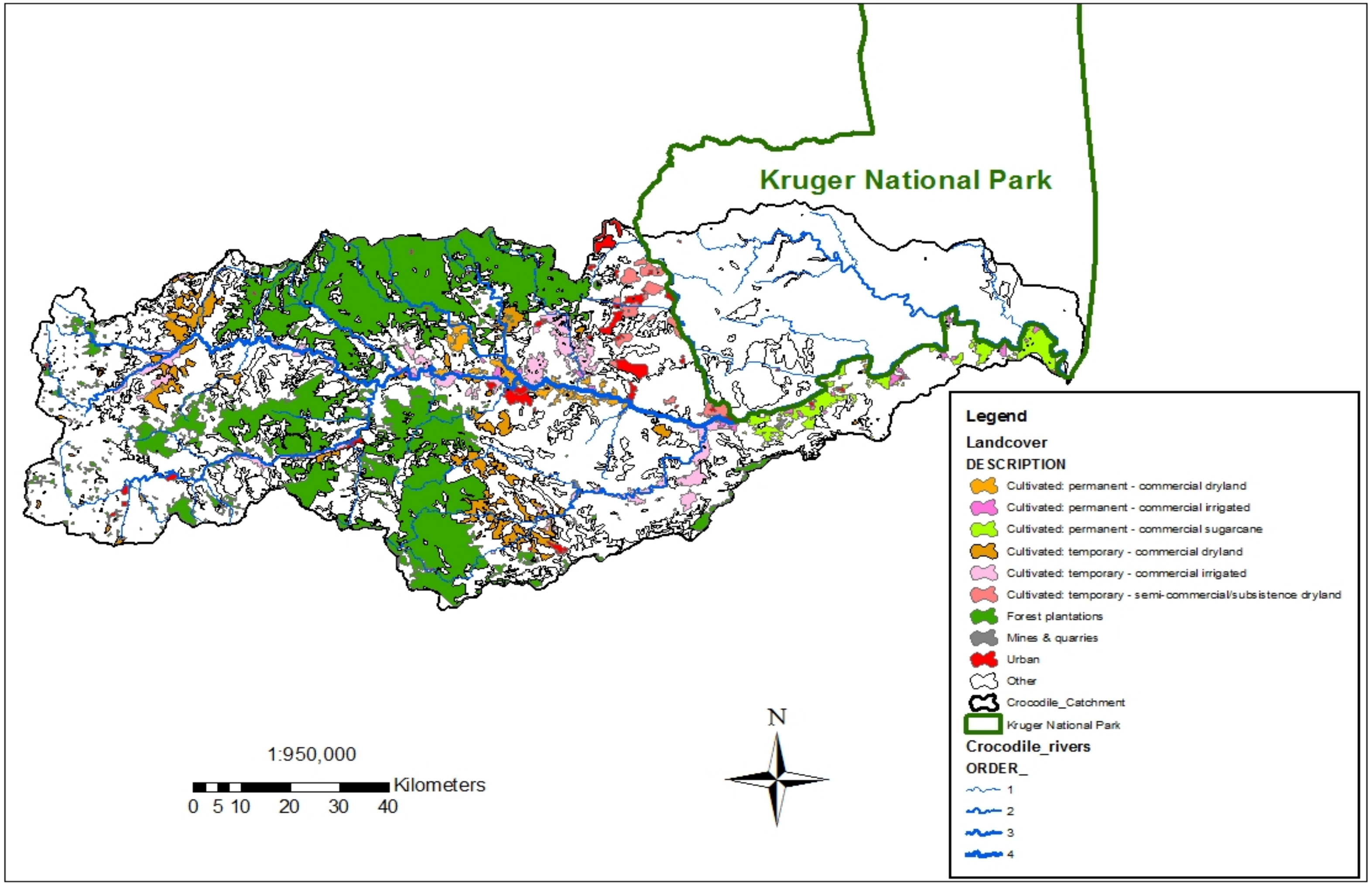


Figure 2.1.4: Map of the study area showing the land use in the Crocodile River Catchment in South Africa (created using Fairbanks *et al*. (2000) G.I.S database)

2.2 Socio-economic aspects

2.2.1 Population Dynamics and Demographics

The population for Crocodile River Catchment in 2007 according to ICMA (2004) was estimated at 723 791 people with approximately 65% of the people living in urban areas (Table 2.2.1). According to DWAF (2003), the catchment has the largest urban population, commercial and industrial activity in the Inkomati Water Management Area. The majority of the urban and rural communities are located close to the Crocodile River and its tributaries. The catchment has one large city known as Nelspruit and it is situated at the centre of the catchment, there are a few towns situated across the catchment such as Barbeton, White River and Malelane, just to name a few.

Table 2.2.1: Population breakdown in Crocodile River Catchment (modified from ICMA, 2004:57)

	Crocodile River Catchment
Rural	219 146
Urban	473 480
Other (Farming Communities and Mining Working towns)	31 165
Total	723 791

2.2.2 Economic aspects

The economic profile of Mpumalanga Province shows that between 1996 and 2001 the province had an average growth rate of 2.5%, which is broadly in line with the growth rate of the rest of the country (ICMA, 2008). Additionally, unlike the rest of the country which has a Growth Domestic Product (GDP) that is dominated by the service sector, Mpumalanga Province is has a GDP dominated by mining, energy and manufacturing sectors, which are highly capital intensive sectors that generate few jobs. Though this is the case provincially, locally the economic picture is much different.

In the Inkomati WMA agriculture plays a more important economic role, forming the catalyst for the manufacturing and industrial activities that are indirectly related to agriculture (ICMA, 2004). Table 2.2.2 below shows the GDP breakdown in the Crocodile River Catchment according to the various sectors. The industry sector is the dominant sector contributing 54% GDP for the Crocodile River Catchment. ICMA (2004:65) specify that the industry that is referred to is irrigation and forestry based. However, it is important to note that though industry and mining are the dominant sectors in terms of contribution to GDP, they provide the least number of jobs compared to irrigated agriculture (Table 2.2.3).

Table 2.2.2: Gross Domestic Product in Crocodile River Catchment (modified from ICMA, 2004: 65)

Crocodile River Catchment		
	GDP (R million)	**Percentage (%)**
Irrigation Agriculture	1717	18
Forestry	657	7
Mining	1859	20
Industry	5057	54

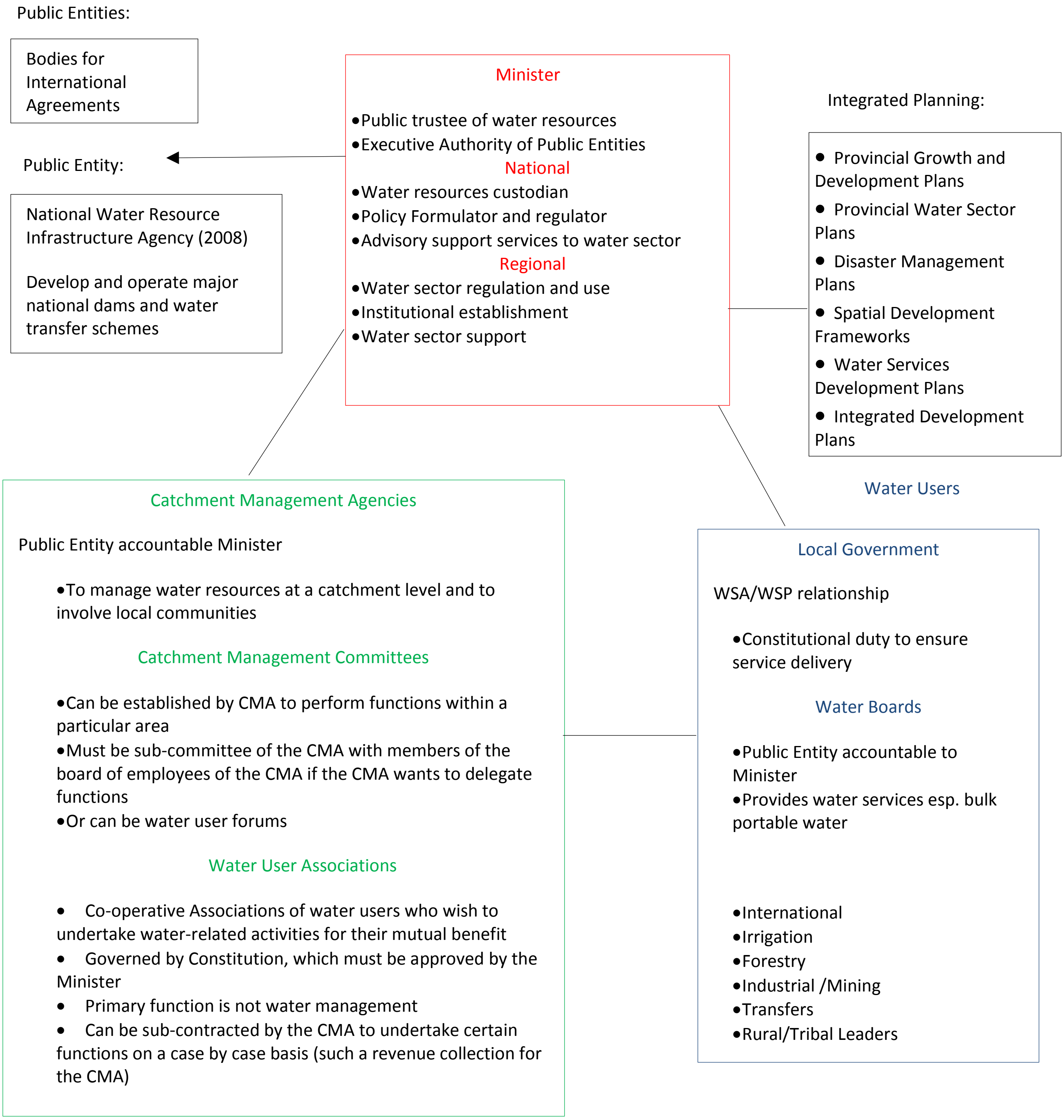
Table 2.2.3: Distribution of employment in Crocodile River Catchment according to the various sectors (modified from ICMA, 2004:66).

Crocodile River Catchment		
	Employment (numbers)	**Percentage (%)**
Irrigation Agriculture	19362	49
Irrigation Forestry	9990	25
Mining	3461	9
Industry	6500	17

As mentioned in Section 2.1.3, irrigated agriculture is one of the dominant water use sectors in the Crocodile River Catchment and with this sector playing a catalyst role for other sectors, the availability of water is currently a limiting factor in the economic growth of this sector and will inevitably affect other sectors as well (ICMA, 2004).

2.3 Institutional Arrangements

Chapter 1 of this thesis introduces the legislation, policies and framework that governs water management in South Africa. Section 1.3.2 specifically outlines the hierarchy of water management institutions, how they should be established, and their overall functions for effective water management in the country. These institutions play various roles in the process of integrated water resource management and the focus of this research is at the level of a catchment management agency. Therefore institutional arrangements or relationships in this section will be described in the perspective of a CMA. Figure 2.3 below presents the general institutional arrangements impacting a CMA directly.



Public Entities:

Bodies for International Agreements

Public Entity:

National Water Resource Infrastructure Agency (2008)

Develop and operate major national dams and water transfer schemes

Minister

- Public trustee of water resources
- Executive Authority of Public Entities

National

- Water resources custodian
- Policy Formulator and regulator
- Advisory support services to water sector

Regional

- Water sector regulation and use
- Institutional establishment
- Water sector support

Integrated Planning:

- Provincial Growth and Development Plans
- Provincial Water Sector Plans
- Disaster Management Plans
- Spatial Development Frameworks
- Water Services Development Plans
- Integrated Development Plans

Catchment Management Agencies

Public Entity accountable Minister

- To manage water resources at a catchment level and to involve local communities

Catchment Management Committees

- Can be established by CMA to perform functions within a particular area
- Must be sub-committee of the CMA with members of the board of employees of the CMA if the CMA wants to delegate functions
- Or can be water user forums

Water User Associations

- Co-operative Associations of water users who wish to undertake water-related activities for their mutual benefit
- Governed by Constitution, which must be approved by the Minister
- Primary function is not water management
- Can be sub-contracted by the CMA to undertake certain functions on a case by case basis (such a revenue collection for the CMA)

Water Users

Local Government

WSA/WSP relationship

- Constitutional duty to ensure service delivery

Water Boards

- Public Entity accountable to Minister
- Provides water services esp. bulk portable water

- International
- Irrigation
- Forestry
- Industrial /Mining
- Transfers
- Rural/Tribal Leaders

Figure 2.3: Institutional Arrangements (Source: ICMA, 2008).

For an adequate understanding of institutional arrangements that influence water resource management in the Inkomati Catchment Management, it is important to outline the underlying factors that contribute to the functioning of the general institutions described in Figure 2.3, especially understanding their current functioning status, particularly in the study area of this research (Pollard and du Toit, 2011b). Table 2.3 provides a summary of the existing or proposed institutions for water resources management and their current status in the Crocodile River Catchment. Pollard and du Toit (2011b) add that in the Crocodile River Catchment it was only through establishment and operationalisation of the Inkomati CMA that irrigation boards have become involved in a more holistic focus on the entire river from the Kwena Dam to the Mozambique Border. Political reform and more substantially consideration of international flow requirements, have been the catalyst for this transformation in the catchment.

Moreover, active monitoring of international flow requirements into Swaziland and Mozambique through the establishment of the Interim Inco-Maputo Agreement (TPTC, 2002) has resulted in much stringent management and concerns can now be raised through the national office of Water and Sanitation. Pollard and du Toit (2011b) also add that since the CMA was established, the Kruger National Park also monitors the Ecological Reserve more proactively, alerting the national office and the ICMA when infringements have occurred.

Even though water resource management institutions have improved, established or in the process of being established, the catchment still experiences water stress and non-compliance. This has been due to a number of reasons, such as delayed transformations of other institutions such as irrigations boards to WUAs, difficulty to bring others water users such as municipalities, mining and industry on board and more important difficulties terms of functions and powers that have not been fully handed over to the ICMA from the national office (Pollard and du Toit, 2011b). This is explained in the section below.

Table 2.3: Summary of existing or proposed institutions for water resources management and their current status in the Crocodile River Catchment (modified from Pollard and du Toit, 2011b:4027).

Institution	Functions	Summary of current status
International water management Bodies	Facilitate international cooperation and the development and operation of large international water resource infrastructure or for co-operative sharing and management of a shared water resource.	Tripartite Permanent Technical Committee (South Africa, Mozambique and Swaziland)
National Department of Water and Sanitation	Oversight function. Certain key functions to remain national responsibility (strategic international agreements, determination of class and Reserve, transfers, assignment of functions, approval of Catchment Management Strategy)	Still in the process of transformation
National Water Resources Infrasturcture Agency (NWRIA)	Newly-established to manage certain dams (flood control; dams that supply more than one sector) and former 'government controlled areas'	Operational in the study area but roles and functions are poorly understood by most stakeholders. In particular, their active participation in establishing and monitoring operating rules is unclear (Pollard and du Toit 2011a).
DWA Regional Offices (RO)	Will assume an oversight and support function once CMAs are established and operational (i.e they have been assigned functions by the Minister of DWA)	In the Crocodile River Catchment they still remain certain functions but in practice many are being carried out by the Inkomati CMA.
Catchment Management Agencies (CMA)	Manage water resources in each of the 9 Water Management Areas (WMA).	Nationally still in the process of being established Inkomati CMA has been established with some assigned but some delegated functions
Water User Associations (WUA)	WUAs are an association of individual water users who wish to undertake water related activities for their mutual benefit. Either newly-established or being established through transforming former irrigation boards to include all water users beyond commercial agriculture alone (e.g. forestry, conservation, municipalities, mining).	The Crocodile River Major Irrigation Board has yet to become a WUA.
Statutory and non-statutory bodies Catchment Management Forums (CMF) or Committees (CMC)	Ensure stakeholder participation in WRM created for each sub-catchment	Established and operational

As described by the NWA (NWA, Act No. 36 of 1998), when a CMA is established, it has inherent powers and initial functions as stipulated in Section 80 and Schedule 3 of the act (ICMA, 2008). Powers are described as competencies given to an institution by law which may be exercised, duties are obbligations imposed by law which must be performed by the institution, while functions are official tasks that are required to exercise power or to perform duties (ICMA, 2008:4).

The five initial functions that a CMA has when it is established are the following (ICMA, 2008:4):

- To investigate and advise on the protection, use, development, conservation, management and control of the water resources in its water management are;
- To develop a catchment management strategy;
- To co-ordinate the activities of the water users and water management institutions within its water management area;
- To promote co-ordination between implementation of its catchment management strategy with implementation of water services development plans by water services authorities; and
- To promote community participation in the protection, use, development, conservation, management, and control, of water resources in its water management area.

According to ICMA (2012), the NWA enables the Minister of Water and Sanitation to either delegate or assign functions to a CMA. Delegation of functions refers to “the transfer of powers to another functionary or body to enable that body to exercise those powers”, while assignment of functions refers to “permanent transfer of that power or function to another body or person” (ICMA, 2012:29).

Currently, the Inkomati CMA has powers contemplated in terms of Schedule 3 of the NWA items 2(a-e), 3(1 and 6), 4 (1 and 2), 5(1,2 and 4), 6(1,2,3,4 and 5) (ICMA,2012: Annexure B). These powers were delegated to the Inkomati CMA in terms of Chapter 2, Sections 72 and 73 of the NWA (NWA, Act No. 36 of 1998).

ICMA (2012) adds that these delegation functions are dependent on various conditions such as the acess to the Water Authorisation Registration Management System (WARMS System) which is unfortunately not yet accessible to the CMA. The section above has highlighted that though there is vast progress in the evolution of IWRM in South Africa, there are still important learnings in terms of implementation of the establishment of institutions to achieve IWRM as stipulated in the NWA. These challenges are discussed further in Chapter 5 of this thesis.

2.4 Water Quality

The Department of Water and Sanitation has described the water quality of Crocodile River Catchment as relatively good to fair, although the quality deteriorates below the Kaap river confluence (Figure 2.1.1) and Lower Crocodile River Catchment with unacceptable values of salts (electrical conductivity), turbidity, pH, phosphates, nitrates and ammonia (DWA, 2010; DWA, 2011; DWAF, 2009a). According to Deksissa *et al*. (2004), the major contribution to the deteriorating water quality of the catchment is industrial and domestic waste water treatment discharge as well as runoff and irrigation return flows from widespread irrigated agriculture (intensively irrigated sugarcane and subtropical fruits), and seepage from abandoned mining activities. The large irrigation water use in the catchment has resulted in significant return flows, with an estimated 10 Mm^3/a contribution from the industrial sector (Ngodwana paper mill and Malelane Sugar mill) and a total return flow estimation of 42 Mm^3/a (expressed as a 1:50 year yield) for the catchment (DWAF, 2004). DWA (2010) adds that the irrigation return seepage is evident during low flow periods in the catchment.

The water quality of the Upper Crocodile River Catchment is in a relatively good condition attributed to good water quality conditions in the upper reaches of Elands River, however the middle and lower reaches of this tributary are of a fair condition due to increased concentrations of salts and nutrients attributed to a large number of communities located along the tributary such as Machadodorp, Watervalboven and Elandshoek, contributing sewage effluent and organic pollution (DWA, 2011). In addition, the increased salt concentrations are a result of diffuse return flows from agriculture, gold mining and the pulp and paper industry.

The Middle Crocodile River Catchment is considered to be an area of increased urbanisation (with the river flowing through urban areas such as Nelspruit, and settlements such as Kanyamazane, Matsulu, Hectorspruit) and industrial activity (ICMA, 2004). The impact of these land use activities is increased nutrients and salts observed in this area. Furthermore, industrial pollution incidents that occur have also resulted in increased levels of cyanide and arsenic in the past from mining activities and recently increased manganese levels in the river (DWA, 2011; DWAF, 2004).

ICMA (2004) emphasises that the water quality of the Lower Crocodile Catchment is of great concern as there is an evident increase in most of the water quality variables that are problematic in this part of the catchment. This poses a threat to the quality of water that is delivered to the Kruger National Park because the park should receive water that is of conservation standards. Moreover, the Crocodile River flows into a neighbouring country, Mozambique and South Africa is governed by international obligations to regulate the quantity and quality of the water leaving the country. The deteriorating water quality of this area is due to a number of drivers such as a large number of tourist lodges that are built along the banks of the Lower Crocodile River, irrigation of sugar cane and citrus, the impact of which is increased nutrient and salt concentrations.

2.5 Water Quality Context in terms of the Sugar Industry

This section describes the water quality needs of the sugar plantations and sugar; the water quality impacts of sugar plantations and sugar mills, highlighting the various sources of environmental impacts relative to key processes and inputs in the cultivation and processing of sugarcane. This section aids in an understanding of the water quality context in which the sugar industry operates and it provides key background information for describing the sugar industry in relation to the water quality system of the Crocodile River Catchment that is provided in Chapter 6 of this thesis.

2.5.1 Water quality needs and impacts of the sugar mills and sugar plantations

2.5.1.1 Introduction

Water scarcity in South Africa is increasing and this means that water resources need to be managed effectively. Development along important rivers in the country poses threats which can have negative impacts on water quality (van der Laan *et al.*, 2012). Additionally, specific points along any river reflect water quality that is related to several major influences in the areas such as climatic and atmospheric conditions, basin lithology and upstream anthropogenic inputs such as industrial or municipal wastewater discharges and agricultural runoff (Bricker and Jones, 1995; Shrestha and Kazama, 2007). Heathwaite and Jones (1996) add that increased crop production within a catchment often results in higher nutrient concentrations in rivers and dams and Matson *et al*., (1997) emphasise that nitrate pollution is common throughout the world in agricultural regions.

Sugarcane production in South Africa occurs exclusively in the eastern regions of the country (van der Laan *et al*., 2012). Sugarcane is a tropical crop that requires a rainfall of between 1100 and 1500 mm that should be abundant in the months of vegetative growth followed by a dry period for the crop to ripen (DAFF, 2012). The water deficit caused by erratic or low rainfall and high evaporation demands limits dryland crop production in most of South Africa and in low rainfall areas such as the lower Crocodile River Catchment, sugar cane production is dependent of irrigation (van Averbeke *et al*., 2011).

In South Africa, rainfed sugarcane production predominates in the regions south of the Tugela River, while irrigated production is more common north of the Tugela River. Irrigation refers to the “artificial application of water to land for the purpose of enhancing plant production” and it reduces water deficit as a limiting factor in plant growth making it possible to grow crops where the climate is too dry (van Averveke *et al*., 2011:797). Additionally, irrigation can increase sugarcane yields, allow better planning and increased flexibility of farming practices (Holden *et al*., 2013). Irrigated agriculture is the largest consumer of available water in South Africa (DWAF, 1996b) and since many irrigation schemes are situated at the lower end of drainage basins, they are often downstream of upstream water quality degradation activities. This results in irrigation farmers having to contend with both deteriorating water quality and diminishing supply of irrigation water. Furthermore, irrigation water users may experience a range of impacts as a result of changes in water quality and these impacts may affect either the crop, soil or the equipment used for irrigation. Table 2.5.1.1 shows the general impacts of changes in irrigation water quality.

Table 2.5.1.1: Effects of changes in irrigation water quality (DWAF, 1996b:9).

Category	**Impacts**
Crop	Reduced crop yield (as a result of increased salinity or the presence of constituents that are toxic to crops); Impaired crop quality (this may result in inferior products or pose a health risk to consumers);
Soil	Impairment of soil suitability (as a result of the degradation of soil properties and accumulation of undesirable constituents or toxic elements); and
Equipment	Damage to irrigation equipment such as corrosion, scaling, fouling, blockages, abrasion, embrittlement and discolouration to name a few.

In the Crocodile River Catchment, sugarcane production is irrigated because the low-lying areas are characterised by 600mm MAP (Deksissa *et al*., 2004). The major sources of irrigation water (in the Malelane and Komatipoort area) are the Crocodile, Lomati and Komati Rivers and some of their tributaries (van der Laan *et al*., 2012). This study focuses on the Crocodile River.

2.5.1.2 Water quality needs of sugar plantations

According to SASRI (1997), the quality of river, dam or borehole water used for irrigation plays a significant role in determining the success or failure of irrigated sugarcane production in South Africa. Baleta and Pegram (2014) add that poor irrigation water quality may impact the ability of farmers or manufacturers to export their produce because they do not meet stringent export regulations and this has a detrimental effect on the agricultural sector and impacts on the sectors trade balance. van der Laan *et al*. (2012) emphasise that irrigating with water that is high in salts can reduce the yields of sugarcane significantly and this negative impact increases in cases where there is poor soil drainage (refer to Table 2.5.1.2a for generic Resource Quality Objectives for salt concentrations measured as TDS).

As described in Chapter 1, Section 1.3, the South African National Water Act (No. 36) of 1998 provides for the protection of aquatic ecosystems by promoting environmentally or ecologically sustainable water use that ensures that water resources are not degraded beyond recovery and that aquatic ecosystems continue to provide goods and services in the future (DWA, 2011). To achieve this, Resource Quality Objectives (RQOs) are set. RQOs are defined in the National Water Act as "clear goals relating to the quality of the relevant water resources". RQOs are numerical and narrative descriptors of quality, quantity, habitat and biotic conditions that need to be met in order to achieve the required management scenario (DWAF, 2007:11).

Resource Water Quality Objectives (RWQOs) are the water quality components of the Resource Quality Objectives (RQOs). They are defined as numeric or descriptive in-stream (or in-aquifer) water quality objectives typically set at a finer resolution (spatial or temporal) than RQOs to provide greater detail upon which to base the management of water quality of the resource. RWQOs outline water user compliance requirements with respect to water quality, as well as their needs with respect to the disposal of water containing waste to the resource and the aquatic ecosystem requirements (DWAF, 2007).

The National Water Act provides for the determination of preliminary RQOs of water resource before formal water resource classification is conducted. Once RQOS have been set, they are enforced by the organ of state or water management institution in charge of that particular water resource (NWA, Act No. 36 of 1998). The RQOs for the Crocodile River are in the process of being established, therefore for the purpose of this study, the Generic RQOs that were established at national level are used for analysis of water quality compliance in the catchment (Table 2.5.1.2a) (DWA, 2011).

Table 2.5.1.2a shows that for riverine protection, generic RQOs for salt concentrations (measured as TDS-Total Dissolved Solids, which is a measure of all negatively and positively charged ions present in water these may include calcium, magnesium, phosphate, sodium, potassium, nitrate and silicate, just to name a few) are given as the following ranges: ideal 200mg/l, acceptable 350mg/l and tolerable 800mg/l. (Fipps, 2003)

Copeland (2011) adds that high salt concentrations in irrigating water increases osmotic pressure across the soil root interface, making moisture less available for the root system. As the sugarcane crops transpire the water sources from irrigated water, salts are left in the soil, and build-up in the root zone leading to saline soils. The higher the salt volume of the irrigated water the greater the leaching requirement and increased salt concentration in the draining water which eventually reaches rivers resulting in subsequent deterioration of water quality of the receiving rivers.

According to Grattan (2002), salts accumulate in the rootzone of crops by two processes, namely: the upward movement of a shallow-saline water table and salts left in the soil due to insufficient leaching. Leaching is described as “the process of applying more water to the field than can be held by the soil in the crop rootzone such that the excess water drains below the root system carrying the salts with it (Grattan, 2002:2). Suarez *et al*. (2006) state that when irrigation water has a high proportion of sodium (Na^+) cations (positively charged salts) in relation to magnesium (Mg^{2+}) and calcium (Ca^{2+}) cations, it create a sodic effect as the high Na levels can lead to clay particle de-flocculation and inhibit infiltration.

According to SASRI (1997), there are four major characteristics or water quality variables that determine the quality of irrigation water and these are listed and described below:

- **Total concentration of soluble salts**: as measured by electrical conductivity (EC) expressed as milli-siemens per metre (mS/m). The higher the EC value the higher the concentration of salts.
- **The concentration of Na and the proportion of Na^+ to Ca^{2+} plus Mg^{2+}, which is known as the sodium absorption ratio (SAR)**: According to Nelson and Ham (2000), the SAR of water predicts how that water will affect the sodicity of the soil. Sodic soils disperse and are difficult to cultivate and irrigate due to poor infiltration and drainage properties. The higher this ratio the higher the sodium (Na^+) concentration of the water. The amount of sodium bicarbonate and sodium carbonate in water (referred to as residual alkali) also influences the sodicity of the soil because these

salts remove Ca^{2+} and Mg^{2+} from attachment to soil particles and replace them with Na^{+}.

- **pH and the concentration of bicarbonates**: A water pH of greater than 8.4 (Table 2.5.1.2c) is not only an indication of high sodium concentration, but also the presence of bicarbonates. Bicarbonates in the soil solution will precipitate out as insoluble Ca^{2+} and Mg^{2+} carbonates and result in a reduced $Ca^{2+}+Mg^{2+}$ content relative to Na^{+}. This effectively increases the SAR of the soil solution, leading to soil physical problems. Grattan (2002) adds that excessive amounts of bicarbonate can also be problematic in sugarcane irrigated with low-pressure systems, such as drip irrigations systems because calcite or scale can build-up near the orifice of the sprinkler or emitter, which can reduce the water discharge.
- **The occurrence of minor elements**: such as chlorine, boron, lithium and other elements in toxic amounts.

SASRI (1997) emphasises that it is extremely important for sugarcane growers to regularly monitor the quality of their irrigation water by sending water samples for analysis to the Fertiliser Advisory Service (FAS) laboratories at Mount Edgecombe, in order to keep soil degradation to a minimum and to sustain crop yields. It is also important to monitor the factors that influence EC and SAR values, which include:

- **Rainfall**: due to the diluting effect of rain, EC values have to be corrected according to local annual rainfall to obtain an Effective EC value (EEC).
- **Bicarbonate**: the bicarbonate content (HCO_3^-) of irrigation water is important and it is expressed in terms of the Residual Sodium Carbonate (RSC). Excess HCO_3^- in water reacts with calcium in the soil solution and precipitates out as calcium carbonate, which causes water to become enriched with sodium and consequently increases the SAR and ESP. RSC-values <1.25 me dm^{-3} are reasonable safe, while values of 2.5 me dm^{-3} and higher indicate unsuitability of irrigation water (The Fertilizer Society of South Africa, 2007:72).

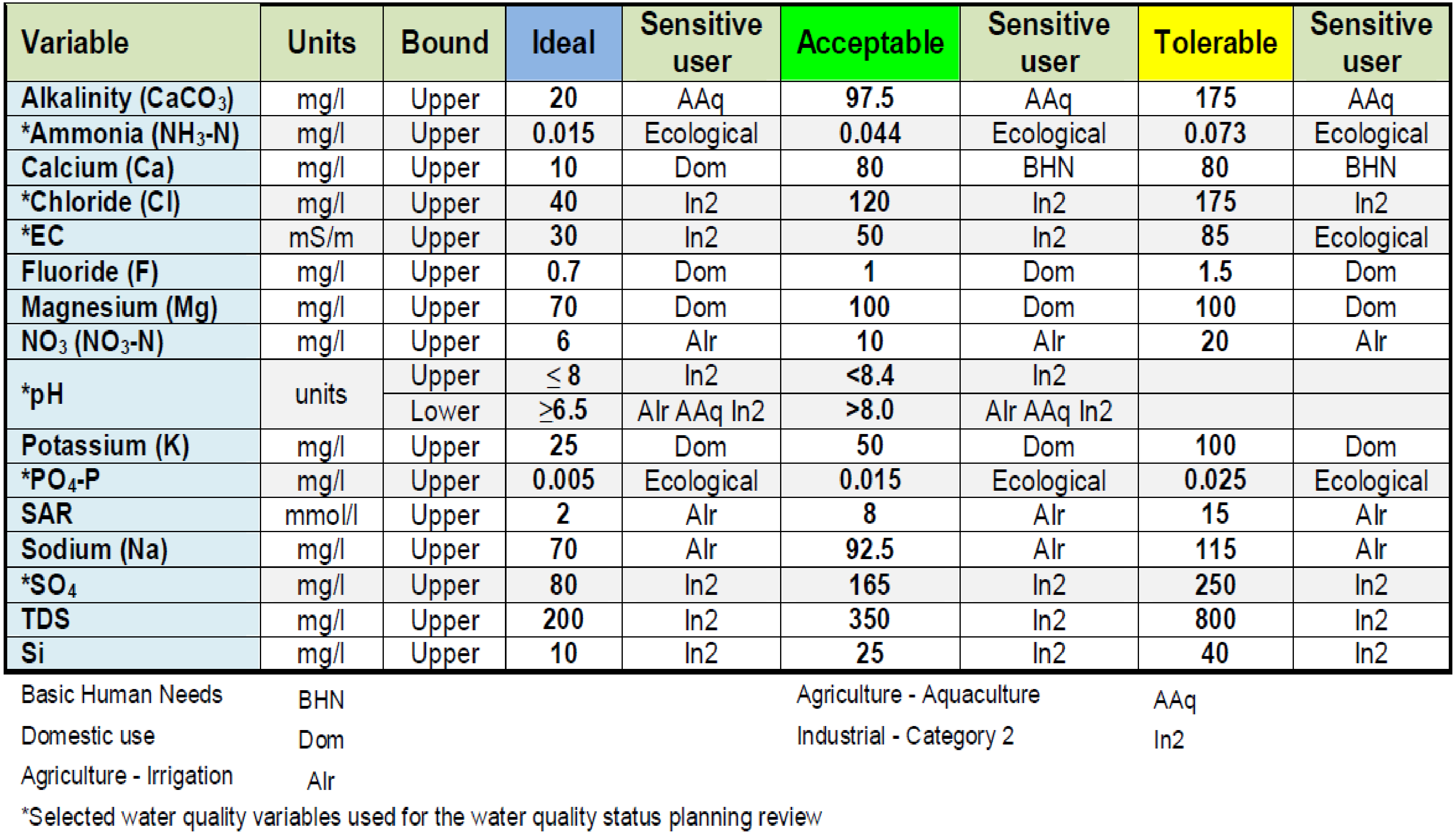
According to Grattan (2002), low EC (low salt content) (Table 2.5.1.2b) of irrigated water and high SAR can result in high potential for permeability or water infiltration problems due to dispersion of soil aggregates. This reduces the number of large pores in the soil which are responsible for aeration and drainage.

The SAR of irrigation water is calculated as follows (expressed in mmol dm^{-3}) (The Fertilizer Society of South Africa, 2007:69):

$\text{SAR} = \text{sodium} \div \sqrt{[\text{calcium} + \text{magnesium}}$

SAR gives an indication of the soil's ultimate Exchangeable Sodium Percentage (ESP) that can be expected once chemical equilibrium is reached in the water. When the SAR of irrigation water is too high, it can be lowered by either lowering the sodium concentration (which is usually expensive) or by raising the calcium and/or magnesium concentration. The best option is usually to add calcium and/or magnesium salts by adding gypsum ($CaSO_4.2H_2O$) to the water, however, this increases the EC levels that may have potential negative effects (The Fertilizer Society of South Africa, 2007).

Table 2.5.1.2a Generic Resource Water Quality Objectives at National Level. Source: (DWA, 2011:25)



Variable	Units	Bound	Ideal	Sensitive user	Acceptable	Sensitive user	Tolerable	Sensitive user
Alkalinity ($CaCO_3$)	mg/l	Upper	20	AAq	97.5	AAq	175	AAq
*Ammonia (NH_3-N)	mg/l	Upper	0.015	Ecological	0.044	Ecological	0.073	Ecological
Calcium (Ca)	mg/l	Upper	10	Dom	80	BHN	80	BHN
*Chloride (Cl)	mg/l	Upper	40	In2	120	In2	175	In2
*EC	mS/m	Upper	30	In2	50	In2	85	Ecological
Fluoride (F)	mg/l	Upper	0.7	Dom	1	Dom	1.5	Dom
Magnesium (Mg)	mg/l	Upper	70	Dom	100	Dom	100	Dom
NO_3 (NO_3-N)	mg/l	Upper	6	AIr	10	AIr	20	AIr
*pH	units	Upper	≤ 8	In2	<8.4	In2		
		Lower	≥ 6.5	AIr AAq In2	>8.0	AIr AAq In2		
Potassium (K)	mg/l	Upper	25	Dom	50	Dom	100	Dom
*PO_4-P	mg/l	Upper	0.005	Ecological	0.015	Ecological	0.025	Ecological
SAR	mmol/l	Upper	2	AIr	8	AIr	15	AIr
Sodium (Na)	mg/l	Upper	70	AIr	92.5	AIr	115	AIr
*SO_4	mg/l	Upper	80	In2	165	In2	250	In2
TDS	mg/l	Upper	200	In2	350	In2	800	In2
Si	mg/l	Upper	10	In2	25	In2	40	In2

Basic Human Needs	BHN	Agriculture - Aquaculture	AAq
Domestic use	Dom	Industrial - Category 2	In2
Agriculture - Irrigation	AIr		

*Selected water quality variables used for the water quality status planning review

Irrigation water can be divided into four classes according to SAR-values (The Fertilizer Society of South Africa, 2007:69) as listed below (Figure 2.5.1.2):

1. **S_1: Low sodium** (<10 mmol dm^{-3}: equivalent to 10mmol/l): Suitable for irrigation where a negligible salinity hazard exists.
2. **S_2: Medium sodium** (10-18 mmol dm^{-}3: equivalent to 10-18 mmol/l): Mainly suitable for sandy soils with good drainage ability. On clay, soil salinity will develop in time. The addition of gypsum is advisable on sandy soils.
3. **S_3: High sodium** (18-26 mmol dm^{-3}: equivalent to 18-26 mmol/l): Unsuitable for use on soils with restricted drainage. Use only on well-drained soils, with special management.
4. **S_4: Very high sodium** (>26 mmol dm^{-3}: equivalent to >26 mmol/l): Not suitable for irrigation because of high sodium content.

Table 2.5.1.2a shows that for riverine protection, generic RQOs for SAR are given as the following ranges: ideal 2 mmol/l, acceptable 8 mmol/l and tolerable 15 mmol/l (DWA, 2011).

Table 2.5.1.2b: Summary of impacts of SAR on crops, soil and irrigation equipment (DWAF, 1996b:130).

Impacts on crops	Crop yield as affected by crop sensitivity to sodium uptake through crop roots. Crop quality as determined by damage to marketed product or regulatory limits on the sodium concentration in the final product.
Impacts on soil	Infiltration rate (because of surface sealing) of soils varying in sensitivity as affected by increasing SAR. Reduction in hydraulic conductivity of soil. Hard setting of soils which affects cultivation.
Impacts on irrigation equipment	No known effects

The Fertilizer Society of South Africa (2007:70) also provides an alternative system of water classification according to electrical conductivity as it is well correlated with the dissolved salt content of the water. Irrigation water is accordingly divided into four classes as follows:

1. **C_1: Low salt content** (<25 mS/m): This water holds no salinity hazard to well-drained soils.
2. **C_2: Medium salt content** (25-75 mS/m): Provision must be made for a reasonable degree of salt leaching and saline-sensitive crops must be avoided.
3. **C_3: High salt content** (75-225 mS/m): Can only be used on well-drained soils. Periodic leaching is expected and salt-resistant crops must be used.
4. **C_4: Very high salt content** (>225 mS/m): Not suitable for use as irrigation water under normal conditions. Can only be used as an emergency measure, under extreme conditions, on sandy soils.

The maximum permissible EC of irrigation water for sugar cane is given as 170 mS/m(The Fertilizer Society of South Africa, 2007:70).

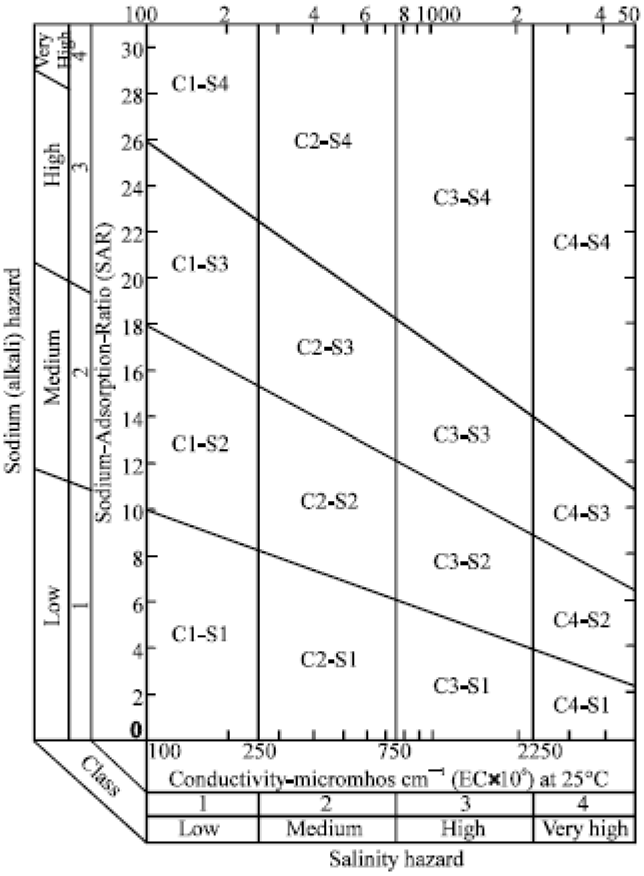


Figure 2.5.1.2: Water classification scheme (USDA, 1954)

Understanding the relationship between alkalinity and pH is important because these factors determine the suitability of water for irrigation of crops (Table 2.5.1.2c). pH is defined as “a measure of the concentration of hydrogen ions (H+) in water or other liquids” and water with a pH value below 7.0 is termed “acidic”, while water with a pH value of above 7.0 is termed “basic or alkaline” (Cox, 1995). On the other hand, alkalinity is defined as “a measure of the water’s ability to neutralise acidity” and an alkaline test measures the concentration of bicarbonate, carbonates and hydroxides in water. In this context carbonates and bi-carbonates also contribute to TDS.

Water for irrigation should have a pH range between 5.0-7.0 and alkalinity levels between 30 and 60ppm (29.97 mg/l and 59.93mg/l) (Cox, 1995). It is important for water quality tests specific for irrigation water to include both pH and alkalinity tests because water with high alkalinity (such as high concentration of bicarbonates or carbonates) always has a pH value of approximately 7.0 and above; however, water with high pH does not always have high alkalinity.

Table 2.5.1.2c: Impacts of pH on crop yield and quality, sustainability of soil and irrigation equipment (DWAF 1996b:116).

pH Range	Impacts on Crop yield and quality	Impacts on Soil sustainability	Impacts on Irrigation Equipment
<6.5	Increasing problems with foliar damage when crop foliage is wet. This could give rise to yield reduction or a decrease in the quality of marketable crops.	Increasing problems with the availability of several micro and macro nutrients in toxic concentrations.	Increasing problems with corrosion of metal and concrete in irrigation equipment. Practically no problems with clogging of drip irrigation systems.
TWQG range 6.5-8.4	This range should not cause foliage damage even when crops are wet.	This range does not present major problems	Mostly no major problems with either corrosion or encrustation of irrigation equipment within this range. Slight to moderate problems with the clogging of drip irrigation systems.
>8.4	Increasing problems with foliar damage affecting yield or decrease in visual quality of crop.	Increasing problems with the unavailability of several micro and macro nutrients in toxic concentrations.	Increasing problems with encrustation of irrigation pipes and clogging of drip irrigation systems in this range.

According to Malan and Day (2005), nitrogen and phosphorus are natural and vital chemical constituents of water resources and it is only when the concentrations of nitrogen and phosphorus are increased that they begin to exert an impact on water resources. Both nitrogen and phosphorus are found in different chemical forms in the water column, in sediments and within living organisms, and for the purpose of monitoring it is important to know exactly what should be measured to assess the nutrient status of a water resource (Sweeting, 1994).

Dallas and Day (2004) add that the generation of nutrients is a common feature of many anthropogenic activities such as disposal of sewerage, agriculture and several manufacturing industries. It is thus important to conduct monitoring and assessment of the concentrations and impacts of these constituents in aquatic ecosystems. Phosphorus is a macronutrient that occurs in both dissolved (abundantly as inorganic ortho-phosphate-PO_4^{3-} ion, poly-phosphates, meta-phosphates, pyro-phosphates and organic compounds) and particulate forms (as bound up in organic compounds, phytoplankton or absorbed in suspended particulate matter such as clay) (Holtan *et al*., 1988). Additionally, the absorbed phosphorus may be released from sediments during high flow conditions or during anoxic conditions in a water column and the release and absorption of the soluble forms of phosphorus influences its bioavailability in water.

According to Holtan *et al*. (1988), there are five fractions of phosphorus found in aquatic systems given as follows:

- Total Phosphorus (TP)
- Particulate Phosphorus (PP)
- Soluble Phosphorus (SP)
- Soluble Reactive Phosphorus (SRP)
- Soluble Unreactive Phosphorus (SUP)

According to DWAF (2002), ortho-phosphate is the most common dissolved form of phosphorus and is immediately available to be taken up by plants. EPA (1999) add that Soluble Reactive Phosphorus (SRP) is the most commonly measured chemical species of phosphorus and it represents the amount of ortho-phosphate plus some poly-phosphates in the water.

On the other hand, nitrogen is described as a major component of living organisms that exists in inorganic forms (ammonia-NH_3, ammonium-NH_4^+, nitrite-NO_2^- and nitrate-NO_3^{2-}) in water as wells as dissolved forms or inorganic nitrogen and those absorbed onto suspended inorganic and organic matter (DWAF, 1996c). Additionally, water temperature and pH control the relative proportions in which they occur within a water resource. According to DWAF (2002), because of the many forms in which this element occurs in aquatic systems, several indicators are measured; in terms of the Reserve methodology for assessing nutrient status nitrogen levels are expressed as Total Inorganic Nitrogen (TIN) which is the sum of concentrations of nitrate, nitrite, ammonia and ammonium.

A study conducted by Malan and Day (2005) investigated the refinement of nutrient assessment methods within the ecological Reserve process and presented a review of indicators used internationally to describe the nutrient status of an aquatic resource as well as the latest method prescribed for use in South African Rivers. The study critically evaluated Target Water Quality Range (TWQR) values for nutrients that are given in South African Water Quality Guidelines for Aquatic Ecosystems. The findings of the study showed that the Target Water Quality Range (TWQR) given as 0.005 mg ℓ^{-1} for inorganic phosphate was too conservative and that the 0.5 mg ℓ^{-1} target for Total Inorganic Nitrogen (TIN) was too lenient. The 75th percentile for TIN (given as 0.12 mg ℓ^{-1}) and Soluble Reactive Phosphorus (SRP) (0.018 mg ℓ^{-1}) were determined using these gauges including two other gauges and these values are the Recommended Target Concentrations (RTC) for TIN and SRC.

Other factors to consider in terms of irrigation water quality include concentrations of elements such as boron, sodium and chlorine. High boron concentrations in irrigation water are toxic from some crops, high sodium and chlorine can also be harmful. Sugarcane is grouped as a moderately sensitive crop in terms of chloride tolerance, tolerating chloride levels <425 mg dm^{-3} (The Fertilizer Society of South Africa, 2007: 74).

Microelements such as arsenic, cadmium, copper and lead present in water can also adverse effects on the suitability of water for irrigation as they are taken up by the plant and can cause poor growth. High levels of iron and/or manganese can block drip-irrigation systems. Suspended silt and clay increase the wear and tear of sprayers, settle in pipes and also block drip systems. The degree to which irrigation water can corrode irrigation systems is calculated by the corrosion index (The Fertilizer Society of South Africa, 2007: 74).

The corrosion index can be calculated as follows and a value > 0.1 indicates aggressive water:

(chloride + sulphate)/ (carbonate+ bicarbonate) (me dm^{-3})

From the information above it is apparent that the chemical composition of irrigation water is important when deciding on irrigation techniques and also the type of crop to be grown.

Water is also used to dilute herbicides and deliver them to the target weeds that are intended to be controlled and poor water quality can adversely affect herbicide performance in the following ways (SASRI, 2012):

- Reduced effectiveness of weed control;
- Higher application rates required with increased costs;
- Damage to the crop, and
- Increased risk of herbicide resistance.

SASRI (2012) highlights three important water quality variables that can impact the activity of many herbicides, and these are:

- **Suspended soil particles**: suspended solids, soil or organic matter can reduce the effectiveness of post-emergence herbicides and sensitive herbicides (e.g. Gramoxone and Roundup [active agent: glyphosate) will bind to the soil and organic particles suspended in the water and will not be available for absorption into weed foliage.
- **pH**: generally, spray water pH should be slightly acidic (pH 4.5-6.0) for most herbicides with some exceptions. Herbicides can be insoluble in certain pH levels and could result in physical incompatibility in the sprayer tank.
- **Dissolved salts**: poor water quality can have a high percentage of dissolved cations like Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} that provoke herbicides. Anions (negatively charged salts) such as bicarbonates, carbonates, chlorides and sulphates are normally non antagonistic. Cations can cause some chemicals to precipitate, affect the balance of the surfactant, affect properties like wetting and dispersion and can cause sensitive herbicides to become inactive by limiting their absorption by weed foliage.

2.5.1.3 Water quality needs of sugar mills

According to Magara (2014), many industries use water to produce certain products and this water has to have particular properties such as solubility, transportation potential or heat exchange potential. Additionally, in industries, water is used for steam generation in boiler systems, processing, product treatment and cleaning, cooling and for other processes. Magara (2014: 3) describes the following uses of water in industry:

- Water is used in boilers to produce hot water, generate electricity, steam or hyper-thermal water and the required water quality for this is usually different for each purpose. However, generally the boiler water needs to be non-corrosive and non-scale forming in the boiler and heat exchange piping or power generating system.
- Water is also used for processing as a raw material or additive in beverages, food processing and other applications and the purpose of the processing water will determine what quality the water must comply with. The processing water must be clean and pathogen free specifically in food related processing plants or factories.
- Water for product treatment and cleaning is used for physical processes such as cleaning, swelling, or dissolving raw material. Intermediate products and final product. The quality and quantity of water for product treatment and cleaning will vary depending on the manufacturing process and final product, however, the quality required for chemical, food, textile and pulp/paper industry is high.
- Water used for cooling mostly comprises the largest part of water consumption for industrial purposes and thus cooling water is often reused in order to save the acquisition cost and the water resource. The reuse of cooling water may result in impairment by scale, slime or corrosion caused by the concentration of soluble salts inside the circulation systems, due to evaporation or emission of cooling water. Therefore, the quality of cooling water is a very important factor in the operation of water systems.

In South Africa, the Department of Water Affairs and Sanitation (DWS), previously Department of Water Affairs and Forestry: DWAF or the Department of Water Affairs: DWA) manages water resources to ensure that their quality remains fit for recognised water uses and that the health of aquatic ecosystems is maintained (DWAF, 1996a). This is achieved through the setting of water requirements for different water uses known as The South African Water Quality Guidelines. The South African Water Quality Guidelines serve as a primary source of information for determining the water quality requirements of different water uses and for the protection and maintenance of aquatic health (DWAF, 1996b). The

South African Water Quality Guidelines for Industrial Water Use are set specifically for the quality of water required for different industrial uses irrespective of its source. The guideline provides a subdivision of water for industrial purposes into subcategories such as water for steam generation, cooling lubrication, humidification and others. This is because the subcategories can have different water quality requirements. DWAF (1996a:4) adds that the water quality requirements for water use are determined by considering the following:

- Typical water quality problems associated with a particular water use or the role that water quality plays in sustaining the use;
- The nature of effects of poor water quality on the use;
- The norms which are commonly used as measures of the effect of water quality on a particular water use;
- The water quality constituents which are generally of concern; and
- Any other site or case-specific characteristics of water use which may influence its water quality requirements.

The quality of water required for industrial use is also assessed in terms of the following aspects (DWAF, 1996a:9):

- Its potential for causing damage to equipment (for example corrosion or abrasion)
- Problems it may cause in the manufacturing process (for example precipitates or colour changes)
- Impairment of product quality (for example taste or discolouration)
- As well as complexity of waste handling as a result of using water of available quality.

The South African Water Quality Guidelines for Industrial Use provides four categories of processes according to the degree of water quality required for the processes. For the purpose of this study, Category 2 is applicable to sugar cane processing and Category 4 is applicable to sugar cane irrigation. These categories are described in Table 2.5.1.3.

Table 2.5.1.3
Industrial processes requiring particular water quality types
Modified from DWAF (1996a:9)

Category 2	Processes that require water of quality intermediate between the high quality required for Category 1 processes and domestic water quality (Category 3 processes). Specifications for some water quality constituents are somewhat tighter or more stringent than required for domestic water quality criteria. Cost for such additional water treatment begins to be significant in the economy of the process	Cooling Water	Evaporative cooling (high recycle)
			Solution cooling
			Water heating
		Steam Generation	High pressure boiler: demineralisation of feedwater
		Process Water	Solvent
			Heat transfer medium
			Humidification
			Lubrication
			Gas Cleaning
		Product Water	Beverages
			Dairy Products
			Petrochemicals
		Wash Water	Reaction vessel washing
Category 4	Processed that are within certain limitations can use water of more or less any quality for their purposes without creating any problems. No additional treatment is usually required and there is therefore no further cost.	Cooling Water	Ash quenching
		Process Water	Transport agent
		Utility Water	Dust suppression
			Fire Fighting
			Irrigation
		Wash water	Rough washing (floors, rough apparatus, trucks, raw materials)

Specifically for sugar manufacturing, water is as much a raw material as sugar cane because sugar cane cannot be processed without the use of water and both these raw materials are of variable compositions and require regular quality control testing (VWG Consulting, 2007). Furthermore, the extraction of sugar from sugar cane depends on steam being available at the mill and thus on the availability of source water of sufficient quantity and quality for the general water requirements of the sugar mill. The type of source water available to sugar mills depends on the catchment areas and thus by the nature of the waters origin and the course of the river or canal the water might take up a number of substances in solution or suspension (Magara, 2014).

Avant-Garde Engineers and Consultants (2012) add that the main grouping of impurities that might be present in source water for sugar mills are dissolved minerals and organic matter, dissolved gases, suspended matter, and microbiological organisms. Moreover, the nature and concentration of the impurities depends on the water source, for instance, surface water often contains organic matter such as plant matter as well as insoluble silt, sand and other inorganic material or contaminants as industrial pollutants. On the other hand, ground water might pick up impurities as it seeps through layers of rocks and may dissolve elements of the rock that it makes contact with.

As mentioned in Chapter 1, the sugar manufacturing process has four water intensive steps which basically involve the washing of raw sugar crystals; adding water to crystals to form a solution; clarifying and decolourising the solution; and re-crystallising and finishing the sucrose (Gumbo *et al*., 2003).

According to VWG Consulting (2007), boilers in sugar mills which are also referred to as steam boilers or water tube boilers are used for steam generation for some of the sugar manufacturing processes and to generate electricity for the sugar mill. In the boilers, bagasse or coal is burnt in the furnace producing hot products of combustion which are then guided from the combustion zone over water-tubes. As the gases flow through the boiler they are cooled by transferring heat to the water contained in the tubes. A mixture of steam and water is formed in the tubes and considerable velocity of flow is maintained as the water and steam move to the drum where the steam is separated for use. The water which has become concentrated by the formation of steam is diluted by incoming feedwater or make-up water (water added to compensate for losses from the steam and condensate system).

The water quality requirements for boiler water are variable depending on the size, pressure, application and feedwater of the boiler (Myron L Company, 2012). However, the two major water related problems that can affect the efficiency of boilers in sugar manufacturing are deposits and corrosion. These issues are caused by the fact that as steam is generated, dissolved minerals are left behind and increase in concentrations and additional dissolved minerals may be added via boiler make-up water to replace the water lost to steam. Eventually, the minerals reach a level of concentration that result in either a loss of efficiency due to scale or damage from corrosion. There are a number of constituents in water that lead to problems that affect the efficiency of boilers in sugar manufacturing. The constituents that lead to these problems are listed and described below (Avant-Garde Engineers and Consultants, 2012: 2):

- **Scale formation in the boiler**: Calcium and magnesium compounds in water are precipitated by the heat and pressure and form scale and sludge that can clog the boiler systems and inhibit heat transfer across equipment and piping surfaces. Additionally, magnesium sulphate is very soluble and it usually reacts with boiler water to form less soluble magnesium salts such as hydroxide. On the other hand, calcium sulphate tends to remain in solution in colder parts of the boiler but becomes a deposit or crystal inside steam bubbles that are forming in the hotter parts of the boiler and this can result in scale damage. Iron, manganese and silica have the same effect, with iron forming a yellow or reddish brown residue that stains on contact and manganese creating deposits and black stains.
- **Foaming in the boiler**: Sodium salts are very soluble and this solubility increases when water is heated. Sodium salts normally do not cause boiler deposits but contribute to causing foam formation and this causes the entrainment of boiler water in the steam which is undesirable.
- **Corrosion of steel in the boiler**: Oxygen and salinity are the two main agents of corrosion of steel in boilers. When water is heated oxygen becomes less soluble and some escapes and as make-up water enters the boiler the oxygen remaining either begins corroding or goes into steam. On the other hand, sodium chloride and

sulphate assist oxygen to penetrate through deposits to steel surfaces, resulting in corrosion. Water with a low pH can also lead to corrosion, while water with alkaline water can lead to corrosion of bronze fittings. An optimum pH of 8.8-9.2 is recommended for make-up water for boilers.

- **Damage to superheaters**: Superheaters that are present in boilers have tubes that carry steam that is heated above the temperature of saturated steam. Maintaining the steel of the tubes within safe temperatures depends on the cooling effect of the flowing steam that is heated and foaming of saline boiler water can cause re-boiling in the superheaters. This can form deposits that can interfere with heat transfer and if excessive can lead to the interruption or restrictions of flow of steam.
- **Damage to turbines**: Sodium salts that are carried with the steam produced in boilers can form incrustations on turbines.

According to VWG Consulting (2007), cooling towers are used in sugar mills to cool warm water through a process of evaporation and the use of cooling towers assists in reducing water usage by allowing recycling of cooling water. Magara (2014) adds that cooling water forms the largest part of consumption of industrial water and thus reusing cooling water saves costs. However, the reuse of cooling water may result in impairment by scale, slime or corrosion because as the water evaporates dissolved minerals are concentrated inside the circulation system.

Furthermore, even though cooling water is reused, some water is lost through evaporation, the entrainment of liquid water droplets into the warm, saturated air stream and losses due to wind, also resulting in increased concentration of dissolved minerals. VWG Consulting (2007) emphasises that to reduce these concentrations to acceptable levels, some cooling water has to be discharged from the system, with subsequent addition of make-up water and this process is known as *blow down*. Therefore, the quality of cooling water and make-up water is a very important factor in the operation of cooling towers and it is influenced by the following water quality variables (Magara, 2014:7):

- **pH**: Low pH of cooling water may result in the corrosion of metal parts used in the cooling water system, while cooling water with high pH may result in the deposition of scale due to calcium, magnesium and silica. Thus, the pH value of cooling water should be controlled within a range of 6-8.

- **Electrical conductivity**: Cooling water with high EC and high soluble salts can cause impairment, such as corrosion and scale deposition. Make-up water with low EC (<30 mS/m) increases the concentration ratio (which is the ratio of the quality of circulated water to that of make-up water) of circulated cooling water and reduces the loss of water because the quality of make-up water is inversely proportional to the concentration ratio.

- **Chloride ion**: The use of groundwater or water with high concentration of chloride ions results in corrosion of piping or equipment.
- **Sulphuric Acid:** High sulphuric acid concentrations (which results in low pH) also have the same effect as high chloride ion concentration and water with high sulphuric acid concentration is not suitable for cooling water.
- **Methyl-red alkalinity:** this is described as the value that indicates the concentration of bicarbonate ion and its combination with elements such as calcium could cause impairment by producing calcium carbonate scale.
- **Hardness:** the sum of calcium and magnesium concentrations, in combination with pH and methyl-red alkalinity, results in the production of scale which is deposited on the heat exchange conductors in the cooling equipment. This results in reduced heat conductivity.
- **Biological growth:** this is another extremely important factor in cooling water management because microbes can cause corrosion, fouling and development of disease.

2.5.2 Water quality impacts of sugar mills and sugar plantations

2.5.2.1 Introduction

In the sugar industry, environmental consideration are becoming increasingly important due to pressure from conservation and local communities, increasingly strict regulations and pressure applied through trading markets (Mallawaarachchi *et al*., 2001; ISO, 2001; SASA, 2002). According to Cheesman (2005), similar to other industries, especially those based on intensive agriculture, the sugar industry needs to address a complex range of environmental concerns. Furthermore, the key challenges include the need to improve production systems to maximize water and nutrient efficiency, conserve soils, better control weeds, pests and diseases while reducing the impact of pesticides. Though the importance of concerns may vary country by country or across local structures and regulations, a similar range of issues exist across the sugar industry. Cheesman (2005) provides a summary of environmental impacts from cultivating and processing sugarcane and these are illustrated in Figures 2.5.2.1a and 2.5.2.1b below. Sugar production can also have an impact on water quality and aquatic ecosystems through both cultivation and processing of the crops and this is the focus of this research and these will be explored in more detail in the following sections.

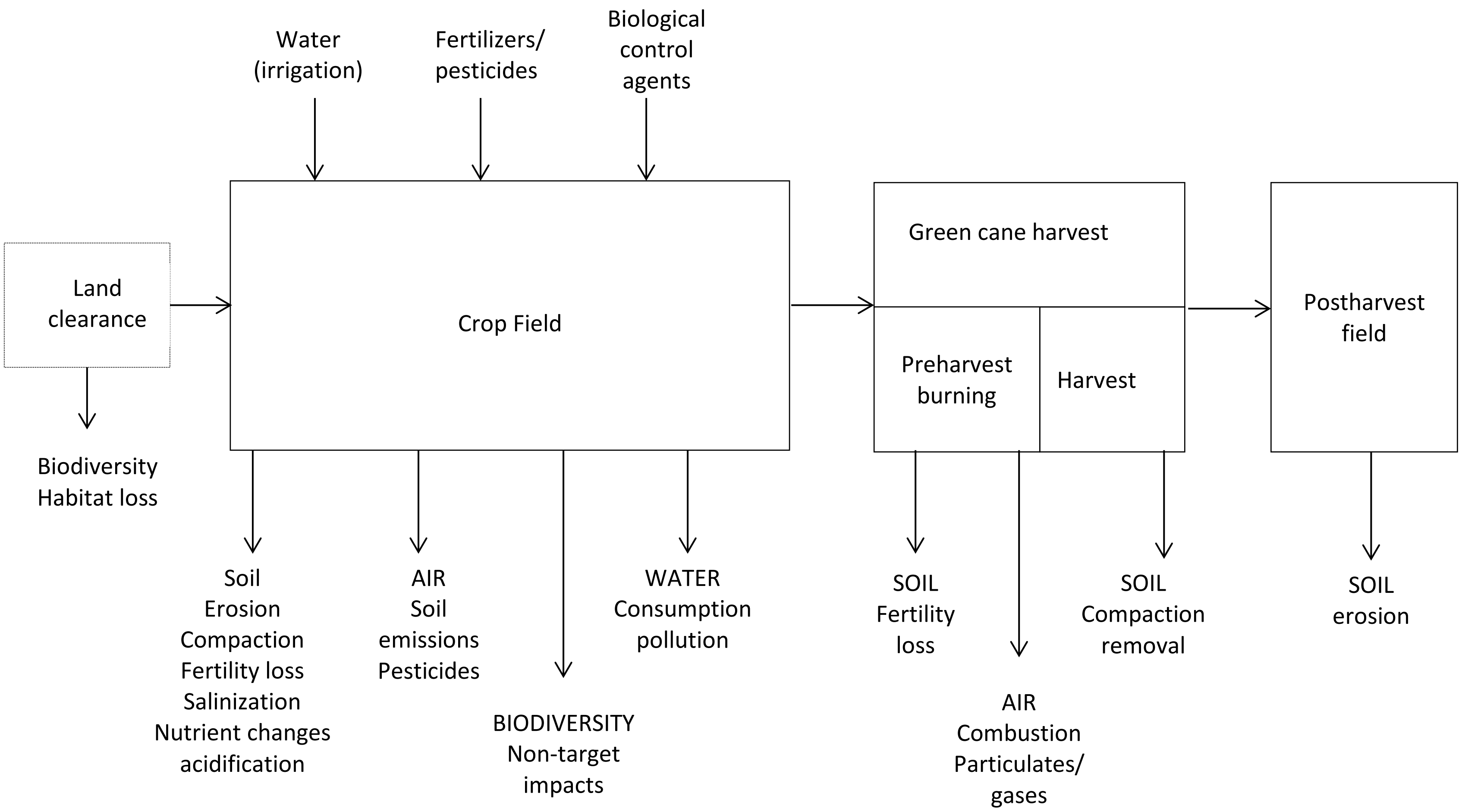


Figure 2.5.2.1a: Sources of environmental impacts relative to key processes and inputs in the cultivation of sugarcane (Cheesman, 2005:13)

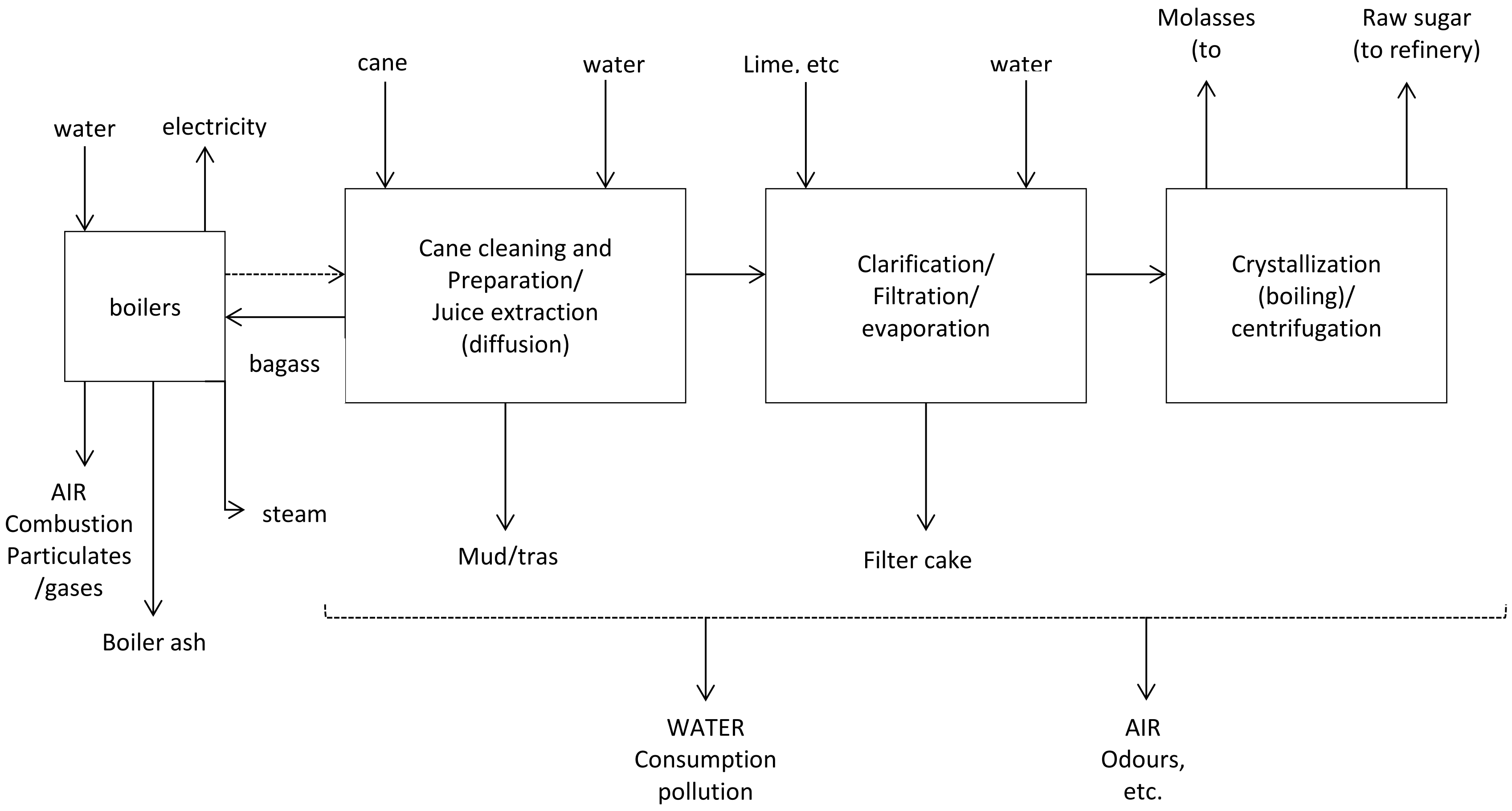


Figure 2.5.2.1b: Sources of environmental impacts relative to key processes and inputs in the processing of sugarcane (Cheesman, 2005:20)

2.5.2.2 Water quality impacts of sugar plantations

In terms of sugarcane cultivation, the major water quality impacts emanate from pollution of the water resources due to runoff and leaching as stated by Cheesman (2005), this often leads to the contamination of groundwater, surface water and ultimately coastal environments. The major pollutants are nutrients such as nitrates and phosphates from fertilizers, agrochemicals such as pesticides and herbicides and increased levels of sediments. According to Feizi (1998) and Ghassemi *et al.*, (1995), irrigation can lead to increased runoff and deep drainage and water quality issues often result when waste or saline waters are used to irrigate, subsequently contributing to saline soils.

As described by Cheesman (2005), water from rainfall or irrigation drains the sugar plantations across the soil surface (flowing as surface runoff) depending on the rate of rainfall or irrigation, topography and soil characteristics such as permeability or porosity that influence infiltration rates. Additionally, the water that drains through the soil carries dissolved nutrients, soil sediments and soluble pesticides residue or insoluble chemical residue and these constituents can result in a range of impacts downstream depending on the concentrations (Arthington *et al.*, 1997).

On the other hand, water that does not drain across the soil surface in sugar plantations infiltrates the soil and much of it may be used by the crop; however, a portion of it may drain from the plantations through the subsurface level and this process is termed *leaching* (Cheesman, 2005). Additionally, this water may carry soluble chemicals and these may be flushed through the soil into the water resources. The rate at which leaching occurs through the soil is enhanced when the sugarcane crops are still in early stages of growth (as they do not require large amounts of water at this stage) and when the sugarcane crops have been harvested (SASA, 2002).

Christensen (2004) adds that leaching of nitrates can lead to eutrophication of freshwater resources and that most leached nitrates appear to come from mineralised soil organic matter; however, some comes from the excessive application of inorganic fertilizers. On the other hand, soils that are acidified promote the leaching of nutrients such as Ca^{2+} and Mg^{2+} (Haynes and Hamilton, 1999). According to Draycott and Christenson (2003), there are other factors that significantly influence the effects of fertilizers and agrochemical inputs on runoff, including local soil characteristics that affect the dynamics of the leaching process, climatic factors, and irrigation regime. Moreover, the hazard of water pollution will also vary between different chemicals because some are more soluble than others and are thus transported. For example, nitrates and sulphates are more mobile than phosphates and ammonium (Draycott and Christenson, 2003). Sediment loads have generally increased from diffuse sources in cane growing areas and major rainfall events can also aid in carrying this material downstream (Johnson *et al*., 1997). In South Africa, sugar plantations are situated mainly in catchment areas with gentle to steep undulations that encourage runoff into rivers. The lack of effectively integrated soil conservation practices such as avoiding planting sugarcane very close to the banks of rivers can lead to riparian vegetation loss that anchors the soil (Tudor-Owen and Wyatt, 1991). Soil erosion can also contribute to the movement of nutrients from sugar plantations with studies from Australia suggesting that 50% of N and 80% of P was transported through binding with sediments (Crossland *et al*., 1997).

In South Africa, irrigated agriculture is the largest water user and this has serious consequences in terms of decreased river flows and falling groundwater levels, and wider environmental impacts such as decreased dilution capacity of rivers downstream of irrigated areas and thus impacts on hydrological processes and biodiversity (Schmidt, 2000; McNeely, 2003). The WWF (2005) also emphasises that sugarcane production has led to wetland habitat loss with about half of the world's wetlands being lost to drainage and conversion to agricultural land. Additionally, low-lying and alluvial areas have been particularly reclaimed and drained for sugarcane cultivation due to the rich soils and good natural supply of water that they provide. Cheesman (2005) adds that the main concern that has been articulated in relation to irrigation in sugarcane cultivation is the over-exploitation of water resources, leading to environmental impacts (such as soil salinization) related to soil water-logging.

2.5.2.3 Water quality impacts of sugar mills

In terms of sugarcane processing, the major water quality impacts result from the discharge of effluents from sugarcane mills. According to Cheesman (2005), relatively large amounts of water are abstracted from rivers for sugar manufacturing and a large amount of waste is produced from processing, that contains a high amount of pollution load with constituents such as waste water with high suspended solids and organic matter, press mud, bagasse and air pollutants. The effluent produced often has high electrical conductivity, high biological oxygen demand (BOD) and chemical oxygen demands (COD) (a measure of the oxygen consuming capabilities of organic matter) and this often leads to dissolved oxygen depletion in-stream, especially if the discharge is during low flow periods (Siddiqui and Waseem, 2012). The liquid effluent from sugar mills often contains sugar, cleaning chemicals (such as lime) and residue from organic and inorganic scale (VWG Consulting, 2007).

To conserve water or to reduce the amount of water consumed during sugar processing, the waste water produced is often used for irrigation and this may lead to groundwater pollution if leaching occurs (VWG Consulting, 2007; Cheesman, 2005).

A study by Siddiqui and Waseem (2012:1900) give a description of the water parameters of treated and untreated sugar mill effluent. The values of some of the parameters measured at the sugar mill for this study are also included to provide the context of this study and it is important to note that the effluent from this sugar mill is not discharged into the water resource, however it is mixed with ash water from the sugar mill and used for irrigation (These values are given in a Water Analysis report from the sugar mill: TSB, 2013).

- **Colour**: the colour of untreated effluent is often dark brownish to black and treated effluent is often light brownish in colour. Colour is a very important factor in terms of the photosynthesis capability for aquatic life and this ability is reduced if dark coloured effluents are discharged into water resources.
- **Temperature**: has a significant role in terms of chemical and biological reactions that take place in water which affect organisms and the habitats in which they live. Depending on the season, waste water discharged from sugar mills has high temperature which can result in changes in the plant communities in the affected areas. The temperature of untreated effluent is often recorded as 40°C and treated effluent at 38°C. The temperature of untreated effluent from the sugar mill specific for this study was recorded at 28.35°C in 2013 and the cooling water (non-contaminated) that is released back into the resource had a temperature of 27.44°C. The irrigation water (10% ash water+90% effluent) had a temperature recorded at 33.63°C in 2013.
- **pH**: of treated and untreated effluent has been recorded as 5 and 6.8 respectively in the study conducted by Siddiqui and Waseem (2012:1900). The relatively low pH

values of sugar mill effluent are due to the use of phosphoric acid and sulphur dioxide during the cleaning of sugarcane juice. If water with such pH values is used for irrigation for long periods of time, soil can become acidic resulting in poor crop growth and decrease in crop yield. The pH of untreated effluent from the sugar mill specific for this study was recorded at 6.89 in 2013 and the cooling water (non-contaminated) that is released back into the resource had a pH value of 7.76. The irrigation water (10% ash water+90% effluent) had a pH recorded at 7.20 in 2013.

- **Dissolved oxygen levels affect most biota. BOD: biological oxygen demand is described** as the amount of oxygen required by microorganisms to stabilize biological decomposition of organic matter in water under aerobic conditions. Organic pollutants are oxidized by certain microorganisms into carbon dioxide and water using dissolved oxygen. Hence measuring the decrease of dissolved oxygen is a measure of BOD. The level of BOD of untreated effluent was recorded at 98mg/l, while treated effluent had 88mg/l.
- **COD**: the measure of chemical oxygen demand determines the amount of oxygen required for chemical oxidation of organic matter with the help of a strong chemical oxidant. The effluent is measured in terms quantity of the oxygen required for oxidation of organic matter to produce carbon dioxide and water. COD is a useful indicator of toxic conditions and the presence of biological matter. The COD value of untreated effluent was recorded at 350mg/l and treated effluent with the COD value of 255mg/l – indicating severe organic pollutants. At the sugar mill specific for this study, the untreated effluent had a COD recorded at 2589.62 mg/l in 2013 and the cooling water (non-contaminated) that is released back into the resource had a COD value of 30.80 mg/L and the irrigation water (10% ash water+90% effluent) had a COD of 892.49mg/L in 2013.
- **TDS**: the total dissolved solids measure represents the concentration of colloidal forms and dissolved particles of matter in effluent. During the rainy season, lower concentrations of total dissolved solids are measured due to the dilution factor of waste water with rain water. The TDS of untreated effluent was measured at 2980 mg/l and 1920 mg/l for treated effluent (equivalent to 497mS/m and 320 mS/m respectively).

- **TSS**: The Total Suspended Solids is a measure of suspended particles that influence turbidity and transparency. Untreated effluent had a TSS value of 110 mg/l and 100mg/l for treated effluent. The untreated effluent at the sugar mill for this study has suspended solids recorded at 914.44 mg/l, 14.03mg/l for the cooling water and 3333.33 mg/l for the irrigation water in 2013.

- **Chlorides**: this is a measure of dissolved slat deposits. Untreated effluent had a value of 210 mg/l chlorides and 175 mg/l for treated effluent.
- **Sulphate**: is also produced through oxidation of sulphate compounds and sulphur itself is considered never to have a limiting factor in aquatic systems. 760 mg/l was recorded in untreated effluent and 420 mg/l in treated effluent.
- **Oil and Grease**: are often washed off from sugar processing equipment during maintenance periods at the sugar mills. 16 mg/l was recorded in untreated effluent and 10 mg/l in treated effluent.

It is evident that even though sugar mills might be taking considerable measures to avoid pollution, additional measures for environmental protection, especially effluent treatment, are necessary (Siddiqui and Waseem, 2012). Cheesman (2005) adds that there are various measures that can be taken to reduce the quantity and polluting potential of sugar mill effluent and a range of techniques are available to treat sugar mill effluents such as simple methods to settle solid wastes and various aerobic and anaerobic treatments. In the context of this study, the sugar mill does not discharge any effluent into the Crocodile River; however, the effluent water (10%) is mixed with the ash water (90%) and pumped to the TSB sugar cane field for irrigation. The water that is discharged into the Crocodile River is the cooling water that is not contaminated. The impact of the sugar mill is assessed in Chapter 6.

CHAPTER 3

Conceptual framing and methodology

This chapter will describe the key concepts and theories that are drawn from for this study, provide the conceptual framework for this thesis and relate these concepts and theories within a broader analytical framework. A description of the methods used and explanation of how these methods interact and interrelate will also be provided in this chapter.

3.1 Introduction and overview of conceptual framework

According to Harris and Vermeulen (2011:19), a conceptual framework is described as a coherent set of theoretical formulations within which a particular analysis is positioned and which provides the theoretical language that will be used in the study. Furthermore, specific theories are within the framework that relate to the management of common pool resources. It is important to note that for the present study all the theories or concepts that are referred to have some link to the overarching framework of Integrated Water Resource Management (IWRM) and complexity theory. Therefore this chapter will start with an overview of IWRM and complexity theory and then present associated theories and concepts that have guided this study.

3.1.1 Integrated Water Resource Management

The variety of challenges related to the management of water resources that are faced by many countries globally (described in chapter one) are often aggravated, among other issues, by the lack of effective and efficient water governance, which in the past was facilitated by sectors (water demand and supply sector plus pollution control sector) that were fragmented and uncoordinated. This resulted in inequitable distribution of water resources within countries (Global Water Partnership, 2000; Funke *et al*., 2007).

Another challenge that has been identified by the Global Water Partnership (GWP) (2000) is the variability in water availability in both space and time. The freshwater that is available for people to use is primarily through precipitation, which varies in space and time. Seasonal and annual variations in rainfall are factors that influence water availability in most tropical and sub-tropical regions of the world. The GWP Technical Committee (2009) adds that in order to achieve water security, investments are needed for infrastructure development and it is necessary to manage water demand and supply effectively. South Africa is one such country that is affected by variability and unequitable distribution. Historical patterns of industrial, agricultural development and social engineering that were influenced by political decisions have resulted in a disparity between locations that have high demand for water and the available water resources (Funke *et al*., 2007). These physical and historical circumstances result in a huge challenge to achieve sustainable social and economic development while dealing with the inequalities caused by past political policies and management.

The GWP Technical Committee (2009) emphasises that many of the challenges mentioned above are not new and they date back to 1992 at the Rio Earth Summit were the principles of the IWRM were discussed and agreed to Agenda 21 provides the historical perspective and evidence of the need for effective management of water resources. It states that "*the widespread scarcity, gradual destruction and aggravated pollution of freshwater resources in many world regions, along with the progressive encroachment of incompatible activities, demand integrated water resources planning and management. Such integration must cover all types of interrelated freshwater bodies, including both surface water and groundwater, and duly consider water quantity and quality*" (United Nations Conference on Environment and Development, 1992:196).

Global Water Partnership (2000:22) defines IWRM as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems'. According to DWAF (2004b), IWRM aims to reach a balance between resource use to improve livelihoods and resource protection for future generations, while also promoting social equity, environmental sustainability and economic efficiency. According to Pollard and du Toit (2008), the IWRM approach is as the centre of the National Water Act No 36 of 1998 of South Africa and as mentioned in chapter one, the Act emphasises the need for integrated management of all aspects of water resources.

The IWRM approach has been adopted as central to this study, as a transformative way of managing water resources at catchment level. This study was conducted through an integrative, co-operative and participative approach to develop an integrated water quality management process for the Crocodile River Catchment. This study draws from a collective of strategies, plans and practices (envisaged in the National Water Act and National Water Resources Strategies) that make up IWRM such as the Catchment Management Strategy, to be discussed in detail below. The interrelations between these components provide an integrated perspective on the research questions examined in this study.

3.1.2 Complexity Theory and Systems Thinking

The world's natural resources are being pushed passed sustainability boundaries (in this instant sustainability refers to maintaining the capacity of ecological systems to support social and economic systems, however due to overexploitation of natural resources, this capacity may not be maintained, Berkes *et al.* 2003), as this happens, we are being forced to address complexity and we live in a rapidly transforming global environment that influences our understanding of how to behave in it, with major consequences on approaches used for addressing present day problems (Pollard *et al*., 2011; Rogers *et al*., 2013). Economic and technological advances have meant that we interact with more people, objects and organisation through communication, production and transport and each of these is increasingly interconnected (Pollard *et al*., 2011:4). Cilliers (2000) adds that complexity has implications for the way the structure of organisations or systems is perceived, as well as the way in which the organisations or systems are managed.

Moreover, it is widely recognised that natural and social systems are complex in their own right and that their interactions add complexity (Pollard and du Toit, 2011a). Berkes *et al*. (2003) emphasised that this has resulted in particular challenges for disciplinary approaches that still use the "silo" method. In addition, there is an emerging consensus regarding the need to look for broader approaches and solutions, not only with resource and environmental issues but also a wide front of societal issues.

According to Berkes *et al*. (2003), for each of the issues that develop in resource management, new theories and explanations are created; however, there is much for more creative forms of collaboration between scientists and society. Theory and policy should also involve a broader range of disciplines and skills needed for the integration Jasanoff *et al*. (1997) also add that broader public participation is important and scientific solutions need to be undertaken with greater attention to their social context. The interaction between science and society is increasingly seen as important.

At present the research that is needed in resource management may be ‘created through processes of co-production in which scholars and stakeholders interact to define important questions, relevant evidence and convincing forms of argument (Friibergh Workshop on Sustainability Science, 2000). In order to achieve this it is important to view the interaction of biophysical and social systems.

Whilst there are many definitions of the systems concept, only one will be briefly described here. Meadows (2011:11) define a system as “an interconnected set of elements that is coherently organized in a way that achieves something”. Following Meadows’ (2011) definition, a system therefore consists of three components: elements (sometimes also referred to as variables); interconnections; and a function or a purpose. Each of these components is briefly described below:

- The *elements* of a system include both tangible, visible components and other intangibles. In a typical water treatment works, the elements would therefore include infrastructure like pumps, ponds, aeration tanks, in addition to intangibles like the expectations of potable water of a particular quality and quantity. These elements can be divided into sub-elements and further into sub-sub elements (Meadows, 2011:13).
- The *interconnections* in a system are the relationships or interactions that hold the elements together and they can include physical and information flows. In a water treatment works, physical flows include the movement of untreated effluent through a treatment process and the subsequent conversion of the effluent into potable water of drinking quality. But the flows could also include how much effluent is at a particular point in the treatment process at a particular time, which could determine how much is required to move through the system at the next point of the treatment process. Meadows (2011:14) describes these type of interconnections as flows of information through the system and they are understood as signals that go to decision points or action points within a system.

- The *function or purpose* of a system is determinable by the behaviour of the system over time and not necessarily expressed explicitly (Meadows, 2011:15).In a water treatment works the purpose might be to supply residents with adequate safe water, yet the behaviour of the system might demonstrate that some residents have more secure supply than other residents due to the effectiveness of the water supply system.

The concept of a system as introduced above is undistinguishably linked to the practice of systems thinking. Systems thinking is a concept or theory based on a holistic worldview that emphasises interrelationships rather than parts, and patterns over time, rather than static components (Meadows, 2011). When systems thinking is applied to water resource management it shifts from focusing on isolated situations and their causes to viewing water resources as a system made up of interacting parts (Simonovic, 2009). In a world faced with climate change and a global water crisis, policy makers have also recognised that "a business as usual approach" to governing water resources is not acceptable and systems thinking and practice are key to effective policy and practice that address long-term complex issues (Ison, 2010: 13)

Systems thinking has also led to the recognition that conventional thinking that was used in the past in resources and environmental management may have contributed to problems instead of providing solutions (Holling and Meffe, 1996). One of the most important lessons from systems thinking is that management processes can be improved by developing practice that is adaptable and flexible, able to deal with uncertainty, and adapt to change by building capacity (Berkes *et al*., 2003). Therefore systems thinking can be used to bridge an integrated understanding of social and biophysical processes to understand, for example, climate, history and effects of human actions on natural resources (McIntosh *et al*., 2000).

Most researchers of social-ecological systems have recognised the paradigm shift that accompanies complexity that emphasises non-linearity, context and contingency-specific interactions among emergent entities (Rogers *et al*., 2013:1). In the study of social-ecological systems it is often the uncertainty of results that is an outcome of the non-linear interactions that forms the focus (Audouin *et al*., 2013). The theory of complexity is found in literature of many academic and professional disciplines from business, philosophy, economics, health, planning and policy, welfare and crime, and the natural and social sciences (Urry, 2005).

Complexity lacks a definition that has been agreed upon that includes an all-encompassing theory, but the working definition of complexity is "the interdisciplinary understanding of reality as composed of complex, open systems with transformational potential" (Preiser, 2012: 37). Cilliers (2000) summarises the key characteristics of complex systems as:

- Open-systems;
- Comprising of many interacting components;
- With non-linear processes;
- With feedback loops between components and processes;
- Where temporal and special scale influences processes and feedbacks; and
- They are adaptive.

Pollard and du Toit (2008) also state that complex systems can be distinguished from simple systems by a number of attributes including non-linearity, uncertainty, emergence, scale, self-organisation, and feedback loops (as seen in Table 1). Furthermore, acknowledging these attributes means accommodating both their implications and lessons for future action (Berkes *et al.*, 2003).

The concept of complexity within the context of water resources management in South Africa is not a new one. South African's policies and legislation make specific reference to complexity or complex systems, and as a result, the need for integration. Even the first edition of the NWRS dedicates a significant portion of its first chapter to the need for IWRM in complex water systems (Pollard and du Toit, 2008). Moreover, the core of complex systems is their inherent variation in space and time that determines the system function and significantly, what causes them to adapt. It is therefore important to strive to see systems holistically, considering them as sub-systems of larger systems that interact with other sub-systems, and the bigger and smaller systems relate. Furthermore, 'phenomena whose causes are multiple, diverse and dispersed cannot be understood, let alone managed or controlled, through scientific activity organized on traditional disciplinary lines' (Jasanoff *et al.*, 1997:2066).

According to Pollard and du Toit (2011a:10), adopting complexity has particular applicability in water resources management with are three key principles:

- Seeing a catchment as a complex system with inter-linkages where all things are potentially connected is an important point of departure for making sense of water resources management processes. The complex nature of IWRM cannot avoid the integratedness of water, linking a multitude of issues in catchments.
- Whatever happens in the real world is not as a result of a single causal mechanism. Events are a result of the interaction of diverse causal and counter-causal tendencies.
- The world is subject to an infinite number of (often mutually exclusive) future possibilities. Governance mechanisms that represent one way of selecting the number of future possibilities (Jessop, 2003).

The above discussion demonstrates that strategies and policies for water resource management should be designed to take account of the complexity of catchments by acknowledging that multiple drivers, multiple outcomes and feedback loops are all realities within the water resource management context (see Table 3.1.2) (Pollard and du Toit, 2008). It is also important to note that since outcomes may have uncertainty linked to them, the process of developing effective ways of managing water resources is a learning and reflective experience. More importantly, the main reason for grounding this study in complexity theory is that it relates to the intentions of the national water legislation in South Africa which are grounded in sustainability principles that recognise complexity. This study acknowledged complexity and used a complexity-based perspective to explore the development of an integrated, participative, water quality management process for the Crocodile River Catchment, focusing on the sugar industry. The study was also embedded in a Strategic Adaptive Management setting in the Inkomati-Usuthu Catchment Management agency, as described in section 3.1.3 below.

TABLE 3.1.2
Key attributes of complex systems
synthesised by Pollard and du Toit, 2008 from Holling (2001), Gunderson and Holling (2002), Berkes et al., (2003) , Walker et al., (2004), Allison and Hobbs (2006)

Attribute	Example
Socio-ecological systems are **heterogeneous, dynamic** and in a state of **flux**. Variability is essential and not a 'management inconvenience or problem'.	Rainfall may vary around an 'average' of 500mm per year- from 200mm in a dry year to 800mm in a wet year. This brings about different effects each year and cumulatively.
Systems have **multiple drivers**, many of which are non-linear in their effects and which operate at different scales. Hence outcomes are usually not entirely predictable. Also some of these drivers may relate to other 'sub-systems' such as a political or global drivers.	A reduction in base flows may reflect increased abstraction, the impacts of a weir and a political decision to expand agriculture, such as biofuels which are seen as a way to improve our foreign exchange or reduce our dependency on imported fuel.
Components of systems are independent and interacting and understanding the linkages is important. In particular **feedback loops** are an important attribute of complex systems.	For example. A reinforcing loop is evident when wetland health improves, causing an increase in the water table which causes a further improvement in wetland health (Pollard and Perret, 2007).
Multiple drivers and feedback loops often mean uncertainty because we **can't predict exact outcomes**; moreover they can lead to unexpected outcomes.	The global drive to reduce dependence on fossil fuels (viewed as a favourable position for sustainability) has increased biofuel initiatives which are impacting on water resources and on food availability
Complex systems display **lags**.	We are unlikely to see immediate benefits from the policy to determine environmental flows because complex socio-economic and political arrangements are needed to achieve this.
Complex systems are not necessarily complicated; in fact, they often only have a **basic set of drivers and responses**.	For example, fire, rainfall and fire management may be the key drivers of savannah eco-systems.

3.1.3 Strategic Adaptive Management

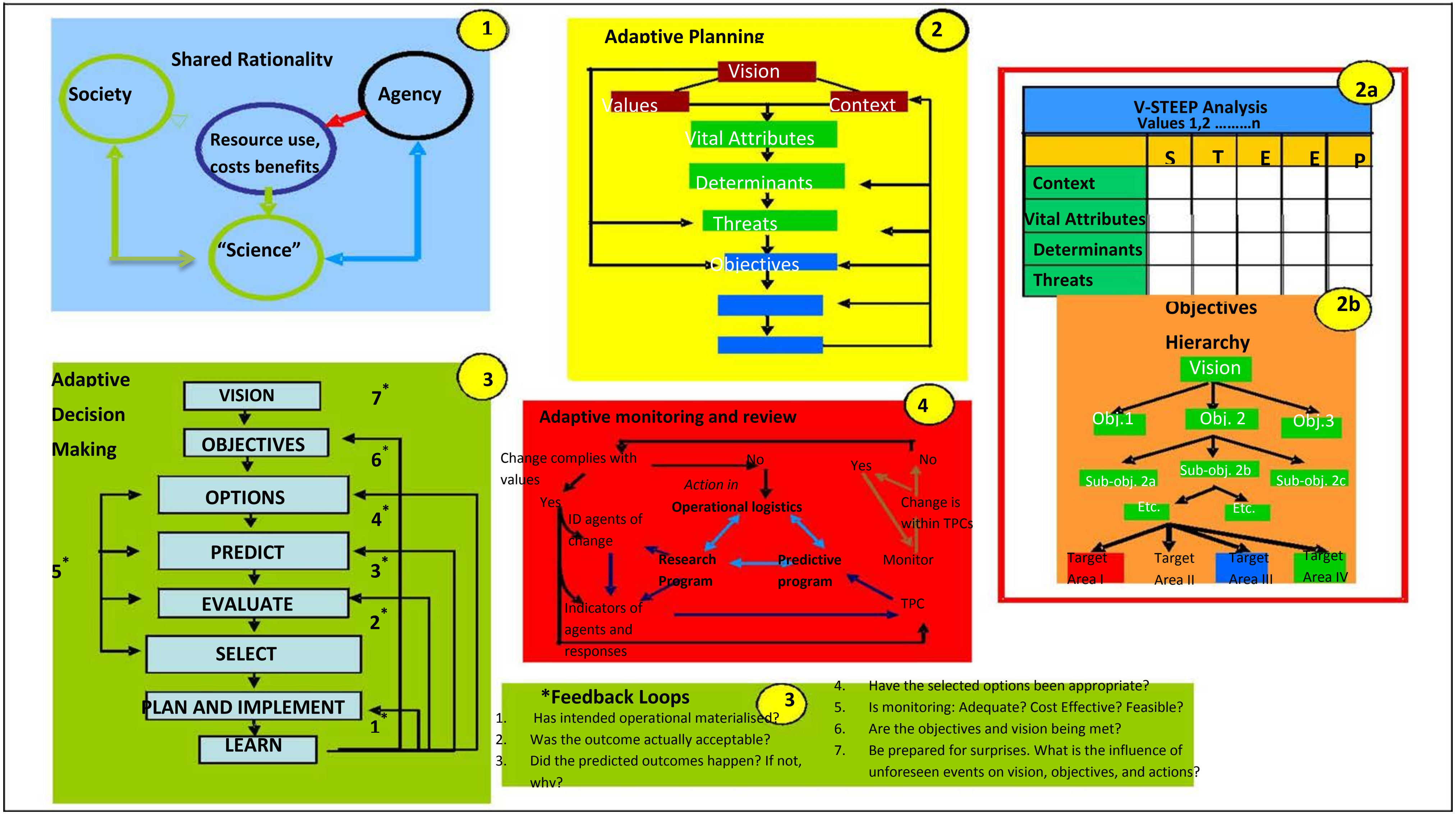
Strategic Adaptive Management (SAM) is defined as “a management approach that is fundamentally stakeholder centred, and it has future building processes that have been used to achieve consensus and cooperation between diverse and divergent stakeholders in a range of situations” (Rogers and Luton, 2010:1). Additionally, SAM is a framework that includes a number of different components (Figure 3.1.3) that should be practised in iterative cycles of planning, implementation, monitoring, reviewing and learning.

SAM has been described in detail in other reports (Rogers and Bestbier, 1997; Biggs and Rogers, 2003; Rogers and Sherwill, 2008), so in this study a summary will be provided as context for discussing the value it has for this research project and the methodology applied. Adaptive Management was first introduced to the domain of natural resource management by Holling (1978) and the term and practice of adaptive management has since evolved into many forms including SAM, which is referred to here.

According to Pollard and du Toit (2011a), SAM was premised on an understanding of the complexity of natural systems, an acceptance that knowledge is imperfect, and a belief that learning is achieved from purposeful, documented objectives and actions. In addition, the SAM framework is applied in the stewardship of South African conservation areas, that is based on ‘learning by doing’, which in most cases is a shift from previous management ethic that was strongly founded on intervention, and viewed ecosystems as stable and linear, reducing variability (Biggs and Rogers, 2003; Pollard and du Toit, 2006).

An important aspect of SAM is that it involves stakeholders in research and management processes as key to helping them cope with the unpredictability of change, to develop resource management practices that adapt to and are flexible in accommodating natural variability and disturbance patterns (Pollard and du Toit, 2011a).

This study has adopted the principle of interaction between stakeholders and researchers in a process of discovery and learning about how each stakeholder’s behaviours affect the catchment, and how this alters the status of water resources in which they have a shared interest. Therefore this study explicitly recognises SAM as a guiding set of principles for addressing future management options that might emerge in subsequent phases of the research.



*Feedback Loops

1. Has intended operational materialised?
2. Was the outcome actually acceptable?
3. Did the predicted outcomes happen? If not, why?
4. Have the selected options been appropriate?
5. Is monitoring: Adequate? Cost Effective? Feasible?
6. Are the objectives and vision being met?
7. Be prepared for surprises. What is the influence of unforeseen events on vision, objectives, and actions?

Figure 3.1.3: The Strategic Adaptive Management Process (V-Steep=Values-Social, Technological, Economic, Environmental, Political; TPC=Threshold of Potential Concern) Source: modified from Rogers and Luton (2010:2).

3.1.4 Transdisciplinarity

Transdisciplinarity has emerged as an integrative approach that enables scientists and stakeholders to collaboratively deal with complex problems that society faces (Thompson Klein *et al.*, 2001; Hirsh Hadorn *et al*., 2006; Max-Neef, 2005; Adam *et al*., 2006). Research that is conducted by academia develops and advances knowledge but this can have insignificant impact on society because key relationships and collaborations between actors or stakeholders in society are often non-existent or ineffective (Brown *et al*., 2003; Bammer, 2005; Apgar *et al*., 2009).

Pade-Khene *et al*. (2013) add that gaps exist between different disciplines, as well as between researchers, industry, practitioners, government and society. The core of transdisciplinary research is generation and integration of knowledge within and outside academia through the concurrent participation of all relevant disciplinary scientists and stakeholders, to address the gaps that are inevitable characteristics of complex problems (Janh, 2008; Mobjörk, 2010). Transdisciplinarity is driven by three key aspects: "the need for research to be problem driven, a recognition that talking across different knowledge spheres when dealing with complex problems is necessary, and a call for participation of all groups affected" (Apgar *et al*., 2009:4).

Johnson *et al*. (2002) highlight that in a natural resource management context, research is mostly applied in the form of management interventions, and natural scientists are increasingly becoming aware that within a complexity paradigm there should a smaller distinction between management and research. Natural resource management approaches that were traditionally mechanistic, where technological problems were identified by expert scientists and technological solutions were developed, that were generally not effective (Lewis, 1997; Pahl-Wostl, 2002; Pahl-Wostl and Hare, 2004).

Approaches used in natural resource management need to allow the widest possible range of stakeholders involved to come together and holistically produce an understanding of the complexity of social, technological, economic, environmental and political systems that they work within to co-operatively identify problems and build trust as the base for decision making and joint action to resolve the problems (Pahl-Wostl and Hare, 2004; Luks and Siebenhüner, 2007; Rogers and Luton, 2010). Johnson *et al*. (2002) emphasises that this type of stakeholder interaction is essential to any natural resource management approach that acknowledges complexity, and includes approaches that aim to incorporate and serve the needs of ecosystems and the needs of stakeholders who depend on the ecosystems. Pade-Khene *et al*. (2013) mention that in South Africa transdisciplinarity is still developing as an emerging practice and a research approach, and the process of conducting transdisciplinary research is still being devised.

This study is conducted with a transdisciplinary approach, involving various disciplines such as water resource science and social science, facilitating participation between researchers, industry, government and practitioners within water resource management at the catchment level. This approach ensures that: 1) the research informs practice, and 2) that social science conceptual tools and methodological principles can be used to understand how work practices can be better theorized and researched, with the aim of providing a basis for improving those practices.

3.1.5 Cultural Historical CHAT

3.1.5.1 Historical background

Cultural historical Activity Theory (CHAT) was originally developed under the classical German philosophy of Kant and Hegel that emphasised both historical developments of ideas as well as the active and constructive role of humans (Jonassen and Rohrer-Murphy, 1999). Furthermore, the philosophy provided the foundation for more modern philosophy of Marx and Engels and the Soviet cultural-historical psychology of Vygotsky, Leont'ev and Luria on which the CHAT is based (Kuutti, 1996). In more recent years the implications of CHAT in organisational development was promoted by the work of Yrjöv Engeström's team at the Centre for Activity Theory and Developmental Work Research at the University of Helsinki, and Mike Cole at the Laboratory of Comparative Human Cognition at the University of California San Diego.

Engeström (2001:134) described the advance from Vygotsky's first generation of CHAT: "The insertion of cultural artifacts into human actions was revolutionary……The individual could no longer be understood without his or her cultural means; and the society could no longer be understood without the agency of individuals who use and produce 'artifacts'. The core of CHAT is the idea that human capabilities develop when, in collaboration with others, people act upon their immediate surroundings, and it focuses on the interaction of human activity and consciousness within its relevant environmental context (Jonassen and Rohrer-Murphy, 1999).

3.1.5.2 What is CHAT?

Cultural Historical Activity Theory is described 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" (Kuutti, 1995:7). CHAT is not a specific theory of a particular domain with specific techniques and procedures, it is rather a framework from which various methods and theories for analyzing how human activity can be developed (Pollard and du Toit, 2011). Moreover, human activity is taken as the basic unit of analysis when using this framework and activity cannot be understood or analysed outside the context in which it occurs (Jonassen and Rohrer-Murphy, 1999; Mwanza, 2002).

Analysing human activity does not only focus on the kinds of activities that people engage in but also who is engaging in that activity, what their goals and intentions are, what objects or products result from the activity, the rules and norms that determine that activity and the larger community in which the activity occurs (Jonassen and Rohrer-Murphy, 1999). The components of an activity system are described below:

- The subject of any activity is described as the individual or group of actors who engage in the activity and acts upon the object.
- The object of an activity is the physical or mental product that the subject is trying to achieve. The nature of the object will influence the way in which the subject acts upon it. The object can be shared for manipulation and transformation by the subject or participants of the activity to reach a particular outcome (Kutti, 1995).
- The tools (which are also referred to as mediating artifacts) of an activity refer to anything that influences the way people think and act, and they can be physical objects, cultural beliefs or mental models. Tools can alter the activity and can in turn be altered by the activity.

In CHAT history, the interplay of the subject, object and tools towards a common goal was described by Vygotsky as an idea of 'mediation' and it was characterised as the first generation of CHAT (Figure 3.1.5.1)(Engeström,2001). However, this structure was considered to be too simple to achieve the consideration of the systemic relations between an individual or group of actors in their environment (Kuutti, 1995). According to Engeström (2001), this was due to the fact that the subject could no longer be well understood without cultural beliefs, and that society could not be well understood without the knowledge of the agents that use and produce the tools that subjects use. This resulted in a limitation in the first generation of CHAT because the unit of analysis only focused on an individual and this was overcome by the development of second generation CHAT from Leont'ev's (1978) work.

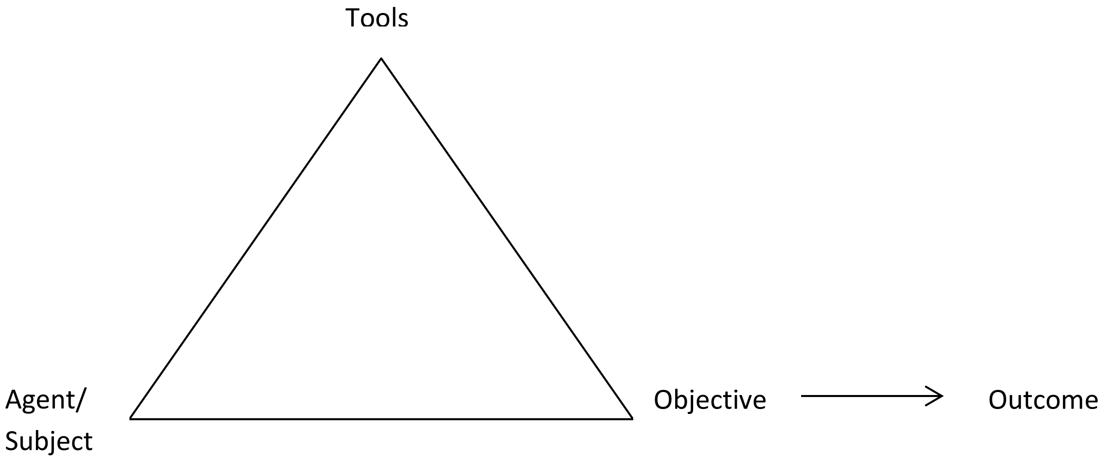


Figure 3.1.5.1: First generation activity system (Modified from: Engeström, 2001)

In the second generation of CHAT, Engeström developed Vygotsky's and Leont'ev's work further, as shown in Figure 3.1.5.2 below. Note that the top triangle is identical to Vygotsky's triangle in Figure 3.1.5.1 above. Engeström however added the bottom triangle to include the rules, community and division of labour, and socio-historical aspects of mediation that were omitted by Vygotsky (Engeström, 1999). Jonassen and Rohrer-Murphy (1999) describe these socio-historical aspects as follows:

- The rules are the explicit or implicit rules of behaviour so that the actions or activities are acceptable by the community.
- The community is the broader social space within which the activity is taking place.
- The division of labour refers to how actions or tasks are divided between different subjects within the activity system.

All the components of an activity system, including the top triangle and the bottom socio-historical components, can result in change not only for the object but for each other. In developing his model, Engeström (1987:78) suggested that:

- The relations between individuals and the object of their activity are mediated by concepts and technologies,
- The relationships between the community and the overall object of its activity are mediated by its division of labour, and
- The relations between individuals and the communities, of which they are a part, are mediated by rules and procedures, which can be explicit or implicit.

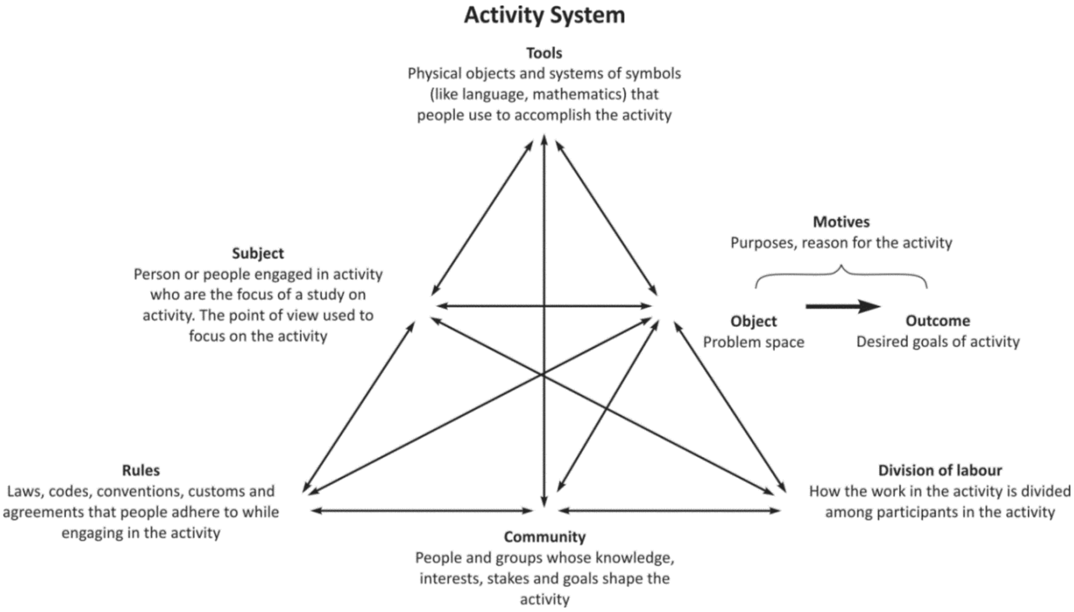


Figure 3.1.5.2: Second generation CHAT (Source: Modified from Engeström, 1987:78).

Engström's model of second generation makes it possible to identify contradictions within activity systems, within and between components of an activity system as the driving force of change and development within that system. Engström (2001:137) describes contradictions as mechanisms of change and emphasises that "*the central role of contradictions as sources of change and development. Contradictions are not the same as problems or conflicts. Contradictions are historically accumulating structural tensions within and between activity systems …Contradictions generate disturbances and conflicts, but also innovate attempts to change the activity*." Identifying contradictions in an activity system assists practitioners and administrators to focus on their efforts to resolve root causes of problems within the system and this is crucial for the establishment of a shared vision for the expansive solution of contradictions (Engeström, 2000).

There are four possible sources or categories of contradictions in CHAT, as identified by Engström (1987) and they are described as follows:

1. Primary contradictions: are contradictions which appear within components of an activity system, such as within the rules;
2. Secondary contradictions: are contradictions which occur when there is tension between components of an activity system, such as between the rules and the object;
3. Tertiary contradictions: happen when an old activity system clashes with a more advanced version of the activity system; and
4. Quaternary contradictions: are those contradictions which occur between activity systems, such as when a tool is used by an organization's object to reduce injuries, and another tool is used to support the same organization's object to sell product.

Engeström went a step further and developed the third generation of CHAT (Engeström, 2001), which exists when there is more than one activity system of the second generation and there is interaction between the activity systems. Third generation CHAT was intended to develop conceptual tools to understand dialogue, multiple perspectives, and networks of interacting activity systems. Figure 3.1.5.3 below shows the minimal model for third generation CHAT. This generation takes collective activity or practice as the unit for analysis, rather than individual activity.

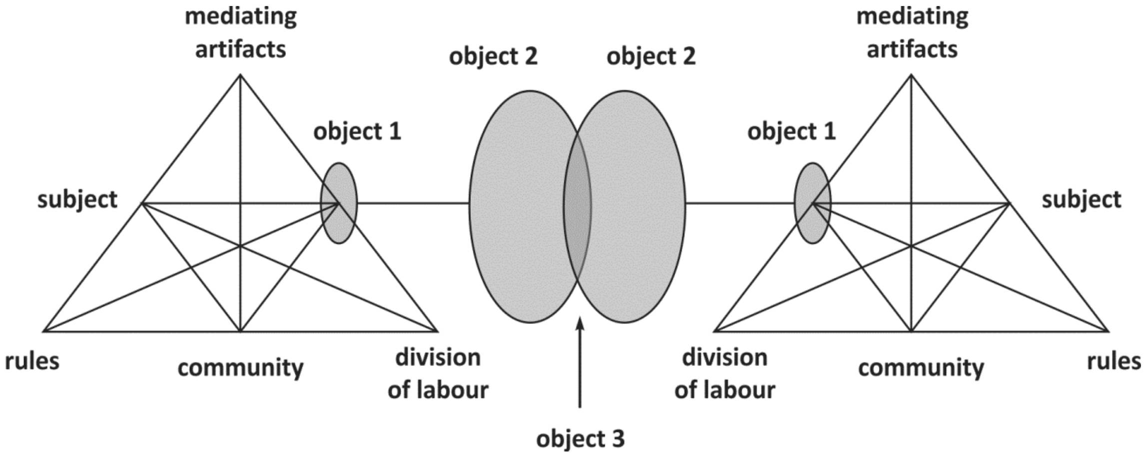


Figure 3.1.5.3: Two interacting activity systems as a minimal model for third generation CHAT (Source: Engeström, 2001:136).

As described above, after a structural analysis of an activity system, a developmental analysis phase is possible involving the search for contradictions and their potential as learning and developmental opportunities (Capper and Williams, 2004). According to Engeström (2001), as the contradictions of an activity system are intensified, some individual participants or objects within the activity system can start to question and deviate from the established rules to resolve the contradictions. In other instances, this may result in collaborative envisaging and a deliberate collective effort to change may be achieved within the activity system. Furthermore, an expansive transformation is possible and is achieved when the object and motive or outcome of an activity system are reconceptualised to adapt to the wider changes, and possibilities are realised in relation to the previous activity system.

This expansive transformation is referred to as expansive learning and it involves how new knowledge or innovation can occur and be nurtured within activity systems (Capper and Williams, 2004). Spinuzzi (2011) emphasises that as CHAT is applied to more complex and interdisciplinary activity systems, the object of the activity system becomes more difficult to describe in cyclical terms and in a more complex collective activity, it is difficult to identify a single object. Furthermore, the subjects or participants of an activity system may have different motives and different perspectives on the shared object.

It is also essential to consider that activities become 'polycontextual, and also involve 'co-configuration' where objects can be expand both temporally and spatially (Engeström, *et al.*, 1995:331; Engeström *et al.*, 2003:154). Activities can also be 'polymotivated' where stakeholders act on the object to achieve various and sometimes contradicting motives (Kaptelinin, 2005; Nardi, 2005). The complications mentioned above have made it difficult to understand activity as 'unitary' and has in turn led to the concept of activity networks in which multiple activities overlap the same spaces, tools, and actors, and may often lead to contradicting objectives (Miettinen, 1999).

The cycle of expansive learning is a central concept to CHAT and it describes that learning can be expansive because the consequences of action may lead to further contradictions within the system; for example, if a new tool is imposed on old rules, or even beyond the boundary of the existing system, such as between activity systems and thus expands the possible boundary of learning beyond the initial focus of the inquiry (Capper and Williams, 2004). This study will however not explore expansive learning.

In relation to water resource management, CHAT provides IWRM with an analytical tool to help achieve the following (AWARD, in press):

a) Understanding how activity systems are currently functioning by analyzing the different components of an activity system highlighting where contradictions and gaps lie.
b) A clear understanding of an activity as it is situated in a cultural-historical context.
c) Develop and simulate 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.
d) 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 towards reaching the collectively agreed outcome of the activity.

This study used CHAT to analyse the management practices of the sugar industry (sugar mill and agricultural practices of the sugarcane fields) in relation to water quality management so as to establish the means by which those practices occurred and also how they are supported. The study interpreted the various components of the sugar mill activity system, the activity system of the agricultural division of the sugar industry divided into two activity systems for emerging sugarcane farmers and an activity system for commercial sugarcane farmers. This interpretation was necessary to obtain a basic understanding about work practices in the sugar industry. CHAT was also used to identify the disturbances or contradictions within the sugar industry in relation to the development of an integrated water quality management process for the Crocodile River Catchment.

3.1.6 Social Learning

There are a number of theories that describe a variety of learning processes (Muro and Jeffrey, 2008). Saljö (1979) described learning as a multidimensional phenomenon that includes the following:

- Acquiring information and increasing knowledge;
- Memorising;
- Acquiring facts, skills and methods;
- Making sense or abstracting meaning; and
- Interpreting and understanding reality in a different way by reinterpreting knowledge.

According to Muro and Jeffrey (2008), social learning theory adopts a more dynamic view to learning that emphasises the interaction between individuals and their environment and it has its roots in different learning theories and social science disciplines. Pollard and du Toit (2011a) add that the concept of social learning is developed under the possibility of confronting diverging norms, values, interests and constructions of reality that move towards sustainable living. Wals (2007) states that the main processes of social learning involve deconstructing the differences in order to understand and analyse the underlying roots of divergence to achieve collaborative change.

In the context of natural resource management, social learning is conceptualised as “a process of social change in which people learn from each in ways that can benefit wider social-ecological systems” (Reed *et al.*, 2010:2). Additionally, the learning that occurs as a result of these social interactions is often defined in relation to the wider additional outcomes that may develop such as improved management of social-ecological systems, enhanced trust between participants, stakeholder empowerment, as well as strengthening of social networks, just to mention a few. Reed *et al.* (2010) emphasise that social learning has been defined in multiple ways that may overlap and it has been confused with the methods required to facilitate social learning. However, for learning to be considered social learning, it should demonstrate improvement in individual understanding as well as consider wider social units and communities.

The aim of social learning is to provide a platform that encourages, promotes and develops social relationships and mutual respect so that a group can become more open to alternative ideas and a space that allows more resilience and responsiveness to internal and external challenges (Pollard and du Toit, 2011). Proost and Leeuwis (2007) give a list of preconditions for social learning as follows:

- Sense of urgency;
- Feelings of interdependence amongst stakeholders (arising from a commonly held interest or goal);
- Stakeholders organise themselves for negotiation: meetings and other opportunities for interaction;
- A degree of confidence that a negotiated outcome satisfactory to all parties will be reached;
- A degree of institutional space to implement outcomes;
- Accepted leadership of the process;
- Process facilitation;
- Reflection built in from the start.

The multi-dimensional nature of social-ecological systems has stimulated many researchers and practitioners to move towards the use of social learning frameworks to promote required behavioural change within the complex context of sustainable natural resource management (Muro and Jeffrey, 2008). Jackson (2004:2) expressed that “the realisation that people’s choices, behaviours and lifestyles will play a vital role in achieving sustainable development is one of the (relatively few) points of agreement to have emerged from international environmental policy debates over the last decade or so”.

Folke *et al.* (2003:356) adds that social learning is important for developing the experience that is needed to cope with uncertainty and change within social-ecological systems. They emphasise that “learning how to sustain social-ecological systems in a world of continuous change needs an institutional and social context within which to develop and act”.

von Korff *et al.* (2012) concur that numerous current water management and planning problems have high levels of complexity, uncertainty and conflict. These problems are increasingly apparent as water resources become scarce, conflicts between water users increase and the ecological and social aspects of water management become more prominent.

It became apparent that a particular group of experts or stakeholders can no longer learn and make decisions on behalf of all other stakeholders, and that social learning is needed (Pahl-Wostl, 2007). Furthermore, actors cannot be pressured to learn but they can be encouraged to learn by creating a learning platform (Rist *et al.*, 2007). Researchers and practitioners have also increasingly expressed the need to modify approaches or frameworks for natural resource management and establish effective participatory learning environments and platforms, where individuals can meet, interact, learn collaboratively and take collective decisions.

Researchers are also interested in understanding what happens when information is exchanged between actors in participatory processes in terms of their understanding of natural and social systems. This involves understanding cognitive learning, the quality of their relationships, their skills, as well as their constructive participation in debates or negotiations and their willingness and ability to reach points of agreement (von Korff *et al.*, 2012).

According to Wenger (1998) we all belong to ‘communities of practice’, at home, at work or in our hobbies, were individuals learn through engaging in the practices of their communities, providing communities with new members and refined practices. Muro and Jeffrey (2008) add that by engaging with each other, different perspectives are likely to adapt to each other, forming shared or complementary perspectives. Jacobson (1996) further claims that in order to learn, one has to become embedded in the culture in which the learning and the development of knowledge has a meaning; thus knowledge develops as a result of interaction among individuals and the context in which it takes place.

Keen *et al.* (2005:7) emphasise that social learning, particularly in participatory natural resources management, not only draws from theories of communicative and transformative learning, but it also employs other concepts and the following quote illustrates this:

“We take an explicitly transdisciplinary approach by drawing out lessons from adaptive and participatory approaches to environmental management that are relevant to social learning. These insights are complemented with other useful concepts including those from systems analysis and organisational learning theory. They speak of five braided strands of social learning that appear to be crucial to environmental management; they include: reflection, systems orientation, integration, negotiation and participation”.

Social learning theory has indeed guided this study as a collective process. In an experience of social learning, a group of people (or social learning platform) was developed. In this case the group comprised water users in the Crocodile River Catchment, who share an interest in improving the management of the Crocodile River water resource and particularly in the quality of instream water, and who take common action in pursuit of that shared interest. Therefore, in this study social learning is not only seen as a prerequisite for individual behavioural change but also for collective action which is described below.

3.1.7 Collective Action

In an attempt to deal with water management concerns, a form of management has been developed in South Africa to closely link biophysical processes related to water resource use and social processes that relate to the people that use the resources. The country is divided into water management areas, and each will have a Catchment Management Agency (CMA), with the aim of enhancing productivity, management practices and to decentralise management functions (DWAF, 2004b). According to du Toit *et al.* (2013), the management of natural resources has been seen as an activity separate from the activities of people that use the resources. This has been replaced with an approach that realises that the activities of people have a direct impact on the health of the resource, whether positively or negatively. Additionally, the increased stress on natural resources highlights the need for natural resource management decisions to be made collectively to ensure sustainable solutions. Agreements are needed between different groups, on what needs to be done to improve the health of natural resources, by whom this is needed, and who is responsible.

However, one common problem encountered when developing a new framework or new ways of managing natural resources, particularly water resources, is the lack of long term commitment in collaborative management processes and this often leads to fragmented action (Pollard and du Toit, 2011). Collective action has been explored as means of improving and formalising integration in water resources management in South Africa and understanding this approach and what is needed to sustain, improve or restore natural resources is crucial to restoring the health of natural resources (du Toit *et al*., 2013). This research is based in a stakeholder engagement setting that embraces collective action as a form of integrating water resources management in the Crocodile River Catchment.

Abundant literature on collective action exists and there are diverse definitions of collective action which focus on what the action of collective action is and what components are needed for an action to be collective (du Toit *et al*., 2013). Ostrom (2004:4) defines collective action as "when more than one individual is required to contribute to an effort in order to achieve an outcome and that a certain level of self-organisation is necessary in order for an action to be executed".

Another form of collective action that has been described involves collective regulation of individual actions (Scott and Silva-Ochoa, 2001; Meinzen-Dick *et al*., 2002; Pender and Scherr, 2002; Gebremedhin *et al.*, 2002). This dimension of collective action does not only refer to the direct actions by groups of stakeholders pursuing common goals, but also collectively agreed upon rules that will govern individual behaviour such as what not to do or responsibilities individual can take on that will contribute to a common goal (German *et al.*, 2012). Furthermore, such collective rules are generally formulated to decrease the negative impacts of an individuals' behaviour on another person or on environmental service of public concern or to strengthen commitments made by individuals to group activities.

In this study, the focus of collective action is towards achieving integrated water resources management by a group of catchment managers and stakeholders selected and self-selected via previous engagement, an invitation and willingness to participate. The focus is on stakeholder practices in the Crocodile River Catchment and how their practices influence activities that comprise improved water resources management processes. Emphasis within this context is that individual stakeholders (mostly representing specific industries or agencies) will perform different roles in order to participate in the development of an integrated, water quality management process for the Crocodile River Catchment, to promote the improvement of instream water quality in the Crocodile River.

The conceptual framework outlined the key concepts and theories that are drawn from for this study and importantly describes some of the challenges inherent to water governance and IWRM approaches. In order to address the integrated nature of the issues addressed in this study without conducting research that is so broad that it is of neither academically useful or practical, the conceptual framework has been stipulated has established key links between the concepts described such as the key link between a system, systems thinking and complexity thinking. By doing so, this conceptual framework supports the use of multiple methods in an integrated manner. This integration of methods is described within the methodology chapter that follows.

CHAPTER 4

4.1 Methodology

4.1.1 Introduction

Research requires the application of particular practices, procedures and rules to investigate any field of study and these are often described as methods or a methodology. According to Ison (2008), numerous authors, researchers and practitioners have argued the importance of using the term methodology instead of methods when investigating systems because methods are often seen as set procedures to follow step by step, while a methodology can be adapted by a particular user in a participatory situation. In addition there is often a risk of treating methodologies as concrete entities rather than as practise that forms from what is done in a given situation. Ison (2008:155) describe a methodology as the conscious combination of theory and practice in a given context. It is important to realise that a methodology is not just a collection of methods, rather a philosophy that supports and provides the motivation for the use of specific methods. This section of the chapter will describe the methods used in this study and explanation of how these methods interact and interrelate (Figure 4.1.1).

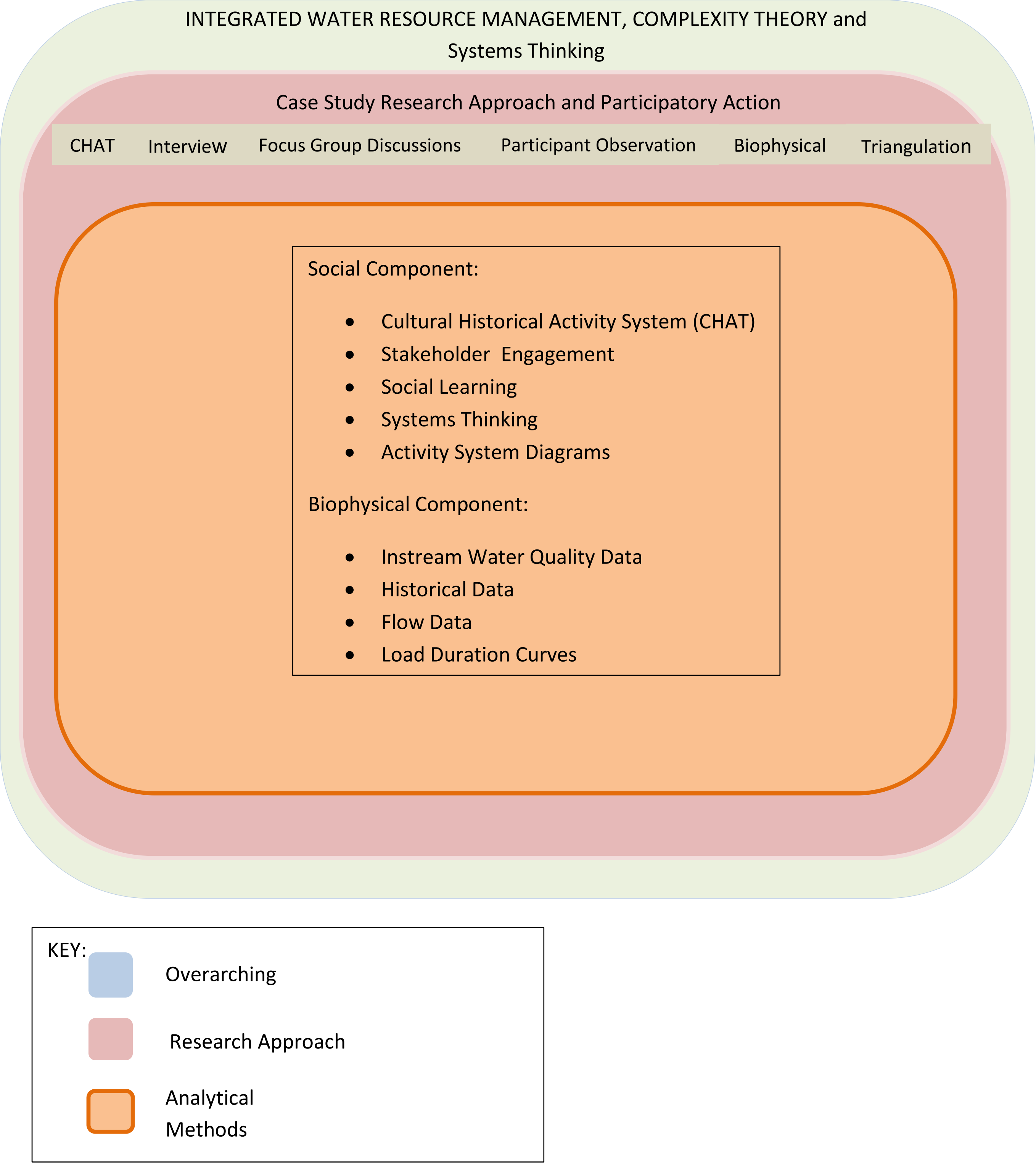


Figure 4.1.1: Methodological Framework

4.1.2 Participatory Action Research

There is currently widespread acknowledgment that water resource management and planning should not only focus on the outcomes but should also be seen as a continually improving process (Bar and Cary, 2000; Stoeckl and Abrahams, 2007). This acknowledgement is evident in the application of theories such as adaptive management and social learning in water resource management, which are described in the conceptual framing section of this chapter (Sections 3.1.3, 3.1.6 and 3.1.7). Adaptive management and social leaning are well aligned with the characteristics of Participatory Action Research which is a methodology used in this study (Hoverman and Ayre, 2012).

Participatory Action Research is described as a research approach were stakeholders take an active co-research and co-learning role, and enter into a collaborative partnership with researchers to facilitate improved practice through direct application of research findings in a practical context (Carr and Kemmis, 1986; Ison, 2008). Furthermore, in this research approach, stakeholders and researchers work together to co-create knowledge through ongoing communication and the findings of the collaboration are jointly implemented and this can be referred to as “learning by doing” (Greenwood and Levin, 1998; Lee, 1999).

According to Kemmis and McTaggart (2005), the research design of action research includes three recurring stages, namely: inquiry, action and reflection. Greenwood and Levin (2003) add that through these stages knowledge and understanding of the participants is improved and it leads to social action and reflections on the actions leads to new understanding, it also opens new areas to be studied.

In the past, conventional management situations involved managers deciding what has to be done while others were expected to do what is instructed; however, action research involves both the managers and the people who are expected to apply the decisions (Dick, 2000). According to Pollard and du Toit (2011a), action research allows the inclusion of wider views, information and experiences through collaboration, as well as recognising the uncertainty and unpredictability of complex systems by providing a flexible and responsive way of addressing problems. Furthermore, the participants in action research contribute to the research by asking questions, interacting, engaging, reviewing and critically reflecting on the objectives of the research, and this means that the research process is highly inclusive.

Participatory Action Research is the main methodological framework applied in this study during the data collection component of the study. The interaction of stakeholders in this study was planned according to the principles of action research that are described above and stakeholders were encouraged through dialogue to confront issues, frame questions and raise issues of concern relating to the development of integrated, participative water quality management process for the Crocodile River Catchment.

4.1.3 Case Study Research Approach

Research that aims to address problems that are context specific or research that is grounded in solving real problem situations often uses the case study research method (Yin, 2009). Flyvberg (2006) also adds that the advantage of using case study research methodology is that it can test views directly in relation to phenomenon as they unfold in practice.

This study was conducted using this research approach where data was collected in a real-life context within the Crocodile River Catchment. Data collection was undertaken through conducting fieldwork in the Crocodile River Catchment as well as specifically within the sugar industry in the catchment between April 2013 and August 2014. The stakeholders participating in this study included a Grower Affairs manager, operations engineer, environmental manager and risk control manager at the mill; commercial sugarcane farmers; emerging sugarcane farmers from two sugarcane farming Co-operatives (Siyathuthuka sugarcane farmers project, Lomshiwo Trust sugarcane farmers) and individual farmers; environmental and managers and officials of the Inkomati Catchment Management Agency.

This study consists of two components, namely:

I. Social Component: This component included analysis of the management practices of the sugar mill as well as examining agricultural practices in the sugar cane fields in relation to water quality management through the use of CHAT described in Section 3.1.5. This component also includes documenting the disturbances or contradictions (Contradictions are historically accumulating structural tensions within and between activity systems and identifying these tension points aids in the establishment of learning opportunities, see detailed explanation in Chapter 3, Section 3.1.5) within the sugar industry in relation to the development of an integrated water quality management process for the Crocodile River Catchment. This will aid the identification of areas within the sugar industry activity systems that need attention.

II. Biophysical Component: This component included the using biophysical data to inform the participation of the sugar industry in the development of the Integrated Water Quality Management Process. Data included: instream water quality data, historical monitoring data (including observed values for the identified parameters of concern available from the website: http://www.dwaf.gov.za/iwqs/report.aspx. Data from TSB's LIMS (Laboratory Information Management System) program was also obtained to assess the water quality needs and impact of sugar processing at the mill on the river water quality. Data analysis was completed in another project on the development of a simple water quality and quantity integration model (WQSAM) (Retief, 2014; Slaughter, 2011). The resultant programme output was applied in this project to the sugar industry and the IWQMP.

Both quantitative and qualitative types of data were collected from and in participation with the stakeholders. Different sources of data with associated data collection techniques were used; qualitative data were collected using participant observation, structured and semi-structured interviews, and focus group discussions. These techniques are described in Section 4.1.4 below.

4.1.4 Participant Observation

Observation is described as a systemic process of recording behavioural patterns of people, objects and occurrences as they occur (Taylor-Powell and Steele, 1996). Observation is useful for gathering detailed descriptions of organisations or events, as well as for obtaining information that would otherwise be inaccessible or would require people's willingness to respond to questions (Kawulich, 2005). Taylor-Powell and Steele (1996:1) adds that observation should be used to gather information when:

- *The observer is trying to understand an ongoing process or situation*: Through observation, the observer can watch or monitor a process or situation that the observer is evaluating as it occurs;

- *The observer is gathering data on individual behaviours or interactions between people*: Observation allows the observer to watch people's behaviours and interactions directly, or watch for the results of behaviours or interactions;
- *The observer needs to know about the physical setting*: Seeing the place or the environment where something takes place can help increase the observer's understanding of the event, activity, or situation that is being evaluated;
- *Data from individuals is not realistic*: If respondents are not willing or not able to provide data through questionnaires or interviews, observation is a method that requires little from the individuals from whom the data is needed.

Observation can be overt (people know that they are being observed) or covert (people do not know that they are being observed), and it can be direct (when the observer watches interactions, processes, or behaviours as they occur) or indirect (when the observer watches the results of interactions, processes or behaviours) (Taylor-Powell and Steele, 1996). In the duration of this study, the researcher was based at the Inkomati Catchment Management Agency premises as part of a project partner agreement and in kind contribution of the agency towards the project. The project team of the larger project was embedded in and accepted by in the IUCMA as part of their water quality team functions, so the project was part of the agency which functions as the water management regulator. This enabled the researcher to successfully conduct the study in a participant observatory setting.

The researcher used participant observation through extended detailed fieldwork undertaken in the Crocodile River Catchment between April 2013 and August 2014. During this time the researcher attended stakeholder engagement meetings, team planning meetings and workshops. The interaction between the researcher and the stakeholders meant that the researcher was continuously involved as a participant in the project and has the understanding of the bigger picture in terms of the development of the IWQMP.

The researcher of this study documented the observations in the form of field notes in a journal (that will be archived as record of data collection) and this data was also complimented by record keeping of the stakeholder meeting minutes. The researcher also participated in taking minutes of the stakeholder meeting and ensuring that the information recorded in the minutes is validated by the participants of the stakeholder minutes for any errors. The validating of minutes and journal field notes aided in the triangulation of observations made by the research as a participant.

According to Mack *et al*. (2005), participant observation is described as an observation method where the researcher participates in the research problem while also being an observer. Furthermore, participation observation is useful for achieving adequate understanding of the physical, social, cultural and economic context in which participants live. It also aids the understanding of relationships between and among the participants, contexts, ideas, norms and events, as well as what the participants do. Guest *et al.* (2013) adds that participant observation involves the researcher being embedded in the action and context of the interaction being observed. Participant observation is used for the following reasons (Bernard, 2006):

- To open up areas of inquiry to collect wider range of data;
- Reducing the problem of reactivity;
- Enabling researchers to know what questions to ask during more detailed interviews;
- Gaining intuitive understanding of the meaning of data;
- Addressing problems that are simply unavailable through other data collection techniques.

Since participant observation provides the ability for providing explanation, context, causality and confirmation, it is often useful in a mixed method study such as the present study (Guest *et al.*, 2013).

4.1.5 Interviews

Interviews are described as a data collection technique designed to draw the participant's perspective on the research topic and the researcher engages with the participant by neutrally posing questions, listening attentively to the participant's responses and asking follow up questions based on the responses (Mack *et al*., 2005). Additionally, these interviews are usually conducted face-to-face but sometimes may be conducted through telephone and they are useful for understanding individual perspective rather than group norms.

Multiple interviews were conducted on various occasions between April 2013 and August 2014 with officials from the sugar mill as well as emerging and commercial sugarcane farmers in the sugar industry. The participants of the sugar industry were divided into two groups according to aspects of the industry (Figure 4.1.5): The sugar manufacturing aspect (that comprises of the sugar mill); and the agricultural aspect (that comprises of the Grower Affairs division and the sugarcane farmers) (divided into emerging and commercial farmers) that produces the sugarcane. The first phase of data collection involved semi-structured interviews using CHAT (explained above) (questions discussed are provided in Appendix A). In this phase, participants from the Risk Control Department of the sugar mill (Operations Engineer, Environmental Manager and Risk Control Manager) were interviewed as well as the Grower Affairs Manager from the agricultural division. The second phase of data collection involved focus group discussions (discussed in detail below) with the emerging and commercial sugarcane farmers to gain in-depth understanding of sugarcane agricultural practices. The focus group discussion questions are provided in Appendix B.

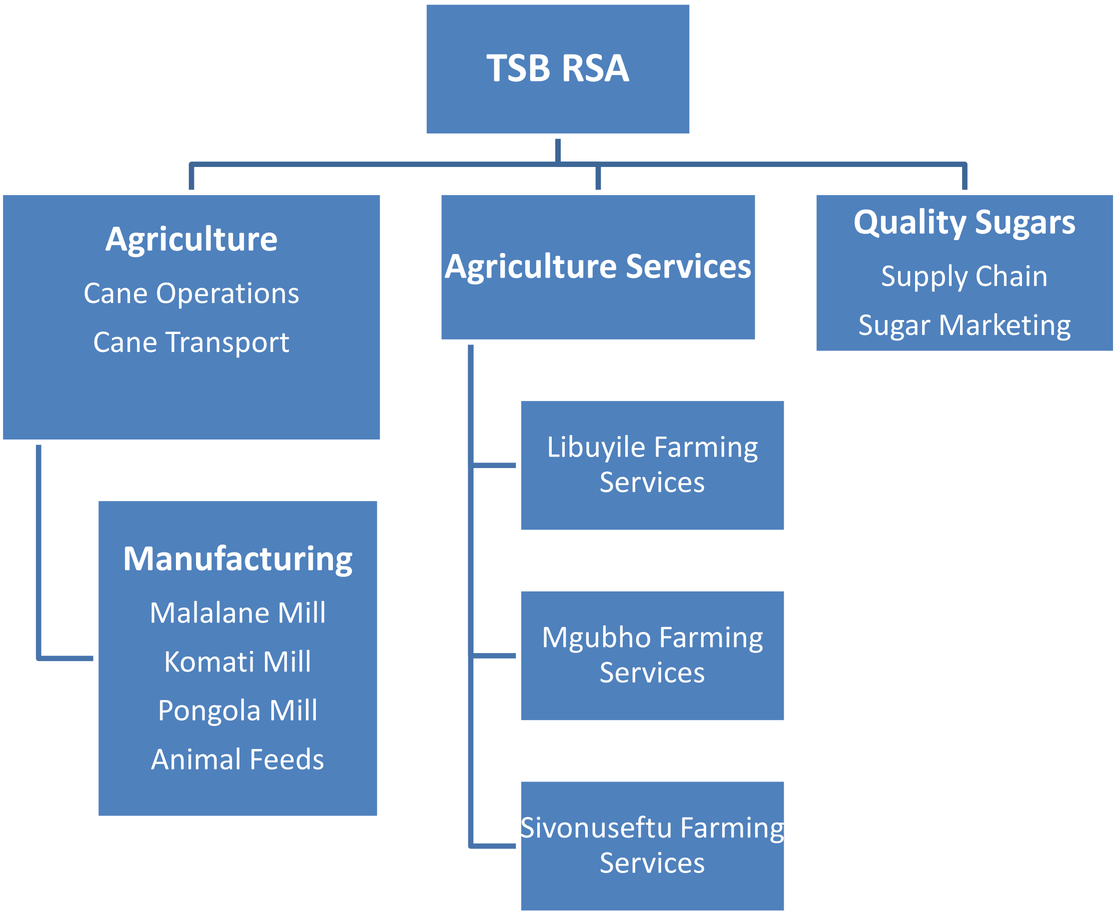


Figure 4.1.5: TSB Sugar Departmental Structure (Source: Modified from http://www.tsb.co.za/company-profile.cfm#.VGjGSPmUf9c)

4.1.6 Focus Group Discussions

A focus group discussion is a data collection method were one or two researchers and several participants meet as a group to discuss a given research topic (Mack *et al.*, 2005). The discussion is often led by one researcher by asking the participants to respond to open-ended questions to yield large amount of information over a short period of time. BMJ (1995) add that focus group discussions are useful for exploring people's knowledge and experiences and this method is often used not only to explore what people think but also explore how they think and why they think that way.

Moreover, focus group discussions are appropriate to use when the researcher has a series of open-ended questions that he or she wishes the research participants to explore in terms of issues of importance to them in their own vocabulary, allowing them to ask questions and engage their own priorities. Mack *et al.* (2005) emphasise that the richness of focus group data will emerge from the group dynamic and the diversity of the group because participants often influence each other through their presence and the way they react to what other participants say.

Advantages of using focus group discussions as a data collection method include the following (BMJ, 1995:2):

- Does not discriminate against people who cannot read or write;
- Can encourage participation from those who are reluctant to be interviewed on their own (such as those intimidated by the formality and isolation of one-on-one interviews);
- Can encourage contributions from people who feel they have nothing to say or who are deemed as unresponsive participants.

In this study, emerging sugarcane farmers from two sugarcane farming Co-operatives in the Crocodile River Catchment (Siyathuthuka sugarcane farmer's project and Lomshiwo Trust sugarcane farmer's project) including individual sugarcane farmers were invited to focus group discussions.

4.1.7 Triangulation

Triangulation refers to "the combination of two or more theories, data sources, methods in one study of a single phenomenon to converge on a single construct and can be employed in both quantitative (validation) and qualitative (inquiry) studies (Yeasmin and Rahman, 2012:156). It also aids in capturing more holistic and contextual interpretation of the research topic, as well as helping to provide confirmation which increases credibility and validity of results of a study (Shih, 1998; Yeasmin and Rahman, 2012). Triangulation has been used in this study to reduce the impact of bias as well as to provide richer and more comprehensive information to address the research questions. In the social component of this study, triangulation of the first phase semi-structured interviews was done through in-depth focus group discussions with the emerging sugar cane farmers, so that the information collected from the Grower Affairs Division was validated. Focused interviews were also conducted with commercial sugar cane farmers to ensure that the information collected during the first phase interviews was validated and represented what was actually happening on the ground.

CHAPTER 5

Sugar Industry Water Quality management analysis

5.1 Introduction

Chapter 3, section 3.1.5 presented the methodology used to generate data that will be used in this chapter to analyse the management practices of the sugar industry in the Crocodile River Catchment (sugar mill and agricultural practices of the sugarcane fields) in relation to water quality management so as to establish the means by which those practices occur and also how they are supported. This chapter will present the data aimed at answering three sub questions that address objectives two and three of this study (Chapter 1, section 1.7.2):

a) ***What are the management practices of the sugar industry in the Crocodile River Catchment (sugar mill and agricultural practices of the sugarcane fields) in relation to water quality management?***
b) ***What are the contradictions (see Chapter 3, Section 3.1.5 for explanation of using this term) within the sugar industry in relation to the development of an IWQMP for the Crocodile River Catchment?***
c) ***What are the contradictions between the sugar industry activity system and the activity system of Inkomati-Usuthu Catchment Management Agency activity system in relation to the development of an IWQMP for the Crocodile River Catchments?***

This chapter begins by providing a brief description of a typical sugar industry activity system followed by a description of water management practices of each activity system. In the context of this study, management practices refer to the actions that contribute to the activity described in each activity system. The sugar industry can be divided into two parts, namely: the sugar manufacturing part that comprises of the sugar mill and the agricultural part that comprises of the Grower Affairs division and the sugarcane farmers (divided into emerging and commercial farmers) who produce the sugarcane. Thus the sugar industry activity system is divided into smaller activity systems for each of the parts for ease of analysis. This chapter will give a description of the components of each activity system in terms of water management practices in the sugar industry.

The data gathered about water management practices in each of the sugar industry parts studied is presented below. These activity systems are constructed from semi-structured interviews, observations as well as data from documents reviewed. The activity systems have been documented using a second generation activity system framework as described by Engeström (2001), described in Chapter 3, Section 3.1.5.

5.2 Description of a general sugar industry activity system

This section presents results that respond to sub research question a) of this study. The sugar industry has been documented as an activity system using the second generation activity system framework as described by Engeström (2001). Here a typical sugar mill activity system consists of *Subjects*, *Objective*, *Tools*, *Rules*, *Community of practice*, *Division of labour* and *Outcome* (see Figure 5.2a below).

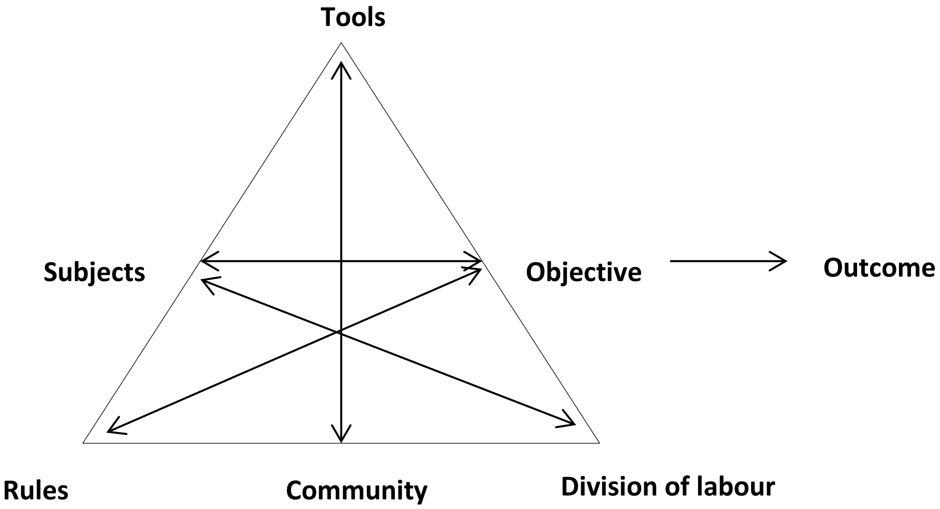


Figure 5.2a: Typical sugar industry activity system (Source: modified from Engeström, 1987:78)

The **subjects** of this activity system are the employees and managers of the sugar mill and the sugarcane farmers (commercial and emerging farmers) that act either as individuals or a collective involved in the management of the sugar manufacturing process as well as in sugarcane production. The subjects have an **objective** or purpose to achieve as they are involved in the sugar manufacturing process and one such objective as reducing water abstracted from the Crocodile River for sugar manufacturing or ensuring sustainable sugarcane production. Where the subjects participate in catchment management structures such as forums, regional steering committees water research projects or irrigation board meetings, there will be an **outcome** such as contributing to the development of an IWQMP for the Crocodile River Catchment.

In order for the subjects to learn water management practices and achieve their objective and outcome there are mediating **tools** that they will use. These tools include conceptual or methodological processes such as the knowledge they have through qualifications, the experience of fellow colleagues in the sugar manufacturing industry, legislation, standard and manuals they apply. The tools also include physical tools and equipment or materials such as cooling tower systems, steam boilers, laboratory information monitoring system, irrigation systems, soil moisture devices and flow meters. The subjects operate within a society with existing collective or individual **rules** which govern their practices. Such rules may be formal such as guidelines or standards stipulated by the National Occupational Safety Association (NOSA) or the Crocodile River Operating rules, government legislation which inform license or permit conditions that the industry practices under. Some rules are informal such as norms or values within the sugar industry.

Subjects also interact within a **community** which can be either as a collective or on individual basis with colleagues with an interest in the objective of the activity system. Members of the community of practice of the sugar industry activity system include the South African Sugar Association, South African Sugar Research Institute and other stakeholders who are interested in addressing any issues within the sugar industry and ensuring sustainable sugar production, as well as other individuals or collectives such as the local and export markets that buy or use the sugar. The sugar industry involves a number of activities and roles which may be arranged in a hierarchy of positions as individuals or collectives through the **division of labour**.

Described above is a typical sugar industry activity system with its components. This descriptive or narrative language will be used consistently through this chapter in order to explicate the findings of this study. The sections below present the activity systems that make up the sugar industry activity system using the second generation activity theory. As described in Section 3.1.5, activity systems often interact with neighbouring activity systems within the third generation activity theory framework. Jonassen and Rohrer-Murphy (1999) explain that individuals who are involved in a particular activity are instantaneously members of other activity systems which often have different objectives, tools and social associations. Furthermore, each component of an activity system is often the result of other activities which produced it and this often results in tool-producing, subject-producing, rule-producing, community-producing, division of labour-producing activity systems (Figure 5.2b).

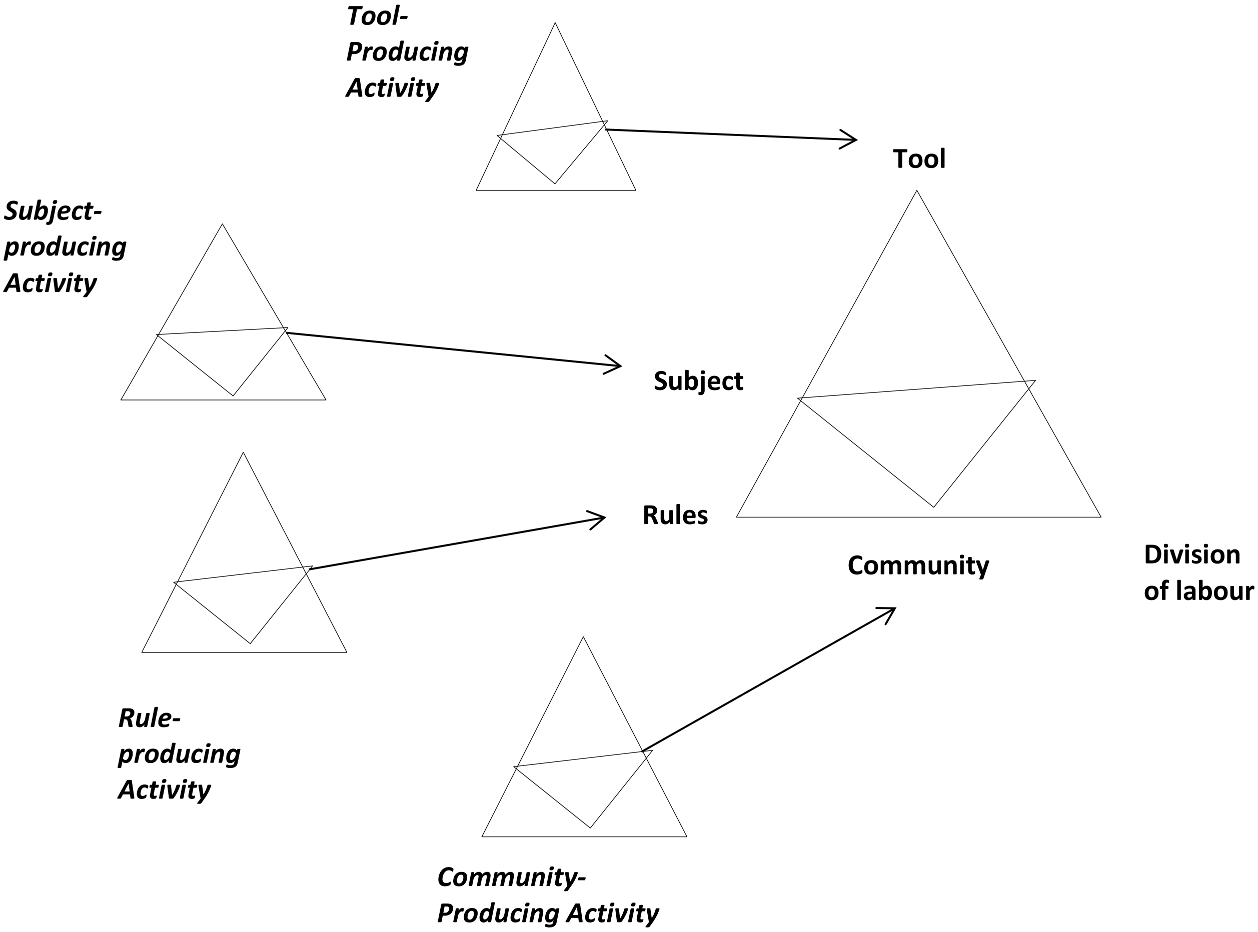


Figure 5.2b: Nested nature of activity theory dynamics (Source: Jonassen and Rohrer-Murphy, 1999:67).

The Inkomati Catchment Management Agency, is now known as the Inkomati-Usuthu Catchment Management Agency (IUCMA) with the amalgamation of the Inkomati WMA with the Usuthu WMA since the establishment of 9 WMA's instead of the previous 19 WMA's (DWA, 2013; ICMA, 2014). The IUCMA can be described as a rule-producing activity system since the institution serves a regulatory role in the Inkomati WMA. The institution has a mandate given under the NWA to ensure the protection of the water resource in the catchment and therefore it provides the rules within which the sugar industry needs to operate. Due to this, the IUCMA is also described as an activity system in section 5.2.5 to aid the understanding of how the institution conducts water management in the Inkomati WMA and how it influences the sugar industry activity system.

After the structural analysis sections (Sections 5.2.1- 5.2.5) of describing the activity systems, a developmental analysis phase will be presented that involves the search for contradictions and their potential as learning and developmental opportunities in Sections 5.3 and 5.4. This will be presented on two levels, were the first level is surfacing primary and secondary contradictions (defined in section 3.1.5) within the individual sugar industry and the IUCMA activity systems in relation to the development of an IWQMP for the Crocodile River Catchment; and the second level where the third generation analysis is presented that surfaces contradictions between the sugar industry activity system and IUCMA activity system in relation to the development of an IWQMP for the Crocodile River Catchment.

5.2.1 Sugar mill activity system

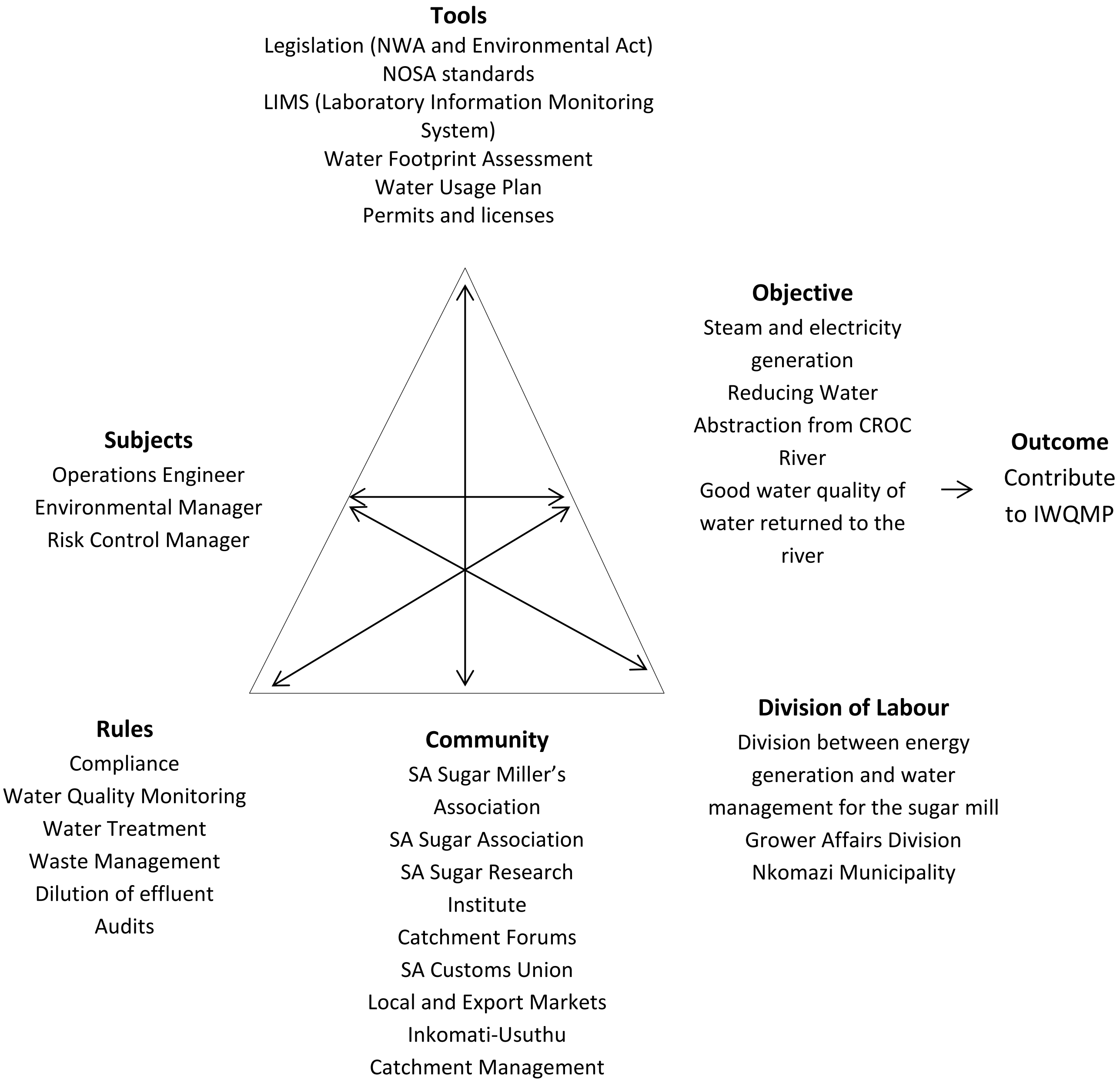


Figure 5.2.1: Sugar Mill Activity System (Source: modified from Engeström, 1987:78).

In the sugar mill activity system (Figure 5.2.1), the **subjects** are three employees of the sugar mill:

- the *operations engineer* who is responsible for steam generation, electricity generation and extracting water from the Crocodile River for the sugar mill operations
- the *environmental manager* in the risk management division for the mill responsible for assisting the sugar mill with sustainable production, monitoring compliance with water use license, permits and associated conditions and being involved in catchment management structures such as the Crocodile River forum, other sub catchment forums, regional steering committees, water research projects and socio-economic task team for the river classification project
- the *risk control manager* who does audits to make sure that the sugar mill complies with its water usage plan.

The **objective** of this activity system is to ensure that adequate steam and electricity is generated for sugar manufacturing processes, water is extracted from the Crocodile river and supplied to the sugar mill and used to produce drinking water, reduction in the amount of water extracted from the Crocodile River, ensuring that good quality water is returned to Crocodile River after use and sustainable sugar production is achieved.

The **tools** in this activity system include the legislation from the National Water Act No. 36 of 1998 and the National Environmental Act which guides the NOSA procedures or standards that the sugar mill has to comply with, as well as provides the permits or licenses. Another tool that is used in this activity system is the Laboratory Information Monitoring System (LIMS) used for real time monitoring of source water from the Crocodile River that measures conductivity, pH, turbidity, suspended solid concentrations and temperature. This system was introduced in the late 1980s. The sugar mill has also developed a water usage plan and water footprint assessment plan. Groundwater monitoring to monitor any impact from the landfill site at the sugar mill is also conducted; however impact from any leaching of chemicals from fertilizers or herbicides is not monitored.

The **rules** of the sugar mill activity system include compliance with the water use licences and permits, water quality monitoring and water treatment to ensure that the water used in the sugar manufacturing processes is of required quality, and waste management such as diluting the effluent that is produced in the sugar manufacturing process to reduce its impact and conducting risk control audits.

The **community** within which this activity system is taking place is broad and ranges from national to catchment level stakeholders. The South African Sugar Association guides the development of the sugar industry in the country. There is a great deal of interaction between the South African Sugar Miller's Association, South African Grower's Association, South African Customs Union, and local and export markets that determine the trading price of sugarcane and the South African Sugar Research Institute. The employees of the sugar mill and sugarcane farmers contribute to these associations in terms of fees and membership and the research that is conducted by the research institute is regularly fed back to the members of the sugar industry. Another institution that forms part of the community component of this activity system is the Inkomati-Usuthu Catchment Management Agency as the regulating water management body at regional level. This institution is responsible for making sure that the sugar mill complies with water use license and permit regulations in terms of water use. At the individual level, the sugar mill employees participate in catchment management structures such as catchment forums, regional steering committees, task teams for water research projects as well as projects undertaken by the Department of Water and Sanitation.

In terms of **division of labour** within this activity system, the employees of the sugar mill have specific roles according to the divisions they operate within at the sugar mill. The operation engineer at the power plant of the sugar mill shares responsibilities with the mechanical engineer and these tasks relate to power generation and water management. The risk control manager also delegates tasks to the environmental manager at the sugar mill to ensure that all processes comply with license and permit conditions. The sugar mill also shares the responsibility of a waste water treatment plant (Mhlati Kop) with Nkomazi Municipality.

The outcome of this activity system is ensuring that the sugar mill has sufficient steam and electricity for sugar manufacturing processes, to use water of the right quality and sufficient quantity and subsequently ensuring sustainable sugar production by working towards reducing the amount of water abstracted from the Crocodile River and that good quality water is returned to the river, thus contributing to the development of an IWQMP for the Crocodile River Catchment.

5.2.2 TSB Grower Affairs Division activity system

The TSB Grower Affairs Division activity system is presented below (Figure 5.2.2). Its role is to ensure improved sugarcane yield and quality of cane supplied to the sugar mill for sugar manufacturing.

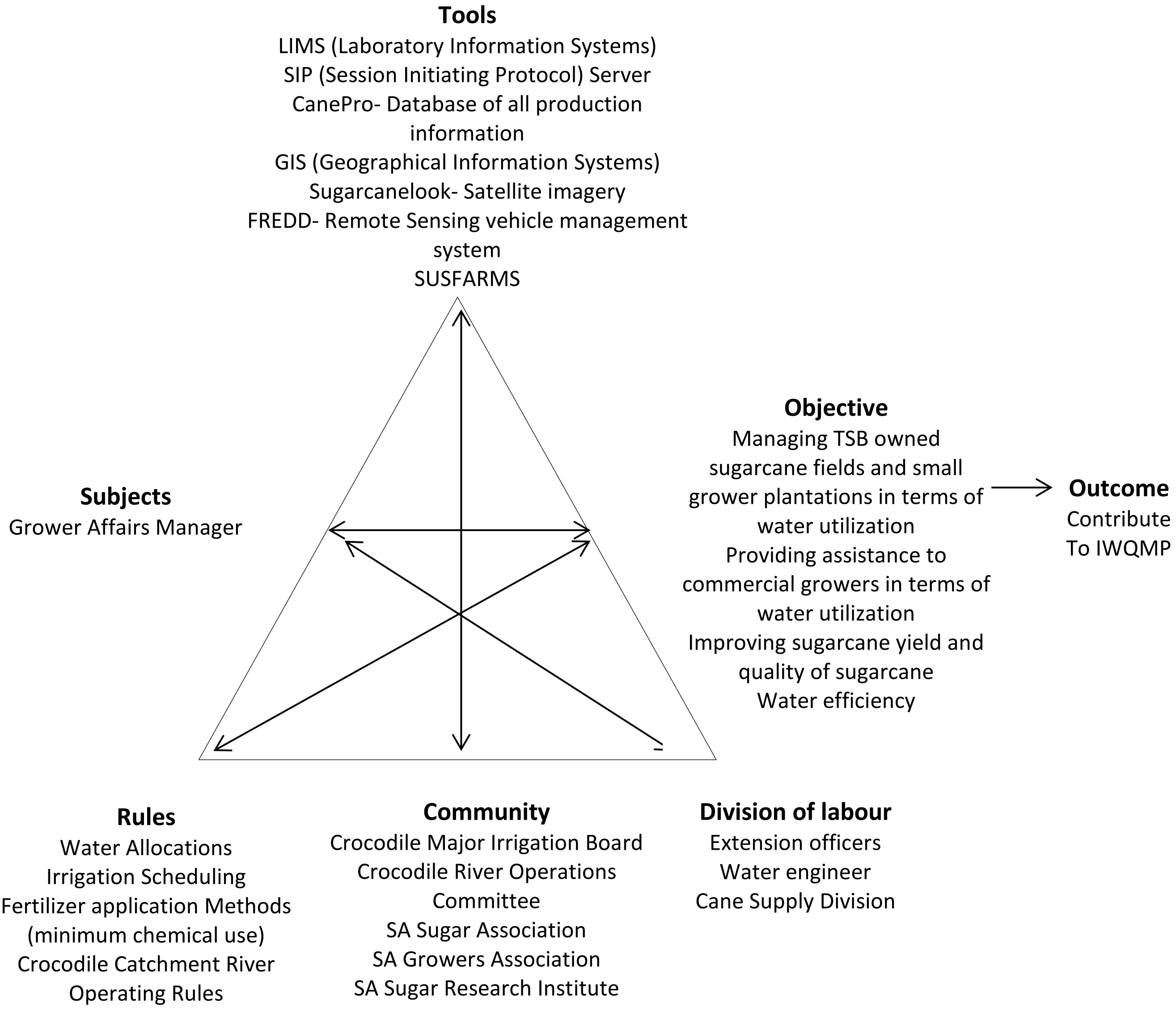


Figure 5.2.2: TSB Grower Affairs Division Activity System (Source: modified from Engeström, 1987:78)

The **subject** of this activity system is the Grower Affairs manager who is responsible for appropriate research and technology innovations to improve the yield and quality of sugar cane. The subject is also responsible for ensuring that the extension officers maintain a relationship with the emerging and commercial sugarcane growers in assisting them to achieve efficient water use.

The **objective** of this activity system is to manage TSB owned irrigated sugar cane fields as well as those owned by small growers in terms of water utilization; providing assistance to commercial sugarcane growers in terms of water utilization and ensuring improved sugarcane yield and adequate quality sugarcane is produced. This activity system also deals with water quantity and water quality issues that affect the cane growers by providing restrictions that should be implemented by the growers during periods of low flow (during winter).

The **tools** of this activity system include the following:

- LIMS (Laboratory Information System)
- SIP (Session Initiating Protocol) Server
- CanePro- Database of all production information
- GIS- Geographic Information System
- Sugarcanelook- Satelite imagery remote sensing
- FREDD- Remote sensing vehicle management system
- SUSFARMS (Sustainable Sugarcane Farm Management System)

A very useful tool has been developed through a remote sensing research project to assess biomass production for sugar cane fields. The programme shows harvested fields as red polygons and mature fields ready for harvest as green polygons. The programme assesses biomass water efficiency (how much water is used to produce how much biomass). It uses a reflectance per week method (Source: http://www.sqrsoftware.co.za/). Satellite imagery has resulted in improved water management because satellite images can show the wetness of a field. In the past water probes were used and only commercial growers could afford them. They managed the water probes themselves and half of them are currently on a scheduling system. However there is still some degree of inefficiency because the amount of water that is needed by the soil is not currently tested. About half the farmers run the irrigation on the system specs, rather than the soil or plant need (and thereby use too much water) and that is why satellite imagery system is implemented.

CanePro provides information on all soil types and helps determine dry off periods (periods when irrigation is withdrawn for about 4-6weeks). The dry off period improves the quality of sucrose solution within the sugar cane and decreases the amount of water that enters the mill reducing sugar cane weight from 75-69%. Harvest planner, which is a component of CanePro, assists with dosing of herbicide. The herbicide is applied at low dose to stop sugar cane growth and to increase the sucrose concentration within the cane. GIS helps determine field sizes, varieties (there are about 10 sugar cane varieties) of sugar cane planted in the fields. A cane delivery agreement contract exists between TSB and the growers which stipulate how much cane they should deliver. TSB then guarantees the growers' space in the capacity of the mill. If the grower fails to deliver the agreed amount of cane, an 80% penalty applies. The FREDD systems records about 500 tons/hour.

SUSFARMS (Sustainable Sugarcane Farm Management System) is another tool that is being modified to improve sustainable farming practices. There is interest in making this programme an audited system which will involve growers getting points for improved farming practices and receiving incentives but it is still being developed. TSB has been participating in this programme for about 18 months (prior to the time when the interview was conducted in October 2013). The concern is that the programme was developed based on the Kwazulu-Natal drylands and there are topographic differences in this area which needs different applications. A proposal has been made to develop two separate programmes for irrigated cane and dryland cane.

The **rules** of the TSB Grower Affairs Division activity system includes ensuring that the sugarcane growers apply water restrictions as well as using effective irrigation scheduling systems to ensure water use efficiency and ensuring that the sugarcane growers apply minimum fertilizer.

The **community** within which this activity system is operating includes the following members: the Crocodile Major Irrigation Board that provides water allocations for each sugarcane grower, the Crocodile River Operations Committee that is managed by the IUCMA regulating water allocations and water restrictions during low flow periods in the Crocodile River, the South African Sugar Association, South African Grower's Association and the South African Sugar Research Institute.

The tasks in the TSB Grower Affairs Division activity system are divided between the manager, extension officers, the water engineer and the cane supply division. The Growers Affairs division used to have 10 extension officers including a water engineer, but at the moment there is no one who is specifically delegated to the small growers division through the cane supply division. The small growers' team is currently being moved to the next building and the plan is to have a one stop shop from one place, finances, water management, in the form of a TSB affiliate Company called TSB Growers, for the small farmers.

A water engineer has been appointed for this division to be responsible for managing the small grower infrastructure from the river to the field's edge. It is hoped that this will improve turnaround time in the sugar cane plantations that belong to small growers to avoid theft and breakdowns. The small growers will be charged a levee from yield profits to deliver the cane to assist them in minimising cable theft. They are currently paying a levee for electricity and water.

Making sure that sugarcane growers do not over fertilize or over irrigate is the **outcome** of this activity system, and through this practise, this activity system can contribute to the development of an IWQMP for the Crocodile River Catchment.

5.2.3 Emerging sugarcane farmer activity systems

The emerging sugarcane farmers within the Crocodile catchment can be described as a whole activity system; however the emerging farmers operate or grow sugarcane in the catchment under differing conditions. Due to this, the emerging farmers have been described as three activity systems allowing for representation of all components of each activity system, thereby preventing conflation between them. The emerging farmers were divided into the following activity systems:

- Siyathuthuka Project emerging farmers
- Lomshiwo Individual emerging farmers
- Tikhontele Agricultural Co-operative emerging farmers

The sections below present the emerging farmer activity systems using the second generation activity theory.

5.2.3.1 Siyathuthuka Project emerging farmer activity system

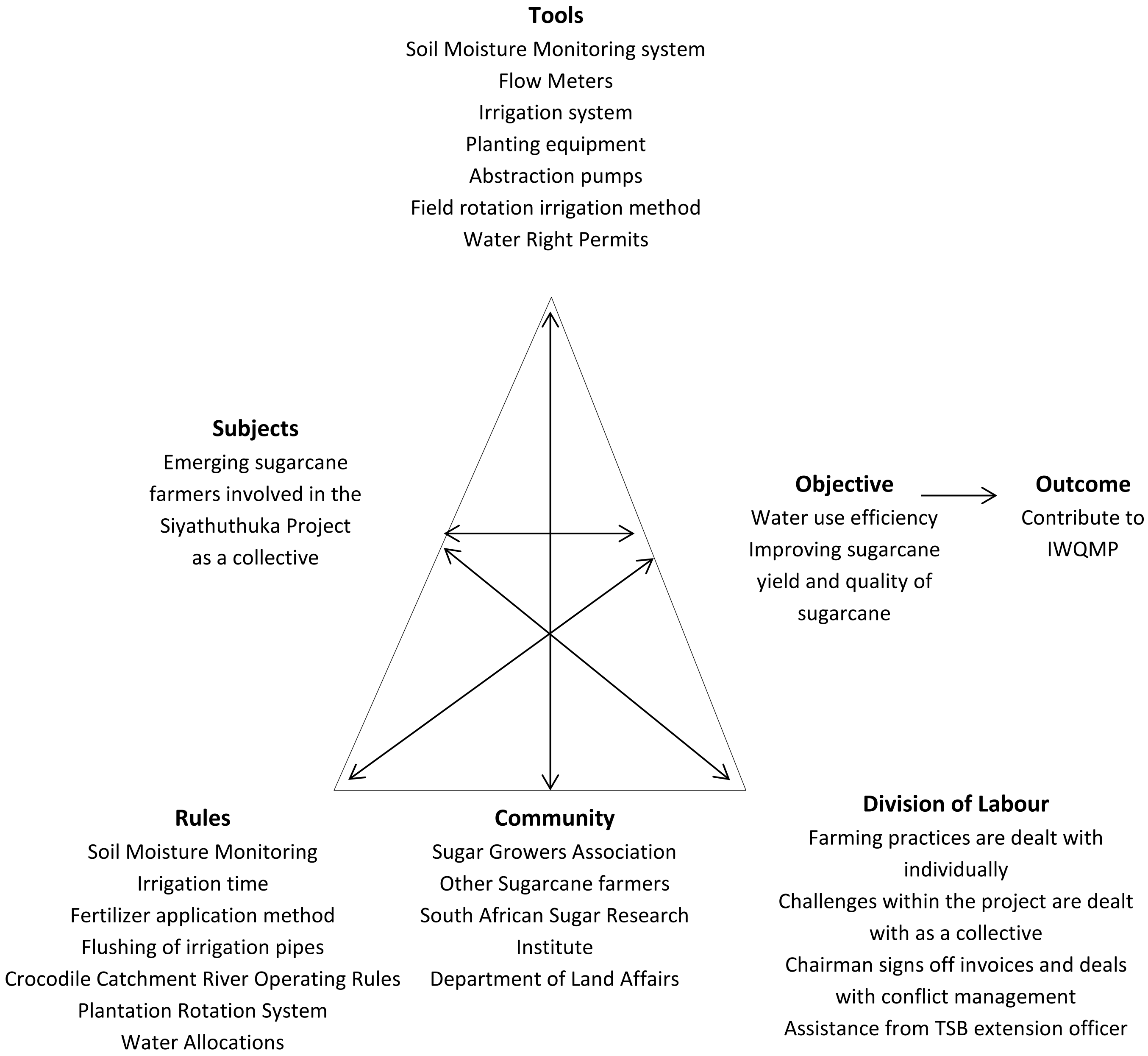


Figure 5.2.3.1: Emerging Farmer: Siyathuthuka Project Activity System (Source: modified from Engeström, 1987:78).

The **subjects** of this activity system are four members of the Siyathuthuka Co-operative project. The co-operative was initiated in 2005 by TSB. A number of individual emerging sugarcane farmers that were performing very well in the catchment were selected to form part of this project. The members of this co-operative manage a number of sugarcane plantations of various sizes (365ha, 41.2ha and 33.6ha).

The **objective** of this activity system is to ensure that the sugarcane produced is of good quality and that sugarcane yields are improved while using water efficiently. The **tools** that are available for this activity system to achieve the objective include sugarcane planting equipment, irrigation systems and abstraction pumps. They also use soil moisture meters that are used to monitor how moist the soil is and record the values. Some of the soil moisture meters are connected to a computer system that updates every two hours to create soil moisture graphs that are checked by the TSB extension officer. This systems helps them monitor how much to irrigate different plantation blocks. However, not all the members of the project have this system. Each farmer has a particular volume of water allocated to them that is monitored by the Crocodile Major Irrigation board. However, most of the emerging farmers do not have flow meters to monitor their abstraction volumes.

The **rules** of this activity system include water restrictions that are set by the Crocodile River Operations committee during low flow periods in the Crocodile River, dry off periods of approximately 6 weeks when they do not irrigate the sugarcane (this process ensures that the sucrose levels within the sugarcane stalk is concentrated), specific fertilizer application methods, specific procedures to flush irrigation pipes when they are blocked, soil moisture monitoring as well as rotating irrigation according to planation blocks. Each farmer irrigates according to the amount of water he or she is allocated by the Crocodile Major Irrigation board.

The **community** within which this activity system operates includes the following members: the Crocodile Major Irrigation Board that provides water allocations for each sugarcane grower, the Crocodile River Operations Committee that is managed by the IUCMA regulating water allocations and water restrictions during low flow periods in the Crocodile River, the Department of Land Affairs, the South African Sugar Association, South African Grower's Association, the South African Sugar Research Institute and other sugarcane growers.

In terms of **division of labour**, farmers in the Siyathuthuka Project mostly deal with farming practices individually unless there are challenges that they need assistance with. The chairperson of the project signs off payments; deals with conflict management with assistance from the TSB extension officer. The **outcome** of this activity system is to ensure that the Siyathuthuka project emerging farmers use water efficiently to produce good quality sugarcane and improve sugarcane yields, if the outcome is achieved effectively, this activity system can contribute to the development of an IWQMP for the Crocodile River catchment.

5.2.3.2 Lomshiwo Individual emerging farmer activity system

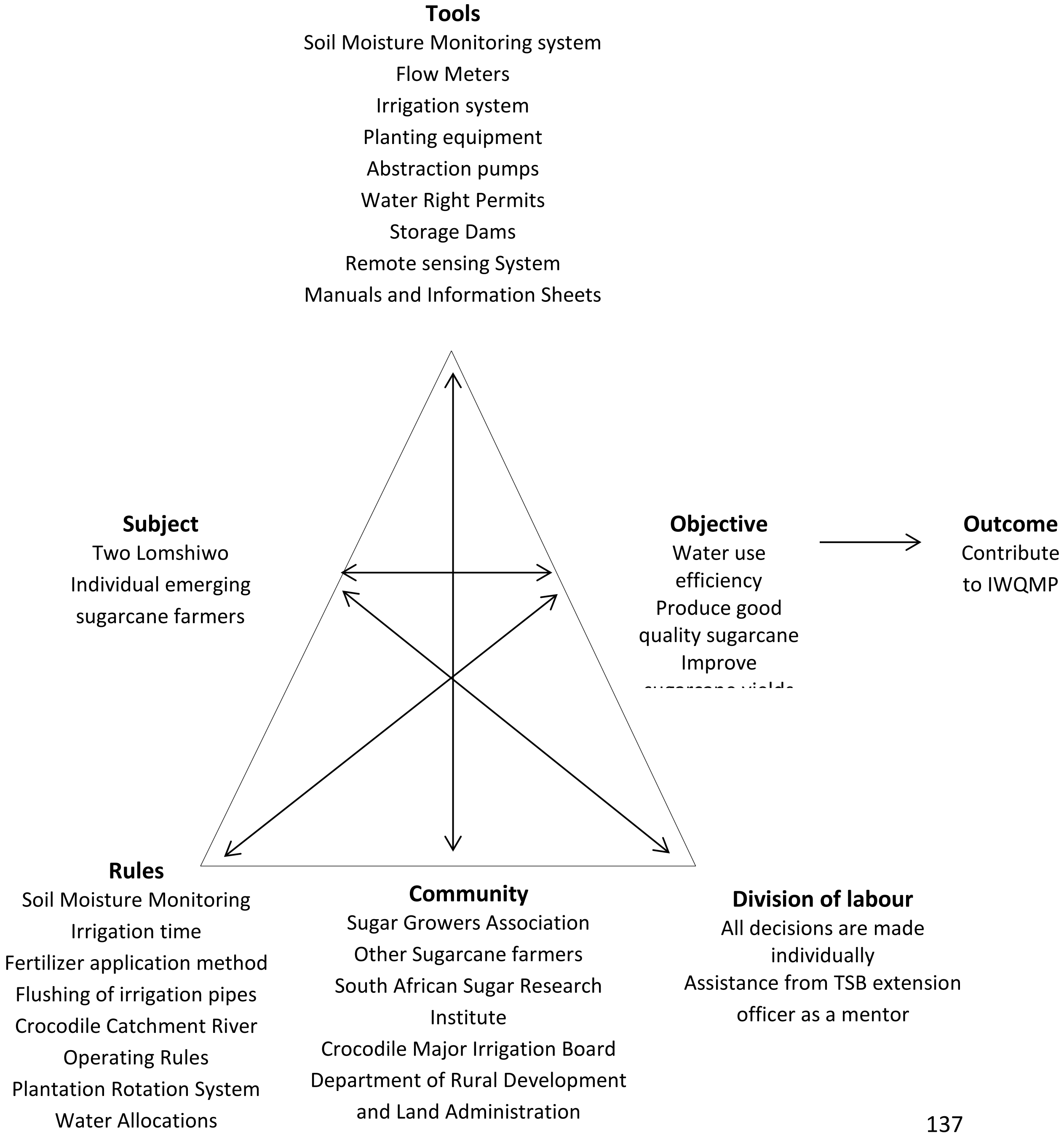


Figure 5.2.3.2: Lomshiwo Individual emerging farmer activity system (Source: modified from Engeström, 1987:78)

The **subjects** of this activity system are two individual emerging sugarcane farmers that were interviewed; one started planting sugarcane in 2007 and the other one in 2005. They manage 64 ha and 60 ha sugarcane plantations respectively. The **objective** of this activity system is to ensure that the sugarcane produced is of good quality and that sugarcane yields are improved while using water efficiently.

The **tools** that are available for this activity system to achieve the objective include sugarcane planting equipment, irrigation systems (drip and sprinkler systems), abstraction pumps and storage dams. They also use soil moisture meters that are used to monitor how moist the soil is for plantation blocks. One of the individual farmers also receives assistance from his neighbour who has a remote sensing system to inform him which plantation blocks to irrigate when. The irrigation board also provides material or information on how to maintain the flow meters at the abstraction point to monitor how much water they use. The TSB extension officer also arranges sub-contractors for maintenance of equipment and visits them approximately every week to provide any assistance needed.

The **rules** of this activity system include water restrictions that are set by the Crocodile River Operations committee during low flow periods in the Crocodile River, dry-off periods of approximately 6 weeks when they do not irrigate the sugarcane (this process ensures that the sucrose levels within the sugarcane stalk is concentrated), specific procedures to flush irrigation pipes when they are blocked, soil moisture monitoring as well as rotating irrigation according to plantation blocks. Each farmer irrigates according to the amount of water they are allocated by the Crocodile Major Irrigation board. The farmers also apply specific fertilizer application methods. Usually soil samples are taken every year by SASRI (South African Sugar Research Institute) to monitor how much fertilizer they should apply and what type of fertilizer they should use. They normally arrange for a fertilizer company to apply fertilizer on their land and then later a top dresser type fertilizer is applied after a certain period. The companies they use are normally Omnia or Impondo Fertilizers. However it is also possible for the farmers to apply fertilizers themselves if they have the capacity.

The **community** within which this activity system is operating includes the following members: the Crocodile Major Irrigation Board that provides water allocations for each sugarcane grower, the Crocodile River Operations Committee that regulating water allocations and water restrictions during low flow periods in the Crocodile River, the South African Sugar Association, South African Grower's Association, the South African Sugar Research Institute, other sugarcane farmers and the Department of Rural Development and Land Administration that often host training sessions about fertilizer use.

In terms of **division of labour**, the individual farmers make all the decisions on their farms and seek assistance from the TSB mentor when they it. The **outcome** of this activity system is to ensure that the Lomshiwo Individual emerging farmers use water efficiently to produce good quality sugarcane and improve sugarcane yields, if the outcome is achieved effectively, this activity system can contribute to the development of an IWQMP for the Crocodile River catchment.

5.2.3.3 Tikhontele emerging farmer activity system

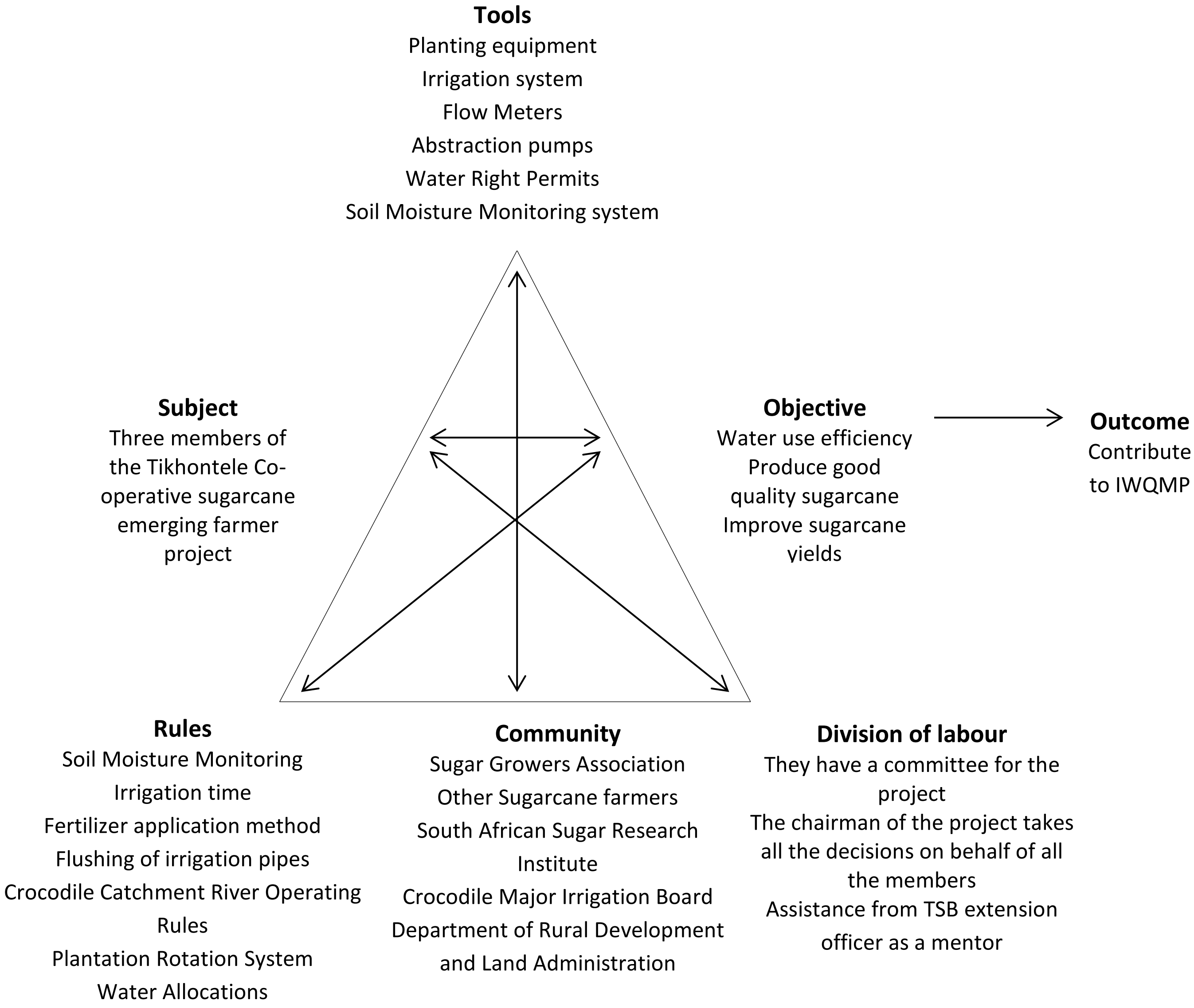


Figure 5.2.3.3: Tikhontele emerging farmer activity system (Source: modified from Engeström, 1987:78).

The **subjects** of this activity system are three emerging sugarcane farmers that are part of a bigger group, which started planting sugarcane in 2007 managing 242 ha of land; 9ha of this is dedicated to a sugarcane nursery that produces sugarcane seed plants. The **objective** of this activity system to ensure that the sugarcane produced is of good quality and that sugarcane yields are improved while using water efficiently.

Sugarcane planting equipment, irrigation systems (Sprinkler irrigation), abstraction pumps, flow meters and soil moisture meters that are used to monitor how moist the soil is are the **tools** that are used in this activity system to achieve the objective. The Tikhontele emerging farmer project also has a specified amount of water allocated to them that is monitored by the Crocodile Major Irrigation board. However, at the moment they are using borehole water to irrigate the 9 ha nursery block because the other plantation blocks have not been planted due to management issues. However, when they have planted in all plantation blocks they use sprinkler irrigation and they irrigate with water abstracted from the Crocodile River.

The **rules** that are applied in this activity system include specific fertilizer application methods and they have soil samples taken regularly by SASRI (South African Sugar Research Institute) or the specific fertilizer company they are using to monitor how much fertilizer they should apply and what type of fertilizer they should use. The fertilizer company applies fertilizer on their land and then later a top dresser type fertilizer is applied after a certain period. The companies they use are normally Omnia or Impondo Fertilizers. However, when they have the capacity they apply fertilizer themselves. They also irrigate according to water restrictions provided by the Crocodile Catchment River operating committee, according to their water allocation and according to how much water is needed in each plantation block by checking soil moisture.

The **community** in which this activity system exists includes the Sugar Growers Association, other sugarcane farmers the subjects of this activity system communicate with, the South African Sugar Research Institute, Crocodile Major Irrigation Board, Crocodile River Operations Committee and the Department of Rural Development and Land Administration.

In terms of **division of labour**, the Tikhontele project has a committee that is led by the chairman who makes all the decisions. However, the members of the project feel the committee is not productive because they do not have regular meetings anymore and this has affected the functioning of the project. The chairman also refused to support appointing a vice-chairman to make decisions when the chairman is not available and thus every decision has to wait until the chairman is available. The **outcome** of this activity system is to ensure that the Tikhontele emerging farmer project reaches a point of adequate productivity, efficient water use to produce good quality sugarcane and improve sugarcane yields, if the outcome is achieved effectively, this activity system can contribute to the development of an IWQMP for the Crocodile River catchment.

5.2.4 Commercial sugarcane farmer activity system

The commercial sugarcane farmers within the Crocodile catchment can be described as a whole activity system; however the commercial farmers operate their farms or grow sugarcane in the catchment under differing water management conditions. Due to this, the commercial farmers have been described as three activity systems allowing for representation of all components of each activity system, thereby preventing conflation between them. The commercial farmers were divided into the following activity systems:

- Crocodile Gorge Canal commercial farmer activity system
- Privately Owned Canal commercial farmer activity system
- TSB and Community Joint Venture commercial farmer activity system.

The sections below present the commercial farmer activity systems using the second generation activity theory.

5.2.4.1 Crocodile Gorge Canal commercial farmer activity system

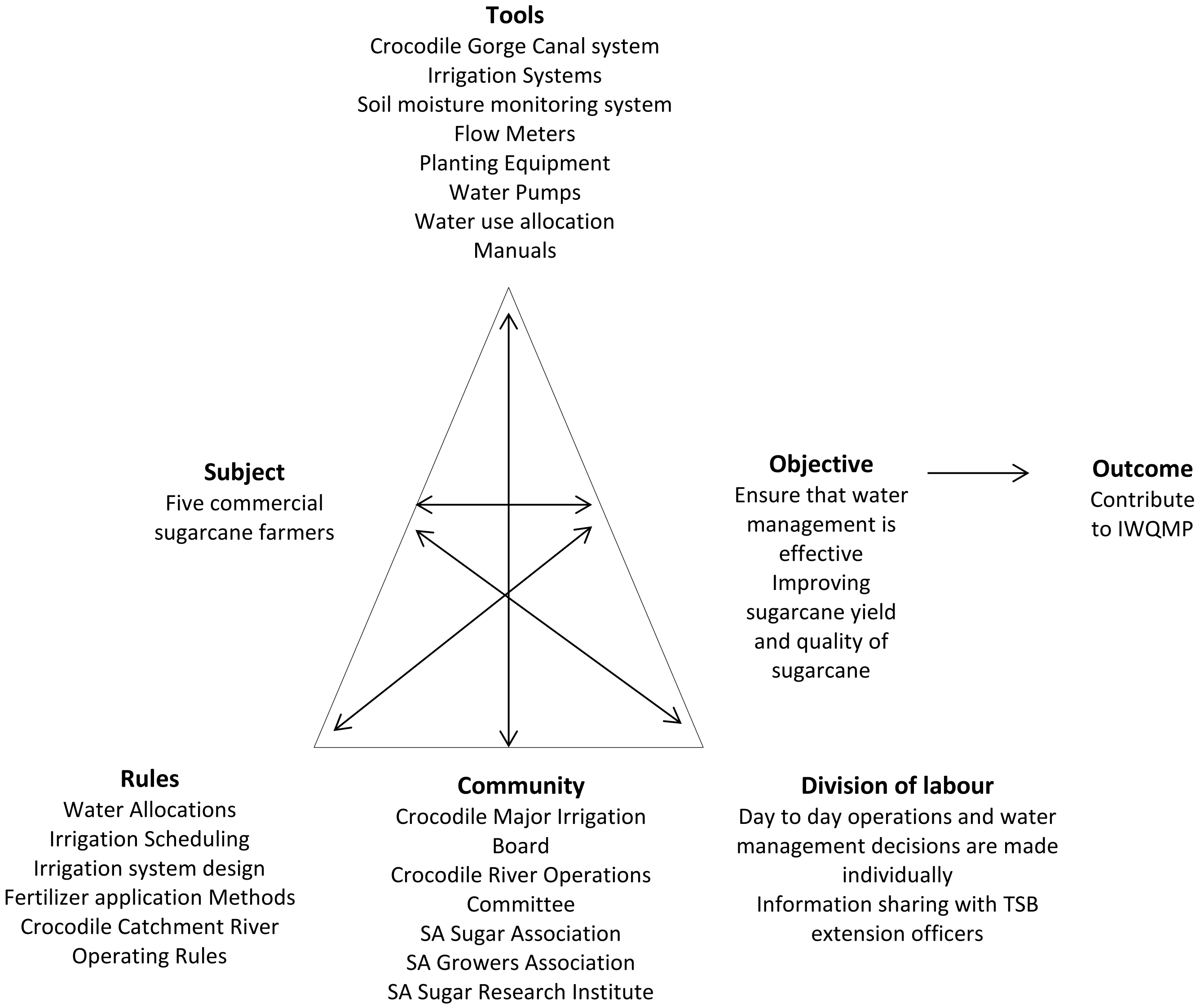


Figure 5.2.4.1: Crocodile Gorge Canal commercial farmer activity system (Source: modified from Engeström, 1987:78).

The **subjects** of this activity system are five commercial sugarcane farmers that abstract water from the Crocodile River Gorge canal. These commercial sugarcane farmers manage farms of varying sizes and receive water from the canal through either gravity feeding or through pumping. The **objective** of this activity system if for the farmers to ensure that the sugarcane produced is of good quality and that sugarcane yields are improved while using water efficiently.

The **tools** that are used in this activity system include irrigations systems and the type of the system the farmers select is determined by the quality of water the farmer receives. Three of the farmers use overhead irrigations system, one uses centre pivot and sprinkler irrigation, while the other uses subsurface drip irrigation. Most of the farmers interviewed would prefer using drip irrigation as it is the most water efficient technology; however maintaining drip irrigation is very expensive due to regular blockages because of the quality of the water they receive. It requires water of high quality which can be achieved through water treatment before irrigation, but which most of them cannot afford.

The water quality variables of concern to the farmers include high concentrations of calcium (that often forms a residue in the irrigation pipes), high pH (which can affect the efficiency of fertilizer and herbicide), high concentration of suspended sediment and algae, high magnesium concentrations (some small streams that run through a number of the farms often catch runoff from a nearby magnesite (magnesium carbonate) mine, Strathmore Mine, which is situated on the south side of N4 road to Maputo and approximately 5km west of Malelane), and high EC in the water they use to irrigate.

One of the farmers uses subsurface drip irrigation and he has installed two types of water purification systems (ozone type and a peroxide dosing system). The farmers also use soil moisture monitoring system that informs them how much they need to irrigate in each plantation block. However not all the farmers have the soil moisture probes installed. The farmers that do not have the soil moisture probes use an old method of using a soil auger or shovel to dig a soil sample and create a small ball shape that is pressed to determine how moist the soil is.

All the farmers have an irrigation scheduling system that they apply and it depends on the type of irrigation system they have installed as well as on the soil types on their farms. The farmer with subsurface drip irrigation also has a computerised irrigation scheduling system that controls the amount of time each plantation block is irrigated. Other tools used in this activity system include planting equipment, flow meters, water use allocations from the irrigation board and manuals or information sheets from the SA Sugar Growers Association and South African Sugar Research Institute.

The **rules** that are applied in this activity system include water allocations from the irrigation board, water restrictions that are set by the Crocodile River Operations committee, dry-off periods when they do not irrigate the sugarcane to increase the sucrose levels within the sugarcane stalk, soil moisture monitoring as well as rotating irrigation according to planation blocks. The farmers also apply specific fertilizer application methods. Usually soil samples are taken regularly by the fertilizer company they have employed to assess the nutrient levels in the soil, which will determine which type of fertilizer to use as well as to determine how much fertilizer they should apply. The companies they use are normally Omnia or Impondo Fertilizers. However, some of the farmers apply the fertilizer themselves if they have the capacity.

The **community** within which this activity system operates includes the following members: the Crocodile Major Irrigation Board that provides water allocations for each sugarcane grower, the Crocodile River Operations Committee that is managed by the Inkomati-Usuthu Catchment Management Agency regulating water allocations and water restrictions during low flow periods in the Crocodile River, the South African Sugar Association, South African Grower’s Association, the South African Sugar Research Institute and other commercial sugarcane growers.

In terms of **division of labour**, the operational decisions and water management decisions are made by the farmers individually however, information in terms of which sugarcane varieties to plant to increase sugarcane crop yields, as well as other water management information is shared with TSB extension officers.

The subjects of this activity system have to constantly adapt to changes in the quality of the water they receive for irrigation and they have to ensure that they use water as efficiently as possible to produce good quality sugarcane and improve crop yields as the **outcome** of the activity system.

5.2.4.2 Privately Owned Canal commercial farmer activity system

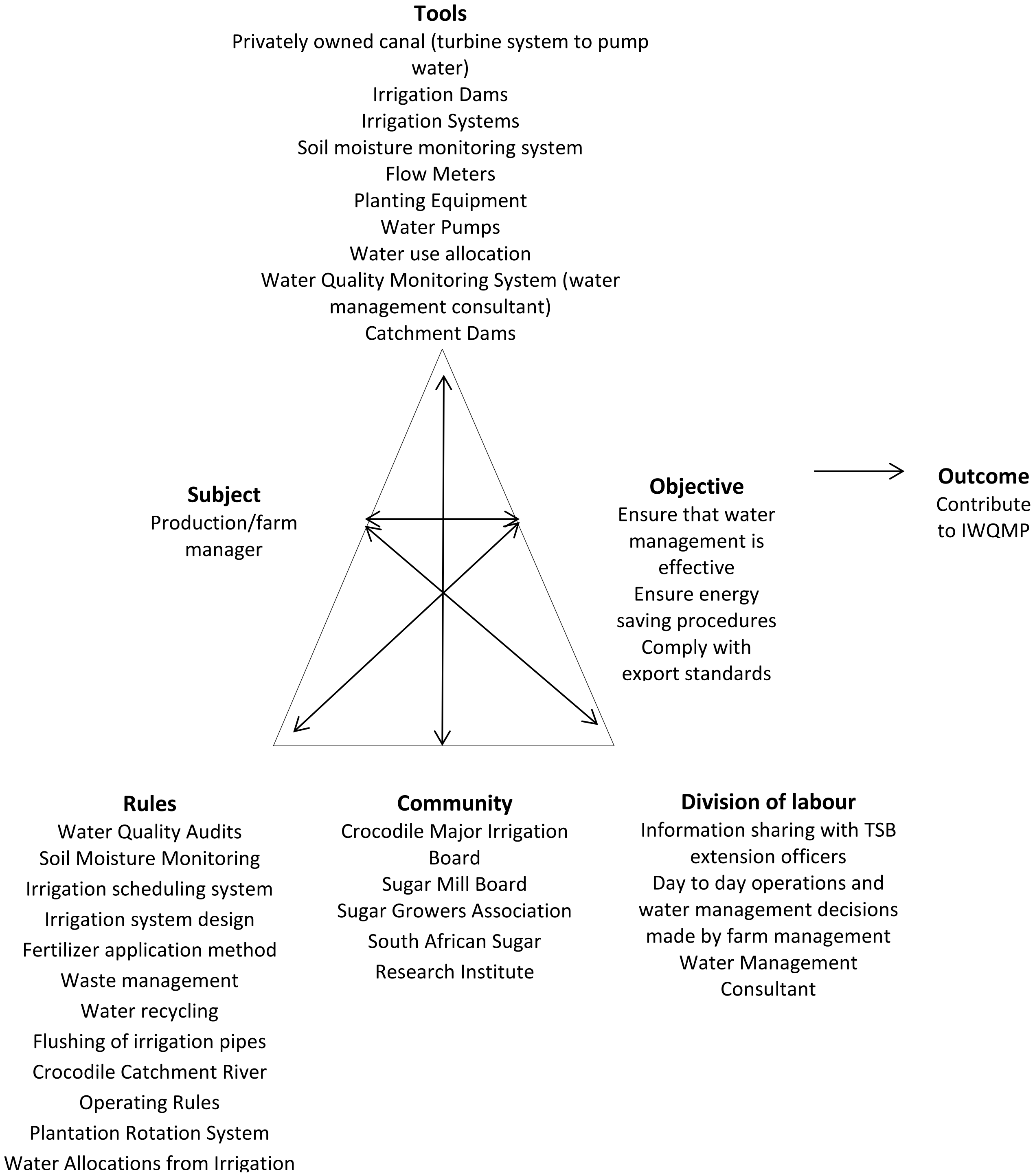


Figure 5.2.4.2: Privately Owned Canal commercial farmer activity system (Source: modified from Engeström, 1987:78).

The **subject** of this activity system is the farm manager of Riverside Farm who manages a farm that grows citrus as well as sugarcane. The sugarcane plantations make up approximately 640 ha of the farm. The **objective** of this activity system is to ensure that water is used effectively on the farm, to ensure energy saving methods are applied as well as to ensure that the farm applies water management procedures that comply with exporting standards.

The **tools** that are used to ensure that the objective of this activity system is achieved include a hydro system that is owned by the farm, this system is made up of retaining walls with a turbine system that pumps water to the irrigation dams on the farm. Water pumps are used to pump the water from the irrigation dams to the sugarcane plantations and this is an energy intensive process. A water management consultant employed by the farm is in charge of a water quality monitoring system that monitors the water quality, soil moisture on the whole farm using soil moisture gauges, weather checks and produces graphs that are used to make irrigation decisions. This information also informs which irrigation systems to use and what methods to use to aid improving water quality specifics for each irrigation system. Sand filters are installed to capture suspended sediment and a spin clean method is also used depending on the irrigation system design. Other tools that are used include water allocation from the irrigation board, planting equipment, flow meters, and an environmental management plan that stipulates the use of catchment dams to contain waste.

The **rules** that are applied in this activity system include strict measures to monitor water quality in the form of audits that are conducted and water quality monitoring. A soil moisture monitoring system is applied, irrigation schedule and crop specific irrigation designs to ensure efficient water use. Soil analysis and leaf analysis is conducted to inform fertilizer application methods and only approved chemicals are used. Other rules include waste management, water recycling, flushing of irrigation pipes and plantation rotation system. The farm irrigates according to the water allocated by the irrigation board and applies water restrictions from the Crocodile River Operating rules. Informal rules that are applied include water management knowledge from experience such as knowing that rocky soils require more water due to increased infiltration and blocks that are near the river often have more clay type soils that need less water due to their ability to retain water.

In terms of the **community** in which the activity system exists, the Managing Director of the farm sits on the Crocodile Major Irrigation Board and on sugar mill board. The subject also communicates with the Sugar Growers Association and the South African Sugar Research Institute.

In relation to **division of labour**, the day to day operations and water management decisions are made by the management of the farm; however, information in terms of which sugarcane varieties to plant to increase sugarcane crop yields is shared with TSB extension officers. The water management consultant also provides vital information that is used to inform water management decisions on the farm.

The **outcome** of this activity system is adapting to the changes in water quality and how those changes influence the improvements that are made on the farm in terms of water management. It is important for water to be used effectively in this activity system and ensure that the farm complies with export standards, contributing to the development of an IWQMP of the Crocodile River Catchment.

5.2.4.3 TSB and Community Joint Venture commercial farmer activity system

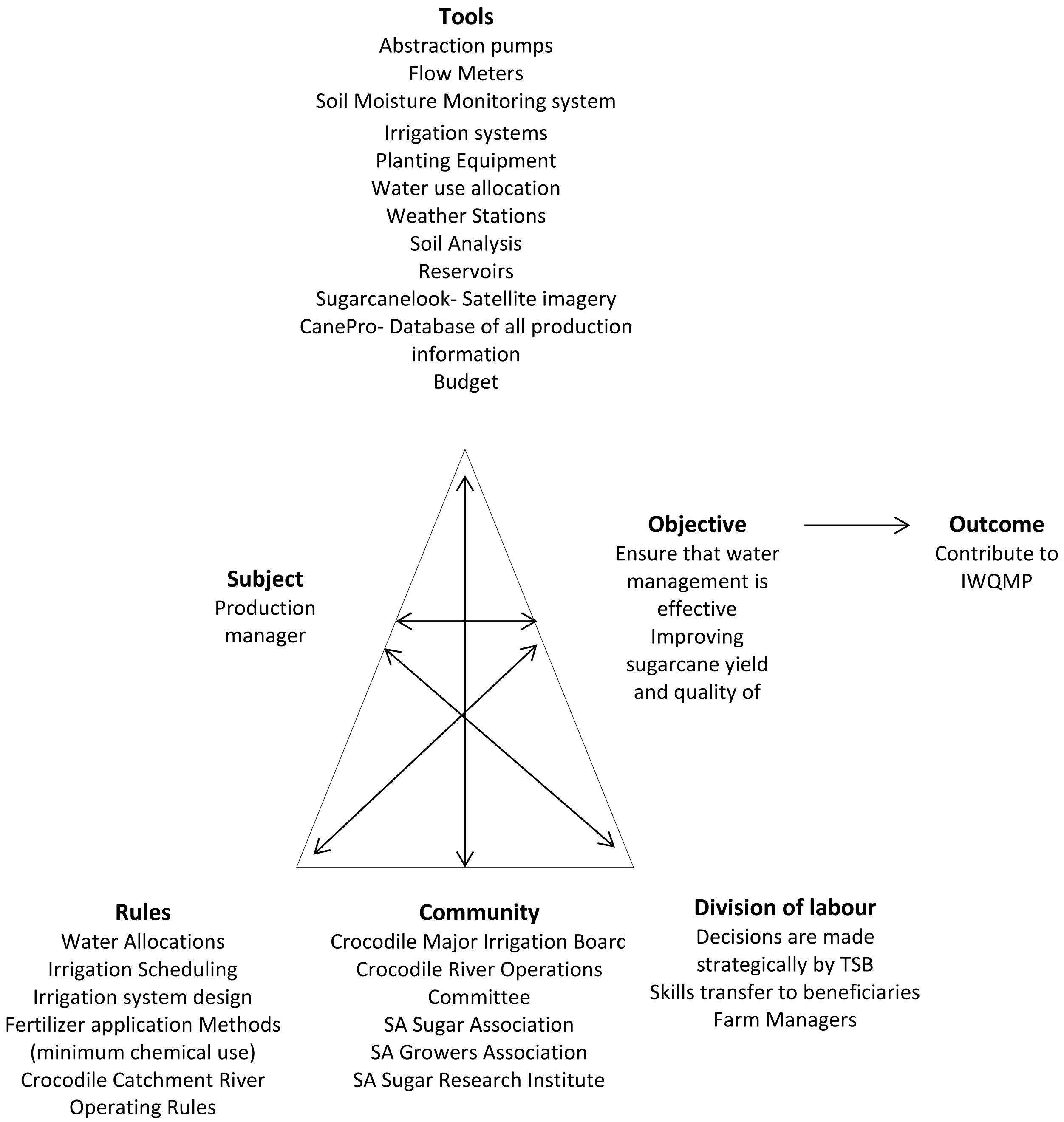


Figure 5.2.4.3: TSB and Community Joint Venture activity system (Source: modified from Engeström, 1987:78).

The **subject** of this activity system is the production manager of the Tenbosch TSB sugar farm. This sugarcane farm was previously owned by TSB; now the farm belongs to the community since 5- 6 years ago; however TSB controls day-to-day operations and decision making. The **objective** of this activity system is ensuring that water is managed effectively and improving sugarcane crop yield and sugarcane quality.

The **tools** used to achieve this include sugarcane planting equipment, irrigation systems, flow meters, abstraction pumps and reservoirs. They also use soil moisture meters that are used to monitor how moist the soil is for plantation blocks. Weather stations that are installed on the farm assist in predicting temperature which influences evapotranspiration and affects water storage by the sugarcane crop. Soil analysis is also done on the whole farm to provide information about root depth, percentage of clay in the soil for water retention and this information is used for decision making. CanePro is used to capture all information at the end of season when the sugarcane fields have been, showing tonnage per 100mm of water. At the moment, farm management is looking into using SugarCaneLook, which is satellite imagery that shows evapotranspiration and water shortage, biomass increase and water use efficiency in plantation blocks.

The **rules** that are applied in this activity system include water restrictions that are set by the Crocodile River Operations committee during low flow periods in the Crocodile River, dry-off periods to increase sucrose levels within sugarcane stalks, soil moisture monitoring as well as rotating irrigation according to planation blocks. The farm is irrigated according to the amount of water allocated by the Crocodile Major Irrigation Board and specific fertilizer application methods are applied that ensure minimal chemical use on the farm.

This activity system exists within a **community** with the following members: Crocodile Major Irrigation Board, Crocodile River Operations Committee, SA Sugar Association, SA Growers Association and the SA Sugar Research Institute.

In terms of **division of labour**, decisions are strategically made by TSB and skills are transferred to beneficiaries on the farm. Every Monday morning, readings are recorded from abstraction pumps and each farm manager is allocated a certain volume of water to pump per week. Each farm manager decides based on soil moisture system on how to irrigate. The **outcome** of this activity system is to ensure that water is used efficiently in the activity system and that good quality sugarcane is produced and sugarcane yields are improved thereby contributing to the development of an IWQMP for the Crocodile River catchment.

Sections 5.2-5.2.4.3 above gave descriptions of the sugar industry as activity systems, this interpretation was necessary to obtain basic understanding about water management practices in the industry and to understand the smaller activity systems that interact to form the whole sugar industry activity system. The next section of this chapter provides descriptions of the IUCMA activity system.

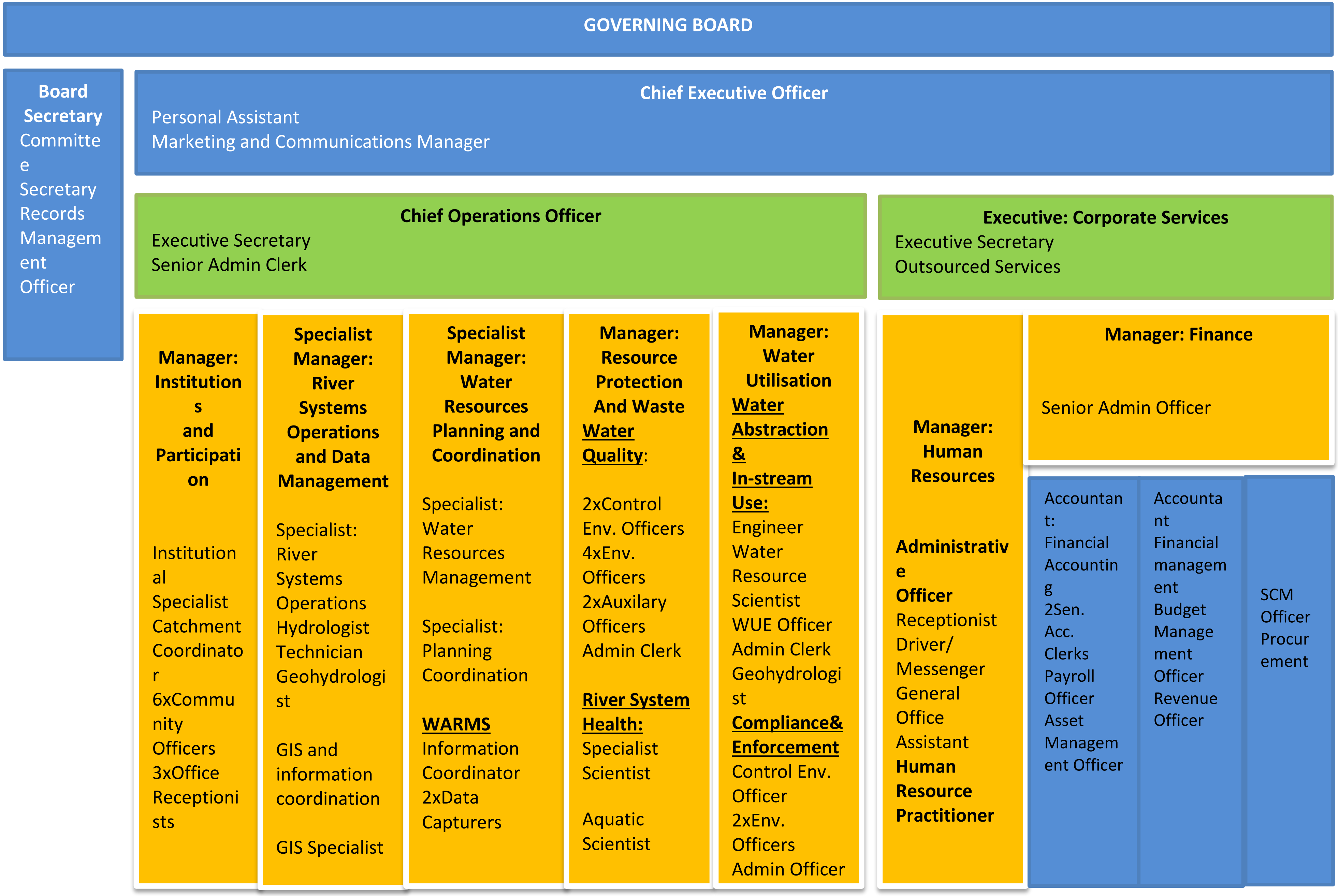
5.2.5 Inkomati-Usuthu Catchment Management Agency (IUCMA) activity system

The Inkomati-Usuthu Catchment Management Agency can be described as a whole activity system; however, the institution has various divisions that have specific objectives to achieve (Figure 5.2.5). Due to this, the IUCMA have been described as six activity systems allowing for representation of all components of each activity system, thereby preventing conflation between them. The IUCMA was divided into the following activity systems:

- Water Quality Division activity system
- Resource Protection and Waste Management activity system
- River Systems Operations and Data Management activity system
- Compliance and Enforcement Division activity system
- Chief Operating Officer activity system
- Communications and Marketing Division activity system

The sections below present the IUCMA activity systems using the second generation activity theory.

Figure 5.2.5: IUCMA ORGANISATIONAL STRUCTURE (ICMA, 2014:24)



5.2.5.1 IUCMA Water Quality Division activity system

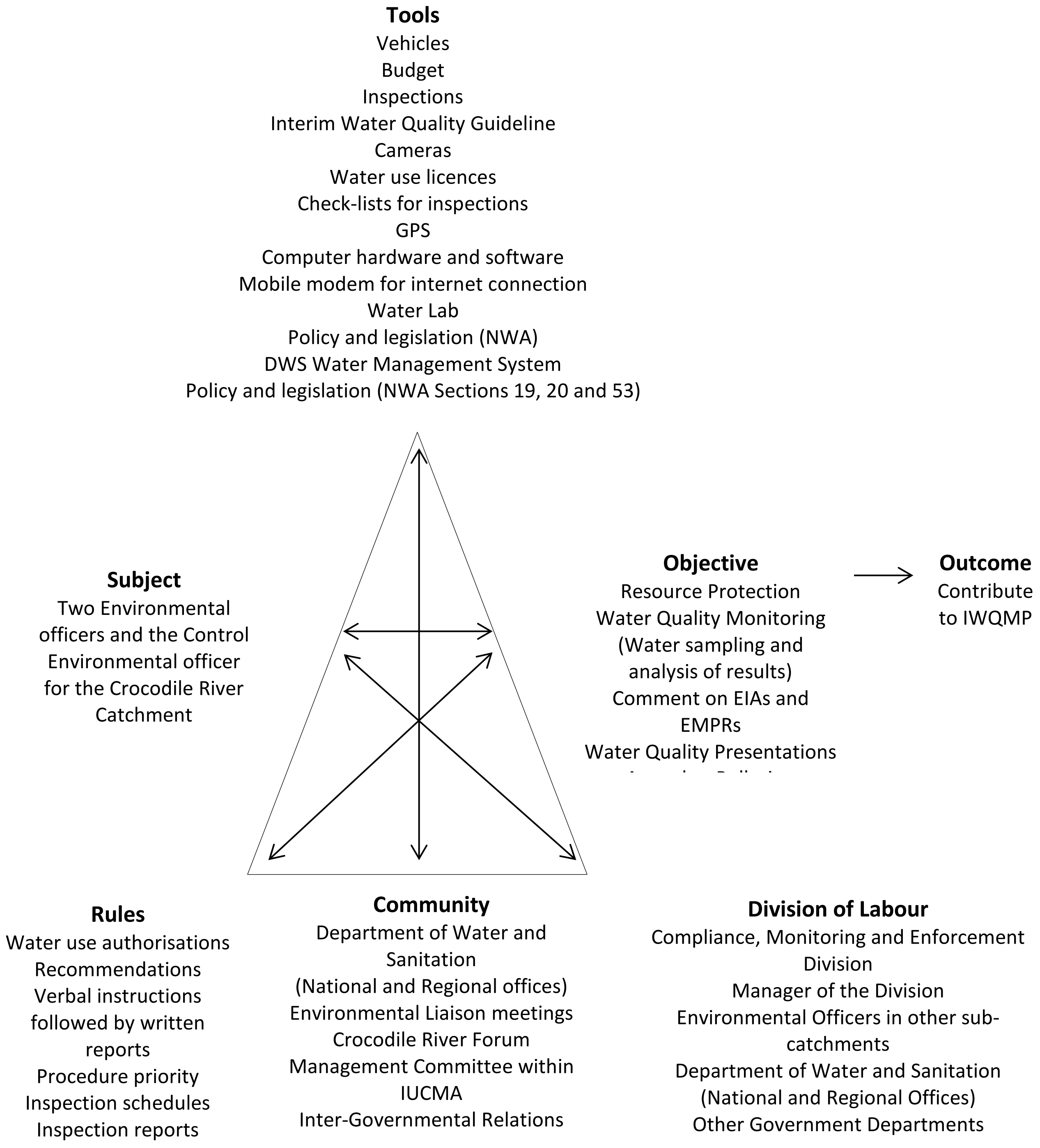


Figure 5.2.5.1: IUCMA Water Quality Division activity system (Source: modified from Engeström, 1987:78).

The **subjects** of this activity system are two environmental officers and one control environmental officer for the Crocodile River Catchment. These officials are responsible for resource protection in the catchment which is the core function of the IUCMA. The **objective** of this activity system include water quality monitoring, conduction site inspections, providing comments on environmental impact assessment studies (EIAs), environmental management programmes (EMPRs), preparing and giving water quality presentations at forum meetings and attending to pollution incidents.

The **tools** that are used by the subjects in this activity system to achieve the objectives include the following: vehicles, budget, interim water quality objectives that were derived with the members of the Crocodile River Forum and DWS, cameras to take pictures at site inspections and pollution incident inspections, water use licences, check-lists that are used during inspections, Global Positioning System device, computer hardware and software, mobile modem for internet connection, the WaterLab that does water sample analysis for chemical and micro-biological parameters on a monthly and ad-hoc basis, as well as the DWS Water Management System for capturing the water quality monitoring data.

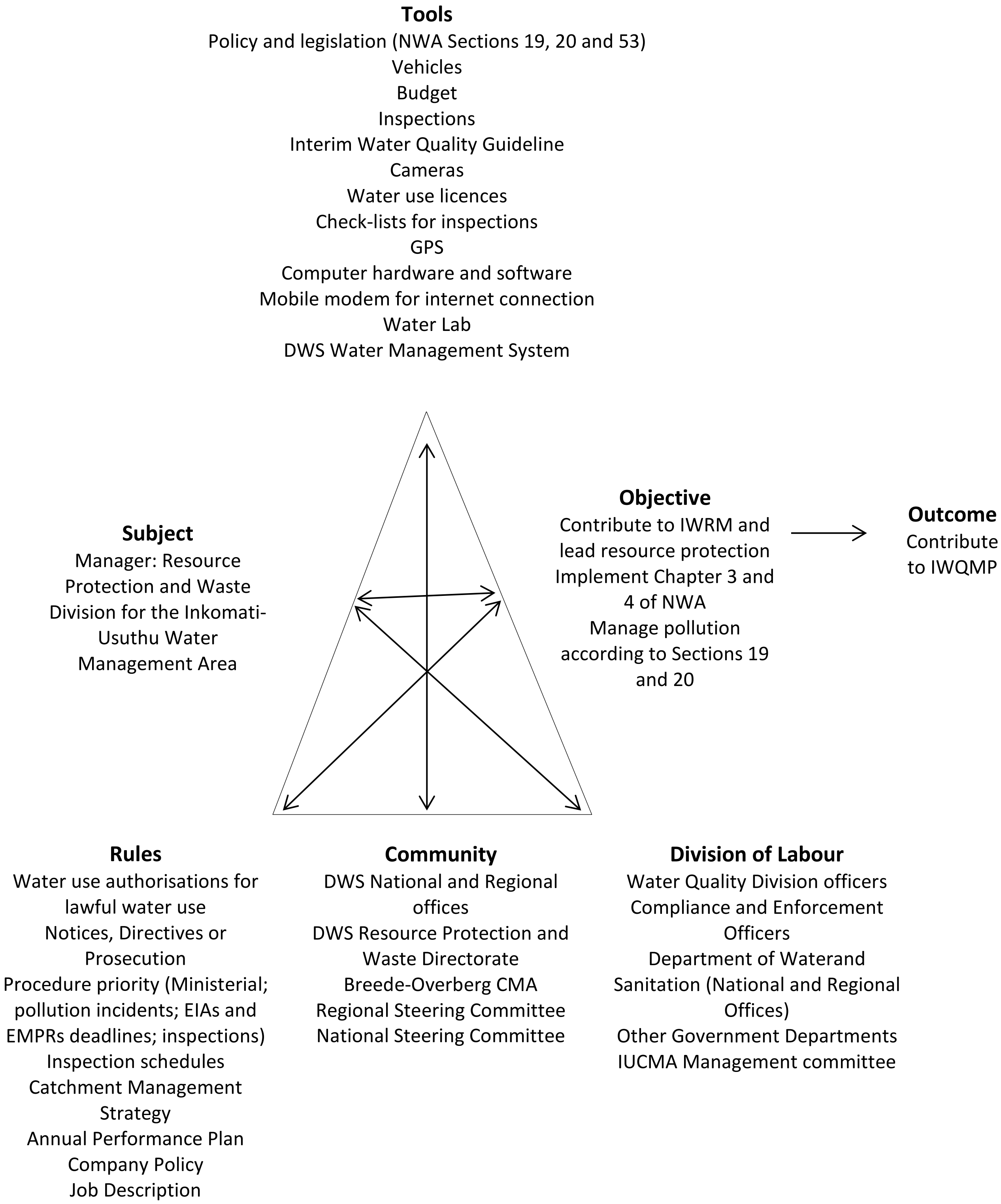
The **rules** in this activity system include water use authorisations that stipulate the conditions each water user in the sub-catchment needs to comply with, recommendations in terms of how water users can handle water use and waste disposal issues, verbal instructions in cases of non-compliance, a priority procedure such as a pollution incident inspection taking priority and inspection schedules.

The **community** within which this activity system operates is broad and includes the regional and national offices of Department of Water and Sanitation, the management committee within the IUCMA and other government departments. The environmental officers also attend environmental liaising meetings and the Crocodile River forum meetings.

The tasks conducted by the officers within the water quality division are shared with the Compliance, Monitoring and Enforcement (C&E) division and the manager of the division ensures that the officers are performing as required. Some tasks are shared with the Department of Water and Sanitation national and regional offices as well as other government departments.

The **outcome** of this activity system is to ensure the protection of the Crocodile River Catchment as the water resource, thus contributing to the development of an IWQMP for the sub-catchment.

5.2.5.2 IUCMA Resource Protection and Waste Management activity system



Tools
Policy and legislation (NWA Sections 19, 20 and 53)
Vehicles
Budget
Inspections
Interim Water Quality Guideline
Cameras
Water use licences
Check-lists for inspections
GPS
Computer hardware and software
Mobile modem for internet connection
Water Lab
DWS Water Management System

Subject
Manager: Resource Protection and Waste Division for the Inkomati-Usuthu Water Management Area

Objective
Contribute to IWRM and lead resource protection
Implement Chapter 3 and 4 of NWA
Manage pollution according to Sections 19 and 20

Outcome
Contribute to IWQMP

Rules
Water use authorisations for lawful water use
Notices, Directives or Prosecution
Procedure priority (Ministerial; pollution incidents; EIAs and EMPRs deadlines; inspections)
Inspection schedules
Catchment Management Strategy
Annual Performance Plan
Company Policy
Job Description

Community
DWS National and Regional offices
DWS Resource Protection and Waste Directorate
Breede-Overberg CMA
Regional Steering Committee
National Steering Committee

Division of Labour
Water Quality Division officers
Compliance and Enforcement Officers
Department of Waterand Sanitation (National and Regional Offices)
Other Government Departments
IUCMA Management committee

Figure 5.2.5.2: IUCMA Resource Protection and Waste Management activity system (Source: modified from Engeström, 1987:78).

The **subject** of this activity system is the manager of the Resource Protection and Waste Division of the IUCMA whose **objective** is to contribute to IWRM and leading resource protection in the Inkomati WMA by implementing Sections 3 and 4 of the NWA and managing pollution according to sections 19 and 20 of the act.

The **tools** that are available in this activity system are the same as the tools used by the environmental officers in section (5.2.5.2) above. The **rules** that are used to operate within this activity system include water use authorisation for lawful water use that specifies conditions of abstraction and waste disposal, notices, directives or prosecution documents that the manager approves and signs off in situations of non-compliance by water users. In terms of responding to external requirements and stakeholders, there is an implicit priority procedure that prioritises responding to the Minister, then attending to pollution incidents, then ensuring that deadlines for EMPRs and EIAs are met; and then the schedule of inspections. At the beginning of each year all water users in the catchment are called in to set up appointments for site inspections and IUCMA officials rate the level of impact of each user. After each inspection a report is compiled and if there is a need a directive is issued. Other rules include the Catchment Management Strategy (CMS), Annual Performance Plan (APP), the manager's job description and the company policy.

In terms of **community** in which this activity system exists, the manager co-operates, works with and consults with the Department of Water and Sanitation national office, the Breede-Overberg CMA, the regional steering committee and the manager reports IUCMA progress at the National Steering Committee.

In terms of **division of labour**, the manager's work is supported by the water quality officers and C&E officers who share inspections (on a 60/40 ratio). The water quality officers operate in sub-catchments, but C&E officers operate across the Inkomati WMA. Officer inspections deal with compliance to licence authorisation specifications. The IUCMA shares IWRM tasks with the DWS in terms of Resource Directed Measures (RDM) such as resource classification; setting the Reserve; signing off and issuing directives; and undertaking prosecution as recommended by the IUCMA; as well as other government departments. The IUCMA has regular management committee meetings and at these meetings it was realised that the support staff at the IUCMA do not understand the work done by the core function so induction meetings were held. Each division presents at the induction meeting and explains their role in the organisation.

The **outcome** of this activity system is to ensure the protection of the Crocodile River Catchment as the water resource, thus contributing to the development of an IWQMP for the sub-catchment.

5.2.5.3 IUCMA River Systems Operations and Data Management activity system

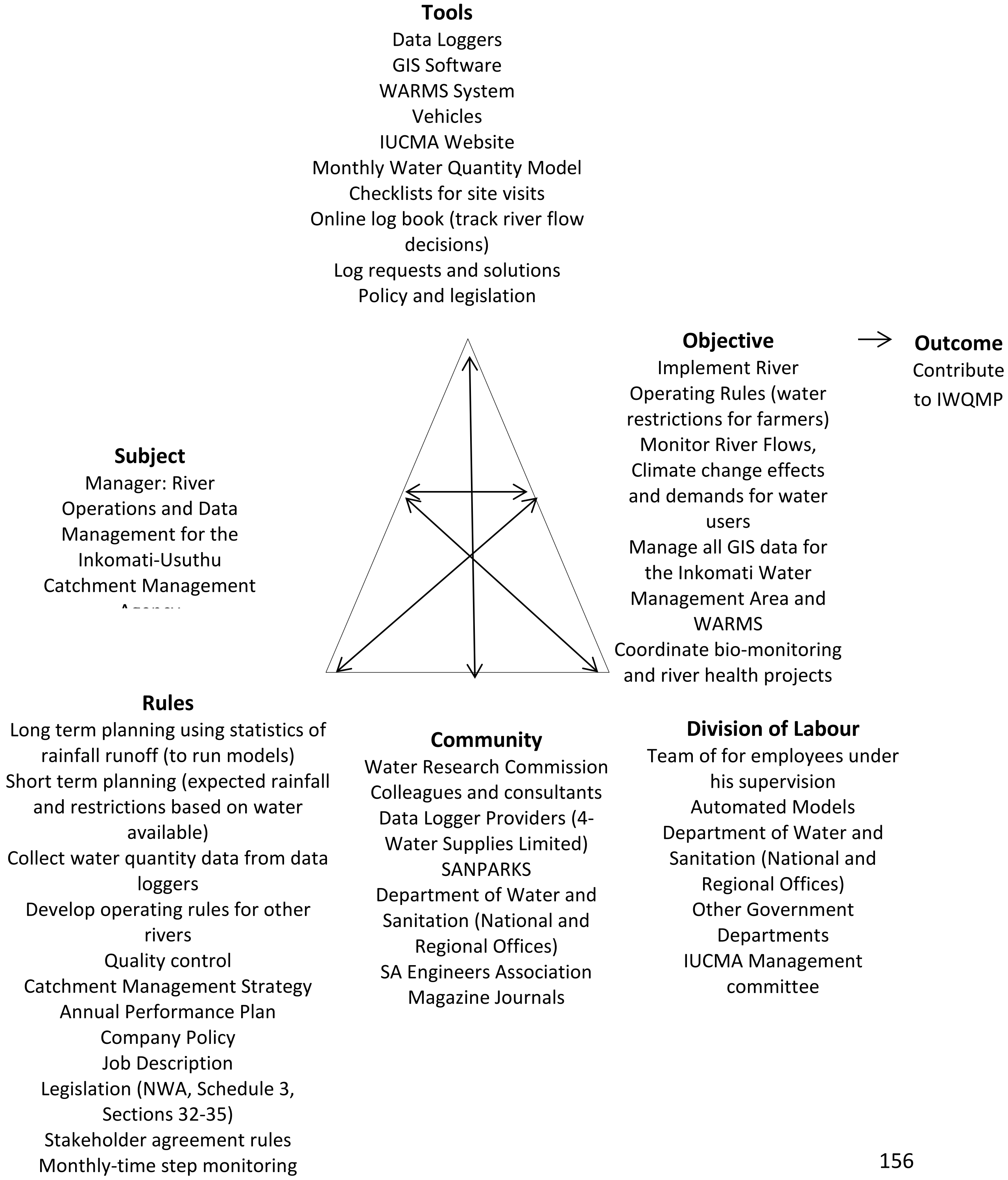


Figure 5.2.5.3: IUCMA River Systems Operations and Data Management activity system (Source: modified from Engeström, 1987:78).

The **subject** of this activity system is the manager of the River Systems Operations and Data Management division at the IUCMA. The **objective** of the activity system includes implementing the River Operating rules that provide water, within the operating rules that include restrictions for farmers; monitoring river flows in the river in the Inkomati WMA, climate change effects and demands from water users; managing all GIS data and WARMS (Water Authorisation and Registration Management System) database; and co-ordinating the bio-monitoring and river health projects.

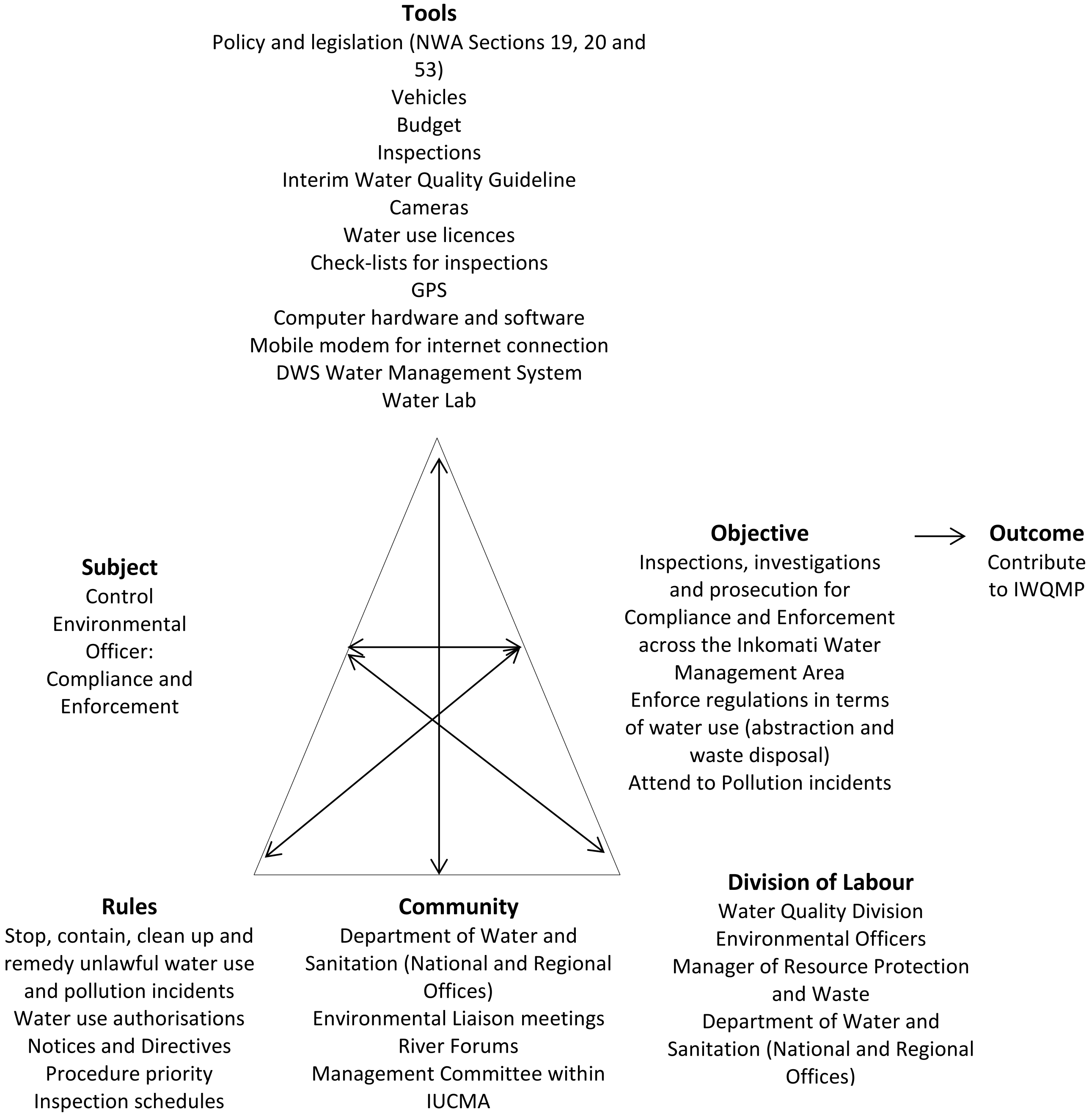
The **tools** used in this activity system include the following: vehicles, data loggers that are installed in the rivers to capture river flows, GIS software, the WARMS system for data capturing, the IUCMA website for providing information to water users and monthly water quantity modelling. The River Operations division also has a checklist for site visits as well as an online log book to track river flow decisions, log requests and solutions. Some procedures are still being developed.

The **rules** that are applied in this activity system include long term and short term rules. Long term rules imply long term planning using statistics of rainfall runoff, in order to run water quantity models. Short term rules deal with short term issues such as expected rainfall and water restrictions uses based on water available. Water quantity data is also collected from installed data loggers and the institution owns gauges. DWS also collects daily average rainfall data. Real time data loggers are also available in the gauging stations which provide data to run daily models. The ICMA gauges can even produce 5 minute interval data when needed. Most river operating rules are developed by the DWS, and the IUCMA adopts and implements them. At the moment, operating rules for the Kaap River are being developed and once those are completed, White River will be next. IUCMA also has agreements with Mpumalanga Parks and SANPARKS (South African National Parks) on on-going collaborative projects such as biomonitoring.

In terms of **community** in which this activity system exists, the manager was involved in a Water Research Commission project that was reviewing different water quantity models. The manager needs to constantly interact with colleagues and consultants, the data-logger provider, co-operate with SANPARKS and DWS, which helps in developing operating rules.

The manager shares tasks with four officials in the division and the current team is sufficient for the work because the models are automated. The division also shares tasks with DWS, other government departments and management committee within the institution. The **outcome** of this activity system is to ensure that river operating rules are developed according to water available and monitoring the river flows to improve water management decisions in relation to climate change and water user demands. This can be integrated with the management of water quality to contribute to the development of an IWQMP for the Crocodile River Catchment.

5.2.5.4 IUCMA Compliance and Enforcement Division activity system



Tools
Policy and legislation (NWA Sections 19, 20 and 53)
Vehicles
Budget
Inspections
Interim Water Quality Guideline
Cameras
Water use licences
Check-lists for inspections
GPS
Computer hardware and software
Mobile modem for internet connection
DWS Water Management System
Water Lab

Subject
Control Environmental Officer: Compliance and Enforcement

Objective
Inspections, investigations and prosecution for Compliance and Enforcement across the Inkomati Water Management Area
Enforce regulations in terms of water use (abstraction and waste disposal)
Attend to Pollution incidents

→ **Outcome**
Contribute to IWQMP

Rules
Stop, contain, clean up and remedy unlawful water use and pollution incidents
Water use authorisations
Notices and Directives
Procedure priority
Inspection schedules

Community
Department of Water and Sanitation (National and Regional Offices)
Environmental Liaison meetings
River Forums
Management Committee within IUCMA
Inter-Governmental Relations

Division of Labour
Water Quality Division
Environmental Officers
Manager of Resource Protection and Waste
Department of Water and Sanitation (National and Regional Offices)

Figure 5.2.5.4: IUCMA Compliance and Enforcement Division activity system (Source: modified from Engeström, 1987:78).

The **subject** of this activity system is the control environmental officer of the C&E division at IUCMA who is responsible for inspections and investigations for compliance, monitoring and enforcement across the Inkomati WMA. The **objective** of the activity system is to enforce regulations that control water use in terms of water abstraction and waste discharge. This involves a process where, if a water user is acting unlawfully such as using water in a manner that is not authorised, DWS enforces Section 53 of the NWA. Once the water use is authorised, the C&E division monitors and inspects in terms of Sections 19 and 20, setting up the possibility of prosecution if there are failures in compliance.

The **tools** used in this activity system are the same as the tools used in the water quality division activity system in section 5.2.5.1. The **rules** that are applied in this activity system include a procedure were a water user that is currently not complying to water use or waste disposal license conditions is requested to stop, contain, clean up or apply recommendations or remedies for compliance. Other rules include water use authorisations for lawful water use that specifies conditions of abstraction and waste disposal, notices, directives or prosecution documents in situations of non-compliance by water users. The C&E officials follow up on site inspections conducted by environmental officers from the water quality divisions were incidences of non-compliance have been noted.

The **community** in which this activity system operates includes the DWS National and Regional Offices, environmental liaising meetings and workshops, Catchment Forum meetings, the management committee within the IUCMA and other government departments.

In terms of **division of labour**, the C&E officials share responsibilities with the environmental officers in the water quality division using a 60/40 ratio. The environmental officers undertake routine inspections and note problems that the C&E officers need to follow up. C&E officers normally do not intervene if there are no issues of non-compliance (this means that if a water user does not have authorisation then the user cannot be deemed as non-compliant and all that can be done is to stop the water use activity). If there is non-compliance, the C&E officers follow up and may sometimes detect issues that are relevant that were missed by the environmental officers.

The **outcome** of this activity system is to ensure that water users in the Inkomati WMA comply with water use authorisations for lawful water use contributing to the protection of the water resource including the Crocodile River, thus contributing to the development of an IWQMP for the Crocodile River Catchment.

5.2.5.5 IUCMA Chief Operating Officer activity system

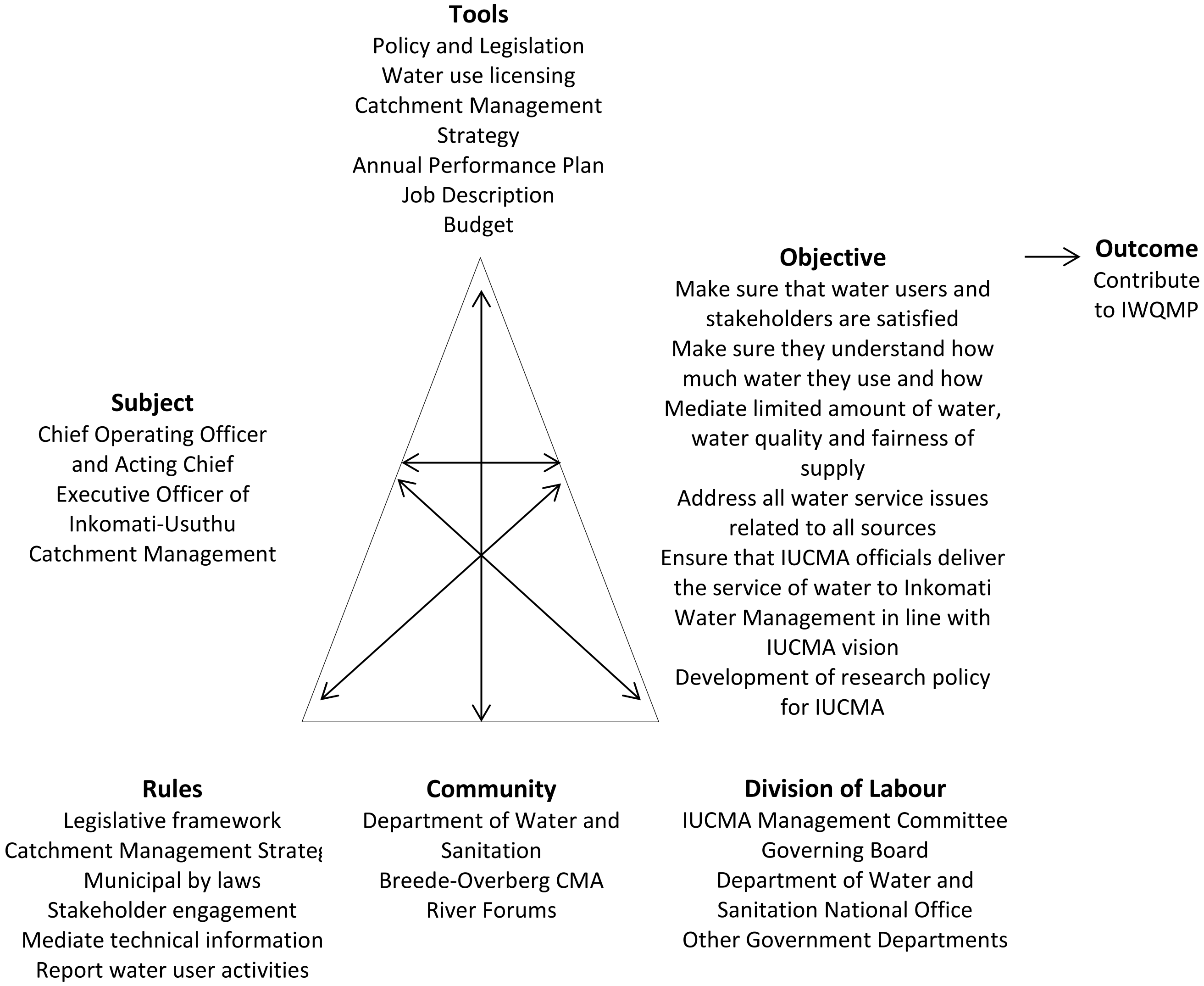


Figure 5.2.5.5: IUCMA Chief Operating Officer activity system (Source: modified from Engeström, 1987:78).

The **subject** of this activity system is the Chief Operating Officer (COO) who is also the Acting Chief Executive Officer (CEO) of the IUCMA, whose **objective** is to ensure that the Inkomati WMA water users and stakeholders are satisfied with the water management outcomes; that water users understand how much water they use and how they use it; as well as ensuring that the IUCMA is an institution that resolves water services issues related to water quality and equitable supply, in line with the IUCMA vision "water for all in the Inkomati" (ICMA, 2014:17).

The **tools** that are applied in this activity system include the CMS which stipulates the strategy for the protection, use, development, management, conservation and control of water resources within the Inkomati WMA, Annual Performance Plan which is a strategy that is developed annually by the Governing Board of the IUCMA with the assistance of the management of IUCMA, that takes into account all relevant policies, legislation and other mandates applicable to the IUCMA, and accurately reflects the performance of the IUCMA each financial year. Other tools include the COO's and CEO's job descriptions, the company policy, budget and water use authorisations.

The **rules** in this activity system include the legislative framework that stipulates the functions of the IUCMA as established in the NWA, the CMS, municipal by-laws that are used in addition to national laws and policy, stakeholder engagement that provides a platform where stakeholder agree that the IUCMA reports on all water use activities in the Inkomati WMA and not only water use activities that might have an impact on the water resource. If there is failure to comply to water use or waste disposal, river forums provide platform for these issues to be discussed, thus shifting the focus from enforcement to providing advice and this is a more co-operative and less adversarial space.

The **community** within which this activity system exists, includes the Department of Water and Sanitation national office; regional and national steering committees, frequent communication, information sharing with the Breede-Overberg CMA; and Catchment forum meetings.

In terms of **division of labour**, the subject of this activity system shares tasks with the management committee within the IUCMA, the Governing Board members, the DWS national office and other government departments. The **outcome** of this activity system is ensuring that all the divisions within the IUCMA work effectively to achieve the functions of the institution in terms of protecting the water resource while maintaining the commitment to generating value for all stakeholders, thus contributing to the development of an IWQMP for the Crocodile River Catchment.

5.2.5.6 IUCMA Communications and Marketing Division activity system

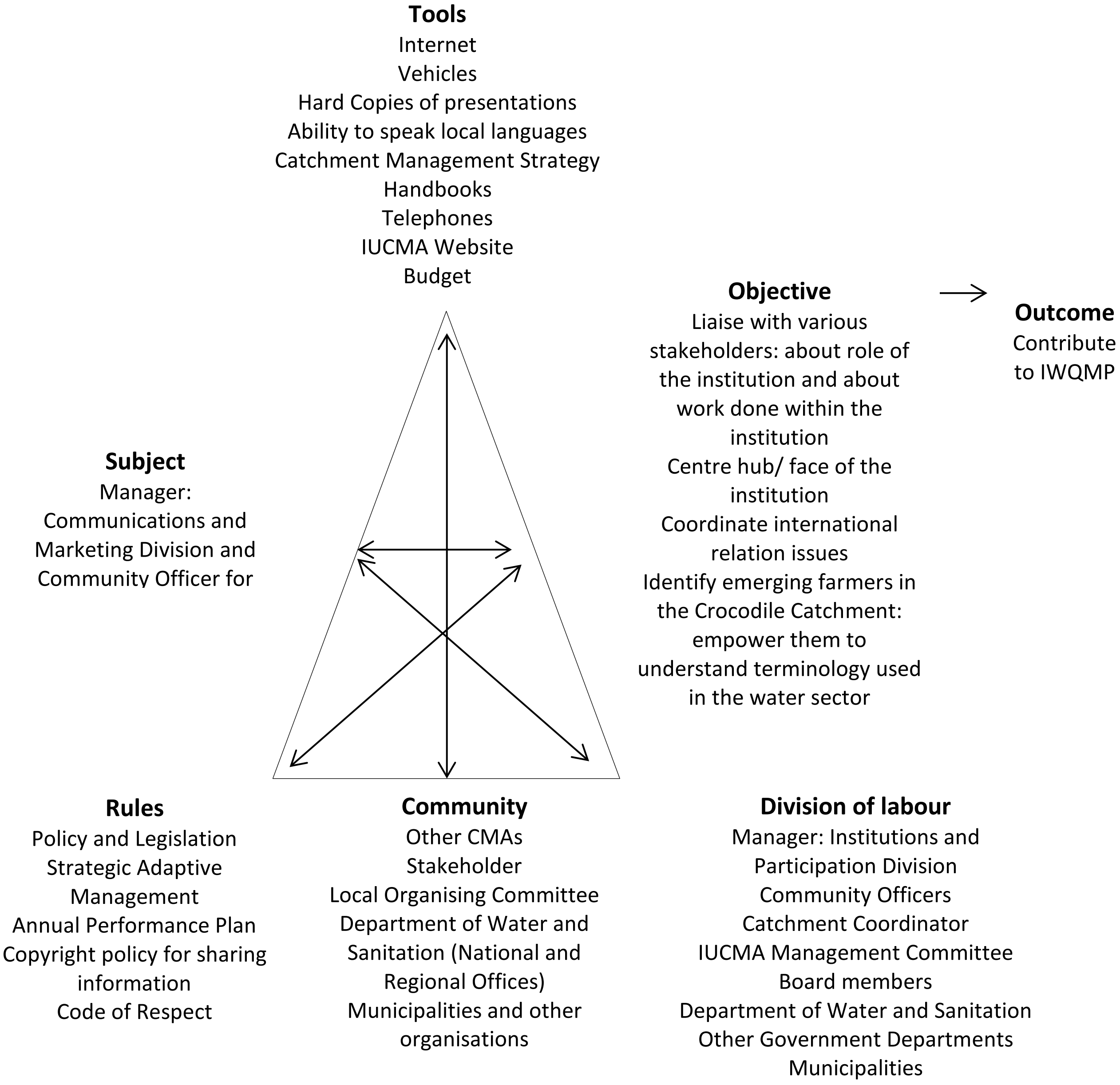


Figure 5.2.5.6: IUCMA Communications and Marketing Division activity system (Source: modified from Engeström, 1987:78).

The **subjects** of this activity system are the manager for the Communications and Marketing Division and the Community Officer for the Crocodile Catchment. The **objective** of the Communications and Marketing Division manager is liaising with various stakeholders such as water users, other government departments (Department of Agriculture, Department of Water and Sanitation, Department of Environmental Affairs, Department of Health, Department of Cooperative Governance, Department of Mineral Resources, Department of Human Settlements) and municipalities. The manager can be described as a centre fold (hub) or the face of the institution; communicating with other stakeholders about the role of the institution as well as work done within the institution in a way that can be understood by a lay person through the use of media. The manager is also responsible for coordinating international relation issues and this has been difficult because her technical skills for this job have been questioned by the management of IUCMA.

The **objective** of the Community Officer is to identify emerging farmers and empower them to understand terminology used in the water sector. Gaps were identified during stakeholder engagement meetings where some members of the communities and farmers could not understand the language of the water value chain. Technical terms were difficult for them to grasp so the communications team has started presenting information in a way that they can understand. This is done to enable them to engage with any water quality information reported to them by the institution or other relevant institutions. This has been the key success story for the communications and marketing division.

The **tools** used in this activity system include the following: the internet as a vital tool for the communications and marketing division. Vehicles are important to be able to hand deliver invitations to events. Printed hard copies of presentations were requested by the stakeholders. It is also essential to be able to communicate in the local languages (Siswati and Tsonga) or provide translations. At the moment English is translated to only one of the local languages but the team is working on translating to both languages. The Catchment management strategy is also being disintegrated into brochures that will be translated into local languages. A handbook is also being developed that will report on the function and establishment of the catchment forums. Telephonic communication and the institutions' website are also important tools.

The **rules** used in this activity system include formal rules such as the NWA as the key piece of legislation, Strategic Adaptive Management, the Annual Performance Plan and copyright policy for sharing information, as well as informal rules such as a deep code of respect.

The **community** within which this activity system operates includes informal communication with other catchment management agencies, which has been supported by the COO of the IUCMA. Engagement with other stakeholders occurs on a need-to-know approach. The IUCMA communication team has a local organising committee that also organises an event during the national water week and invites the Department of Water and Sanitation, municipalities and other organisations. The IUCMA also organises events for stakeholders.

In terms of **division of labour**, the technical teams (from the water quality division and river operations and data management divisions) within the IUCMA provide information that should be presented in newsletters about the activities of the institution. The essence of the information should be the work done by the core function. Information provided by the research partners and stakeholders is also presented. The **outcome** of this activity system is to ensure information sharing and stakeholder engagement in terms of water management issues in the Inkomati WMA and specifically within the sub-catchments. This outcome contributes to the development of the IWQMP of the Crocodile River Catchment.

Sections 5.2.5-5.2.5.6 above gave descriptions of the IUCMA as an activity system. This interpretation was necessary to provide an understanding about how the institution serves as a rule-producing activity system that governs water management practices in the Inkomati WMA and to understand the smaller activity systems that interact to form the whole IUCMA activity system. The next section of this chapter provides a synthesis of contradictions that exist within the sugar industry activity system and the contradictions that exist between the sugar industry activity system and the IUCMA activity system in relation to the development of an IWQMP for the Crocodile River Catchment.

5.3 Surfacing contradictions within each sugar industry activity system in relation to IWQMP

The information presented in this section was produced through an interpretation process using an analytical tool represented in Table 5.3 below (modified from Jonassen and Rohrer-Murphy, 1999:73). The analytical tool incorporates diagnostic open-ended questions based on various components of the activity system as shown in the table.

Table 5.3 shows the various components of an activity system and indicates the relevant questions to ask when translating the activity system in relation to water management practices being examined in the study. Using the analytical tool to answer the questions in relation to water management practices assisted in pin pointing areas of focus for the second level investigation and analysis of the water management practices of the sugar industry in relation to water quality management in the Crocodile River Catchment. This enabled the surfacing of primary and secondary contradictions within the sugar industry. This section presents results that respond to sub research question b) of this study.

Table 5.3: Analytical Tool (modified from Jonassen and Rohrer-Murphy, 1999: summarised)

Component of Activity System	**Analytical questions**
Subject	• Who is/should be involved in IWQM? • What are their roles? • Do subjects have sufficient skills to use the available tools effectively in support of IWQM? (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 and artefacts are in place & being used to support IWQM? • Are the tools in use well suited to IWQM? • In what ways are the tools in use constraining or influencing IWQM? • What other tools could be needed for the work? What knowledge and skills are needed? Are they present? Can they be sourced? From where? How and by who? • How readily available are the tools?
Rules	• What socio-historical norms and rules govern IWQM • What are the formal rules (manuals, standard operating procedures, etc.) that promote or IWQM? • What are the informal (cultural) rules that promote or constrain IWQM? • What are the other structures that shape the way the work is done around IWQM? • What other systems must supply inputs in order for the IWQM work to proceed? How are all these systems connected to IWQM? • What other implicit (invisible or (un)discussible) events and circumstances shape IWQM? • Between whom are they (un)discussible? What rules, roles, tools, objects and histories mediate these undiscussibles?
Division of Labour	• Who does what, who should do what in IWQM? Who does what in the organization/institution in relation to IWQM? • Does this matter, or is it merely a sensible division of labour? • In what ways does the division of labour constrain or enable IWQM? • Is there any need to share the work of IWQM in a different way? Why and how?
Community of Practice	• Who else is involved/should be involved and how in IWQM? • How does location in the system affect you and you affect it? • How do conflicts in your location/community affect/influence interactions? • How do other water users around you view and value the goals of IWQM?

5.3.1 Contradictions within the Sugar Mill activity system

The primary contradiction that exists within the sugar mill activity system relates to the subjects and their role in the activity system in terms of achieving the objective of the activity system. In terms of the sugar manufacturing process at the sugar mill, the subjects are responsible for their sections and only have control in decision making related to water management in their designated roles. The operation engineer only has control to make water related decisions relevant to his role and does not have control over other areas such as mechanical engineering. The operation engineer explained that, "I am in charge of supplying water to the sugar mill and producing drinking water from the same source; the energy producing section is controlled by the mechanical engineer" (TSB Sugar mill Representative, personal communication, 2013a).

There is also a secondary contradiction in this activity system that is related to the rules in the activity system. There is a disagreement between the sugar mill and the IUCMA about where the IUCMA water quality monitoring point should be located. The employees of the sugar mill believe that the IUCMA water quality monitoring point should be located at the sugar mill's water abstraction point from the Crocodile River and not a point at Malalane Bridge as stated by the IUCMA. One of the participants stated that, "The IUCMA monitoring point is actually the sugar mill's abstraction point and not at the Malelane Bridge" (TSB Sugar mill Representative, personal communication, 2013b). This secondary contradiction can evolve into a tertiary contradiction between the sugar mill activity system and the IUCMA activity system.

5.3.2 Contradictions within the Grower Affairs Division activity system

The primary contradictions that exist in this activity system relate to the tools of the activity systems and how the tools are applied differently by emerging and commercial farmers that are managed by the Grower Affairs Division. Emerging farmers are sometimes not able to comply with water use restrictions because they do not have flow meters to record their water use due to lack of funds. Emerging farmers also have fewer security measures on their sugar cane fields; they also mostly stop irrigating after 4pm each day, leaving the equipment unattended and there is no security which results in cable theft and this often results in the farmers remaining out of commission for long periods. The participant explained that, “Small growers may refuse to put in water meters. There is also more cable theft, because most of the small growers leave the project premises at 4pm, so there is no security at the pump stations” (Grower Affairs Division representative, personal communication, 2013).

These primary contradictions can evolve into secondary contradictions between the tools and rules in this activity system because the absence of a tool for the emerging farmers will make it difficult for the Grower Affair Division to apply monitoring rules in terms of managing water efficiency of emerging farmers.

Some commercial sugarcane farmers do not have soil moisture gauges because they cannot afford them and the farmers use an irrigation scheduling system; however there is still some degree of inefficiency because the amount of water that is need by the soil is not currently being tested by the farmers that do not have soil moisture gauges.

Another primary contradiction that exists within this activity system is that the water that the farmers abstract from the Crocodile Gorge canal often has poor quality which leads to blockages in irrigation systems particularly the drip irrigation. Drip irrigation is the most water efficient irrigation system. However, most farmers are forced to convert to other irrigation systems such as overhead irrigation due to high maintenance costs of drip irrigation and lack of funds to purify the water before irrigation. The participant stated that, “Manganese clogs the dripper system, it forms a gel inside the pipes and the farmers have to stop irrigating and use harsh chemicals to flush with” (Grower Affairs Division representative, personal communication, 2013).

5.3.3 Contradictions within the Siyathuthuka Project farmer activity system

The sugarcane emerging farmers that are part of this project do not have a formal irrigation scheduling system to monitor consumption. One participant explained that, “we use our knowledge on rotating irrigation between the plantation blocks, maybe irrigating on three plantation blocks on a particular day and then the next day you irrigate the other blocks” (Siyathuthuka farmer, personal communication, 2014). This is a primary contradiction within the tools component of this activity system and it can evolve into a secondary contradiction that results in a clash between the rules and tools of this activity system because the absence of a tool such as a monitoring schedule will make it difficult to develop or comply with monitoring rules.

As mentioned under the Siyathuthuka Project emerging farmer activity system (section 5.2.3.1), each farmer has a particular volume allocated to them which is provided by the irrigation board and each farmer should use water within this allocation. However, most emerging farmers do not have flow meters to monitor their abstraction volumes. Even though the soil moisture meters inform the farmers on how much to irrigate, they do not know whether they have exceeded their allocated volumes.

The farmers also do not have access to the water pumps because they are locked and they do not have control over how much water is allocated and they are not responsible for paying the water bill. One participant specified that, "I receive my water allocation from the Crocodile River through the canal and I receive about 22 m^3/ day for irrigation but I cannot control how I use this water because the pumps are locked" (Siyathuthuka farmer, personal communication, 2014). TSB controls the payments and the maintenance of the equipment. This contradiction may result in a constraint in terms of water management decisions within this activity system because the farmers to not have powers to make decisions that can improve water management.

The subjects of this activity system also do not have sufficient skills to use available tools effectively without prior training due to poor literacy skills and lack of technical knowledge. The subjects often use indigenous knowledge or experience as their skills base.

5.3.4 Contradictions within the Lomshiwo Individual emerging farmer activity system

The individual emerging farmers in this activity system abstract water directly from the Crocodile River and pump the water into storage dams. One of the farmers uses a sprinkler irrigation system and experiences blockages in the irrigation pipes due to poor water quality. The farmer also believes that the system would improve if he had a powerful pump to run the system. He feels this system is not efficient because it wastes water when it is does not have blockages. He sometimes experiences periods were he cannot irrigate when the pump is not working. This is a primary contradiction within the tools component of this activity system that results in a constraint in water management decisions.

5.3.5 Contradictions within the Tikhontele emerging farmer activity system

The primary contradiction identified in this activity system relates to the division of labour component. The Tikhontele Co-operative emerging farmers have a committee with a chairman who makes all the decisions on behalf of the members of the project and the farmers feel that the committee is not productive because they do not have regular meetings anymore. The chairman wants to make all the decisions for the project and he refused to have a vice-chairman to assist when he is not available so every decision that needs to be made has to wait until the chairman is available. One participant indicated that, "the chairman wants to make all the decisions for the project and he refused to have a vice-chairman to assist when he is not available" (Tikhontele farmer, personal communication, 2014). This affects water management decisions made within this activity system.

5.3.6 Contradictions within the Crocodile Gorge Canal commercial farmer activity system

The primary contradictions that have been identified within this activity system relate to the community and the tools of this activity system. At the moment, there is no explicit platform available for the commercial farmers to discuss water quality issues, since issues are only raised at the irrigation board meetings if the farmers have a specific issue to raise for discussion, and the irrigation board mostly prioritises water quantity. The participants responded and said the following about how water quality issues are discussed in the catchment (Crocodile Gorge Canal Commercial Farmers, personal communication, 2014):

"No I do not have any discussions with other farmers about water quality. Most farmers just accept problems with water".

"I do not think there is a platform to discuss water quality issues I face, I am happy that there is someone coming to talk about water quality issues because each farmer adapts to situations by themselves".

"Yes we discuss water quality issues at the Mpumalanga Cane Growers Association around a braai with beers".

"We only discuss water quality issues informally, no study group available".

There is also no integration within the commercial famers on what measures to take to resolve water quality issues; they often just opt to use irrigation systems that are not affected by water quality issues and they feel that they cannot do anything to change water quality issues.

Not all farmers have soil moisture gauges because they cannot afford them and the farmers use an irrigation scheduling system; however there is still some degree of inefficiency because the amount of water that is need by the soil in not currently being tested by the farmers that do not have soil moisture gauges.

The commercial farmers used to have study groups where they would share knowledge on how to handle water quality issues and address how they can improve water use efficiency, but the groups do not exist anymore although they were useful.

Water quality affects the irrigations systems they use, by affecting water use efficiency and this influences the decisions the farmers make in terms of water management. Most farmers do not have a water treatment system because they cannot afford it. Water quality is mostly monitored specifically for fertilizer and herbicide application. Buffers are often used to control high pH levels in the water or the soil before fertilizer or herbicide is applied.

Another primary contradiction that exists in terms of the tools that are available in this activity system is the lack of pollution warning mechanisms from upstream to inform the farmers of spills that could affect the quality of the water they receive and there is currently no penalty system in the Crocodile River catchment for polluters.

5.3.7 Contradictions within the Privately Owned Canal commercial farmer activity system

In this activity system, the primary contradiction exists within the tools component. Water quality monitoring is highly prioritised for citrus production rather than sugarcane because of strict export standards. The participant stated that, “Stricter measures are in place for standard of water quality specifically for citrus production, I resume this is still coming for sugar cane” (Privately owned canal commercial farmer, personal communication, 2014). However, this water is used to irrigate nurseries for the sugarcane to ensure that the seedlings are in good condition before planting.

Water quality affects the irrigation systems they use, affecting water use efficiency and this influences the decisions they make in terms of water management as well as affecting future planning and farming practices.

5.3.8 Contradictions within the TSB and Community Joint Venture commercial farmer activity system

The primary contradiction that has been identified within this activity system relates to the community within which this activity system exists. At the moment, water quality issues are not discussed explicitly, and issues are only raised at the irrigation board meetings, where water quantity is primarily prioritised.

5.3.9 Contradictions within the IUCMA Water Quality Division activity system

This section presents results that respond to sub research question c) of this study. The primary contradictions identified in this activity system that relate to the tools component of this activity system include the following:

- The environmental officers sometimes have difficulties when conducting site inspections in mines were they are required to climb up tailing dams for visual inspections.
- The water quality division at the IUCMA does not monitor groundwater in the sub catchment, so they often rely on groundwater data from the water users. This primary contradiction can evolve into a secondary contradiction between tools and rules because if the IUCMA does not have adequate groundwater data it will be difficult to prove that a certain water user is not complying.
- Financial constraints, which are caused by a limited budget provided to the IUCMA by DWS, have often limited the work done by the water quality division. One of the environmental officers indicated that, “Our travelling has been limited due to budget cuts” (IUCMA Water Quality Division Representative, personal communication, 2013). This has also resulted in big companies being prioritised for site inspections instead of the smaller companies in the catchment.
- Some of the water use activities in the sub catchments have only recently been inspected, such as TSB water use activities and water use activities of a number of lodges. Ideally all water user activities in the catchment should be monitored, but this is often not the case. One of the environmental officers hared that, “We only recently started having site inspections at the sugar mill” (IUCMA Water Quality Division Representative, personal communication, 2013).

- When monitoring water user activities that have not been monitored before, it often takes three inspections to fully understand the water use activities. This can result in a secondary contradiction between the tools and the rules components because an environmental officer may not be able to provide adequate recommendations on the inspection report if the water use activities are not yet fully understood. This can also result in the officers missing signs of non-compliance.
- The RQOs are in the process of being set for the Inkomati WMA and because of this the IUCMA uses Target Water Quality Guidelines that were developed through the Crocodile River Forum with assistance from DWS. However, the other sub catchments do not have these guidelines so the tools used within the Inkomati WMA are not standard. A secondary contradiction between tools and rules component can evolve here because the absence of standard water quality guidelines can affect the integration of water quality management in the WMA. At the time of writing this thesis, the RQOs for the Inkomati WMA were in the process of being established.
- The DWS has not assigned all functions of water management to the IUCMA according to the NWA. Sections 19 and 20 of the NWA have been assigned, however Sections 53 and 54 are delegated functions. Due to this the environmental officers in this activity system can process water use licenses but the licenses are signed off by DWS. This primary contradiction evolves into a secondary contradiction between the tools, rules and objective of this activity system, because it affects the ability of the water quality division to function fully and it often leads to confusion amongst water users in term of what role the IUCMA is playing in water management in the WMA. This primary contradiction can also lead to a third generation contradiction between the IUCMA activity system and other water user activity systems.
- The environmental officers in the water quality division do not have 3G internet modems and when they are out of town they cannot communicate with water users or colleagues in the office.

The primary and secondary contradictions mentioned above lead to constraints for the environmental officers and often affect the quality of work they can do.

5.3.10 Contradictions within the IUCMA Resource Protection and Waste Management activity system

The water management decisions that can be taken in this activity system are limited by the fact that the IUCMA has delegated and assigned functions and this can result in a primary contradictions in the tools component of this activity system because the officers can take a water use activity through the water use license application process and make recommendations towards compliance but they cannot approve and sign off the water use license. The manager stated that, "This is the heart of the problem as we cannot take the process of water use licenses through to signing of the licence and recommendations for movement towards compliance because DWS signs it off" (IUCMA Resource Protection and Waste Manager, personal communication, 2013).

Another primary contradiction within the tools component is that the IUCMA environmental officers currently cannot access the WMS system to capture or retrieve data because the system is still housed at the DWS regional office. The manager indicated that, "In this regard there is a limitation in functioning as IUCMA officials are not yet empowered to directly access and load data on the WMS system" (IUCMA Resource Protection and Waste Manager, personal communication, 2013). This primary contradiction evolves into a secondary contradiction between the tools and the objective of this activity system because the officers need to prepare water quality monitoring presentation using the data and make follow-up inspections based on the data.

In terms of division of labour within this activity system, the IUCMA has regular management committee meetings and at these meetings the manager of Resource Protection and Waste, realised that the IUCMA support staff, did not understand the work done by the water quality division even though this division is the core function of the institution. This has been addressed by conducting induction meetings were each division at the IUCMA is expected to present and explain their role in the institution.

The institution also deals with difficulties with inter-governmental co-operation which result in a primary contradiction within the division of labour in this activity system because key government departments and municipalities do not communicate with the IUCMA effectively, thus limiting the institution's effectiveness in dealing with issues that need collaboration. Examples include water use issues related to agricultural land use that need to be addressed with the Department of Agriculture, or water use activities related to mining processes such as closed mines that are decanting. The manager stated that, “the inter-governmental relationship framework does not work well, which limits IUCMA effectiveness in dealing with issues to do with land use by agriculture or mining” (IUCMA Resource Protection and Waste Manager, personal communication, 2013).

Regarding the community in which this activity system exists, there are also a number of primary contradictions such as the lack of training (including orientation and training courses) that used to be provided by the DWS to the Resource Protection and Waste Division. A senior level position within the DWS Resource Protection and Waste Division at National office was vacant at the time of writing this thesis and thus there is therefore no interface about whether the policies used in the division are still relevant.

5.3.11 Contradictions within the IUCMA River Operations and Data Management activity system

The water management decisions made within this activity system are affected by a number of contradictions that exist within the activity system which include budget constraints that are experienced by the institution. This affects operations within this activity system. Another contradiction is that that some members of the Governing Board of the IUCMA often do not have adequate knowledge about the importance of prioritising this division as part of the core function of the IUCMA which affects the management decisions. The manager stated that, “the Governing Board does not make things easy since most of them do not have the knowledge of water issues” (IUCMA River Operations and Data Management Manager, personal communication, 2013).

Concerning the division of labour within this activity system, there is also lack of integration between the River Operations and Data Management division and the Resource Protection and Waste division within the IUCMA; this is currently being addressed through the development of a model that will integrate these divisions. River Operations and Data Management division also does not often receive needed support from the finance, human resources or corporate services divisions while these divisions have ample staff, the core function divisions still have positions that have not been filled. “The water quality and water quantity sectors are not integrated in the IUCM hence we need a budget to run a model that will integrate the two sectors" (IUCMA River Operations and Data Management Manager, personal communication, 2013).

In terms of the tools used in this activity system, the division uses a monthly model to monitor the flows in the Crocodile River and a daily time step model needs to be applied to improve accuracy; however, DWS sets the rules and the models and the IUCMA is forced to apply the tools DWS provides. "I need to do away with some tools especially the monthly model, I need to adopt the daily time step model but since DWS set the rules and the models, we are forced to work with it" (IUCMA River Operations and Data Management Manager, personal communication, 2013). The internet in the IUCMA also needs to be upgraded to provide the high speed required to run the models used in this division; however this is not prioritised by the management committee within IUCMA.

5.3.12 Contradictions within the IUCMA Compliance Monitoring and Enforcement Division activity system

The objective of this activity system is to enforce regulations that control water use in the Inkomati WMA in terms of water abstraction and waste discharger; however, due to the fact that the IUCMA has delegated and assigned functions, the Compliance Monitoring and Enforcement division cannot fully exercise its responsibilities. The water management enforcement decisions that can be taken under this activity system are limited because if a water user is using water unlawfully, the IUCMA has to wait until DWS enforces Section 53. Once that is done then the division can implement Section 19 and 20. This process is not efficient and results in a primary contradiction in the tools component of this activity system. Financial constraints in terms of limited budget provided to the IUCMA have also affected this division.

In terms of division of labour, the DWS still controls the WMS system for capturing water quality monitoring data and the C&E officers struggle to re-assess relevant data due to lack of access. It is often difficult to get the data when it is needed to prepare graphs for water quality reports. "We have to upload the WMS data at the regional office which check it and it is not easy to re-assess relevant data when needed, due to this it is hard to prepare maps and graphs for reports" (IUCMA Compliance Monitoring and Enforcement Division Representative, personal communication, 2013). The DWS national office used to provide training in the shape of an orientation course for C&E officers, but this training is no longer available. The C&E officers often experience issues related to procurement of items they need to conduct inspections or collect samples such as sealable bags that are need for water samples that are collected specifically for prosecution.

The C&E officers have basic training on how to conduct enforcement but they are not professionally trained as lawyers so they are not specialists in terms of prosecution. This is a primary contradiction between the subjects of this activity system because they might not have sufficient skills to effectively use some of the tools at their disposal to support water management decisions.

5.3.13 Contradictions within the IUCMA Chief Operating Officer activity system

The main constraint that limits the water management decisions in this activity system is the limited power of the IUCMA. The DWS views the IUCMA as competition but DWS does not have the capacity to perform regional water management duties. Another primary contradiction within this activity system relates to the tools. The IUCMA often experiences budget cuts which are instituted by DWS National office, with no consultation with IUCMA management. “Sometimes our budget is cut with no consultation and with no chance to discuss” (IUCMA Chief Operating Officer, personal communication, 2013). IUCMA also needs to develop and implement a river health programme which has not been successful so far.

5.3.14 Contradictions within the IUCMA Communications and Marketing Division activity system

The IUCMA is divided into divisions that have specific objectives and professionals within the institution are divided according to their roles. However this has created an undermining space between colleagues from the technical team and support function team within the institution. This is a primary contradiction within the subjects of this activity system; currently it is being addressed through the implementation of Strategic Adaptive Management (SAM). SAM has provided a shift in the institution because in the past colleagues didn’t think that collaboration between the different divisions was important. For example, the Human Resources officials often did not understand Integrated Water Management but they were often expected to represent IUCMA at meetings and workshops. The introduction of SAM has caused a shift and support staff are being seen as primary to the institution. The Human Resources also takes initiative to attend meetings about the processing of water use license applications, since the use of SAM as an intervention.

In terms of division of labour, a primary contradiction exists within this activity system which emerged when an Equity Working Group was established within the IUCMA after the development of the Catchment Management Strategy. The Equity Working Group includes officials from the Institution and participations division, Office of the CEO and the Communications and marketing divisions at the IUCMA. This group is responsible for making sure that valuable information is accessible to the disadvantaged communities. However, the efforts of this group have not been adequately communicated to the other divisions within the IUCMA. There is an opportunity to explore the interface of the Equity Working Group with the water quality division in the IUCMA.

The Communications and Marketing manager has also expressed difficulty in sharing information within the IUCMA and in getting relevant information to report to stakeholders as some issues may not be reported to her. Her job requires a good community of practice to keep her in the loop of information that should be communicated to the community. “The team used to do profiles on individuals within the institution but it became really sensitive because other staff members would complain why they were not profiled” (IUCMA Communications and Marketing Division Representative, personal communication, 2013). These include issues such as water pollution incidents that are reported to the institution where a report or feedback is required by stakeholders on how the matter was resolved for record purposes.

Another primary contradiction within the division of labour component is the difficulty to liaise with senior officials in other government departments or companies because they undermine the Communications and Marketing manager’s professional position. It is often necessary for the Communications and Marketing manager to be accompanied by the COO of IUCMA to other stakeholder engagement meetings for her to be taken seriously. Other departments require the Communications and Marketing manager to go to their offices for them to respond and municipalities can be difficult to work with.

5.3 Third Generation Analysis: contradictions between sugar industry activity system and Inkomati-Usuthu Catchment Management Agency activity system in relation to IWQMP

In this section, third generation activity theory as outlined in Chapter 3, Section 3.1.5 is used to describe contradictions between components of activity systems with a shared objective, the Sugar Industry activity system and the IUCMA as a rule-producing activity system (Figure 5.3). This section presents results that respond to sub research question c) of this study.

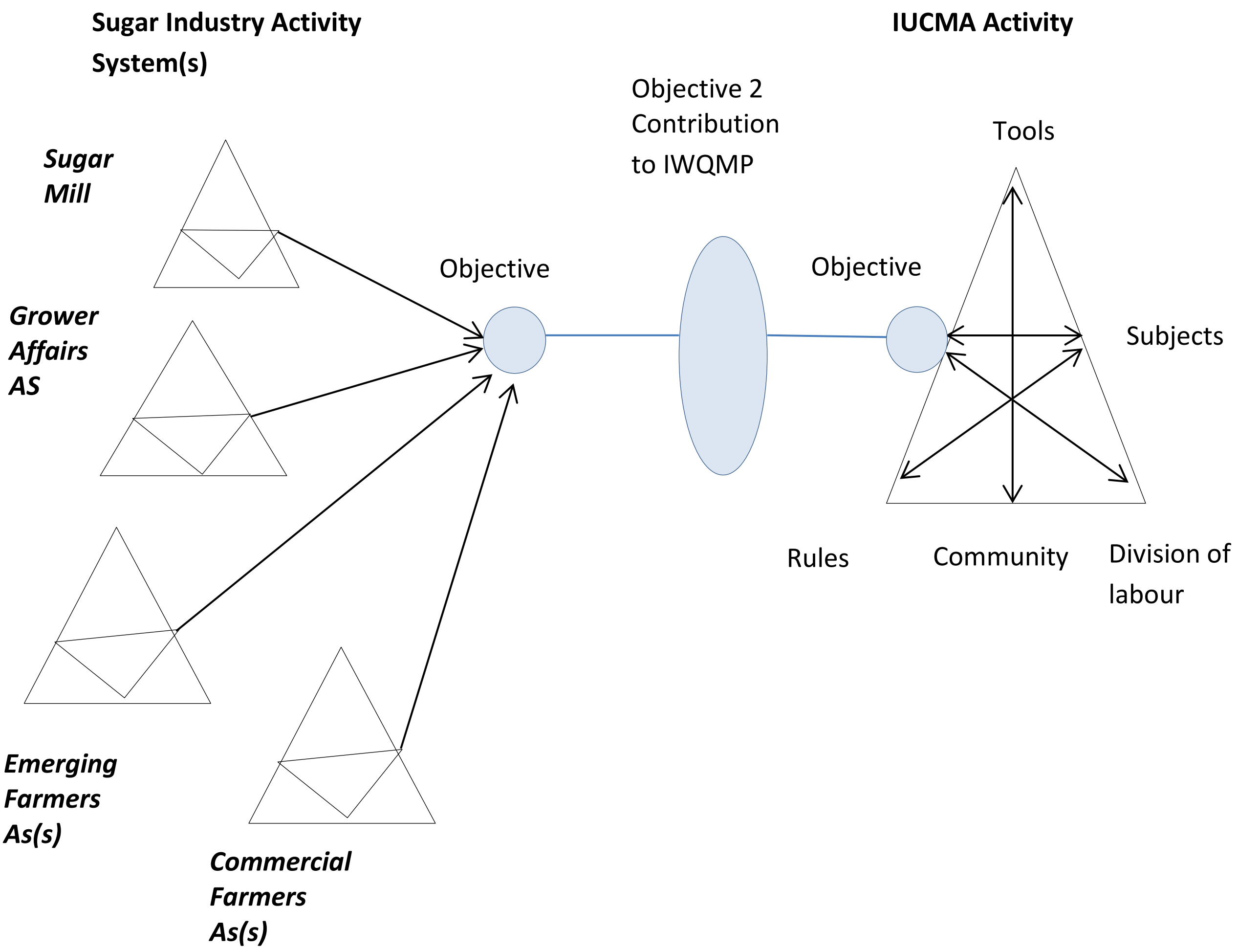


Figure 5.3: Activity Systems that make up the Sugar Industry interacting with the IUCMA activity system with a shared objective (Source: Jonassen and Rohrer-Murphy, 1999:67).

As depicted in Figure 5.3 above, the activity systems that make up the sugar industry have an objective to achieve (defined as objective 1 in this interaction) which is to produce sugarcane in a sustainable manner by ensuring water efficiency in sugarcane irrigation, to produce good quality sugarcane, and to reduce the amount of water used in sugar manufacturing. On the other hand, the IUCMA has an objective to protect the Crocodile River as a water resource by implementing policy and legislation in the NWA.

As mentioned in Chapter 1, Section 1.5, the sugar industry is a downstream water user within the Crocodile River Catchment and it is affected by the activities of upstream water users, and is thus dependent on the stakeholders upstream participating in effective management of the resource. This has motivated the sugar industry to participate in the development of an IWQMP for the Crocodile River Catchment as an investment to improve in-stream water quality. The IUCMA also invested in participating in the development of an IWQMP for the sub catchment and being appointed the implementing agent of the plan once it is developed. The IWQMP will contribute to the IUCMA's objective of protecting the water resource. These activity systems interact and contribute to the development of the IWQMP as a shared objective (depicted as objective 2 in Figure 5.3).

Third generation activity theory was used to identify contradictions that exist between components of these interacting activity systems and most of tertiary contradictions that evolve from primary and secondary contradictions that exist within the components of each activity system. These third generation contractions are described below:

- The absence of a tool such as flow meters within the emerging sugarcane farmer's activity system evolves into a clash between the tools component of the sugar industry activity system and the rule component of the IUCMA River Operations and Data Management Division activity system. If the emerging farmers cannot measure the amount of water they use for irrigation then it will be difficult for them to comply with water restrictions set by the Crocodile River Operations Committee as a rule in the IUCMA River Operations and Data Management Division activity system.

- The lack of an adequate groundwater monitoring system from the tools components in the IUCMA Water Quality division activity system results in a third generation contradiction because the institution cannot adequately monitor environmental impact from the sugar industry that would be a result of any chemicals in fertilizers or herbicides leaching into groundwater sources and affecting groundwater quality. The groundwater monitoring that is a tool in the sugar mill activity system is used specifically to monitor environmental impact from the land fill at the sugar industry and not to monitor leaching from the sugar plantations.

- The financial constraints that are experienced in the IUCMA Resource Protection and Waste Division have affected the work of the officials within this activity system. It has also resulted in low inspection rate of various water use activities in the catchment. Inspection of water use activities at the sugar mill has also only started about a year ago.
- The lack of standard water quality guidelines such as RQOs as a tool in the IUCMA Resource Protection and Waste Division activity system has resulted in a clash between the tools component of this activity system and the rules component of the sugar industry because the IUCMA uses Interim Water Quality Guidelines that might be either too lenient or too strict. This secondary contradiction evolves into a tertiary contradiction and the IUCMA Resource Protection and Waster Division activity system is also interact with other activity systems other than the Sugar industry. For example the DWS activity system that is not described in this thesis as a form of tool producing activity system (responsible for establishing Resource Quality Objectives that are supposed to be used instead of the Interim Water Quality Objectives). This contradiction arising between the IUCMA activity system and the DWS activity system disturbs the interaction of the IUCMA activity system with the Sugar Industry activity system.

- The difficulties with inter-governmental co-operation faced by the Water Quality Division cause clash between the components of the IUCMA activity system and the Sugar Industry activity system because lack of co-operation from municipalities and poor performing Waste Water Treatment Works (WWTWs) results in poor water quality received by the sugar industry.
- The use of monthly time step instead of daily time step in the model used as a tool in the IUCMA River Operations and Data Management Division activity system

affects the accuracy of flow calculations that are implemented in the Operating rules to set water restrictions for the sugarcane farmers.

- The secondary contradiction about the disagreement between the sugar mill and the IUCMA about where the IUCMA water quality monitoring point should be located evolves into a third generation contradiction because it creates a clash between the tool component of the IUCMA activity system and the rule component of the sugar industry.

The third generation contradictions presented above provide opportunities for learning and change; they also provide areas of focus to consider in the development of an IWQMP for the Crocodile River Catchment by describing the areas that need to be addressed in the components of each activity system. An effort of collective change between the IUCMA and sugar industry is needed in terms of what particular actions they can take to address these contradictions to improve their ability to contribute to the shared objectives.

5.4 Conclusion

This chapter has provided a description of management practices of the sugar industry in the Crocodile River Catchment in relation to water quality management through the use of second generation activity theory framework. A typical sugar industry activity system and its elements were described from the point of view of emerging farmers, commercial farmers, the Grower Affairs Division at the sugar mill and the sugar mill Risk Control Division using a second generation framework.

The different interacting activity systems within the sugar industry were then presented and described, providing a fuller understanding of their interaction with the central activity system. The description of the interacting activity systems within the IUCMA activity system also provided a fuller understanding of the institution as a rule-producing activity system. Surfacing contradictions within the sugar industry activity system and IUCMA activity systems highlighted areas of potential for change and the third generation analysis provided a description of how these contradictions can lead to clashes between the components of these activity systems relating to water quality management in the Crocodile River Catchment.

This has made evident the need for elucidation of water quality description for the sugar industry as a stakeholder need stipulated in Sections 5.3.2, 5.3.6 and 5.3.9. Firstly as a need to clarify how water quality affects irrigation of sugarcane plantations and identifying particularly water quality threats specific to sugarcane production. Secondly, providing detailed water quality information related to the sugar industry for the commercial sugarcane growers to improve communication of these issues at existing communication structures such as irrigation board meetings. Thirdly, as provision of in-depth preliminary information of the sugar industry that had only been recently monitored industry by the ICMA, to improve quality of recommendations on the inspection reports if the water use activities do not comply with water management requirements. Chapter 6 below provides a description of the disaggregation of water chemistry monitoring data in the perspective of the water quality impact on the sugar industry and the impact of the sugar industry on the in-stream water quality of the river below the industry.

CHAPTER 6

The Sugar Industry in relation to the water quality system of Crocodile River Catchment

6.1 Introduction

In Chapter 4, Section 4.1 the water quality needs of the sugar plantations and sugar mills were described in detail. The chapter highlighted the various impacts of poor water quality on sugar plantations (such as crop yield, crop quality, soil suitability and effectiveness of irrigation equipment) and sugar mills (efficiency of boilers, quality of cooling water and make-up water). The chapter also described the water quality impacts of sugar plantations and sugar mills, highlighting the various sources of environmental impacts relative to key processes and inputs in the cultivation and processing of sugarcane.

Chapter 5 followed on to present a description of the management practices of the sugar industry in the Crocodile River Catchment (sugar mill and agricultural practices of the sugarcane fields) as activity systems, in relation to water quality management to provide an understanding of the water quality management processes within the sugar industry. The chapter also presented the IUCMA as a rule-producing activity system that governs water management practices in the Inkomati WMA, as well as an analysis of contradictions that exist within the sugar industry activity system in relation to the development of an IWQMP for the Crocodile River Catchment and the contradictions that exist between the sugar industry activity system and the IUCMA activity system in relation to the development of an IWQMP. These two chapters aid in understanding the social processes that influence water management within the sugar industry as well as processes that influence the role of the IUCMA in water management in the WMA.

Chapter 6 will focus on the biophysical context of water quality in the Lower Crocodile catchment where the sugar industry is located. A description of the disaggregation of water chemistry monitoring data will be presented in the perspective of the water quality impact on the sugar industry and the impact of the sugar industry on the in-stream water quality of the river below the industry. The data that are interpreted in this chapter is part of Mr Hugo Retief's MSc Research focusing on investigating integrated catchment management scenarios using a 'simple' water quality and quantity model: A case study of the Crocodile

River Catchment, South Africa (Retief, 2014). The data are used to discuss water quality in the Lower Crocodile in the context of the sugar industry.

6.2 Water Quality of the Lower Crocodile River Catchment in the context of the Sugar Industry

In Chapter 2, Section 2.3 the water quality of the Crocodile River Catchment was briefly described as part of a description of the study area of this research. The Lower Crocodile River Catchment is described as an area of water quality concern in the Crocodile River Catchment due to increased concentrations of most water quality variables of concern. This Section of Chapter 6 will provide a more detailed disaggregation of water chemistry monitoring data from selected DWS gauge monitoring points in the context of the sugar industry.

As referred to in Chapter 1, Section 1.2, water quantity and quality are closely linked, however these aspects are often dealt with separately. Nilsson and Renöfalt (2008:2) explain that the definition of water quality "incorporates the concentration of different constituents in the water (such as oxygen, nutrients, toxicants, organic matter, and inorganic sediment) and also its temperature and state". Additionally, major processes related to transport retention and processing, such as decomposition of organic matter, govern water quality within a catchment. Moreover, specific concentrations of various substances, the temperature of water and its state has different impacts on the processes and the ecosystems within which these processes occur during different times of the year.

On the other hand, water quantity often "relates only to discharge and water mass, but equally important is the way water flow varies spatially and temporally", and this variation in flow is crucial to freshwater ecosystems as the discharge and mass of water has impacts on physical and chemical aspects of water quality (Nilsson and Renöfalt, 2008:2). Bonta and Cleland (2003) support this and add that the temporal and spatial variability in flow is due to regional climatic conditions, seasonal weather patterns and changing landscape conditions. In hydrology, duration curves are used to understand these variations and duration curves are described as "a summary of the percent of time that a given value is equalled or exceeded" (Johnson *et al*., 2009:655). Flow duration curves are established from historic flow data at the site, providing a snapshot of the flow record at that location over a certain period of time. FDCs serve as the foundation for the development of load duration curves

(LDCs), which work on a similar principle to FDCs, and instead of addressing flows, LDCs represent the likelihood of equalling or exceeding a given pollutant load at a specific location (USEPA, 2007; Johnson *et al.*, 2009). According to Johnson (2014), the pollutant load at a specific point is calculated by multiplying the flow by the pollutant concentration and a conversion factor (to align units) for the pollutant of concern, to give pollutant load per day. Furthermore, target loading curves can be created by combining FDC with the water quality standard for the parameter of interest, where measured concentrations are converted to loads and added to the curve. Data points falling above the target curve are out of compliance; and points falling below the curve are in compliance. An example of a load duration curve is shown in Figure 6.2a below.

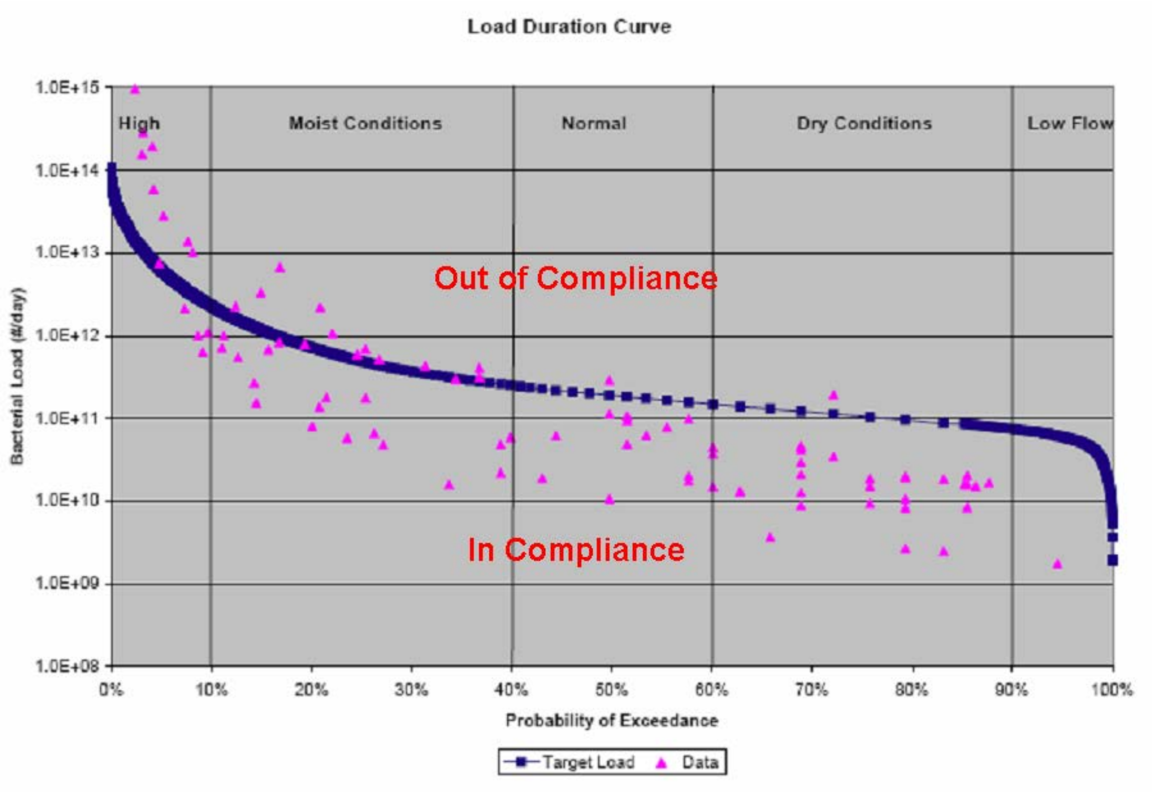


Figure 6.2a: An example of a load duration curve (Johnson, 2014:2).

The USEPA (2007) also add that duration curves have intervals which can be used as a general indicator of hydrological condition such as wet or dry and to what degree each hydrological condition is prevailing in terms of percentage. As illustrated in Figure 6.2a, there are five zones representing: high flows (0-10%), moist conditions (10-40%), normal or mid-range conditions (40-60%), dry conditions (60-90%), and low flow conditions (90-100%). Moreover, the pattern of where loads plot relative to these zones can be examined to see if it occurs across all flow conditions or strictly during high flows events or only during low flows. Loads plotting in the low flow zone typically indicate the influence of point source pollutions, while those that plot in during high flow events reflect potential non-point source contributions (USEPA, 2007). According to Cleland (2003) and USEPA (2007), LDCs can give an insight of various aspects of pollutant loading such as patterns in loading under various conditions, impacts of point and non-point source pollution, as well as insights on how to improve management practices.

Above, the relationship between flow and water quality is described and shows how flow has a major influence on the concentration of water quality constituents in a catchment. Therefore, in the next sections of this chapter, water quality and flow data are analysed together in the form of water quality loads. Within this analysis, water quality thresholds are given by the generic Resource Water Quality Objectives (RWQO) at a national level for South Africa (DWA, 2011:25) (Table 4.1.2a, Chapter 4). The Table of generic RWQOs was derived before the DWS Classification of Water Resources for the Inkomati WMA processes derived resource quality objectives for the area. In the generic RWQOs, the "most sensitive user is always the ecosystem, unless a user is more sensitive than the ecosystem" (Scherman pers comm. 2014). Target Water Quality Objectives or Interim Water Quality Objectives that are currently used in the management of the sub-catchment of the Inkomati WMA will be superseded by RQOs after the classification of the Inkomati WMA (Crocodile River catchment being a sub-catchment of this WMA) is complete.

The flow and water quality data from four DWS gauges (X2H032, X2H022, X2H046 and X2H016 as shown in Figure 6.2b were analysed as these are the monitoring points most relevant to the sugar industry. The stations were selected based on their positioning within the catchment, so that the selected stations give a spatially representation of the water quality impact on the sugar industry and the impact of the sugar industry on the in-stream water quality of the river below the industry. The water quality and flow observed data analysed at these monitoring points are for the 2002 to 2009 period, and this period was chosen because the inclusion of earlier data would result in an under estimation of current conditions. The water quality concentrations for Total Dissolved Solids (TDS) and Total Alkalinity (TAL) were used in combination with the daily flow data to construct LDCs (Figure 6.2.1-6.2.4). This data can also be presented in the form of seasonal loads for TDS and TAL (refer to Appendix C). This information is provided because it is useful to be able to identify how TDS and TAL loads vary seasonally in the monitoring points presented.

The percentage of observed TDS measurements within RWQO ranges at each of the four DWS gauges is given in Table 6.2a. The percentage of observed TAL and pH measurements within RWQO ranges at each of the four DWS gauges is also given to investigate the relationship between alkalinity and pH (refer to Chapter 4, section 4.1.2 for explanation of this relationship) at each point in Table 6.2b and 6.2c respectively.

Section 6.3 of this chapter presents an assessment of nutrients in the form of Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorus (SRP) for the four DWS gauges (X2H032, X2H022, X2H046 and X2H016 as shown in Figure 6.2b) including a reference site (X2H010) which is on a tributary of the Crocodile River (The upper reaches of Elands River as representative of least impacted in this part of the Crocodile River Catchment).

Section 6.4 provides an assessment of the contribution of TDS and TAL from two WWTWs (Matsulu and Hectorspruit) that are located in the Lower Crocodile Catchment. This assessment is necessary because of growing concern about the point source contributions from municipal wastewater discharges that affect the quality of water in the Lower Crocodile River. There are in the order of, 30 sewage treatment works discharging effluent directly into the Middle Crocodile River Catchment and its tributaries (Deksissa *et al.*, 2004). This section will also include a profile the Matsulu and Hectorspruit WWTWs in terms of authorisations to discharge, classification status, in terms of the requirements of regulation 2834 (DWA, Regulation No 2834 of 1985), classification status of process controllers that operate the WWTWs, operation in respect of design capacity and compliance with discharge conditions or standards. These profiles will allow the assessment of; differences in the way the WWTWs are managed and the influence of management on their water quality impact (ICMA, 2014).

Section 6.5 provides an aquatic assessment of the Lower Crocodile River, including ecological information, present ecological status of the associated aquatic habitat of the Lower Crocodile River, and trends in aquatic health over time as determined from biomonitoring. The Department of Water Affairs and Forestry (now referred to Department of Water and Sanitation) initiated the River Health Programme (RHP) to monitor the health of rivers in South Africa. The RHP forms part of a larger initiative known as the National Aquatic Ecosystem Health Monitoring Programme which is meant to eventually cover all surface water resources (including wetlands and estuaries). The information provided by the RHP is provided to assist water resource managers to understand how aquatic ecosystems function and respond to multiple stressors and to provide them with sufficient information to make informed decisions to ensure water resources are used sustainably (CSIR, 2007). Additionally, the RHP focusses biological characteristics as indicators (For example macro-invertebrates, fish communities and Instream and riparian habitat) of river health. The rationale behind this programme (which can also be referred to as “biomonitoring”) is that measuring only physical and chemical water quality variables does not provide an accurate account of the overall condition of aquatic ecosystem (CSIR, 2007).

The backbone of this programme was a method developed by Chutter (1994) known as the South African Scoring System (SASS) which was based on the Biological Monitoring Working Party (BMWP) (Thirion *et al.*, 1995). SASS is a scoring system that is based on benthic invertebrates where each taxon is given a tolerance score according to the water quality conditions it is known to be tolerable to (BRL, 2005). The higher the SASS score, the greater the organism’s sensitivity and the lower its tolerance. The scores are interpreted based on two indices: SASS score index and Average score per taxon (ASPT) index (Dickens and Graham, 2002). SASS has been updated to numerous versions and the current upgrade is version 5 described in Dickens and Graham (2002). The indices that are used to determine the condition of the biological characteristics include the following (Roux and Selepe, 2013):

- FRAI: an assessment index based on the environmental intolerances and preferences of the reference fish assemblage and the response of the constituent species of the assemblage to particular groups of environmental determinants of rivers.
- MIRAI: a rule-based model which integrates the ecological requirements of the invertebrate taxa in a community assemblage or assemblage to their response to modified habitat conditions.

According to Roux and Selepe (2013), through biomonitoring, the Present Ecological Status (PES) of a river is also determined and is expressed in terms of various components such as drivers (physio-chemical, geomorphology, and hydrology) and biological responses (fish, riparian vegetation and aquatic invertebrates. An integrated ecological status is also determined in the form of an Ecostatus score.

Five different states of health of a river are described, from an A class (natural) to an E class (unacceptable) (given in Table 6.1 below).

Table 6.1: States of health of a river given by classes (Roux and Selepe, 2013:15)

Class	Ecological State of River	Description
A	Natural	No measurable modification
B	Good	Largely unmodified
C	Fair	Moderately modified
D	Poor	Largely modified
E	Unacceptable	Seriously/critically modified

The IUCMA had appointed a service provider to conduct biomonitoring within the Crocodile River Catchment to determine the present Ecostatus of the river system for the 2012/2013 period. The information presented in this section is obtained from the Ecostatus report produced from the biomonitoring survey (Roux and Selepe, 2014). This information is relevant to identify point specific impacts in the Lower Crocodile River in the context of the sugar industry and to examine whether the water quality presented in sections 6.3 and 6.4 affect the aquatic health in the Lower Crocodile River Catchment.

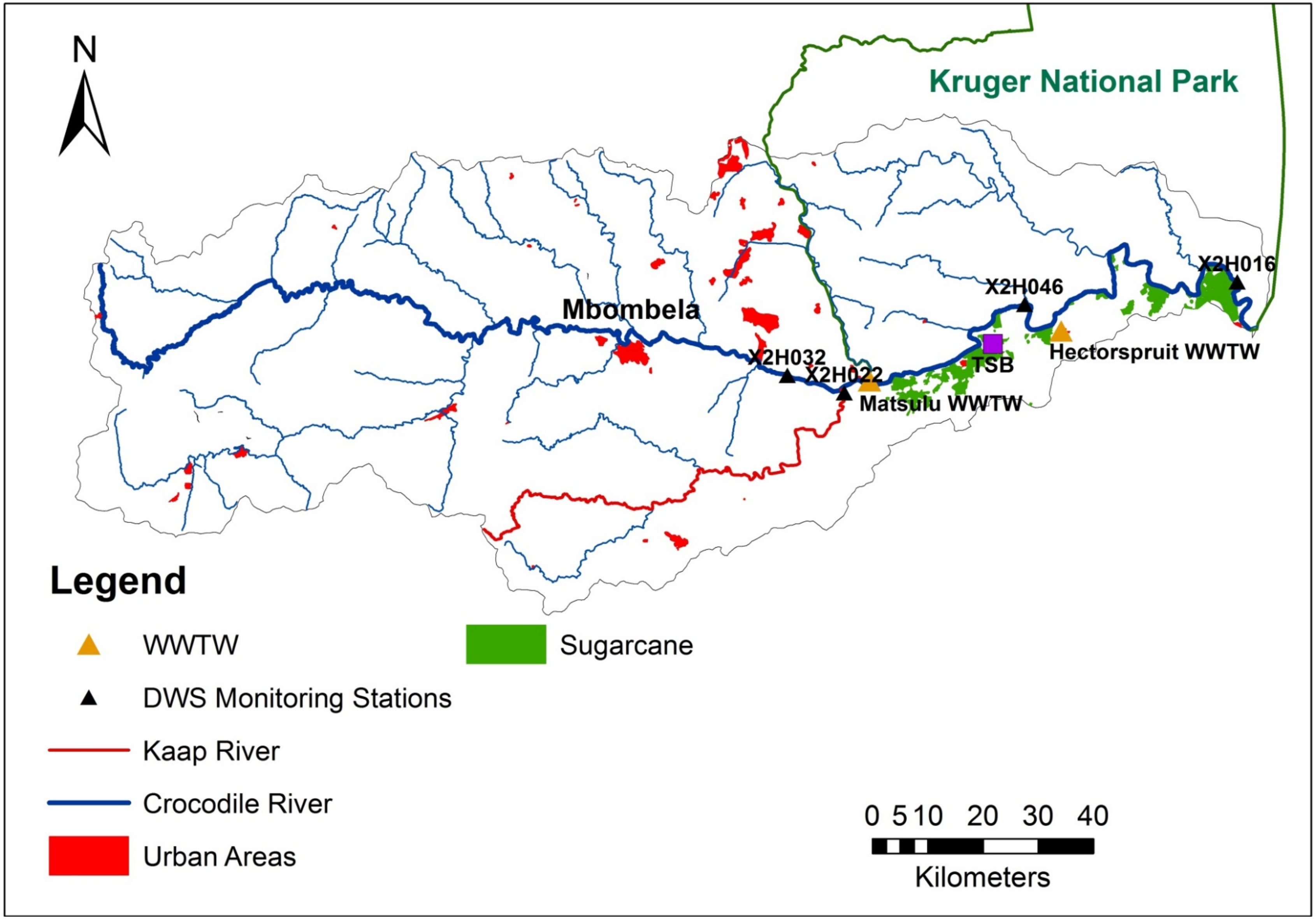


Figure 6.2b: Map showing DWS gauges used to construct Load Duration Curves (LDCs) (Retief, 2014)

6.2.1 Water Quality Results for Lower Crocodile River below Mbombela (DWS gauge X2H032)

Figure 6.2.1a: X2H032 on the Crocodile River at Weltevrede below Mbombela (photo taken from RQS DWS, 2014)

The water quality and flow data used to construct the LDC in Figure 6.2 A and B above was from the DWS water quality and flow gauge X2H032 which is located in the lower end of the Crocodile River below Nelspruit and above the Crocodile/Kaap River confluence (Figure 6.2b). The water quality as this point reflects the impacts of water use and waste disposal from the Crocodile Catchment up to a point below Mbombela Municipality. Figure 6.2.1A shows that majority (77.67%;Table 6.2a) of observed TDS loads are within the ideal to acceptable range, with several loads (20.47%) in the acceptable to tolerable range exceeding the ideal range in the upper 50% of the exceedance distribution and a few (1.86%) in the tolerable to unacceptable range. This can be a reflection of point source pollution contributions. At this gauge, TDS loads have not yet moved to a high risk even though this point is below the Mbombela urban area.

6.2.1.1 Relationship between pH and alkalinity at monitoring point X2H032

Figure 6.2.1B shows that majority (81.86% Table 6.2b) of TAL loads at monitoring point X2H032 are within the acceptable range, with a few measurements (16.28%) within the ideal to acceptable and acceptable to tolerable range, while few plot within the tolerable to unacceptable range at low flow conditions. This shows that at this monitoring point, TAL is only slightly starting to move into high risk range according to the limits set in RWQOs. However it is important to note that in terms of the quality of irrigation water, TAL is mostly within an "acceptable" TWQO range of 97.5 mg/L as given in Table 6.2b (1 mg/L=approximately 1 ppm; Smarte.org, 2008), this is too high for irrigation water (30-60 ppm (29.97 mg/l and 59.93mg/l) acceptable range for irrigation water) (Cox, 1995).

In terms of pH, Table 6.2c shows that majority of pH observed values at monitoring point X2H032 are within the ideal to acceptable range. However a few of the pH values plot above this range into the tolerable to unacceptable range, reflecting unacceptable conditions. The use of lime to buffer low pH in soil in the sugarcane plantations may be leached into the water resource, this may result in the water becoming more alkaline (with a higher pH value). In terms of the low pH values, it could be attributed to the contribution of waste from the citrus industry in the area which may have high levels of acidity. In this case the pH is moving occasionally into a high risk range.

6.2.2 Water Quality Results for the Lower Kaap River before the Kaap/Crocodile confluence (DWS gauge X2H022)

Figure 6.2.2a: X2H022 on the Kaap River at Dalton (photo taken from RQS DWS, 2014)

The DWS water quality and flow gauge X2H022 is located in the lower Kaap River before the Crocodile/Kaap River confluence (Figure 6.2.1a). The majority of TDS loads at this monitoring point (Figure 6.2.2A) plot within the tolerable to acceptable range (66.24%; Table 6.2a) exceeding the acceptable range mostly in the upper 50% of the exceedance distribution, with several loads (29.94%) in the acceptable to tolerable range and a few (3.82%) in the ideal to acceptable range. The TDS loads that exceed the acceptable range in the dry conditions to low flow zone of hydrological conditions typically indicate the influence of point source pollution. TDS contribution from this monitoring point is worse than the contribution from the upper Crocodile Catchment reflected at monitoring point X2H032 above and this can be attributed to the presence of various mines (such as Gold Mines in the Kaap River catchment area.

6.2.2.1 Relationship between pH and alkalinity at monitoring point X2H022

Figure 6.2.2B shows that the majority of TAL loads are within tolerable to unacceptable range (67.52% as shown in Table 6.2b) with most of these points exceeding this range during dry to low flow conditions. This reflects point source contributions. Several TAL loads plot within the tolerable to unacceptable range (26.75%), with a few loads within the acceptable to tolerable range and ideal to acceptable ranges at 2.55% and 3.18% respectively.

In terms of pH, Table 6.2c shows that majority of pH observed values at monitoring point X2H022 are within the acceptable range and some above the ideal range plotting within the unacceptable range (25.48% as shown in Table 6.2c) within all measurements within the upper limit with pH value greater than 8.4. Only a few of the pH values plot within the ideal to acceptable range, at 8.28%.

The water quality at monitoring point X2H022 reflects high TDS and alkalinity loads (Figure 6.2.2B and Table 6.2b respectively), as well as very high pH values. The Kaap River reach of the Crocodile River Catchment poses a very high water quality risk for downstream water users, especially the water quality of irrigation water for sugar production and water used for processing sugarcane. The Kaap River reflects water quality that is worse than the water quality from the Upper Crocodile River Catchment.

6.2.3 Water Quality Results for the Lower Crocodile River below TSB sugar mill (DWS gauge X2H046)

Figure 6.2.3a: X2H046 on the Crocodile River (photo taken from RQS DWS, 2014)

The DWS water quality and flow gauge X2H046 in Figure 6.2.3A is located on the Lower Crocodile River below the Kaap/Crocodile confluence, and in the middle of the sugar producing reaches of the catchment. The water quality at this monitoring point reflects the combined impacts of water use and waste disposal from the Matsulu residential area, Matsulu WWTW, Malelane urban area, sugar plantations and the sugar mill. Figure 6.2.3A shows that the majority (72.81%; Table 6.2a) of observed TDS loads are within the acceptable to tolerable range and a few (7.02%) in the tolerable to unacceptable range. At this gauge, TDS loads are worse than at monitoring point X2H032 on the main stem of the Crocodile River, but not as high as TDS loads from monitoring point X2H022 on the Kaap River before the Kaap/Crocodile confluence. Therefore, the Crocodile River main stem is diluting of the high TDS loads from monitoring point X2H022.

6.2.3.1 Relationship between pH and alkalinity at monitoring point X2H046

TAL loads at monitoring point X2H046 in Figure 6.2.3B shows that the majority of TAL loads are within tolerable to unacceptable range (67.98% as shown in Table 6.2b) with most of these points exceeding this range during dry to low flow conditions. This reflects point source contributions. At this monitoring point, TAL loads are worse than at monitoring point X2H032 on the main stem of the Crocodile River, but not as high as TAL loads from monitoring point X2H022 on the Kaap River before the Kaap/Crocodile confluence. Therefore, the Crocodile River main stem is acting as a diluent of the high TAL loads from monitoring point X2H022.

In terms of pH, Table 6.2c shows that majority of observed pH values at monitoring point X2H046 are within the acceptable range, however a few of the pH values plot above the ideal to acceptable range into the tolerable to unacceptable range. The use of lime to buffer low pH in soil in the sugarcane plantations may be leached into the water resource, this may result in the water becoming more alkaline (with a higher pH value). The low pH values can be attributed to the contribution of waste from the citrus industry in the area which may have high levels of acidity. In this case the pH is moving occasionally into a high risk range.

6.2.4 Water Quality Results for the Lower Crocodile River (DWS gauge X2H016)

Figure 6.2.4a: X2H016 at Ten Bosch on the Crocodile River (photo taken from RQS DWS, 2014)

The DWS water quality and flow gauge X2H016 in Figure 6.2.4A is located on the Lower Crocodile River at Tenbosch, which is the last monitoring point before the river runs into Mozambique (Figure 6.2b). The water quality as this monitoring point reflects the combined impacts of water use and waste disposal from the Matsulu residential area, Matsulu WWTW, Malelane urban area, sugar plantations and the sugar mill, Hectorspruit WWTW, Mhlati Kop WWTW and Mhlathi Kop WWTW. Figure 6.2.4A shows that majority (46.61% as shown in Table 6.2.a) of observed TDS loads are within the tolerable to unacceptable range, with several loads (40.25%) exceeding the ideal range in the upper 50% of the exceedance distribution and a few (13.14%) in the ideal range. This can be a reflection of point source pollution contributions.

At this monitoring point, TDS loads are slightly worse than at monitoring point X2H032 on the main stem of the Crocodile River, but not as high as TDS loads from monitoring point X2H022 on the Kaap River before the Kaap/Crocodile confluence. Therefore, the Crocodile River main stem is acting as a diluent on the high TDS loads from monitoring point X2H022. When observing TDS loads from monitoring point X2H032 to monitoring point X2H016, there is a noticeable net increase in salinity in the Lower Crocodile River. One of the major tributaries of the Crocodile River, Kaap River, greatly influences TDS loads in the Lower Crocodile River. This poses a major threat to the quality of water the sugar industry receives even though the Crocodile main stem serves as a diluent. The major sources of TDS in the Lower Crocodile River are point source dominated, which may be attributed to the extensive mining and industrial activities that occur across the lower catchment.

6.2.4.1 Relationship between pH and alkalinity at monitoring point X2H016

Observed TAL loads at monitoring point X2H016 in Figure 6.2.4B shows that majority of TAL loads are within the tolerable to unacceptable range (42.37% as shown in Table 6.2b) with most of these points exceeding this range during dry to low flow conditions. This reflects point source contributions. At this monitoring point, TAL loads are worse than at monitoring point X2H032 on the main stem of the Crocodile River, but not as high as TAL loads from monitoring point X2H022 on the Kaap River before the Kaap/Crocodile confluence. Therefore, the Crocodile River main stem is acting as a diluent on the high TAL loads from monitoring point X2H022.

Table 6.2c shows that majority of pH observed values at monitoring point X2H016 are within the ideal to acceptable range (55.26% as shown in Table 6.2c), however some pH values plot within the tolerable to unacceptable range at 26.32% with majority of measurements within the upper limit and only a few within the lower limit. When observing pH values from monitoring point X2H032 to monitoring point X2H016, there is a noticeable net decrease in the quality of the water in the Lower Crocodile River, with the Kaap River contributing a negative effect that is ameliorated by the Crocodile main stem.

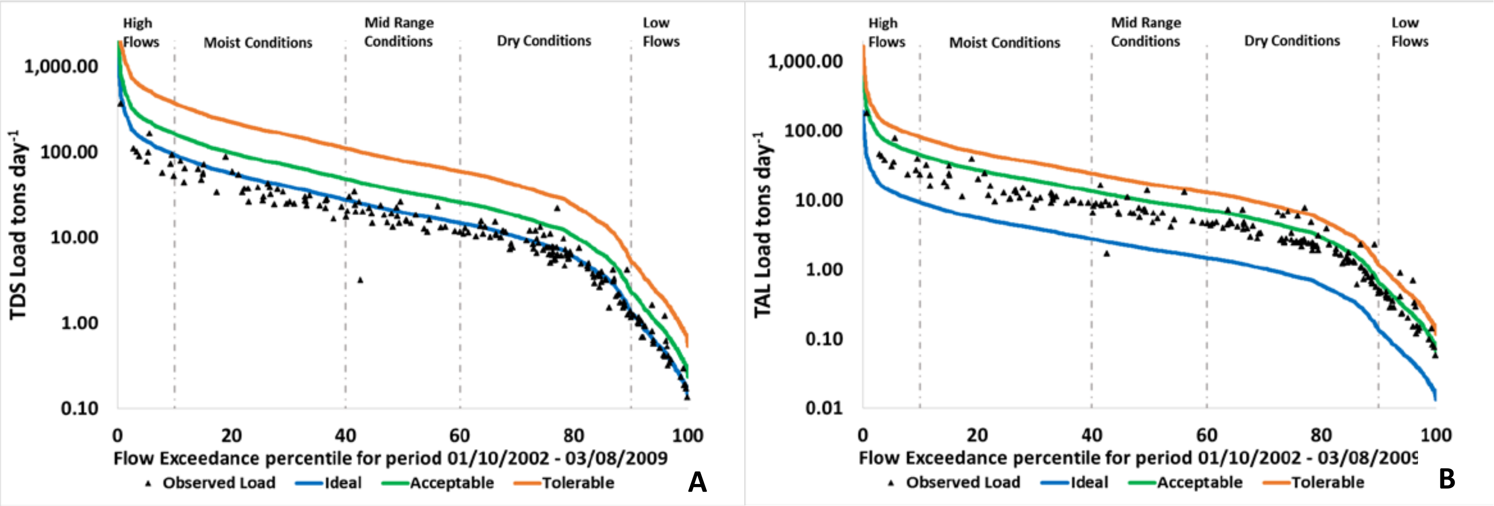


Figure 6.2.1: Load Duration Curves (LDCs) for monitoring point X2H032 situated along the Crocodile River. ***A:*** TDS and ***B:*** TAL (Retief, 2014)

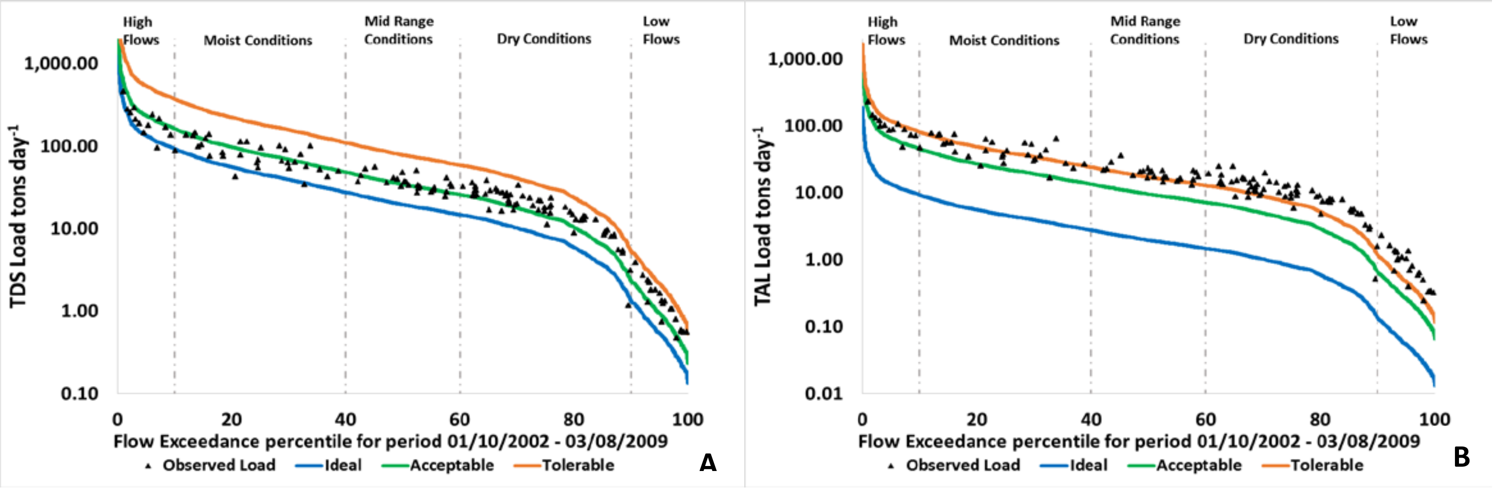


Figure 6.2.2: Load Duration Curves (LDCs) for monitoring point X2H022 situated on the Lower Kaap River before the Kaap/Crocodile confluence. ***A***: TDS and ***B:*** TAL (Retief, 2014)

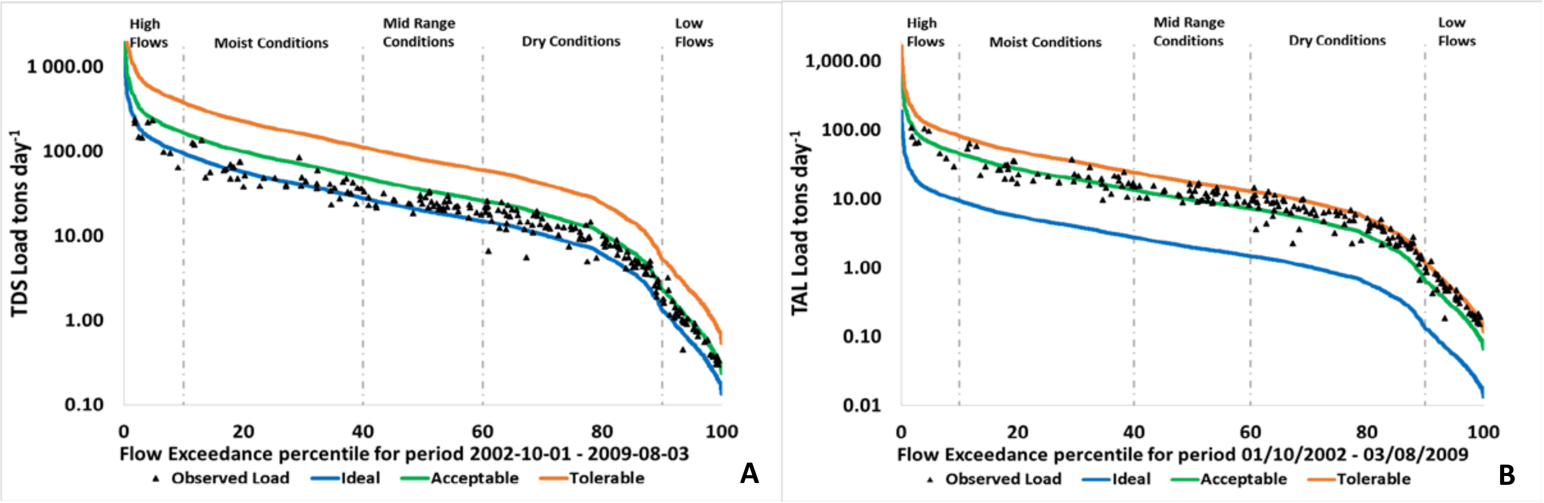


Figure 6.2.3: Load Duration Curves (LDCs) for monitoring point X2H046 situated along the Crocodile River. ***A:*** TDS and ***B:*** TAL (Retief, 2014)

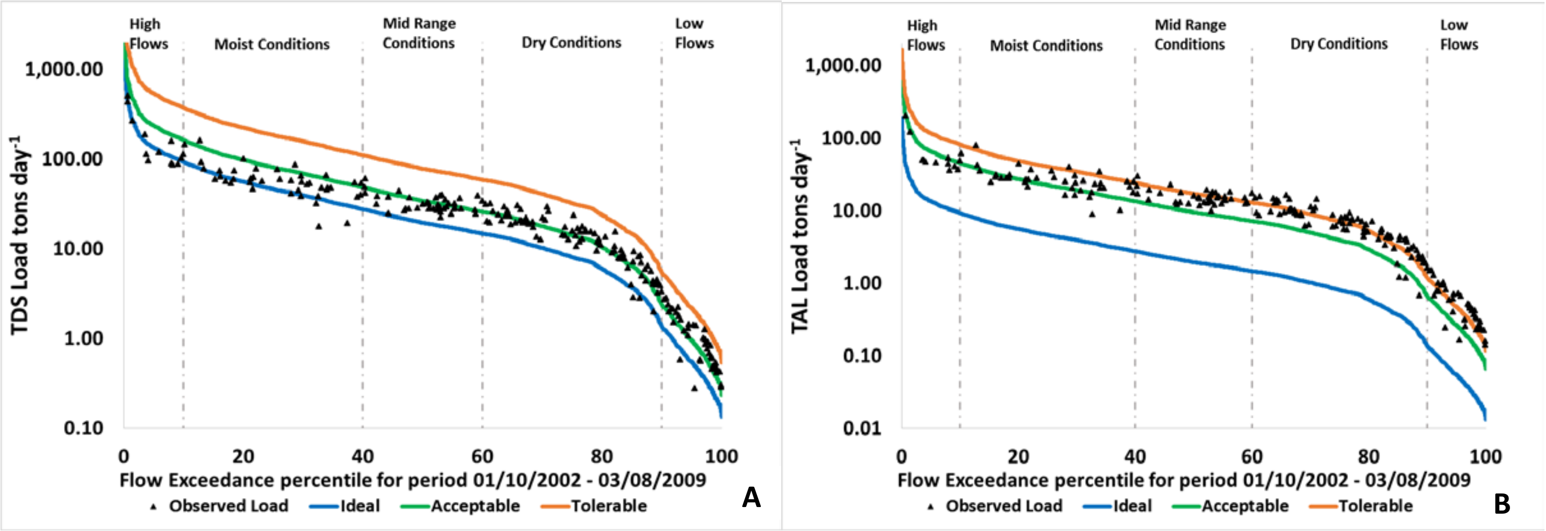


Figure 6.2.4: Load Duration Curves (LDCs) for monitoring point X2H016 situated along the Crocodile River at Ten Bosch. ***A:*** TDS and ***B:*** TAL (Retief, 2014)

Table 6.2a: Percentage of observed TDS (mg/L) measurements within RWQO ranges for monitoring points X2H032, X2H022, X2H046 and X2H016 (Retief, 2014).

Monitoring Point	Range	No. Measurements	%
X2H032	**Ideal**	167	77.67
	Acceptable	44	20.47
	Tolerable	4	1.86
	Unacceptable	0	0.00
	Total	215	100.00
X2H022	**Ideal**	6	3.82
	Acceptable	47	29.94
	Tolerable	104	66.24
	Unacceptable	0	0.00
	Total	157	100.00
X2H046	**Ideal**	46	20.18
	Acceptable	166	72.81
	Tolerable	16	7.02
	Unacceptable	0	0.00
	Total	228	100.00
X2H016	**Ideal**	31	13.14
	Acceptable	95	40.25
	Tolerable	110	46.61
	Unacceptable	0	0.00
	Total	236	100.00

Table 6.2b: Percentage of observed TAL (mg/l CaCO3) measurements within RWQO ranges for monitoring points X2H032, X2H022, X2H046 and X2H016 (Retief, 2014).

Monitoring Point	Range	No. Measurements	%
X2H032	**Ideal**	17	7.91
	Acceptable	176	81.86
	Tolerable	18	8.37
	Unacceptable	4	1.86
	Total	215	100.00
X2H022	**Ideal**	5	3.18
	Acceptable	4	2.55
	Tolerable	42	26.75
	Unacceptable	106	67.52
	Total	157	100.00
X2H046	**Ideal**	11	4.82
	Acceptable	47	20.61
	Tolerable	155	67.98
	Unacceptable	15	6.58
	Total	228	100.00
X2H016	**Ideal**	14	5.93
	Acceptable	34	14.41
	Tolerable	88	37.29
	Unacceptable	100	42.37
	Total	236	100.00

Table 6.2c: percentage of observed pH measurements within RWQO ranges for monitoring points X2H032, X2H022 and X2H046 (Retief, 2014).

Monitoring Point	Category	Range	Measurements	%
X2H032	Ideal	≤ 8 (Upper)	160	74.42
		≥ 6.5 (Lower)		
	Acceptable	< 8.4 (Upper)	44	20.47
		> 8 (Lower)		
	Unacceptable	>8.4	2	5.12
		<6.5	9	
	Total		215	100.00
X2H022	Ideal	≤ 8 (Upper)	13	8.28
		≥ 6.5 (Lower)		
	Acceptable	< 8.4 (Upper)	104	66.24
		> 8 (Lower)		
	Unacceptable	>8.4	40	25.48
		<6.5	0	
	Total		157	100.00
X2H046	Ideal	≤ 8 (Upper)	83	36.40
		≥ 6.5 (Lower)		
	Acceptable	< 8.4 (Upper)	129	56.58
		> 8 (Lower)		
	Unacceptable	>8.4	9	7.02
		<6.5	7	
	Total		228	100.00
X2H016	Ideal	≤ 8 (Upper)	42	18.42
		≥ 6.5 (Lower)		
	Acceptable	< 8.4 (Upper)	126	55.26
		> 8 (Lower)		
	Unacceptable	>8.4	51	26.32
		<6.5	9	
	Total		228	100.00

6.3 Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorus (SRP) concentrations for various DWS monitoring sites along the Crocodile River

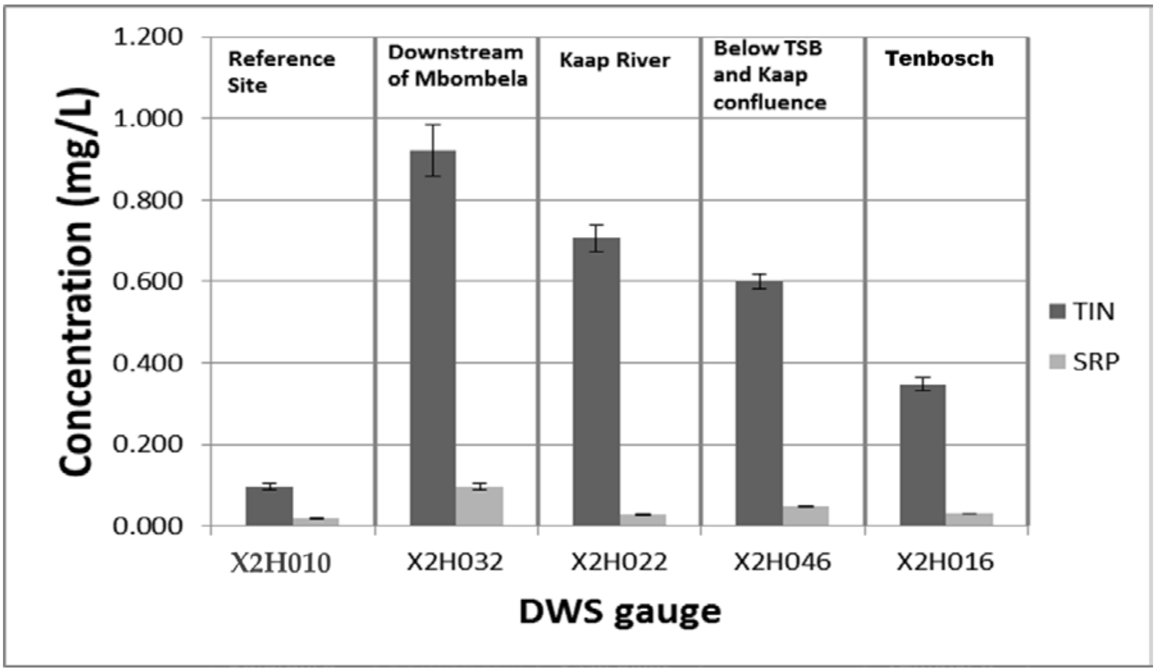


Figure 6.3: Graph showing mean Total Inorganic Nitrogen (TIN) (±S.E) and mean Soluble Reactive Phosphorus (SRP) (±S.E) concentrations for various DWS sites that fall within the study area (Retief, 2014).

The assessment of nutrients in the form of Total Inorganic Nitrogen (TIN) and Soluble Reactive Phosphorus (SRP) for the four DWS gauges (X2H032, X2H022, X2H046 and X2H016 is shown in Figure 6.2b) in comparison with a reference site (X2H010) which is on a tributary of the Crocodile River (The upper reaches of Elands River as representative of least impacted in this part of the Crocodile River Catchment) is presented in Figure 6.3 above. The reference site (X2H010) exhibits low nutrient concentrations while TIN and SRP concentrations increase considerably from Upper Crocodile River to the Lower Crocodile at monitoring point X2H032. At monitoring point X2H022 on Kaap River (a tributary of Crocodile), TIN and SRP concentrations decrease however they are still considerable higher than the reference site. TIN concentrations show a steady decrease from monitoring point X2H032 to X2H016. SRP concentrations at point X2H022 are lower than SRP concentrations at monitoring point X2H032, thus the Kaap River contributes less nutrients in terms of phosphorus. SRP concentrations show a slight increase at X2H046 and then a slight decrease again at X2H016, however concentrations at all monitoring points are higher than the reference site.

The decreasing in TIN and SRP concentrations in the Lower Crocodile River can be attributed to the extensive sugar cane plantations located in the area (as shown in Figure 6.2b), which results from the absorption of nutrients from irrigation water in the lower reaches of the river. Therefore, the sugar plantations act as an “agricultural wetland” that serves a function of bioremediation resulting in large scale absorption of nutrients. However it is important to note that a proportion of these nutrients will be adsorbed in the soil, and once the soil reaches a point of saturation, the nutrients might not be held effectively, or any event of soil erosion may lead to water quality problems due to nutrient enrichment (Hodges, 2010).

6.4 Total Dissolved Salts (TDS) and Total Inorganic Nitrogen (TAL) Contribution from Matsulu WWTW and Hectorspruit WWTW

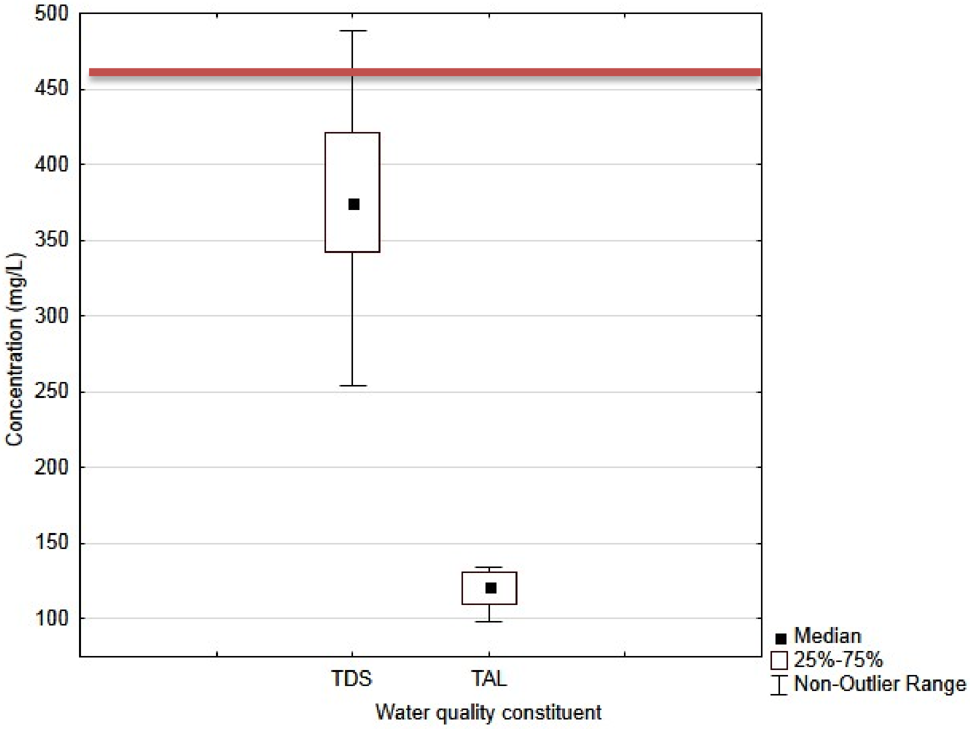


Figure 6.4a: Box plot of TDS and TAL (mg/L discharged from Matsulu WWTW (this data also from 2002-2009) showing the TDS general effluent limit (455 mg/L calculated from the EC limit using the conversion factor 6.5) in red. The TAL general effluent limit is 500 mg/L (Retief, 2014).

Figure 6.4a shows TDS and TAL concentrations discharged from Matsulu WWTW. Total Dissolved Solids concentrations discharged from Matsulu are still within the general limit and alkalinity of the effluent from Matsulu is also low. Therefore, Matsulu WWTW does not contribute significant concentrations of TDS and TAL into the Crocodile River Catchment, and does not pose a risk to the quality of the water that the sugar industry receives as long as the effluent from the municipality complies with discharge standards. Section 6.4.1 below presents the profile of this WWTW and provides information about its performance during the period from April 2013 to January 2014.

6.4.1 Matsulu WWTW profile (ICMA, 2014:53)

The WWTW was commissioned in 2001 and it uses an activated sludge process. The WWTW is authorised to discharge effluent into the Crocodile River and the authorisation was issued in 2009. The effluent discharge quality is shown in Table 6.4.1a below. The WWTW has been classified as a Class C in terms of the requirements of regulation 2834 and the supervisor has been classified as a Class IV (DWA,2012:Appendix C). The WWTW has a design capacity of 6ML/day and operates at a capacity of 3ML/day. Figure 6.4.1b shows the discharge point with effluent clear of debris and suspended solids.

Table 6.4.1a: Matsulu WWTW- Final effluent quality from April 2013 to January 2012 (ICMA, 2014:54)

Parameter	Licence Limit	Matsulu WWTW									
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
pH	5.5-9.5	8.3	8.3	7.9	8.3	8.2	8.2	8.3	7.5	7.8	7.0
Electrical Conductivity (mS/m)	70 mS/m	56.0	56.2	55.5	57.6	62.6	59.4	54.0	56.6	49.4	54.7
Nitrate/Nitrite as Nitrogen (mg/l)	15	8.1	10	12	11	9.7	8.3	5.9	6.8	7.2	6.7
Ortho-Phosphate (mg/l)	1	**2.3**	**2.3**	**3.2**	**2.9**	**1.9**	**1.1**	**1.0**	**1.2**	**3.1**	
Chemical Oxygen Demand (mg/l)	75	12	<10	<10	20	12	16	12	<10	20	
E. coli (per 100 ml)	0 count/100ml	0	0	0	0	**44**	**3**	0	0	0	**1**
Ammonia (mg/l)	3	<0.2	<0.2	**15**	0.2	0.2	0.3	0.2	0.2	<0.2	0.2

The table above indicates that although the WWTW is compliant most of the time, there are times when ortho-phosphates, NH_3 and *E. coli* are not complying with the effluent discharge standards. Ortho-phosphates did not comply for almost the whole duration of the reporting period. High PO_4 may contribute to nutrients which could result in eutrophication and the water not being fit for use. High *E. coli* is a health threat, especially if crops eaten raw, and may also lead to waterborne diseases for those people who use water directly from the resource.

a. Inlet free of debris and screenings properly disposed of

b. Activated sludge

c. Clarifiers clear of algal growth

d. Final effluent disinfected and clear of scum

Figure 6.4.1b: Pictures showing various components of the Matsulu WWTW (ICMA,2014:55)

As presented in the section above, the Matsulu WWTW has been authorised and classified according to regulations and it is currently operated within its design capacity. In terms of the final effluent discharged from this WWTW from the period from April 2013 to January 2014, the quality is compliant with pH, EC, nitrates or nitrites and COD, however there are times when the effluent quality does not comply with ortho-phosphates, NH_3 and *E.coli* effluent discharge standards and this poses a threat in terms of nutrient levels that can affect the quality of water for irrigation in the sugar industry. Currently the Matsulu WWTW (Figure 6.4.1b) is managed within required authorisations and standards; however improvements in terms of phosphates, ammonia and *E.coli* levels are needed.

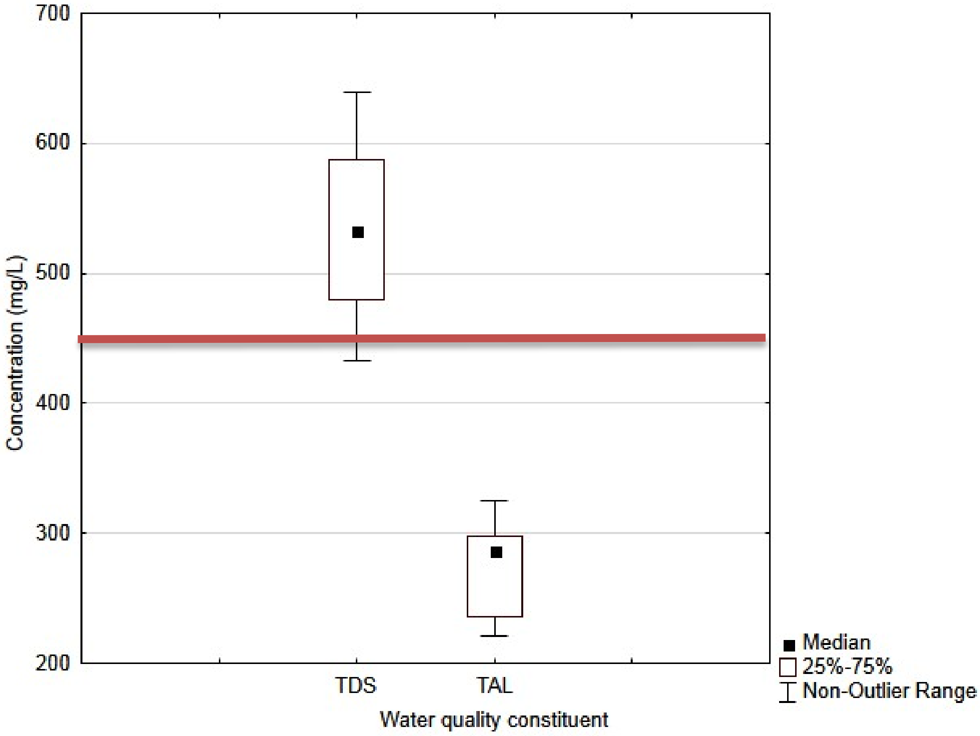


Figure 6.4b: Box plot of TDS and TAL (mg/L) discharged from Hectorspruit WWTW showing the TDS general effluent limit (455mg/L calculated from the EC limit using the conversion factor 6.5) in red. The TAL general effluent limit is 500 mg/L (Retief, 2014).

Figure 6.4b shows TDS and TAL concentrations discharged from Hectorspruit WWTW. Total Dissolved Solids concentrations in the effluent discharged from Hectorspruit is considerably higher than the general TDS limit and Hectorspruit WWTW contributes excessive TDS concentrations into the Crocodile River compared to Matsulu WWTW. In terms of alkalinity, TAL concentrations in the effluent discharged from Hectorspruit are within the TAL general limit, but are higher than the TAL concentrations contributed by Matsulu WWTW into the Crocodile River. The high concentrations of TDS pose a risk in terms of the quality of water received by the sugar industry downstream due to impacts on crop production (refer to Chapter 4, section 4.1.2). This may also be the contributing factor in the increase in alkalinity concentrations downstream Hectorspruit WWTW.

6.4.2 Hectorspruit WWTW profile

This WWTW uses oxidation ponds. The WWTW has a design capacity of 0.265 ML/day; however, the average daily flow (operational) capacity is unknown because the plant does not have flow measuring devices. The WWTW has not been registered in terms of the requirements of regulation 2834 and therefore the class of the plant is not known. The WWTW does not have a water use authorisation for the discharge of effluent into the Crocodile River. There was no raw sewage inflow into the WWTW at the time of reporting, however, the average effluent discharge quality for the period when the pumps were operational is shown in Table 6.4.2a. The copies of the process controllers’ and supervisor’s classification certificates were not available at the WWTW and therefore could not be verified.

The plant has built-up scum at ponds 1 and 2 and the pumps at the pump station had been removed for repairs. See Figure 6.4.2b. The removed pumps are normally used to pump raw sewage from the pump station to the oxidation ponds. There was no overflow of sewage from the pump station at the time of reporting.

Table 6.4.2a: Hectorspruit WWTW- Final effluent quality from April 2013 to January 2014 (ICMA, 2014: 66).

Substance Parameter	General Limit	Hectorspruit WWTW									
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
pH	5.5-9.5	8.2	8.4	8.1	8.3	7.9	7.9		8.1	7.9	7.9
Electrical Conductivity (mS/m)	75 mS/m	72	75.7	66.5	71.3	**85.5**	**86.7**		**80.3**	**78.4**	72.8
Nitrate/ Nitrite as Nitrogen (mg/l)	No limit	0.1	0.2	0.3	0.2	02	0.3		0.5	0.3	0.1
Ortho-Phosphate (mg/l)	1	**3.6**	**3.5**	**3.5**	**4.5**	**4.8**	**4.4**		**4**	**4.4**	**9.4**
Chemical Oxygen Demand (mg/l)	75	36	28	32	52	52	68		60	44	47
E. coli (per 100 ml)	0 count/ 100ml	**2**	0	0	**3**	0	0		**14**	**170**	**14**
Ammonia (free and saline) (mg/l)	1	0.2	0.2	0.4	**3.7**	**13**	**9.9**		**1.1**	**1.5**	**1.7**

The table above indicates that ortho-phosphates, EC, NH_3 and *E. coli* are not complying with the effluent discharge standards. High PO_4 and nitrates may contribute to nutrients which could result in eutrophication and the water not being fit for use. High *E. coli* is a threat for crop production, especially those crops eaten raw, and may also lead to waterborne diseases for those people who use water directly from the resource. Oxidation ponds are not designed to discharge, so this is regarded as an illegal overflow.

a. Final pond into chlorination channel with no outflow (HTH tablets)

b. Discharge point

c. Inlet with no screens

d. Sump full of sewage with no pump

Figure 6.4.2b: Pictures showing various components of Hectorspruit WWTW (ICMA, 2014:67).

The Hectorspruit WWTW has not been authorised and classified according to regulations and the capacity within which the plant is operated unknown due to lack of flow meters. Sometimes the pumps in the WWTW break down; however when they are functional, the plant discharges effluent illegally because the plant is not authorised to discharge at all since the process technology in the plant is currently comprises oxidation ponds. In terms of the final effluent discharged from this WWTW for the period from April 2013 to January 2014, the quality is compliant in terms of pH, nitrates or nitrites and COD; however there are times when the effluent quality does not comply with ortho-phosphates, EC, NH_3 and *E.coli* effluent discharge standards and this poses a threat in terms of nutrient and EC levels that can affect the quality of water for irrigation in the sugar industry. Currently the Hectorspruit WWTW is not managed within required authorisations and standards (Figure 6.4.2b).

6.5 Biomonitoring within the lower Crocodile River Catchment 2012/2013 (Roux and Selepe, 2014)

In this section, biomonitoring results from four reaches (X22-01018, X24C-01033, X24E-00982 and X24F-00953) on the Crocodile River are presented (Figures 6.5a and b). These sites were selected specifically because they correspond to the locations of the monitoring points presented in section 6.3 and will therefore give a view of how water quality in terms of TDS, TAL and pH at these reaches may affect aquatic health. However it is important to note that there are other water quality variables that were not assessed in this study that may pose a risk to aquatic health.

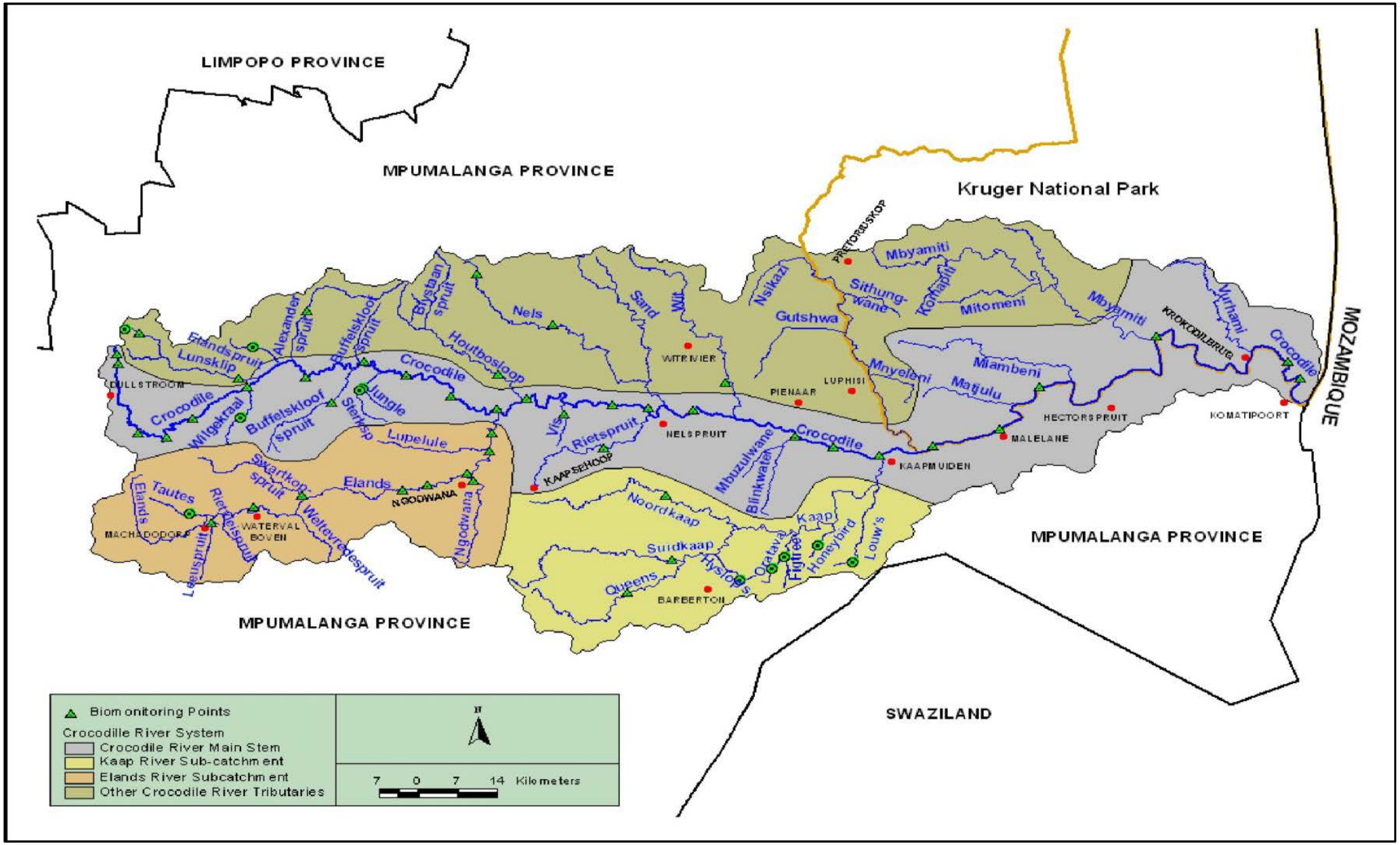


Figure 6.5a: Map of the Crocodile River Catchment showing all the Biomonitoring points (Roux and Selepe, 2014:9).

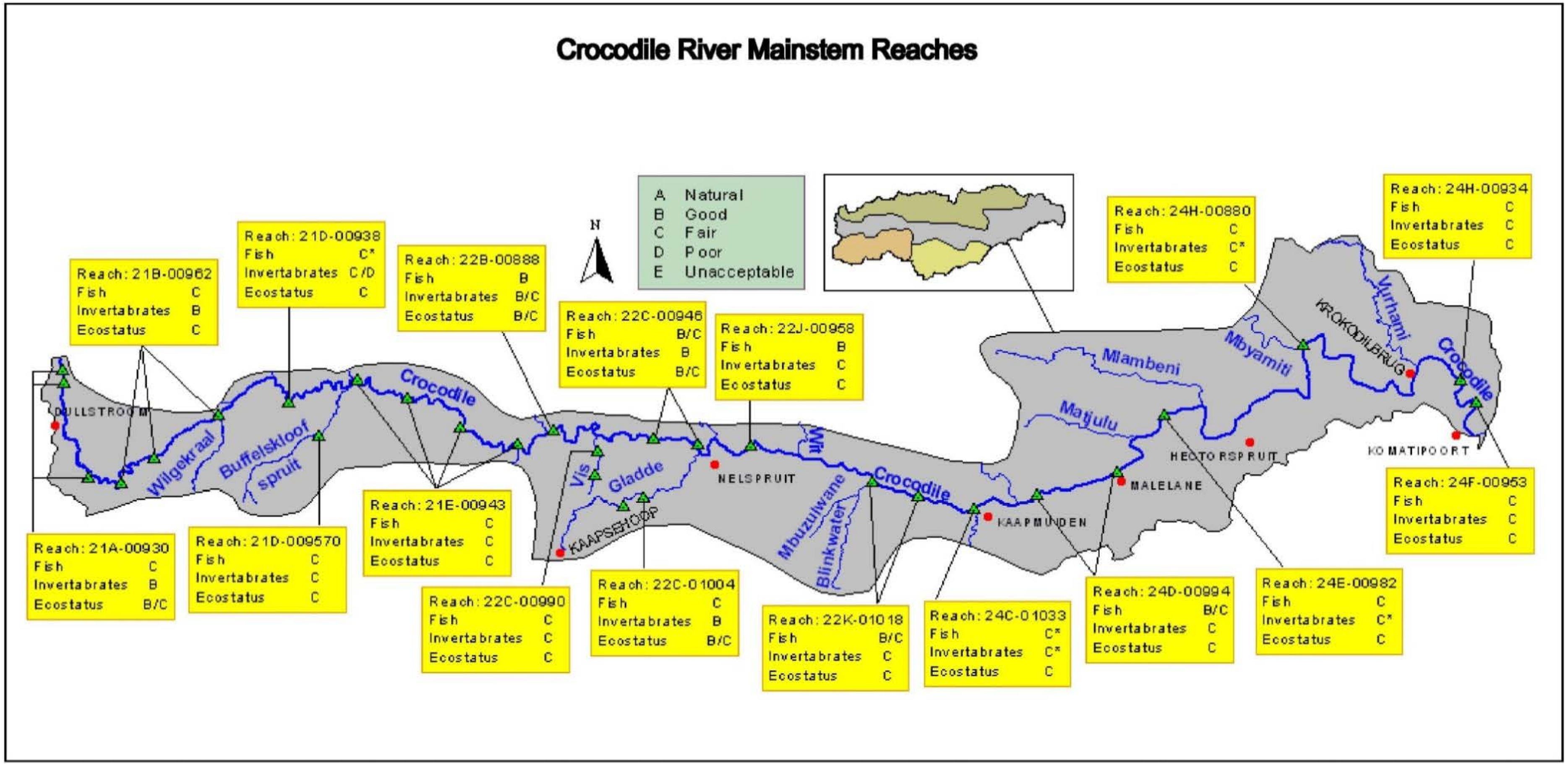


Figure 6.5b: Map showing Crocodile River Main stem reaches indicating Fish, Invertebrates and Ecostatus Ratings for each reach (Roux and Selepe, 2014:19).

6.5.1 Reach X22K-01018: Blinkwater-Kaap

Table 6.5.1: Biomonitoring results for reach X22K-01018 (Roux and Selepe, 2013:32).

SQ Reach (downstream→)	SQR Name	Fish Sites	SASS Sites	FRAI	MIRAI	Integrated Ecostatus	PES Category	Riparian PES	Length km
X22K-01018	Crocodile	X2CROC-N4ROA; X2CROC-WELT1	X2CROC-N4ROA; X2CROC-WELT1	BC	C	BC	C	C	15.22

Legend for table:
SQ: Subquatenary
SQR: Subquatenary River
SASS: South African Scoring System
FRAI: Fish Response Assessment Index
MIRAI: Macro-invertebrate Response Assessment Index
PES: Present Ecological State

This reach falls within the area that is locally known as the Crocodile Gorge where the sugarcane farmers abstract water for irrigation. The upper boundary of the reach is below the confluence with the Blinkwater, tributary, and the lower boundary the Crocodile/Kaap River confluence. Most of the natural vegetation in the gorge is still intact, with roads along the edge of the river, and a few scattered citrus farms at the edges of the reach boundary. Two sites (X2CROC-N4ROA and X2CROC-WELT1) were sampled within this reach (Roux and Selepe, 2014) (Table 6.5.1).

According to Roux and Selepe (2014:32), a Fish Response Assessment Index (FRAI) score of 81.95% was calculated for this reach placing the reach in an Ecological Class BC which is slightly to moderately impaired with a low density and abundance of fish species. Additionally, in terms of invertebrates, at one point that was sampled, all SASS-biotopes were well represented. The taxon diversity was high, but taxa that are considered sensitive in the SASS index were absent, or present at low abundances. The absence of sensitive taxa in this reach indicates that the condition in the reach was impaired at the time of sampling.

The Ecostatus of the reach was considered to be in the BC Class indicating a slightly to moderately impaired habitat.

The location of this reach corresponds with monitoring point X2H032 presented in section 6.2.1. The water quality at this point shows TDS concentrations that are still within acceptable range however TAL and pH concentrations are high. This point does not yet pose a high risk water quality risk to aquatic health in terms of TDS, TAL and pH.

6.5.2 Reach X24C-01033: Kaap-Nsikazi

Table 6.5.2: Biomonitoring results for reach X24C-01033 (Roux and Selepe, 2013:33).

SQ Reach (downstream→)	SQR Name	Fish Sites	SASS Sites	FRAI	MIRAI	Integrated Ecostatus	PES Category	Riparian PES	Length km
X24C-01033	Crocodile	X2CROC-KAAPM	X2CROC-KAAPM	C	C	C	D	C	7.22

This reach has the Kaap River as upstream boundary and the Nsikazi River (Figure 2.1.1) as the downstream boundary of the reach. The Kaap River is the only major tributary of the Crocodile River that contributes to this reach. The main land-use is sugarcane, citrus, subsistence farming and the Matsulu settlement area (including the Matsulu WWTW). Crops are planted very close to the river in some areas in this reach. One site (X2CROC-KAAPM) was sampled within this reach by Roux and Selepe (2014:34) and a FRAI score of 76.2% was calculated with an Ecological Class C which is moderately impaired with a low diversity and abundance fish species (Table 6.5.2).

In terms of invertebrates, no sampling was carried out in this reach during 2012 and the reach was categorised as a Class C which is moderately impaired, based on historical data (Matthew, 1968). The Ecostatus for this reach was a Class C.

The location of this reach corresponds with the location of monitoring point X2H022 in section 6.2.2 before the Crocodile/Kaap confluence. The water quality presented at this monitoring point shows very high levels of TDS, TAL and pH and this poses a high water quality risk on the aquatic health of this reach. As mentioned in section 6.2.2, the Kaap River, tributary of the Crocodile River Catchment, poses a very high water quality risk for downstream water users below the Kaap/Crocodile confluence and it reflects water quality that is worse than the water quality from the Upper Crocodile River Catchment.

6.5.3 Reach X24E-00982: Matjulu-Mlambeni

Table 6.5.3: Biomonitoring results for reach X24E-00982 (Roux and Selepe, 2013:37).

SQ Reach (downstream→)	**SQR Name**	**Fish Sites**	**SASS Sites**	**FRAI**	**MIRAI**	**Integrated Ecostatus**	**PES Category**	**Riparian PES**	**Length km**
X24E-00982	Crocodile	X2CROC-RIVE1	X2CROC-RIVE1	C	C	C	D	C	11.22

This reach is located below the town of Malelane and falls within the Kruger National Park (KNP) protected area. Only one site (X2CROC-RIVE1) was sampled in this reach. The main land use in the area includes conservation, sugarcane, citrus and the Leopard Creek Golf Estate. An FRAI score of 78.85% was calculated for this reach with an Ecological Class C which is moderately impaired with low density and abundance of fish species (Roux and Selepe, 2014:37) (Table 6.5.3).

Additionally, in terms of invertebrates, no sampling was conducted in this reach during 2012, so the reach was categorised as a Class C based on historical data. The Ecostatus of the reach is a Class C with the southern bank of the river mostly impacted by irrigated agriculture.

The location of this reach corresponds with the location of monitoring point X2H046 in section 6.2.3 located on the Lower Crocodile River below the Kaap/Crocodile confluence. At this monitoring point, the water quality in terms of TDS, TAL and pH levels is worse than at monitoring point X2H032 on the main stem of the Crocodile River, but not high as monitoring point X2H022 on the Kaap River before the Kaap/Crocodile confluence. Therefore, the Crocodile River main stem is acting as a diluent on the high TDS, TAL and pH levels from monitoring point X2H022. The aquatic health of this reach is slightly better than the Kaap River reach with a higher FRAI score showing slightly improved habitat conditions.

6.5.4 Reach X24F-00953: Mlambeni-Mbyamiti

Table 6.5.4: Biomonitoring results for reach X24F-00953 (Roux and Selepe, 2013:38).

SQ Reach (downstream→)	SQR Name	Fish Sites	SASS Sites	FRAI	MIRAI	Integrated Ecostatus	PES Category	Riparian PES	Length km
X24F-00953	Crocodile	X2CROC-NKONG	X2CROC-NKONG	C	C	C	D	C	31.02

This reach is the last biomonitoring site before the Crocodile River flows into Mozambique. The river forms the boundary of the KNP and a large weir is located in this reach (known as Van Graan Dam). One site (X2CROC-NKONG) was sampled in this reach. The main land use in the area includes conservation, sugarcane and citrus.

According to Roux and Selepe (2014:38), a FRAI score of 73.2% was calculated for this reach with an Ecological Class C which is moderately impaired with a high diversity of fish species. In terms of invertebrates, the PES category Class C was given and an Ecostatus of Class C (Table 6.5.4).

The location of this reach corresponds to the location of monitoring point X2H016 in section 6.2.4. At this monitoring point, the water quality in terms of TDS, TAL and pH levels is worse than at monitoring point X2H032 on the main stem of the Crocodile River, but not high as monitoring point X2H022 on the Kaap River before the Kaap/Crocodile confluence. Therefore, the Crocodile River main stem is acting as a diluent on the high TDS, TAL and pH levels from monitoring point X2H022. Even though the quality of water in this reach is better than the Kaap River reach, there is still a high water quality risk to aquatic health.

Even though there are slight differences in the Ecostatus scores between the reaches presented above, longitudinally, the biomonitoring data shows no substantial change downstream for aquatic health in the Lower Crocodile River Catchment. The Lower Crocodile River Catchment has an extensive agricultural land use in terms of sugar cane and citrus production, due to this it could be expected that the aquatic health in the area would be adversely affected by pollution from this agricultural area. However, the biomonitoring results show that the Crocodile River is unexpectedly not in a toxic state in terms of aquatic health. From this one can deduce that there are no acute pesticide impacts from the agricultural land use in the catchment (though one cannot discount chronic). This is a means that pesticide use is strictly controlled in the sugar and citrus industry in the Crocodile River Catchment. It is very important for the sugar industry to maintain this pesticide management.

6.6 Summary of water quality of Lower Crocodile River in relation to the sugar industry

The Load Duration Curves presented in sections 6.2.1 to 6.2.4 provide information on the possible sources of pollution in the Lower Crocodile River, as well as the dilution capacity of the Crocodile River reach below the Crocodile/Kaap River confluence. The TDS loads exceed the tolerable range (The generic National RWQOs: Table 6.1.2a, were used in the analysis of water quality data for this study because during the period this data analysis was conducted, the RQOs for the Crocodile River Catchment were still being determined the Table 6.1.2a) in the lower reaches of the Crocodile River, with the Kaap River contributing a negative effect in the Crocodile River main stem. This poses a high water quality risk for downstream water users, especially the water quality of irrigation water for sugar production and water used for processing sugarcane. The Kaap River reflects water quality that is worse than the water quality from the Upper Crocodile River Catchment. The major sources of TDS in the Lower Crocodile River are point source dominated, which may be attributed to the extensive mining, industrial and municipal activities that occur across the catchment.

When observing TAL and pH values from monitoring point X2H032 to monitoring point X2H016 (Figure 6.2b), there is a decrease (TAL loads moving from ideal to acceptable range at 81.86% to tolerable to unacceptable range at 42.37%, pH values moving from acceptable to unacceptable range at 5.12% to acceptable to unacceptable range at 26.32%) in the quality of the water in the Lower Crocodile River, with the Kaap River contributing a negative effect that is diluted by the Crocodile main stem. The Hectorspruit WWTW contributes high concentrations of TDS and TAL into the Crocodile River in terms of the general effluent discharge limit and this is influenced by the differences in terms of the performance and management of these WWTWs.

Figure 6.3 shows a decrease in TIN and SRP concentrations in the lower reaches of the Crocodile River compared with the river below Mbombela, which can be attributed to the extensive sugar cane plantations located in the Lower Crocodile River Catchment acting as an “agricultural wetland” that serves a function of bioremediation resulting in large scale absorption of nutrients. However, it is still important to note that even though there is a decrease in TIN and SRP concentrations in the lower reaches of the Crocodile River, these concentrations are still elevated compared to the reference site (recommended target concentrations given as 0.12 mg/l for TIN and 0.018 mg/l for SRP). This is an interesting result as earlier assumptions were that fertiliser application would result in an overall increase in nutrient loads and concentrations.

Biomonitoring data also shows no substantial change in aquatic health from X22K-01018 reach to X24F-00953 reach, however, there are slight differences in the Ecostatus scores of the reaches. For a catchment that has an extensive agricultural land use in terms of sugarcane and citrus production, the Crocodile River is unexpectedly not in a toxic state in terms of aquatic health. This is a positive result and it means that pesticide use is strictly controlled in the sugar and citrus industry in the Crocodile River Catchment. It is very important for the sugar industry to maintain this pesticide management.

CHAPTER 7

Concluding Discussion

7.1 Introduction

South Africa can be described as a country with a history of water shortage or scarcity. This is one of the major problems facing the South African Government, specifically in the view of an increasing population and expansion of industrial development. Rivers are the main conduit of freshwater in South Africa and the country depends on surface water resources, with major storage in dams, for industrial, urban and irrigation water requirements. However, freshwater systems in South Africa are adversely affected by excessive water abstraction and pollution.

The Crocodile River Catchment in the Mpumalanga province in South Africa was identified through previous research, as a catchment faced with the deterioration of source water for water users in the catchment (Palmer *et al.,* 2012). Poor source water quality is becoming a sufficiently acute concern for the stakeholders in this catchment to be willing to co-operate in developing a process to improve integrated water quality management. Such a process would assist with compliance control of water use and waste disposal to reduce costs, decrease industrial risks as water quality compliance increases, and improve source water quality. Affected industries in the Crocodile River Catchment include water boards, water user associations, mines, forestry, pulp and paper manufacturing and sugar mills. Critically, local government and the management of waste water treatment works must be included. A viable solution to address this matter is for stakeholders to co-operate with each other and with the regulator in designing and complying with agreed management processes and to collectively hold each other to account.

As mentioned in Chapter 1, Section 1.5 of this study, the sugar industry is the most downstream industrial and agricultural water user within the Crocodile River Catchment, and is affected by the activities of all upstream water users, and is dependent on the stakeholders upstream participating in the effective management of the resource. The sugar industry is also located just before the confluence of the Crocodile River and Komati River upstream of the Mozambique border, thus the water quality of the sugar industry will affect the quality of the water that flows into Mozambique. The sugar industry is on the opposite river bank to the Kruger National Park, which has high water resource protection goals. Therefore, the sugar industry has a national role to play in the management of water resources in the Crocodile River Catchment.

This study provides a focused view of the role of the sugar industry in the development of a co-operative, integrated water quality management process (IWQMP) in the Crocodile River Catchment. In order to address the objectives of this study, this research drew from an understanding of the social processes that influence water management practices within the sugar industry as well as social processes that influence the role of the Inkomati-Usuthu Catchment Management Agency as a regulating agency in water management in the Inkomati Water Management Area.

The study also drew from an understanding of scientific knowledge in terms of water quality analysis as a biophysical component to describe the water quality impact from upstream water use activities on the sugar industry and the impact of the sugar industry on the in-stream water quality of the river below the industry. The use of scientific knowledge in terms of an understanding of the biophysical processes that influence water quality in the Crocodile River Catchment is important to inform societal responses and decision making that will improve water quality management in the catchment.

While an understanding of biophysical processes through scientific knowledge is critical in water management decision making, it is evident that an understanding of other actors, institutions and networks that inform water quality management decision making also plays a significant role. The notion of improving the role of scientific or biophysical knowledge in contributing to socio-ecologically robust knowledge co-creation, decisions and actions towards resolving water quality problems is emphasised through this study. Specifically, moving towards improving interactions between scientists and other actors (water users in the Crocodile Catchment in this case), so that scientific practices become more orientated towards societal platforms were water quality management is tackled to enable improved water quality management practices. Linking the social and biophysical components in this study provides a holistic understanding of how the sugar industry can contribute to the development of an IWQMP for the Crocodile River catchment.

Chapter 3 of this thesis presents a detailed description of the key concepts and theories that are drawn on in this study, providing the conceptual framing for this thesis and relating these concepts and theories within a broader analytical framework, as well as a detailed description of the methods used and explanation of how these methods interact and interrelate. This concluding discussion provides examples of how the concepts, theories and methods were applied in this study to provide an exploration of how the sugar industry has contributed to the development of an IWQMP for the Crocodile River catchment. In sections 7.2, 7.3 and 7.4, the progress that has been made towards the development of an IWMQP for the Crocodile River Catchment is presented, together with the contribution that this study has made, the challenges encountered with resultant limitations to the work, and the way forward in terms of operationalising the IWQMP once it has been established.

This research is located within an overarching framework of Integrated Water Resource Management (IWRM) and general complexity theory (Cilliers 2000, Audoin *et al.,* 2014). IWRM as described in Chapter 3, section 3.1.1, is a management approach which requires the active participation of multiple parties, across multiple levels in many different ways. This leads to a change from single-sector, centralised, delivery-orientated management to sector-integrated, locally focused management which includes the interests of diverse stakeholder. General complexity theory acknowledges complex systems, such as social ecological systems (Pollard *et al*., 2008) as comprising of many interacting parts, non-linear relationship pathways and feedback mechanisms between parts and processes. This understanding leads sensibly to transdisciplinary, adaptive research and practice responses (Palmer *et al.,* 2014). This framing of IWRM in a complex social-ecological system context has shaped the way this research was conducted by informing the specific methods that were applied in the study.

In Chapter 3, Section 3.1.2, the emphasis of understanding the interactions between social and biophysical systems is made and in the context of water, the recognition of these as social-ecological systems is important as it enables taking account of the characteristics of complex systems when dealing with water issues. In order for this approach to be possible, it is important to draw from a wide range of knowledge in an integrated way – an aspiration of this study. The work is embedded in complexity thinking and the understanding of the characteristics of complex systems. For example, one of the characteristics of complex systems as described in Section 3.1.2 is that they have feedback loops between components and processes and this is evident in the activity systems described in Chapter 5 that exhibit feedback loops. Chapter 5, Section 5.3, provides a description of the primary and secondary contradictions within the sugar industry and explains how primary contradictions can evolve to potential secondary contradictions within the activity systems and this is one of the areas were feedbacks have been taken into account in the study.

Although a systemic analysis, such as one using system dynamics modelling, was not conducted in this study, the study was conducted with a systemic view of the sugar industry in the catchment. This view included an understanding of the links between the social and biophysical components of the system, where actions towards water quality management were identified and encouraged. The researcher in this study was based at the Inkomati-Usuthu Catchment Management Agency (IUCMA) for the entire period of the study, and had the opportunity to work embedded within the IUCMA. The Catchment Management Strategy (CMS) of the IUCMA (ICMA, 2004) was developed through the application of Strategic Adaptive Management (SAM) (Rogers and Luton, 2010) with the centrality of the role of monitoring, response and adaptation being more important than static goals and preconceived outcomes. During the course of this research, SAM workshops were conducted with IUCMA officials in the Resource Protection and Waste Division, with the aim of reviving the application of SAM as part of the functioning of the division. All the data that were collected in this study moved into a SAM based process on learning to practice SAM by actually practising it while conducting the research.

As soon as one accepts that IWRM occurs within complex social-ecological systems, it becomes clear that a variety of sources of knowledge and skills need to be applied in an attempt to resolve complex problems. It is also important to recognise that knowledge exists in all the people that are involved in a particular action and that co-creation of knowledge as well as the exchange of knowledge from different sources is crucial. A transdisciplinary framing (Palmer *et al.,* 2014), which argues for the integration of multiple disciplines and understandings in order to tackle complex problems, has been a particularly useful approach in this study.

The application of this way of thinking, made it possible for the researcher to look through different sources of knowledge to tackle the main research question and to address the specific objectives of this study. For instance, using CHAT allowed the identification or surfacing of contradictions within the sugar industry that are considered as areas of “tension” that can be loosened or focused on to improve the contribution the sugar industry can make to the IWQMP. On the other hand, the analysis of water quality as part of the biophysical component enabled the identification of higher risk influences of poor source water quality affecting the sugar industry. This biophysical understanding is positively supported by the identification of key relational areas that can be focus, discussion and negotiation points amongst the stakeholders involved in the development of the IWQMP for the Crocodile River Catchment.

The importance of stakeholder engagement has been emphasised as facilitating progress towards goals such as the development of the IWQMP within the complex social-ecological system of catchment. Social learning has been central to this emphasis and as much as the research approach that was applied in this study took a systemic view, it also took account of a relation-based view of understanding the sugar industry and the IUCMA. The researcher participated continuously and consistently in stakeholder engagement meetings to ensure that the researcher was also embedded in the stakeholder learning platform. Engagement and participation ensured that a continuous process of input and feedback was maintained while conducting the research, and that the research was always alert to the current situation, while exploring the development of the IWQMP; as well as documenting the actions and responses taken in the stakeholder engagement meetings.

The participant observation and workshop aspects of the data collection process of this study required developing facilitation skills, especially during focus group discussions, as well as strong communication and interpersonal skills. Key skills that the researcher started developing within this research include the ability to think and work across disciplines and across scales; and the ability to conceptualise and take a systems perspective on complex problems as mentioned above.

The application of these various techniques and concepts has enabled the researcher to conduct the study in a process of explicitly building trust and developing ways of tackling or assessing the research objectives that supports a crucial understanding of the implications of various inputs and outcomes.

7.2 Progress towards the development of an IWQMP for the Crocodile River Catchment

Chapters 5 and 6 of this thesis provided descriptions of the social and biophysical components of this research respectively. The linking of these components has enabled this study to contribute to developing both a technical and relationship-based view of the sugar industry that will be integrated into IUCMA operational processes. This study provides a systemic view of the sugar industry that the IUCMA had not yet developed, and this understanding can be applied in the management of the water quality needs and impacts of the sugar industry by the regulating agency. The study has also aided the identification of areas of "tension" that are fruitful potential sources of change within the IUCMA, which, if addressed, can improve the functioning of the IUCMA as the water management institution in the region (Chapter 5). The study also identified the key areas that the sugar industry can focus on as part of their contribution to the IWQMP, and because the larger project (Chapter 1,section 1.5 and section 7.3 below) is still in progress, that provides an opportunity for these focus areas to be addressed as the larger project moves forward. Section 7.4 below explores the options the sugar industry can take as a way forward.

The methods applied in this study as well as the insights that have developed through the study can also be extended to other stakeholders that are involved in the development of the IWQMP to provide a systemic understanding of water management in the Crocodile River Catchment. This is the progress that this study has contributed to in the development of the IWQMP.

7.3 Contributions and limitations

This research is undertaken within a larger research project, entitled: "*Building a co-operative, implemented Integrated Water Quality Management Process (IWQMP) for the Crocodile River Catchment"*, funded by NRF THRIP (National Research Foundation: Technology and Human Resources for Industry Programme) (described in Chapter 1, section 1.5). It is one of two MSc projects within the larger project, the other MSc project being Mr Hugo Retief's study which is focusing on investigating integrated catchment management scenarios using a 'simple' water quality and quantity model: A case study of the Crocodile

River Catchment, South Africa (Retief, 2014). The larger project is conducted with the co-ordinating role of an academic political ecologist, Dr Victor Munnik with contributions from the two MSc project, as well as stakeholders and the Inkomati-Usuthu Catchment Management Agency.

This study contributes a focused view of the role that the sugar industry can play in contributing to the development of an IWQMP for the Crocodile River Catchment as its primary aim. The research objectives describe how the primary research aim is met is described in greater detail through the research objectives. Each research objective correlates to specific chapters that make up this thesis. This information is summarised in Table 7.3 below.

Table 7.3: Summary of research objectives and chapters within which the objectives were addressed.

Objective	Proposed chapter
Objective 1: To analyse the management practices of the sugar industry (sugar mill and agricultural practices of the sugar cane plantations) in relation to water quality management	**Chapter 5**: Sugar Industry Water Quality Management Analysis
Objective 2: To identify the disturbances within the sugar industry in relation to the development of an integrated water quality management process for the Crocodile River Catchment	**Chapter 5**: Sugar Industry Water Quality Management Analysis
Objective 3: To identify the disturbances between the sugar industry activity system and the activity system of Inkomati Catchment Management Agency activity system in relation to the development of an IWQMP for the Crocodile River Catchment.	**Chapter 5**: Sugar Industry Water Quality Management Analysis
Objective 4: To identify water quality needs for the sugar industry (cane growers and the sugar mills)	**Chapter 2, Section 2.5**: Water Quality Context **Chapter 6**: An integrated view of the Sugar Industry as part of the water quality system of the Crocodile River Catchment
Objective 5: To identify water quality impacts of the sugar industry	**Chapter 2, Section 2.5**: Water Quality Context **Chapter 6**: An integrated view of the Sugar Industry as part of the water quality system of the Crocodile River Catchment
Objective 6: To explore the contribution the sugar industry can make to a catchment-wide collaborative Integrated Water Quality Management Process to secure their water quality needs.	**Chapter 5**: Sugar Industry Water Quality Management Analysis **Chapter 6**: An integrated view of the Sugar Industry as part of the water quality system of the Crocodile River Catchment **Chapter 7**: Concluding Discussion

The researcher conducted this study in an entirely conceptually and practically supportive environment, which is a very rare research setting. As mentioned in Chapter 4, Section 4.1.4, the project was embedded in and accepted by in the IUCMA as part of their water quality team functions, so the project was part of the agency which functions as the water management regulator. The IUCMA will also be the implementing agency of the IWQMP once it is established. This enabled the researcher to successfully conduct the study in an action research setting. From the commencement of the larger project, the researcher was part of the on-site project team that took on the role of organising stakeholder engagement meetings, data collection, as well as being involved in the reflection and social learning as part of the project. This meant that the researcher was continuously involved as a participant in the project and has the understanding of the bigger picture in terms of the development of the IWQMP.

As part of the opportunity of being based at the IUCMA for the duration of the research, the researcher became a participating member of the IUCMA Water Quality Division, which meant involvement in meetings to discuss the performance of the division in terms of water management in the Inkomati Water Management Area. The researcher was also provided the opportunity to report on the progress of the larger project at these meetings as well as the progress of this study. This made available a constant space of identifying the applicability of this study towards a contribution to the functioning of the IUCMA and how the project can be operationalised at completion.

As part of the on-site project team, the researcher was also involved in early discussions with stakeholders about the expectations they had about how the IWQMP will be useful to address water quality management in the Crocodile River Catchment. These views were recorded as part of stakeholder engagement process of the larger project and included views such as highlighted in some of the quotes below from stakeholders:

- “The company expects to be actively involved in the development of the IWQMP they want to make a significant contribution to the IWQMP” (Manganese Metal Company Representative, personal communication, 2013).

- “Expects the establishment of the framework to address the water quality issues in the catchment” (TSB Representative, personal communication, 2013).
- “The company is looking forward to efficient information sharing, establishing a plan or guideline for water quality monitoring” (Assmang Chrome Metal Company Representative, personal communication, 2013).
- “The framework to influence water quality enforcement in the catchment” (Semcorp Silulumanzi Representative, personal communication, 2013).
- “We need to empower the ICMA for this project to be effectively implemented” (Crocodile Major Irrigation Board Representative, personal communication, 2013).

The results of this research were also presented to the Chief Executive Officer and the General Manager of the Cane Supply Division at the sugar mill. The General Manager’s views of the contribution of this project to the IWQMP were as follows:

“The work was well done and very well presented. The method of analysis and presentation gave the raw data meaning and created quick understanding. The end results confirmed certain theories we had and showed up some areas that we were not aware of. The methodology can form the basis of analysing and understanding water quality issues in order to determine the management route to be taken.

“In the form as it is now, the study has already contributed towards the sugar industry by clearly showing that the sugar cane non-point source pollution is if virtually not significance. For the IUCMA the work gives a handy base to use when determining the quality standards and the management measures required going forward” (TSB Representative, personal communication, 2014).

The comments given above show that this study has made a valuable, and valued, contribution to the progress of the development of the IWQMP for the Crocodile River, with a focus on the sugar industry.

This study acknowledges that the research of a contemporary phenomenon in its real-life context has various limitations. The multifaceted, multi-layered and interlinking dimensions to water management in the Crocodile River Catchment highlight that this is indeed a complex problem: as such, tackling one aspect of the problem was understood to possibly have unexpected effects and raise issues of uncertainty about other aspects of the problem. The limitations that the researcher experienced while conducting this researcher are listed below relating to the social and biophysical components of the study:

Summary of the social component limitations

- Language barrier when conducting interviews that resulted in the need to have assistance for translating. The emerging sugarcane farmers converse in IsiSwati and some of the commercial farmers converse in Afrikaans. Accuracy of record keeping can be affected due to this language barrier.
- Avoiding deception and the undue creation of expectations with regards to the research aims and objectives. It was very important to ensure that the respondents during interviews understood the aims and objectives of the project to ensure that the information provided related to the project. However, sometimes the respondents would see the interview as an opportunity to voice dissatisfaction about other aspects in the catchment that may not be related to the project and this can be time consuming.
- Taking into account pressures from respondents' peers or management in their company and the wider institutional settings. This aspect was a factor especially when interviewing employees at the sugar mill who were nominated as representatives of the sugar industry for the project. It is important to be aware that sometimes the representatives may be putting their contributions aside and focusing on what the views of management of the company or colleagues would be.
- In terms of the Grower Affairs Division, only the manager of the division was interviewed and the extension officers were not interviewed. This is a shortfall in terms of understanding how the division operates on the ground.
- The CHAT analysis focused on the surfacing of contradictions and did not explore the aspect of expansive learning which involves how new knowledge or innovation can occur and be nurtured within activity systems. This was done due to the scope of this study.

Summary of the biophysical component limitations

- One of the greatest limitations in terms of water quality data analysis is the availability of a set of reliable, continuous water quality data (including flow and water quality measurements). This availability, which can never truly be satisfied in the context of water quality analysis, due to missing observed measurements, influences the period that can be chosen for analysis of current conditions.
- This study focused on in-stream water quality analysis and groundwater quality was not analysed.

7.4 Way forward

As mentioned in the early sections of this chapter, this study has explored the development of an IWQMP for the Crocodile River Catchment with a technical and social-based understanding of the sugar industry. However, also important is examining how the information provided in this thesis can be used to contribute to the implementation of the IWQMP once it is established. There are various options that can be taken by the sugar industry as a way forward to moving towards applying the information made available by this research and these options are listed below:

The water quality analysis shows that the Kaap River contributes a negative effect in the Crocodile River main stem in terms of TDS, pH and alkalinity, posing a very high water quality risk for irrigation water for sugar production and water used for processing sugarcane. The poor water quality from the Kaap River is attributed to extensive mining in the catchment area of the river. The social component results that were produced though CHAT work, highlighting the CMA as an overarching institution or rule-producing activity system has made it clear that the elucidation of water quality description emerged as a stakeholder need. Even though the pollution contribution of WWTWs in the Lower Crocodile River Catchment has been known, the negative contributions from the Kaap River, compared with Mbombela, was not explicit and this shifts the relationship between the sugar industry and the IUCMA and indicates focus areas for IUCMA. This information is now available for the sugar industry to address and this may be done in various ways. Such as making the information available to the IUCMA and nominating the institution to facilitate a discussion between the mines and the affected downstream water users. The IUCMA can also do a further detailed investigation of whether the mines in the catchment area of Kaap River comply in terms of their license conditions and if they do not comply, what actions need to be taken. This information may already be available at the IUCMA, however it may have not been made available by the IUCMA to the sugar industry.

The water quality analysis also shows that the Hectorspruit WWTW contributes high concentrations of TDS and TAL into the Crocodile River in terms of the general effluent discharge limit and this is influenced by the performance and management of this WWTW. This aspect can be addressed through a subsidiary project that was developed as part of the larger project to address the performance of WWTWs in the Crocodile River Catchment and the project is known as the GreenDrop Support Campaign. Hectorspruit WWTW can be added to the priority WWTWs in the catchment that needs assistance in terms of their performance in waste management. The sugar industry can participate in the discussion to assist as an affected party.

The IUCMA Compliance and Enforcement Division can participate in the above discussions to assist with any relevant information in terms of the measures that can be put in place to reduce TDS, pH and alkalinity loads from mining activities and WWTWs.

The biomonitoring results that are presented in Section 6.5 in Chapter 6 show that for a catchment that has an extensive agricultural land use in terms of sugarcane and citrus production, the Crocodile River is unexpectedly not in a potentially adverse or chronic state in terms of aquatic health. From this one can deduce that there are no acute pesticide impacts from the agricultural land use in the catchment (though chronic effects cannot be discounted). This is a positive result and it means that pesticide use is strictly controlled in the sugar and citrus industry in the Crocodile River Catchment. It is very important for the sugar industry to maintain this pesticide management.

Another major aspect that came out from the social component of the research is the need for an explicit platform for communication of water quality issues that the sugar industry faces. This was influenced by the difficulty of access to information about the water quality issues specific to the sugar, and other industries. This study is a crucial step towards making this information available for discussion at existing communication platforms in the Crocodile River Catchment, and can influence the IUCMA to accelerate plans to develop a web-based water quality reporting platform. The lack of monitoring tools such as flow meters and soil moisture meters was also a contradiction identified within the sugar industry and the sugar industry can be involved in facilitating ways of subsidising the provision of such tools. More generally, the study has demonstrated the value of integrated, engaged, transdisciplinary research in progressing realistic natural resource sustainability across landscapes.

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APPENDICES

APPENDIX A: Cultural Historical Activity System Interview Questions (Source: Modified from Jonassen and Rohrer-Murphy, 1999)

Question 1: The subject of any activity is the individual engaged in the activity.

Please tell me what your responsibilities are for water quality in your company (or institution).

How did you end up in this job? Did you choose it and were you specifically trained for it?

Is it easy or is it quite difficult? Do you enjoy it?

Is water quality an important issue for your company? Does it receive a lot of attention?

Question 2: Objective

What is the objective of your work? I suppose that is basically your job description…

And what would it look like if you have achieved the outcomes you are responsible for?

Question 3: Tools

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

What is the basic production process? What water impacts does it have that you have to cope with? How do you deal with them?

And what sort of procedures, protocols and paper work is there?

Can you tell us about changes that have happened, or that you accept to happen in the production process or the treatment processes?

Which tools work well for you, and which would you like to change?

Question 4: Sharing the tasks

Now I would like to ask you about the people or the team, inside your company (or institution) that share tasks with you.

Do you manage a team? What do they need to do to achieve the objective of good water quality effluent from your works? How are they doing?

How does your position relate to the people in the hierarchy above you/? How do they enable your job? Are there pressures they transmit to you? What opportunities do they provide to you, and how do they support you?

Question 5: Community of practice, or peers

And outside your company? Do you have fellow professionals that you meet with, or discuss with? Do you belong to a professional society, have access to trade or professional publications? Or do you basically work on your own in this respect?

As you are part of the Croc IWQMP process, have you found that to be an interesting place to discuss these issues? **(Allow the person to unpack any issues that may come up at this point, including about the project).**

In your contact with your fellow professionals, what are the water quality topics that are most discussed? Are you concerned about the state of water quality in the Crocodile, and what do you think could be done about it?

Question 6: The rules of the game

So what are the formal rules and procedure for the job you are doing? Where do they come from?

And what are the informal ones, the ones that make sure that the job actually gets done? Sometimes it is these informal rules that enable you to actually deal with the challenges, isn't it?

Do you think these rules have been changing, or are changing now?

Question 7: The past and the future in the present

In my final question I want to ask you to share with us your experiences about the past – what has shaped your job, what are the important turning points you remember or you have heard about for your company (or institution) – as well your expectations and concerns about the future.

How long has your company been here? How are things going – for example, have you been affected by the recession?

What does the future of water quality in the catchment look like to you?

Thank you

Thank you very much for your time and co-operation. We will be feeding back the results of these interviews and our analysis to you at our stakeholders' meeting on 6 December 2013.

APPENDIX B: Focus group Discussion Questions

History of local sugarcane farming practices

How long have you been in the sugarcane industry in the Crocodile River Catchment?

Currently how is water management conducted in the sugar industry?

How have the sugarcane farming practices changed in relation to water management?

What practices have been improved to achieve efficient water use?

Have you ever spoken about or been involved in Integrated Water Quality Management (IWQM) Discussions?

Are there IWQM practices in the sugar industry?

Tools

What tools are in place that are used to support IWQM in sugarcane farming?

Are these tools readily available to you?

Are the tools well suited to achieve IWQM? What improvements can be made?

Rules

What are the formal and informal rules that are in place that promote or constrain IWQM?

What other events or circumstances that shapes your farming practices in relation to IWQM?

What are the formal and informal rules in place within the Siyathuthuka Project? How are these rules connected to improve IWQM?

Division of Labour

Who does what in the Siyathuthuka Project?

Who should do what in relation to IWQM?

Which tasks are shared with TSB that are in relation to IWQM?

Community of practice

Are you part of any platform that discusses IWQM issues in the catchment?

How does your location in the system affect you in relation to IWQM decisions made in the catchment?

How do conflicts in your community affect or influence interactions?

How do other water users around you view and value the goals of IWQM?

In Closure

What are your concerns and expectations in terms of IWQM in the catchment?

What does the future of water quality in the catchment look like to you?

APPENDIX C: Seasonal Loads for TDS and TAL for monitoring sites X2H032, X2H022, X2H046 and X2H016.

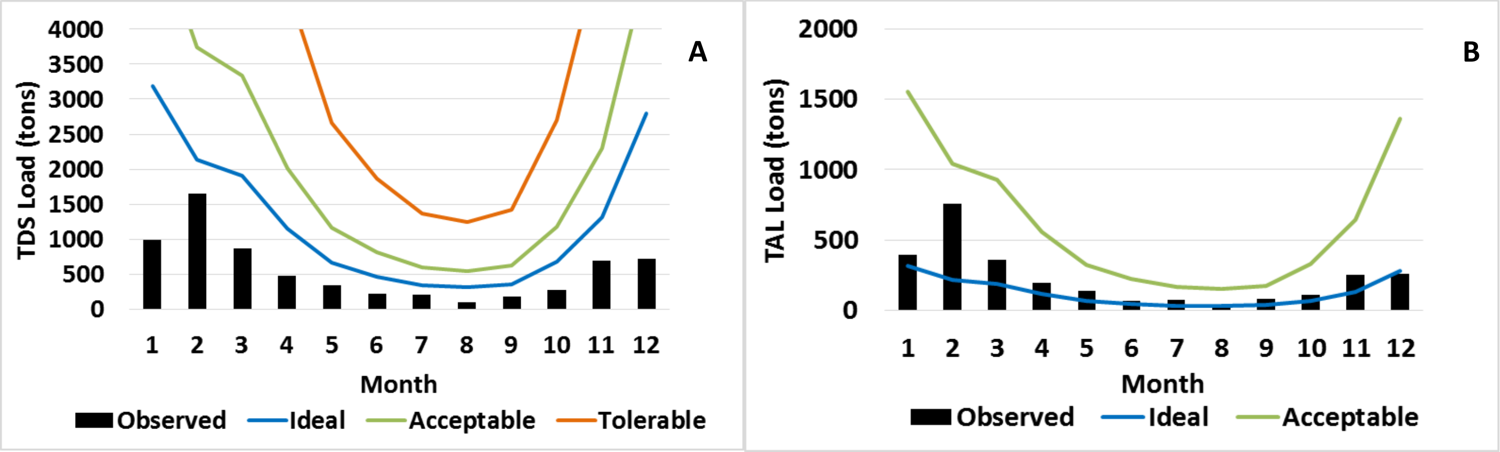

Figure 6.2.5: Seasonal Loads for monitoring point X2H032 situated along the Crocodile River. ***A:*** *TDS and* ***B:*** *TAL* (Retief, 2014).

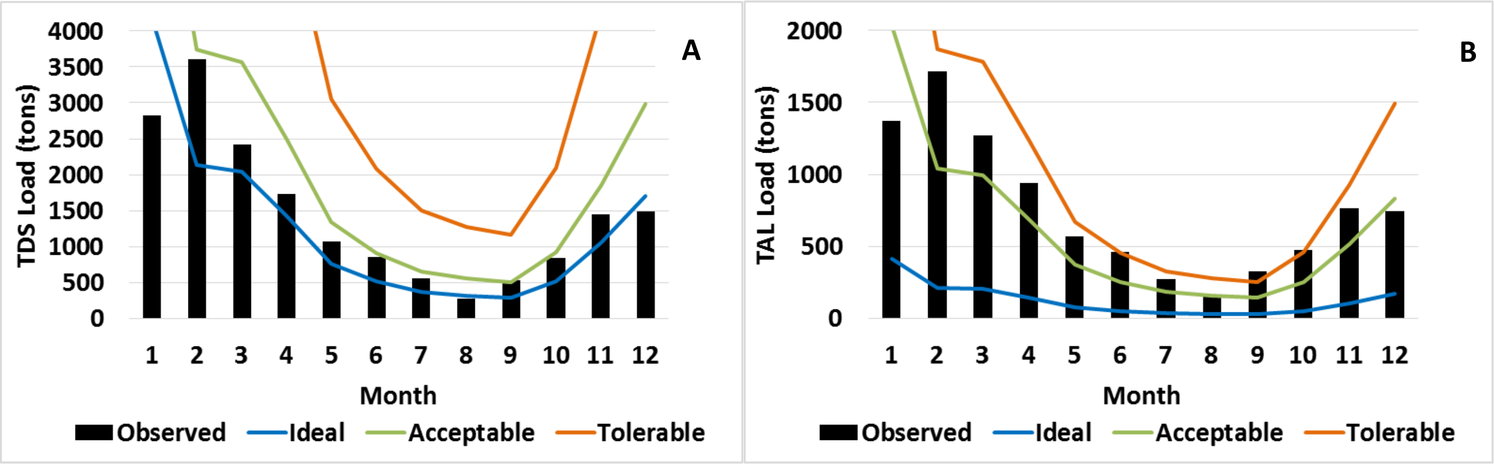

Figure 6.2.6: Seasonal Loads for monitoring point X2H022 situated on the Lower Kaap River before the Kaap/Crocodile confluence. ***A:*** *TDS and* ***B:*** *TAL* (Retief, 2014).

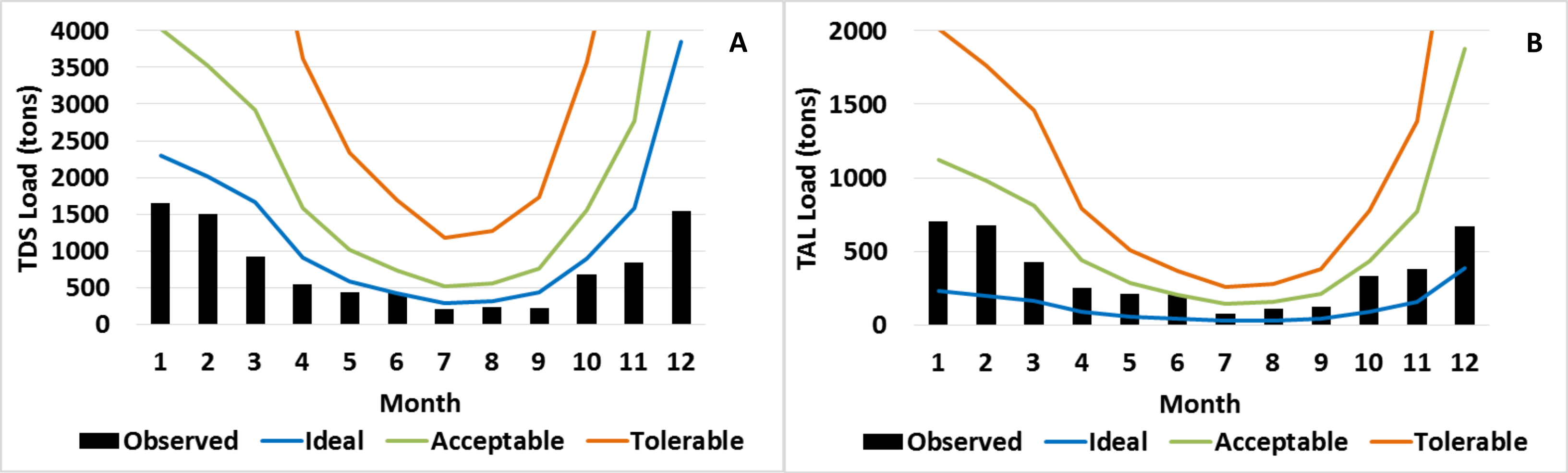

Figure 6.2.7: Seasonal Loads for monitoring point X2H046 situated along the Crocodile River. ***A:*** *TDS and* ***B****: TAL* (Retief, 2014).

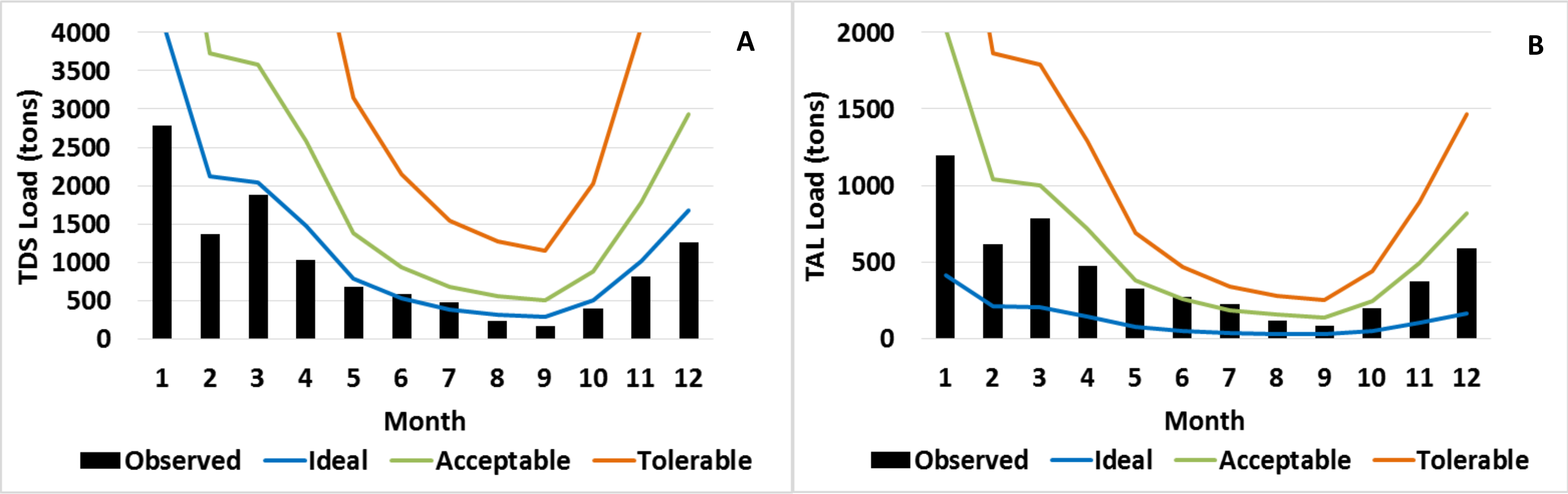

Figure 6.2.8: Seasonal Loads for monitoring point X2H016 situated along the Crocodile River at Ten Bosch. ***A:*** *TDS and* ***B****: TAL* (Retief, 2014).