A CONSTANT STATE OF FAILURE: CHARACTERISATION OF THE WATER MANAGEMENT SYSTEM OF A SMALL SOUTH AFRICAN TOWN

BY

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THESIS

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ABSTRACT

Access to reliable water is a fundamental human right, yet Makhanda, a small town in South Africa, faces ongoing challenges in water service delivery, leading to widespread dissatisfaction. This research adopts a socio-technical systems approach, leveraging Human Factors and Ergonomics (HFE) methods, to analyse and these issues within Makhanda's Eastern water management system.

Through the workplace observations and semi-structured interviews, of twelve municipal water officials, the study identified key interactions between, individuals, tasks, tools, organisations, and their working environments. Data were mapped using models based on the Systems Engineering Initiative for Patient Safety (SEIPS) framework, and were further analysed with a deductive and inductive approach revealing recurring systemic themes, that persisted as either facilitators or barriers to the water systems' functioning.

The findings highlighted critical barriers such as mismanagement of finances, insufficient funding, resource shortages, staff vacancies, and brittle infrastructure prone to frequent breakages. These barriers were linked to poor systemic vertical integration, ineffective feedback loops, and a drift toward failure due to unattended alarm feedback signals, delayed responses and inadequate/ ineffective counter gradients.

While some barriers are deeply rooted and time-consuming to address, a key first step is leveraging resilient water system employees. Strengthening communication and recognizing individual contributions can enhance vertical integration, improving mishap reporting and response times. Streamlining processes, reducing job vacancies, and fostering a culture of learning will further boost efficiency. These efforts will help mitigate errors, enhance water service delivery, restore community trust, and support sustainable water management in Makhanda.

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THESIS ABBREVIATIONS

AM	Ante Meridiem
CMF	Catchment Management Forum
CMS	Catchment Management Strategies
CWA	Cognitive Work Analysis
DSM	Dynamic Safety Model
EAST	Event Analysis of Systemic Teamwork
FRAM	Functional Resonance Analysis Method
HFACS	Human Factor Analysis and Classification System
HFE	Human Factors and Ergonomics
HTA	Hierarchical Task Analysis
IWRM	Integrated Water Resource Management
LGSETA	Local Government Sector Education and Training Authority
MIG	Municipal Infrastructure Grant
MM	Municipal Manager
MWIG	Municipal Water Infrastructure Grant
Net-HARMS	Networked Hazard Analysis and Risk Management System
NGO	Non-profit Organisation
NWA	National Water Act
NWRS	National Water Resource Strategy
PETT	People, Environment, Task, Tools
PH	Potential of Hydrogen
PM	Post Meridian
PPE	Personal Protective Equipment
SANS	South African National Standard
SCM	Reasons Swiss Cheese Model
SEIPS	Systems Engineering Initiative for Patient Safety
SHR	Rasmussens Structural Hierarchy of Risk Management
SIEPS	Systems Engineering Initiative for Patient Safety
SIU	Special Investigation Unit
STAMP	Systems Theoretic Accident Model and Process
STPA	Systems-Theoretic Process Analysis
TLB	Tractor Loader Backhoe
WIFI	Wireless Fidelity
WRCS	Water Resources Classification System
WSA	Water Services Act

GLOSSARY OF TERMS:

Office tools:

- Staplers
- Computer
- Office landlines
- Pens
- Paper to record water readings
- Printers
- WIFI
- Internet

Plumbing tools:

- Valves
- Pumps
- Airlocks
- Wrenches
- Spanners
- Nuts
- Bolts

Water testing supplies:

- Jar test machine
- PH measure (to be used in place of jar test machine)
- Chlorometer measure (to be used in place of jar test machine)
- Turbidity measurer measure (to be used in place of jar test machine)
- Beakers
- Pipettes
- Beaker carrier for water testing
- Gas masks
- Torches

PPE working gear

- Steel toe boots
- Protective overalls
- Gas masks
- Gas bottle and mask (on wall outside of the chlorination building)

General tools

- TLB (digging machines)
- Generators
- Alternators

Electrical tools:

- Generators
- Substations
- Transformers
- Breakers
- Feeders/Soft starters
- Pump Motors

Water purifying essentials:

- Water
- Sand for the sand filter
- Water Flocculant
- Chlorine gas

Desktop related tools:

- Microsoft Word
- Microsoft PowerPoint
- Microsoft Excel
- Slide shows
- Google Teams
- Zoom

PREFACE

Living in a city that you have grown up in and which holds memories that span decades makes the place very special to you. Makanda, formally known as Grahamstown, will always be dear to me. Its beauty, rich arts and culture, the school where I learnt to be me, where I had my first love, my first heart break, where I met my best friends and where I embarked on many runs, hikes, dog play dates and late-night drives with the music blazing singing my heart out. It is the city where I walked the streets and stared at the beauty of the Jacaranda trees and mountains that envelope our small town and where I witnessed the very intimidating Rhodes students for the first time who all looked much older and wiser than me, little did I know I would become one of these older and arguably wiser people. These are the cornerstones of life, and I've experienced them all here. In this little quaint town in the middle of the Eastern Cape. Makanda has seen my highs and lows and almost like symmetry I've seen its highs but also its slow decline into its lowest times.

When I thought about what I wanted to research for my master's thesis, I knew I wanted it to be impactful. I knew I wanted to give back to the town that has my heart, and which has taken such good care of me for as long as I can remember.

In a time where so much is seemingly going wrong in Makanda, I wanted to understand the intricate contributory factors to these situations and show others that, as a community, we need to help each other get our city back to its former glory and not bash each other down. I want to show that there is hope. I want to create an ideology where instead of just watching the slow decent into disfunction we work together and do our own parts no matter how small to create an impact and to leave a legacy of triumph and grit.

My hope for this thesis is for it to inspire, inform and aid in creating a better more sustainable future for Makanda. My research will hopefully be the first step in more collaboratory research between Rhodes University and the Makana Municipality to create a more sustainable future. I want this to be my contribution to our city. My home

Chapter 1 Introduction and Literature Review

Introduction

This study investigated the causes of the poor performance of the water management system in Makhanda, a town in the Eastern Cape of South Africa which is known for its unsatisfactory water service delivery. Chapter 1 begins with an overview of Human Factors and Ergonomics (HFE), the scientific discipline that seeks to understand humans' interactions with other elements within systems to achieve overall system performance and the well-being of individuals working with or influenced by these systems (Bridger, 2018). It covers various HFE frameworks and methods, with a focus on the selected framework, the Systems Initiative for Patient Safety and the Swiss Cheese Model, Rasmussen's Structural Hierarchy of Risk Management and the Dynamic Safety Model.

The second section focuses on the importance of water and how these systems physically transport water from water sources to consumers. Section 3 presents the legislation that sets out how water should be governed in South Africa. The fourth section analyses the context of water management in the east of a local South African town. Wilson (2014) and Dul et al. (2012) note that it is important to sketch the context of a study, as different settings give rise to varied interactions, events, artefacts, individuals/roles, and activities (Wilson, 2014) that all interact and are interdependent (Dul et al., 2012). The numerous complex interactions between humans and technologies (De Haan et al., 2013) constitute socio-technical systems that need to be understood to assess HFE (Patorniti et al., 2017; Kroemer et al., 1994). The last section sets out the problem statement and research question.

1 Literature Review

1.1. Human Factors and Ergonomics:

Human Factors and Ergonomics (HFE) is “the scientific discipline concerned with understanding the interactions among humans with other elements of the system and the profession that applies theory, principles, data, and methods to design to optimise human well-being and overall system performance. HFE professionals contribute to the design and evaluation of tasks, jobs, products, environments, and systems to make them compatible with the capabilities and limitations of people” (IEA, 2003). These systems range from interactions between an individual and other individuals to tasks, tools, organisations and the environment (Bridger, 2018; Dul et al., 2012). HFE specialists, known as Ergonomists, apply theories, data, design methods, and principles to achieve these goals (Dul et al., 2012). The systems it analyses can be simple singular-person systems, singular tool systems, complex multi-person systems and anything in between (Khayal, 2019; Kroemer et al., 1994).

1.1.1. Focus on performance and well-being

HFE focuses on two main outcomes of its application, namely, to improve system performance and the well-being of individuals interacting with or impacted by the system (Bridger, 2018). This is achieved by fitting the environment to the human, resulting in individual well-being, health and safety, satisfaction, personal development, pleasure and learning (Dul et al., 2012). It also promotes system performance: efficiency, reliability, safety and security, productivity, quality and innovation (Dul et al., 2012).

Performance and well-being are not independent outcomes of a system; they interact and are interdependent (Dul et al., 2012). Performance can influence well-being and vice-versa (Dul et al., 2012). For example, a system worker with poor well-being will not perform well, resulting in decreased system performance and vice versa.

The dual nature of HFE and its outcomes sets the discipline apart from others, for example, psychology which examines human well-being or engineering in relation to

system performance (Dul et al., 2012). The goals themselves are weighted in a hierarchical manner (Kroemer et al., 1994), enabling the identification of those that require immediate attention

1.1.2. Goal Hierarchy

When it comes to designing products and work, the Ergonomist's goal is for the product to be developed for the user, and the job for the worker (Kroemer et al., 1994). This is achieved by designing jobs, work environments, tasks, products and systems that are compatible with humans' needs, skills and limitations (Khayal, 2019; IEA, 2000). However, work imagined at a general level does not always align with how it is done (Shorrock, 2016b). If the deviations between work done and imagined persist, the task does not abide by the procedures created to ensure it is safe and efficient (Amalberti et al., 2006). While this misalignment is sometimes due to violations, it is mainly because the systems are not designed for those that interact with them (Shorrock, 2016a). Research collaboration with stakeholders is essential to understand how work is done and what is really going on in the system. If it is not possible to fit the work environment and task to the human, the human will be selected to fit the environment or be trained to suit the system (Dul et al., 2012). The philosophy that informs HFE should be kept in mind in order to achieve systemic performance and well-being.

1.1.3. Human Factors and Ergonomics' Philosophy

1.1.3.1. Ergonomics' human-centered philosophy

Kroemer et al. (1994) state that HFE calls for systems with a human-centred approach whether for consumers, the individuals involved in operations, or the organisation's higher-ranking officials who provide the service or products (Holden et al., 2021; Shorrock & Williams 2016)**.** HFE is human-centred by nature as it focuses on designing systems to work for people (Richardson & Thatcher, 2024; Kroemer et al., 1994). Thus, the various individuals within systems must be identified and understood to understand the system and why it is, or is not, working for those for whom it is designed.

1.1.3.1.1. Stakeholders' roles in Ergonomics

HFE addresses interactions between systems and system stakeholders at different systemic levels (Kroemer et al., 1994). Stakeholder engagement is vital as it narrows the gap between policy, practice and research (Hignett et al., 2005). Participatory practices with stakeholders inform system designers about realities within the system that can improve its design and ensure that it is designed for those who will use it (Boaz et al., 2018).

1.1.3.1.2. Benefits of participatory ergonomics

Working in a participatory manner with all system stakeholders enables Ergonomists to understand the system of interest which they may have little to no knowledge of or agency in (Jones, 2018). This promotes common understanding of patterns and behaviours (Jones, 2018), and identification of areas where intervention is required (Golde & Gawler, 2005). Participatory approaches enable stakeholders at all levels of the system to contribute and feel valued (Reed et al., 2017). They also feel free to speak their minds on how the systems policies/management impact their lives and the system processes (Bellucci et al., 2019), resulting in improved system sustainability (Dwived, 2021), success (Donaldson, 2002), performance (Dwived, 2021), system dynamics (Golde & Gawler, 2005), stakeholder trust (Jolibert & Wesselink, 2012), working relationships (Reed et al., 2017) and reduced conflict (Reed et al., 2017).

1.1.3.2. Design-driven philosophy

HFE subscribes to a design-driven philosophy achieved through analyses and assessments, resulting in recommendations for system design (Norros, 2014; Dul et al., 2012). It can be involved in all stages of system design, from planning to design, implementation, evaluation, maintenance, redesign, and continuous adaptation (Woods & Dekker, 2010). These stages are dynamic, and decisions made at one or more stage(s) can impact or be affected by those at others (Dul et al., 2012).

1.1.3.3. Green ergonomics philosophy

Although HFE is human-centred, given the growing need for sustainability research to ensure that our planet is safe and liveable, some ergonomists have recently reconsidered their approaches to design. They acknowledge that, in order to maintain human well-being, the planet needs to be maintained. This is known as green ergonomics (Thatcher, 2013). Green ergonomics focuses on designing systems that require limited resources, reducing the negative environmental impact while ensuring that humans benefit from the system (Richardson & Thatcher, 2024). When human needs are prioritised without acknowledging nature in design, there can be unintentional consequences for ecosystems (Borthwick et al., 2022). Thus, these interactions need to occur within the context of re-fitting humans to nature (Richardson & Thatcher, 2024).

Green ergonomics is important given global warming and other negative impacts. Socio-ecological studies have acknowledged the environment in research for many years (Sinclair et al., 2021; Cote & Nightingale, 2011; Turner et al*.,* 2003).

1.1.3.4. Ergonomics systems' philosophy

Ergonomics always adopts a systems approach (Dul et al., 2012). A system consists of many interacting and interdependent components/interactions that form a whole that is specifically designed with a goal/purpose in mind (Wilson, 2014). Once system interactions have occurred, they can either constitute system facilitators (strengths) or system barriers (weaknesses/interactions that inhibit system performance), which are understood as relational concepts and help to explain what affords and constrains a system to function (Majchrzak & Markus, 2013). A constraint is a social, physical or knowledge-related limitation to action that can be visible or invisible (Vicente, 1999), making an affordance the opposite. HFE looks at systems and designs them to limit constraints for better overall operation (Norros, 2014). The three factors encompassing HFE promote understanding of the contexts in which it identifies system interactions, particularly between an individual and other individuals, tasks, tools, organisations and the environment (Bridger, 2018).

1.1.4. Human Factors and Ergonomics comprises three factors

HFE comprises three factors: cognitive, physical and organisational (Panjaitan & Ali, 2019; IEA, 2018). These all exist within the environment, an important consideration because external environmental stimuli can affect the factors and their interactions with each other (Malatji et al., 2019). Marras and Hancock (2014) recommended that HFE examine the whole human within the context of the environment in its entirety (internal and external environments). Cognitive factors focus on information processing, memory, perception and motor responses as well as reasoning (Hollnagel, 2003), while physical factors deal with anthropometrics, human anatomy, physiology and biomechanics as these all relate to physical activity (Karwowski & Marras, 1999; Kroemer et al., 1994; Pheasant & Haslegrave, 1986). Lastly, organisational factors include socio-technical systems and their organisational structures, processes and policies (Reason, 1997), including the design of working times, quality management, participatory work design, crew resource management, teamwork, community ergonomics and communication (Karwowski, 2006). The IEA (2018) states that the organisational factor focuses on optimising the organisational aspects surrounding human workers and how they operate in systems in systems.

Figure 1 shows the factors involved in HFE. It also depicts how they overlap, indicating the interdependencies and interactions between each factor within their environments and how they work together to form responses. These interactions are vital in the study of HFE (Bridger, 2018; Dul et al., 2012).

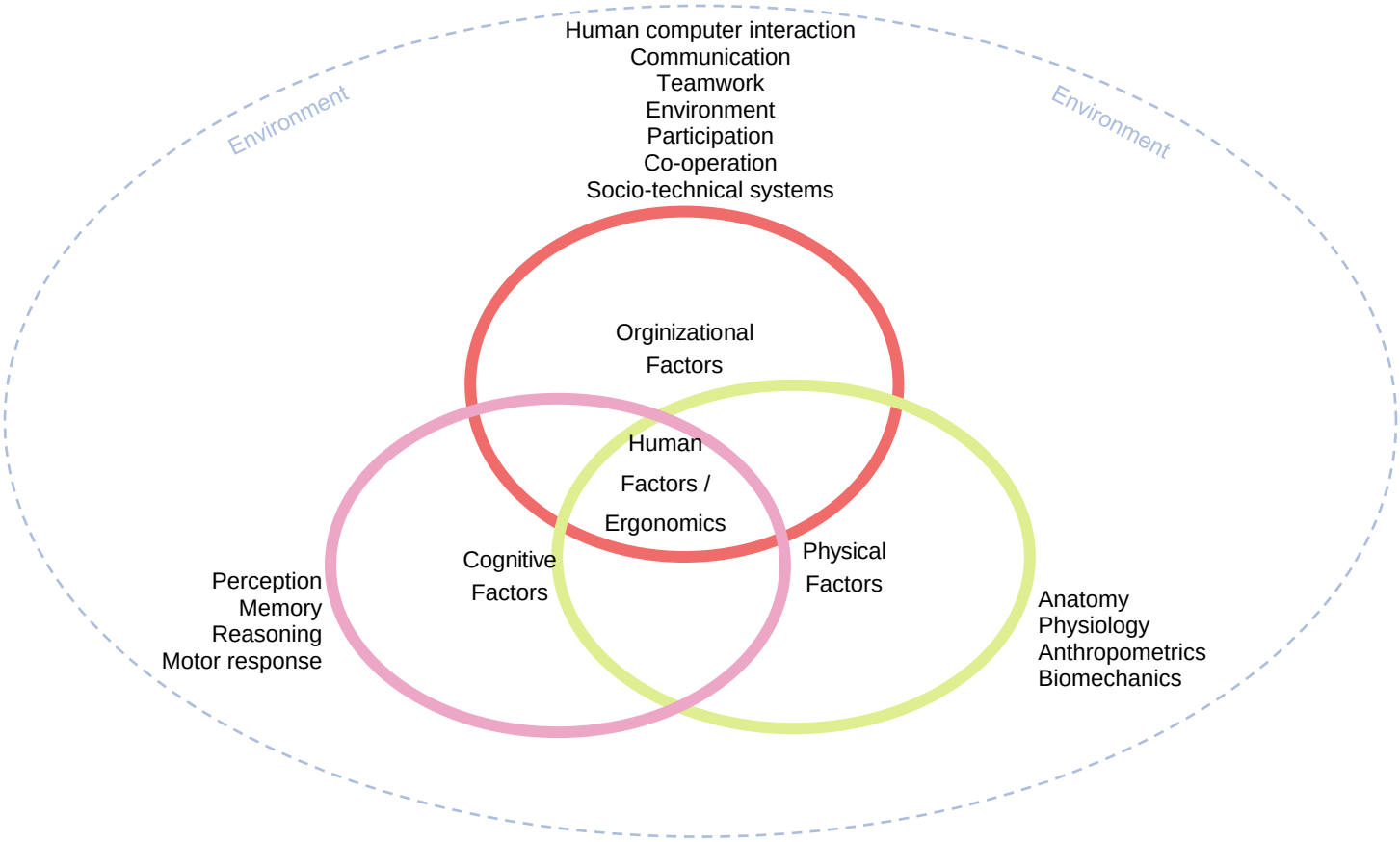

Figure 1: Factors involved in HFE (adapted from IEA (2018).

1.2. Understanding Human Factors and Ergonomics' interactions

The work systems model depicted in Figure 2 below promotes understanding of how these interactions work together and what they comprise. In line with HFE's performance and well-being objectives, it is based on balance theory, a systems approach that considers all elements in a work system (the environment, the tools and tasks within the context, the people involved within the work system and the organisational aspects) to increase system performance and human well-being (Carayon & Smith, 2000).

The environment that a work system identifies can be internal or external (Weaver et al., 2021). The former comprises the quality of the working space and the air quality, temperature, lighting, noise, and workplace layout (Carayon et al*.,* 2006; Carayon & Smith, 2000), while the latter concerns policy and societal or economic factors (Weaver et al., 2021). The tools refer to the technologies required for the job (Carayon & Smith, 2000), and their HFE characteristics like usability (Carayon et al*.,* 2006) and functionality (Weaver et al., 2021). Tasks refer to job demands (the worker's attention, time, stress),

job content (what they are expected to do, its repetitive nature and how challenging it is) and job control (Carayon & Lim, 2003). The organisational aspect examines the organisation and how it structures work shifts, career development (Carayon & Smith, 2000), the organisational culture, social relationships, management style and teamwork (Carayon et al., 2006). Lastly, the human element concerns the worker and his/her relationship with others in the work environment, and his/her skills, physical health, personality, goals, physical conditioning, prior experiences and learning (Carayon & Smith, 2000).

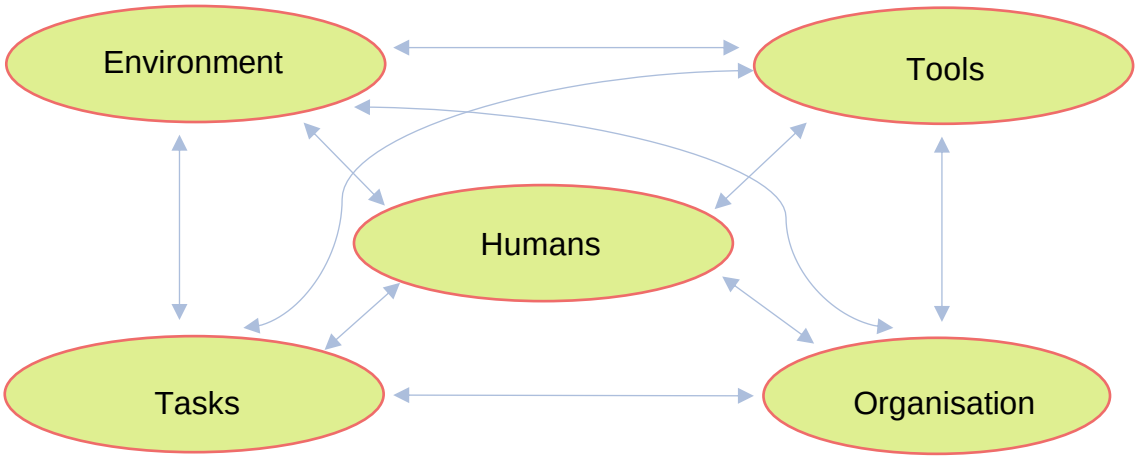

Figure 2: The work systems model (adapted from Carayon & Smith (2000)).

These five elements interact and influence one another to achieve system performance and well-being goals (Carayon et al., 2006; Carayon & Smith, 2000). Based on this model, one of the creators, Pascal Carayon and colleagues, created a model known as the Systems Engineering Initiative for Patient Safety (SEIPS), which ergonomists often use in HFE systems analysis (Carayon et al., 2006). HFE employs systems thinking when conducting systems analysis; examples include studies by Holden and Carayon (2021); Thatcher and Yeow (2015) and Wilson (2014).

1.3. Systems Thinking

Systems thinking helps to predict the behaviour of and improvement of systems (Arnold & Wade, 2015) and to understand how emergent outcomes emanate from these system component interactions (McNab et al., 2020). Emergence occurs when a system's

outcomes/properties form unexpectedly as result of system interactions (Wilson, 2014). Systems thinking uses analytical skills to improve the ability to identify and understand systems (Arnold & Wade, 2015). In general systems thinking, if a system is designed by changing one aspect without considering how such changes could affect other parts of the system, its overall effectiveness is reduced (Hendrick, 1997). Systems can be found in science, engineering, and all aspects of life (Arnold & Wade, 2015).

Furthermore, systems thinking enables interventions to adjust outcomes where necessary (Arnold & Wade, 2015). This is important in the context of globalisation, with countries becoming increasingly interconnected, giving rise to complex, new social systems that must be understood and guided (Arnold & Wade, 2015). Complexity occurs when something is made up of many different connected parts, comprising multiple interactions that make understanding the system challenging (Cilliers, 1998). Figure 3 illustrates how systems thinking occurs and the interconnections between the various stages. It also highlights that systems thinking does not progress from one stage to the next in a logical way, but is non-linear. Non-linear relationships do not start at event A, move to event B and stop at C. Instead, they begin at A and go to B, then C, with the outcomes of the interactions feeding back into the system informing it with new learnings so it can improve and even reorder itself.

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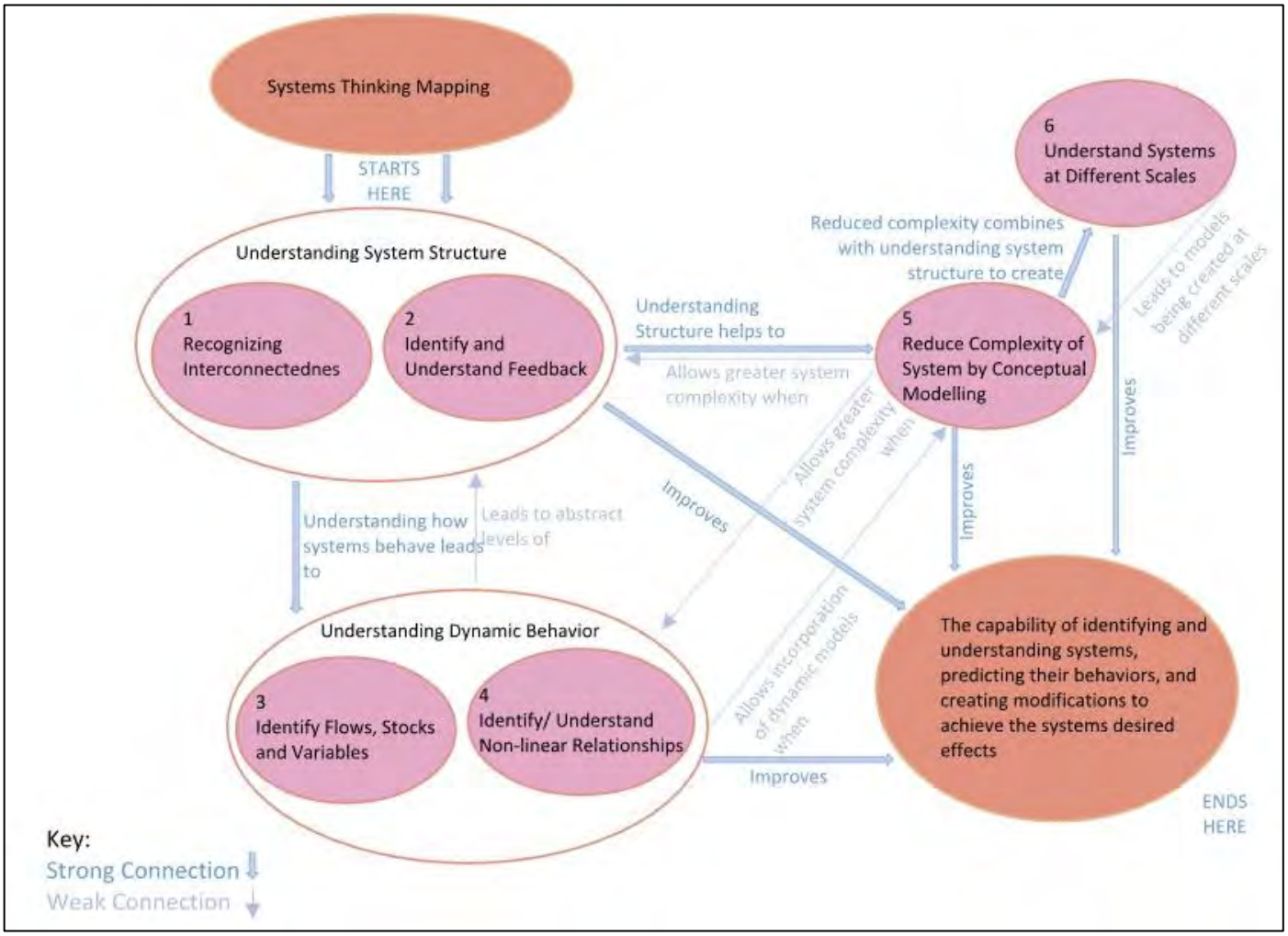

Figure 3: The operation of systems thinking (adapted from Arnold & Wade. (2015)).

For systems thinking to predict and intervene, it requires an understanding of various system characteristics. Firstly, it calls for an understanding of the structure of the system and how it enables the system to behave (Richmond, 1994). The system structure consists of elements and the interconnections between them (Arnold & Wade, 2015). Recognising such interconnections and understanding the feedback is fundamental to understanding the structure of a system (Arnold & Wade, 2015). Feedback loops transmit and return information, with the system outcome effects continuously fed back into the system to inform it (Kim, 1999). Feedback can be positive or negative (Chirumalla, 2017).

Systems must be seen as continuously changing and busy (dynamic), with non-linear relationships that are ever-changing due to the effects on dynamic systems from their feedback loops and environments (Arnold & Wade, 2015). Dynamic behaviour is how interconnections feed into feedback loops and how the feedback loops influence other

elements of systems. It is also evident when the feedback loops consist of stocks, flows (Hendijani, 2021; Meadows, 2008) and variables (Arnold & Wade, 2015). Stocks are any form of resource in a system - informal or intangible (Arnold & Wade, 2015). Flows are the changes in these levels (Hendijani, 2021), while variables are dynamic parts of a system that affect the stocks and thus, the flows (Arnold & Wade, 2015).

Reducing system complexity requires conceptual modelling of its different parts and viewing the system in different ways (Arnold & Wade, 2015). Systems thinking is thus a way to simplify a system through reduction, transformation or abstraction (Arnold & Wade, 2015). Systems thinking influences the way ergonomists approach the systems they investigate and the work systems they are interested in analysing.

1.4. Human Factors and Ergonomics in depth

HFE adopted systems thinking from general systems thinking (Marras & Hancock, 2014) and various ergonomists have championed its use in HFE contexts (see Holden & Carayon, 2021; Thatcher & Yeow, 2015; Wilson, 2014, Dekker, 2013; Dul et al., 2012) as it helps HFE to fulfil its role in socio-technical system analysis and design (Salmon et al., 2016).

1.4.1. Socio-technical systems

Systems comprising humans and technology are known as “socio-technical” systems (Read et al., 2014). Systems theories promote understanding of the interrelatedness of the social and technical aspects of socio-technical systems (Underwood & Waterson, 2013; Walker et al., 2008). Such interactions create either adverse or favourable outcomes (Walker et al., 2008) because interactions that occur between multiple system components within complex socio-technical systems and their outcomes often occur in unpredictable and dynamic ways (Read et al., 2021; Coury et al., 2010). This results from humans acting in unexpected ways, unlike more predictable technology (Walker et al., 2008). Socio-technical systems theory thus aims to create socio-technical systems that are adaptive when faced with disturbance from external factors (Read et al., 2014). This is achieved simultaneously as without joint optimisation of a system’s social and technical

aspects, it will confront increased unpredictability and produce potentially hazardous outcomes (Walker et al*.,* 2008).

Wilson (2014); Read et al*.* (2021); Thatcher et al. (2017) and Saurin (2016) are among the scholars that have supported the use of systems thinking with an HFE lens. Wilson (2014) explains that this calls for a systems-focused perspective that considers the context and various interactions within the system as a whole. This involves being aware of how these interactions emerge and embedding oneself within the system to gain an accurate understanding of the situation and its true dynamics.

Dekker (2013) observes that systems thinking looks beyond a single system and thus promotes understanding of a system by acknowledging that it is part of a more extensive network of other systems or parent systems (Dekker, 2013). Thus, systems thinking maps the relationships between the system and this network of systems and examines how they affect and are affected by interactions in other systems, including those that exist in the future (Dekker, 2013). Parental systems are overarching systems, while sibling systems are small systems that relate to one another and interact (Wilson, 2014). Lastly, child systems are smaller systems encompassed by larger systems (Thatcher & Yeow, 2015).

Thatcher and Yeow (2015) recommended that parent-sibling**-**child systems be harnessed for sustainability as failure to do so could result in the complex interrelationships between the different hierarchical levels of the interlinked system being overlooked (Thatcher & Yeow, 2022; Costanza & Patten 1995). This is in line with Richardson and Thatcher's (2024) assertion that sustainability studies in ergonomics should look to the future.

Linked to the above, ergonomics acknowledges that systems comprise of various levels. Thus, one must be able to identify systems at the micro, meso and macro levels and create boundaries around a system (Arnold & Wade, 2015). Micro levels are the minor levels of system analysis (Jaspal et al*.,* 2015) that typically focus on the impacts on individuals within the organisation (Niskanen et al*.,* 2016; Karsh et al*.,* 2014) as well as

their attitudes, actions, attributes (Jaspal et al., 2015) and cognitive styles (Jaspal et al., 2015, Karsh et al., 2014). The meso level focuses on micro and macro-level links (Niskanen et al., 2016) and is the next level of analysis after the micro level (Jaspal et al., 2015) that focuses on group or team processes (Karsh et al., 2014). Lastly, the macro level is the highest level of analysis, including societal ideologies (Jaspal et al., 2015), legislation (Niskanen et al., 2016) and other factors that impact the organisational system (Karsh et al., 2014).

The HFE discipline has shifted from its primary focus on the science of human work (Jastrzebowski, 1857), towards this concept of systems thinking. This was due to acknowledgement of the reductionist nature of many other ergonomic methods (Salmon et al., 2016). Such approaches are not favoured due to their assumption that there is one root cause or a small group of root causes that usually portray a simple linear narrative (Peerally et al., 2016), which can overlook the more complex accounts of multiple and interacting factors that explain how an event transpired (Peerally et al., 2016). Linear models can cope with simple systems, but cannot be used to understand and analyse complex socio-technical systems (Leveson, 2012). Thus, systems thinking explains systemic failures as opposed to a limited description of errors, for example, human errors (Rasmussen, 1997).

HFE uses the concepts from general systems thinking to develop tools and methods that help to unpack the various factors in systems. These methods influence interactions within these systems to achieve satisfactory performance and well-being.

1.5. Human Factors and Ergonomics Frameworks

HFE offers an array of frameworks for understanding complex systems taught to and practised by HFE professionals while being learnable to others (Stanton et al., 2013). HFE frameworks can bring to light the HFE mindset or be used for research (Holden et al., 2021). There are multitudes of HFE frameworks that can be used in a multitude of different contexts (Shorrock & Willams, 2016), some of which have multiple variations each (Carayon et al., 2016). Thus, there is a large number of frameworks that can be used and, therefore, they must be explained. However, it is not possible to give a full

review of all of them, so in this thesis, a table depicting a select few is tabulated below in Table 1. The most relevant will be used, highlighting the positive and negative aspects of each along with what research papers utilised them and the strengths and weaknesses of the frameworks because they all have pros and cons attached to using them (Stanton et al., 2013).

Although these frameworks share a common goal in HFE, they have differing theory leading to unique analytical approaches (Salmon et al., 2018). There is a common saying, “all models are wrong but some are useful” - George E. P. Box, which tells a story that no framework can account for every single complexity in the world. However, these frameworks are still useful and have their own unique strengths to identify some of the complexities within systems. Indicating, no framework is robust enough to account for everything, meaning all frameworks have their own weaknesses, which is why more than one framework is usually preferred. Combining multiple frameworks allows for more comprehensive and well-rounded outcomes (Stanton et al., 2013). Historically, using multiple frameworks in HFE research has been common practice (Salmon et al., 2018). However, due to the time constraints of a master's thesis, this study will utilise only one framework. Working with people in complex systems requires significant time, and prioritising a thorough data collection phase leaves limited capacity for applying multiple in-depth frameworks. Therefore, a single framework will be selected that captures as many system aspects as possible.

This thesis adopts an incident investigation approach, meaning only a subset of the frameworks listed in Table 1 are applicable. The relevant frameworks for incident analysis include the Systems Engineering Initiative for Patient Safety (SEIPS 101), Cognitive Work Analysis (CWA), Event Analysis of Systemic Teamwork (EAST), Functional Resonance Analysis Method (FRAM), Human Factor Analysis and Classification System (HFACS), Systems-Theoretic Process Analysis (STPA), and Networked Hazard Analysis and Risk Management System (Net-HARMS).

From these, a single framework was selected for the study, as justified in Table 1 with supporting references. The following incident frameworks were not chosen. FRAM requires expertise, making it less accessible for novice researchers and limiting replicability. EAST focuses on team dynamics rather than entire systems, whereas this research examines the broader water management system. HFACS does not account for external influences, which are crucial in this context. Net-HARMS is still undergoing validation and reliability testing. STPA cannot identify emergent risks, which are likely in complex systems. CWA, while comprehensive, is highly time-consuming, and using only select stages risks losing key interdependencies.

SEIPS was the chosen framework as it considers both internal and external system interactions and incorporates stakeholder mapping, aiding in understanding system relationships. While SEIPS 101 requires further validation, its foundational models are well-established. Further details on SEIPS are provided in the section following Table 1.

Table 1: Human Factors and Ergonomics Frameworks

Framework	What it does	Strengths	Weaknesses	Research that used it
Systems Engineering Initiative for Patient Safety (SEIPS 101)	Maps systems' various interactions, tasks, tools, people, organisations and environments through PETT scans (Holden & Carayon, 2021).	Can construct stakeholder maps and identify gaps in systems functionality through flexible PETT scans (Holden & Carayon, 2021).	SEIPS 101 is the most simplified version of SEIPS (Holden & Carayon, 2021) that requires evaluation and validation studies (Holden & Carayon, 2021).	• Patient adherence issues (Ma et al., 2023). Investigation of patient safety incidents (Weaver et al., 2021).
Systems Theoretic Accident Model and Process (STAMP)	Identifies feedback loops and system controls that facilitate safe operation while determining system constraints and why they violate the system's safe functioning (Leveson, 2012)	This comprehensive, thorough method can be applied to different situations and can improve safety systems (Zhang et al., 2022).	Due to its holistic nature, it cannot pinpoint the parties that need to pay for damages because it does not lay blame on individuals (Zhang et al., 2022).	• Investigation of an aircraft's rapid decompression incident (Allison et al., 2017). • Jet missile stimulation exercise (Stanton et al., 2019).
Systems-Theoretic Process Analysis (STPA)	Identifies control and feedback failures based on a control model of the system (Hulme et al., 2021).	A holistic view accounting for interactions between humans and non-human factors across multiple systemic levels (Rising & Leveson 2018).	Lacks the ability to account for emergent risks (Hulme et al., 2021).	• Hazards of proton exchange membrane (Zhu et al., 2023). • Aircraft wheel braking system (Chopart & Lalis, 2022).
Networked Hazard Analysis and Risk Management System (Net-HARMS)	Identifies emergent risks according to a description of the interacting tasks and activities occurring within a system (Dallat et al., 2019)	Comprehensive and scalable, it facilitates examination of the relationships and interactions among agents and factors across entire socio-technical systems (Hulme et al., 2021).	Experts using Net-HARMS produce more accurate results than novices (Dallat et al., 2023). It is still new and needs validity and reliability studies (Dallat et al., 2023).	• Five- day hiking and rafting programme risks (Dallat et al., 2017) • Risks in Railway (Hulme et al., 2021).
Cognitive Work Analysis (CWA)	Identifies constraints affecting behaviour and describes how they influence decision making and strategies (Jenkins et al., 2017).	Maps both human and non-human interactions and their behaviours, identifies system constraints at all levels mapped (a holistic approach to constraints) and helps formulate recommendations to cope with unanticipated situations (Jenkins et al., 2017). Draws on Ecology and Human Information Processing (Vicente, 1999).	Following all the CWA's stages is time consuming and unrealistic, which is why most researchers use the stages in isolation, However, this could result in critical interdependencies being overlooked (Dadashi et al., 2010). It is thus vital to select appropriate stages so that all relevant aspects are taken into account (Dadashi et al., 2010).	• Team co-operation in a ship control room (He et al., 2023). • Analysis of cardiac care nurses' remote screening of patients to determine their condition and the care required (Burns et al., 2008).
Event Analysis of Systemic Teamwork (EAST)	Looks at WHO is involved, WHEN tasks are performed, WHERE stakeholders are located, HOW stakeholders communicate and	Includes a hierarchical task analysis, coordination demand analysis, a communications usage diagram, social network	Analyses have typically not focused on whole systems, which led to a focus on safety related activities at either the sharp or blunt end as	• Investigation of vulnerability to disruption in a darknet market (Lane et al, 2019).

	collaborate to achieve system goals and WHAT tasks are performed (Walker et al., 2006)	analysis, and the critical decision method (Walker et al., 2006).	opposed to a holistic examination of both (Salmon et al., 2018). EAST often incorporated safety management aspects without analysing them in depth (Salmon et al., 2018).	• Analysis of railway maintenance tasks (Gibson et al., 2023).
Functional Resonance Analysis Method (FRAM)	Graphically depicts systems as a network of inter-related sub-systems and functions that have varying degrees of performance variation (Hollnagel & Goteman, 2004).	Can be used as both an accident and risk analysis framework (Hollnagel & Goteman, 2004). Guides users to identifying systemic factors that led to accidents and why they occurred (Herrera & Woltjer, 2010).	The framework's theoretical blueprint requires HFE experience and training to use; thus, it is not easily used by novices (Hollnagel & Spezali, 2008).	• Aviation safety (Tian & Caponecchia, 2020). • Healthcare (Sujan et al., 2023). • Paediatric homecare risk management (Hoy et al., 2023).
Human Factor Analysis and Classification System (HFACS)	Provides analyses and classifications of failures across four levels; unsafe acts, unsafe supervision, organisational influences and pre-conditions for unsafe acts (Shappell & Wiegmann, 2000).	Takes into account at least 19 categories of systemic contributory factors that could have led to a system's outcomes (Hulme et al., 2019; Li & Harris 2006). HFACS has a formal structure to help to identify and categorise factors (Hulme et al., 2019).	Lacks a broader focus on the external environment (government regulations etc.) of a system beyond the organisation (Hulme et al., 2019).	• Aviation accident report (Wiegmann & Shappell, 2017). • Marine accidents (Kaptan et al., 2021).

1.6. The selected Human Factors and Ergonomic framework

1.6.1. Systems Engineering Initiative for Patient Safety

The SEIPS framework was developed to promote patient safety in healthcare (Carayon, 2006) by understanding its contributory systemic factors (Carayon et al., 2020). The SEIPS iterations include SEIPS 1, 2, 3 and 101. All have three major components, the work system, the processes and the outcomes of the system (Carayon et al., 2022). The work system consists of interactions between the people in the system, their tasks, the tools they use, their working environment and the organisation they are part of (Holden & Carayon, 2021; Bridger, 2018). The outcomes of the work system's interactions and the processes they initiate can be desirable or undesirable and can affect patients/families, citizens, professionals or organisations (Holden & Carayon, 2021). SEIP understands systems as interactions.

1.6.1.1. System integration

All interactions (barriers or facilitators) within a system work together and influence one another to form an emergent outcome (Bridger, 2018). Typically, multiple causal factors interact non-linearly to produce system outcomes (Leveson, 2012). For example, if system designers do not adopt participatory approaches to system design, the systems are likely to not be user-friendly for the individuals that have to work within them, leading in part to them working in unanticipated ways to make the system work (Wilson, 2014). If a system was not designed correctly in the first place, and even if it was, there is a tendency for systems, particularly complex ones, to stray from operating as they initially did, naturally drifting to failure/unexpected or negative outcomes (Dekker, 2011; Rasmussen, 1997). A drift to failure is characterised by system operations gradually moving towards errors and failures caused by a lack of robust safeguards and constraints to keep a system functioning safely when stresses are applied (Dekker, 2011).

Badly designed, vulnerable and failure prone systems could be avoided by system designers designing for the stakeholders impacting or being impacted by the system. This usually takes the form of designers embedding within a system to fully understand its

various complex interactions (Wilson, 2014). Hopefully, the natural drift into failure can be managed by designing for the system's needs/abilities while consistently adapting and improving (Rasmussen, 1997). In short, models like SEIPS highlight that it is essential for system design to understand the various complex interactions that make up a system.

1.6.1.2. Variations of the Systems Engineering Initiative for Patient Safety

The first version of SEIPS published in 2006 focused on work from the 1960s, while the second depicted in Figure 4 below, focused on work done by non-professionals and expanded on the work system, work processes and outcomes through the creation of the diagram tool (Holden & Carayon, 2021). The third version paid more attention to work processes and incorporated hospital patients' journeys in hospitals (Holden & Carayon, 2021). Lastly, the SEIPS 101 simplified SEIPS to address only the most essential SEIPS components through a "practically minded sketch" (Holden & Carayon, 2021). The SEIPS framework is not specific to healthcare as it is a straightforward systems engineering tool that helps to map socio-technical systems and their various interactions and promotes stakeholder analyses via people maps (Holden & Carayon, 2021). SEIPS has thus been used to understand a variety of socio-technical systems (Holden et al*.,* 2013; Holden & Carayon, 2021). The following section draws on Holden and Carayon (2021) to explain how a SEIPS framework is populated and created.

1.6.2. Performing a Systems Engineering Initiative for Patient Safety

The SEIPS analysis entailed the following steps:

- **Understand the system** – Including factors and interactions like water resources (rivers, catchment areas, pipes, pumps), key stakeholders and laws.
- **Understand the work processes** – The various work roles need to be understood throughout the water treatment process.
- **Analysis of work system factors**
    - The people – their roles, skills, interactions, human factors, workload and communication/reporting channels.

- The tasks – the variety of tasks, job content, challenges and utilisation of skills, participation, job control and autonomy.
- Tools and technology – Assess the technology and equipment used in the system for its usability, reliability, and potential for harm.
- Environment – Investigate the physical and social environments including infrastructure, laws, climate, environmental hazards and the social dynamics of the workplace/ community.

- **Identify Safety Risks/Constraints** – Through the mappings created with SEIPS, communication errors, equipment failure, errors, violations, etc., were identified.
- **Proposed Interventions** – possible interventions were proposed to combat the identified system risks to improve system performance and the well-being of the individuals within and impacted by the system.

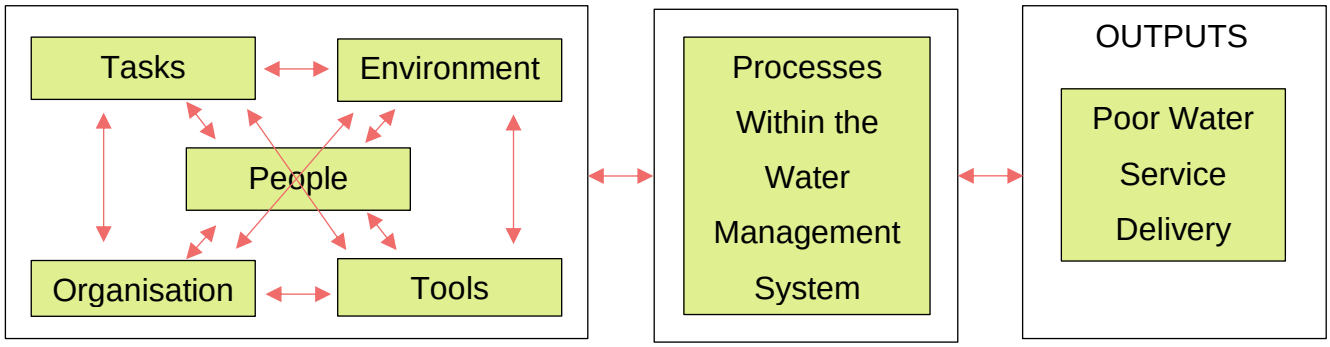

Figure 4: Systems Engineering Initiative for Patient Safety model (adapted from Xie & Carayon. (2014)).

SEIPS helps obtain the data needed for research. However, HFE frameworks work alongside other HFE models to portray this data through a clearer, more concise HFE lens. Some of the more favourable models were listed in the preceding section.

1.7. Popular models in Human Factors and Ergonomics

Well-known HFE models that have led to and been used in conjunction with some of the aforementioned HFE frameworks include Reason's Swiss Cheese Model (SCM) (Reason, 1990), Rasmussen's Structural Hierarchy of Risk (SHR) and his Dynamic Safety Model (DSM) (Rasmussen, 1997). These are popular due to their emphasis on

investigating incidents/ accidents through a systems approach, enabling “meaningful learning and prevention” (Dallat et al*.,* 2019). Accidents and incidents have similarities; the former are unplanned incidents that cause harm or damage, while the latter are unplanned situations that do not cause harm, but may act as a warning (Nemmers, 2023). Mclean et al*.* (2022) note that accident analysis methods like the ones cited above are being applied to multiple critical safety domains, confirming Rasmussen et al.’s (1990) claim that accidents are the outcome of multiple interactions between events, relationships and processes in complex systems (Rasmussen et al., 1990). Such models are now regarded as appropriate to understand adverse events and incidents (Salmon et al*.,* 2020; Waterson et al., 2017). In short, systems thinking and systems models and methods are fundamental in fully understanding the complexity of socio-technical systems and the multitude of factors that interact to cause accidents (Hulme et al., 2019) and incidents. As a systems discipline, HFE is thus well-positioned to apply these methods in incident investigations in various contexts. The following section explains the SCM, DSM and SHR models.

1.7.1. The Models

Reason: Swiss Cheese model:

Reason’s SCM is widely used in risk management. It depicts systems as layers of defence ("cheese slices") with innate weaknesses ("holes"). Failure occurs when the holes align, allowing an incident to bypass all safety measures (Reason et al., 2006). This model emphasises that accidents result from interactions between latent system flaws and active failures, rather than isolated human error (Reason et al., 2006; Perneger, 2005). Active failures are actions that result in errors and/or violations, which have an immediate adverse effect (De Florio, 2016). The SCM is depicted below.

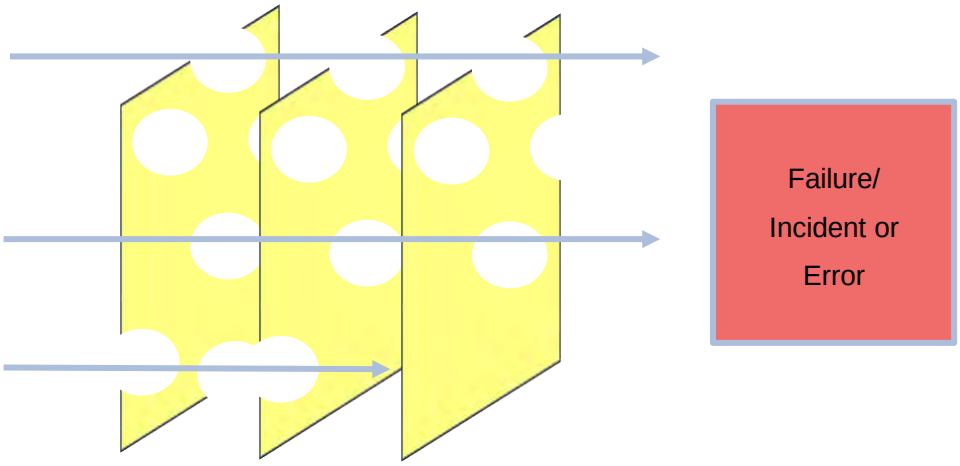

Figure 5: Reason's Swiss Cheese Model (adapted from Reason (1990)).

1.7.1.1. Rasmussen:

Rasmussen's ideas have been described as a standard of thinking in cognitive engineering (Reason, 1990). This study employed Rasmussen's model and his Structural Hierarchy of Risk (SHR).

1.7.1.1.1. Dynamic Safety Model:

The Dynamic Safety Model (DSM) plays an important role in safety sciences due to its combination of two characteristics (Morrison & Wears, 2021). First, it focuses on the system's structure and behaviour, rather than blaming individuals for accidents because of their actions (Morrison & Wears, 2021). Secondly, it describes system dynamics and proposes a system structure that generates those dynamics (Morrison & Wears, 2021). Essentially, the DSM describes a dynamic system inside a "performance envelope" (Cook & Rasmussen, 2005; Chen et al., 2022) that comprises an inner boundary that defines acceptable performance, alongside an adjacent error margin boundary to the far left, representing the threshold where poor performance may lead to errors (Chen et al., 2022). As seen in Figure 6 below, the DSM model shows how a heavy workload and economic pressure can act on a system and that if the pressures are too high, they can shift the system from safe performance, pushing it closer to the margin of error (Cook & Rasmussen, 2005; Chen et al., 2022). If a system is shifted by one or both pressures, the system's operating point can be moved out of the boundary of acceptable performance to cross the error margin, leading to system failures such as accidents or incidents (Cook & Rasmussen, 2005; Chen et al., 2022). This can also be termed a 'drift into failure' as

proposed by Dekker (2011), which is a gradual, decline into the error/ failure zone that occurs due to the push of various pressures (environmental, social, economic, technological) and a lack of counter gradients (Cook & Rasmussen, 2005; Chen et al., 2022). As shown in Figure 6, the operating point is no longer in the safe zone (green zone) and incidents and accidents can occur due to it being in the failure/unsafe zone (red zone).

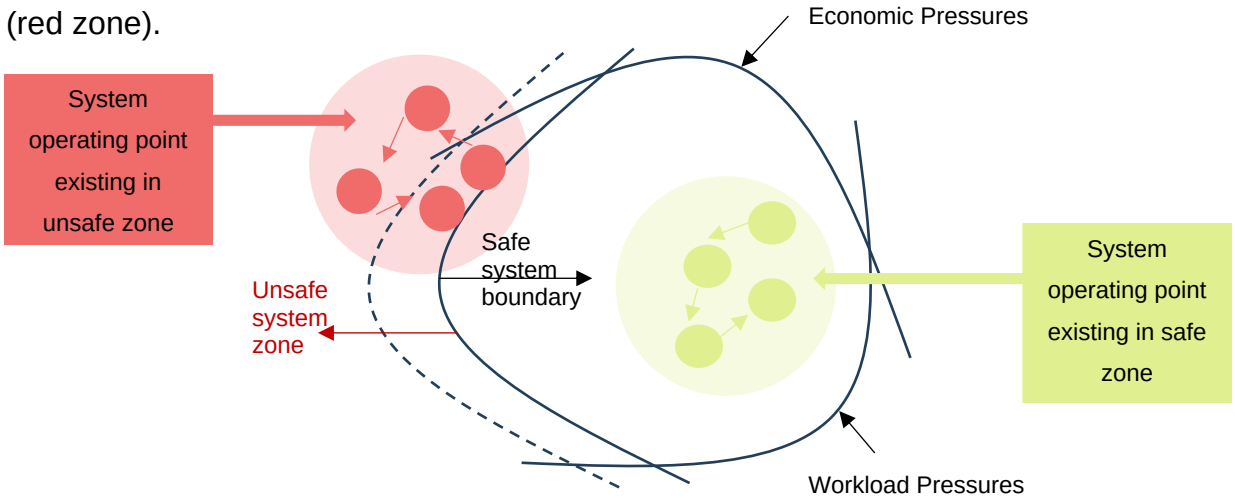

Figure 6: Rasmussen's Dynamic Safety Model (adapted from Rasmussen (1997)).

1.7.1.1.2. Structural Hierarchy of Risk:

Rasmussen argued that risk management should be based on the identification of decision makers at all levels of socio-technical systems (Brady & Naikar, 2022) as they all contribute to the system's safety management by controlling the hazardous processes that occur as a result of laws, instructions, rules and the act of performing work (Rasmussen, 1997). The SHR reveals how decisions made at the top level of a system filter down through the preceding levels and affect operations and actions at these levels (Rasmussen, 1997) (Seen Figure 7 below). Managing risk involves maintaining control within socio-technical systems, as failures arise when control over physical processes is lost, placing people and systems at risk (Rasmussen, 1997). Rasmussen further emphasised that safety relies on effectively managing work processes while navigating the pressures and constraints of the operational environment.

Multiple hierarchical systemic levels are involved in controlling a system's safety as well as external influences that can impact the system (Rasmussen & Svedung, 2000). The

top level is the government and the bottom where the work is done (Rasmussen, 1997). In between are four other levels, each depicting a category of stakeholders in the system. Figure 7 below depicts the model.

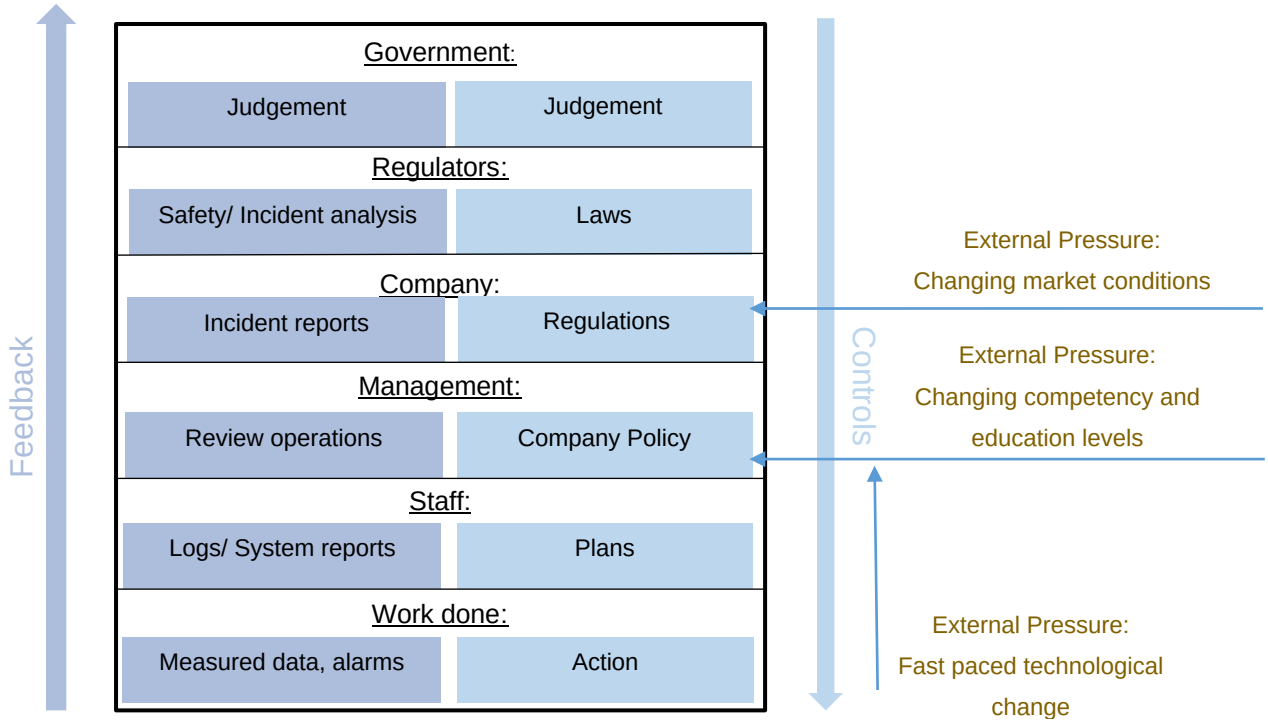

Figure 7: Structural Hierarchy of Risk model (adapted from Brady & Naikar. (2022)).

Rasmussen argued that for systems to function efficiently and safely, decisions made at its governance, regulatory, and managerial levels should funnel down and affect the decisions and actions occurring at the lower levels (Rasmussen & Svedung, 2000). Furthermore, information held at the lower levels regarding the system's status need to transfer up the hierarchy to inform the decisions and actions occurring at higher levels (Rasmussen & Svedung, 2000).

Rasmussen termed this 'vertical integration' which centres around creating feedback loops which are critical to the operation of the system (Salmon et al., 2012). This is important as decisions made at the top levels of the organisation need to be reflected in actions and decisions at the bottom levels (Salmon et al., 2012; Branford et al., 2007). Rasmussen further argued that without vertical integration, systems can lose control of the processes they are designed to control, creating an opportunity for system failure

(Salmon et al., 2012; Branford et al., 2007; Rasmussen & Svedung, 2000). The communication flow between these decision makers is thus important to mitigate any potentially dangerous side effects of their actions (Brady & Naikar, 2022). In short, Rasmussen's theory holds that multiple factors at multiple hierarchical levels of socio-technical systems rather than at the level of frontline operators cause accidents/incidents (Brady & Naikar, 2022). Communication and feedback are essential to improve the quality of work within and performance of the systems and mitigate such incidents. The following section discusses the applicability of HFE and its practices, and its application in a variety of different contexts.

1.8. Human Factors and Ergonomics' Applicability

HFE can be applied to many different situations, including aviation incidents (Allison et al*.,* 2017), healthcare (Igene et al*.,* 2021), city development (Safari, 2016), railway incidents (Gibson et al., 2023) and much more as it is a multi-disciplinary science (Dul et al*.,* 2012) whose knowledge and practice are drawn from many different disciplines (Thatcher et al., 2018).

Over the past two decades, several prominent HFE specialists have emphasised the need for HFE to contribute to tackling society's complex systemic social and environmental problems in order to facilitate sustainability (Fischer et al*.,* 2021; Sinclair et al., 2021; Thatcher et al*.,* 2018; Thatcher & Yeow, 2015). Thatcher et al*.* (2018) referred to problems that affect society as global issues. To name but a few, they include healthcare and issues relating to food, energy and water (Thatcher et al*.,* 2018). The situation regarding water is the most troubling, with the World Health Organization reporting that around 2.2 billion people lack access to safe drinking water that is managed correctly (World Health Organization, 2023). In 2022, 1.7 billion people globally were found to have been drinking water contaminated by faeces (World Health Organization, 2023), which is intrinsically linked to how water is managed. Water research is significant for Africa because it is a major factor in the social-economic development and rejuvenation of the continent (Economic Commission for Africa, 2020). This study employed HFE methods to examine the global issue of water in a South African context.

1.9. Water's importance

"There is no life without water" - Albert Szent. Water and water resources are vital for all living organisms' internal and external environments (Hossain, 2015; Kilic, 2020) and one of the most essential life needs (Kilic, 2020; Hossain, 2015) because the cells of human, animal and plant bodies are mainly made up of water that needs to be replenished daily (Hossain, 2015). Water is also essential for all living organisms because water vapour regulates atmospheric temperatures, making it one of the main contributors to the Earth's climate (Amonovich et al., 2023). It achieves this by releasing heat when it condenses and cool air when it evaporates (Schneider et al., 2010). Therefore, water helps maintain the Earth's surface in an ideal state for living organisms to survive (Metzger, 1996).

1.9.1. Water for Hygiene and against disease

The essential nature of water is acknowledged worldwide, which is why access to unrestricted water, sanitation and hygiene is regarded as necessary for human sustainability and well-being (Yaya et al., 2018). The World Health Organization and United Nations' International Children's Emergency Fund's water monitoring programme seeks to ensure that communities have an adequate supply of water, sanitation and hygiene by safely managing water to ensure that it is accessible, uncontaminated and constantly available (World Health Organization and the United Nations Children's Fund, 2017).

Such programmes are essential because hygiene is directly influenced by water, and without it, diseases such as diarrhea and cholera can spread, increasing mortality rates (World Health Organization, 2019; Yaya et al., 2018). In Nigeria, these diseases are responsible for the eighth highest mortality rate in children under the age of five (Adewemimo et al*.,* 2017). Appropriate water, sanitation and hygiene practices can ameliorate this situation (Yaya et al*.,* 2018). However, around half the urban population in Africa lacks adequate access to water and, as a result, dignified sanitation (UNICEF, 2017).

1.9.2. Water uses in everyday life

Around the world, water is used extensively for drinking, cleaning, washing, cooking and growing food (Hossain, 2015). On average, individuals in South Africa use around 237 litres of water per day for domestic purposes (Murwirapachena, 2021), with more used daily by industries to generate electricity, manufacture products and transport people, along with goods (Hossain, 2015; Murwirapachena, 2021). Water is thus vital for the continued survival of industry and all living organisms. However, water management is imperative to achieve adequate provision.

1.10. The process of getting water

In South Africa, water is managed through water management systems which consist of raw water resources (see Figure 8), including rain water that flows into catchment areas, water from rivers and water that is already in the water system, but has been treated for impurities, for example, human waste (Marsalek et al., 2014). Water is interconnected and interrelated with nature (Holmes, 2015). The urban water cycle helps to explain how water goes through the primary water management stage (Holmes, 2015) from the river source to the consumer and back again (Figure 8).

1.10.1. Urban water cycle

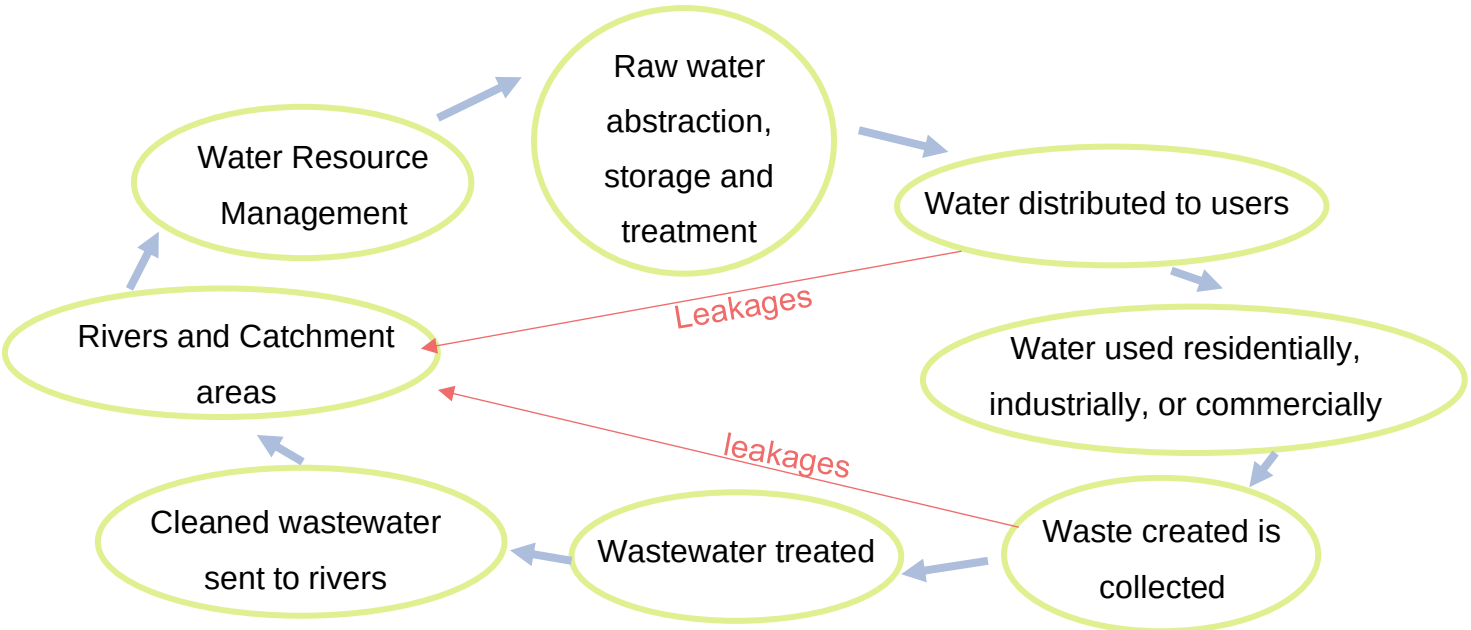

Figure 8: Urban water cycle (adapted from Marsalek et al. (2014)).

The urban water system does not exist in isolation, but interacts with its sibling system the water management system, which is encapsulated by a larger parental city system that comprises social and technical (Truong et al., 2022; Hillier, 2012) as well as social and ecological aspects (Frank, 2017; Du Plessis, 2008). The water management system is complex and interrelated; therefore, all factors making up the system must be acknowledged (Manny, 2023; Abdullaev & Mollinga, 2010). Systems made up of the environment, society and technology, like city systems, are known as eco-socio-technical systems (Thatcher & Yeow, 2022). These are described below.

1.11. Socio-technical and Social-ecological systems

1.11.1. Socio-technical systems

Read et al. (2014) note that systems comprising humans and technology are called “socio-technical” systems. These were discussed in section 1.4.1.

1.11.2. Social-ecological systems

Social-ecological systems, also known as coupled human-environment systems (Turner et al., 2003), comprise the interactions between humans and the environment (Turner et al., 2003). A social-ecological view of systems sees the world as a variety of interconnected social and ecological systems. They cannot be viewed in isolation because human systems are part of and shape ecological systems (Cote & Nightingale, 2011); in other words, they are mutually interdependent (Fidel et al., 2014). These interactions are dynamic and unpredictable, rendering them complex by nature (Preiser et al., 2018). Therefore, social-ecological systems theory encourages holistic approaches and embraces complexity (Cote & Nightingale, 2011).

Ecologically, a social-ecological view would look at systems like water and how it flows through landscapes and ecosystems. Socially, it acknowledges social and technical systems (Preiser et al., 2018), for example, people, infrastructure, organisations and the relationships between them (see Section 1.9.1). Therefore, social-ecological systems’

views incorporate those of socio-technical systems. Given that ergonomics usually utilises socio-technical views, this approach was adopted for the current study.

1.12. Water Management Systems as Socio-technical-ecological Systems

Scholars such as Manny (2023), Newman et al. (2011) and Abdullaev and Mollinga (2010) treated water management systems as socio-technical systems. These are complex and occur within broader city systems that are socio-ecological (McPhearson et al., 2022) due to numerous interactions between humans, tools, technologies, organisations, natural resources, job requirements and the public, to name but a few. The tools and technologies in the system are pipes, pumps, valves, etc. (Marsalek et al., 2014), the organisations are national, regional and local officials and non-profit organisations (Weaver et al., 2017) and the natural resource is the raw water collected in catchment areas as rain drains into rivers that are captured in dams and other water bodies (Weaver et al., 2017). Lastly, relevant job requirements include water protection, delegation, treatment and infrastructure maintenance (The National Treasury, 2004). Figure 9 below illustrates how various socio-technical systems exist within a larger socio-technical-ecological city system.

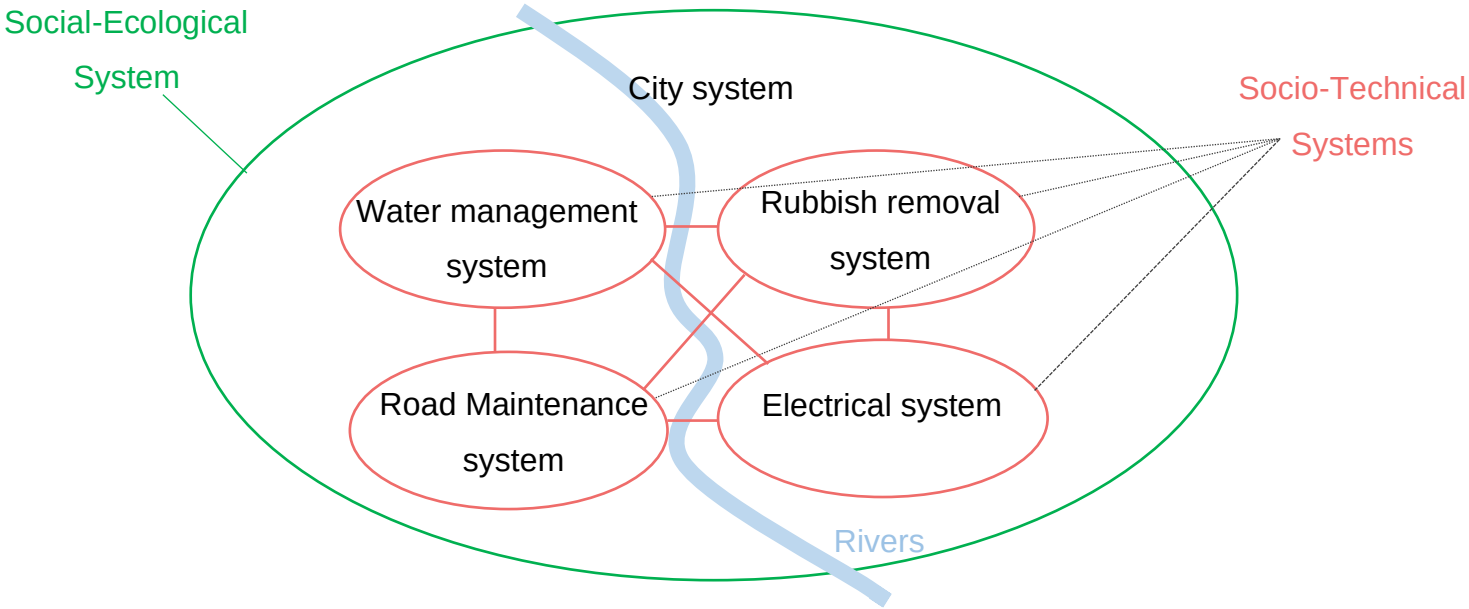

Figure 9: City system as a social-ecological system consisting of various nested socio-technical systems (own design).

It is important to note that the larger socio-ecological city system is understood through socio-technical theories (Petrosillo et al*.,* 2015) that are holistic and consider the environment, humans and technologies (Malatji et al., 2019; Cummings, 1978). Wilson (2014) spoke of larger systems like the city system as parental city systems that encompass the smaller underlying systems. The latter are child systems within the more extensive parent system (Wilson, 2014). Child systems interact with other child systems, creating relationships where they interact and rely on one another; these interactions form their own systems, known as sibling systems (Wilson, 2014). As seen in Figure 9 above, child systems interact with one another to create sibling system networks that help the parent system to function. These system networks and their various interactions develop systems of systems networks (Thatcher & Yeow, 2016).

1.12.1. Parent, Child and Sibling Systems in a City Context

A complex system comprising multiple smaller systems, and the interactions between them creates complexity within the system (Read et al., 2021). They exist within a hierarchy of organisational levels, with each level more complex than the one beneath it (Leveson, 2011). Many smaller child socio-technical systems (electrical, water, road maintenance, etc.) exist and interact with one another to ensure the larger city system functions appropriately. The interactions between the child systems form sibling systems.

The various child systems require their system components to be operationally independent to support the parent system in their own way (Maier, 1996). The outcomes of one system may affect others in unexpected ways due to the complexity of the components of the system's non-linear relationships (Maier, 1996). This could result in smaller child systems creating disturbances to the parent system and vice versa (Thatcher & Yeow, 2016).

1.13. Understanding water as a complex system

Urban water management systems have the characteristics of complex socio-technical systems (De Haan et al., 2013). Due to the interactions between the people and

mechanisms (raw water, environment, infrastructure, processes, laws, people, etc.) used to manage it, water management exists within a more extensive city system, a socio-ecological system. In its most basic form, it is made up of people and the environment with technologies produced by people to make their lives easier, thus creating smaller systems like water management systems. HFE, a complex socio-technical systems thinking discipline, is often applied to interpret, understand, guide and improve such systems and was adopted for this study to examine global water issues in a local South African city context, with the aim of promoting system improvement and sustainability.

The following section sketches the context in which water exists in South Africa. It begins by examining the country's water legislation, preparing the ground to compare the local laws and legal frameworks with the conclusions reached by the South African water management literature and enabling identification of strengths and weaknesses. This is followed by an examination of ideal water resource management and service delivery and the institutional structures that govern water. The last part discusses how water services are actually managed and delivered.

1.14. South African Water Management

The most current water resource legislation is the National Water Act 36 of 1998 that aims to protect, conserve, use, develop and manage water in a sustainable manner that prioritises equity, ensuring that all South Africans benefit (The Republic of South Africa, 1998). The following section describes the legal frameworks governing South African water management, key water management laws, how water resources are managed and delivered and the stakeholders in charge of water management.

1.14.1. Legal Framework

South African water is managed under the Water Services Act (WSA) of 1997 and the National Water Act (NWA), Act 36 of 1998. The NWA regulates use of, management of and conservation of water, while the WSA regulates water services for water sanitation and provision (Seago, 2016). The NWA introduced the concept of a reserve (the amount

of water in a river required to fulfil basic human needs and protect the ecological functioning of a water resource) and classification of water resources. The water resource classification system was established in 2010 and is rolled out on a catchment-by-catchment basis (Seago, 2016).

The NWA is implemented through the National Water Resource Strategy (NWRS), which is reviewed every five years (Department of Water Affairs and Forestry, 2004). Central to the NWA and NWRS is Integrated Water Resource Management (IWRM), which involves all stakeholders in order to achieve sustainability of water resources at the catchment, regional, national and international scale while maintaining water integrity (quality and quantity) at the catchment scale (Jones et al*.,* 2006). IWRM seeks to balance water for livelihoods and its protection for future generations whilst ensuring equity, economic efficiency and environmental sustainability (Department of Water Affairs and Forestry, 2004). It asserts that all South Africans have the right to an environment that does not harm their health or well-being and is well-maintained and preserved for current and future generations (Pollard & Du Toit, 2019). Such integration fits well with an HFE perspective, where citizens participate in the water management system. Thus, the minister and other higher-level officials and individuals who work in their respective regions are all part of the process.

The first NWRS divided South Africa's water resources into 19 water management areas comprising the regional and catchment areas where water was initially managed (Department of Water Affairs and Forestry, 2004). This was followed by NWRS 2 and the current NWRS 3. NWRS 2 consolidated the 19 areas into nine, as some of the original areas lacked sufficient water (Department of Water and Sanitation, 2013). NWRS 3 further reduced the number of water management areas to six (Department of Water and Sanitation, 2023). The National Water and Sanitation, Master Plan was developed to complement NWRS 3 (Figure 10). The two must align to meet specific timelines and budgets (Department of Water and Sanitation, 2023). The plan is designed to guide investment planning in the water sector, focusing on the development of water resources and delivery of Water and Sanitation services (Department of Water and Sanitation,

2023). Together, the Act and Strategy provide a framework for sustainable water resource management and service delivery (Seago, 2016).

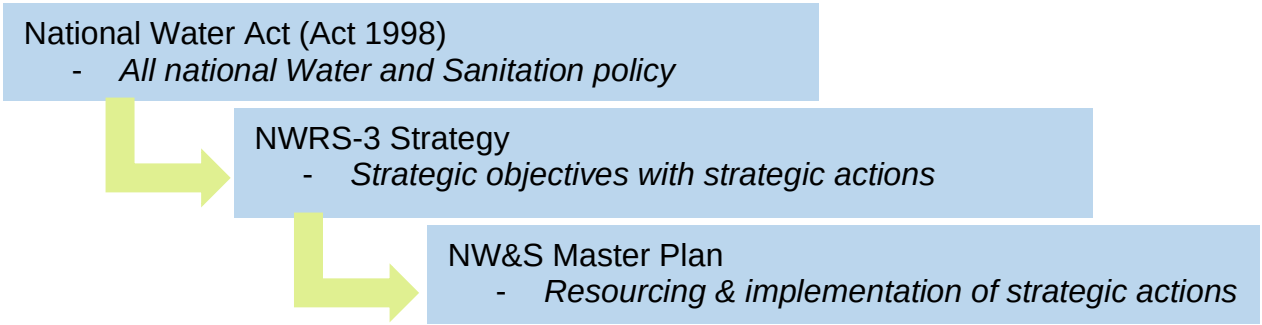

Figure 10: Diagram depicting how the NWA, NWRS-3 and Master Plan interact (Department of Water and Sanitation, 2023).

Water service delivery and resource management are controlled by different entities. Local municipalities that are water service authorities have authority over the local water specific to their municipality and also contract water service providers. Water resource management is delegated to Catchment Management Agencies (which are established in terms of the National Water Act) through Water User Associations and Irrigation Boards. The following section briefly discusses important aspects of the legislation in order to understand how water should be delivered and managed. This informed comparison of the research outcomes with the legal requirements. Lastly, the focus shifts to how water resources are managed and how water services are delivered.

1.14.2. Important water legislation:

The law requires that the water authorities ensure sufficient provision of water to the current population and sustainable supply for future generations by applying the NWRS (Seago, 2016). All citizens should receive 25 litres of water per day or six kilolitres per month per household (Department of Water Affairs and Forestry, 2002) and equal access is imperative (Seago, 2016; Republic of South Africa Department of Water Affairs, 2013; Department of Water Affairs and Forestry, 2004). In the event of interrupted supply, alternative supplies must be provided (Department of Water Affairs and Forestry, 2002). Furthermore, a consumer service must be established to lodge complaints (Department of Water Affairs and Forestry, 2002). Additional legislation requires the water authorities

to conduct annual audits to compare their water services to their water services development plan (Section 18 (1) of the Water Services Act (Parliament of the Republic of South Africa, 1997)). The latest NWRS notes growing demand for water (Seago, 2016; Republic of South Africa Department of Water Affairs, 2013) and highlights the need for institutions to be appropriately staffed and resourced, emphasising the need to improve employees' skills and capacity (Department of Water and Sanitation, 2023). There are other water quality related legislations but they have been intentionally kept out of the review because water quality falls within the waste water treatment facilities which are beyond the scope of this study.

1.14.3. Water resource management

South Africa manages its water resources through Catchment Management Strategies (CMS), which outline the vision and strategic action for integrated water resource management shaped by specific Water Management Areas (Department of Water Affairs and Forestry, 2004). Each area is overseen by a Catchment Management Agency responsible for ensuring water conservation, proper management, infrastructure maintenance, and equitable distribution (Seago, 2016). Some water resources require additional protection due to their ecological and economic significance (Seago, 2016).

The Water Resources Classification System (WRCS) was developed to support sustainable development. It classifies water resources based on their economic and social importance. The NWA supports this process through an integrated, catchment-based approach to water resource management (Seago, 2016).

1.14.4. Water Service Delivery

Before 1997, national government managed South African water centrally (Parliament of the Republic of South Africa, 1997). The South African Water Services Act was passed in that year, introducing a decentralised approach (Parliament of the Republic of South Africa, 1997).

1.14.5. Decentralisation

Decentralisation was inspired by the concept of subsidiarity (Water Partnership Program of the African Development Bank, n.d) that holds that social and political issues should be handled at the most local level (Cambridge Dictionary, 2024). In line with this principle, water basin management and service delivery were shifted to the lowest level of government (Parliament of the Republic of South Africa, 1997) (see Figure 11 below).

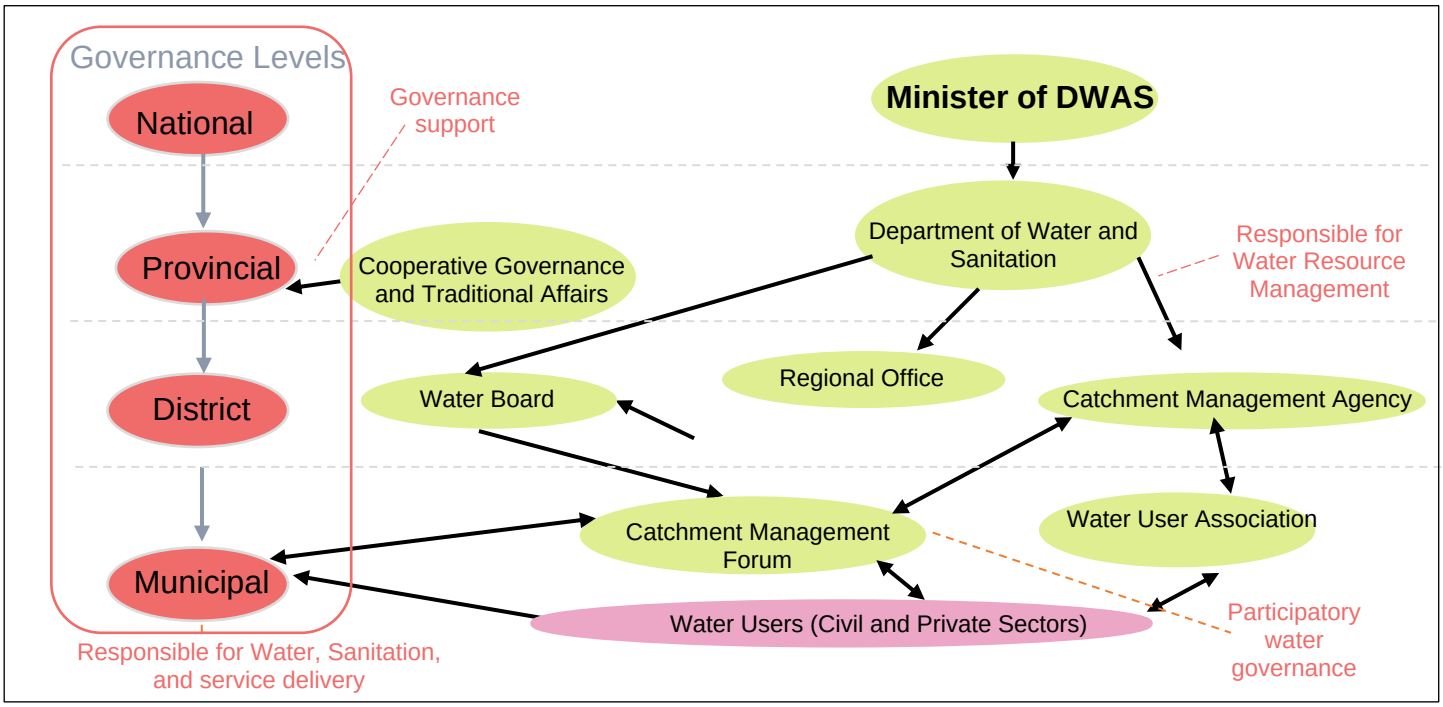

Figure 11: Map of stakeholders involved in the broader water cycle (adapted from Weaver et al. (2017)).

Decentralisation was promoted for two reasons: centralised national government management resulted in unequal access to water, limited stakeholder engagement, uncoordinated sector policies, limited financial capacity at basin level, poor service delivery and infrastructure, and a decline in water quality (Hassan et al., 2014; Swatuk, 2005). The decentralised system incorporated the Bill of Rights, acknowledging that water is a basic human right (Republic of South Africa, 1998). The new system also promotes community participation and stakeholder engagement at all levels to achieve local-level accountability and transparent water management processes (Parliament of the Republic of South Africa, 1997). This encouraged previously disadvantaged stakeholders to

participate in water management decisions, providing a fairer balance of power (Swatuk, 2005). In essence, decentralisation decreased government control and increased stakeholder engagement while creating new roles and responsibilities for the new decentralised organisations (Jonker et al., 2010).

However, the decentralisation model also suffered from weaknesses. Managing water locally placed municipalities that lack capacity under pressure (Koelble & Siddle, 2013; Laubcher, 2012), resulting in the hiring of external experts to manage water (Adom & Simatele, 2021). The new water legislation and strategies applied by these experts initially provided sufficient water to individuals and communities. However, they did not equip municipal employees with the necessary knowledge and expertise to manage water and maintain the system on their own (Adom & Simatele, 2021). Without proper training and widespread education on water conservation, the country's water security is at significant risk (Koelble & Siddle, 2013). Government and municipalities consist of stakeholders who deliver and maintain services. The following section discusses the water system's stakeholders.

1.15. Water system stakeholders

The stakeholders in the water system play both formal and informal roles. The formal structures include the government and municipalities, while the informal involve consumers (Toxopeus et al., 2018; Molobela & Sinha, 2011) and non-governmental organisations (NGOs) who have no statutory power in the system but can influence it. Formal water stakeholders perform specific roles such as financial governance, policy formulation, producing and approving water service development plans, water distribution and working at the front line of water maintenance and operations (Republic of South Africa, 2000; The National Treasury, 2004). Informal stakeholders such as consumers use the water service, while NGOs act as external stimuli and can impact the system.

1.15.1. Governmental and local stakeholders and their responsibilities

Individuals within each organisation are assigned different roles to achieve optimal water management performance. The Municipal Systems Act of 2000 controls service delivery

and participatory, organisational, and planning systems (Republic of South Africa, 2000), thus bridging the gap between the new municipal 'developmental local government' and the 1998 Municipal Structures Act (Republic of South Africa, 2000). It thus provides a governance framework for optimal performance of the water management system. The key stakeholders in the South African National Water Management System and their responsibilities are listed in Appendix A and the key local water system stakeholders and their roles in Appendix B.

This study focused on water supply and service delivery rather than water resource management. The following section reviews the literature on the nature of current water service delivery in South Africa (work as done).

1.16. Water service delivery in South Africa

The literature from the early 21st century noted that the institutional sectors (government and private) in charge of the water sector were undergoing change and improving water management in South Africa (Wostl et al*.,* 2007; Saleth & Dinar, 2005; Veeman & Politylo, 2002). However, recent studies point to changes in water management over the past 10-15 years. Toxopeus et al. (2018) concluded that water legislation and policies had not been properly applied, resulting in the water authorities being unable to deliver water to consumers. Karodia and Khan. (2015) reached a similar conclusion.

Factors contributing to the shift towards a water crisis

South Africa's poor water service delivery has been attributed to various factors, including ill-equipped and poorly maintained water infrastructure (Muller et al., 2009), water shortages (Hemson, 2016), the state of country-wide water treatment facilities (Du Plessis, 2024; Momba et al., 2009) and poor water quality (Viljoen & Van der Walt, 2018). This resulted in water scarcity (Chikoore & Jury, 2021), failure to adhere to laws and legislation (Karodia & Khan, 2015), mismanagement by officials (Karodia & Khan, 2015) and decentralised control of local water (Mutondo et al., 2016) have also been identified.

These factors emanate from systems factors that act in isolation or, more often than not, together to create an undesirable outcome (Bromfield & Landry, 2019). It has been estimated that if current water management trends continue, South Africa's water demand will exceed availability by 2025 (World Wide Fund for Nature, 2017; Molobela & Sinha, 2011; Fuzile, 2011). Furthermore, these shortages will affect many other sectors such as energy, mining, agriculture, health, education, and urban/rural development (Molobela & Sinha, 2011). The following subsection discusses these factors in more detail.

1.16.1. Factors leading to South Africa's water crisis

1.16.2. Water Infrastructure

Ill-equipped and poorly maintained water infrastructure (Muller et al*.,* 2009) results in around 35-37% of municipal water being lost annually through leakages (Oxlee, 2018; Molewa & Balzer, 2013) and treated water not being paid for (Proude, 2024). These leakages are usually from pipelines bringing water to users and taking wastewater from them to the treatment facilities (Marsalek et al*.,* 2014).

1.16.3. Electricity infrastructure

Load shedding to conserve the load of electricity on the power grid (Nowakowska & Tubis, 2015) results in blackouts that affect water pumps' ability to distribute water to consumers when it is available (Karodia & Khan, 2015).

1.16.4. Water treatment facilities

Water treatment facilities in South Africa, specifically small scale ones, face a variety of barriers to their successful functioning. These include poor working conditions, frequent depletion of chemical stocks, a poor maintenance culture, a lack of emergency preparedness and poor communication (Momba et al., 2009; Mackintosh & Colvin, 2003; Swartz, 2000). In addition, many water treatment facilities are remote and secluded, resulting in limited technical support and leading to dysfunctional disinfection systems. This is evident in reports of poor quality water that harbours disease and is thus unsafe for human consumption (Momba et al., 2009). In 2023, a country-wide audit found that the quality of drinkable water is getting worse, with 46% of water supply systems posing

acute human health risks because of bacteria or other pathogens in the drinking water (Du Plessis, 2024). The audit also found that 67.6% of all water treatment works were close to failure.

1.16.5. Water Scarcity and Poor Quality

South Africa faces both first and second order water scarcity (Toxopeus et al*.,* 2018). First order relates to scarcity due to a lack of available water (drought), while second order water scarcity is the lack of water due to people's inability to provide clean water to others (management and/or infrastructural constraints) (Toxopeus et al*.,* 2018). Natural and non-natural causes can be temporary or permanent (Kilic, 2020). Temporary factors consist of drought, accidental situations like dam walls blocking the flow to areas further downstream or burst water pipes (Kilic, 2020). South Africa is among the top 30 driest countries in the world and experiences 40% less rainfall per annum than the global average (Department of Communication and Information System, 2015) highlighting the need to manage water (Nieuwoudt, 2004).

Permanent water scarcity is due to various factors such as excessive demand as the human population and economies grow, resulting in increased demand and consumption, a lack of infrastructure to store and transport water (Kilic, 2020; Nieuwoudt, 2004), a lack of maintenance and investment, unequal access to water reserves (Viljoen & Van der Walt, 2018; Nieuwoudt, 2004) and a lack of skilled water engineers (Viljoen & Van der Walt, 2018).

Furthermore, the water that South Africa has access to tends to be of poor quality due to pollution from wastewater runoff (Murwirapachena, 2021; Muller et al., 2009), agricultural runoff (Bwapwa, 2018), solid waste (rubbish) (Murwirapachena, 2021; Muller et al., 2009), mining, power generation, changing land to forests to exploit the resource (Bwapwa, 2018) and erosion (Du Preez & Van Huyssteen, 2020).

1.16.6. Mismanagement and corruption

Mismanagement of country-wide infrastructure and a lack of training/education lead to leaks in the system, while financial mismanagement results in revenue not being collected. Financial mismanagement has a direct relationship with whether the government can finance on-going operations and maintenance of water reticulation infrastructure. Van De Zaag (2009) noted that poor governance was one of the leading factors in the South African water crisis. It exacerbates the water crisis through corruption and a lack of monitoring and evaluation of water management (Van De Zaag, 2009).

Water governance shortfalls include municipalities not charging for water as they should and not adhering to water laws and legislation (Karodia & Khan, 2015) and the government's on-going inability to manage or put an end to the theft of electrical cables, resulting in further electricity outages which disrupt pumps' ability to distribute water to consumers (Karodia & Khan, 2015). State capture, tender corruption and political interference at ministerial level have crippled the Department of Water and Sanitation (Water Integrity Network, 2020).

Financial mismanagement leads to incorrect allocation of funds (Laubcher, 2012) and revenue not being collected (Karodia & Khan, 2015), which is illegal according to Article 96 of Act 32 of the 2000 Municipal Systems Act (Republic of South Africa, 2000).

The revenue lost through leaks and funds not being collected stood at R11 billion in 2015 alone (Karodia & Khan, 2015). In 2018, an audit revealed that the National Department of Water and Sanitation had enormous debt and multiple failed projects, and had spent billions on irregular expenditure (Water Integrity Network, 2020). Many of these problems have been linked to corruption within government (Water Integrity Network, 2020).

1.16.7. A lack of municipal capacity and skills

The democratic government that came to power in 1994 sought to address the injustices of the apartheid past by implementing affirmative action, which is both necessary and desirable in a country where political biases historically marginalised and disempowered entire racial groups (De Klerk, 2000). However, implementation led to impulsive employment of individuals that were not properly prepared for the roles they played (Laubcher, 2012; De Klerk, 2000). The lack of comprehensive policy also led to nepotism in hiring, possibly resulting in individuals without the relevant knowledge and skills being appointed (De Klerk, 2000).

Laubcher (2012) and Benjamin (2007) suggest that municipal positions are awarded to individuals who align with parties' agendas and that skilled professionals are being denied jobs as they are not part of these networks. Both researchers state that until the government couples affirmative action with mentorship programmes and continuous training and abandons its bias, the issue of unskilled workers in positions (even managerial ones) that require skills will persist and impact the functioning of the country and its services.

The transition from centralised government control to more localised governance encountered some unanticipated "negative outcomes" (Republic of South Africa Department of Labour, 2008). A Local Government Sector Education and Training Authority (LGSETA) report published in 2008 found that 35% of technical managers did not have engineering qualifications (Republic of South Africa Department of Labour, 2008), undermining the water management system (Mutondo et al., 2016; Republic of South Africa Department of Labour, 2008). A report produced four years ago also noted a lack of experience among engineering managers (Local Government Sector Education and Training Authority, 2021). In 2019 alone, there were 23 vacant posts in local government for South African civil engineers, 28 for town planning technicians, and 11 in the water disaster management sector (Local Government Sector Education and Training Authority, 2021). All these positions involve infrastructure or are linked to water. In addition, 31% of engineering managers in local government positions were due to retire in 2019 (Local Government Sector Education and Training Authority, 2021), resulting in

engineering managers without the generational knowledge of the retired managers being employed within four years.

The lack of ability, resources, and skills and competency has prevented enforcement of water governance legislation and standards (The Development Bank of Southern Africa, 2009). There is a high turnover rate of appropriately capacitated staff within the Department of Water and Sanitation that is unable to implement the National Water Act (The Development Bank of Southern Africa, 2009).

Lastly, the lack of capacitated individuals in the department (Local Government Sector Education and Training Authority, 2021) has resulted in increased reliance on contracting out infrastructure development and maintenance to private consultants and companies which comes at great cost to the government (Water Integrity Network, 2020; Laubcher, 2012). All too often, private businesses pay bribes to secure tenders that they do not deserve (Water Integrity Network, 2020). These contracts are unlawful and should be penalised (Water Integrity Network, 2020).

1.16.8. Conclusion

The multiple contributing factors of drought, poor infrastructure, inability to keep up with water demand, financial and overall mismanagement and municipalities' lack of skilled workers contribute to water service delivery failures at a national scale. This will have significant social, environmental, economic, political and legal impacts on the lives of South Africans and the country (Seago, 2016). While water is a basic human right and essential for life, poor water service delivery prevents the country from meeting the needs and rights of its residents. Moreover, the fragile water management system puts South Africa's future at risk. It is for this reason that this study focused on understanding local municipal-scale dysfunction within the water management system to determine if the factors at a micro (local) level are comparable to those at the macro (national) level. The following section discusses the local town selected as the water system case study, the reasons for its selection and the scope of the study.

1.17. South African Case Study

HFE socio-technical systems methods were applied to a case study of the water management system in a small South African town. Since its founding in the 1800s, Makhanda's water system has faced system constraints, leading to weaknesses in water supply (Mullins, 2011). In 2013, its university, Rhodes almost closed its doors due to extreme water shortages (Karodia & Khan, 2015). The town has a weak water management system, resulting in residents going for days and weeks without water in their taps, as well as burst water and sewage pipes, blown water pumps and frustrated citizens (Karodia & Khan, 2015). The town's survival is rooted in the supply of water (Mullins, 2011). It is thus important to identify and understand the nature of the Makhanda water system's facilitators and barriers, which can inform interventions to improve its functioning and water outputs.

As a complex socio-technical system, urban water management can benefit from the application of ergonomic integrated systemic approaches, enabling the complexities between its system elements and their interactions to be analysed. These approaches comprise of ergonomic socio-technical systems frameworks (Patorniti et al., 2017). All systems comprise of other smaller systems and are encompassed by larger systems. It is thus not feasible to take every single system into consideration. Therefore, boundaries have to be drawn around the systems of interest (Arnold & Wade, 2015).

The following section discusses the scope of the study that focused on Makhanda's water management system. While all city and municipal systems outside this boundary are not analysed, they are acknowledged.

1.18. Scope of the Study

Wilson (2014), argued that it is important to place a "boundary" around the system under analysis and that it should be placed "where it is useful". Two main water treatment facilities supply East and West Makhanda. Given time and financial constraints, the facility that supplies Makhanda East was selected. An additional consideration was that it was easier to access.

This boundary seen in Figure 12 was drawn to prevent the study from being too complex. However, the larger system must be acknowledged as it interacts with the system of interest. The water system is a child system that interacts with other similar sibling systems, such as the electrical, waste removal and road systems, all of which were beyond the scope of this research. The child and sibling systems exist within the more extensive Makhanda parental system.

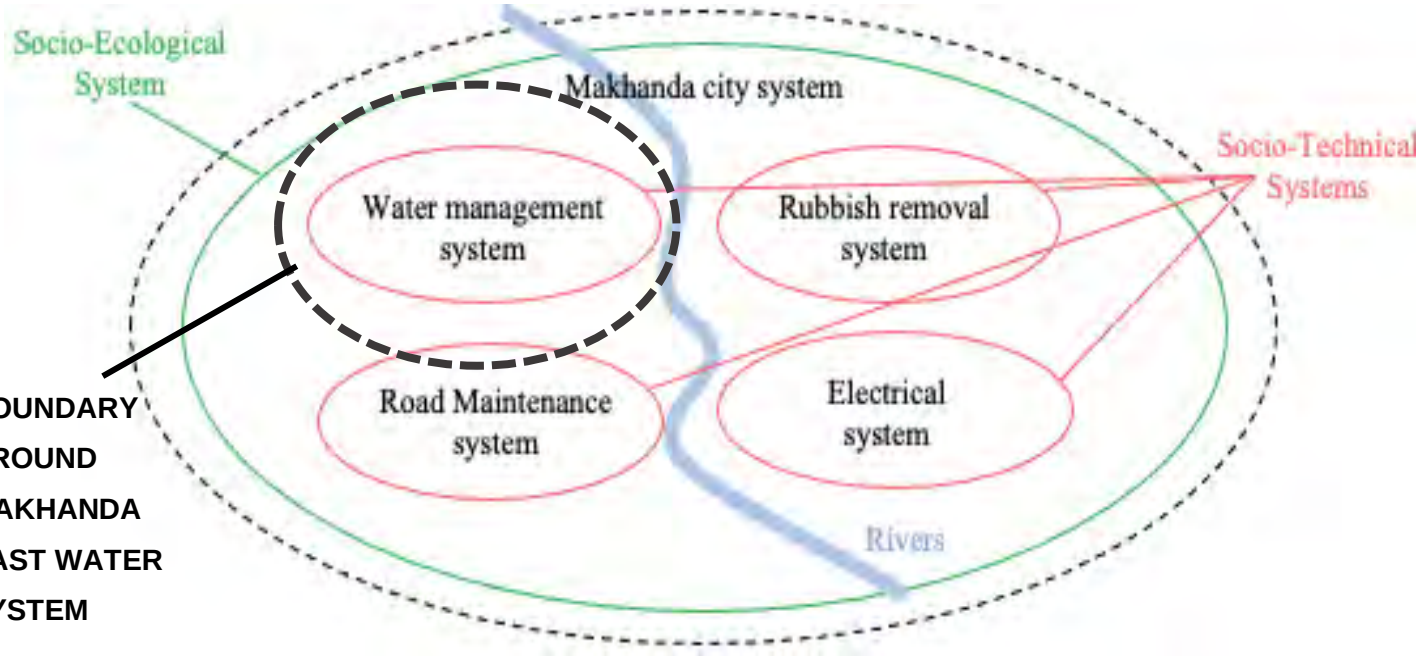

Figure 12: Boundary around the water management system

1.18.1. Research boundary

It is acknowledged that the road maintenance, rubbish removal and electrical systems can influence the water system. For example, without electricity, pumps cannot pump water, without road maintenance, water pipes can be exposed and broken, and if rubbish is not collected, water can be polluted and storm drains can be clogged, causing flooding and further infrastructural damage. However, given that water was the focus of this study, these systems were not investigated. After consulting with local water experts, the James Kleynhans Water Treatment Works (which is governed by Makana Municipality in the city of Makhanda) was chosen based on its physical access and staff's willingness to

participate. The two water treatment works and their water sources and storage facilities are shown in Figure 13.

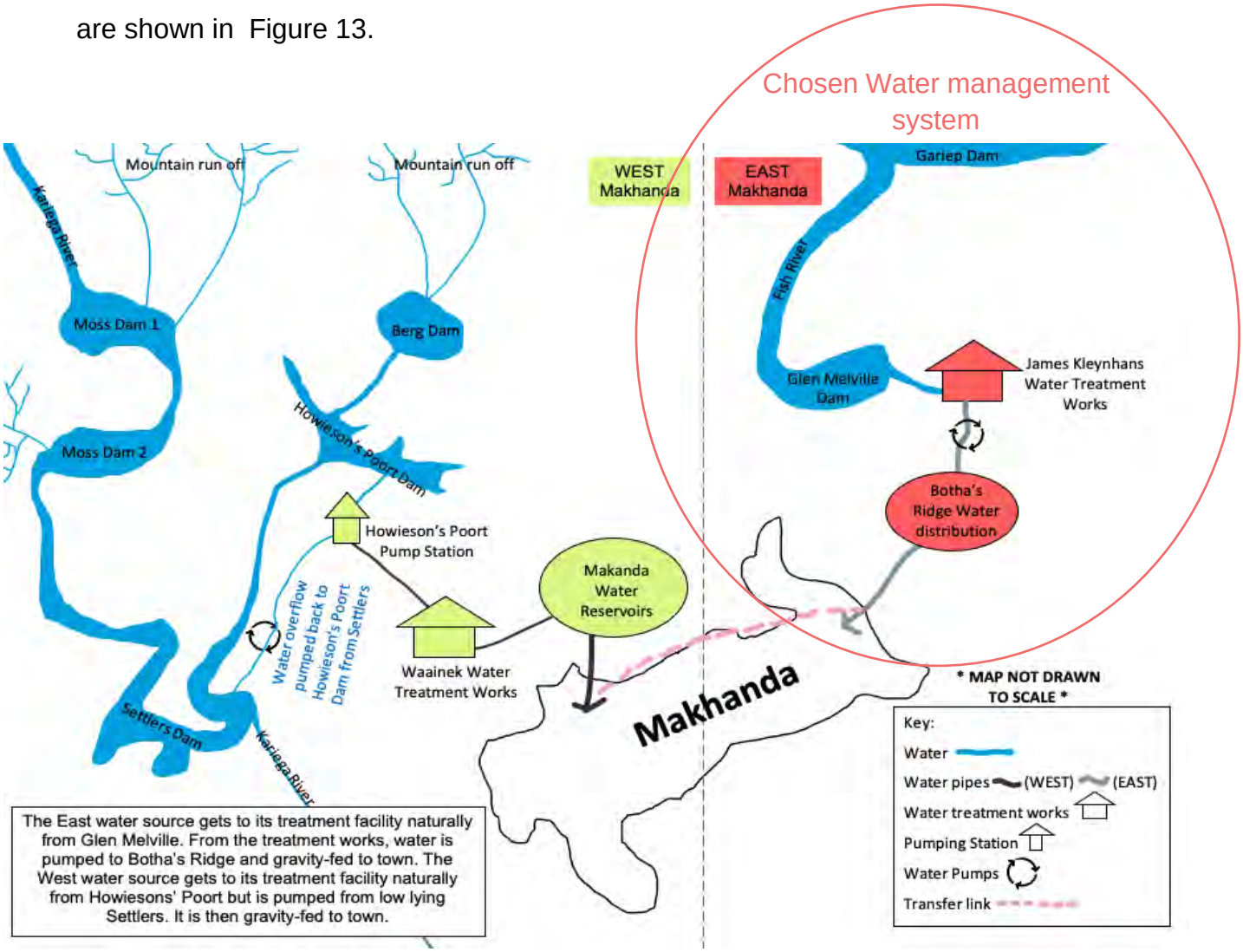

Figure 13: Makhanda water system from sources to town (adapted from MBB Consulting Engineers (2019)).

The Eastern water supply also supplies the west side of Makhanda, with Botha's Ridge supplied when the Waainek Water Works cannot operate. The water, which runs to consumers via gravity through pipes, needs to travel quite a distance and at times over hills. Therefore, high pressure is required to force it through the pipes and the pipes that supply the Eastern side must be closed, resulting in no water delivery to the East. However, the Western side cannot supply water to the East, supporting the importance of research into Eastern Makhanda's water management system.

This study aimed to shed light on the nature of the current processes and interactions in Makhanda East's water management system. HFE methods were employed to identify the barriers and facilitators that have led to poor water service delivery.

1.19. Research Question

Makhanda experiences inadequately maintained/broken water infrastructure, poor water service delivery and dissatisfied consumers. Insufficient water delivery is a human rights issue, raising the need to understand how this occurred. Against this background, the study aimed to answer the following research question:

How do systemic factors contribute to water service unreliability in Makhanda's Eastern water supply system, and what interventions could enhance service delivery resilience?

The following objectives were set to fully understand the system and answer the research question:

1.19.1. Research objectives

- To develop an understanding of South African water management systems and how they function (stakeholders, laws)
- Use HFE principles to identify:
    - Work as imagined and done.
    - Municipal stakeholders' relationships, tasks, performance and ideologies.
    - Barriers and facilitators that act on the system, affecting its functioning.
- Concisely map the factors and interactions.
- Identify interventions to address the barriers in the system to improve Makhanda's water delivery services and the well-being of those who depend on/work with it.

These objectives were identified and achieved by implementing a HFE method and the research question was answered. The following section outlines the structure of the thesis using a thesis roadmap.

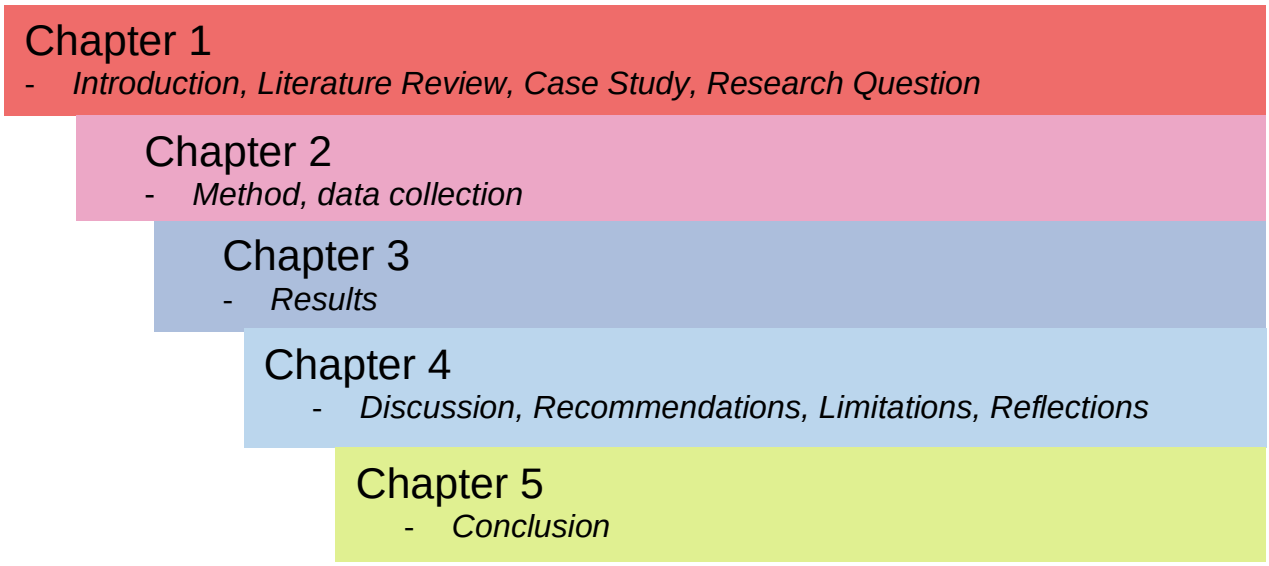

Figure 14: Thesis Road map

Chapter 2 Methods

Introduction

This chapter describes the type of research conducted, the methods used, how the data were analysed, and the ethical considerations taken into account. Figure 15 depicts the structure of this chapter.

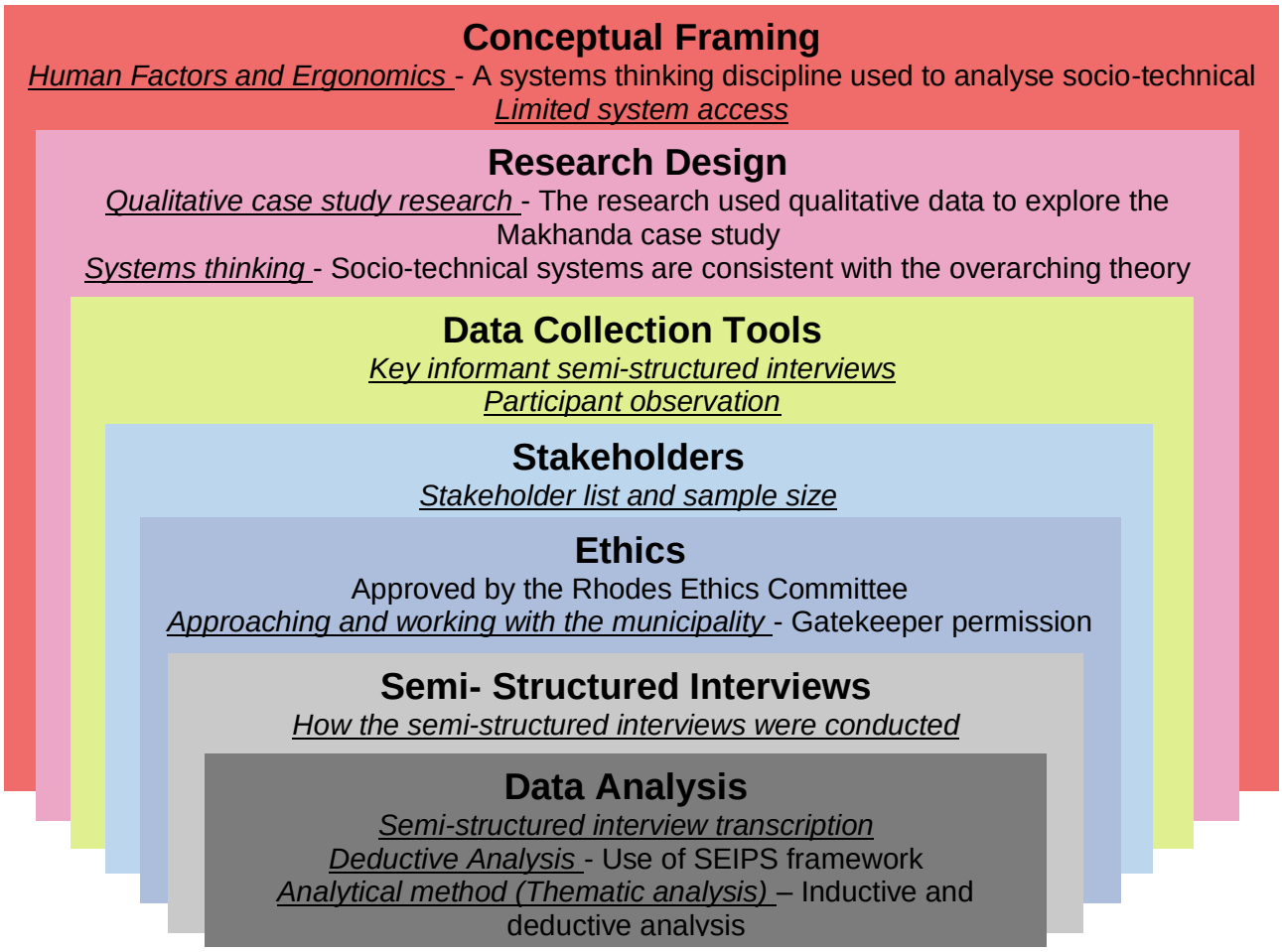

Figure 15: Methods chapter layout

2. Study Design

HFE suggests a whole system (or at least a bounded system) analysis is necessary to gain a comprehensive understanding of said system. This requires access to, if not all aspects, most of aspects of the system, sometimes within a system which may not always be willing or able to give such access to a researcher. Under such circumstances Wilson

(2014) argued that it is necessary to put boundaries where they are useful. Although the municipality was very willing to partake in the research, they only allowed partial access to the system due to the nature of the topic and the sensitivity around the water system, as such entire system access and analysis was not possible. Therefore, the boundary of the analysis was limited by what was accessible to the research. Consequently, a socio-technical systems approach was employed to analyse the most accessible and impactful water treatment facility, out of the two existing in Makhanda. It was selected because it distributed water to the entire Eastern part of town, can deliver water to the Western part of town (thereby influences the entire Makhanda population) and due to its accessibility. This treatment facility is James Kleynhans which is linked to the Eastern side of the Makhanda water management system.

2.1. Research design

Socio-technical tools enabled the researcher to identify and analyse the various social and technical interactions (Read et al., 2014) within the water management system such as those between the people, tasks, tools, environment and the organisation. To address the barriers and facilitators to water delivery in Makhanda, a qualitative case study research design was employed to promote an in-depth appreciation of systems in their natural, real-life contexts (Crowe et al*.,* 2011). Qualitative research helps to frame situations into representations using photographs, interviews, conversations, recordings and field notes (Denzin & Lincoln, 2005). It also gives meaning to social or human problems (Creswell & Poth, 2016).

2.1.1. Qualitative data

Qualitative data were collected from the organisational structures of the Makhanda water management system and then mapped using Systems Engineering Initiative for Patient Safety as a reference framework. Various tools were used to collect the data that were mapped.

2.2. Data collection tools

The qualitative data were collected using observation of work environments (Carayon, et al. 2020) and semi-structured interviews with the various stakeholders (government officials and local municipal workers). Photographs were also taken and the interviews were recorded.

2.2.1. Observation

Observation is one of the key tools to collect data in qualitative research (Creswell, 2016). It helps one gain a “rich picture” of a setting using multiple senses (Fox, 1998). Observation promoted understanding of the work environments and the nature of the work done by local municipal workers in Makhanda's Eastern Water Management system. Observation and walkabouts at the James Kleynhans Water Treatment Works occurred from 10 April to 18 June 2024 at the Glen Melville Dam and Botha's Ridge water storage unit. System experts (Process Controllers) explained the clarification and distribution process and photos were taken of the infrastructure and tools in the environment, while field notes recorded how the clarification process occurs (these helped to create Figure 18). Observation also took place from 22 April to 15 October 2024 at the offices of the municipal officials and in town where water infrastructure is maintained. Photos were taken of these environments to portray the quality of tools and infrastructure available to the municipality. An observation table depicting times and places is presented in Appendix C.

2.2.2. Semi-structured interviews

Various stakeholder perceptions and knowledge of the water management system were important to understand the interactions between system components. Furthermore an analysis through these interviews of the vertical integration of the various levels of the system was deemed as important for addressing the research question. Eleven semi-structured interviews were conducted to gather these data, from twelve participants. All of which ranged between 30-90minutes. Each interview was recorded with the researcher’s cell phone microphone to be saved for transcription at a later stage. Magaldi

and Berler (2020) define a semi-structured interview as a set of questions which focus on the main topic and provide a general pattern from which other questions and answers naturally result. Semi-structured interviews were conducted with key system stakeholders because they enabled flexible and adaptable questions (Ruslin et al., 2022). The work systems model and the associated SEIPS models, including SEIPS 101 have been shown to be an effective tool for mapping systems and their outcomes (Ma *et al.,* 2023 ; Holden & Carayon, 2021 ; Weaver et al., 2021). In particular the interactions map according to Holden and Carayon. (2021) is used to "to depict the relevant subset of work system factors whose interactions are meaningful". Creators of SEIPS, Holden and Carayon stated that SEIPS comprises seven key tools which can be used individually or as combinations (Holden & Carayon, 2021). Of these seven tools are interaction maps which were utilised in the thesis. Consequently, the questions presented in Appendix D were formulated with SEIPS in mind and were guided by pre-identified categories, namely, interactions between the water system's people, their tasks, work environment, the organisation, the tools they used and the outcomes of these interactions. The specific stakeholders to be interviewed were identified prior to applying for ethical clearance.

2.3. Stakeholders

Large infrastructure governance is generally characterised by many stakeholders at multiple levels of governance (De Haan et al., 2013). To understand a system, each relevant hierarchical level and its relationship with other levels must be analysed. Higher hierarchy levels offer deeper understanding of system goals, whereas lower levels reveal how functions meet the objectives (Vicente, 1999). Therefore, the study participants listed in Table 2 below included government officials and municipal workers at various levels in the Eastern half of the water management system of Makhanda.

Table 2: List of participants from the Makhanda East Water Management system. (the numbers in brackets indicate how many people were interviewed from each group and how many individuals there are within each group)

Stakeholder job role
(1/1) Municipal Manager
(1/1) Director of Engineering and Infrastructure
(1/1) Financial Manager
(1/1) Manager of Water and Sanitation
(1/1) Senior Technician
(1/1) Senior Foreman (Bulk Water – James Kleynhans)
(1/1) Senior Foreman (Reticulation Water –Plumbing)
(4/4) Process Controllers at James Kleynhans
(1/1) Plumber from the plumbing team

The stakeholder list was compiled through online research and conversations with individuals who work with or report to stakeholders in the water system. In line with Vasileiou et al. (2018) and Braun and Clarke's (2016) recommendation that qualitative studies require a minimum sample of 12 to reach data saturation, the researcher aimed for 12 participants and achieved this target.

The stakeholders were from all levels of the hierarchical structure of the water management system. This enabled information to be obtained from the top of the system where decisions are made to the bottom where work is done and back up again, facilitating understanding of operations at all system levels. Data were also gathered on what other levels of a system see at levels higher or below their own. This was important because individuals may not always disclose the true nature of what occurs at their personal level. The following section describes the ethical considerations taken into account in conducting the study.

2.4. Research ethics

The research was approved by Rhodes University's Ethics Committee (see Appendix E) and given the ethical clearance number: **2024-7447-8390**. All participants were informed about the study's aims and objectives and given letters of consent. No-one was forced to participate in the study. Given that the study posed the risk of uncovering data that could implicate individuals or question their morals or capabilities, all names and identifiable characteristics were excluded from the data. However, this was not possible with those who held titles. In that case they were assured that there was no pressure to answer any question that made them uncomfortable.

2.5. Procedure of approaching and working with the municipality

Once ethical clearance was obtained, the researcher visited the municipality's offices and spoke with the Municipal Manager's secretary. An email was forwarded to both explaining the reasons for the research and how it would benefit the municipality. It included a brief description of HFE and how it would be applied (Appendices F). The email was well-received and within two weeks, the office manager contacted the researcher, expressing the Municipal Manager's support. The letters granting gatekeeper permission to interview municipal workers and take photographs are presented in Appendices G and H.

Following receipt of gatekeeper permission, the researcher met with municipal officials on 8 April. They were supportive and a liaison officer was assigned to assist with the research. Initial interviews were arranged by this officer including one with a Financial Manager. Contact with the Senior Foreman and Senior Technician helped to secure interviews with additional staff. Most interviews were organised relatively easily, although some, particularly with higher ranking officials like the Municipal Manager, were challenging due to their busy schedules. After numerous attempts, the interview with the Municipal Manager took place on 15 October 2024.

The interviews took place at the water treatment facility and in the offices of the individuals interviewed that offered both a comfortable space and a less busy environment. A list of

questions was provided for each interview and the conversations were recorded using the researcher's cell phone. The following section discusses how the data were analysed.

2.6. Data analysis

2.6.1. Transcription

To ensure recordings that could be submitted to Turboscribe, a transcription application, the audio had to be of high quality, which was achieved by selecting a quiet environment. Turboscribe was chosen because multiple students in the Human Kinetics and Ergonomics recommended it for its accuracy and ease of use. Once all audio files had been downloaded and uploaded into Turboscribe to be transcribed, the researcher downloaded the text files and opened them in Word to edit each file while listening to the audio again. This promoted accurate record keeping. The text files were then analysed and placed in individual SEIPS models.

2.6.2. SEIPS models

As previously mentioned, it proved difficult to gain total access to the water management system. The researcher was allowed to interview stakeholders and have limited observations of the various workplaces, but more detailed analysis of the system was not possible. Therefore, SEIPS techniques requiring detailed information on system aspects could not be fully utilised. Specific details—such as who performed each task, why, how often, when, and with what tools, technologies, or artifacts, as well as the overall usability of these tools—are essential for SEIPS methods like task tool matrices (Holden & Carayon, 2021). However, these authors also argue that it is not necessary as "The millions of combinations of these components are unrealistic to depict, analyse or design, so the goal should be to attend as much as possible to the relevant people, environments, tools, tasks, processes and outcomes." (Holden & Carayon, 2021. p. 2). However, due to the researcher's limited access, not all of this information could be obtained Furthermore, the matrices were not in line with the study's objective of understanding the broader stakeholders and barriers in the Eastern water management system. Therefore, the data from each interview text file was manually organised into one of eight unique

SEIPS models inspired by the original SEIPS framework, one for each of the eight job roles. The SEIPS models were used to map each stakeholder in a clear, concise way to be thematically analysed at a later stage. The mapping was achieved by pairing the interviewees' responses/qualitative data into the SEIPS models' categories. The themes were the interactions between the water system and its people, their tasks, work environments, the organisation, the tools they used and the various outcomes of these interactions. Once the qualitative data populated the SEIPS models, it underwent analysis.

2.6.3. Analytical methods

Analytical methods were used to analyse the data in the SEIPS models to reveal trends in how the system functions. Analytics helps to highlight important data in a dataset (Sale, 2022). Thus, analytical models were used to highlight the prominent barriers and facilitators in the system. Both deductive and inductive analysis were utilised.

2.6.3.1. Thematic analysis

Thematic analysis ensured top-down and bottom-up reasoning (Maguire & Delahunt, 2017). In a system with a hierarchy of stakeholders such as the water system, this is important because the top and bottom must communicate and work together for system success (Rasmussen, 1997). Thematic analysis was also selected because it enabled the results to be grouped into various themes, which simplified system understanding (Maguire & Delahunt, 2017).

2.6.3.1.1. Inductive thematic analysis:

Inductive analysis ensured that the themes and categories were deduced from the data itself and not preconceived (Dawadi, 2020), thus eliminating bias (Dawadi, 2020) or incorrect conclusions (Simundic, 2012). Furthermore, the case study exists in an environment where people are frustrated and experience negative emotions surrounding the services rendered by, and the work done in the system. The water management

system is also complex, calling for themes that were not preconceived to enable unanticipated data to emerge.

2.6.3.1.2. Deductive thematic analysis:

Deductive analysis was also used because the questions asked were scaffolded by the SEIPS model, which mirrors deductive analysis. Furthermore, it was selected due to its ability to apply predetermined codes to the data (Bingham, 2021). The multiple questions posed in the semi-structured interviews related to the individual job positions, tasks, tools, organisation, environment and human-human interactions within the system. This ensured that the SEIPS models could be populated sufficiently from each interview.

The deductive and inductive analysis of the research was conducted as follows. Once semi-structured interviews were transcribed the researcher read through each transcription and highlighted important data, for example, what the different interviews stated about tasks, environments, tools, ethos, organisational aspects for the deductive analysis. All other unique and important statements that naturally occurred due to the conversational manner of the semi-structured interviews were highlighted for the inductive thematic analysis. These data revealed themes, some of which recurred, while others were repetitive. The latter included mismanagement, a lack of financial and other resources, distrust, poor reporting, a lack of vertical integration, poor quality infrastructure, job vacancies and high staff turnover. These themes and others more specific to certain interviews are discussed in detail in the following chapter. The themes that were repetitive were a sign that they are experienced across the various levels of the system. The following section will now discuss the results of the data collection phase. It will depict results in written, pictorial and diagram formats for visual and written comprehension of the findings.

Chapter 3 Results

3. Introduction

This chapter presents the data from the semi-structured interviews with municipal water officials and observation of the system's work environment. There were 11 interviews, which in total constituted 12 participants, one interview had two participants and in one other interview a participant stayed after their own interview and joined in on the next interview with their colleague. The data informed nine SEIPS frameworks, mapping the water management system at micro and macro levels.

The frameworks cover the system's interactions and the roles of key personnel, including Process Controllers, the Senior Foreman for James Kleynhans, Plumbing Teams, the Plumbing Foreman, the Senior Technician, the Manager of Water and Sanitation, the Director of Infrastructure and Engineering, and the Municipal Manager. No SEIPS was created for the Financial Manager, as this role is not directly tied to water management; instead, this interview (9) provided insights into the system's financial context and can be found in appendix P. The results of the observation of the work environment are presented first, followed by those of the SEIPS frameworks.

3.1. Observation results

The observation took place at the James Kleynhans Water Treatment Facility offices in town and its premises. Section 3.1.1.1 depicts the water clarification process at James Kleynhans and the storage facility for final clarified water before it is gravity fed to the town. Section 3.1.1.2 portrays photographs of the work environment within the water management system at James Kleynhans and in town in order to shed light on the Process Controllers and General Workers' tasks in clarifying the water. It also offers an overview of the municipal employees' work environment and the barriers they face, for example, a lack of tools, material and poor working conditions.

3.1.1. Process of collecting, clarifying and distributing water in Makhanda

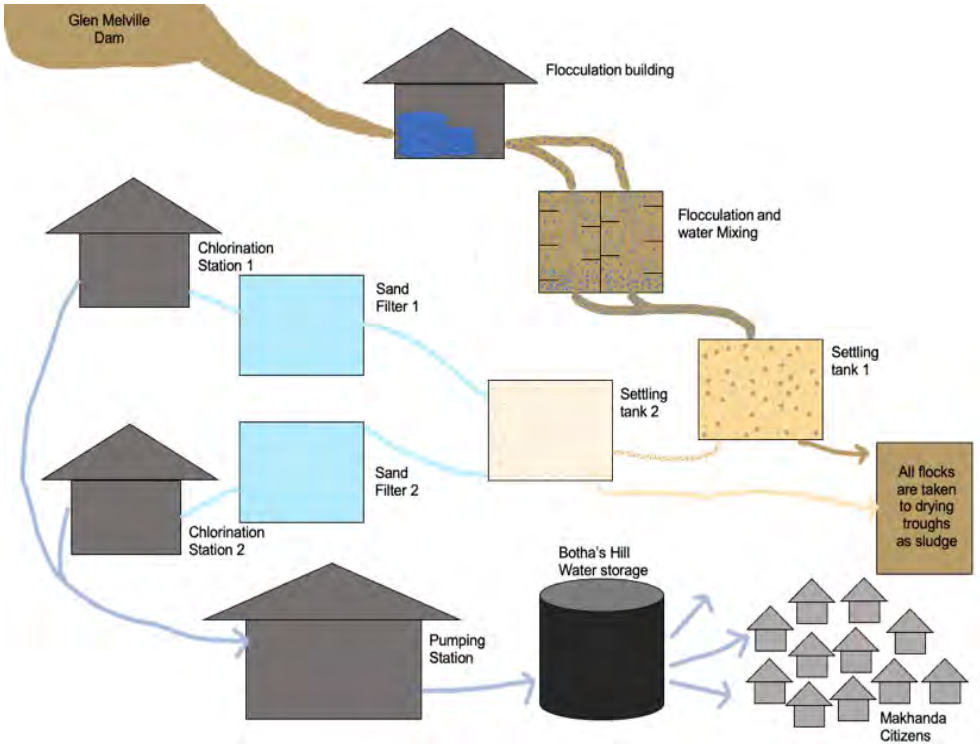

Figure 16: Water process flow from collection to distribution, drawn by observations of the plant.

3.1.2. Photos of water system environment (first two at James Kleynhans, the next three in town).

Figure 17: (Left) State of James Kleynhans tools - handmade net. (Right) James Kleynhans office chair made of car seat and metal crate.

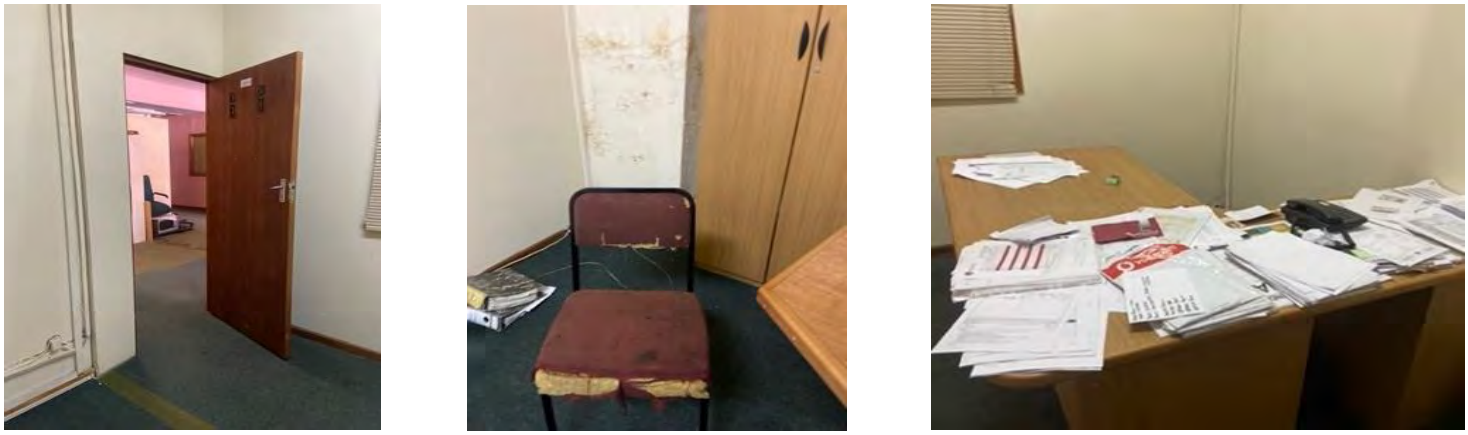

Figure 18: (Left) A cluttered passageway in the intown Water System office. (Middle) Damaged and unmaintained furniture and infrastructure in a water system officials office. (Right) The state of an office belonging to a water official.

3.1.2.1. Photograph explanation

In Figure 17, first two photographs, depict tools and furniture at James Kleynhans Water Treatment Facility. Figure 17 (Left) is a make-shift net made by the Process Controllers out of metal pipes, wire and green plastic mesh which they use to scoop leaves, dirt and foam out of the settlement tanks and mixing tanks. Figure 17 (Right) depicts the chair in the office which the Process Controllers use, it was made from an old car seat, wire and a metal crate. These images show that there is a lack of resources at the Water Treatment Facility, however, they also show the resourcefulness of the employees at James Kleynhans.

The next three photographs in Figure 18, depict the working environments of the water management system of employees at their intown offices. Figure 18 (Left), depicts the state of the passageways, populated by broken equipment, broken chairs and other clutter. The image also shows the water damage on the carpet. Figure 18 (Right), shows an otherwise barren office with no chair and a desk with one phone and paper scattered all over the desk, suggesting a lack of filing procedures Lastly, Figure 18 (Middle), shows a chair, badly stained and in poor condition. Behind the chair is a wall that is also water-damaged with peeling paint. Overall, the last three pictures show a working environment that is lacking resources, badly maintained and is generally not conducive. The working environment indicates that the municipality doesn't just have no money for service delivery, it has no money in general to maintain or upgrade any of its assets.

3.2. Systems Engineering Initiative for Patient Safety

This section commences with a SEIPS model of the entire integrated Eastern Water Management system to promote an overall understanding at the macro level. It is followed by an in-depth analysis of the system, illustrating various key interactions. The people map displays the stakeholders in the water system and the nature of the interactions and relations between them in their work environment. Each detailed SEIPS model for the eight actors responsible for the system's management and operation, including the Process Controllers, Senior Foreman, Plumbing Teams, Plumbing Foreman, Senior Technician, Manager of Water and Sanitation, Director of Infrastructure and Engineering and the Municipal Manager is accompanied by a narrative synthesised from the thematic analysis of relevant key informant interviews. The narrations cover the five key interactions that SEIPS focuses on (People, Tasks, Tools, Organisation, Environment) and each of these interactions' facilitators and barriers. Comprehensive narratives for each system actor role are provided in Appendices I-O. One comprehensive narrative for the Process Controllers is provided as an example in the results, while the remaining seven are presented in condensed format to improve readability. The Process Controller's SEIPS was selected because it showcases where the actual physical work is done in obtaining water, purifying it and sending it to the reservoirs for distribution to consumers, while all other system actors support this work and the legalities surrounding it.

The SEIPS models illustrate interactions among the system elements, highlighting barriers and facilitators that influence both personnel and water outcomes (social and technical). These are shaped by the procedures managing system interactions. Each SEIPS framework is colour-coded for clarity and the results that follow summarise key barriers and facilitators, with supporting evidence detailed in the appendices. The colour-coding for the SEIPS models is depicted below.

Figure 19: Key for SEIPS models

3.2.1. Summary of the Makhanda East Water Management system

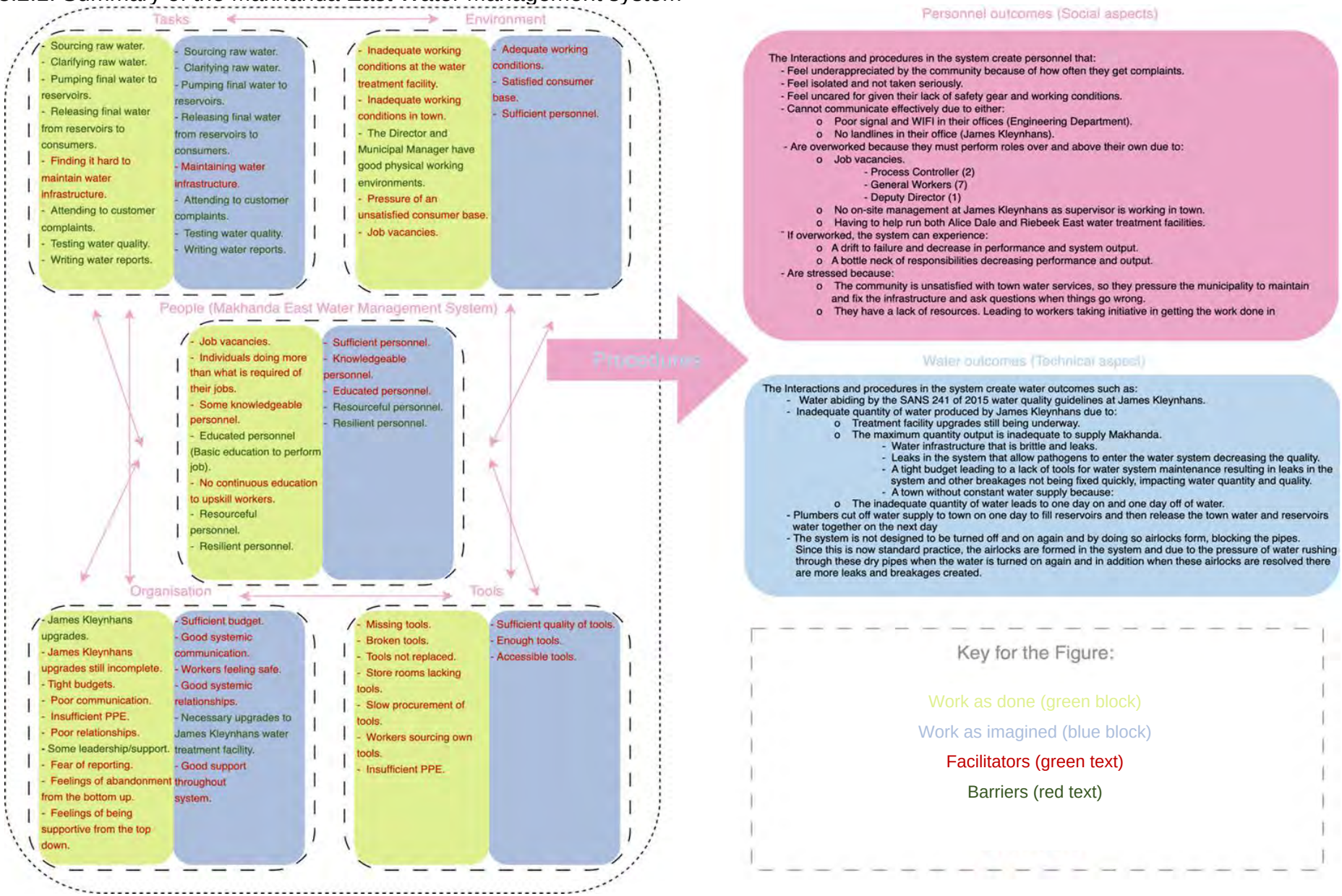

Figure 20:Summary of Makhanda East Water Management System SEIPS.

3.2.1.1. Summary of the Makhanda East Water Management System's SEIPS results:

Barriers:

Tasks: *Infrastructure:*

Outdated and broken infrastructure introduces a myriad of new tasks to the water management system to fix and maintain it, while staff and resource shortages make performing these tasks more difficult. As a result, the task of providing sufficient water to consumers is made more complex and time-consuming, impairing water delivery.

Environment: *Poor work environment and tools:*

The Director and Municipal Manager have adequate office environments while workers at other levels in the system do not. For example, workers at James Kleynhans and in town are exposed to poor housekeeping in their work environment. Those in town are also exposed to poor maintenance with office infrastructure in decay, resulting in demotivated and frustrated municipal workers.

Environment: *Dissatisfied consumers:*

Dissatisfied water consumers result in municipal officials constantly being contacted via WhatsApp messages and phone calls, resulting in an additional workload of responding to complaints from the community and decreased morale.

People (Makhanda East Water Management System): *Job vacancies:*

The vacancies in the water management system include a permanent Municipal Director, a Deputy Director, two Process Controllers and five General Workers at James Kleynhans and a lead plumber for one of the Plumbing Teams. This results in municipal workers being overworked.

Organisation: *Financial mismanagement:*

There is evidence of poor financial management throughout the system. The lack of resources, poor work environment, poor infrastructure and poor service delivery are all indicators of this, leading to a dysfunctional system.

Organisation: *Inadequate financial resources:*

Inadequate financial resources result in several barriers. Firstly, it is not possible to source the required tools and material for maintenance, etc. Secondly, it is not possible to pay external contractors. Both

these factors limit the system's ability to respond effectively. Furthermore, workers feel they are not paid fairly for their work, particularly overtime, resulting in them being reluctant to work.

Organisation: *Incomplete upgrades to James Kleynhans:*

Upgrades to James Kleynhans will double current water outputs. These have been on-going since 2015 and should have been completed in 2017, but the various contractors employed were subsequently asked to leave the job. One company underwent liquidation while the next two took too long to reach their targets. The upgrades were thus incomplete at the end of 2024, constraining the municipality's ability to provide sufficient water.

Organisation: *Municipal workers feeling undervalued:*

The Process Controllers at James Kleynhans work with toxic gas (chlorine), requiring protective masks. However, the masks provided expired in 2007. Municipal workers feel unprotected and uncared for, which demotivates them. Furthermore, by putting employees' health at risk the system could face legal charges.

Organisation: *Reporting/Blame culture:*

Individuals lower in the hierarchy fear reporting due to the blame culture they feel is present in some areas of the system. Individuals feel that when an error or incident occurs, the organisation looks to blame someone for the problem, which causes them to withhold information. Thus, reports sometimes depict incidents inaccurately. Individuals higher in the hierarchy use these reports to produce their own, causing inaccurate reporting at all levels of the system that do not depict its true nature.

Affordances:

Tasks: *Abiding by water standards law:*

Water at James Kleynhans is tested and treated so that it abides by the quality regulations set by national government, providing water that is of legally acceptable quality.

People (Makhanda East Water Management System): *Resilient workforce:*

Municipal workers are resilient and resourceful and do their best with what they have to ensure that residents have access to water. This results in water distribution being achieved despite a lack of resources.

Organisation: *Good Leadership:*

Counter to the argument of a blame culture, some individuals in leadership roles try their best to support and educate other workers in the system for increased functionality. This results in workers feeling valued and supported. They are thus happy to work, and the system's performance improves.

Organisation: *Planning for the future:*

The municipality is proposing multiple new strategies to improve the water system and combat poor service delivery. Firstly, it is looking into smart water meters that will restrict overuse of water. Secondly, an infrastructure maintenance budget is being formulated to begin maintaining and fixing the system.

Tools: *Reliable electricity:*

James Kleynhans experiences no load-shedding because of an agreement with Eskom. If there is a power outage, the plant has various generators to keep the treatment facility up and running.

Tools: *Reliable supply of raw water:*

It was observed and is noted in the literature that James Kleynhans has a supply of raw water from the Orange River/Gariep/Fish River system, resulting in a high volume of available water.

The following section presents the results on the internal relationships between the system actors in the water management system. The SEIPS framework enables researchers to depict stakeholders' relationships with a mapping tool called a people map. The people map and results are depicted and narrated to form an understanding of how individuals in the system communicate and exist together.

3.2.1.2. People map showing relationships between system individuals.

The water management system comprises of multiple people at different levels that must work together to ensure a well-aligned system that operates as it should. The people map below depicts the relationships between various stakeholders in the water management system to show how each level interacts with another and if there is misalignment, which would indicate a system not operating optimally. These relationships were formulated from data collected from the semi-structured interviews and mapped.

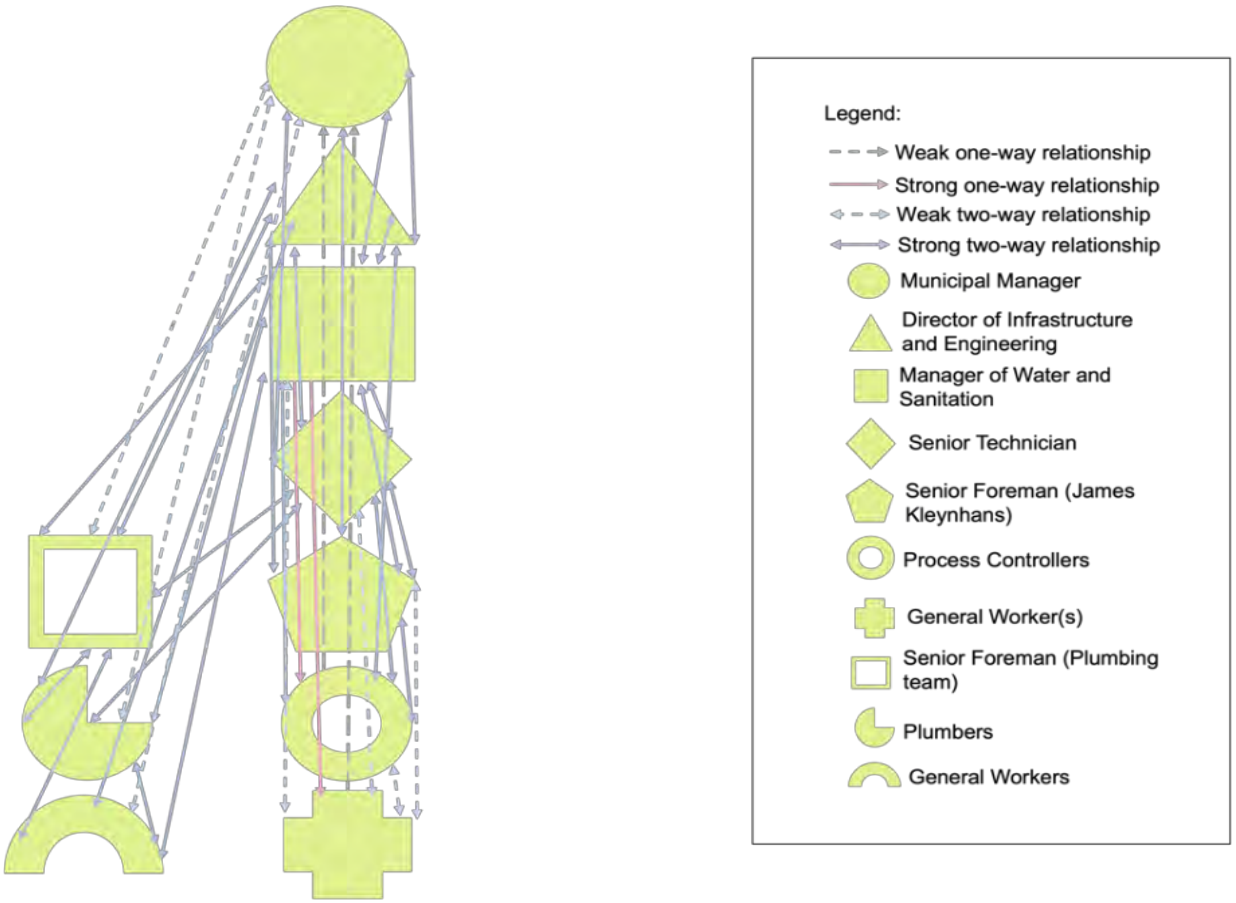

Figure 21: People map depicting relationships between system individuals

The relationships between individuals and those they report to directly are generally positive, except for the General Worker and the Process Controllers. The only General Worker in the James Kleynhans system interacts and works with only one Process Controller, limiting connections with the team. Thus, it was reported that there is a weak relationship between Process Controllers and the General Worker.

Stronger relationships were observed among individuals higher in the hierarchy, particularly between the Senior Technician and the Municipal Manager and all positions that fall between them. For instance, one respondent noted, "*We do coordinate with management, with the directors, so also we've got support*" - Interview 1. However, employees in lower positions reported less support from management, stating, "*We need support from our management*" - Interview 5, and "*If we can just have someone that can stand with us, that will help*" - Interview 6. A Process Controller also expressed concern about communication: "*They will take a decision without coming to us*" - Interview 5. The Process Controllers have a close relationship with their Senior Foreman, who was described as "*a big brother to us*." Conversely, there is no interaction between the Plumbing Teams, the Plumbing Foreman and the Process Controllers or their Foreman.

The Senior Technician and the Director of Infrastructure and Engineering generally maintain strong, two-way relationships with other stakeholders. However, while higher-level managers perceive themselves as approachable, with one stating, "*My office door is always open*" - Interview 10, some employees expressed reluctance to approach them due to past experience of being redirected with comments like, "*What's your supervisor saying?*" - Interview 5.

This analysis of stakeholder relationships sets the stage for the subsequent discussion on Process Controllers' tasks, including a detailed Hierarchical Task Analysis (HTA). This reflects their pivotal role in water clarification and storage compared to other system actors who primarily oversee processes and infrastructure.

3.2.2. Process Controllers

As depicted in Figure 22, the Process Controllers perform the entire water clarification process at James Kleynhans. They are also required to write reports when any incidents occur at the plant, and they initiate the procurement process. However, Process Controllers do more than required due to job vacancies at the plant and a lack of on-site management. This results in them performing the roles of General Workers and Senior Foremen as well as their own duties, resulting in heavy workloads.

In the water clarification process at the James Kleynhans Water Treatment facility, Process Controllers first open a valve to allow water from the Glen Melville Dam into the facility. The valve measures the water volume for billing to the municipality, as the dam is owned by the Department of Water and Sanitation. Inside the facility, a chemical flocculant is added to the water, binding dirt and debris into clumps. The amount of flocculant used depends on the water's turbidity. The water then moves through mixing and settlement tanks. Dirt and debris sink to the bottom in the settlement tanks, forming sludge, which is later drained. The cleaner water flows to sand filtration tanks, where it passes through sand layers for further purification. These tanks are cleaned using air and water backwashing. After filtration, chlorine gas is added to disinfect the water, which is then pumped to Botha's Ridge for storage. From there, it is released to the community as needed through a gravity-fed system. Throughout the process, the water is tested for turbidity, pH, and chlorine at various stages (see the hierarchical task analysis below in Figure 22 for further details). The next section displays the Process Controllers' Hierarchical Task Analysis, followed by the comprehensive Process Controller SEIPS results. After which all other seven SEIPS models with their individual condensed results sections will follow, while their comprehensive results can be found in appendices I-O as mentioned above.

"*Terri, but, I so wish this research of yours can, can somehow find them. Yeah, yeah. Can somehow find them so that they know that we are dealing with this thing. We just want to be, we just want to be valued*" - Interview 5.

s seen above, each SEIPS section begins with a key quote from an interview corresponding to the stakeholder level that foreshadows the results. The Process Controllers' hierarchical task analysis below captures their imagined and performed duties and the water clarification process at James Kleynhans. This analysis was populated from interviews with system actors and experts and the researcher's observation.

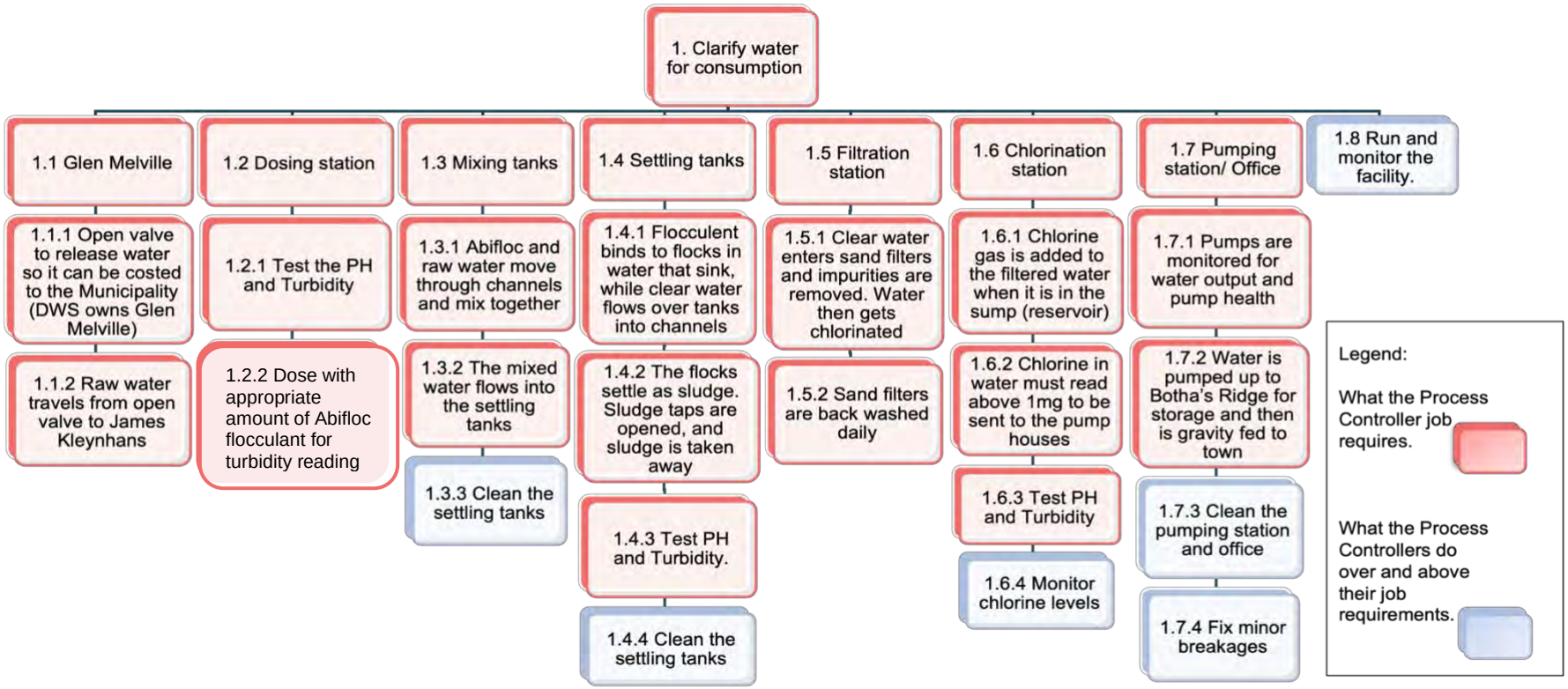

Figure 22: Hierarchical Task Analysis for the Process Controller at James Kleynhans

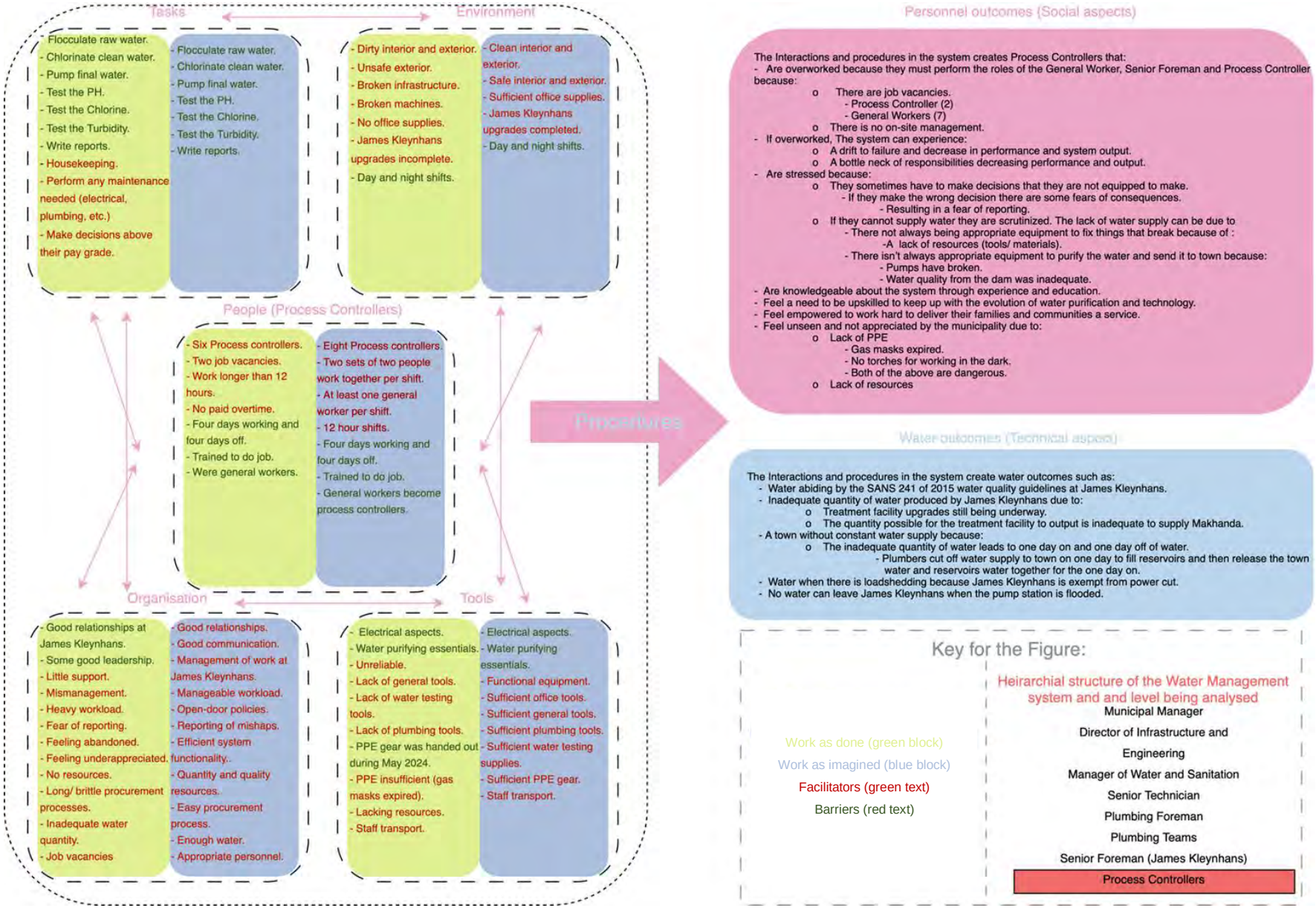

Figure 23: Process Controller SEIPS

3.2.2.1. Comprehensive narrative of Process Controllers' SEIPS

Tasks:

Barriers:

Overworked:

There are perceptions of a high workload as James Kleynhans has not completed its upgrades, which will double the amount of water produced every day. When the upgrades are completed, more Process Controllers and General Workers will be needed per shift to cope with the increased workload. For example, at present, there are four sand filters, while there will be eight after the upgrade. Currently, one person takes "*three to four hours, backwashing those filters*"- Interview 7. After the upgrades, this time will double. At the same time, someone needs to check the pH and turbidity at the raw water and settling tanks and the pH, turbidity, and chlorine concentration of the final water. These tests are done every two hours, and the results are recorded. The same individual must also desludge, monitor the pump house, and attend to other aspects of the job. According to the Process Controllers, their workload is "*too much*" – Interview 7. This results in employees being stressed and fatigued, leading to poor decision-making and incidents such as errors in the clarification process, missing the two-hour water testing period or not being able to timeously detect a flood in the pumping station, resulting in system failures.

In addition, if there is an electrical or plumbing issue and it is a small job, the Process Controllers attend to it themselves. This is because they know that "*it takes time to call the repair guys to come from town. Maybe we'll call them now. Then there's a problem now. Then they won't be able to come now. So, we have to make sure that we do some stuff so that we can minimise whatever the problem is, so that it does not escalate*" – Interview 5. This adds to their workload and results in less time to perform their job requirements and tasks.

Poorly designed infrastructure:

The poorly designed infrastructure introduces risks. For example, the pumps lie a few metres below ground level in a pit, and other pumps are needed to pump water from where the generators lie when water infrastructure inside the pump station breaks (valves, joints or pipes). Otherwise, the motors will get wet and malfunction. "*It's such bad design, it makes no sense. If they've done it properly the first time, it would have been so easy*"- Interview 5. If the pump station is flooding the Process Controllers must react quickly. "*I think the only nightmare is the flood*"- Interview 5. Currently, it is a two-person job.

If "*we have a flood…you can't do it alone. If you go there alone, even if you close it, when you are done, the water will have flooded the entire building*"- Interview 5. The poorly designed infrastructure means that when there is a flood in the station, the facility shuts down so the employees can attend to it, resulting in a shortage of water in the community.

Poor reporting:

If an incident occurs, the Process Controllers must submit a written report on what went wrong. This must be given to the Senior Foreman who accompanies it with his own report. Both are then sent to the Senior Technician for investigation. This is a barrier in the system because the Senior Foreman is supposed to monitor and work with the Process Controllers "*He's supposed to be here*"- Interview 6. By not overseeing operations at the plant, he won't know first-hand what occurs. The Process Controllers' reports are thus unable to be validated, which can mean that poor reporting goes undetected, rendering reports that rely on the initial reports unreliable.

Mismanagement:

Due to the Senior Foreman not being on site, the Process Controllers must make decisions outside their job specifications. However, they do not have the same knowledge of the system as a Foreman. As reported by the Process Controllers in Interview 7, the Foreman is not on site or unreachable by phone. When situations occur that need immediate action they are forced to make decisions that the Foreman should make. They "*don't know whether it's a good or bad decision*" – Interview 5. Not having the Senior Foreman at James Kleynhans also creates other problems. For example, a Process Controller stated, "*it feels as if I've just left on the dustbin, because most of the time, the contractors are working in here. They ask questions that I cannot answer about the plant, because I'm not a Senior Foreman. The Senior Foreman should be here all the time … I'm not a manager. I'm not a senior foreman. I'm nothing. But I have to answer those things*" – Interview 7. This can lead to decisions being made at the plant that can diminish the system's performance through unnecessary incidents.

Facilitators:

Communication:

The current upgrades to James Kleynhans show that the Process Controllers "*preaching all these years*" – Interview 5, led to the municipality instructing contractors "*to dig up a trench to prevent the flooding*" – Interview 5, in the pump station. In addition, "*with the refurbishment, they'll put an electrical*

valve for the rising main, an actuator" – Interview 5; this will further help to automatically prevent flooding in the pump station. At the same time, Process Controllers can continue doing their duties. By listening to and communicating with others in the system, decision makers could make the necessary changes to improve it.

Abiding by job requirements:

The Process Controllers do their job to the best of their abilities. They run the plant autonomously and do the required pH and turbidity sampling of raw and settled water along with the pH, turbidity and Chlorine sampling of the final water every two hours. By performing work as prescribed, the system should continue to perform as expected.

<u>Environment:</u>

Barriers:

Work environment:

Process Controllers work in the office to test the water samples and monitor the pump station. The internal office environment is unpleasant; it was observed that it has dirty smears on the walls, dust-covered surfaces and is cluttered with broken chairs and old equipment. The filtration and dosing station interior has broken windows, glass on the floor and dust-covered surfaces, while the filtration station is cluttered with old, discarded filtration nozzles. The external environment is littered with broken fences and pipes, pipes that still need to be installed, uncovered trenches, broken glass, litter, and abandoned infrastructure. Construction workers have been at the plant for the past few years and construction material lies scattered and can cause injuries.

Hazardous environment:

Process Controllers work both night and day shifts. The night shifts struggle to see the pathways and water clarification tanks when needing to check the water clarification process because there are no lights on the exterior of the buildings and they lack torches, which they have been asking for. Instead, they use their phone torches, but the illumination is not strong enough, resulting in anticipated hazards like uncovered trenches that they "*can fall in*" - Interview 6 and snakes that "*are crawling around at night*"- Interview 5.

Facilitators:

N/A

People (Process Controllers):

Barriers:

N/A

Facilitators:

Shift work:

There are two shifts each day that are structured in a four-day on, four-day off format. "*They should run over twelve-hour periods*" – Interview 5. This gives employees sufficient breaks between shifts, which can mitigate the effects of fatigue.

Knowledgeable/ Trained:

All Process Controllers "*started as General Workers*" – Interview 7 and are thus familiar the procedures and processes. As apprentices, they gained knowledge about their specific system, but to become Process Controllers, they first needed to be formally "*trained*" – Interview 6 to optimise their skills.

Organisation:

Barriers:

Job vacancies:

There should be eight Process Controllers in the system who work as a pair per shift, and at least one General Worker should be on site to "*assist the Process Controllers*" - Interview 5, by performing housekeeping duties, including cleaning the settlement and filtration tanks, the office and outside the facility, clearing paths, and removing broken infrastructure, equipment, and rubbish. They also fetch tools/material and work with the Process Controllers when needed. However, there is currently only one General Worker and six Process Controllers. This means there are two Process Controller vacancies and multiple General Worker vacancies – Interviews 4-6.

At present, two shifts have a pair of Process Controllers working together to run the whole plant with no General Workers. One shift is only run by one Process Controller during the day, and when he is on night shift, one of the other Process Controllers from another shift must help him. The last shift has one

Process Controller and the only General Worker in the system working together. This is less helpful than if there was another educated Process Controller on shift – Interview 4.

The lack of General Workers is because there were Process Controller vacancies, and the municipality sent almost all James Kleynhans' General Workers to be trained to become Process Controllers. The Process Controllers believe that the current lack of General Workers is because of a lack of "*money*" – Interview 7. They thus have to perform the duties of a General Worker, resulting in less time to carry out their tasks and adding to their workload.

Delayed upgrades to James Kleynhans:

The James Kleynhans water treatment facility currently outputs close to 10 megalitres of water a day, which is insufficient to supply Makhanda, which requires "*18 megalitres per day*"- Interview 1. The upgrades underway will double this output to increase the quantity of water available to Makhanda from "*10 to 20*" megalitres per day - Interview 6. However, the upgrades are taking a long time and until they are complete the water treatment facility will face the barrier of outputting insufficient water – Interview 10.

Fear of and poor reporting:

As noted previously, when an incident occurs, reports must be written. For example, if "*there's a flood, we know that we're gonna have to write a report, and we could be sent home anytime. They always target somebody*" – Interview 5. This narrative of *"someone has to be blamed*" – Interview 5, creates a fear of reporting, resulting in incidents not being reported and leading to employees that are unaware of systemic challenges that may need to be addressed before more serious incidents occur.

The fear of consequences when reporting leads to other problems, such as poor reporting or underreporting. Thus, system employees believe that there must be "*two stories. The real one, and the story we're going to push out there*" - Interview 5. People would rather say "*let's put it like this, so that things cannot be sour for you*" – Interview 5. However, this creates false narratives of the nature of the system and its problems which can lead to further incidents because the contributory factors leading to problems are not identified.

Lack of perceived value:

Not everyone fears the consequences of reporting. "*I know that they won't fire me. I'm feeling safe. I would feel better if they can come and listen to our audiences, all those things*" – Interview 6. However, there is a trend of feeling undervalued. "*Terri, but, I so wish this, research of yours can, can somehow find them. Yeah, yeah. Can somehow find them so they know we are dealing with this thing. We, just want to be, we just want to be valued*" - Interview 5. "*I mean, if we can just have someone that can stand with us, just to talk, that will help, and things can just be delivered to the plants*" – Interview 7. Better communication would lead to a better functioning system where employees work together. This is a common theme amongst the Process Controllers: "*They used to know our names. They used to come down here*" – Interview 5. They wait a long time for their orders, or they never come. "*Some of the stuff, the managers don't take it seriously*" - Interview 5. There is a feeling that "*being a Process Controller in the municipality is like we are being undermined*" - Interview 5; "*I'm nothing*" – Interview 7. This can lead to adverse emotions, affecting individual performance which hinders system operations and outputs.

Lack of management:

All four Process Controllers interviewed suggested that they need more on-the-ground support with their Senior Foreman being stationed in town instead of at the facility: "*The Senior Foreman should be here all the time, because the contractors are working in here*" – Interview 6. "*We need more support from our management*" – Interview 5. "*We manage without a manager most of the time*" - Interview 7. "*He's not here at all, it feels as if I've just left on the dustbin*" - Interview 6. "*Some of the times there are things that happen, there are challenges that you need your guidance from the one who's above you so that you can sometimes, you will think, if you have a second opinion maybe then you can see it clearly but sometimes when you're alone then you make that decision maybe it's going to… you don't know whether it's a bad or good decision*" - Interview 5. If a decision results in an incident at the plant the Process Controllers need to write reports explaining what happened. This can be difficult because, again, there is a perception that someone will be blamed.

Lack of PPE/ Safety gear:

The Process Controllers lack PPE gear, specifically, appropriate gas masks, which protect against the "*very dangerous*" – Interview 6 toxic chlorine gas used to sterilise the water. "*The gas masks expired in 2007*" – Interviews 6 and 7 but are still used. There is also a safety mask with an oxygen tank outside

the chlorine gas store room. However, the tank is empty, and the gear hasn't been used for years, "*It's long here*" - Interview 6, and it has also expired. In addition, Process Controllers are supposed to wear PPE overalls, but had not received new PPE ones since "*2021*"- Interview 7, which resulted in them "*working in our own clothes*" – Interview 6. The PPE gear provided consisted of steel toe boots and fire-retardant overalls. Some didn't fit properly, "*resulting in them not using it. If I can show you my overall top now, it stands here* (shows it's too small to fit*). I can't wear it all the time, all day, just because it's holding me tight here*" - Interview 5. This has led to feelings of neglect: "*I'm not protected at all. That's why I cannot enjoy my job anymore. No one... No one is looking after us in terms of the job. So, we just get discouraged by that*" – Interview 6. Staff retention would be easier if municipal employees felt that they are taken seriously and cared for.

A vulnerable water reticulation system:

James Kleynhans abides by the water quality guidelines set by SANS "*241 of 2015*" - Interview 3. However, Makhanda residents still don't drink tap water. The quality of the water has decreased due to the broken pipes and reservoirs, allowing pathogens to seep into the stored water. "*No one talks about the system, the leaks in the system whenever they find bacteria in the water*" - Interview 5. "*What I wish the management could do is try and protect these reservoirs at the location just because you will find out there's certain bacteria that are being found in the location while those bacteria are not being found on the plan*" – Interview 5. Water quality could be more efficiently protected by protecting reservoirs and other infrastructure.

Lack of transport:

The lack of transport is "*the main challenge*" – Interview 1. According to interviewee 1, a vehicle should be at Waainek and James Kleynhans for their reticulation foreman and another per the five plumbing teams, with one extra vehicle for the plumbing foreman, meaning a total of eight vehicles are needed. At present there are "*three*" – Interview 10. However, when data collection began on 22 April 2024, it was stated that there was only "*one bakkie*" – Interview 1. In interview 10, almost four months later, it was stated that although there are two new vehicles and the municipality listened to the demands of the water department, two of the bakkies' brake pads were already worn down and they were in for repairs. If there is no vehicle for the James Kleynhans Foreman, he cannot get from town to the facility. If he works at the facility with no vehicle, there are other problems like snakes because "*if someone can get bitten … by the snake, where can we go? There is no transport in here. There is no car*" -

Interview 6. Again, if there are not enough vehicles, all workers in the bulk and reticulation departments have to be fetched and dropped off by two to three vehicles and must rely on one another to do this timelessly for either calls to be attended to or for shift change.

The Process Controllers must use municipal transport to and from work. This is important because if the transport bringing the new shift to relieve the old shift is running late and someone from the old shift has found their own way home, nobody will run and monitor the plant between the beginning and end of shifts. Thus, due to a lack of transport, "*some shifts tend to go longer than 12 hours with no paid overtime*" – Interview 5 to ensure that there are always Process Controllers at the plant.

Facilitators:

Some good relationships:

The Process Controllers have good relationships and "*protect each other*" - Interview 5, while other employees are trying to bridge the gap between the Process Controllers and higher-ranking individuals to decrease the impression of a disjointed system. For example, the Senior Technician, Senior Foreman and acting Director, "*I don't want to lie. They treat us well. When we say to them, we've got a problem, they take care of us*" - Interview 7; "W*orking with the Foreman and Senior Technician, it's quite right. If they can just deliver resources*" - Interview 6. "*If I have a problem, I just call the Foreman. Even if I don't get hold of the Foreman, I just phone the Senior Technician. I tell him I need this thing on the plant immediately. Even if the pump is broken, the pipe is broken, or the contractor is working, just call*" – Interview 6. According to the manager and director of Water and Sanitation they adopt an open door policy - Interviews 2 and 3. Lastly, the Director bridges the gap by going to James Kleynhans to help. "*He visits, Even yesterday. Yesterday he was here, he left at midnight*" – Interview 7. This shows that some individuals are trying to form relationships and work together, improving their ethos, willingness to ask for help, feeling valued, and system performance.

Upgrades to James Kleynhans (not yet completed)

Two complaints were addressed about the plans of the new upgrades. One is the water quantity produced, and the other is the pump station's flooding. Upgrades are underway at James Kleynhans, increasing water output to almost double the current amount. The enhancements also include digging a low-lying trench that will help with flooding of the pump station (flooding often occurs, resulting in the plant being shut down). Additionally, in the "*second stage of the upgrades, there will be an actuator*

installed" – Interview 5, to shut off water fast, automatically to avoid flooding of the generator pit.

Tools:

Barriers:

Chlorine tablets:

Chlorine tablets are a last resort and an alternative to the chlorine gas used to chemically clean the final water so that it is appropriately sanitised for consumption. However, chlorine tablets should be replaced with chlorine gas when stock arrives because "*using the tablets we don't know how much chlorine is in the water in the final water*" - Interview 6. "*Those chlorine tablets doesn't give you the exact chlorine that is on the water. You cannot test the amount of gas in water in those machines we have when you are using tablets*" - Interview 6. "*And ma'am, I have to be honest now. We are working... as best as we can, but we have no resources*" - Interview 6. The use of tablets is attributed to issues in the past with chlorine gas procurement nationwide, for example, during the COVID-19 pandemic - Interview 6. This results in unreliable reporting.

Lack of resources:

The feelings of neglect are exacerbated by the broken equipment lying around and a lack of essential equipment for day-to-day system performance and maintenance; "*we have no resources*" - Interview 6. The Process Controllers "*don't have office equipment or chairs*" - Interview 5 and resorted to making a chair from a "car seat" - Interview 5 and a metal crate. "*We don't have a phone*"- Interview 7; "*There's no phone here."* – Interview 5. *"We use our own phone*" - Interview 7. *"We're all using our own airtime whenever there's a problem"* – Interview 5*. "Sometimes you will find out you come to work, and you have no airtime" – Interview 5.* The Process Controllers sometimes source their own tools that might be unfit for purpose. "*If you need a second spanner, you go ask the contractor. He does the job. He does whatever. Or maybe go to the neighbour's house. And ask for that tool if they have"* - Interview 5. This creates unsatisfactory working conditions, which impacts employees' morale and performance. "*If I was valued, they would give me a pen*" – Interview 6.

A chain of command must be followed in the procurement process. There used to be storerooms stocked with resources but nowadays those "*stores are not stocked*" - Interview 9. This results in long delays in receiving tools and material. Even a small thing like a torch can take months to order, causing disillusionment among the Process Controllers. "*The torch is just a simple thing*" - Interview 6, and they

don’t have one at the facility during night shifts when it is time to “*test to get your samples*”. “*We are supposed to have torches. Because we work night shift, some of the places that we work, it's very dark. So we didn't see what’s outside*” – Interview 7. The lack of resources is disheartening, “*Waking up at 6, coming to work, feeling sad. That was the whole day. Because we were crying about the torch*” - Interview 6. Again, this affects workers’ ability to perform, negatively impacting the system.

Insufficient water testing supplies and general tools:

The water testing machine called a jar test machine “*stopped working for years*” - Interview 5. It still sits dormant, taking up office space and collecting dust. Currently, they use a turbidity meter, pH reader and chlorometer. Unfortunately, “*sometimes they give us the wrong readings*” - Interview 7. A digger called a TLB is used to dig the pipelines, but the municipality doesn’t have one so if there is a burst pipe “*they can't fix it*” - Interview 11.

Raw water quality:

Glen Melville dam water can sometimes be very full of sediment and the chemical flocculant used by the municipality “*is not designed to treat sludge*” - Interview 5. “*If water affairs is giving us the water that is so dirty, we are unable to treat it”* – Interview 6. The sediment filled water is simply caused by Glen Melville’s natural environment. The Fish River system which feeds Glen Melville is naturally high in salinity as a result of the natural geology of the river floor. This along with increased sediment movement from runoff after rainfall results in a high sediment loads and generally poor raw water quality in the rivers and dams which are fed by this water system. At times the is less rainfall so water entering James Kleynhans is clear and other times after heavy rain, water is highly sedimented. All pending on the climate system. If the water has concentrated sediment, for the sludge to be treated the plant needs to be physically “*shut down*” - Interview 5, so that the Process Controllers can “*physically get their hands in there”* - Interview 5, get rid of the sludge and then wait for the water to settle to continue with the water treatment process. Shutting down the plant due to weak chemical and sludge results in no water production during that time, leading to a frustrated community with water shortages.

Communication/ Lack of teamwork:

Communication is a constraint because the municipality “*don't usually engage with us … We will find out that they will come with an idea and tell us that we should do this and this and this. Or maybe they will take a decision without coming to us*” - Interview 5. The municipality makes decisions without

consulting with the Process Controllers on "*how can we deal with it, they don't ask. They just tell you what to do*" – Interview 5. This results in work imagined not aligning with how it is done, destabilising the system and its outputs.

Facilitators:

Reliable electricity:

James Kleynhans has no load-shedding because of a deal with Eskom. If there is a power outage, the plant has various generators to keep the treatment facility up and running.

Reliable supply of water:

It was observed and is noted in the literature that James Kleynhans has a constant supply of water to treat from the Orange River/Gariep/Fish River system. This results in a stable and reliable supply.

Water clarification essentials:

The mixing, settlement and filtration tanks are operational and use chemical flocculant, which is always available. In the case of chlorine, if no gas is in stock, plans are made to source chlorine tablets quickly. The system thus does not have to shut down operations. When the chemicals are unavailable, there is backup in place to perform the clarification and deliver water to consumers.

3.2.3. James Kleynhans Senior Foreman

"*When I started working here this thing of not being appreciated used to get in my head and this thing of not being from here, being a foreigner. I've been in Durban, Cape Town but this is the first time I've been treated like a foreigner*" - Interview 4.

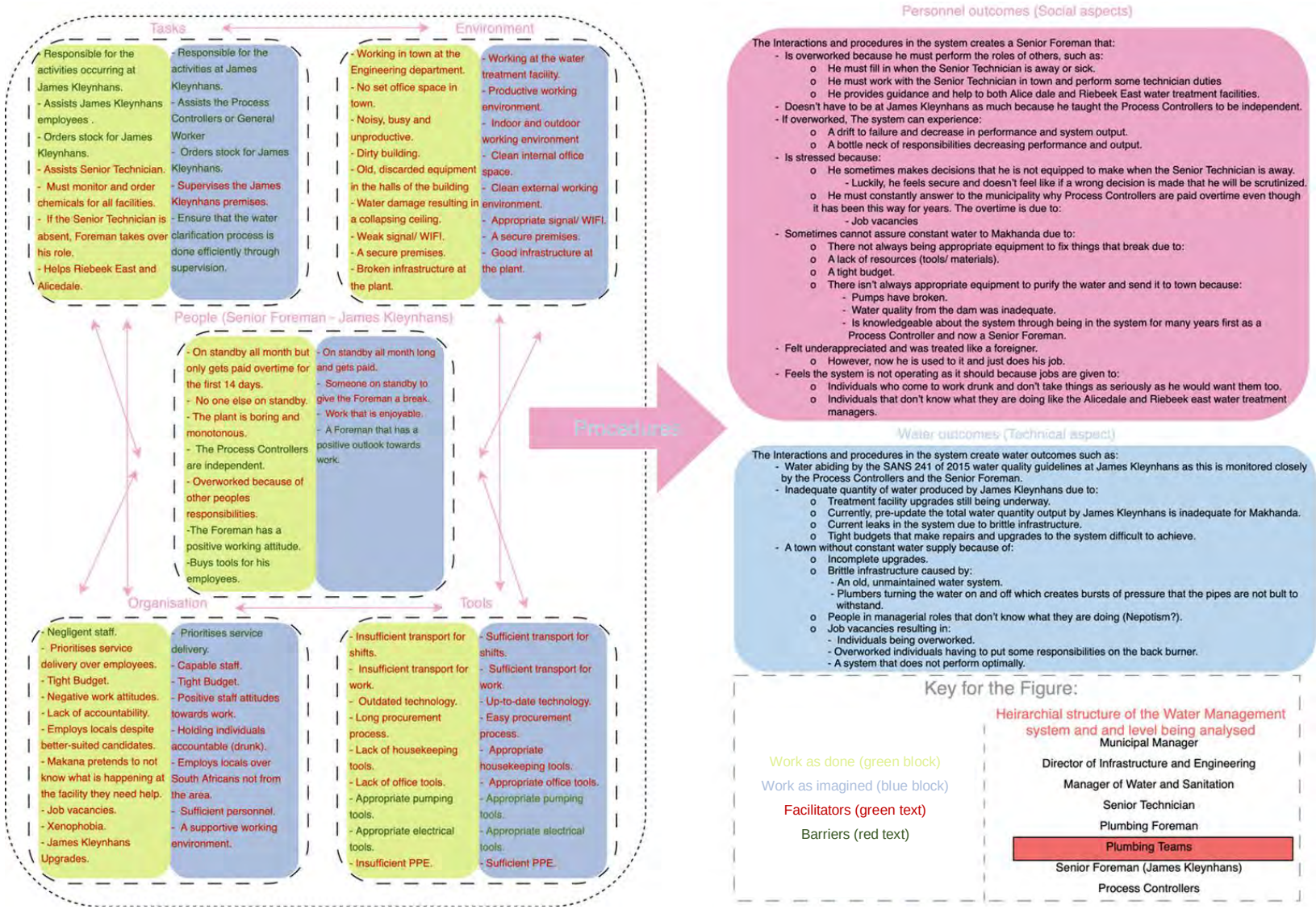

Figure 24: James Kleynhans Senior Foreman SEIPS

3.2.3.1. James Kleynhans Senior Foreman's SEIPS condensed narrative (Comprehensive narrative in Appendix I):

Barriers:

Environment: *Inadequate working environment:*

Observation at James Kleynhans revealed broken glass, old, discarded water infrastructure, rubble, litter and trenches outside. Inside the office there was dirt and dust on surfaces as well as broken equipment. In town, the Foreman works in a storeroom in an office building that is poorly maintained. This inadequate working space results in demotivation and disillusionment with the municipality.

Organisation: *Overworked:*

The Foreman assists the Senior Technician with his duties because *"it's a lot of work*" - Interview 4 and water treatment facilities in two Eastern Cape towns, Alicedale and Riebeek East. However, what started as assisting ended in "*taking over*" - Interview 4. This constrains the system because if the Foreman is doing other work, "*It means that I'm going to lack doing my work*" - Interview 4, resulting in a lack of management and workers feeling thrown in "*the dustbin*" - Interview 6.

Organisation: *Lack of financial resources:*

The Senior Foreman is expected to work 24 hours a day, seven days a week, because there is nobody to help him with the standby shift. However, the "*municipality only pays us only for a standby of 14 days. So, the rest of the time is just, we're just working for free*" - Interview 4, resulting in fatigue and demotivation.

Organisation: *Prioritise consumers at the cost of employees:*

Interviewee 5 stated that the Senior Foreman knows that the Process Controllers' gas masks have expired and tried to order new ones, but was told there was not enough budget, and that chemicals, which are more important, needed to be purchased. By choosing the community over employees in a safety-related matter, employees could feel that they are "*not valued at all*"- Interview 6, and stop caring about their jobs, which will impact system performance and water outputs.

Organisation: *Negligence*:

"I always say [that] *… the municipality only uses 30% of the staff… Or maybe 40%"* - Interview 4. "*The other employees are present but are not functional, because they do the bare minimum to collect their pay check at month end"* – Interview 11. Dysfunctional employees create a dysfunctional system.

Tools: *Lack of resources:*

The Foreman stated that "*there is no bakkie to take me to the office and back to the plant, so I stay in town*" - Interview 4. This leaves James Kleynhans employees without supervision or help if an incident occurs, destabilising the system.

Facilitators:

Tasks*: Oversees James Kleynhans:*

Due to a lack of transport and an overworked system, the Foreman works in town with the Senior Technician. This helps James Kleynhans because by working with the Technician who escalates procurement orders, stock can be ordered efficiently. However, the procurement "*process is long*" - Interview 4, and employees can wait for tools for a "*year*"- Interview 10.

People (The Senior Foreman): *Independent workforce:*

James Kleynhans functions without the Foreman on site: "*I always train the Process Controllers to, to do more than they should*" - Interview 4. This results in resourceful, proactive employees who attend to incidents without waiting for instructions. However, decisions are made without the knowledge and expertise of a qualified Senior Foreman.

Organisation*: Prioritises consumers:*

The Foreman ordered gas masks for the Process Controllers which expired in "*2007*" - Interviews 5 and 6. However, there was "*no money*" – Interview 4, so the municipality had to choose between gas masks and ordering more chemicals for Makhanda's water to be clarified. The Foreman had "*to prioritise*" and "*put the gas-mask order on hold*" - Interview 4. This suggests that the municipality does not prioritise employees' health and safety, resulting in those at the lower levels feeling undervalued.

3.2.4. Plumbing Teams

"*They blame us as well. It's not our fault because we're just there to do what we can*" – Interview 10.

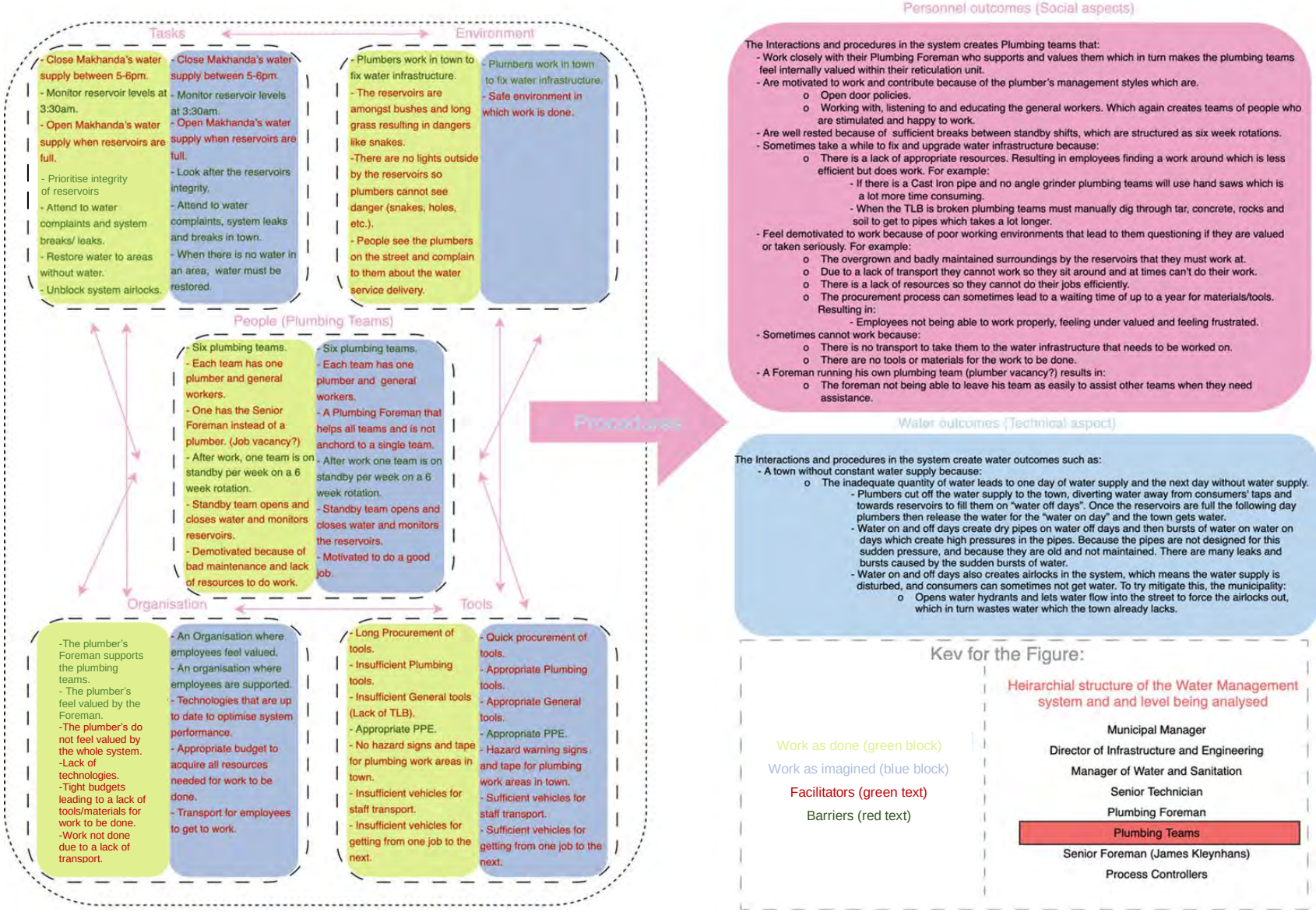

Figure 25: Plumbing Teams' SEIPS

3.2.4.1. Plumbing Teams' condensed SEIPS narrative (See comprehensive narrative in Appendix J):

Barriers:

Tasks: *Lack of resources*

The lack of resources makes the plumbers' jobs harder as it causes both delays and results in shifts that may not work as well as traditional solutions. "*It's a bit difficult with the resources because we don't have the resources. But we can do our job. We do it very well … If we had the resources everything would be easier*" - Interview 10.

Tasks: *Insufficient water/On and off days:*

The inability to provide sufficient clean water led to the service being provided one day on and one day off. "*Our goal for now is to close the reservoirs at night so it can get full and when the reservoirs are full We open it*" - Interview 10. "*The water system isn't designed to start and stop. This creates airlocks and high pressure when the water returns that burst pipes/ creates leaks"* – Interview 4.

Environment: *Maintenance:*

The reservoirs that the Plumbing Teams work with are surrounded by "*a lot of bushes and grass … Last time we saw a snake, there was a big snake, a black mamba*" - Interview 10. This causes workers to be "*demotivated*" - Interview 10.

Organisation: *Infrastructure:*

The city loses water constantly because of "*leaks and the abrupt burst of water pipes, that are caused mainly by the ageing infrastructure*" - Interview 2.

Organisation: *Job vacancies:*

"*You've got some few plumbers, as compared to the volume and the amount of work*" - Interview 2.

The water infrastructure is old and human capital is not available to maintain it. This results in backlogs, new breakages and existing breaks not being attended to.

Organisation: *Lack of financial resources:*

The municipality has a tight budget and as such "*there's not a lot of resources*" - Interview 10. The lack of tools means that work cannot be done.

Tools: *Transport:*

A crucial issue is the "*the transport" - Interview 6,* because Makhanda is *"short on transport*" - Interview 4, and employees cannot get to and from work. Furthermore, callouts to repair infrastructure cannot be attended to, resulting in system leaks being unattended to and loss of water.

Tools: *Long procurement process:*

Procurement of tools is a "*long process. If you want to get the fittings, we take a year to get the tools*" - Interview 10. This results in tasks taking long to be completed.

Facilitators:

Tasks: *Attending to complaints:*

"I'm a plumber, I do the network, I repair the pipes. And I also open and close the water. And when there's no water, maybe in a certain area, I go and check and make sure that the area is watered" - Interview 10. Plumbing Teams try to attend to all water complaints.

People (Plumbing teams): *Resourceful workforce:*

While there is a lack of resources (tools, material, transport) at the Plumbing Teams disposal, team members are resourceful and inventive, because they "*actually do* [the work] *… without resources*" - Interview 10.

People (Plumbing teams): *Shift work:*

"There are six Plumbing Teams who all work from 7:30 am to 16:30 pm. The standby shifts run in a weekly order where one team is on standby each week on a six-week rotation" – Interview 10. This means that employees get sufficient rest after a week of overtime, which makes the plumbers more efficient.

Organisation: *Good management:*

The Plumbing Teams feel supported by the Plumbing Foreman and the Senior Technician, "*they do their best to give us the resources we need. And even when we have a problem, they are always there to deal with us in darkness"* - Interview 10, Resulting in employees who feel supported.

3.2.5. Plumbing Foreman

"*Because he's so under pressure, he switches off his phone.*"- Interview 4 (about the Plumbing Foreman).

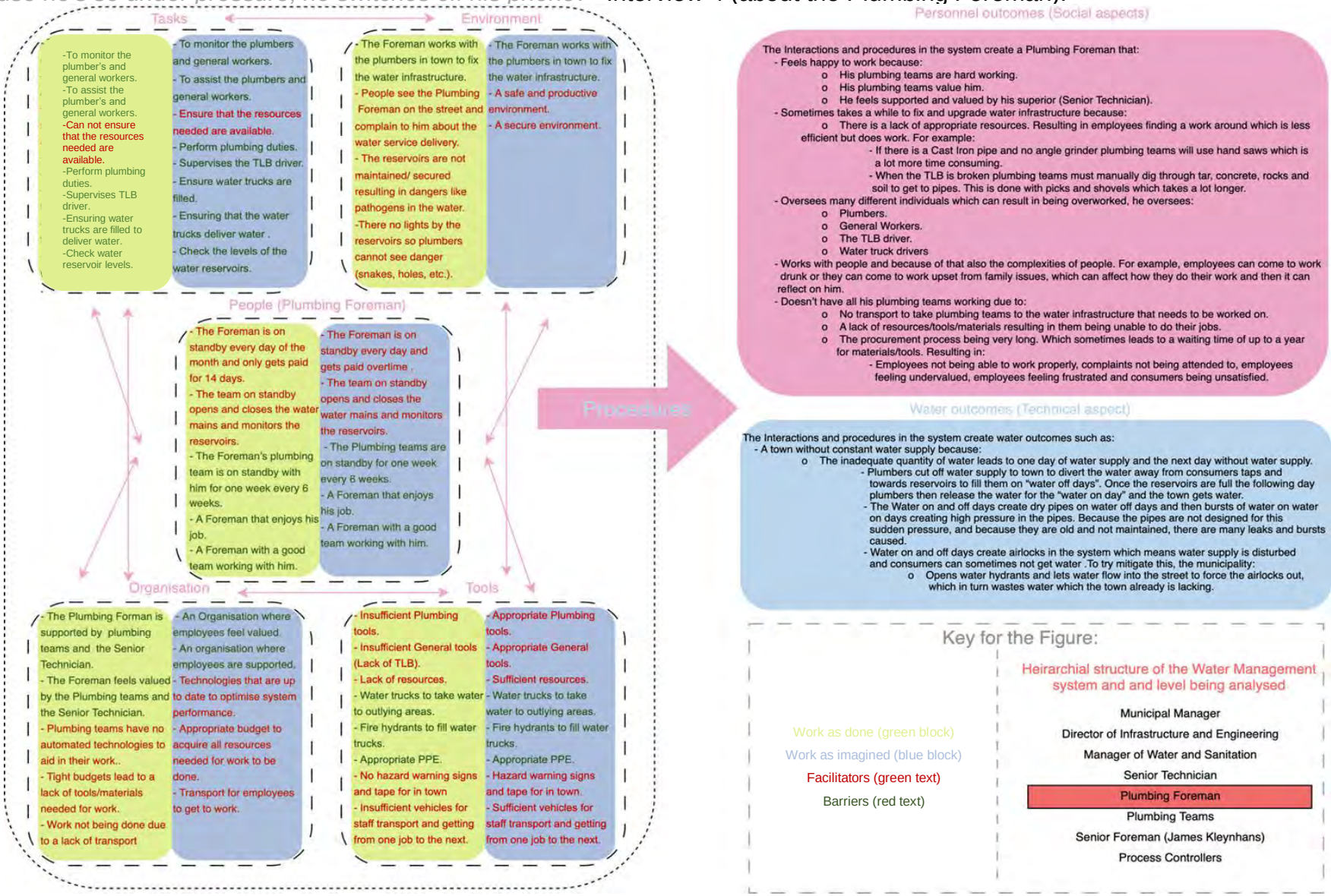

Figure 26: Plumbing Foreman's SEIPS

3.2.5.1. Plumbing Foreman condensed SEIPS narrative (Comprehensive narrative in Appendix K):

Barriers:

Tasks: *Long procurement process:*

"*This procurement procedure it's the one that makes things even more difficult*" - Interview 5. If the plumbers need anything the Foreman tries to ensure they "*get what they want*" - Interview 10. However, this is a long process and it can "*take a year to get the tools*" - Interview 10, that are needed. If there are no available resources, then work is done at a much slower rate.

Environment: *Dissatisfied consumers:*

Being in town, working on water infrastructure, the Foreman and his teams are visible to the community. This results in consumers complaining to the Plumbing Teams and Foreman while they are on the job. The complaints stem from disappointment with "*the services that we give*" - Interview 10. This can demotivate the Plumbing Teams because, "*it's not our fault*" - Interview 10.

People (Plumbing Foreman): *Overworked:*

Although the Plumbing Foreman's team is on standby once every six weeks, the Plumbing Foreman is on standby all the time. The Foreman works for the full month on standby from "*the 1st to the 31st /30th of the month"* - Interview 10.

People (Plumbing Foreman): *Underpaid:*

The Foreman on standby does not get paid overtime for every day of the month. The municipality pays for the first 14 days of work and he must "*assist after those 14 days*" - Interview 10. This leads to him feeling exhausted and unhappy.

Organisation: *James Kleynhans upgrades:*

As noted in interviews 1-7, the municipality aims for specific quality and quantity water targets. However, the Plumbing Teams stated that it is not achieving these targets and attributed this to the delayed upgrades to James Kleynhans. "*I don't think it's being met because we are, I think we're still waiting for the upgrade to be finished at James Kleynhans*" - Interview 10. This suggests that Plumbers believe that once the upgrades are complete, the water output should help alleviate Makhanda's problems.

Organisation: *Lack of financial resources:*

The tight budgets noted in Interviews 1-7,9 and 11 lead to the municipality "*not* [having] *a lot of resources*" - Interview 10, resulting in incomplete work, while that that is able to be completed is more difficult without the appropriate resources: "*If we had the resources everything would be easier*" - Interview 10.

Tools: *Vehicles/Transport:*

Currently, two of the three bakkies "*are in the workshop*" - Interview 10, leaving one to transport both water treatment staff and the plumbing team to and from work. Plumbing Teams should *"have six"* - Interview 10 to attend to "*complaints better and faster for the community*" - Interview 10. Without bakkies, staff members either arrive late for shifts or work longer shifts and complaints are not dealt with efficiently.

Facilitators:

Tasks: *Good management:*

The Plumbing Foreman works alongside the Plumbing Teams in town. This enables on-the-ground management, support and monitoring. The Plumbing Teams also feel that the Foreman does his "*best to give us the resources we need*" - Interview 10 and that their managers "*support us*" - Interview 10. This points to good management that results in a grateful and efficient workforce, leading to increased overall system performance.

Organisation: *Good support:*

The Foreman stated that he enjoys being a Foreman because his Plumbing Teams are "*working hard*" - Interview 10. He added that his superior, the Senior Technician, "*supports me very well. He's a good guy. So, I don't feel a lot of pressure*" - Interview 10. This suggests that he is supported by his employees and his superiors and that he is happy to work.

Tools: *Water trucks:*

When areas without infrastructure or outdated infrastructure need water, trucks are dispatched. This demonstrates that "*the municipality* [is] *abiding by South African water laws, which indicate water must be made accessible to everyone* – Interview 10.

3.2.6. Senior Technician

"*We're just going to have to ensure that the basic things that the people need, they do get. And then the other things can follow*" – Interview 1.

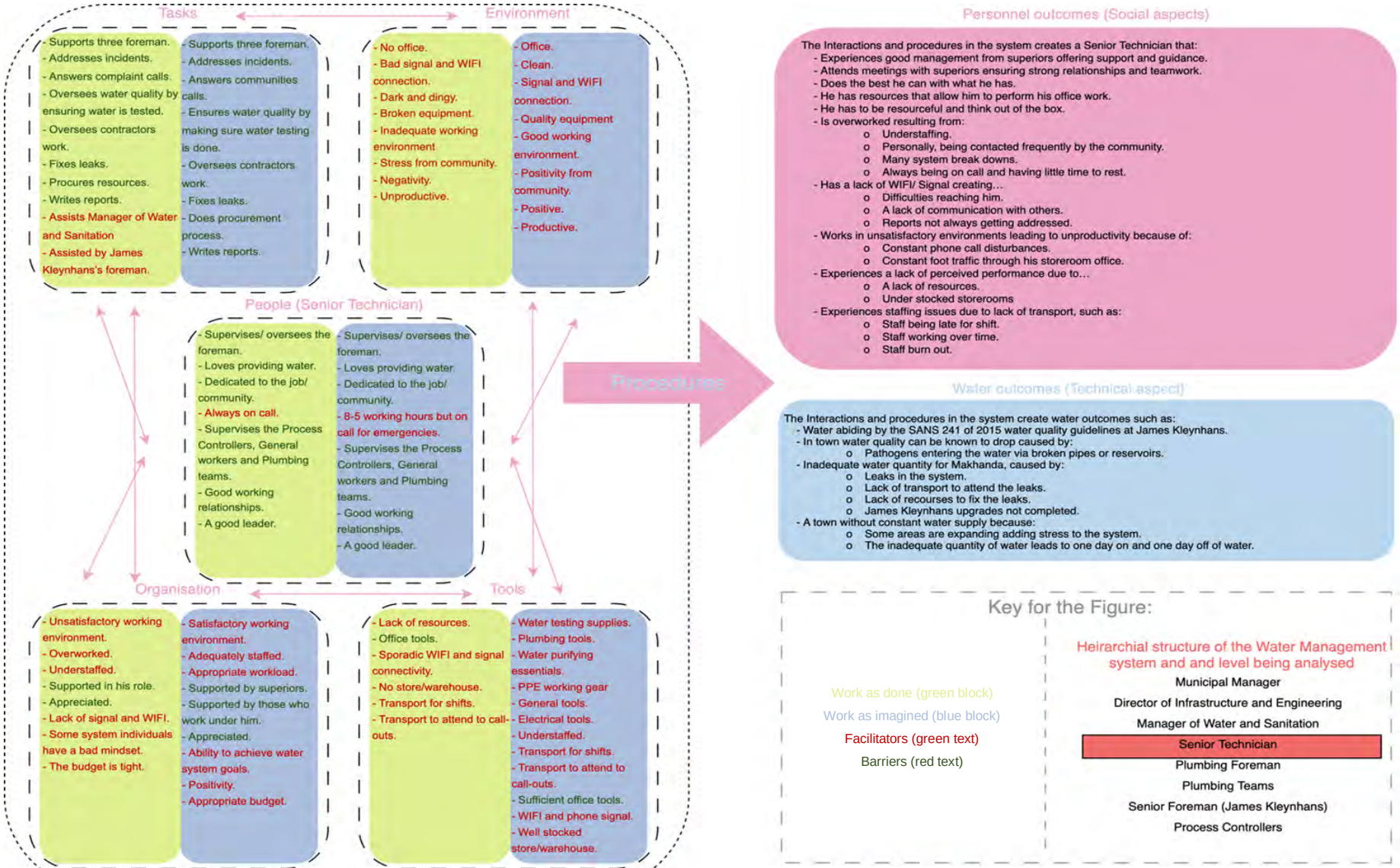

Figure 27: Senior Technician's SEIPS

3.2.6.1. Senior Technician's condensed SEIPS narrative (Comprehensive narrative in Appendix L):

Barriers:

Tasks: *Overworked:*

The Senior Technician responds to complaints, is responsible for all those working below him in the bulk and reticulation sectors, procures resources for the facilities and Plumbers, and assists the Manager of Water and Sanitation when necessary. Due to this heavy workload, the Senior Foreman from James Kleynhans was brought in to "*assist* - Interview 4. While this has eased the burden on the Technician, there is now no supervision at James Kleynhans in case of emergencies, making the system vulnerable.

Environment: *Inadequate environment:*

The environment is *"not good"* - Interview 1. "*I use that office or storage, I don't know what it is, but I'm using that, and the network, it's a challenge…sometimes they have to call the front desk so that they can get a hold of me*" – Interview 1. This causes communication challenges and an unproductive environment for the Senior Technician, impacting system performance.

Environment*: Demanding work environment:*

During the interview, the Technician's phone rang constantly, and it was evident that he was being called out by various people. "*We're getting calls all over the place... it's just chaotic … People, they're always shouting, sometimes, even if it's after hours*." – Interview 1. This creates stress, for the Technician, affecting his work and the system's performance.

Environment*: Overly accessible to the public:*

It is expected that municipal workers must also be available because their phone numbers "*are all over the place. They are on Facebook …They also call the manager they call the director …they call everyone*" – Interview 1. This causes them to neglect their other responsibilities, creating bottlenecks that affect system performance.

Organisation: *Lack of financial resources:*

"*The basic things that I need, we'll have to try with that tight budget*" – Interview 1. The lack of finances results in scarce resources, affecting task completion.

Organisation: *Delayed upgrades to James Kleynhans:*

The contractors that are upgrading James Kleynhans have not completed the work. Once they are complete, water output will go from 10 to 20 megalitres and "*there will be enough water to supply town without the Western water treatment works*" - Interview 10.

Tools: Lack of transport:

"*The bakkies are the main challenge because at the moment, as we speak today, I've got just one bakkie*" – Interview 1. There are six plumbers and "*each plumber must have his own bakkie*" – Interview 1 to adequately assist the Makhanda community. Furthermore, "*the foreman for the James Kleynhans plant must have a bakkie, and the foreman for Waainek must have a bakkie*" - Interview 1.

Tools: *Lack of resources:*

A challenge is "*the old infrastructure … because we've got … burst pipe*[s] *all over, all over the place, without resources*" – Interview 1. The lack of resources renders it difficult to maintain water infrastructure. As a result, leaks get worse and new ones occur more frequently.

Facilitators:

Tasks: *Good management:*

The bulk and reticulation Foreman attends to the system and any incidents. "*If they can't, then they have to call me, then we see what to do*" - Interview 1. The Technician's good management makes him dependable and makes his employees feel safe: He "*supports me very well. He's a good guy. So I don't feel a lot of pressure*" - Interview 10.

People (Senior Technician): *Driven to perform:*

The Senior Technician loves his job. "*To give people water. That's what I enjoy the most*" - Interview 1. When someone loves their job they succeed more often and are happy to give more of themselves, benefitting the system.

Organisation:

Good support/ Good relationships:

The Technician's superiors value him and "*give us support so that we can perform better...Especially the current one*" –Interview 1, adding to the love he feels for his job.

3.2.7. Manager of Water and Sanitation

"*All these challenges to me, they make me excited. Because I want to prove all the time to someone that I'm going to conquer this problem and I'm going win it*"- Interview 2.

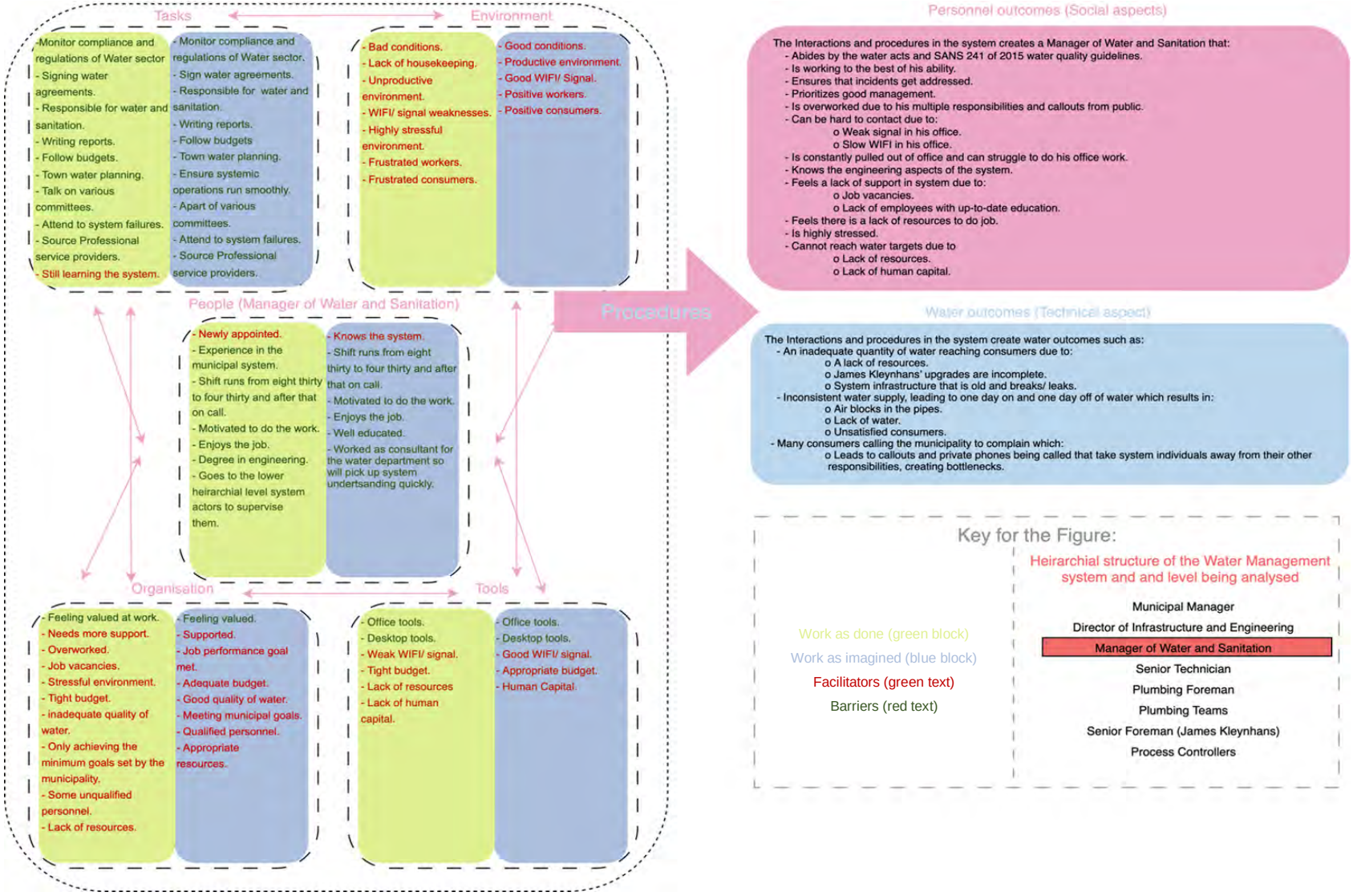

Figure 28: Manager of Water and Sanitation's SEIPS

3.2.7.1. Manager of Water and Sanitation condensed SEIPS narrative (Comprehensive narrative in Appendix M):

3.2.7.2. Barriers:

Tasks: *Overworked:*

The Manager of Water and Sanitation oversees Makhanda reticulation and bulk water services, ensuring Water and Sanitation delivery complies with legislation and regulations. "*He writes reports, attends to water complaints, oversees the system's management, planning and budgeting aspects, and lastly, he pays and monitors all service providers"* - Interview 2. However, this heavy workload can have negative effects on individual performance and well-being, impacting system performance.

Environment: *Inadequate environment (Manager's office):*

It was observed that the Manager's office has no windows, is water-damaged, and there is a lack of housekeeping. There is also a poor signal and Wi-Fi, making placing and taking calls, and sending and receiving emails difficult. The Water and Sanitation Manager needs to be contacted in case of emergency, or incidents can occur which destabilise the system.

Environment: *Too accessible:*

It is not the Manager's job to attend to complaints; this is the Technician's responsibility (Interview 1). However, his number is "*all over the place*" - Interview 1, requiring him to respond and distracting him from his responsibilities, which causes backlogs and destabilises the water management system.

Organisation: *Feelings of frustration:*

The lack of resources contributes "*to the attitude of the personnel... because they are also frustrated, disillusioned, discouraged…because of the shortage of those things*" - Interview 2. This means that they cannot do their jobs, and the system cannot achieve its goal of adequate quality and quantity water, leading to frustration among both employees and the community.

Organisation: *Job vacancies:*

There are gaps in the organogram, with the Manager of Water and Sanitation stating that "*my feeling is that there should be a Deputy Director*" - Interview 2. There was once a deputy director but "*that Deputy Director retired, and his position was never filled*" - Interview 9. Job vacancies lead to overworked employees and diminished performance, affecting overall system performance.

Organisation: *Lack of financial resources:*

The municipality is "*financially scrambling*" - Interview 3. This is partly attributed to the *"economic and social economy of the country"* - Interview 2 that results in limited resources for water services.

Organisation: *Achieving the minimum:*

"*I'm not having to touch, or managing to touch everything that I want to, to do justice. Many of them, …is just to make sure that there's a minimum that has been done, but not achieving the maximum"* - Interview 2. This means that the system is not perform optimally.

Organisation: *Lack of knowledgeable employees:*

"*You see, you need human resources, qualified people to assist you, which I don't really have*" - Interview 2. This results in overworked system individuals that lack appropriate system knowledge.

Tools: *Under-resourced:*

"*The reality, yes, we are, we are under-resourced*" - Interview 2. As a result, only a minimum of what needs to be done is achievable, resulting in water targets not being met.

Affordances:

Tasks: *Operates according to the law:*

The Manager of Water and Sanitation ensures that the "*municipality is compliant in terms of the regulations and the rules of the country in terms of providing Water and Sanitation to the residents or community of Makhanda*" - Interview 2.

Tasks: *Good report writing:*

The Manager of Water and Sanitation writes, "*all the government reports*" - Interview 2 on a weekly, monthly and annual basis, ensuring that national government is always aware of the status of Makhanda's water.

People (The Manager of Water and Sanitation): *Motivated:*

Systemic challenges excite the Manager: *"I want to prove all the time to someone that I'm going to conquer this problem and I'm going win it*" - Interview 2. His motivation and determination to overcome difficulties can help improve system performance

3.2.8. Director of Infrastructure and Engineering

"*You need to listen to your people. You need to be part of them, you see. You need to work with them*" – Interview 3.

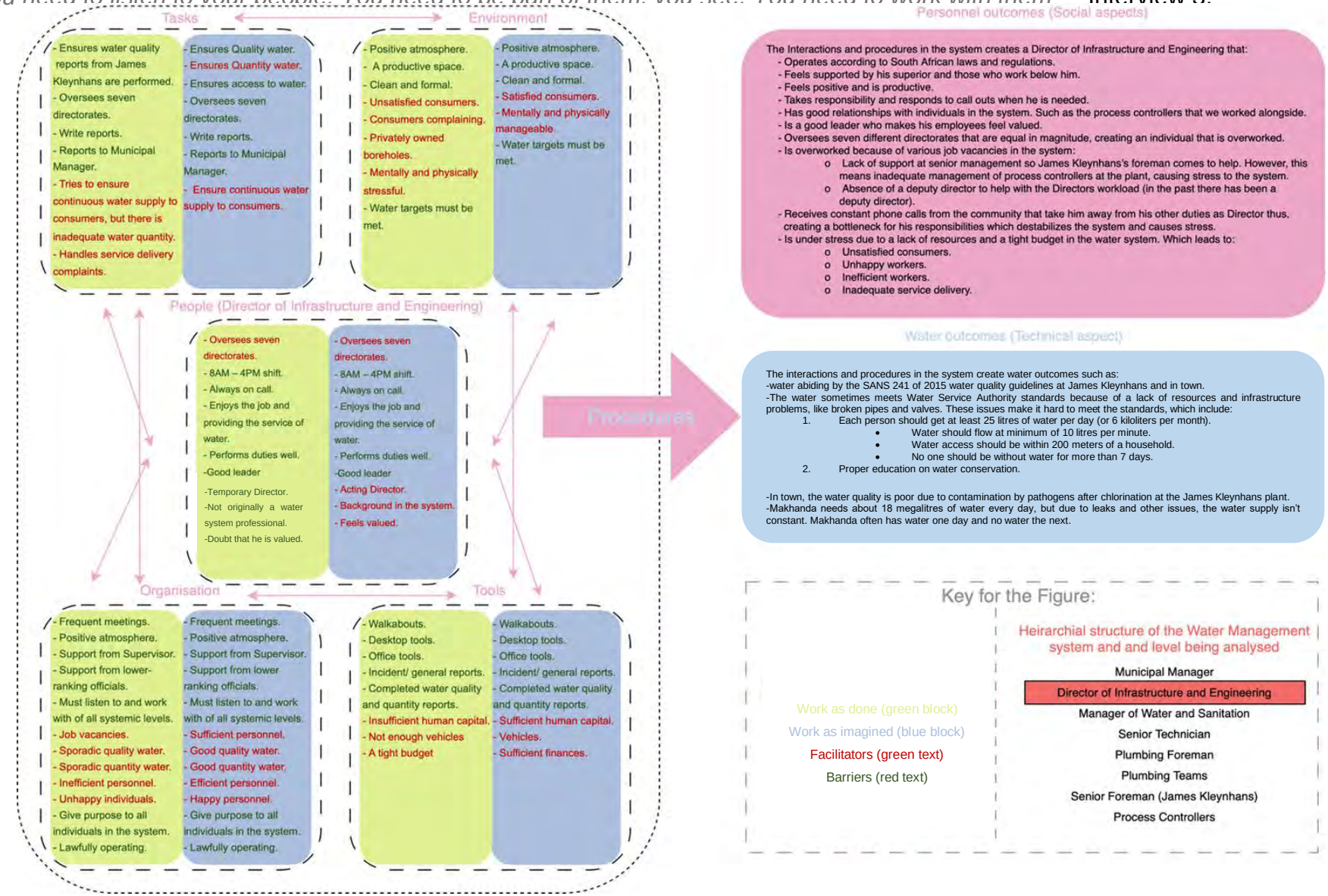

Figure 29: Director of Infrastructure and Engineering's SEIPS

3.2.8.1. Director of Infrastructure and Engineering's condensed SEIPS narrative (Comprehensive narrative in Appendix N):

Constraints:

Tasks: *Inadequate water quantity:*

Water services in Makhanda are unstable due to various factors, including the fact that the Western water system is producing less water than needed and there are many leaks. This results in water shortages. "*Until the upgrades to James Kleynhans are completed, improving Makhanda's water outputs, the quantity of water produced will be inadequate"* – Interview 3.

Tasks: *Too accessible:*

It is not the Director's job to attend to complaints but because his phone number is "*all over the place*" - Interview 1, he has to take calls that should be directed to staff lower in the hierarchy based on the municipality's job structure. When people call the director it adds to his workload, as he already has other duties.

Tasks: *A bottleneck of responsibilities:*

The constant phone calls lead to the Director's responsibilities being put on hold, as he cannot ignore complaints. Backlogs are thus created, and the system becomes dysfunctional.

Environment: *Dissatisfied consumers/Customer complaints:*

Makhanda's poor water service delivery has resulted in dissatisfied consumers. This is evident in the multitude of complaints on WhatsApp groups, Facebook posts, newspaper articles and phone calls to the municipality.

Environment: *Failing infrastructure:*

"*The infrastructure itself, it has its own failures*" Interview 3. This challenge was also cited in other interviews. For example, "*the challenge that we've got, … is the old infrastructure*" - Interview 1 and "*the infrastructure by Joza, it's still old*" - Interview 5. Old, unmaintained infrastructure will break, and water will be lost, affecting service delivery.

People (The Director of Engineering and Infrastructure): *Overworked:*

The Director oversees seven directorates. He is in charge of "*Infrastructure and Engineering, Water*

and sanitation, Roads and storm water, Waste disposal, the Electrical department, Buildings and facilities and lastly, Human settlement" - Interview 2. These are all large directorates and in his own words, the workload "*it is bad. It's a lot*" - Interview 3.

People (The Director of Engineering and Infrastructure): *Job vacancies:*

Below the Director "*there should be a deputy director, which we don't have*" - Interview 2. This results in a heavy workload for the Director who delegates a few responsibilities to various system managers, one of whom is the Manager of Water and Sanitation who is "*battling to find time*" – Interview 2, to do his own work. With a Deputy Director there would be less work per individual as the system wouldn't "*have shared those responsibilities*" – Interview 2, improving individual and system performance.

Organisation: *Basic training without upskilling:*

Process Controllers are trained, but "*not in line with the change of technology… It needs to be aligned to constant growth*" - Interview 3. Another interviewee stated that "*there are no workshops for the Process Controller, there is nothing*" - Interview 6. Upskilling employees increases knowledge, resulting in them being able to sustain the system's performance.

Organisation: *Unfinished upgrades to James Kleynhans:*

The upgrades began in 2015 and are still underway. There have been three subcontractors since then and upgrades are still incomplete towards the end of 2024 - Interview 3. Creating further water shortages.

Tools: *High expenses:*

The municipality incurs high expenses like, "*buying water, it's a cost on its own. The cost of chemicals, very expensive. The cost of actually, usage of electricity, because you buy from Eskom. Then the cost of actually the human capital that is there*" - Interview 3. After all of these are met, little remains for other resources (tools, material, machines), jeopardising the system's ability to maintain itself and produce water.

Tools: *Lack of financial resources:*

The Director stated that, if there was more money available, the system could be more efficient. He added, *"We are financially scrambling… The money, our budget is very, very, tight in terms of actually doing things. We want to do it, but we can't"* - Interview 3.

Tools: *Long procurement process:*

Interviewee 3 stated that, in order to improve the procurement process, the municipality's "*finance muscle*" must be applied to ensure that the necessary tools or services are available. "*It needs to be made available quicker* … [This] "*will make our job very easy*" - Interview 3.

Tools: *Lack of vehicles:*

Interviewee 3 asserted that If there were enough vehicles, employees could attend to complaints faster and more efficiently.

Facilitators:

Tasks: *Laws are followed:*

The Director ensures that the Water Act and SANS 241 of 2015 are followed, resulting in water that is "*safe for all people that consume it*" - Interview 3.

Environment: *Water targets must be met:*

The Director stated that he is managed in a manner in which he must "*deliver*, *meet targets*" and "*produce*" as much as he can. This assists the system because there is pressure on the municipality to achieve its goals.

People (The Director of Infrastructure and Engineering): *Good Leadership:*

The Director believes that "*you need to listen to your people. You need to be part of them…you need to work with them*" – Interview 3. His actions honour these words. The Process Controllers stated that the Director worked alongside them "*until midnight*" - Interview 7, while the researcher observed over the weekend of 24 August that when no Process Controllers reported for work, the Director went to the water treatment facility and operated the pumping station alone, ensuring water delivery to the community.

3.2.9. Municipal Manager

"*A municipality is meant to be, or is designed to be an organ of state that is entrusted with the responsibility of providing services for the people at the lowest level. In other words, it's a government next door. It's a government that can be easily accessible*" – Interview 11.

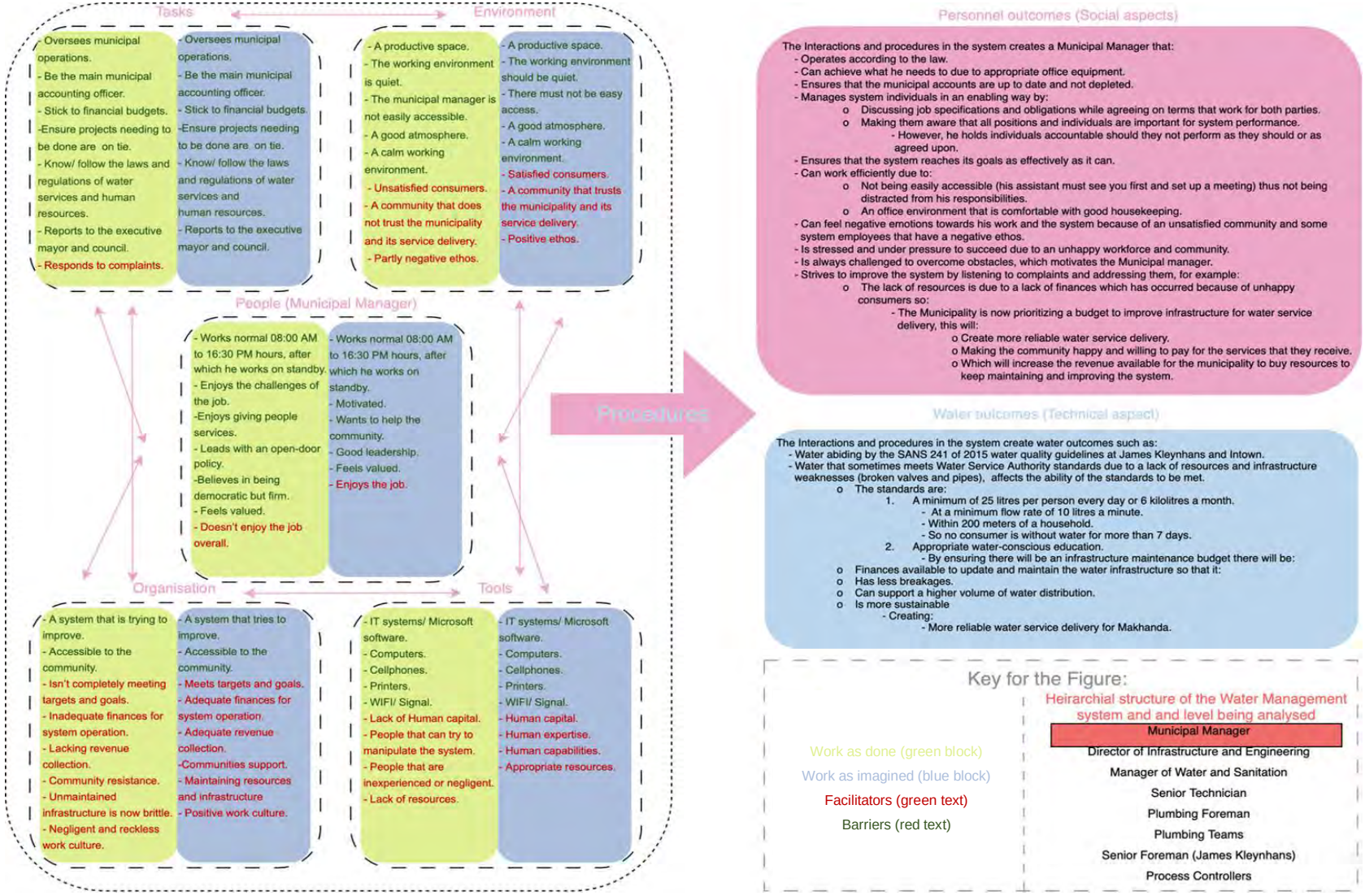

Figure 30: Municipal Manager's SEIPS

3.2.9.1. Municipal Manager's narrative (Comprehensive narrative in Appendix O):

Barriers:

Environment: *Distrust from the community:*

Makhanda Municipality is finding it difficult to collect revenue from the community, partly because of community distrust – Interview 11. This reduces its financial resources, impacting its ability to provide services.

Organisation: *Negligence:*

"I always say … the municipality only uses 30% of the staff. Only 30% of the staff is functional. Yeah. Or maybe 40% is functional" - Interview 4. This is because people are used to a "*culture of recklessness, negligence, lawlessness*" - Interview 11. Staff that do not do their jobs properly hinder the system's performance and contribute to inadequate water services.

Organisation: *Lack of financial resources:*

Makhanda municipality is "*financially scrambling*"- Interview 3. Interviewee 9 stated that most revenue is made up of consumers' payments. However, there is a poor payment culture due to the lack of "*trust that the communities have*" - Interview 11 in the institution. This results in insufficient financial resources to purchase the tools and material required.

Organisation: Infrastructure:

"*I think for the longest time, the municipality has not been focusing on operation and maintenance of their infrastructure*" - Interview 1. Now "*the infrastructure itself, it has its own failures*" - Interview 3, resulting in broken pipes that cause water loss and disruptions.

Tools: *Lack of resources (heavy duty):*

A fundamental resource that the municipality lacks is "*heavy industrial equipment*" - Interview 11, forcing it to "*hire*" it - Interview 11. Without these machines, work cannot be done. For example, if there is a burst pipe "*they can't fix it because they don't have a TLB*" - Interview 11.

Tools: *Human resources:*

The municipality relies heavily on human resources because it is not "*advanced in technology*" - Interview 11. This constrains the system because some people don't do "*what they are supposed to*

do, but still get their salary at the end of the day" - Interview 11. Negligence results in diminished system performance and water services.

Facilitators:

Tasks: *Good management:*

The Municipal Manager has an open door policy. His management style is democratic, but firm and he ensures engagement. However, once there is agreement on what needs to be done, it must be done. He stated that he likes order and not chaos – Interview 11. This creates employees that know what to do, how to do it and are accountable for their actions.

People (The Municipal Manager): *Community driven:*

The Municipal Manager stated that he enjoys contending with "*the problems that our communities are facing and being part of the resolution*" – Interview 11. He wants to see Makhanda succeed, and he aims for a day that community members "*are all happy*" - Interview 11. This positive outlook and drive to succeed create a system that prioritises community services and needs.

Organisation: *Planning for the future:*

"*We are trying to improve our revenue collection… to set aside a budget for maintenance of our infrastructure*" - Interview 11. This will make up "*10% of our operating budget*" - Interview 11. This indicates that steps are being taken to improve water infrastructure, which will, in turn, improve service delivery capabilities, resulting in fewer dissatisfied consumers.

Organisation: *Accessible to the community:*

"*A municipality is meant to be…a government that can be easily accessible by a person on the ground*" - Interview 11, ensuring that the community and municipality can come together to discuss important matters. The community provides an on-the-ground perspective and relays information to the municipality, which has the power to take the appropriate steps to respond.

3.3. Conclusion:

The results of the SEIPS models indicate that multiple systemic factors have impacted Makhanda Municipality's water system's ability to perform. Poor service delivery is the result of the multiple decisions, actions, and events that occur across the different organisational levels.

The systemic factors identified in each of the SEIPS were portrayed as the key themes in each interview. The following chapter discusses the results of the SEIPS models. The discussion is framed using the key themes that provide the basis for recommendations aimed at strengthening interactions in the system, promoting positive change to create a better functioning system that can deliver more reliable water services.

Chapter 4 Discussion

4. Introduction:

The purpose of this chapter is to discuss the key results, discuss their implications while providing recommendations that aim to prevent the continuation of an unreliable system that fails to meet its targets. However, to start this process the research question must first be re-introduced to start this process for clarity.

4.1. Research question:

"How do systemic factors contribute to water service unreliability in Makhanda's Eastern water supply system, and what interventions could enhance service delivery resilience?"

4.2. The systemic factors leading to an unreliable system

The SEIPS frameworks indicate significant systemic weaknesses in Makhanda's water management system, resulting in multiple inefficiencies and failures. Reason's Swiss Cheese model (Reason, 1990), was selected to depict these because it illustrates the breaches in system defences in a clear and concise way. As illustrated in Figure 31, the model has many barriers (holes), increasing the likelihood of failures when these weaknesses align (Reason et al., 2006). This concurs with the findings in the literature, which attribute accidents to interactions between latent system flaws and active failures (Reason et al., 2006; Perneger, 2005). These complex, systemic issues have rendered the water management system fragile and prone to collapse.

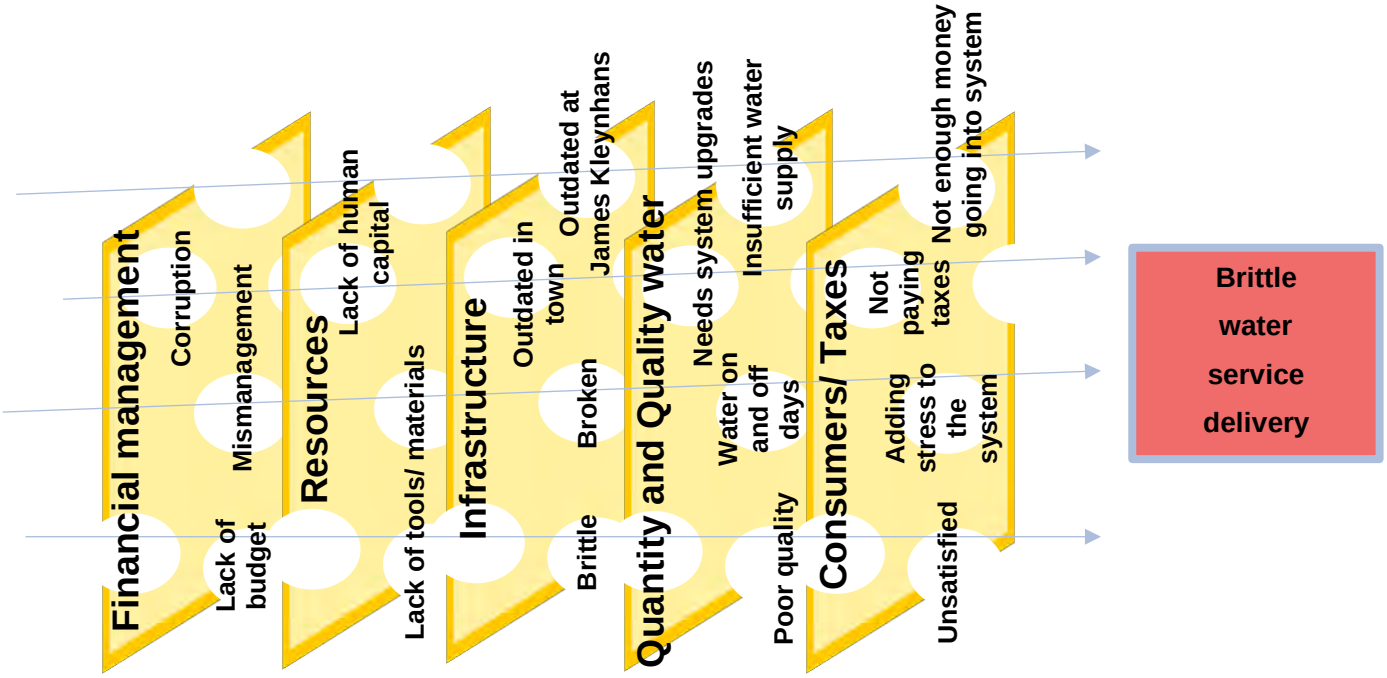

Figure 31: Swiss Cheese Model of The Eastern Water System (adapted from Reason (2016)).

Figure 31 depicts five defence layers, Financial management, Resources, Infrastructure, Quantity and Quality water and Consumers/Taxes. Effective functioning of each layer is required to maintain system performance. However, each has weaknesses, illustrated by the holes that are labelled. For example, financial management exhibits weaknesses because of a budget shortfall, partly due to mismanagement and partly to corruption. There are thus holes in the resource layer because there is no money to acquire resources, impacting the infrastructure layer. The infrastructure is broken and outdated which, in turn, impacts the water quality and quantity layer, that produces water with pathogens due to compromised infrastructure and leaks, a lack of resources and a lack of infrastructure to treat and supply adequate water quantities. A lack of quality and quantity water impacts consumers and their willingness to pay for services, which results in further budget shortfalls and the cycle begins again.

HFE models such as the Swiss Cheese Model (SCM) are often used to shine a light on the reality of systems and their interactions and how these led to the outcomes. This study initially described two risk management studies by Rasmussen. The Dynamic Safety Model (DSM) and the Structural Hierarchy of Risk Management (SHR) are appropriate for the Makhanda water management system because it is a highly volatile socio-

technical system, with multiple dynamic factors that span various system levels. The following section discusses the findings of the DSM and SHR, their implications and how to mitigate them.

4.3. Integration of models and SEIPS frameworks

Rasmussen's SHR and DSM were integrated to form one model to offer a systemic understanding of Makhanda's Eastern water management system. Thoroman et al. (2018) adopted the same approach. These models were chosen because of their emphasis on investigating accidents/ incidents through a systems approach, enabling "meaningful learning and prevention" (Dallat et al., 2019). The reason why they have been integrated into one model is linked to text in section 1.5, because of the saying that "all models are wrong but some are useful" - George E. P. Box, which tells a story that no model can account for every single complexity in the world. Therefore, combining them allows for more comprehensive and well-rounded outcomes (Stanton et al., 2013).The new model showcases how the SHR's operational aspects feed into the pressures that the system experiences that lead to poor system performance and incidents, which are depicted in the DSM. Successful counter gradients to failure require effective feedback from system procedures and adequate controls to manage identified risks. The research identified insufficient feedback due to inaccurate reports and a lack of communication between levels. Thus, effective controls cannot be implemented to manage risk or incidents. This is depicted below in Figure 33. The SHR model is on the left and the DSM non the right. Each influences the other. As controls and feedback occur in the hierarchy, the system's operations are impacted. If the operations fail and there are insufficient alarms/feedback, the controls will not fit the reality of the system's operations. For ease of understanding, colours have been added to the diagram as follows:

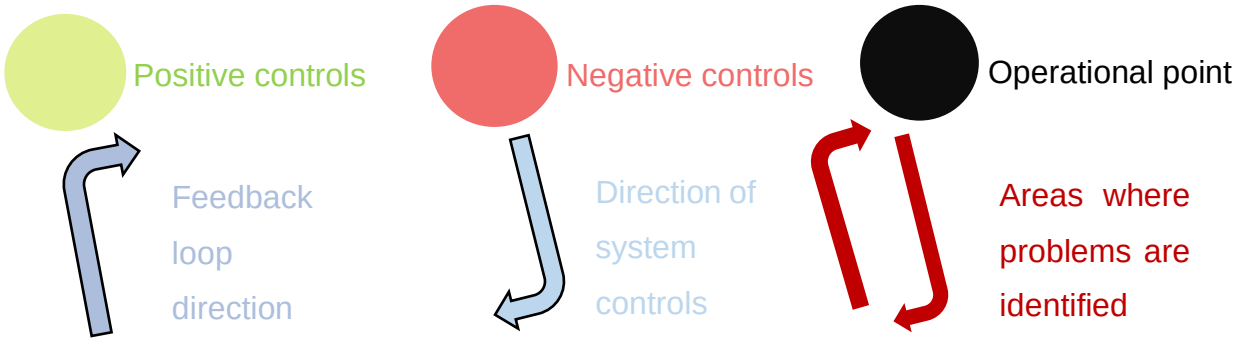

Figure 32: Key for Figure 33

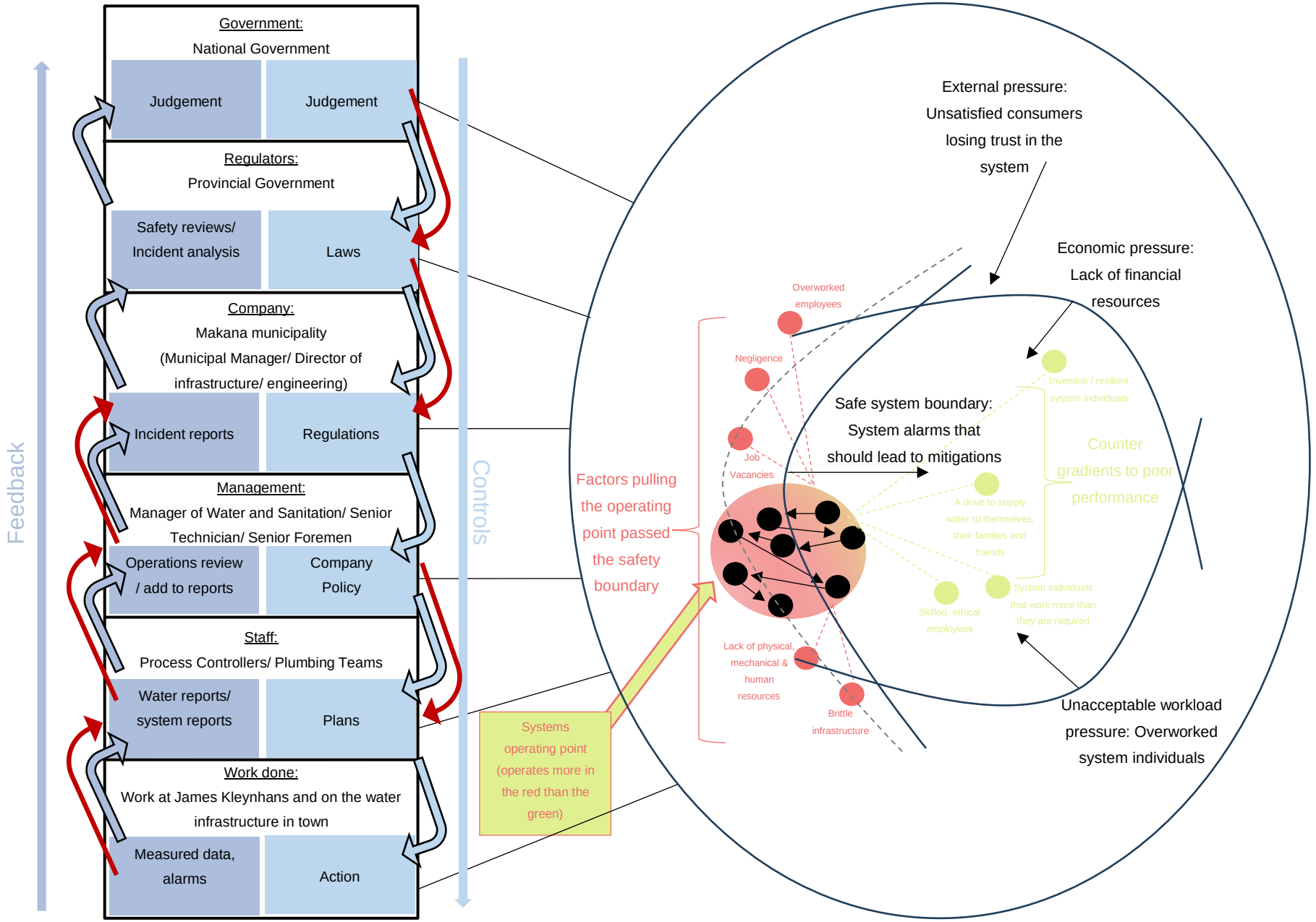

Figure 33: Adapted Structural Hierarchy of Risk Management and Dynamic Safety Model (Rasmussen's, 1997).

Makhanda's water management system confronts multiple barriers at various levels, propagating throughout the system and causing it to mainly operate beyond its safe boundaries, often in the "red zone", where failures are more likely to occur. For example, the results indicate that there are regular burst pipes which result in water loss, impacting water service delivery. The repair of said pipes often takes a while to complete as resources need to be procured before any repairs can be done. While the employees wait for resources the community has no water and they get frustrated with the service delivered by the Makana water system so they refuse to pay and then there is less money in the system to buy the very resources needed to fix infrastructure breaks like burst pipes. Barriers such as these cause stress and pressure to the operations of the system and all contribute to Makhanda's poor water service delivery, with overworked employees and a lack of funding and resources. These affect a system's operations by constraining the operating point and over time, a lack of safety measures or counter gradients cause it to drift into failure, where the system becomes dysfunctional and incidents occur (Chen et al., 2022: Cook & Rasmussen, 2005; Rasmussen, 1997).

The SHR shows poor system feedback or "vertical integration", which is critical to the system's operation (Salmon et al., 2012). Without it, systems can lose control of the processes they are designed to control, creating an opportunity for system failure (Salmon et al., 2012; Branford et al., 2007; Rasmussen & Svedung, 2000). Various system areas are highlighted as lacking vertical integration and are thus weaknesses that must be addressed to avoid failure.

Firstly, the James Kleynhans staff craft unreliable incident and water reports as stated by two water system employees in interview 5. This is caused by measured data being challenging to achieve when incorrect chlorine is ordered. Staff cannot accurately test for chlorine levels when tablets are used instead of gas. Although tablets are only used in emergencies, when they are used, the water reports sent to the supervisors are inaccurate, which results in, all other reports on water quality leaving James Kleynhans being unreliable and a system that is not accurately informed . Thus, correct judgements

cannot be made and effective laws and regulations put in place to improve the functioning of the system. If chlorine tablets are used and they are inefficient and the management thinks that the levels of chlorine in the final water is as it should be due to inaccurate reports then they will keep ordering the product. Additionally, statements to the public can not be sent out informing them of insufficient or overly chlorinated water because management has no records of whether or not there is a problem with the water in the first place.

In addition, the system's alarms are not sufficiently robust to signal the rest of the organisation when errors may occur due to the high pressure placed on the system. This results in action not being taken to stop incidents/failure. For example, there have been times according to interview 5, where the pump station at James Kleynhans begins to flood but because the Process Controller(s) on site are on the other end of the facility they do not notice the incident occur, leading to flooding of the pumping station and water supply being suspended while the pumping station is drained. The water suspension could take longer pending on if the flooding was caught soon enough to stop the water before it damaged any pumps. However if system alarms were more robust with say a loud alarm that signals once water leaks into the pump station flooding could be avoided. The lack of system alarms is apparent because the operating point mainly exists in the "red zone" of the DSM in Figure 33. Another reason for the water system's poor alarms is that when an incident occurs, the Process Controllers have, at times, crafted unreliable reports due to perceptions of a blame culture and the fear of repercussions as seen on page 72 under the "fear of and poor reporting" subheading. Thus, their reports do not tell the whole story and the feedback loop is compromised. A blame culture refers to "an environment where people, or groups/teams of people, are frequently singled out and blamed, criticised and fault is apportioned for mistakes and errors" (Wilkinson, 2020).

Secondly, the fact that staff produce inaccurate reports has the cascading effect of increasing unreliability up the chain of command. This results in inaccurate incident reports at utility level that filter up to the national level where judgements are made. Due

to the work done (lack of reporting accurately due to fear of blame culture as stated in interview 5) and imagined (the ideology that there are open door policies as stated in interview 3 and 11, and that employees feel safe to speak up and report) not aligning, faulty judgements lead to a lack of appropriate laws and regulations and the system will be less likely to protect itself and its employees from harm. Overall, this results in a lack of appropriate counter gradients to keep the operating point within the safe system boundary as depicted in the DSM. If it moves out of the boundary of acceptable performance and crosses the error margin, this will lead to system failures such as accidents or incidents (Chen et al., 2022; Cook & Rasmussen, 2005). However, even when counter gradients are introduced, these interventions are often delayed. It typically takes multiple failures to trigger interventions at the higher level. These come in the form of municipalities being placed under administration, which Makhanda Municipality is currently facing (Nowicki, 2020), or government delegations coming to town to try and turn the system around. This occurred in 2024, when Democratic Alliance officials tried to understand and help improve its system operations (Knoetze, 2024).

Furthermore, the gap between work done and that imagined creates space for performance discrepancies/deviations. It is imagined that the Process Controllers and Plumbing Teams will have constant supervision to ensure processes are followed and incidents dealt with. However, both the Plumbing Foreman and James Kleyhnas Senior Foreman cannot supervise their staff appropriately due to job vacancies elsewhere in the system. There is no lead plumber so the Plumbing Foreman must lead a team and therefore is less available to oversee work done by teams that are not his own. The James Kleynhans Foreman works in town to help the Senior Technician with his work load but by doing so he cannot oversee operations at James Kleynhans and Process Controllers much do their jobs and the job of Senior Foreman. Additionally, it is imagined that if a water system break occurs that the system employees will fix the break. However, in reality the work is not done that way as there are no resources for employees to address the incident. If these malalignments persist, they shift the task further away from the procedures created to ensure the task is safe and efficient (Amalberti et al., 2006), thus,

moving the operations past the safety boundary into unsafe territory (Amalberti et al., 2006). The more the work is misaligned, the more unplanned it is, and unpredictable situations will occur.

Lastly, in relation to the SHR, it is important to note the problem area identified between government decisions and laws/regulations. This is where the systemic barrier of decentralisation is experienced. When the government introduced decentralisation, it formulated regulations and laws that ensured social and political issues are handled at the most local or relevant level (Cambridge Dictionary, 2024; Parliament of the Republic of South Africa, 1997). This aimed to enhance transparency and address the challenge of poor service delivery, infrastructure, and water quality (Swatuk, 2005). However, its implementation led to unintended consequences, as some locally employed individuals lacked the necessary education, knowledge and skills to fulfil their roles effectively (Mutondo et al*.,* 2016; Laubcher, 2012; Republic of South Africa Department of Labour, 2008; De Klerk, 2000), impairing both individual and systemic performance. South Africa's failure to prioritise vocational training has exacerbated this issue, contributing to a nationwide skills shortage (The New Humanitarian, 2023; Rasool & Botha, 2011; Daniels, 2007). The lack of skilled employees in Makhanda Municipality reflects a national rather than an isolated challenge. South African municipalities need upskilling and increased human and physical resources (Department of Water and Sanitation, 2023). This will be addressed by new legislation in the NWRS-3, which will focus on building local government technical capacity (Department of Water and Sanitation, 2023).

In conclusion, the Makhanda water system primarily exists between the inner edge of the safe system boundary and past it; hence, the unstable and inadequate nature of the water services and the constant breakdown of infrastructure and organisational structures. However, the system does not drift to failure due to constraints pushing the operating point past the safe operating point over time (Chen et al., 2022; Dekker, 2011; Cook & Rasmussen, 2005). Instead, it is highly volatile and erratic, with water supply continuously unreliable due to multiple persistent systemic failures that cannot be controlled. The

system fails and tries to right itself, another failure occurs, and the cycle continues. Until the feedback loops/vertical integration are improved and more robust alarms/counter gradients to system failure are created, it will be in a perpetual state of failure.

4.4. Discussion of key themes

Sanya (2020) and Frame and Russel. (2009) state that water and water management are wicked problems faced by society. Wicked problems are defined as complex social or environmental problems resulting from multiple independent factors making solutions difficult to achieve (Peters, 2017). Makana Municipality's wicked problem is a result of multiple complex systemic factors all contributing to the downfall of its water management. These multiple factors will be discussed below. However, given the large number of factors identified in the results and as recommended by Maguire and Delahunt (2017), key recurrent themes and sub-themes were distilled to simplify the discussion. The key themes are:

1) Lack of municipal finances.
    - High staff turnover.
    - Growing indigent populations.
    - Unpaid rates and taxes.
2) Mismanagement of finances.
    - Corruption.
    - No infrastructure maintenance budget, leading to poor infrastructure.
    - Inadequate municipal audits.
    - A long procurement process.
    - A lack of adequate resources (machine/tools/staff).
3) Workplace cultural disconnect.
    - Dissatisfied consumers.
4) Delayed upgrades to James Kleynhans/inadequate quantity of water.
5) Worker resilience.

It is integral to understand that it is due to multiple contributing complex systemic factors that water management in South Africa is facing a downfall. Wicked problems are problems that span over large geographical areas and involve many systems that contribute to the problem while the wicked problem has to solve, adapt and change accordingly (Thatcher & Yeow, 2022). Water is seen as a wicked problem because of the complex nature of its influences and because it itself is difficult to interpret (Muller, 2013). As seen below, water is faced with a variety of complex characteristics that impact its state, these factors are crucial to understand how the Makhanda water system has become so fragile. These themes manifest differently across various organisational levels, with their presence and impact varying depending on the specific layer. They serve as the foundation for the following discussion.

4.4.1. Lack of municipal finances

4.4.1.1. Lack of municipal finances:

Most municipal revenue emanates from property rates and payments made by communities for the services they receive. South Africans municipalities are mainly self-funded with a small number receiving grants from the government (Schoeman, 2011). Part of the municipal budget is financed by subsidies from national government, but this accounts for a small percentage that includes the subsidies for the services rendered to indigent populations (the Equitable Share Government Transfer (Cooperative Governance and Traditional Affairs, 2023)), that cannot afford the services they need to survive, and government grants for large scale projects. Some grants relate to largescale water and infrastructure projects, including the Municipal Infrastructure Grant (Cooperative Governance and Traditional Affairs, 2025), the Regional Bulk Infrastructure Grant and the Water Services Infrastructure Grant (Moore, 2024).

The current lack of finances available to the municipality is due to various reasons such as financial mismanagement (interview 11), and rates and taxes not being paid (interview 9). Karodia and Khan (2015) noted that South African municipalities generally face financial hardship due to a lack of revenue collection, while Glasser and Wright (2020)

asserted that the country's financial stress is partly caused by political dysfunction (Sangotsha, 2024; Dyongman, 2023; Amner, 2022) and dysfunctional audit findings (Mjekula, 2024b; Dodovu, 2020), suggesting that the current lack of finances available to the municipality is also due to corruption. The countries lack of finances is not a newfound reality, South Africa has been experiencing financial problems for years, for example, the National Treasury reported that 43 South African municipalities were facing financial crises in 2002.

4.4.1.2. High staff turnover

There is high staff turnover in the Makhanda water system. The Development Bank of Southern Africa (2009) noted that South Africa has a high turnover rate of appropriately capacitated staff, especially high-level officials who tend to stay for a short period before moving on, which creates new problems because each manager has their own way of doing things. Furthermore, over a period of six years, many high-level officials have been suspended or asked to step down due to mismanagement (Dyongman, 2023; Amner, 2022). This can be attributed to the municipality hiring individuals without the relevant knowledge and skills and at times because of the lack of proper hiring policy, leading to potential nepotism (De Klerk, 2000). this creates instability and uncertainty because each new manager introduces new operating routines that employees must learn. Furthermore, a person new to the system needs time to understand it and its work culture as well as build relationships with employees.

4.4.1.3. A growing population

As Makhanda grows, specifically its urbanisation, more people depend on water infrastructure. However, it is currently unable to produce enough water to cater for its population. The South African water system is stressed because it cannot cope with growing populations (Karodia & Khan, 2015). In addition, water infrastructure is not being upgraded at a rate equal to the growth rate; thus, old infrastructure does not connect to the new settlements. With many more people depending on the service, more strain is placed on an already stressed system.

Consequently, indigent urbanisation pressure, leads to more individuals using municipal water who cannot afford to pay for it. As noted in the literature review, water is a fundamental human right and all South Africans should have equal access to a constant supply of clean water (The Republic of South Africa, 1998). Indigent people are the poorest of the poor among communities that receive free basic amenities from South African municipalities (Ruiters, 2016). They need to be registered on the indigent register in order for the municipality to receive the additional equitable share portion (Cooperative Governance and Traditional Affairs, 2019). National government's Local Government Equitable Share Grant subsidises the indigent for up to six kilolitres of water per household per month, and on exceeding this, the normal water tariff applies (Makana Municipality, 2023; Cooperative Governance and Traditional Affairs, 2023). However, financing indigent populations can be a challenge for some municipalities as not all have the capacity to support all those in informal settlements that require assistance (Pillay & Mutereko, 2022). As the indigent population increases there are more people and fewer resources to supply services.

4.4.1.4. Unpaid rates and taxes

Interviews 1,2,9,10 and 11 state that currently, many water consumers in Makhanda are increasingly frustrated with the service. The lack of finances is attributed to revenue not being collected, which is directly linked to the mismanagement of funds (Karodia & Khan, 2015), and community members' reluctance to pay due to mistrust in the government and its legitimacy (Tropp et al., 2016). Kardoia and Khan (2015) further observed that around R11 billion in government income was lost in 2015 due to taxes not being paid and leaks in the water system., resulting in the municipality not being able to afford maintenance or run services such as water, electricity, waste removal, road maintenance, etc. (Patji & Selepe, 2022) and leading to further dissatisfaction with service delivery. Furthermore, when the municipality is financially stretched, better-off households and businesses bear the burden, causing dissatisfaction (Patji & Selepe, 2022).

4.4.2. Mismanagement of funds:

Mismanagement “leads to incorrect allocation of funds” (Laubcher, 2012). The study’s results from interview 11 point to a lack of funds to operate the water management system, with the budget that the municipality has, not being allocated to maintenance and operations. This has led to the system being poorly maintained. There have been instances where high-level officials have been charged with mismanagement of funds. For example, a previous Director of Services was suspended in 2018 for allegations of unauthorised salary increases (Dayimani, 2018). Mismanagement is apparent in the disbandment of the municipal council in 2019 due to a lack of service delivery, institutional and financial matters and poor governance (Dodovu, 2020). Since then, Makhanda has issued statements that the municipality has adopted interventions like paying debts and crafting plans for indigent populations to receive services and improve the quality and quantity of water (Makana Municipality, 2020).

4.4.2.1. Corruption

The Makhanda Municipality has experienced multiple corruption scandals in the water system. For example, the previous Director of Infrastructure was asked to step aside in 2023 amidst allegations of financial negligence when R2,9 million was spent on a water pump for Howieson Poort, but never arrived (Dyongman, 2023). The previous Manager of Water and Sanitation was under scrutiny for being involved in procurement fraud relating to a R25 million toilet tender that went wrong (Amner, 2022). Corruption results in delays and threatens development; it hinders the public sector’s performance and its ability to provide water through reduced investment and mistrust in the government (Tropp et al., 2016). On 1 November 2024 the Special Investigating Unit (SIU) and the Hawks raided Makhanda Municipality’s offices due to allegations of unlawful conduct between 1 January 2019 and 18 October 2024 (Sangotsha, 2024).

4.4.2.2. No maintenance budget

Makhanda does not have a water infrastructure maintenance budget. Ill-equipped and poorly maintained infrastructure is one of South Africa's biggest hindrances to water service delivery (Muller et al., 2009). While the Eastern James Kleynhans water management system currently supplies close to ten megalitres to the town, leaks result in less reaching the community. On average, South Africa loses around 35-37% of municipal water through leakages each year (Oxlee, 2018; Molewa & Balzer, 2013).

The national standards outlined in the National Infrastructure Maintenance Strategy (Department of Public Works, 2007) require a maintenance budget, while National Treasury recommends that municipalities allocate at least 10% of total expenditure to capital expenditure (The National Treasury of the Republic of South Africa, 2022). However, there is currently no infrastructure budget set aside by Makana to maintain and update the town's infrastructure as reported by interview 11. According to interview 11, over the years, budgets for infrastructure have been repurposed for projects like public housing. While these are essential for the previously disadvantaged, this has led to the unexpected emergence of poor service delivery, violating the basic human right to water.

4.4.2.3. Inadequate municipal audits

The municipality has a history of unclean audits, with four disclaimers issued by 2020 because the Auditor General could not find sufficient evidence to provide an opinion on the financial statements (Dodovu, 2020). By 2024 there were still not clean (Mjekula, 2024b). This means that money spent by the municipality cannot be tracked, which compromises accountability and ethical spending practices.

4.4.2.4. Long procurement process

A new finding not noted in the literature was the long procurement process. The Financial Manager (interview 9) stated that a person requiring a tool/ material must liaise with their supervisor who will send the request to the head of department's secretary. The secretary

forwards it to the supply chain management unit and obtains various quotes. The more expensive the item, the more quotes will be needed and they must all be provided by companies registered on the municipal supplier database. Once quotes are obtained, a supplier is selected and a requisition is processed. The relevant department receives an invoice and asks the department head to authorise payment, which will only be done if all the documents and supporting documents show that the proper process was followed. The order is then placed and delivery made. Many employees must thus obtain various quotes before ordering the products and the procurement process must ensure good value for money and that bidding is open, fair, ethical, and transparent. Lastly, it must ensure equity (Ambe & Badenhorst-Weiss, 2012; National Treasury, n.d.). This is designed to prevent corruption (Penfold & Reyburn, n.d.). However, the counter gradient to corruption in the form of a more detailed procurement process has led to unintended system emergence. The inability to procure materials and tools timelessly has led to the emergent characteristic of a water system that is not functioning optimally because breakages cannot be fixed and infrastructure cannot be upgraded. This results in, workers becoming frustrated because they cannot do their jobs and consumers being dissatisfied.

4.4.2.5. Lack of resources

The municipality lacks human, mechanical and physical resources. In 2022 it was found that 75% of South African municipalities lack the technical skills and capacity to deliver basic services effectively (National Treasury of the Republic of South Africa, 2021). If there are insufficient resources, even driven individuals with good intentions cannot perform the work required and they become demotivated and seem incompetent. The following paragraphs discuss the lack of human, mechanical and physical resources and the implications.

4.4.2.5.1. Lack of mechanical resources

Interview 11 stated that the municipality does not own many heavy-duty machines, including a TLB which is essential, therefore, one has to be hired. According to interview 1 different departments compete to use it, resulting in long hiring times leading to

unnecessary expenses. These expenses mean less money for essentials like infrastructure maintenance, which currently is not budgeted for according to interview 11. In addition, jobs take longer to complete as there is a waiting period to use the hired TLB.

4.4.2.5.2. Lack of human resources:

There are job vacancies in the water management system and individuals without the appropriate knowledge to perform their work efficiently are employed, adding stress to the system.

4.4.2.5.2.1. Job vacancies:

According to the 2022 Auditor General's report and National Treasury's state of local government finances report, an estimated 50% of technical positions in water and engineering departments were vacant or filled by underqualified staff (National Treasury of the Republic of South Africa, 2021). This puts pressure on other employees who have to carry the workload, resulting in stress and fatigue which can contribute to injuries or poor decision making (MacDonald, 2003). James Kleynhans has had vacancies for Process Controllers since 2017 and while efforts have been made to fill these posts, the two successful candidates were not employed because they were not from Makhanda. Koelble and Siddle (2013) asserted that South African municipalities have used decentralisation to make "unauthorised appointments". Given South Africa's past, there has been a drive to employ the previously disadvantaged, specifically local people in deprived areas. This mirrors national policies (Jonker et al., 2010). However, the way affirmative action has been implemented has led to undesirable outcomes. In this case, interview 4 stated that there is a lack of human capital at the facility due to biased hiring techniques. This leads to overworked, fatigued and stressed Process Controllers who often work more shifts than they should because more mistakes tend to occur after dark. General worker vacancies have also not been filled, and their maintenance and housekeeping duties have to be performed by Process Controllers.

There are also vacancies higher up in the system. As per interview 2 and 3, the position of Deputy Director no longer exists, creating a gap that has led to other officials such as

the Director of Infrastructure and Engineering and the Manager of Water and Sanitation experiencing work overload. To cope, according to interview 4 the Senior Technician was given more responsibility, and when he felt overworked, he called on the James Kleynhans Senior Foreman to work alongside him in town. This resulted in James Kleynhans being unsupervised and Process Controllers having to take over his duties which was expressed in interviews 5-7. Furthermore, Process Controllers lack the knowledge and expertise of a qualified Senior Foreman, raising the risk of incidents/instability. Since there is a perception of blame culture in the system as per interview 5, Process Controllers are sometimes scared to tell the whole truth because of the consequences they might face. Thus, when things go wrong the poor reporting of incidents can lead to the possibility of further unintended incidents that could be avoided if there was systemic trust and understanding. Wightman et al. (2022) observed that vacancies at any level of a hierarchy will result in goods and services not being delivery effectively or efficiently.

4.4.2.5.2.2. Lack of knowledge:

The study found that some employees lack the knowledge required for the work they do and the positions they hold. For example according to interview 4, two water treatment facility Foremen from different towns run by Makana Municipality do not have the necessary qualifications for the job roles, one is a Horticulturist and another a Fine Art graduate. A past acting Municipal Manager stated that one of the previous Directors of Services appointed in 2017 only just passed the competency test (Dayimani, 2018), one level above the lowest level of “basic”. This creates knowledge gaps. While it is linked to affirmative action (Moraka & Jansen van Rensburg, 2015), it can result in impulsive employment of individuals that lack the expertise required for the job (Laubcher, 2012; Republic of South Africa Department of Labour, 2008; De Klerk, 2000).

When the new employees were hired, there was no effective transfer of knowledge from experienced system experts (Phaladi & Ngulube, 2024). Hollnagel (2011), stated that knowledge is a determinant of resilient systems and that those that lack resilience cannot

adapt to change while maintaining stability. Furthermore, resilience is tied to practice over the years. Therefore, system stability calls for employees to either remain in the system for long periods of time or acquire the necessary knowledge from other employees that have.

The lack of knowledge transfer resulted in the loss of valuable tacit knowledge accumulated by individuals who had worked in the system for many years. Tacit knowledge, which includes nuanced understanding of job intricacies, is knowledge gained and retained by individual minds, often developed over years of hands-on experience (Sanchez, 2005). This makes it difficult to acquire the same knowledge through formal education or training. Jamshidi et al. (2018) maintained that 90% of the knowledge in any organisation is created and embedded in people's minds. In conclusion, unless knowledge is shared and employees are appropriately educated and trained for their jobs, under-skilled workers will negatively impact the functioning of the country and its services (Laubcher, 2012; Benjamin, 2007).

4.4.2.5.2.3. Lack of physical resources:

One of the most prominent barriers in the water system, spoken about most consistently throughout the interviews, was the lack of tools and materials required to maintain, fix and upgrade water infrastructure. This is one of the main reasons why South Africa faces a water crisis (The Development Bank of Southern Africa, 2009), which, judging by the thesis' interviews (interviews 1-7) is still applicable in 2025. Work cannot be done without the appropriate tools and materials to ensure system functionality. If there is no material, a job must wait for the procurement process to be completed. The study found that this is a long and tedious process and employees sometimes wait months if not up to a year for their orders to materialise. If there are no tools, employees sometimes create or borrow what they can, which can lead to tools being used that are not fit for purpose, resulting in damage or longer repair times, which delay operations. Both result in inadequate water delivery and dissatisfied consumers.

4.4.3. Workplace cultural disconnect

There are discrepancies between how the management and workers of the system conceive of the water system's organisational culture. Management believes it has an open-door policy as reported in interview 3, while some workers feel that they are ignored and unsupported by their managers. In addition, according to interview 5 some workers feel that they cannot be truthful when reporting because they fear blame and consequences. Nzewi et al. (2016) concluded that a strong organisational culture can facilitate or act as a barrier to accurate reporting. Municipalities can lack operational dynamics and a desire to change, which can create an environment where employees fear reporting issues (Nzewi et al., 2016).

Some employees believe that some of the management team do not know their names, while management say they work alongside their employees and thus know them well. Additionally, all four Process Controllers throughout interviews 5,6 and 7 discussed their need for resources like torches, they suggest that they have asked for torches but they never get any. However the Financial manager interviewed in interview 9 states that torchers are supplied and that they Process Controllers must request them. This conflicting data implies that there is a disconnect due to a lack of vertical integration (see Section 4.3 and Figure 33). It is critical to the water system's operation that vertical integration occurs. Without it, the system can fail by losing control of its processes (Salmon et al., 2012; Branford et al., 2007; Rasmussen & Svedung, 2000) as failure undermines its performance, resulting in dissatisfied consumers.

4.4.3.1. Dissatisfied consumers

The water consumers in Makhanda are dissatisfied, which is noted in interviews 1,2,10 and 11. The communities dissatisfaction has led to taxes being withheld as noted in interview 10. In South Africa reduced investment by the community (which taxes are a part of) result from mistrust in the government (Tropp et al., 2016). As dissatisfaction increases, so will resistance to the municipal system. Examples include protest action (Thusi & Selepe, 2023), and withholding payment (Pillay & Mutereko, 2022). Community

resistance will hinder the government's ability to achieve its budgets, and there will be less money for the municipality to invest in water, electricity, roads, etc. (Pillay & Mutereko, 2022), further impacting the system's functioning and satisfaction with services.

4.4.4. Delayed upgrades to James Kleynhans/ inadequate quantity of water

JHK needs to be updated and equipped to produce enough water to supply the Makhanda population. Since 2015, James Kleynhans has been undergoing upgrades which will double the water produced by improving its old infrastructure and processes. However, there is no set timeline for completion because the contractors keep pushing the date back. There have been issues with the contractors, leading to the termination of their contracts and restarting tendering and recruiting, negatively impacting the budget and creating further delays. It is apparent that the project could have been completed a long time ago if Makhanda's council had actively pushed for this (Mjekula, 2024a). Amatola Water was appointed as the implementing agent of the James Kleynhans upgrades, with Bosch Projects as the consulting engineers (Makana Municipality, 2022). They found and employed the original construction company (Mamlambo Construction) which was liquidated in 2022 (Dyongman, 2023). After which Amatola and Bosch appointed Water and Wastewater Technology SA (Dyongman, 2023); however, the researcher was informed that the municipality was not satisfied with its progress and that its contract might be terminated. Until these upgrades are completed, there will be insufficient service delivery.

4.4.5. Worker resilience:

Worker resilience affords the system because resilient employees are able to find effective and flexible solutions when confronted with challenges (Meneghel et al., 2016), they positively moderate the relationship between operational improvement and service recovery performance (Yang et al., 2015) and improve team cohesion and cooperation (West et al., 2009). Some individuals in the water management system perform well and stay as positive as they can with little support, limited resources and community backlash as reported in interviews 1-7 and 11. They are motivated and resourceful, do their jobs

well and do more than is required, ensuring that the system operates. For example, creating their own tools (image 17), working overtime without pay seen in interviews 4,5 and 10 and taking on the important water system responsibilities of vacant posts to help with system performance, this is seen in interviews 2,4,6 and 7. This is a novel finding for water system research, that is important because resilient, adaptive and motivated employees can overcome barriers and avoid debilitating consequences for the system. HFE highlights that human and system performance are intertwined (Dul et al*.,* 2012).

The following section of the discussion examines the system's weaknesses, which outnumber its strengths, and offers recommendations to mitigate them and strengthen the overall system.

4.5. Recommended counter gradients to failure:

The SEIPS models highlight the complexity of Makhanda's water system, illustrating its many weaknesses across different levels involving multiple stakeholders. The proposed recommendations will thus take time and effort to implement. To introduce this section, a tenet table adapted from Grant et al. (2018) is set out below. These bring order to systems thinking in incident/accident causation (Salmon et al*.,* 2022), which this case study falls under because of the incidental nature of its failures. Grant et al. (2018) proposed 15 tenets, not all of which were used based on their applicability to the research (Grant et al*.,* 2018). The ten relevant to the study are depicted below.

Table 3: Table of tenets (adapted from Grant et al. (2018)).

Tenet	Definition	Undesirable system description	Examples from the results	Recommendations
Vertical Integration	Interactions between elements within and across levels of the system hierarchy.	Decisions and actions do not filter through the system and impact behaviour. Information regarding the current status of the system across levels is not used when making decisions.	- When system breaks occur, the perception of a blame culture inhibits accurate reporting. - The occasional use of chlorine tablets results in chlorine levels that cannot be tested. - Without chlorine level data and reliable incident reports, system reports are inaccurate. - Inaccurate system reports lead to inaccurate judgements. - Inaccurate judgements result in laws, procedures and plans that do not accurately depict the nature of the system, - indicating a lack of systemic vertical integration.	- Leadership should promote accurate, reliable reporting throughout the system so that its nature is fully understood for overall improvement. - Educate leadership on the importance of accountability and learning, without resorting to a blame culture and filter this down the system. - Encourage open door policies that are understood and utilised by employees. - Hold frequent meetings for all employees to discuss operations/concerns and improve vertical integration.
Constraints	System elements that impose limits on, or influence, other elements.	An element that has failed to perform its function and/or restricted an appropriate response, behaviour or the desired variability in performance.	- Testing for chlorine levels in final water with tablets renders James Kleynhans unreliable as it could be over or under chlorinated. - Water reports can be unreliable and thus, uninformative. Resulting in system alarms not being known and attended to timelessly to avoid incidents. - There are no warning signs for the Plumbing Teams to protect people from danger. - A lack of PPE gear at James Kleynhans can result in hazardous events for the Process Controllers.	- Ensure chlorine gas is ordered in bulk, avoiding the use of tablets. - Ensure that appropriate equipment is available to protect employees and community members from harm. - Promote accurate report writing and follow up on reports to ensure they are accurate.
Emergence	Outcomes that result from interactions between elements in the system that cannot be fully explained or reliably predicted in advance by examining the elements in isolation.	Emergent behaviours or outcomes that are unsafe or undermine the goals of the system.	- Decentralisation resulted in local individuals being employed that may have appropriate education, skills or knowledge to perform their roles. - This creates system instability through unnecessary errors and lapses in judgement. - Employing individuals based on nepotism rather than merit can lead to employment of unfit individuals who can be negligent or corrupt.	- Ensure that those hired have the necessary skills and education to perform the job well. - Upskill current individuals that are less capacitated to ensure that they can perform as they should. - Do background checks on employees to ensure they are morally sound and have no criminal record.
Tight Coupling	The degree of interdependence between system elements.	Cascading failures that propagate quickly and widely through the system when one element breaks down.	- There are not enough pumps at James Kleynhans and when one breaks there are none on standby to continue operations. - When the water from Glen Melville has high turbidity (sediment levels) the chemical used is too weak as a flocculant, resulting in the system producing water that appears dirty and still contains dirt.	- Ensure that more pumps are available for rotation. - Perform routine maintenance on machinery before incidents occur. - Use a stronger chemical flocculant.

Loose Coupling	The degree of interdependence that exists between elements.	Loss of control regulating behaviours. Too much independence between elements.	- High turnover results in new individuals being unsure of procedures and the nature of the system, so they cannot control it, creating instability. - The new individuals may not be trusted, hindering their employees from feeling safe to report to them. - There are many undetected leaks in the system.	- Focus on ways to retain staff, so that the system stays as stable as possible. - Ensure that new staff are familiar with policies and that the system is comfortable with them. - Promote accurate reporting by creating a safe space for employees. - Create a leak management system.
Feedback Loops	Self-reinforcing and self-correcting forms of feedback between system elements which influence the system's behaviour.	Feedback mechanisms are not controlled and amplify through the system, increasing the potential of risk and accidents.	Feedback loops are lacking due to poor communication and inaccurate reporting. - Measured data is incorrect, which leads to incorrect reports. - The reports are not verified. - Thus, feedback from the bottom of the system to the top is jeopardised. - Due to poor bottom-up feedback, top-down controls will be insufficient.	- Improve and increase communication between all levels of the system. - Promote reporting, learning, interventions, application of interventions and feedback.
Modularity	Sub-systems and elements that are designed to operate independently of one another.	The system is tightly integrated and complex; substitutions cannot be made (e.g., no contingencies).	- The bulk water and water reticulation systems are tightly integrated in water service delivery. If there is an issue at one end, the whole system's delivery is compromised. - For example, a burst main pipe (reticulation) results in James Kleynhans (bulk) being shut down so that the water produced is not lost and a broken pump (bulk) leads to no water being pumped into the pipes (reticulation).	- Ensure that system breakdowns are responded to immediately so that operations can resume as soon as possible. - The system must be repaired to a high standard so that the repairs lasts, and breakages do not persist. - Regular maintenance must occur.
Sensitive dependence on initial conditions	Characteristics of the originally designed system that influence system behaviour at a later point in time.	No understanding of initial conditions and their influence on the system.	- Aging infrastructure that was not maintained led to small leaks, which are now bigger ones that can lead to system breakdowns. - Unsecured reservoirs and breaks in water infrastructure allow pollutants/pathogens into the water system and affect the quality of drinking water. - The population has increased and thus water demand and the system is not coping. - Loss of institutional knowledge of the nature, location and functioning of the system over time as old employees do not pass on systemic knowledge to the newly employed.	- Maintain infrastructure to avoid breaks and address system breaks before they get worse. - Secure water reservoirs so that pollutants/pathogens do not enter the stored water. - Ensure that James Kleynhans' water upgrades will be sufficient and sustainable for the growth of the township and town. - Bridge the gap between past specialists and newly employed individuals, ensuring knowledge transfer.
Decrementalism	Minor and accepted modifications to system elements that gradually create a significant change in system behaviour.	Constant small changes eventually create unsafe behaviours and practice through migration and drift.	- Initially one day on and one day off water was accepted to preserve and collect enough to distribute to the community. - However, there was a gradual drift to one day on and two days off. - It gradually became normal to have multiple days with no water. - The poor infrastructure breaks when water is turned back on.	- Ensure that the upgrades are completed so that there is enough water for everyday delivery. - After the upgrades, the water should not be turned on and off in order to avoid breakages.
Performance Variability	System elements vary their behaviour in response to changing conditions in the system and its environment.	Behaviours are adjusted to cope with changing circumstances; however, the outcome is not desirable.	- Aging infrastructure and a lack of resources have led to water rationing. - The job vacancies in the system have led to work being divided amongst individuals but this has overloaded them, resulting in some duties being neglected. - Following decentralisation, locals were employed but some did not have the knowledge or education to perform their jobs, hindering system performance.	- Focus on infrastructure maintenance for sustainability. - Fill job vacancies where possible. - If it is financially impossible to fill high ranking roles, introduce lower-level positions that can take on junior level workloads. - Upskill employees or hire appropriately capacitated individuals.

The above tenet recommendations provide an adequate array of implementations to start introducing mitigations for system improvement. For example, by upskilling current staff and promoting the transmission of tacit knowledge, system knowledge and employee retention can be improved which will increase system suitability and performance. Additionally if more focus is put on maintaining and upgrading infrastructure then there will be fewer system breakdowns and when complaints are taken up with Makana, the newly upskilled water system employees will have more knowledge to efficiently address said complaints and more resources to do so because of the increased focus placed on system maintenance. However, not all of the important water management system weaknesses needing to be addressed and mitigated could be defined by Grant et al., 2018's tenet table. The following section offers further recommendations to address the system's weaknesses.

4.5.1. Further recommendations

The remainder of the recommendations are presented in two categories, Local and National recommendations. This is because Makana is not a silo and a lot of what the chosen case study is facing is experienced throughout municipalities in South Africa, which is seen in the literature review in section 1.16.2. In the recommendations such as, capacity building and upskilling of current personnel, financial aid, promoting accountability, creating an infrastructure maintenance budget, employing appropriate personnel, establish a call centre, better management of funds, communication (which is twofold), monitor water supply and consumption, restoring community trust, and lastly, leveraging existing worker resilience and knowledge.

4.5.1.1. National recommendations

4.5.1.1.1. Capacity building and upskilling of current personnel

It is important to acknowledge that there are individuals in the water management system at large that want system progress and who work hard in their job capacities. It is vital to continuously upskill personnel to encourage drive for success, retention and promotions. To achieve this there can be National training programmers leading this intervention. Additionally, there could be Nationwide knowledge transfer programs initiated to pass

tacit knowledge from system experts to new or otherwise interested water system employees. By upskilling personnel, the system will benefit from more skilled and knowledgeable employees who will be better equipped to face challenges/ incidents faced by the system, resulting in better system resilience and performance.

4.5.1.1.2. Financial aid:

Increase financial grant to struggling Municipalities, while monitoring the Municipalities progress. Struggling Municipalities like Makana Municipality can request financial assistance from the National Government through schemes such as the Municipal Infrastructure Grant (MIG) and Municipal Water Infrastructure Grant (MWIG) (Department of Science and Technology, 2014). This extra income could help struggling municipalities get the basic resources needed for their systems to be maintained and thus, can help upgrade its water infrastructure to improve system reliability.

4.5.1.1.3. Promoting Accountability:

Enforce consequences for non-preforming municipal officials who do not do their jobs correctly and those who mismanage finances. This will set a precedent that others will follow and may help deter others from violating the system too.

4.5.1.2. Local recommendations:

4.5.1.2.1. Create an infrastructure maintenance budget:

The municipality should focus on creating a maintenance infrastructure budget so that when system breakdowns occur or upgrades are required, they can be provided quickly and efficiently. A maintenance budget will enable resources (tools, materials and machinery) to be purchased and readily accessible. The budget can be created by increasing water tariffs as South Africans pay very little for water in order to ensure affordability for lower-income groups. However, this creates gaps in municipal revenue, hindering investment in system upgrades and sustainably (Ramcharan-Kotze, n.d.). The budget could also be financed by reallocating small percentages from those for road maintenance, housing and parks and recreation.

4.5.1.2.2. Employ appropriate personnel:

Employing appropriately capacitated individuals will improve operations and performance, while recruitment and selection of high ranking officials (the Municipal Manager, Director of Infrastructure and Engineering and the Manager of Water and Sanitation) should be transparent to promote accountability. Individuals should be hired based on their knowledge, education and no prior criminal records or scandals. This would decrease unnecessary errors that lead to system dysfunction. Furthermore, employees should be upskilled.

4.5.1.2.3. Establish a call centre:

A call centre should be established to decrease the number of calls from the community to municipal officials as these create bottlenecks. As stipulated by the Department of Water Affairs and Forestry (2002), this should already be in place. A call centre could also result in communities feeling heard, improving their trust in the system. To finance the call center Makana municipality could reach out to National Government to fund the operation as according to the Department of Water Affairs and Forestry. (2002), the government acknowledges the importance of call centers in water management and promotes the need for them. Once finances are put back into the water system from the revenue collected through water taxes a small portion could be feasible to employ call center employees.

4.5.1.2.4. Better management of funds:

Revenue collected for water management should be invested in the system to ensure sustainability. If funds go missing, there should be appropriate repercussions thus ensuring a decrease in mismanagement of funds ensuring appropriate personnel are employed. Better management of funds will result in tools, materials, and machinery being hired/ sourced. This is a realistic and feasible way forward that should not be time consuming to instil given appropriate initial set up and management.

4.5.1.2.5. Communication (In the municipal water system):

The system's vertical integration and culture require improvement as seen in figure 33. Communication channels need to be reassessed and conversations should be held between all stakeholders on employee and organisational accountability, the need for unity, the importance of being heard, listening to others from different levels and the effects of the blame culture and how to avoid it. Individuals in leadership roles must encourage sound reporting and create safe spaces for employees to express concerns and offer feedback encouraging good reporting (Carmeli et al., 2010). Thus improving the feedback loops to support vertical integration and reducing the probability of system failures/errors.

4.5.1.2.6. Communication (Between the community and municipality):

Makhanda's Catchment Management Forum, which disbanded following the COVID-19 pandemic, is being reinstated. There have been two meetings, one on 25 April 2023, and the other on 27 November 2024. This could enhance communication between local and national government and communities. It will promote transparency and allow all stakeholders to raise concerns and be informed of the nature of the system and its objectives. Allowing community members to attend meetings will provide valuable on-the-ground accounts of issues, enhancing the municipality/government's awareness of and ability to address communities' concerns and ensuring that their members feel valued.

4.5.1.2.7. Monitor water supply and consumption:

All households should be documented and monitored to ensure that their water supply and consumption is appropriate, thus ensuring that sufficient water is supplied to them and that the water used does not exceed what is paid for by indigent community members and government subsidies. This should be facilitated by the new smart meters that are being installed as the water can be disconnected once capacity has been reached. Additionally, water must be billed and collected regularly.

4.5.1.2.8. Restore community trust:

This is imperative for the success of the system. However, it is not easy and will probably only be possible once changes such as those above have been implemented. If municipal budgets are spent wisely, appropriately qualified people are employed and sufficient resources are available to maintain the system, the community will regain its trust in it and be more willing to pay for water, enabling the system to sustain itself.

4.5.1.2.9. Leveraging existing worker resilience and knowledge:

Despite systemic challenges, many individuals within the Makana water management system are dedicated to maintaining and improving water service delivery in Makhanda. For instance, in Interview 7, it was noted that the acting Director of Infrastructure and Engineering actively engaged with stakeholders at all levels and independently learned how the water clarification system works. This knowledge proved invaluable when he had to manage James Kleynhans alone during a workers' strike in August 2024.

Other employees also demonstrate resilience, ingenuity and valuable knowledge. Process Controllers create improvised tools to compensate for resource shortages (Figure 17), while the Senior Technician maintains strong stakeholder relationships due to working with various system stakeholders. Additionally the Senior Technician along with the James Kleynhans Senior Foreman, Process Controllers and other system employees that have worked in the water system for many years, possess extensive system knowledge.

These positive contributions (resourcefulness, innovation, collaboration, and tacit expertise) are crucial for system performance. Recognising and rewarding these efforts can help retain skilled employees, encourage continued dedication, and promote a culture of resilience and knowledge-sharing within the system.

4.5.2. Conclusion

In conclusion, these recommendations offer a way forward for the Makhanda water management system to improve its overall performance. They could also be applied to other water systems confronting similar barriers. An HFE lens helps to understand systemic function and failure, pinpoint key areas for intervention and inform recommendations for improved system function.

The next step is implementing these recommendations and creating better awareness of practices that can mitigate errors/incidents both Nationally and Locally. However, implementation and creating awareness is beyond the scope of this study. The numerous challenges and recommendations highlight how challenging it is for municipalities to turn service delivery failure around. An organisational and systemic culture that is resistant to change, often exacerbated by poor leadership, renders this more difficult. This needs to change. The following section outlines the study's limitations.

4.6. Limitations:

No study is perfect. and its limitations impact its outcomes. This research confronted the following limitations:

- **One aspect of the system:** Two water treatment facilities in Makhanda distribute water to either side of the town. This study focused on one and its results thus cannot be automatically applied to the other as they may confront different challenges. Future studies could examine both systems to provide a more accurate description. Furthermore due to the limited access to the workplace it was not possible to do comprehensive observations of all tasks in order to map the system effectively. However gaining access within such a system with significant problems is an important step in the right direction to embedding HFE and HFE research within the system.
- **Time constraints:** Some interviews were short because of the participants' busy schedules, resulting in less detailed information.
- **Researcher's lack of experience:** As a researcher in HFE with no previous knowledge of water systems or experience with SEIPS, it is essential to

acknowledge the potential limitations and biases that may have arisen. However, the researcher consulted with various system experts to mitigate this and requested one to be part of her supervisor's team. This highlights the importance of multidisciplinary teams that promote improved understanding of systems and their contexts.

- **Possible dishonesty:** There is no way to know whether or not the participants' statements were fabricated. This limits the study's overall reliability. Dishonesty could stem from fear of consequences.

The following section discusses the study's significance and how it could improve Makhanda's water system and similar cases. It also explores how future studies can build on these findings to drive water management improvements in Makhanda. This is followed by the researcher's reflections and the conclusion.

4.7. Significance of the research

The significance of research that aims to address systemic social injustices such as a lack of water includes:

- **Identifying systemic strengths and weaknesses:**
  - By examining systemic barriers and facilitators, such research offers a clearer understanding of the factors influencing the water system's performance, helping to improve overall efficiency and reliability.
- **Acknowledging good in the system:**
  - Many individuals in the system work hard to create a positive impact despite systemic barriers. Their efforts should be recognized and appreciated, as their contributions often go unnoticed. As John Hunter (2015) stated, "A bad system beats a good person every time".
- **Promoting vertical integration:**
  - Collaboration between different system levels can improve individual well-being, optimise working environments and enhance overall system performance.
- **Raising awareness of complexity:**

- This research can educate stakeholders on the complex factors contributing to Makhanda's poor water service delivery, fostering a more comprehensive understanding of how systems operate and why specific outcomes occur.

- **Informing broader systems:**
  - Insights gained from addressing weaknesses in one system can help guide other systems, enabling them to avoid similar challenges in the future.
- **Attracting funding and support:**
  - Evidence-based insights into the town's water challenges can attract funding from government programmes, NGOs, and international donors.
- **Creating accountability and transparency:**
  - The research can put pressure on the authorities to act and improve service delivery.

4.8. Suggestions for future studies

This study is the first on Makhanda Municipality's water system to use ergonomics as the research lens. The good relationships were formed between the researcher and system stakeholders should be built upon to work towards systemic change and improvements in the community through participatory practices.

1. Future studies should consider, if not one, then both the systems that are intrinsically connected to the Eastern water management system, the western water management system and the wastewater system. This would provide greater understanding of the nature of the whole system, which will result in more sustainable improvements.
2. An important step in gaining access to the municipality was achieved in this study. However, in future a more participatory approach should be taken with the municipality. The researcher interacted with system stakeholders through meetings and one semi-structured interview per participant. In future, multiple visits and conversations around what the system believes works and doesn't work, along with recommendations, should be considered.

3. It would be interesting to examine how a brittle system like Makhanda's water system operates compared to a robust one that operates well, how their strengths and weaknesses differ and which are similar.
4. Lastly, because many of the service delivery systems in the municipality have the same Directors and share the same Municipal Manager, future studies could compare how they operate.

4.9. Reflexivity

When I initially told my supervisor that I was interested in this research, he cautioned me to be prepared for a tough journey. This did not refer to academic writing, data analysis and writing the report, which did prove challenging at times, but to my intention to work with the municipality which many researchers have been unable to do or found it very difficult in the past. Since I was dead set on my topic, I smiled and said I was still eager to tackle it.

Understanding the water system was one of the most challenging aspects of my research because water and sustainability are not my specialties. However, I identified many water system experts through my job of house-sitting. On visiting the Institute for Water Research in Makhanda's website, I identified three individuals whom I house sit for. I set up meetings with all of them, and through these conversations and those with ward councillors, I was able to form an understanding of South African and the Makhanda water management system. In true Ergonomics fashion, I was now working collaboratively with system professionals who knew more than me and it was wonderful to finally have direction. From one of them, I gained a co-supervisor who made a crucial contribution to my research.

To this day, I have not regretted my decision. This research has been incredibly eye opening, and I have learnt a lot. I spoke to municipal workers whose stories made me sad, inspired me and made me understand that people are just people at the end of the day and we are all trying our best with what we have access to. In addition, knowing that

the research could help to improve the human right to water has been a driving factor for me and something I am very proud of.

I was lucky that the process was seamless and that I managed to speak to all the municipal stakeholders that I wanted to. From day one, the Municipal Manager was very eager to have the system work with me and everyone welcomed me, with some providing interesting data while others were informative but less giving. Either way, I was appreciative because on multiple occasions, I could see that they remained in the interview regardless of being called out. They were accommodating and helpful and for that, I will be forever grateful.

Finally, I hope that my research contributes to the broader community's betterment and forms the building blocks for future research. The municipality is not as inaccessible and closed off as people imagine and should thus be willing to work with other researchers from Rhodes University to conduct further studies.

Chapter 5 Conclusion

In conclusion, the study identified multiple barriers in the Makhanda water management system and few facilitators, leading to poor water service delivery and a dissatisfied community. The facilitators are mainly stakeholders who are inventive and driven to make things work with no resources and little support.

Financial mismanagement, a lack of financial resources and capacitated staff, job vacancies and poorly maintained infrastructure that constantly forms leaks are some of the main problems. These systemic barriers largely relate to a lack of systemic vertical integration and a drift to failure because warning signals are not attended to in time, resulting in a system that exists in constant failure. The constant state of failure is due to systemic factors for example, bad systems, which will beat good people every time.

The constant, state of failure has led to a community that has lost trust in the municipality and stopped paying for water, further contributing to the system's financial pressure. Until such time as vertical integration through systemic communication occurs and the system's feedback loops are improved, errors will persist. In addition, until the municipality's financial situation improves through government subsidies, and increased tax collection there will be no money for the physical and mechanical resources required to repair and maintain the system to improve water service delivery. .

Once there is sufficient money and resources for the system to function appropriately, laws, regulations, and procedures need to be followed. Individuals who do not adhere to the laws, regulations, and procedures need to be held accountable to prevent further mismanagement and dysfunction and avoid the system falling back into the same negative patterns. This will promote an efficient system that can deliver sustainable water service delivery, resulting in the regaining of community trust.

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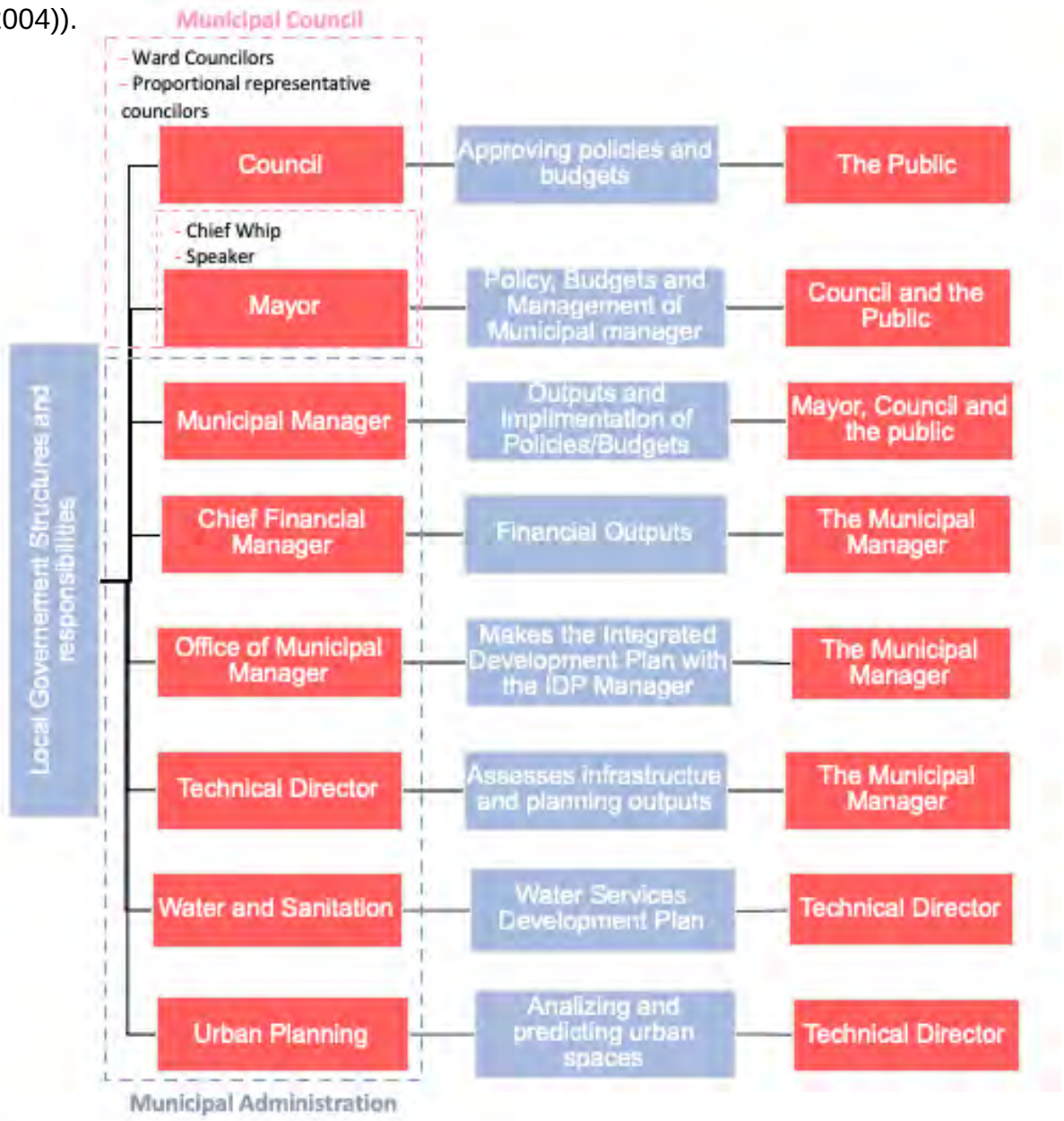
Appendices

Appendices A- A list of stakeholders in the National Water system adapted from (The National Treasury, 2004; and Makana Municipality official website)).

Stakeholder	Responsibility/knowledge
Minister of the Department Water and Sanitations	Conducts assessments of and oversees water management.
Department of Water and Sanitation (DWS)	Ensures the Country's water resources are protected.
Regional Office	Responsible for zoning water.
Water Board	Operates water recourses.
Catchment Management Agency	Delegates local water.
Municipal Manager	Implements/ oversees policy and budgets.
Director of Engineering and Infrastructure	Oversees all directorates related to engineering and infrastructure and ensures they operate efficiently.
Chief Financial Manager	Looks into and manages financial outputs.
Office of Municipal Manager	Creates integrated development plan.
Technical Director	Assesses infrastructure and ensures its maintenance.
City Mayor	Oversees the cities functionality.
Urban Planning	Analyses and manages urban spaces.
Municipal workers	Maintains operations of the system and its infrastructure.
Private Contractors	Contracted to maintain, build, update, test or build facilities, pumps, pipes and other mechanisms for the country's water system.
Water User Association	Manages the local infrastructure.
Catchment Management Forum	Forum where water is debated by the community, Department of Water and Sanitation and the government.
Non-Governmental Organisations (NGOs)	Organisations that potentially influence the system with acts/ ideas: Community groups, Gift of the givers, The circle of unity
Water users	Users of water

Appendices B: Layout of the local government structures as well as responsibilities, who the stakeholders report to and their committees, (adapted from (The National Treasury, 2004)).



Committees:
Accountable for
Participation in

Executive Committee = Municipal Council and Municipal Manager
Management Committee = Municipal Manager and Municipal Council
Infrastructure & Planning Standing Committee = Proportional Representative Councillors and Technical Director
Ward Committee = Ward Councillors, Residents, Civil Society

Appendices C: Observational timeline

Observation Date	What was observed	Who was observed	Remarks
9 April 2024	James Kleynhans Water Clarification Process	Two Process Controllers	The Process Controllers were very knowledgeable about the process and were very open and forthcoming. They helped the researcher with understanding the system.
12 June 2024	James Kleynhans Water Treatment Works (The working environment)	One Process Controller and a General Worker	The tools were outdated and some were broken. The workers use some make-shift tools and made their own chair to sit on I the office. The employees were welcoming.
13 August 2024	The Engineering Building in the city of Makhanda and the offices and of the water officials working inside it.	No person was observed.	There was water damage to the walls, roof, carpets and furniture. There was also broken furniture and equipment lying around the premises as well as a poor filing system. However, staff were helpful and welcoming although they were busy.
15 October 2024	City Hall (The office of the Municipal Manager, Director of Infrastructure and Engineering and surrounding environment/ offices)	Interactions between the individuals in the office were observed	The City Hall offices were in better condition than other offices. The employees were welcoming, had seemingly good working relationships amongst each other as they smiled and laughed with one another

Appendices D- Semi-structured interview questions asked to participants

Standardised Questions:

- What is your job title?
- In the process of getting water from Glen Melville Dam to water consumers, what is your role?
- What are you expected to do according to your job title?
- Can you do what is expected of your job, given the resources available to you? Please explain.
- What types to tools/ technologies do you work with every day and how effective are they?
- What are resources you don't have that you think would make your job easier?
- What do you enjoy about your job?
- What do you find most challenging about your job?
- If there were things that you would change about your job, what would they be?
- Please tell me a bit about your organisation, specifically?
    - Describe what the ethos/ atmosphere is like?
    - What are your working hours?
    - Describe what the management style is like?
    - To what extent do you feel valued or undervalued at work?
- How do you feel about water management in Makanda?
    - Do you feel valued by the Makanda Community?
    - If not why? / if yes why?
- If you could draw a list from the most senior to most junior level jobs in the Makhanda water system, who would you put where?
- Please explain what the roles are and what each of these people do in their jobs (refer to the list the participant had developed)?
    -What is their role in the water process?
    -Can they achieve what they need to do their job successfully?
    - If they do not achieve what they need to/are meant to why do you think this is?
- Who do you report to?
- Who are you responsible for?
- From my list of interviewees, is there anyone else whom you recommend I talk to, to understand the Makhanda East Water Management System better?
- Is there anything else you would like to add or share related to working in the water management system?
- Do you have any questions for me?

Appendices E: Rhodes University Ethical approval

Rhodes University Human Research Ethics Committee
PO Box 94, Makhanda, 6140, South Africa
t: +27 (0) 46 603 7727
f: +27 (0) 46 603 8822
e: ethics-committee@ru.ac.za
NHREC Registration number: RC-241114-045
https://www.ru.ac.za/researchgateway/ethics/

10 April 2024

terri harris

Email: g19h5141@campus.ru.ac.za g19h5141@campus.ru.ac.za

Review Reference: 2024-7447-8390

Dear terri harris

Title: Utilizing Human Factors and Ergonomics Socio-Technical Systems methods to identify Constraints and Affordances in the Water Management System in Makhanda

Researcher: terri harris

Supervisor(s): Mr Andrew Todd and Dr Matthew Weaver.

This letter confirms that the above research proposal has been reviewed and **APPROVED** by the Rhodes University Human Research Ethics Committee (RU-HREC). Your Approval number is: 2024-7447-8390

Approval has been granted for 1 year. An annual progress report will be required in order to renew approval for an additional period. You will receive an email notifying you when the annual report is due.

Please ensure that the ethical standards committee is notified should any substantive change(s) be made, for whatever reason, during the research process. This includes changes in investigators. Please also ensure that a brief report is submitted to the ethics committee on the completion of the research. The purpose of this report is to indicate whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the ethical standards committee should be aware of. If a thesis or dissertation arising from this research is submitted to the library's electronic theses and dissertations (ETD) repository, please notify the committee of the date of submission and/or any reference or cataloguing number allocated.

Sincerely,

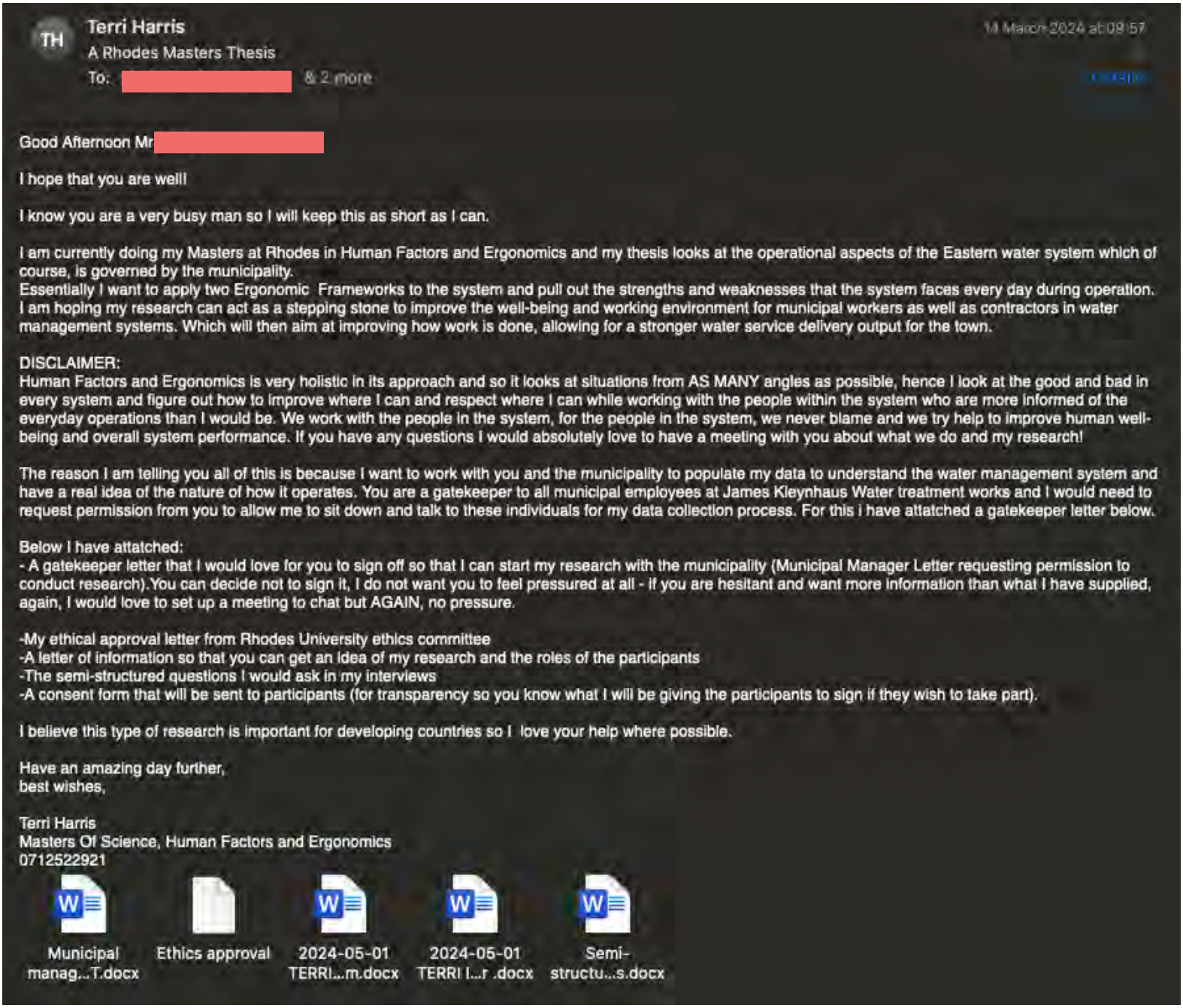
Janet Hayward

Dr Janet Hayward

Chair: Rhodes University Human Research Ethics Committee, RU-HREC

cc: Ethics Coordinator

Appendices F: Initial email sent to the Municipal Manager about conducting research at the municipality



Terri Harris
A Rhodes Masters Thesis
To: [redacted] & 2 more
14 March 2024 at 09:57

Good Afternoon Mr [redacted]

I hope that you are well!

I know you are a very busy man so I will keep this as short as I can.

I am currently doing my Masters at Rhodes in Human Factors and Ergonomics and my thesis looks at the operational aspects of the Eastern water system which of course, is governed by the municipality.
Essentially I want to apply two Ergonomic Frameworks to the system and pull out the strengths and weaknesses that the system faces every day during operation. I am hoping my research can act as a stepping stone to improve the well-being and working environment for municipal workers as well as contractors in water management systems. Which will then aim at improving how work is done, allowing for a stronger water service delivery output for the town.

DISCLAIMER:
Human Factors and Ergonomics is very holistic in its approach and so it looks at situations from AS MANY angles as possible, hence I look at the good and bad in every system and figure out how to improve where I can and respect where I can while working with the people within the system who are more informed of the everyday operations than I would be. We work with the people in the system, for the people in the system, we never blame and we try help to improve human well-being and overall system performance. If you have any questions I would absolutely love to have a meeting with you about what we do and my research!

The reason I am telling you all of this is because I want to work with you and the municipality to populate my data to understand the water management system and have a real idea of the nature of how it operates. You are a gatekeeper to all municipal employees at James Kleynhaus Water treatment works and I would need to request permission from you to allow me to sit down and talk to these individuals for my data collection process. For this i have attatched a gatekeeper letter below.

Below I have attatched:
- A gatekeeper letter that I would love for you to sign off so that I can start my research with the municipality (Municipal Manager Letter requesting permission to conduct research).You can decide not to sign it, I do not want you to feel pressured at all - if you are hesitant and want more information than what I have supplied, again, I would love to set up a meeting to chat but AGAIN, no pressure.

-My ethical approval letter from Rhodes University ethics committee
-A letter of information so that you can get an idea of my research and the roles of the participants
-The semi-structured questions I would ask in my interviews
-A consent form that will be sent to participants (for transparency so you know what I will be giving the participants to sign if they wish to take part).

I believe this type of research is important for developing countries so I love your help where possible.

Have an amazing day further,
best wishes,

Terri Harris
Masters Of Science, Human Factors and Ergonomics
0712522921

Municipal manag...T.docx
Ethics approval
2024-05-01 TERRI...m.docx
2024-05-01 TERRI I...r .docx
Semi-structu...s.docx

Appendices G: Gatekeeper permission to conduct the research

MAKANA
MUNICIPALITY | EASTERN CAPE
.. a great place to be

OFFICE OF THE MUNICIPAL MANAGER

Enq: PM Kate **File Ref No**: 4/2/1 **Date**: 08 April 2024
Tel: 046 603 6131

Student Researcher: Department of Human Kinetics and Ergonomics
Terri Harris
Rhodes University
Drosty Road
Makhanda
6139

SUBJECT: REQUEST FOR PERMISSION TO CONDUCT RESEARCH FOR MASTERS DEGREE

Your e-mailed correspondence for my attention and consideration in which a special request for you to have access to the municipal officials for research purposes was received. Indeed I considered it and it gives me pleasure to inform you that it was favourably look at.

This letter serves as a letter of authorization to grant you access to the municipality and the officials you would be conducting the research on.

The targeted or identified officials should sign all the necessary documentation before commencing with the interviews.

I have also assigned Mr Likhaya Ngandi, Manager in the Municipal Manager's office, as a contact person should you need any other assistance pertaining your research.

Yours truly,

Mr P. M Kate
MUNICIPAL MANAGER
MAKANA MUNICIPALITY

Appendices H: Gatekeeper permission to include photography in the research

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MUNICIPAL MANAGER'S OFFICE

Ref: PM/pr **file ref**: 13/1/1 **07 February 2025**

I, Pumelelo Maxwell Kate, in my capacity as the Municipal Manager of Makana Local Municipality, hereby declare that Terri Harris of Rhodes University can utilize photographs of the water management system in her Master's Thesis titled: ***Utilising an ergonomic socio-technical model to understand the water management system of a small South African town***.

These photographs will be used to identify the environment that the Municipal officials work in every day. In addition, they will portray the James Kleynhans Water treatment works water clarification process.

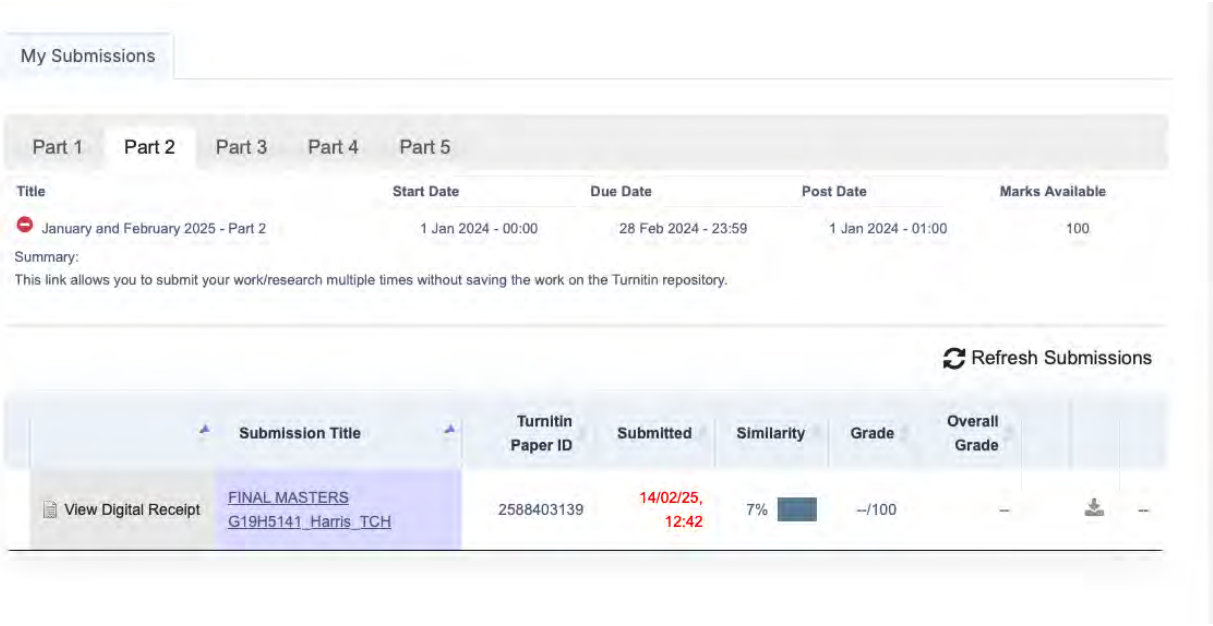
Signature: _____

Date: 07 - 02 - 2025

Place: MAKHANDA

Appendices I- P are withdrawn from this library copy due to the sensitive nature of the information. If it is at all required, these appendices can be accessed via the department of Human Kinetics and Ergonomics records only if valid authorisation from the municipality is provided.

Appendices Q: Turnitin Report



My Submissions

Part 1 | Part 2 | Part 3 | Part 4 | Part 5

Title	Start Date	Due Date	Post Date	Marks Available
January and February 2025 - Part 2	1 Jan 2024 - 00:00	28 Feb 2024 - 23:59	1 Jan 2024 - 01:00	100

Summary:
This link allows you to submit your work/research multiple times without saving the work on the Turnitin repository.

Refresh Submissions

	Submission Title	Turnitin Paper ID	Submitted	Similarity	Grade	Overall Grade		
View Digital Receipt	FINAL MASTERS G19H5141_Harris_TCH	2588403139	14/02/25, 12:42	7%	--/100	--		--

THANK YOU FOR READING

THE END.