THE SOUTH AFRICAN WATER INNOVATION STORY

African Centre for a Green Economy

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THE SOUTH AFRICAN WATER INNOVATION STORY

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by

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EXECUTIVE SUMMARY

Background

Water is a strategic resource critical for basic human needs and for powering key economic sectors such as agriculture, food processing, manufacturing and resource extraction. Water scarcity, which is defined as the lack of available water resources to meet needs sufficiently, has been ranked among the top three global risks over three consecutive years (World Economic Forum, 2016). This is partly attributed to increasing consumption patterns, demographic change, ineffective management practices and dynamic governance of a public good, which pose significant challenges to human well-being and the environment. For example, the global population is projected to exceed 9 billion people by 2050; it is estimated that 4 billion people will live in water-scarce regions with chronic water supply challenges (Clark & King, 2004).

South Africa is classified as a water-scarce country with an average rainfall of 450 mm per annum – almost 50% less than the global average of 860 mm per year. There are three major challenges regarding the availability of water across the country. Firstly, the spatial distribution and seasonality of rainfall is uneven as 43% of rain falls on 13% of the land. Secondly, the relatively low stream flow in rivers limits the proportion of stream flow that can be relied upon for use. Thirdly, the location of major urban and industrial developments in water-scarce regions necessitates large-scale water transfer schemes across borders, which is expensive (DWA, 2012). The continuing trend in industrialisation and urbanisation is expected to place further pressure on South Africa's water sources unless appropriate corrective action is taken (DWA, 2012).

Historically, the management of water resources has focused on the supply side as opposed to demand management. This necessitated a strong focus on the development of hard infrastructure, which included the construction of large dams, reservoirs, tunnels and pipelines, the local construction of systems of weirs, pump stations and irrigation canals. However, with escalating water demand threatening to surpass supply, South Africa is now faced with an urgent need for holistic water management efforts that emphasise demand management and new infrastructure, and maintenance and operations equally. The emphasis of building new infrastructure, often with minimal operations and maintenance budgets, has contributed significantly to the plethora of complex challenges South Africa faces.

South Africa is ranked nineteenth in the world for its contribution to published research related to water and waste water (Pouris, 2013). However, Rose and Winter (2015) highlight that the challenge is to address how to translate this world-class research into innovations that address current and future socio-economic challenges and develop a knowledge-based economy. Innovation is one of the critical success factors central to identifying solutions for addressing the systemic water challenges and interrelated socio-economic transformation. Yet, this requires concerted effort from government, business and civil society to build a robust innovation ecosystem. Even though South Africa has developed innovative technologies in the water sector for decades, with many of these innovations being adopted globally, the country still faces significant water challenges. Solutions that help improve access to water for impoverished rural communities, leakage detection and the treatment of water, are all needed to manage water resources effectively.

To accelerate the deployment of water innovations, South Africa has increased its funding for water-related research. For example, this funding increased has from R1.4 billion in 2000 to R2.1 billion in 2014, with government and businesses being the major funders (Pouris, 2015). The Water Research Commission (WRC) has shown commitment to driving water innovations and remains the main funder for water-related research in South Africa; they support up to 65% of water-related research in 2014 (Pouris, 2015).

The Department of Science and Technology (DST) together with its agencies such as the Technology Innovation Agency (TIA) and the Council for Scientific and Industrial Research (CSIR), among others, are mandated to drive the South African National System of Innovation (NSI). In recent years, the Industrial Development Corporation and the Public Investment Corporation has initiated the development of their water strategies and project funding mechanisms. Other institutions in South Africa are yet to prioritise water innovations to accelerate their deployment.

Objectives

This book aims to document South Africa's water innovation story from the perspective of innovators by specifically developing an understanding of the effectiveness of the South African innovation ecosystem including the NSI. To address this objective, four research questions were posed to water innovators:

- What is the status of the deployment of water-related innovations that have been developed in South Africa in the last 20 years?
- What are the enabling factors that are key for accelerating the deployment of water innovations in South Africa?
- What are the perceived barriers and opportunities for accelerating water innovations?
- To what extent have South African innovations achieved commercial and global success?

Methodology

The study used a combination of a literature review, case studies and structured interview sessions with innovation ecosystem actors, including innovators, entrepreneurs, researchers, research funders and private equity asset managers. Water innovations were mapped through expert knowledge of existing innovations, and a comprehensive literature review that has identified more than 100 water innovations that have emerged in South Africa over the past 20 years. Each of the innovations was scored against specific criteria, which included the type and stage of deployment of the innovation, type of water challenges it addresses etc. The innovations that received the highest scores were shortlisted for further review by experts, and an extensive interview with the innovators.

Based on this approach, 19 initiatives, which included both technological, process and social innovations, were selected for consideration in this study. The water innovations discussed are used to highlight the types of innovation that have emerged in the water sector. However, it needs to be noted that the list of water-related innovations discussed is not comprehensive in relation to the total innovations. The selected case study broadly covers specific issues that address water challenges related to rural sanitation, drinking water quality, water efficiency, water recovery and energy, and decision support systems (DSSs) for water management, as prioritised by the Water Research, Development and Innovation (RDI) Roadmap.

Results and discussion

To respond to the challenges it faces, South Africa has developed robust multifaceted interventions aimed at driving innovation. The water sector in South Africa is arguably one of the most robust in terms of innovation activity. The strong legislative framework that led to the set-up of institutions such as the WRC has ensured that the water sector is given high priority in terms of research and development (R&D). The adoption of the NSI approach and the development of the National Water RDI Roadmap are some of the robust South African interventions that ensure that innovation is given high priority to address some of the challenges facing the country.

The South African NSI

To position itself as a knowledge-based economy, South Africa was one of the first countries globally to adopt the NSI approach. The NSI concept was first articulated in terms of the Science and Technology White Paper (1996). The South African NSI specifically acknowledged the need for a transition to a low carbon economy in recognition of the sustainability challenges due to climate change, population growth and environmental degradation. The country has made progress in improving the governance of the innovation system since it gained democracy in 1994 (Zhang, 2012). This is evident from strategies, socio-economic policies and government interventions that have emerged in the country.

- South Africa spends approximately R24 billion a year on R&D, which translates to a gross domestic product of 0.76%. The country has set an overall target of achieving an R&D intensity ratio of 1.5% by 2019 (Pouris, 2015).
- The development of policies and strategies to focus on innovation was further boosted by the establishment of the National Advisory Council on Innovation (NACI) in 2000.
- The NACI was established to advise the minister and government on a wide range of matters pertaining to innovation and systems in South Africa (Marais & Pienaar, 2010).
- Organisations such as the TIA were also established, which led to the development of public funding mechanisms for stimulating and supporting innovation in South Africa.

Despite the progress made by South Africa, the NSI has been criticised for various reasons by some researchers (see Hart et al., 2015; Manzini, 2015). For some of the innovators interviewed for this study, these reasons included the following:

- Innovation was defined in a very narrow context. The focus was on technological innovations that emphasise social innovations less and that limit the potential of the NSI to effectively address the systemic challenges of poverty, unemployment and crime, which is a multifaceted approach rather than depending entirely on technological innovations (Hart et al., 2015; Manzini, 2015).

- Poor performance and implementation of the policies and strategies that have been developed remain a huge challenge for South Africa. For example, mechanisms such as the Support Programme for Industrial Innovation, and the Technology and Human Resource for Industry Programme have suffered from poor execution despite being conceptually excellent mechanisms (RIIS & The Embassy of Switzerland and South Africa, 2016).
- One of the major shortcomings of the NSI is that it is championed by academics and publicsector institutions, with the private sector not fully engaged in government efforts to promote innovation.
- There is no effective coordination across all government ministries. The sole responsibility for driving innovation is given to government institutions and government departments such as the DST, WRC and TIA. There is a little joint effort between government and industry – the industry is within organisational boundaries.
- The public sector does not have an innovation culture or one that welcomes change in the processes, decision support etc. Specifically, there is no ringfenced budget across departments to support the testing of innovations at technology readiness level 5 to 9 and thus accelerate innovation to market or application.

In general, the NSI should be more holistic in its endeavour to promote innovation in the country. Both technical and non-technical innovations should be prioritised. The institutions responsible for executing policies and strategies need to improve their performance to ensure that the support is available for all emerging innovations in South Africa. There is a need for a clear coordination between the actors involved in the innovation ecosystem.

The National Water RDI Roadmap

Responding to the growing water scarcity, which is further exacerbated by the recent drought, the South African government adopted a robust approach by establishing the Water RDI Roadmap, which:

- Aims to increase the number of technology-based small and medium enterprises operating in the water sector.
- Stresses that to achieve all the objectives of the roadmap over the 10-year period (from 2015–2025), an overall investment of R8.49 billion is required.
- Presents an opportunity for other well-established institutions in South Africa, such as the TIA, CSIR, Agricultural Research Council and Mintek, to partner and play a more focused and social needs-based role in water sector.

Overview of water innovations in South Africa

The following section provides an overview of selected water innovations in South Africa with a focus on sanitation, water quality, resource recovery and water efficiency. The case studies track the journey of various water-related innovations in South Africa from R&D, demonstration and all the way to commercialisation to understand the effectiveness of the South African innovation ecosystem. More specifically, the case studies unpack the experiences of individual innovators, including their motivation, challenges encountered and the kind of support they require or have received.

Innovations in rural water and sanitation

There is significant concern relating to provide adequate sanitation – particularly in rural areas of South Africa. By 2019, the South African government aims to increase access to improved functional sanitation services to 90% and eliminate bucket sanitation (Stats SA, 2016). The Community Survey 2016 revealed that nationally the percentage of households with access to improved sanitation facilities increased from 62.3% in 2002 to 80% in 2015. However, there are still large variations between rural and urban areas in terms of access to sanitation facilities. Of rural households, 5.6% still lack sanitation services compared to only 1.1% of urban households (Stats SA, 2016). A range of toilet technologies are currently used in South Africa to address the backlog, which includes buckets, chemical toilets, pit toilets, ventilated improved pit toilets (VIPs), dehydrating and composting toilets, aqua-privies, flush toilets with septic tanks, and flush toilets connected to central treatment works.

The challenge regarding access to sanitation, especially in the rural context, is the negative perception towards innovations that are not waterborne as they are considered inferior to conventional waterborne systems. This lack of social acceptance impedes the uptake of water efficient innovations in areas that lack adequate sanitation services. Currently, the VIP is a widely used technology for providing sanitation services due to its robust technology, although there are challenges with sludge disposal when a VIP is full (Tissington, 2011).

The provision of safe and adequate toilet facilities accessible to the poor can significantly decrease the burden and therefore health costs. To this end, a range of innovations has emerged in South Africa that seeks to address this critical challenge, as shown by the three case studies that were selected for this study:

Pour-flush/low-flush toilet

A pour-flush toilet is similar to a full-flush toilet except that water is poured in by the user rather than coming from a cistern. The incoming water forms a water seal in the bend portion of the pipe to prevent any smell from the pit coming back up to the toilet. The leach pit is placed a distance away from the toilet structure. The pit is not visible to pour-flush toilet users, thus preventing any danger or health hazard. The pour-flush toilet is designed to be as simple as possible to avoid parts that can break or block. While it looks like a full-flush toilet, there is no water tank, cistern, flusher or liquefier.

Arumloo

Arumloo is a micro-flush toilet designed to flush between 1 L and 2.5 L of water per flush. Most modern dual-flush toilets provide a 3 L small flush and a 6 L large flush. The Arumloo is set to save one-third of water used for toilet flushing. The Arumloo uses a dual-flush mechanism. A flush is achieved using an innovative pan design that creates a vortex to remove stools more efficiently and a gush of water (gush flush) that enters into the P-trap. The innovative flushing features enable the micro-flush toilet to use as little as between 1 L and 2.5 L of water per flush while offering an appearance and operation similar to that of other conventional toilets.

Social franchising

Social franchising is defined as a model where a small enterprise enters into a business partnership as a franchisee with a franchisor using a tried-and-tested approach for undertaking the activities required to ensure that sanitation and water facilities, and other systems are operating in a reliable manner and to suitable hygienic standards (Wall et al., 2012). This innovative business model developed by Amanz' abantu Services in collaboration with CSIR enables franchised small businesses to operate sustainably by providing training and nurturing support as well as offering entrepreneurship opportunities to local communities. The social franchise supports small enterprises to provide appropriate local service solutions by way of its proven systems, thus ensuring quality and reliability of services, peer learning, skills transfers, and health and safety training.

Improved waste water management

Poor sanitation and management of waste water treatment plants contaminates water supply systems. It has been estimated that up to 90% of sewage generated in cities in developing countries is discharged untreated (Corcoran et al., 2010). While the problem is less concentrated in South Africa, the trend in recent years is showing deterioration in our management of sanitation services and waste water treatment plants. Numerous innovations have emerged to address the waste water management challenge in South Africa, as shown by the following example.

Integrated algae ponding system

The integrated algae ponding system (IAPS) is a cost-effective waste water treatment technology for small- to medium-sized communities, including most small towns and cities in South Africa, that produce three by-products: energy from biomass, biomass to be used as fertiliser, and effluent suitable to be used for irrigation or direct discharge into the river (Wells et al., n.d.). With conventional waste water treatment, large amounts of electric energy, mechanical equipment, chemical and specific skills are required to run a plant effectively. IAPS could be a more cost-effective option to construct, operate and maintain.

The technology uses biological processes and micro-organisms that occur naturally in all sewage treatment processes. It produces an effluent that meets general authorisations without needing an external electricity supply, sludge handling and highly skilled operators. This makes it easier to operate and maintain, larger scale-up and reuse of water and products like algae for fertiliser.

Drinking water: a lack of access to potable drinking water

Access to safe drinking water is a fundamental human need and a basic right (WHO, 2003). In South Africa, section 27 (1) (b) of the Bill of Rights states that everyone has a right to have access to sufficient water. The lack of potable water of adequate quality is widely recognised as being a major barrier to health and economic development in most developing economies. However, despite the significant improvements made by government in water services provision, people still depend on untreated water from rivers and other sources, which is particularly true in some rural areas and townships in South Africa. The two examples of innovations that represent progress in addressing this challenge include VulAmanz and the Hippo Roller.

VulAmanz

The VulAmanz, also known as the Woven Fabric Microfiltration Gravity Filter, is a new point-of-use (POU) water treatment technology developed by inventor Prof. Lingam Pillay (Department of Process Engineering) and Laurie Barwell. Such POU water treatment units play a critical role in the short- to medium-term provision of safe drinking water to rural areas in South Africa and other developing countries where communities have to rely on untreated water extracted from rivers, dams and boreholes.

The module consists of a PVC frame incorporating a permeate outlet, two sheets of fabric glued to either side of the frame, and a spacer between the sheets of fabric to facilitate fluid flow to the permeate outlet. The operation of the unit is simple to use: the user pours raw water onto the tank, the tap is opened, and product can be collected. The VulAmanz can provide much-needed water in rural communities where people are forced to consume untreated water due to the unavailability of treated tap water. The technology can produce approximately 25 L/hr per user. This is quite significant considering that according to the World Health Organization, between 50 L and 100 L of water per person per day is needed to ensure that the most basic needs are met, and few health concerns arise. In addition, this innovation does not require any form of electricity as the treatment is gravity-driven, which contributes to energy efficiency, and it does not require significant infrastructure.

Hippo Roller

The Hippo Roller was invented in 1991 by Johan Jonker and Pettie Petzer. The Hippo Roller is designed to help people in rural communities with their struggles of fetching water from community taps, rivers and boreholes. It improves people's access to water sources while at the same time reducing the workload of having to carry buckets. It stores clean water for its users, mobilises and promotes social investments for the local communities by mobilising government, non-governmental organisations, corporations and individuals to invest in the well-being of the water-stressed communities.

The Hippo Roller is a barrel-shaped container that has a still handle attached to it so that it can roll easily. It is made from UV-stabilised linear low-density polyethylene for coping with bumpy and rough rural roads. It has a proven five-year lifespan and can carry up to 90 L of water at once. It is user-friendly as it does not require much effort to be pushed/pulled when transporting water.

Water efficiency

Many water supply systems in South Africa comprise huge losses of water referred to as non-revenue water. Non-revenue water in South Africa is estimated to be 36.8% (Mckenzie et al., 2012), which is the water lost through dilapidated municipal water mains, leaking toilets, sinks and rusting steel pipes located on domestic properties. Other inefficiencies in water supply arise from poor operational service delivery practices and a lack of technical capacity, including the knowledge needed to obtain financing for required interventions. Aging infrastructure accompanied by theft and vandalism of water infrastructure in South Africa present huge challenges for South African municipalities and government due to the costs of maintenance and replacement of stolen goods such as water taps and pipes (Parliamentary Monitoring Group, 2015).

Innovations that have emerged to address the challenge of water inefficiency include the Geasy and Aquatrip.

Geasy

The Geasy is an intelligent geyser management system. It provides full geyser control via any Internet-connected device and saves electricity through optimised scheduling. It is attached to a geyser to save energy and monitor water flow. The innovation allows the user to detect bursts and shuts off the supply of water and electricity once the burst has been detected. The user can also schedule control to optimise energy usage. The Geasy comes with a SIM card and a modem that automatically reports to the server where the data is processed, and feedback is given to the user.

Aquatrip

The Aquatrip is a permanently installed and patented leak detection system with a built-in control valve. It monitors the flow of water in commercial, industrial, domestic and retail properties. The Aquatrip automatically shuts the water supply off if the tap is left running, if it leaks or if a burst pipe is detected. It offers users cost-saving benefits in water bills, monitors property damage in case of unexpected burst pipes while also saving water by preventing wastage.

Water recovery and energy

Water and energy are interconnected, and this translates to the interdependence between these resources. At the heart of the relationship is the interdependence of resources – how demand for the one can drive the demand for the other, similarly, how the cost of one resource can determine the efficiency of the production of the other. For example, South Africa’s electricity-generation activities and large industries account for 6–8% of water resources and are located within moderately and severely constrained water management areas (Pouris & Thopil, 2015). As demand for water and energy increase and is expected to increase even further in the next coming decades due to the increasing population and the fast-growing economy, alternative sources of water and energy are needed urgently. Therefore, reliable and sustainable solutions for water and energy are necessary. Innovations addressing this challenge include wave energy reverse osmosis (WEROP) and eutectic freeze crystallization (EFC).

WEROP

WEROP is a local technology that provides clean, safe drinking water and electricity from renewable resources. WEROP is a patented locally built unit that sits on the seabed anywhere between 500 m and 1.5 km out to sea. The pump uses wave power to push water through an undersea pipe to a land unit that can be configured to run either through a reverse osmosis unit to produce fresh drinking water, or through a turbine to produce electricity, or both. The water can also be pumped at high volume for land-based seawater mariculture. The technology is the first of its kind to be designed and built in South Africa. The innovation also offers a sustainable, cost-effective and environmentally friendly option compared to current desalination technology.

EFC

EFC is an innovation offering a waste management solution for saline brines that result from using desalination technologies such as reverse osmosis, especially in the mining industry. EFC offers a novel, sustainable method for treating brines and concentrates that were previously regarded as difficult to treat due their complex nature. Consequently, they were discharged to evaporation ponds. The innovation is cost-effective to implement and offers a sustainable solution to waste water treatment.

Water quality management

Water quality in South Africa is affected by different anthropogenic factors including urbanisation, agricultural activities and extractive operations such as mining. Water innovations such as VitaSOFT,alternative reverse osmosis, miniSASS and fish telemetry are some of the innovations that have emerged to address the water quality challenge in South Africa.

VitaSOFT

The VitaSOFT process is an active biological process for treating acid mine drainage (AMD). VitaSOFT integrates four active biological processes, including biological sulphate reduction, with various chemical processes to achieve water quality of potable standard, converting an environmental threat into a valuable water resource for domestic and irrigation purposes while producing valuable by-products (secondary resources). The process is unique in its design compared to other AMD solutions developed in South Africa. The VitaSOFT process can effectively replace high-density sludge processes by removing heavy metals using the alkalinity and sulphides generated in the biological sulphate-reducing reactors, thus greatly reducing the amount of sludge produced compared to the high-density sludge process (Joubert & Pocock, 2016).

Alternative reverse osmosis

Alternative reverse osmosis is a treatment technology for primary treatment (desalination) of AMD. It offers a medium- to long-term solution for the desalination of AMD to water quality to meet water supply and demand. The Department of Water and Sanitation's investigation into the feasibility of various options for the long-term management of mine water on the Witwatersrand has identified alternative reverse osmosis process as a treatment method that has potential for mitigating the mine water situation in that region. Alternative reverse osmosis is a unique and exclusive South African technology that produces rapid and complete chemical reactions resulting in a dramatically reduced plant footprint and capital costs (Engineering News, 2013).

Local Fish Biotelemetry System

The biotelemetry system involves the use of transmitting devices to monitor the behaviour and physiology of aquatic animals in their natural environment over time. Used internationally, the system is a combination of remote and manual tracking and monitoring systems as well as smart tags or transceivers. The tags are attached to the aquatic organisms being monitored after which they are released back to their natural environments to re-establish normal behaviour patterns. Since its development the technology has been helping aquatic scientists understand animal behaviour in water.

miniSASS

The development of the miniSASS methodology was derived from the South African Scoring System (SASS), developed by aquatic ecologist Mark Chutter in 1998. The SASS is a relatively simple technique used by trained practitioners to identify the health of water bodies based on the identification of up to 90 invertebrate families. With the rising concern of river health and pollution a suitable tool was required for both scientists and non-scientists. The miniSASS used a reduced SASS assessment of 13 groups to produce citizen-science data.

Decision Support Systems (DSSs)

DSSs include frameworks, protocols, processes, methods, tools and models for integrated water resource management to improve decision-making (Stewart et al., 2000 in CPH Water, 2001). DSSs can assist water service providers to improve water management, water and waste water treatment operations, water distribution and infrastructure asset management. In addition, DSSs help water stakeholders with critical issues such as managing budgets for water treatment, managing water services efficiently, and providing municipalities with crucial information and knowledge about budget allocations to make decisions about which water services should be prioritised in municipal budgets. Examples of DSSs innovations include the Downstream Response to Imposed Flow Transformations (DRIFT) Methodology, Mine Water Atlas (MWA), WATCOST and Waste Water Risk Abatement Plant (W_2RAP).

DRIFT methodology

The DRIFT is a process and computer program for managing knowledge on the links between river flow and ecosystem functioning by using a combination of data, knowledge and experience of scientists and local people to predict how the river ecosystem will change if there is a water resource development. The DRIFT was developed to provide detailed and transparent predictions on how the ecosystem could change over time because of water resource developments such as dams. These predictions are based under a range of client-selected water development scenarios, for discussions and negotiations among governments and other stakeholders.

WATCOST

WATCOST is a costing manual to predict the cost of water supply systems. The manual estimates the cost for operation, maintenance, and management of water supply services. It estimates all the cost for all stages of drinking water supply process (raw water, water treatment plants, clean water storage and the distribution of water). The costing model also provides the users with estimated costs for orders and operation costs of water supply systems, while also providing estimates on the cost of maintenance and the value of the existing water supply systems.

The Mine Water Atlas

The Mine Water Atlas is the first of its kind to be developed globally. The innovation introduces mine water in geological, hydrological and legal contexts, while also examining geographical foundations of water quality, quantity and distribution. It is envisaged that the innovation will also provide insights into the challenges and opportunities facing South Africa regarding the quantity, quality, protection and use of its water resources.

Waste Water Risk Abatement Plant (W2RAP)

The W2RAP is a means of managing and identifying risks and offers a valuable solution to enhance municipal water and wastewater service delivery. It draws its principles and concepts from other risk management approaches and emerged at a time when the Department of Water and Affairs (DWA) needed to develop a programme to improve wastewater treatment services in South Africa. Developed to support the Green Drop incentive-based regulation, the innovation was deployed across South Africa with support from public and private sectors.

Emerging trends in the water innovation ecosystem in South Africa: an innovator's perspective

South Africa faces significant water challenges, ranging from poor water quality attributed to various factors such as mining activities (AMD), agricultural run-off and poor waste water management infrastructure. Most of the key economic hubs, such as Cape Town and Johannesburg, are in water management areas where water demand has outstripped supply. South Africa has the capacity to develop water innovations as seen with the technologies that have emerged in the sector.

The country has a strong scientific community capable of developing water innovations to tackle the country's water crisis. The main challenges as highlighted by the innovators and some stakeholders include the lack of adequate funding to support innovations across its value chain. Significant bureaucratic processes associated with setting up small business and poor linkages to industry have hindered potential innovations that could have been deployed successfully to the benefit of the country. Some of the key emerging trends that have been observed include:

Limited links between the various actors and institutions in the innovation ecosystem

South African universities have spearheaded water innovations with several centres of excellence and research chairs located in various universities across the country. However, the linkages between universities and other spheres of the economy, which is key to the commercialisation of water innovations, are often not sufficiently strong enough despite the recently established technology transfer offices. As a result of these and other factors, innovations that could have been commercialised or widely deployed have not made it to market.

Intellectual property related challenges

South Africa has adequate intellectual property rights and policies to promote innovations, R&D, and technology transfer to support a growing, sustainable economy. While engaging with the relevant stakeholders and innovators, it emerged that there is a lack of understanding and awareness around intellectual property policies in South Africa. This has had significant negative impacts on the transfer of innovation.

Inadequate support for uptake of new innovations by the public sector

It has been reported that municipalities can play an inhabiting role in the successful deployment of innovations. Municipalities work closely with their appointed consultants and, in some cases, they resist the introduction of radical innovation. Collaboration between municipalities, universities and other research institutions is insufficient to optimise on the water innovation pipeline that is being developed to improve services and efficiencies.

Funding challenges for water innovations

Generally, South Africa has funding available for R&D-related aspects of water innovation with institutions such as the WRC and the National Research Foundation as key champions of R&D in water and sciences in general. One of the major challenges experienced by innovators is the lack of funding availability beyond the R&D stage when innovations move into the commercialisation stage beyond the proof of concept. Since most of the funding is concentrated in the R&D stage and late commercialisation, there is a real challenge with securing funding for early stage innovations in South Africa. This is not only unique to the water sector but is prevalent in every initiative seeking to commercialise, which is often referred to as the 'valley of death' (House of Commons Science and Technology Committee, 2013). The solution is to earmark bridging finance to target projects that are at an intermediary stage and may require a mix of grant-type research funding and commercial financing mechanisms. The skills and competency mix of water innovators have equally been questioned by funders and investors and need to be addressed.

Lack of access to markets for emerging innovations

Lack of access to market presents a real challenge for many innovations in South Africa; often the products are niche with small potential current already captured markets (when viewed in conjunction systemic factors above) resulting in what is experienced as intense competition and barriers to entry for new entrants. Investors, who are equally risk averse, are perceived as uninterested in supporting initiatives that cannot demonstrate potential for commercialisation and a return on investment. It should also be noted that most water innovations in South Africa have emanated from universities and research institutions, and many emerging water innovators who have developed the ideas often lack crucial entrepreneurial skills. This is partly attributed to the fact that most science courses at tertiary level do not incorporate business training in their programmes.

Engaging with local communities

There is a great need for researchers and innovators to engage with community members and industry to determine the most pressing problems where solutions are required. This includes the nuanced social contexts to embed enablers for successful transfer at a later stage. Innovations should not be imposed on key communities due to their real or perceived lack of knowledge and information. Due to the push approach, communities have been reluctant to try emerging innovations that seek to address water challenges.

Concluding remarks and recommendations

South Africa's water sector is faced with a plethora of challenges due to natural and anthropogenic causes. These complex and often interrelated issues provide an opportunity to develop innovations that are crucial for sustainable water management and socio-economic development. A wide range of innovations (technological and non-technological) have emerged in the water sector. However, engagements with the innovators and some stakeholders in the innovation ecosystem have shown that despite the robust R&D of water innovations in South Africa, many water innovations have struggled to move beyond R&D stage due to pertinent challenges encountered by the actors involved in the innovation ecosystem.

Limited linkages between the actors in the innovation ecosystem and funding access for innovations remain the main challenges hindering the success of water innovations in South Africa. A very strong legislative framework has ensured that water is given a high priority in terms of research. Ideologically, policies and strategies are well framed and structured; however, the implementation and performance thereof are not a reflection of this. Innovation should receive the necessary support from R&D to the commercialisation stage of development.

Despite the concentrated efforts shown by different actors involved in supporting water-related innovation in South Africa, there is still a lack of coordination between the various actors in the innovation ecosystem. There is a need to build more exclusive collaborative efforts across enabling partners to facilitate opportunities provided by water challenges in South Africa.

As a way forward, the following steps are recommended as best possible solutions that will help to accelerate the deployment and application of water innovations in South Africa:

- Build more linkages between the various actors involved in the innovation ecosystem to solidify the linkages between these actors, being the major role player in the NSI. The government (through its departments mandated to drive innovation) should drive this coordination by developing enabling policies and providing the necessary support.

- Form partnerships. Partnerships are important as a way of making an idea commercially viable to benefit established businesses, innovators and the public. Collaborating with incubators and investors who have the capacity and financial muscle to drive the development of water innovations, and the development of partnerships between researchers, public institutions and businesses can play a critical role.
- Write case studies about innovations that have failed to reach the deployment stage as a learning curve that will provide an opportunity for other innovators to not make the same mistakes.
- Being the major funder of water-related R&D, the WRC should ensure that mechanisms are put in place to trace the progress of water innovations they have funded. This will help accelerate deployment of water innovations in the country by understanding which key barriers hinder the deployment of water innovations.

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ABBREVIATIONS

AfDB	African Development Bank
AMD	Acid Mine Drainage
BRICS	Brazil, Russia, India, China and South Africa
CAB	Community Ablution Block
CSIR	Council Scientific and Industrial Research
DEA	Department of Environmental Affairs
DRIFT	Downstream Response to Imposed Flow Transformations
DSS	Decision Support System
DST	Department of Science and Technology
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EBRU	Environmental Biotechnology, Rhodes University
EFC	Eutectic Freeze Crystallization
EFlow	Environmental Flow
GDP	Gross Domestic Product
HDI	Human Development Index
HDS	High-density Sludge
IAPS	Integrated Algal Ponding System
ICT	Information and Communication Technology
IDD	Isidima Design and Development
IMT	Institute of Maritime Technology
Miwatek	Mine Water Treatment Technologies
MWA	Mine Water Atlas
NACI	National Advisory Council on Innovation
NGO	Non-Governmental Organisation
NRF	National Research Foundation
NSI	National System of Innovation
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-operation and Development
POU	Point of Use
R&D	Research and Development
RIIS	Research Institute for Innovation and Sustainability
S&T	Science and Technology
SASS	South African Scoring System

SET	Science, Engineering and Technology
SMME	Small, Medium and Micro Enterprise
TCTA	Trans Caledon Tunnel Authority
THRIP	Technology and Human Resource for Industry Programme
TIA	Technology Innovation Agency
UCT	University of Cape Town
USA	United States of America
VIP	Ventilated Improved Pit Toilet
WADER	Water Technologies Demonstration Programme
Water RDI Roadmap	National Water Research, Development and Innovation Roadmap
WEROP	Wave Energy Reverse Osmosis Pump
WFMF-GF	Woven Fabric Microfiltration Gravity Filter
WRC	Water Research Commission
WSA	Water Service Authority
W2RAP	Waste Water Risk Abatement Plant

1 INTRODUCTION

Water is an enabling strategic resource critical for basic human needs and for powering key economic sectors such as agriculture, food processing, manufacturing and resource extraction. Economic growth has not been sufficiently decoupled from water resource use; as the economy grows, so does the demand for water (Henderson & Parker, 2012). This presents significant challenges in the sustainable management of water resources across the globe.

Water scarcity, which is defined as the lack of available water resources to meet needs sufficiently, has been ranked among the top three global risks over three consecutive years (World Economic Forum, 2016). This is partly attributed to increasing consumption patterns, demographic change, ineffective management practices and dynamic governance of a public good, which pose significant challenges to human well-being and the environment. For example, the global population is projected to exceed 9 billion people by 2050; it is estimated that 4 billion people will live in water-scarce regions with chronic water supply challenges (Clark & King, 2004).

South Africa is classified as a water-scarce country with an average rainfall of 450 mm per annum – almost 50% less than the global average of 860 mm per year. There are three major challenges regarding the availability of water across the country. Firstly, the spatial distribution and seasonality of rainfall is uneven as 43% of rain falls on 13% of the land. Secondly, the relatively low stream flow in rivers limits the proportion of stream flow that can be relied upon for use. Thirdly, the location of major urban and industrial developments in water-scarce regions necessitates large-scale water transfer schemes across borders, which is very expensive (DWA, 2012). The continuing trend in industrialisation and urbanisation is expected to place further pressure on South Africa's water sources unless appropriate corrective action is taken (DWA, 2012).

Failing water infrastructure is also a major challenge in South Africa: 37% of water is reported to be non-revenue water, which is water use not accounted for (Mckenzie et al., 2012). The amount matches the global average but is above the global best benchmark, which is closer to 10%. This large amount of water is often lost due to lack of infrastructure maintenance, misuse of water through taps that are left to run, old water infrastructure, vandalism and theft of water infrastructure, billing errors and unbilled authorised consumption (fire-fighting, mains flushing). To contribute to the efficiency of this already scarce resource, monitoring and leakage detection devices play an important role. It is also a way of comparing consumption patterns and creating awareness.

Historically, the management of water resources has focused on the supply side as opposed to demand management. This necessitated a strong focus on the development of hard infrastructure, which included the construction of large dams, reservoirs, tunnels and pipelines, and the local construction of systems of weirs, pump stations and irrigation canals. However, with escalating water demand threatening to surpass supply, South Africa is now faced with an urgent need for holistic water management efforts that put equal emphasis on demand management as well as new infrastructure, and maintenance and operations. The emphasis of building new infrastructure, often with minimal operations and maintenance budgets, has contributed significantly to the plethora of complex challenges South Africa faces.

South Africa is ranked nineteenth in the world for its contribution to published research related to water and waste water (Pouris, 2013). However, Rose and Winter (2015) highlight that the challenge is how to translate this world-class research into innovations that address current and future socio-economic challenges and develop a knowledge-based economy. Innovation is one of the critical success factors central to identifying solutions for addressing the systemic water challenges and interrelated socio-economic transformation. Yet, this requires concerted effort from government, business and civil society to build a robust innovation ecosystem. Even though South Africa has been developing innovative technologies in the water sector for decades with many of these innovations adopted globally, the country still faces significant water challenges. Solutions that improve access to water for impoverished rural communities, detect leaks and treat water, are needed to manage water resources effectively.

To accelerate the deployment of water innovations, South Africa has increased its funding for water-related research; for example, funding increased from R1.4 billion in 2000 to R2.1 billion in 2014, with government and businesses being the major funders (Pouris, 2015). The Water Research Commission (WRC) has shown commitment to driving water innovations and remains the main funder for water-related research in South Africa – they supported up to 65% of water-related research in 2014 (Pouris, 2015).

The Department of Science and Technology (DST) together with its agencies such as the Technology Innovation Agency (TIA) and the Council for Scientific and Industrial Research (CSIR), among others, are mandated to drive the South African National System of Innovation (NSI). In recent years, the Industrial Development Corporation and the Public Investment Corporation have started developing their water strategies and project funding mechanisms. Other institutions in South Africa are yet to prioritise water innovations to accelerate their deployment.

This book aims to document South Africa's water innovation story from the perspective of innovators by specifically developing an understanding of the effectiveness of the South African innovation ecosystem, which includes the NSI. To address this objective, four research questions were posed to water innovators:

- What is the status of the deployment of water-related innovations that have been developed in South Africa in the last 20 years?
- What are the enabling factors that are key for accelerating the deployment of water innovations in South Africa?
- What are the perceived barriers and opportunities for accelerating water innovations?
- To what extent have South African innovations achieved commercial and global success?

The book is divided into five parts. Chapter 1 highlights the importance of water resources for basic human needs and powering the country's economic sectors. The chapter summarises the water situation of South Africa and also highlights the necessity for developing and accelerating the deployment of water innovations in South Africa. The chapter furthermore presents the key research questions for the research and the methodology used to undertake the research.

Chapter 2 presents the review of literature: it starts by providing an understanding of the innovation ecosystem, and then goes on to critically discuss the South African NSI. The chapter concludes by presenting the South African National Water Research, Development and Innovation Roadmap (Water RDI Roadmap) that was developed to prepare the country to solve its water crisis.

Chapter 3 of the book presents some of the water challenges facing South Africa and some of the water innovations that have emerged in the country to address the documented water challenges.

Chapter 4 presents the findings and analysis of the research. The chapter discusses the key challenges that are barriers to accelerating the deployment of water innovations. It also provides directions on how South Africa can achieve successful deployment of water innovations.

Chapter 5 concludes the book and provides recommendations for accelerating the deployment of water innovations in South Africa.

2 RESEARCH METHODOLOGY

The study used a combination of a literature review, case studies and structured interview sessions with innovation ecosystem actors, including innovators, entrepreneurs, researchers, research funders and private equity asset managers. Water innovations were mapped through expert knowledge of existing innovations, and a comprehensive literature review that has identified more than 100 water innovations that have emerged in South Africa over the past 20 years. Each of the innovations was scored against specific criteria, which included the type and stage of deployment of the innovation, type of water challenges it addresses etc. The innovations that received the highest scores were shortlisted for further review by experts, and an extensive interview with the innovators.

Based on this approach, 19 initiatives, which included both technological, process and social innovations, were selected for consideration in this study. The water innovations discussed are used to highlight the types of innovations that have emerged in the water sector, but it needs to be noted that the list of water-related innovations discussed is not comprehensive in relation to the total innovations. The selected case study broadly covered specific issues that address water challenges related to rural sanitation, drinking water quality, water efficiency, water recovery and energy, and decision support systems (DSSs) for water management.

3 UNDERSTANDING INNOVATION ECOSYSTEM

The water sector is faced with a plethora of challenges. The complexity of these challenges in a rapidly changing world opens a window of opportunity for new, locally adapted and innovative solutions. Innovations not only apply to new sustainable technologies but also to new partnerships extending across public administration, research and industry: new business models and new forms of governance that are not only innovative themselves, but that can also stimulate and support technological innovations (Martins et al., 2013; Moore et al., 2014).

Furthermore, innovations do not necessarily need to be entirely new technologies or concepts but a combination of innovative ideas to improve current technologies and systems. However, for the purposes of this book, the sphere of innovation is defined in broader terms, encompassing significant improvements to goods and services, and the operational processes and business models.

To facilitate analysis, we describe innovation in terms of both innovation activities and the innovation ecosystem that supports those activities. Hence, an innovation ecosystem is a representation of the various actors interacting in the economic, political, and technological system to catalyse the innovation. This is illustrated in Figure 1.

3.1 Stages in the Development of Innovations

Any innovation commences with a novel idea and ideally progresses to implementation in the economy and society. This continuum can be usefully broken down into three broad stages, namely, early, middle, and late. Irrespective of the type of innovation, the stages in the innovation are sequential.

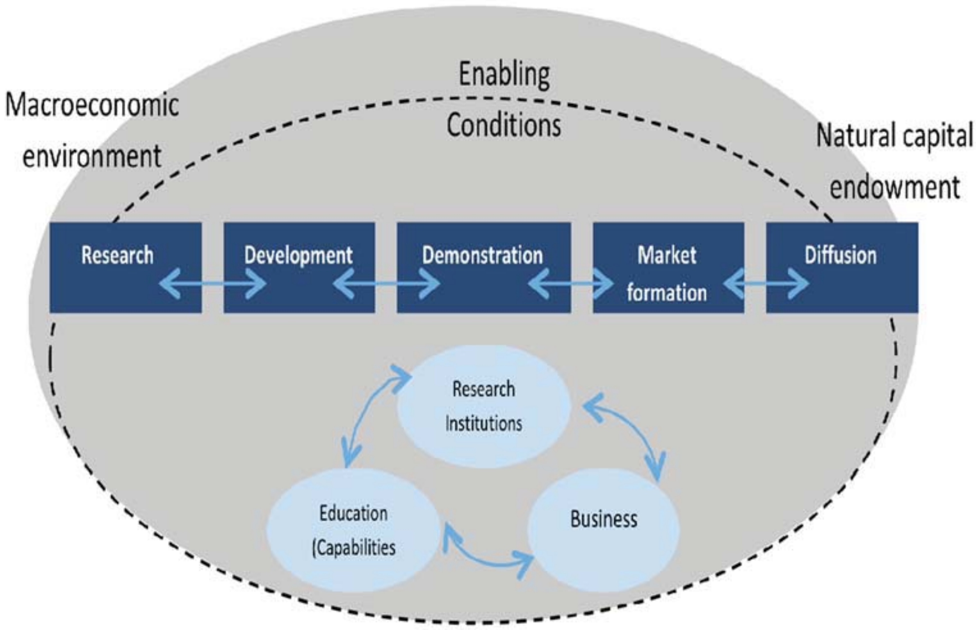

Figure 1: Key stages in the innovation ecosystem

All innovation activity involves a creative step, which is either radical or incremental, formal or informal. For the purposes of this book, it is useful to distinguish between frontier and adaptive innovation activities. Frontier innovation activities are novel solutions that have not been introduced yet. These novel solutions may be either radical or incremental and are most common during research and development (R&D). Adaptive innovation activities apply existing technologies into new contexts (Hultman et al., 2012). This adoption may be an entirely off-the-shelf transfer, or it may involve ancillary adaptations. It is most common during demonstration and deployment, and primarily involves learning by doing. Although the distinction between frontier and adaptive innovation should be seen as relative, at the extremes it helps distinguish pragmatically between the different requirements for creation (frontier) vs. replication'(adaptive) (Hultman et al., 2012).

While countries at all levels of development can engage in all types of innovation activity, higher income countries generally have far more overall innovation activity, relatively more R&D activity, and more reliance on frontier innovation to drive growth. In contrast, lower income countries have less overall innovation activity and a relatively greater focus on adaptive innovation. While there is no definitive model for how and how quickly the transition should occur, historical development experience has tended to emphasise the importance of adaptive innovation for developing countries over a relatively long 'catch-up phase' (Hultman et al., 2012). Since innovation is a dynamic, unpredictable and an uncertain process, success depends on creating the right conditions (Figure 2). Hence, a robust treatment of innovation requires an understanding of the innovation ecosystem and its absorptive capacity. Figure 2 shows the stages of innovation process and key obstacles to acceleration of innovations.

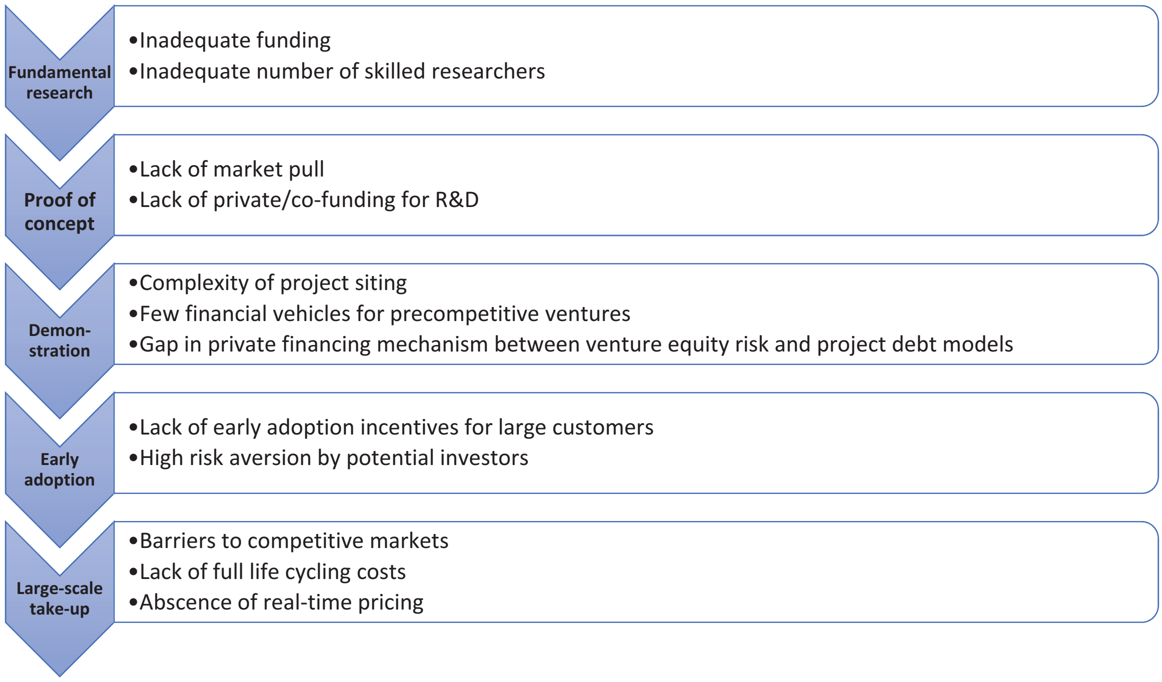

Figure 2: Key challenges encountered in the various stages of innovation and deployment (adopted from: National Academies of Science, Engineering and Medicine, 2016)

3.2 Key Actors in the Innovation Ecosystems

The innovation ecosystem reflects the individuals and organisations acting and interacting in political, economic, and technological systems to catalyse and sustain innovation activity. Its boundaries are unstructured and impossible to control; its interactions are multiple and subject to constant realignment, of a diverse nature and often intangible. It depends heavily on the effective circulation and communication of knowledge.

Figure 3 graphically represents the interrelated nature of the three components of the innovation ecosystem: actors, organisations and enabling conditions.

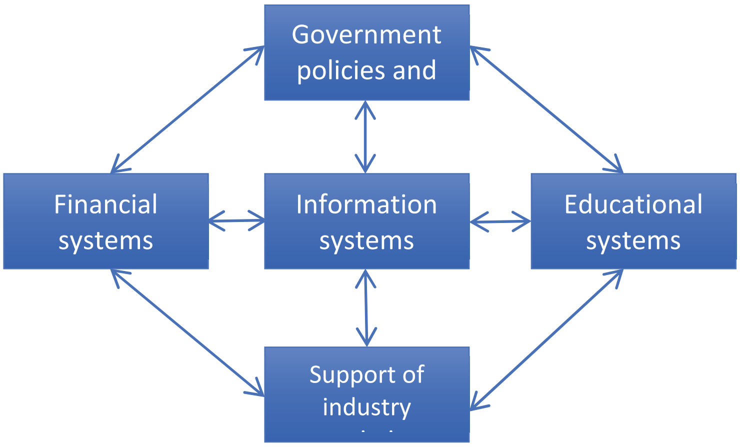

Figure 3: Main elements and linkages in the NSI (source: APCTT, n.d.)

Actors include the researchers, entrepreneurs, financiers and other individuals engaging in the innovation. These actors include individual innovators or institutions within which innovations are conceived or organisations that are mandated to promote innovation. Such organisations include universities, research institutions, science councils, business and knowledge networks (Hultman et al., 2012). In addition to actors and organisations, the enabling conditions include education and training support, direct public funding and private sector funding for innovation, a sufficient legal framework to allow innovators to benefit from their activity, infrastructure (e.g. the Internet), and supply-demand mechanisms that communicate economic and social conditions.

The robustness of an innovation ecosystem may also be influenced by other factors such as the macroeconomic environment and natural capital endowment. Macroeconomic factors such as inflation, fiscal policies and various regulations may have a direct implication on innovation activity and thus constitute an important factor of an innovation ecosystem (Hultman et al., 2012). The natural capital endowment of a country is also an important driver of innovation activity, with innovation initially focused on those natural resources but not exclusively. Similarly, countries that are less endowed with natural resources may be forced to innovate in such a manner as to overcome the shortfall of critical natural resources required to grow their economies. Critical to these enabling conditions is how well they link and align incentives of the innovation actors and organisations, and their activities; for example, the robustness of links between research universities and entrepreneurs to inform the direction of the former and feed commercialisation opportunities to the latter.

There is no definitive model for an optimal innovation ecosystem, and it depends on both the level of development and the nature of broader political, economic and social systems. However, all countries that have harnessed innovation for growth successfully have had the full set of actors, organisations and enabling conditions. While organisations may be either public or private and vary greatly across countries, the enabling conditions such as the policy and regulatory context, as well as market operations are closely dependent on government action except in mature ecosystems such as the United States of America (USA) and Finland where the private sector plays the key role in market operations. Moreover, these enabling conditions are set almost entirely by national- or subnational-level governments, with the global innovation ecosystem forced to work across (or as a supplement to) them. For developing countries, the robustness of its innovation ecosystem determines its absorptive capacity – its ability to adopt, adapt and successfully implement innovation (Hultman et al., 2012).

Unpacking these multiple interacting factors in the innovation ecosystem is essential to identify leverage points, through which innovation activity can be catalysed. Often there is a narrow focus on the key drivers of innovation, such as R&D and policies, while neglecting other important driver's such as markets or non-scientific social innovation and investment in water-related research. Therefore, a systems approach to understanding the innovation ecosystem is a useful way of unlocking systemic barriers to innovation activity. Due to the multiple levels of interactions, focusing on a specific issue such as water could provide useful insight into the robustness of existing innovation ecosystems. Despite water being a complex subject, R&D in the sector has thrived over the years; however, the challenges still faced by the sector are enormous.

3.3 The South African NSI

The concept of NSI rests on the premise that understanding the linkages among the actors involved in innovation is key to improving technology performance (OECD, 1997) (Figure 2). Innovation and the technical progress are the result of a complex set of relationships among actors producing, distributing and applying various kinds of knowledge to deploy and commercialise emerging innovations. The process of innovation is crucial to drive the country's economic growth and human development. Thus, the Organisation for Economic Co-operation and Development (OECD) (2010) highlights that the process of innovation helps to accelerate economic recovery and put countries back on the path of sustainability and greener development. Therefore, it is crucial that South Africa's NSI should be developed adequately to drive both economic growth and human development.

To position itself for a knowledge-based economy, South Africa was one of the first countries globally to adopt the NSI approach. The NSI concept was first articulated in terms of the Science and Technology White Paper (1996). The NSI was also documented in other policies in South Africa including The National Research and Technology Foresight (2000), and The National Research and Development Strategy (2002) (DST, 2014). The government also published the Ten-Year Innovation Plan, which was designed to shift South Africa's economy from one that depends on resources to a knowledge-based economy driven by developing strong technological innovation that would drive the economy and social development.

South Africa has made a good progress in improving the governance of the innovation system since it gained democracy in 1994 (Zhang, 2012). This is evident from strategies and socio-economic policies and government interventions that have emerged in the country. For example, the Gauteng Provincial Government establishing government bodies such as The Innovation Hub shows improvement in innovation ecosystem awareness. The re-establishment of South Africa's science and technology (S&T) policies in the form of the NSI reaffirmed the country's commitment to driving innovation. The transformation of organisational structures of public governance for S&T and the creation of new mechanisms for public funding of R&D have been achieved. However, the programmes that have been put in place by the South African government have not effectively achieved the desired results, which is to promote inclusive economic growth in the country.

It can be argued that innovation development has been achieved for a developing country; however, it has not translated into economic growth opportunities for South Africa. There are still inefficiencies and deficits in the development of an inclusive culture of innovation and the transformation of NSI (The Innovation Hub, 2016). Strategies developed in South Africa include strategies for indigenous knowledge, nanotechnology, astronomy and intellectual property, which have been derived from publicly funded research (Zhang, 2012). The strategies are significant and important steps towards building a strong NSI, but there is also a need for developing a comprehensive strategy around priorities, funding and need for support for non-market related innovations.

It should be noted that South Africa has inherited the basic building blocks of the innovation systems from the pre-democracy era. Thus, significant work was needed to restructure, rescale and re-orientate the poor framework of the 1990s and prior to that while also adding new elements to the innovations system (OECD, 2007). The newly developed South African NSI specifically acknowledged the need for transition into a low carbon economy in recognition of the sustainability challenges due to climate change, population growth and environmental degradation. The key purpose was to shift the innovation system, which served one set of social, economic and political goals, to a more inclusive system that serves different and a wider set of goals and that is also inclusive of the environment. It should be highlighted that South Africa has made tremendous progress in trying to make this shift happen. South Africa spends approximately R24 billion a year on R&D, which translates to a 0.76% of gross domestic product (GDP). The country has set an overall target of achieving an R&D intensity ratio of 1.5% by 2019 (Pouris, 2015). Policies, strategies, supporting institutions have been developed in post-apartheid South Africa to drive innovation in the country.

The development of policies and strategies to focus on innovation were further boosted by establishing the National Advisory Council on Innovation (NACI) in 2000. The NACI was established to advise the minister and government on a wide range of matters pertaining to innovation and systems in South Africa (Marais & Pienaar, 2010). The creation of the separate ministry of S&T in 2004 to raise political status of S&T in South Africa. This exclusive focus on promoting science, technology and innovation, and increase human capital development showed the country's commitment in operationalising the NSI in favour of a shift towards knowledge-based economy. The creation of a separate DST also led to institutions such as the

TIA and the National Intellectual Property Management Office being established to bridge the innovation gap between R&D from higher education institutions, science councils, public entities and private sector (Marais & Pienaar, 2010).

The establishment of the TIA led to the development of public funding mechanisms for stimulating and supporting innovation in South Africa. Funds such as the Seed Fund, Technology Development Fund, Commercialisation Fund and Youth Technological Fund were made publicly available to assist innovators in developing innovations from R&D to commercialisation stage. Establishing the Technology and Human Resources for Industry Programme (THRIP) also reaffirmed the country's commitment in driving innovation. THRIP is a Department of Trade and Industry fund, which was managed via the DST until recently. The broad reviews of policies and strategies the country has undertaken to focus on science, technology and innovation demonstrate that South Africa is committed to innovation and "innovation is an important policy construct in South Africa" (Manzini, 2015).

The key actors supporting R&D in South Africa include the government, science councils, higher education institutions, business enterprises and non-governmental organisations (NGOs). All sectors involved in R&D in South Africa recorded an increase in R&D expenditure in 2012/13, with the higher education sector having the greatest increase (HRSC, 2014). South Africa is headed in the right direction in terms of investment and capacity building in R&D to support innovation for economic and social development. South Africa has a strong capacity in technological and non-technological innovation-performing firms. The OECD (2007) suggests that these firms are largely business enterprises who also account for the bulk of capital input for R&D in institutions such as universities, even more than in other countries. However, Figure 4 also demonstrates that the skills, capacity and education in research, science and engineering are still very low compared to the global average.

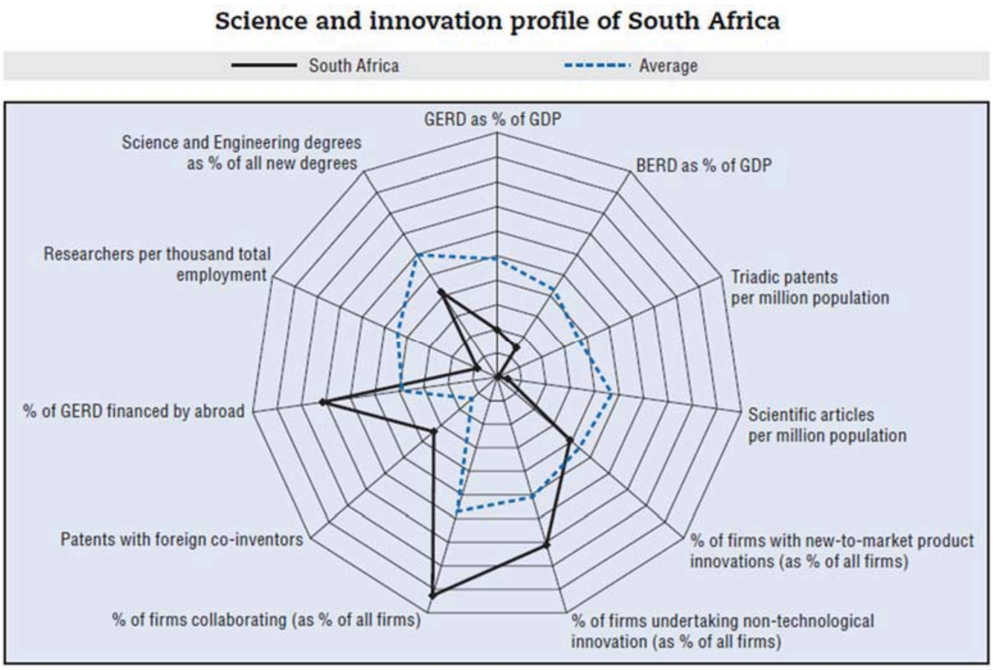

Figure 4: Indicators of South Africa's R&D and innovation capacity versus the world average

The strategies, policies and other supporting mechanisms in South Africa have seen the country making progress in innovation. For example, according to data from the World Economic Forum Global Competitiveness Index, the country shows a slow but steady improvement in the innovation pillar: the country was placed as the 38th most innovative nation in the world in 2015/16 (The RIIS & The Embassy of Switzerland and South Africa, 2016). Despite South Africa making progress in innovation, its R&D for innovation has remained technically driven. The focus has been more on S&T while social innovation and business-related elements of innovation critical for scaling up have not been given primary focus (Hart et al., 2015; Manzini, 2015). For example, it has been argued that innovation has been defined in a very narrow context, thereby limiting the potential of the NSI to address some of the systemic challenges the country faces, such as unemployment, poverty, crime, climate and demographic change.

The current South African NSI focuses on S&T-based innovation. As a result, other forms of innovation that could also be crucial and contribute significantly to the country's economic and social development are not being measured. Examples of innovations not measured in the current innovation indicators of South Africa as highlighted by Manzini (2015) include:

- **Soft innovation** – innovation that takes place across all sectors of the economy. Soft innovation adds significant value in the form of product design and packaging. It is likely to be missed in the current innovation metrics because it does not always create a new or significantly improved product.
- **Social innovation** – a value-adding outcome that emanates from different interactions between people; social innovation tends to focus on products and services. It also contributes to economic and social development.

The focus of innovation has been on the major industries that have contributed immensely to R&D in South Africa over the years (Manzini, 2015). These are sectors such as agriculture, mining and manufacturing, which are relatively small in terms of contribution to the country's GDP. However, there has been limited focus in sectors that are more dominant components of the country's GDP, but which do not innovate through R&D or in the manner that is anticipated by the current innovation metric of South Africa (Manzini, 2015). These include sectors such as finance, real estate, business and government services.

The Research Institute for Innovation and Sustainability (RIIS) and The Embassy of Switzerland and South Africa (2016) also argue that, in general, S&T-led innovations are more likely to be successful in raising funding, while social innovations are usually relegated to enterprise development or corporate social investment efforts. The return on social innovations is also envisaged to be smaller than that of massively scalable technology innovations; however, "social and soft innovations have the ability to contribute significantly in the pipeline of innovation project" (RIIS & The Embassy of Switzerland and South Africa, 2016).

Even though South Africa spends a significant amount of funding on R&D, relative to GDP it is inadequate. For example, in the financial year 2013/14, more than R25 million was spent on R&D, which amounts to 0.73% of the national GDP. This amount is relatively small, as its generally accepted that national expenditure on GDP should be 1.5% of the national GDP (HSRC, 2014).

Developed countries such as the USA and Finland, including some Brazil, Russia, India, China and South Africa (BRICS) countries, have invested significantly in R&D (Table 1). In terms of the Human Development Index (HDI), South Africa ranks below most BRICS countries except for India, which ranks last (Table 1). Understanding the HDI of a country is crucial for driving innovation: it can enable R&D policies that will help to harness innovation potential by adopting innovation and inclusive growth to drive economic development and social well-being. UNDP (2004) states that HDI is grounded in national and regional perspectives; therefore, HDI reports are ideally placed to make substantial impacts on policies and practices.

Table 1: HDI and GDP spent on research, development and innovation by BRICS countries (source: UNDP, 2016)

Country	Life expectancy (years)	Expenditure on education (% of GDP)	Adult literacy	Gross national income per capita (2011 PPP $)	Employment to population ration (% ages 15 and older)	GDP spent on R&D and innovation (%)
South Africa	57.7	6.1	94.3	12.1	39.9	0.75
China	76.0	n/a	96.4	13.3	67.6	2.01
Brazil	74.7	5.9	92.6	14.1	62.3	1.24
Russia	70.3	4.2	99.7	23.3	59.8	1.13
India	68.3	3.8	72.1	5.7	51.9	0.85

It cannot be denied that in terms of the structures, policies, strategies that exist to stimulate and support innovation, South Africa should be one of the leading countries in innovation globally. However, the main challenge remains on the performance and implementation of these policies. Hence, RIIS and The Embassy of Switzerland and South Africa (2016) note that there are several instruments and policies in South Africa, but that there is a significant need to enhance their performance and implementation. For example, mechanisms such as THRIP, which is a conceptually excellent programme, have suffered from poor execution.

Zhang (2012) highlights that one of the major reservations concerned with the difficulty of implementing policies in South Africa is attributed to the lack of human resources – meaning that there is a lack of professional staff members for proper implementation. Despite the lack of human capital, South Africa has shown excellent growth in science, engineering and technology (SET) university graduates in both numbers as well as gender balance, with SET graduates growing from 33 500 in 2005 to 55 500 in 2014 (RIIS & The Embassy of Switzerland and South Africa, 2016). This growth is crucial since science-led innovation is considered as a key component of the overall innovation system. Although there has been an increase in the number of people involved in R&D in South Africa over the years, engineers and scientists in South Africa are still ranked low at 106 out of 140 countries and the adoption of modern innovation by government ranked 119 out of 140 countries (RIIS & The Embassy of Switzerland and South Africa, 2016).

One of the major shortcomings of the NSI is that it is championed by academics, which excludes businesses and the private sector. However, for the NSI to be successful, the private sector should drive the investments in innovation. The government should not bear the full burden of funding for innovation in South Africa because the business sector also has an interest in innovation, thus it should be consulted in policymaking. Despite continued support for innovation activities in South Africa, the emphasis is on the formal R&D, thus disregarding some of the most crucial stages in innovation development, which include deployment and diffusion of the innovations. The NSI does not have a clear framework that involves or mandates both the business sector and the government to be responsible for driving innovation development in South Africa. There is a need for clear articulation on how both the private sector and government should work together to enhance innovation in South Africa to drive socio-economic development.

Lack of effective coordination across government ministries has resulted in poor political support for innovation from the government, the sole responsibility for driving innovation is given to government institutions such as the TIA, WRC etc. Specifically, there is no ringfenced budget across departments to support the testing of innovations at technology readiness level 5 to 9 and thus accelerate innovation to market or application. The public sector does not have an innovation culture or one that welcomes change in the processes, decision support etc.

In conclusion, to improve innovation in South Africa, the NSI should be inclusive, all the innovations should be regarded as equally important even if they are technological or social innovations as long as they contribute to social and economic development of the country. The institutions responsible for executing policies need to improve their performance to ensure the support is available, whether technical or financial, for all emerging innovations in South Africa.

Innovation is naturally seen as risky (RIIS & The Embassy of Switzerland and South Africa, 2016). The NSI should minimise this risk through specially designed instruments to attract private sector equity or venture capital investment. The length and the time before the innovation starts turning a profit also need to be scrutinized in the NSI to attract private investments. Education should drive innovation and entrepreneurship culture in South Africa. This will accelerate industrialisation, manufacturing competitiveness and overall operational efficiencies in organisations throughout the country (RIIS & The Embassy of Switzerland and South Africa, 2016).

The success of innovation depends on how the actors in the NSI framework relate to each other as elements of a collective system of knowledge creation as well as the technologies they use. Any single brilliant innovative idea without successful commercialisation means nothing to the entire NSI (Zhang, 2012). For example, if a brilliant innovation does not reach all the stages in the innovation ecosystem, it does not contribute to the entire NSI. Therefore, for the NSI to be effective, all actors – including the private sector – should be well aligned, coordinated, funded and incentivised around risk and market development.

3.4 The Water RDI of South Africa

Responding to the growing water scarcity, which is further exacerbated by the recent drought, the South African government adopted a robust approach to improve and encourage the need for innovative water solutions and highly skilled individuals to help ease the negative effects of the drought. In collaboration with the WRC and the Department of Water and Sanitation (DWS), the DST created the Water RDI Roadmap to prepare the country to solve the country's water crisis.

Compared to other middle-income countries, South Africa is recognised as a leader in the development and deployment of water management practices and technologies. The Water RDI Roadmap aims to elevate the key priorities areas that all water sector institutions should focus on by supporting innovation, building human capital and commissioning research by co-ordinating and aligning resources and funds. This approach will also make South Africa more competitive in the developing world and position South African innovators as key players globally. The Water RDI Roadmap sets a target of at least one breakthrough innovation every five years (WRC, DST & DWS, 2015).

The Water RDI Roadmap aims to increase the number of technology-based small and medium enterprises operating in the water sector. It also mentions that the enterprises should not only be consultancies as it has been the case over the past year. Small, medium and micro enterprises (SMMEs) should take the responsibility of developing cutting-edge technologies to address water challenges facing South Africa. The Water RDI Roadmap also aims to create jobs in the water sector and increase water access in communities, while providing sustainable sanitation.

The Water RDI Roadmap furthermore stresses that to achieve all the objectives of the roadmap over the 10-year period (from 2015 to 2025), an overall investment of R8.49 billion is required. This funding/investment is expected to come from the Water Levy (via the WRC), DST through funding organisations such as TIA, National Research Foundation (NRF), government departments such as the DWS, Department of Environmental Affairs (DEA), and Department of Agriculture, Forestry and Fisheries, and industrial funding from private sector and state-owned enterprises (WRC, DST & DWS, 2015). To achieve water security in South Africa, the Water RDI Roadmap emphasises that the focus should be on developing innovations to address customer needs; this approach is defined as a customer-driven approach.

The customers in the Water RDI Roadmap are categorised in four sectors, namely, agriculture, industry, the public sector and environmental protection. The customer needs identified in the Water RDI Roadmap are as follows (WRC, DST & DWS, 2015):

Water supply

- Increase ability to use more sources of water, including alternatives.
- Improve governance, planning and management of supply and delivery.
- Improve adequacy and performance of supply infrastructure.
- Run water as a financially sustainable business by improving operational performance.

Water demand

- Improve governance, planning, and management of demand and use.
- Reduce losses and increase efficiency of productive use.
- Improve performance of pricing, monitoring, billing, metering and collection.

The success of the development and implementation of the Water RDI Roadmap depends on the willingness from different stakeholders involved to engage and work with one another to achieve the vision of the Water RDI Roadmap.

The water sector in South Africa is arguably one of the most robust in terms of innovation activity. The strong legislative framework that set up the WRC as an entity and the Water Research Fund have ensured that the water sector is given high priority in terms of research. The Water RDI Roadmap presents an opportunity for other well-established institutions in South Africa, such as the TIA, CSIR, Agricultural Research Council and Mintek to partner and play a more focused and social needs-based role in water sector. This can be achieved by increasing funds and creating enabling policies that will support water-related R&D in South Africa.

4 CASE STUDIES OF SELECTED WATER INNOVATION IN SOUTH AFRICA

The following section provides an overview of selected water innovations in South Africa with a focus on sanitation, water quality, resource recovery and water efficiency. The case studies track the journey of various water-related innovations in South Africa from R&D, demonstration all the way to commercialisation, to understand the effectiveness of the South African innovation ecosystem. More specifically, the case studies unpack the experiences of individual innovators, including their motivation, challenges encountered and the kind of support they require or have received.

4.1 Innovations in Rural Sanitation

There is significant concern related to the provision of adequate sanitation, particularly in rural areas of South Africa. To address this, the South African government aims to increase access to improved functional sanitation services to 90% by 2019 and eliminate bucket sanitation (Stats SA, 2016). The Community Survey 2016 revealed that the percentage of households nationally with access to improved sanitation facilities increased from 62.3% in 2002 to 80% in 2015. However, there are still large variations between rural and urban areas in terms of access to sanitation facilities. Of rural households, 5.6% still lack sanitation services compared to only 1.1% of urban households (Stats SA, 2016). A range of toilet technologies are currently used in South Africa to address the backlog, which include buckets, chemical toilets, pit toilets, ventilated improved pit toilets (VIPs), dehydrating and composting toilets, aqua-privies, flush toilets with septic tanks, and flush toilets connected to central treatment works.

Figure 5: A VIP in a rural area (source: Infrastructure News, 2014: Picture: Mark Andrews)

VIPs have been previously accepted as the sanitation system that represents the minimum level of service (Tissington, 2011). A VIP is a dry on-site sanitation system consisting of a well-ventilated top structure built over a pit in which organic material decomposes. It is emptied every five years (Tissington, 2011). The VIPs are suitable for water-scarce and less densely populated areas, as well as areas that are not in close proximity to sewered networks. There are, however, two arguments against the government's choice of VIP technology:

Firstly, in a South African context, flush toilets are perceived as having a higher status. Therefore, many communities see flush toilets as a symbol of progress to which they aspire, which results in dissatisfaction with dry sanitation systems. Secondly, in most cases VIPs are poorly constructed, resulting in bad odour and lack of privacy (Roma et al., 2013). Thirdly, VIPs get full very fast, which presents a logistical challenge to municipalities. Many pits ultimately must be emptied manually – a job that is not only messy and unpleasant, but also dangerous as sludge typically contains a range of infectious human pathogens.

Over 85% of the approximately 2 million VIPs built in the last 15 years are now older than 5 years, with municipalities reporting that 82% of VIPs require emptying after 5–8 years or they may soon be faced with a situation where the excreta achieved through basic sanitation delivery are reversed (Still & Louton, 2012). In some rural areas and informal settlements, people still practice open defecation. This does not only affect their health and their environment, but it also strips people of their dignity.

Challenge: Poor sanitation in South Africa

In 2013, the Human Rights Commission found that approximately 11% (1.4 million) of formal and informal households in South Africa (predominantly in rural settlements of KwaZulu-Natal, North West and the Eastern Cape) still lack formal sanitation services. These households have never received a government-supported sanitation intervention. At least 26% of households (3.8 million) within formal areas had sanitation services that did not meet required standards. This was mainly due to the deterioration of infrastructure caused by lack of technical capacity to ensure effective operation, timeous maintenance, refurbishment and/or upgrading, pit emptying services and/or insufficient water resources. Some of the government implemented have failed to yield the required results, thus meaning that some people remain without access to proper sanitation

The provision of safe and adequate toilet facilities that are accessible to the poor can significantly decrease the burden of disease and therefore health costs. Improved health in turn gives rise to improved education achievements and economic output and thus help to improve the high levels of poverty in our country. With the advent of safe sanitation, contamination of sewage into the environment can be significantly reduced, thereby also protecting South Africa's vulnerable water sources. A range of innovative sanitation solutions have emerged in South Africa, which addresses three main needs:

- Interim sanitation solutions.
- Water efficient toilets.
- Operation and maintenance (O&M) of sanitation facilities.

Figure 6: An example of poorly constructed, demeaning and unsafe toilet (source: Mail & Guardian, 2014)

4.1.1 Case study 1: The pour-flush as a sanitation solution

In South Africa, there is a challenge with poor sanitation. Sanitation falls in two categories whereby in urban areas people use full-flush toilets and in rural areas people typically use VIPs whether supplied by the government or home-built. Both these sanitation solutions come with huge disadvantages. Full-flush toilets are expensive in terms of O&M and they use large amounts of water. VIPs are not safe (especially for children), unhealthy and fill up very fast. To bridge the gap between full-flush toilets and VIPs, the WRC looked for alternate and/or hybrid solutions that would bridge the gaps of acceptability, low water use and convenience.

The idea of the pour-flush toilets originates from the Asian standard pour-flush pan, which was originally designed for people who squat and use water for cleansing purpose. It had to be adapted to the South African conditions where people sit and use paper or toilet paper for cleaning purposes. The WRC then put out terms of reference that funded Partners in Development (Pty) Ltd to design, develop and test pour-flush toilets that would be suitable for users who sit and use paper. Following successful piloting of the pour-flush toilets in in 2010 and 2011 in KwaZulu-Natal, Envirosan Sanitation Solutions, a commercial entity, provided expertise and support for scaling up purposes in 2012.

> *"It all started with a vision inspired by several challenges that are faced by South Africa around providing sanitation to the poor and closing the sanitation gap … from a behavioural side people were not easily accepting the dry on-site sanitation of VIPs, and therefore we had to be innovative." (Jay Bhagwan, WRC, 2016)*

A pour-flush toilet is similar to a full-flush toilet except that water is poured in by the user rather than coming from a cistern. The incoming water forms a water seal in the bend of the pipe to prevent any smell from the pit coming back up into the toilet. The leach pit is placed a distance away from the toilet structure and it is not visible to the pour-flush toilet users, thus preventing any danger or health hazard. The pour-flush toilet is designed to be as simple as possible to avoid parts that can break or block. While looking similar to a full-flush toilet, there is no water tank, cistern, flusher or liquefier. The pour-flush toilet does not require plumbing, which means that there is no possibility of water leakages. After using the pour-flush toilet, the user pours between 1 litre and 3 litre of water into the pan to flush.

A pour-flush toilet is estimated to cost the same as a VIP to construct. The pour-flush toilet can be installed inside houses. It has been made safe to use by children. Envirosan developed child-friendly seats for the pour-flush toilet. The success of the pour-flush toilets has mainly resulted from the willingness of people to use them because they perceive the pour-flush toilet to be low in complexity and relatively easy to use, while consecutively bringing joy to the users because it functions almost like conventional full-flush toilets do. This is special for under-privileged communities whether in rural areas or poor urban informal settlements.

Figure 7: A fully constructed pour-flush toilet (source: Still, 2015)

Pour-flush toilet have been deployed successfully across South Africa. It has been commercialised by Envirosan. Pour-flush toilets have been undergoing extensive research and testing since 2009. The first two pilot projects were installed in Pietermaritzburg in September 2010. The pilots were then tested, which showed that pour-flush toilets operate successfully in the Eastern Cape, KwaZulu-Natal, Western Cape and Limpopo. The pour-flush toilets were tested in both household and school settings. The first major demonstration of the pour-flush was in Amajuba District Municipality in KwaZulu-Natal and 125 units were completed in 2015. Furthermore, the efficacy of the pour-flush toilets in dense settlements was successfully tested in the Western Cape.

To date, over 3000 pour-flush toilets have been installed in some South African provinces. In 2015, the eThekwini Municipality built 700 new homes in Verulam just outside Durban. These new homes were the first housing project where pour-flush toilets were installed inside. It is estimated that in KwaZulu-Natal alone there are about 1500 units of pour-flush toilets installed, while there are over 700 units in the Eastern Cape, almost 300 units in Mpumalanga and over 100 units in the Western Cape.

Figure 8: Construction of the pour-flush toilets in a school in Limpopo (Still, 2015)

Currently pour-flush toilets are available on the market; however, Envirosan changed the name from low/pour-flush to Eaziflush. Over the last few years, Envirosan has invested their own capital to develop injection moulds to make high-quality plastic pedestals and P-traps designed along the lines of the fibreglass pour-flush prototypes used to date. The WRC has been championing the pilot testing and demonstration of the pour-flush toilet over the years through various projects.

Figure 9: A commercialised low-flush/pour-flush toilet by Envirosan (source: Still, 2015)

4.1.2 Case study 2: Arumloo

The Arumloo is patented to Isidima Design and Development (IDD), which is an innovative engineering consultancy based in Cape Town. The company is committed to providing solutions to water and sanitation challenges facing the South African population residing in urban settlements. The development of the Arumloo was inspired by the experience of Jonny Harris in working with the WRC to install pour-flush toilets in the dense settlements of the Western Cape in 2013. The success in the Western Cape inspired Jonny Harris to develop a micro-flush toilet of a high-quality product that is suitable for all regular toilet uses. The WRC funded the development of the first prototype, which was tested in 2014. After the successful trials of the first prototype, Jonny Harris developed the design for the micro-flush toilet that was named Arumloo because its design mimics water movement in an arum lily.

Arumloo is a micro-flush toilet designed to use from 1–2.5 litres of water per flush. With most modern dual-flush toilets providing a three-litre small flush and six-litre large flush, the Arumloo is set to save one-third of water used for toilet flushing. The Arumloo uses a dual-flush mechanism. A flush is achieved using an innovative pan design that creates a vortex to remove stools more efficiently and a gush of water (gush flush) that enters into the P-trap. The innovative flushing features enable the micro-flush toilet to use from 1–2.5 litres of water per flush while offering an appearance and operation similar to that of other conventional toilets.

The Arumloo also bridges the aspiration gap between users of dry toilets and conventional toilets with a green conscience. It is best suited to more urbanised households who already have access to water infrastructure, and highly recommended for customers who are currently building houses since it is water efficient and will go a long way to save household water.

Figure 10: Image of Arumloo (source: IDD, n.d.)

> *"Product development is a long-involved process. We have been let down by various potential manufacturers quite far along in the process which has been very challenging. There seems to be a good demand for the product, but it is frustrating to have to keep customers waiting while we find new manufacturers." (Debbie Harris, Arumloo Business Manager, 2017, Interview with African Centre for a Green Economy)*

The Arumloo has the potential for scaling up; however, there have been some challenges that have prevented the technology from moving from R&D to deployment stage. It was predicted in 2016 that the innovation would be available in selected retail stores in the middle of 2017; however, that has not been achieved due to some challenges encountered by the developers of the technology. The developers reported that unavailability of funding and non-commitment from the potential manufacturers of the technology have been the main obstacles in deploying the technology.

In 2017, Arumloo hosted an investor show with the aim of attracting investors to help move the innovation from R&D to deployment stage. Although the investor show was deemed not as successful as envisaged by the developers of the innovation, it did manage to attract investments that will cover the patent and mould production costs of the innovation. There have also been some challenges with securing potential manufacturers for the technology. However, after the partnership was formed with investors, there are still negotiations currently underway with the potential manufacturers who are willing to manufacture the Arumloo.

A prototype of the Arumloo has been developed, which was tested successfully with toilet paper and a synthetic stool made from soya paste and newspaper. It has passed international maximum performance tests used for toilets. The first official Arumloo was installed on 17 November 2016. A journey to full-scale production for the Arumloo has been ongoing since the R&D of the innovation; however, full-scale production has not been reached yet. The Water Technologies Demonstration Programme (WADER) installed two prototypes of Arumloo in schools in Johannesburg to test and check whether the Arumloo flushes on as little as 2 litres per flush as it has been envisaged.

When it is available commercially, the company is planning to sell a ceramic Arumloo and a plastic Arumloo. The ceramic Arumloo aims to target new housing developments, hotels and individual homeowners. The ceramic Arumloo is set to be made available in one of the big bathroom retailers in South Africa at an estimated price of R2250. The plastic Arumloo will target schools, communities and Reconstruction and Development Programme (RDP) housing developments across the country at a price of R1400 per unit. The company already has a potential order of about 1000 toilets for when manufacturing commences.

4.1.3 Case study 3: Social franchising

The development of social franchising partnership innovation emanated from a research study funded by the WRC. The research was led by the CSIR and Amanz' abantu Services, which is a private sector water service provider. The research found that a social franchising concept could be critical for improving the institutional models for O&M of public sector sanitation and water service infrastructure.

The concept and approach to using a social franchising model to provide water and sanitation services to rural and urban poor communities has developed over a period of about 14 years. The initial work done towards investigation of the concept of franchising as a possible model for application for municipal water services was undertaken in the early 2000s. After cumulative reports, it was found that there is a huge backlog in the Eastern Cape regarding O&M of existing sanitation and water infrastructure. In 2008, Amanz' abantu responded to the findings of the research by developing Impilo Yabantu (which means hygiene of the people in isiXhosa) to play the role of a franchisor to develop social franchising partnerships in the Eastern Cape to assist in O&M of public sanitation and water service infrastructure.

Social franchising is defined as a model where a small enterprise enters into a business partnership as a franchisee with a franchisor using a tried-and-tested approach for undertaking the activities required to ensure that sanitation and water facilities, and other systems are operating in a reliable manner and to suitable hygienic standards. This innovative business model enables these franchised small businesses to operate sustainably by providing training and nurturing support, and by offering entrepreneurship opportunities for local communities. The social franchise supports small enterprises to provide appropriate local service solutions by way of its proven systems thus ensuring quality and reliability of services, peer learning, skills transfers, and health and safety training.

The water services franchising model was first developed in its current form on the Butterworth Pilot Project, which provided services to 400 rural schools from 2009 to 2012. Based on the results from the research, the Department of Education and the Amathole District Municipality entered into a contract with the emergent social franchise company, Impilo Yabantu Services (Pty) Ltd, to undertake certain O&M services at schools and rural households comprising cleaning, maintaining and desludging on-site systems.

The social franchising pilot programme for sanitation and water services also aimed to develop and test an outsourcing concept that could be rolled out to more than 6000 schools in 23 districts in the Eastern Cape. The programme aimed at expanding beyond the services offered to schools and rural households to include services to other public and private sector entities. The markets presently serviced by the social franchising partnerships are schools, clinics, rural villages and peri-urban areas where on-site sanitation is used (i.e. no sewerage).

Figure 11: Local franchisees at work in Butterworth (source: Wall et al., 2012)

The first pilot phase of the innovation in Butterworth encountered minor challenges that were mainly of administrative, procedural, and technical nature. The first major challenge during R&D was the reluctance of the municipalities to pioneer this new and untested concept, particularly where they were uncertain of what was allowed under the Public Finance Management Act, the Municipal Finance Management Act and supply chain regulations. This prompted the franchisor to seek development partners who were willing to grant funding for testing methodology and pioneering the innovation.

The Eastern Cape Department of Education was the first to adopt the innovation and approve a pilot project. Challenges encountered by the franchisor and the franchisees during the first pilot stage included delay of payments and some schools having no working or even repairable sanitation water facilities. In summary, these challenges are ideological, financial, alignment and interpretation of procurement systems, red tape, existing vested interests, competition, reluctance to adopt change management procedures and introduce a new way of doing business by deploying the small local entrepreneurs as franchisees operating in remote areas.

Despite the challenges encountered, the innovation has been deployed successfully in some parts of the Eastern Cape. As they gain experience, the franchisees no longer need the same level of guidance, and some have started contracting directly with infrastructure owners and are managing their own interactions with their new clients. To date, the innovation has created employment, developed small enterprises through training and have also improved O&M of site sanitation systems in rural villages, schools and peri-urban areas.

Figure 12: Franchisee at work (source: Amanz` abantu Services; n.d.)

Further confidence was demonstrated for social franchising of water services to schools in the Eastern Cape, when in 2015, an agreement was reached between the Eastern Cape Department of Education, the WRC and Amanz' abantu to expand on the model by introducing information and communication technology (ICT) management system solutions, menstrual hygiene, health and hygiene clubs, and the handling, testing and treating of faecal sludge in the East London district. The project is funded by the African Development Bank (AfDB) with the WRC being the implementing agency.

The success achieved in the application of the social franchising model caught the attention of the AfDB, which has provided funding to assist the franchise company, Impilo Yabantu Services, to expand its service offering and hopefully to take the innovation beyond the Eastern Cape Province into the broader African context. For example, Impilo Yabantu has been investigating the application of the social franchising model to manage community ablution blocks (CABs), which are public facilities installed by many municipalities to provide informal settlements access to basic water and sanitation.

Metropolitan municipalities who have installed CABs include eThekwini Municipality, Buffalo City, Nelson Mandela Bay and Cape Town. Some of these metros have shown interest in adopting the social franchising model for O&M of these CABs. However, there are still procedural and procurement protocols to be followed and contractual frameworks to be developed and tested in order to build confidence to use the social franchising model. This is another example of innovation developed fully up to application in field. However, there still appears to be a need to develop the commercial enterprises or the models that allow such social models to be replicated across the provinces, Africa and for other services.

4.2 Improved Waste Water Management

Poor sanitation and management of waste water treatment plants contaminate the environment. It has been estimated that up to 90% of sewage generated in cities in developing countries is discharged untreated (Corcoran et al., 2010). While the problem is less concentrated in South Africa, the trend in recent years is showing a deterioration in our management of sanitation services and waste water treatment plants. The provision of sewage treatment facilities does not in itself ensure satisfactory effluent water quality as evidenced from the results of the Green Drop audits previously managed by the DWS. Municipal sewage may contain contaminants such as plastics, rags, plant debris, pathogenic bacteria, fats, greases, nitrates, phosphates, heavy metals and other potentially hazardous compounds (Ansa et al., 2012). Unless removed or rendered harmless in the waste water treatment process, these can affect the environment and human health adversely.

Thus, any remedial or containment process must achieve an appropriate concentration of minerals and nutrients to avoid any acute or gradual influx into the environment (Sekomo et al., 2011. The South African government, through the DWS, has therefore mandated the remediation of all effluent (waste water) prior to discharge to the environment to ensure that treated effluent streams released by municipalities and industries comply with either general or specific standards and will not be detrimental and/or damaging to the environment. Innovation and advancement in the sector can play a significant role in the advancement of waste water treatment works to improve the management and remediation of waste water (Bdoura et al., 2009). Even so, managing and financing waste water treatment works, and controlling final effluent quality/discharge is complex. Some of the associated challenges include land availability, capacity at municipalities, complexity and financing of operations, maintenance and refurbishment (Muga & Mihelcic, 2008).

South Africa is a highly regulated water sector and while it does not prescribe the technology type, it does require the use of proven technology to treat waste water. This has led to a highly risk averse environment, which is a disadvantage to the testing of new technologies. Waste water treatment technologies currently deployed in South Africa to treat municipal sewage include waste stabilisation ponds or oxidation ponds, activated sludge plants, bio-filtration, biological nutrient removal, constructed wetlands, or combinations thereof (Tomar & Suthar, 2011).

Poor revenue collection in rural municipalities has led to a need to investigate simpler low-end technologies for such environments. The integrated algae ponding system (IAPS) offers a solution to waste water treatment in South Africa and has thus been adapted and tested for SA.

4.2.1 Case study 4: IAPS for treating waste water

The IAPS is a derivation of the Algal Integrated Waste Water Ponding Systems designed by Prof. William Oswald of the University of California, Berkley. The system consists of a primary facultative pond, containing a fermentation pit followed by a series of high-rate algae ponds. The IAPS does not include a pretreatment step followed by a trickling filter and waste stabilisation ponds unlike other waste water treatment plants, since the suspended solids are removed and degraded in an anaerobic pit of the primary facultative pond.

Although the innovation was first introduced in 1996 in South Africa, it was already being used in other countries such as the USA, Australia, Brazil, China and Belgium. The first pilot of the innovation was designed and commissioned in Belmont Valley waste water treatment works in Grahamstown. The first pilot was commissioned by Rhodes University with the support of the WRC and some significant support through industrial partnerships to drive the development of the innovation in South Africa.

The IAPS is a cost-effective waste water treatment technology for small- to medium-sized communities and most small towns and cities in South Africa that produce three by-products: energy from biomass, biomass to be used as fertiliser, and effluent suitable to be used for irrigation or direct discharge into the river (Wells et al., n.d.). With conventional waste water treatment, large amounts of electric energy, mechanical equipment, chemical and specific skills are required to run a plant effectively. IAPS could be a more cost-effective option to construct and operate and maintain.

The technology uses biological processes and micro-organisms that occur naturally in all sewage treatment processes. It produces an effluent that meets general authorisations without needing an external electricity supply, sludge handling and highly skilled operators. This makes it easier to operate and maintain as it has a larger scale-up and reuses water and products such as algae for fertiliser. It also has the potential to contribute to empowerment and development of local communities by creating employment and increasing productivity from improved water access and economic incentives in marketable by-products.

"A system like this has the potential to change the lives of people living in smaller areas who may not have experienced the benefits of access to water. It could create opportunities for entrepreneurship which had not previously existed in certain communities and at the very least improve the quality of lives of people who would have an improved water source for domestic and agricultural use," [Prof. Keith Cowan, Director of Environmental Biotechnology, Rhodes University (EBRU) in Institute for Environmental Biotechnology, Rhodes University, 2014]

Although this innovation has been fully piloted in South Africa, developing the IAPS has been challenging. The issue of poor waste water treatment has been prevalent many years ago; however, some local governments have not supported the approach that has severely hindered the success that could have been harnessed earlier by more municipalities and the private sector. Hence, IAPS has received limited support from local government. This is illustrated by Prof. Rose, who has actively been involved in the development of the IAPS.

"Government departments have been very slow. In fact, in some instances counterproductive in moving innovations forward in critical areas … Our group and others, and I have worked in collaboration and a number of other research institution such as the University of Cape Town (UCT) and Natal and we have developed really cutting-edge technologies, right through to industrial application, with absolutely no support from government." (Prof. Rose, Rhodes University, 2017, interview with African Centre for a Green Economy)

This highlights the contestation between the various actors and the importance of having the actors actively collaborating and working in partnership with each other, including the innovators understanding of the sector, business and different pathways such as licencing to get to the market. It is apparent from the quote above that there is a lack of understanding regarding the role of innovators in moving the innovation to deployment.

The IAPS innovation has been piloted across South Africa by various industries. In a study in collaboration between Rhodes University and the WRC to add to the treatment of domestic sewage, IAPS was investigated as a possible solution to treat winery, abattoir, tannery, distillery, mine drainage wastewaters and applications of water recycle and reuse in horticulture job creation programmes. The study was completed in 2010 and saw ten reports published and strong support from both the public sector and private sector was established. Currently, the innovation is in industrial application stage. The first IAPS demonstration plant in South Africa was built in Grahamstown by the EBRU in collaboration with Makana Municipality and the WRC. The Belmont Valley IAPS was intended to be a demonstration plant for the innovation.

Companies that piloted and supported the innovation include Western Planning in Wellington (but has since closed), abattoirs in Cartridge in KwaZulu-Natal, Sasol and East Rand Water Care Company. The DEA also piloted the technology nationally. In 2012, South African Breweries launched a strategic partnership with EBRU to develop Project Eden, which used high-rate algae ponds and constructed a wetland technology to treat effluent from the brewery's anaerobic digestion plant. The project was implemented in iBhayi Brewery in Port Elizabeth. The treatment plant successfully treated about 0.15% of water during its pilot phase. This technology has been piloted and probably requires a suitable commercial partner to take it further.

4.3 Drinking Water: A Lack of Access to Potable Drinking Water

Access to safe drinking water is a fundamental human need and a basic right (WHO, 2003). In South Africa, section 27(1)(b) of the Bill of Rights states that everyone has a right to have access to sufficient water. The lack of potable water of adequate quality is widely recognised as being a major barrier to health and economic development in most developing economies, and hence the production and provision of potable water is regarded as a major developmental priority in developing economies. Although access to drinking water is not only limited to rural areas, it is however predominantly an issue in rural areas and peri-urban/informal settlements. Rural areas pose challenges in terms of potable water provision including difficult topographies, population distribution over a very wide area, lack of skills for O&M of water treatment systems, difficult logistics and a lack of finance.

Figure 13: Drinking water conditions in some South African rural areas (source: The Water Project, n.d.)

However, despite the significant improvements made by the government in water service provision, many people still depend on water from rivers and other sources, which is particularly true in some rural areas and townships. The Community Survey in 2016 found that 89.8% of households nationally used piped water as their main source of drinking water, while 4.3% of households relied on water from unsafe water sources (Stats SA, 2016).

There are large variations between provinces that comprise mainly rural settlements and those that comprise mostly urban and informal settlements. Gauteng (97.4%), Western Cape (99%) and Free State (96.2%) have the highest percentage of households with access to piped water.

However, in provinces such as the Eastern Cape (17. 9%), KwaZulu-Natal (7.6%) and Limpopo (6.7%), households still rely on unsafe water sources (Stats SA, 2016).

Municipal waste water treatment uses a centralised treatment approach, which requires water transfer and distribution pipelines to be constructed for the reclaimed water to reach consumers/users (Ahluwalia, 2012). Therefore, the centralised systems approach is expensive because there are construction costs and operation costs for the transfer and distribution of pipelines. Responding to the disadvantages of a centralised approach, decentralised systems for waste water treatment and reuse have gained recognition (Ahluwalia, 2012). The promotion of decentralised waste water treatment and recovery technologies results in small-scale facilities that can be distributed evenly to benefit everyone (Ahluwalia, 2012).

The promotion of this approach benefits the most remote and isolated areas where water access is a challenge. Rural municipalities will benefit significantly from using a decentralised approach, as it leads to a more efficient use of available water, and it allows for independent, self-maintained and self-sustained facilities and technologies capable of recovering waste water resources (Ahluwalia, 2012; Domènech, 2011). Point-of-use (POU) innovations such as the VulAmanz rural water filter (to be discussed in Section 4.3.1) play a significant role in ensuring water access to remote communities; more especially in rural settings where waste water treatment infrastructure does not exist.

Rural municipalities face the greatest difficulty in supplying water of adequate quality and quantity because they have small customer bases and therefore often lack the revenues needed to hire experienced managers and to maintain and upgrade their water supply facilities. Interruptions in water service due to inadequate management as well as violations of drinking water standards are problems for some of these systems. Rural areas in South Africa such as those in the Eastern Cape, Limpopo and North West are often characterised by inferior infrastructure, low income, poor site conditions, unreliable water availability, and poor access to health facilities.

Water should be as accessible and affordable as possible, particularly for the most marginalised and vulnerable citizens. According to WHO (2016), home water treatment and safe storage of water can reduce diarrhoeal diseases by as much as 45% and save thousands of young children every year. The VulAmanz rural water filter is a perfect home water treatment technology that has the potential to provide safe drinking water for communities who have no access to drinking water and those who have limited access to access to drinking water. The POU water filtration system developed by VulAmanz Water Systems (Pty) is one such innovation that assists with generating safe drinking water for people who fetch water from rivers or dams.

4.3.1 Case study 5: VulAmanz rural water filter

The VulAmanz rural water filter is a product of research initiated as early as 2008 that has been tested, refined and transformed into a successful product. This research was led by Prof. Lingam Pillay (2009), who at that time was with the Water Technology Group at the Durban University of Technology. The main aim of the research was to develop a POU rural household water treatment unit on membrane technology. The research was primarily funded by the WRC, with significant funding also received from Umgeni Water. Savannah State University, USA, and the Asian Institute of Technology, Thailand, were collaborators on the project.

At that time, existing commercial microfiltration membranes were either not robust enough, or expensive, and hence suitable alternative local microfiltration materials were sought. The research group teamed with a local specialist fabric company, Gelvenor, to secure a unique microfiltration fabric that was used as a filter. The first Woven Fabric Microfiltration Gravity Filter (WFMF-GF) prototype or laboratory version was developed in 2012. Over the years, the primary inventor Prof. Lingam Pillay, now with the Department of Process Engineering in the University of Stellenbosch, together with Laurie Barwell of Innovus Commercialization Projects have put in significant effort to transform the prototype into what is now called the current VulAmanz rural water filter.

Figure 14: Pilot of VulAmanz in Limpopo (source: Gelvenor Textiles, n.d.)

The VulAmanz rural water filter is a new POU water treatment that uses a unique woven polyester microfiltration fabric membrane to treat water contaminated with bacteria and suspended solids, which is typical of waters drawn from rivers and other water sources in rural areas. The module consists of a PVC frame incorporating a permeate outlet, two sheets of fabric glued to either side of the frame, and a spacer between the sheets of fabric to facilitate fluid flow to the permeate outlet.

The unit is simple to use: the user pours raw water onto the tank, opens the tap, and collects the product. Although the device can remove bacterial contamination, an appropriate disinfectant is also added to the collecting vessel to maintain water quality during storage. Such POU water treatment units play a critical role in the short- to medium-term provision of safe drinking water to rural areas in South Africa and other developing countries where communities have to rely on untreated water extracted from rivers, dams and/or boreholes.

The VulAmanz can provide much-needed water in rural communities where people are forced to consume untreated water due to unavailable piped municipal supplies. The technology can produce approximately 25 L/hr per user. This is quite significant: according to the WHO, between 50 litres and 100 litres of water per person per day is needed to ensure that the most basic needs are met, and few health concerns arise. In addition, this innovation does not require any form of electricity as the treatment is gravity-driven, which contributes to energy efficiency. The technology does not require significant infrastructure. Not only does it remove sediment, particles and plant matter in the water, but it can also filter out *Escherichia coli* bacteria as proven in water quality tests conducted by the CSIR analytical water quality laboratory.

Figure 15: Energy efficient gravity-driven VulAmanz rural water filter innovation (WRC)

However, irrespective of the water quality produced by a water treatment device, it will be essential to add a disinfectant (typically chlorine) to cater for contamination of the vessels used for storage. Thus, it is necessary that the water treatment produces a top-quality product free of suspended solids, colloids, and most pathogens, and that can be disinfected easily.

"We were greeted with cheers!"

Apparently, the most vulnerable inhabitants, those under 1 year of age, did not have to go to the clinic as they did every month, due to the new quality of their drinking water. No more diarrhoea. No more dehydration.

"They were all now perfectly health" (Lauri Barwell in Innovus, E-News 31st Edition, 2014).

Figure 16: Prototype of the gravity-driven VulAmanz Technology (WRC)

The VulAmanz has been accepted by the communities where it has been piloted as it has presented them with many benefits. The innovation is contributing immensely in the fight for clean drinking water in rural areas of South Africa. It also sought out to address an ongoing barrier to health and development in rural South Africa that is caused by the unavailability of clean drinking water.

VulAmanz initially started by developing 25 units and surveys that were distributed in Limpopo to ascertain what people's expectation of the unit was. After gaining acceptance, 500 units were developed and piloted in two villages – Capricorn and Mbizana Municipality – over a period of one year, serving more than 2800 people. In Capricorn Municipality, the VulAmanz has been faced with limited challenges as the municipality was very supportive and co-operative. However, in Mbizana, there has been significant challenges due to:

- The village being completely remote, which makes it difficult to even communicate with potential users.
- The municipality having poor structures and communication channels.

The roll-out of 1000 prototype units for field tests is currently underway in the Capricorn District Municipality in Limpopo as part of a project funded by the national DST. The demand for the technology from other rural areas is expected to drive the large-scale commercial production and mass roll-out of this technology.

In 2014, VulAmanz Water Systems (Pty) Ltd was set up to commercialise VulAmanz. Currently the idea of the company is still alive; however, the innovators of the technology are waiting for the project funded by the DST/WRC to be completed to pursue commercialisation. Currently, there are three potential partners who are willing to partner with VulAmanz Water Systems (Pty) Ltd to commercialise the technology. It is expected that after the completion of the project in the next six months the company will be ready to start operating.

4.3.2 Case study 6: Hippo Roller

The Hippo Roller was invented in 1991 by two South Africans: Johan Jonker and Pettie Petzer. It was developed as a solution for people in rural areas who struggled to carry water in buckets on their heads. Although both developers worked in the military at the time, they grew up on farms. They were inspired by the impact of the water crisis in rural environments. After seeing the rural population struggling to carry water in buckets on their heads, Johan and Pettie decided to put their engineering skills to use to find a solution to the daily struggle of collecting water in rural communities. Initially, the Hippo Roller was known as the Aqua Roller, but the name was changed. It received public support during its development. Former president Nelson Mandela gave the project his personal endorsement, appealing to the private and corporate sectors, as well as donors, to actively support it:

> *"A personal appeal is made to your organisation to actively support a national project which will positively change the lives of millions of our fellow South Africans."*
> *(http://atlasofthefuture.org/project/hippo-water-roller-project/)*

The entire process of developing the innovation was self-funded despite being a critical innovative solution that would help ease the burden of having to carry water especially for young girls and women in rural communities.

Figure 17: Community members using their Hippo Rollers (source: Hippo Roller.org, n.d.)

The Hippo Roller is a barrel-shaped container that has a still handle attached to it so that it can roll easily. It is made from UV-stabilised linear low-density polyethylene for coping with bumpy and rough rural roads. It has a proven five-year lifespan and can carry up to 90 L of water at once. It is user-friendly to men, women, children and physically weak individuals because it does not require much effort to be pushed/pulled when transporting water.

The Hippo Roller is designed to help people in rural communities with their struggles of fetching water from community taps, rivers and boreholes etc., and is designed specially to ease the work of women and children who in most cases are tasked with the duty of fetching water for their households. It improves people's access to water sources while at the same time reducing the workload of having to carry buckets. It ensures hygienic storage of clean water for its users, mobilises and promotes social investment for the local communities by mobilising government, NGOs, corporations and individuals to invest in the well-being of the water-stressed communities.

Since its development, the Hippo Roller has contributed immensely to the socio-economic well-being of rural communities, it saves time by being able to collect more water in less time and this has far-reaching effects for rural populations, for example:

- It allows children to attend school more regularly without being delayed by the duties of fetching water.
- It allows women to attend to other household tasks/seek employment.
- It contributes to sustainable farming and ultimately breaks the poverty cycle.

The Hippo Roller also has positive effects on the environment in rural communities. The Hippo Roller compacts soil while rolling along the ground, which assists in preventing soil erosion, especially along well-used paths to and from water sources. It has a lifespan of five years or more. If it has been damaged, it can be used for other purposes such as animal feeding troughs or storage containers.

Initially the original idea of Johan and Pettie was to design a wheelbarrow with a water tank built into it with a low centre of gravity. However, when they were costing the model, they realised that the wheel would be the most expensive part of the solution. Thus, the initial idea changed, and they decided to put the water in the wheel rather than building a wheelbarrow with a water tank built on it.

Scaling up the innovation at first was a challenge, simply because the Hippo Roller business model relies on donor funding and sponsorship to provide it to those who need them the most. The model for individual purchases of the Hippo Rollers in a retail environment has not been tested although the demand exists. Getting the Hippo Rollers to remote rural communities is one of the challenges that have been experienced during deployment of the Hippo Rollers.

Over the years of development and deploying the Hippo Roller across the world, some lessons have emerged to help make the innovation better. The innovators have now realised the need for testing the innovation in the community and getting the acceptance of the product beforehand to counter any challenge that may arise after the product has been deployed. There has also been a need to redesign the shape of the drum, which is to have rounded edges to allow for easier handling and manoeuvring when the drum is full. The men in rural communities have started to help with water collection because of the Hippo Rollers, and they are proud of using the innovation. This also breaks the tradition in many rural areas where fetching water is viewed as a girl's or woman's responsibility.

Figure 18: Women using their Hippo Rollers for the first time (source: Inhabitat News, 2008)

The Hippo Roller is an example of a successful innovation that has emerged in South Africa. Despite relying on donor funding and sponsorship, the technology has been deployed across South Africa and it has also reached diffusion stage. It has been used in African countries and outside African borders, for example, it has been deployed in rural parts of India and Indonesia.

The Hippo Roller has a proven track record of over 25 years. In those 25 years, approximately 55 000 Hippo Rollers have been distributed in 29 countries, with most of those countries in Africa. It has reached rural women, children and elderly and currently there has been a rise in the off-grid market, as well as urban areas where water infrastructure is not consistent, or not available.

For further wider uptake, the Hippo Roller company is at the stage of scaling up production, which will see more moulds and outsourcing to other factories in West and East Africa, as well as possible the USA. There is also a possibility of developing a smaller version of the Hippo Roller that will be sold to urban users through retail outlets, which will be called Hippo Roller Lite. Adding to the Hippo Roller the company is also marketing their new complementary product, which is the Hippo Spaza, designed specifically with informal traders in mind.

The development of the Hippo Roller Spaza is expected to enable transportation and display of products for sale.

Figure 19: The Hippo Roller Spaza (source: Hippo Roller.org, n.d.)

4.4 Water Efficiency

Since democracy, the South African government has aimed to provide millions of people with access to potable water. However, many water supply systems in South Africa are compromised by huge losses of water referred to as non-revenue water (Mckenzie et al., 2012), especially in previously disadvantaged areas neglected during the apartheid period. Vast quantities of water are lost through dilapidated municipal water, leaking toilets, sinks and rusting steel pipes located on domestic properties.

Other inefficiencies in water supply arise from inefficient operational service delivery practices and a lack of technical capacity, including the knowledge needed to obtain financing for required interventions. Non-revenue water in South Africa is estimated at 36.8% (Mckenzie et al., 2012). The aging water infrastructure, ineffective water metering technologies, theft and vandalism of water infrastructure are a few of the many causes of water losses in South Africa. Aging infrastructure accompanied by theft and vandalism of water infrastructure in South Africa present a huge challenge for South African municipalities and the government due to the costs of maintenance and replacement of stolen goods such as water taps and pipes (Parliamentary Monitoring Group, 2015).

Figure 20 Water wastage in South Africa (source: Property24, 2012)

Water scarcity not only results from quantitative or qualitative scarcity, but also from inefficient use and poor water management (Dinar, 2003). Therefore, the need for efficient, equitable and sustainable water allocation policies has increased and new water management aims at investigating innovative strategies to yield more efficient water allocation and usage (Ringler, 2001; Rosegrant et al., 2000). It is questionable whether relying on the augmentation of supply, and particularly on imports, is a sustainable solution to water scarcity.

Firstly, there is only a fixed amount of fresh water available. If South Africa can increase its imports from equally water-scarce neighbours, it risks supply security in the face of regional disputes or disaster. Thus, 'getting more water' is not going to suffice in the long term if water is not used efficiently in the present. We require ways of ensuring that South Africa has effective water conservation and demand management programmes. This may require innovative tools and technologies to change behaviour, and to monitor, meter and repair infrastructure. It will also require organisational innovation to ensure robust revenue collection and customer support.

Figure 21: Water wastage in South Africa (source: Thomson Reuters Foundation, 2011)

Smart water management has become one of the key policy issues in the course of the growing challenges of scarce water at a global stage. Strong emphasis must to be placed on development and deployment of smart metering technologies to improve water management because the existing strategies have not been successful. The data available shows high water loss through leakages in the country. Smart meter devices can provide water users with detailed data at more regular intervals than conventional metering solutions. Therefore, they have the potential to simultaneously cut financial costs for the water users that result from high water bills and contribute to water efficiency by preventing water leakages. To contribute to this, the Geasy and the Aquatrip technologies were developed to ensure that users are able to monitor their water consumption and energy.

4.4.1 Case study 7: The Geasy

The Geasy was developed by engineers at Stellenbosch University and MTN Intelligence Lab, with significant funding support from the WRC, TIA and UCT. Dr Thinus Booysen who led the team that developed the innovation is the co-creator of the innovation. His research focus is on the Internet of things, with a focus on smart water and electricity metering and intelligent transport systems (specifically its application in the informal public transport industry in sub-Saharan Africa). Since the conception of Geasy, much has changed from the initial idea. Initially, the aim was purely to create a device that can monitor energy consumption. However, because of engagements with funders and other researchers, the idea of a device measuring both energy and water consumption attracted significant attention.

Figure 22: The Geasy equipment

The Geasy is an intelligent geyser management system. It provides full geyser control via any Internet-connected device and saves electricity through optimised scheduling. It is attached to a geyser to save energy and monitor water flow. The innovation allows the user to detect bursts and shuts off the supply of water and electricity once the burst has been detected. The user can also schedule control to optimise energy usage. The Geasy comes with a SIM card and a modem that automatically reports to their server where the data is processed, and feedback is given to the user.

If the user forgets to switch off the geyser before leaving the house, it can be switched off through an application on a phone or a program on a computer. This can be either done on the browser or on an application that is available on the Play Store.

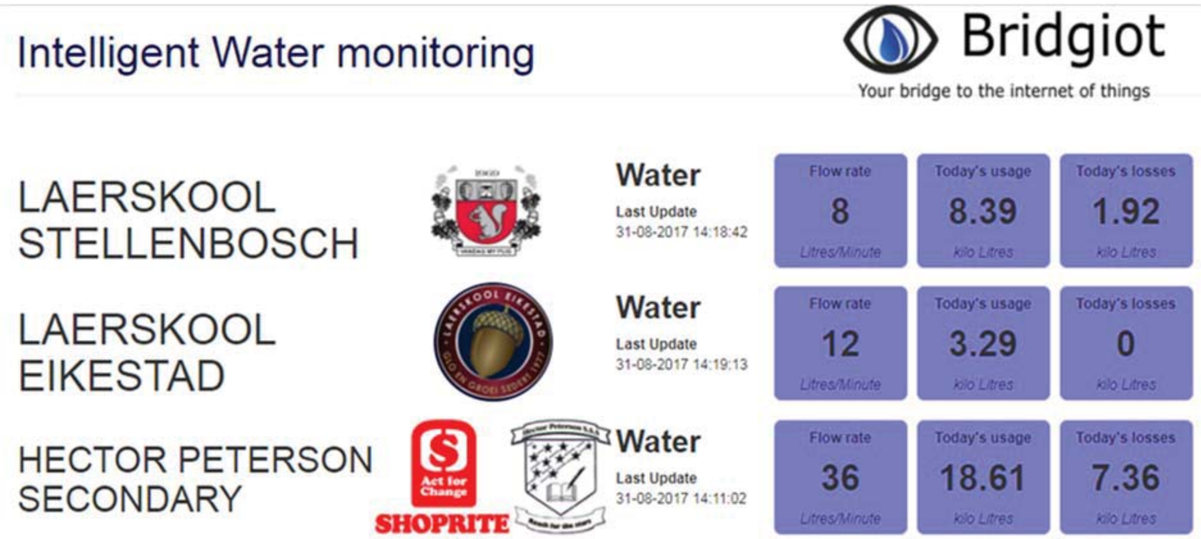

Figure 23: A Geasy daily monitoring report for three schools in Stellenbosch (source: Bridgiot)

The Geasy tracks how many baths, showers, and other usage events have occurred at what times. Apart from providing consumption analysis, the user can control settings (schedule and temperature) and predict the expected savings based on the control scheme changes through their mobile phone. The Geasy helps users to reduce the cost of electricity and reduce their water consumption. This is critical in a water-stressed country such as South Africa because it promotes water efficiency.

Several challenges were encountered when the Geasy was piloted in Mpumalanga through WRC funding. Poor plumbing standards at Chief Albert Luthuli Local Municipality and Mkhondo Local Municipality were the major challenges encountered. The municipalities involved were not technologically ready to receive it. Geyser plumbing standards were poor in both areas. In some cases, basic safety measures like pressure valves and earthing were not in place. This could not have been known until installation had begun. In addition, there was limited trust between the community and the municipality.

A survey was conducted to understand why people did not want a Geasy. Findings revealed that people do not trust anything that is free; they do not trust the municipality to have control of their hot water (despite the municipality not having control over an individual's Geasy). A lack of trust in the municipality coupled with the lack of awareness among consumers about the technology to be installed, demonstrated a need for extensive initial community engagement. Unfortunately, this was only discovered when the Geasy units were being installed. Poor cell phone network in Mkhondo was another setback. The MTN network in Piet Retief was not functional in some areas. This resulted in the units that had permanent MTN SIM cards to be removed. This was a significant setback, in terms of debugging time and installation time.

Despite the challenges encountered during the pilot phase, there were positive outcomes achieved that include: savings in water and electricity, additional partners were obtained, and the surplus units left over have created a market to offset cost of manufacturing units that were not used. Findings show that one participant reduced their consumption of hot water per day from 500 litres to 320–350 litres. That is about a 40% reduction in terms of water consumption. In terms of energy consumption, there was a 30% reduction in energy without any effect on the consumer.

The impact of the Geasy however is significant on a much larger scale. The project has been successful in terms of savings it generated and is able to do, but the unforeseen implementation problems hindered the project. It has proven that community acceptance and support of the product and innovation are crucial to the success of the product. The shortcoming of the Geasy is that it does not detect exact potential leaks in the water system and this provides a loophole as there are innovations also necessary to inform users of exactly where a leak is and switching the system off in that event.

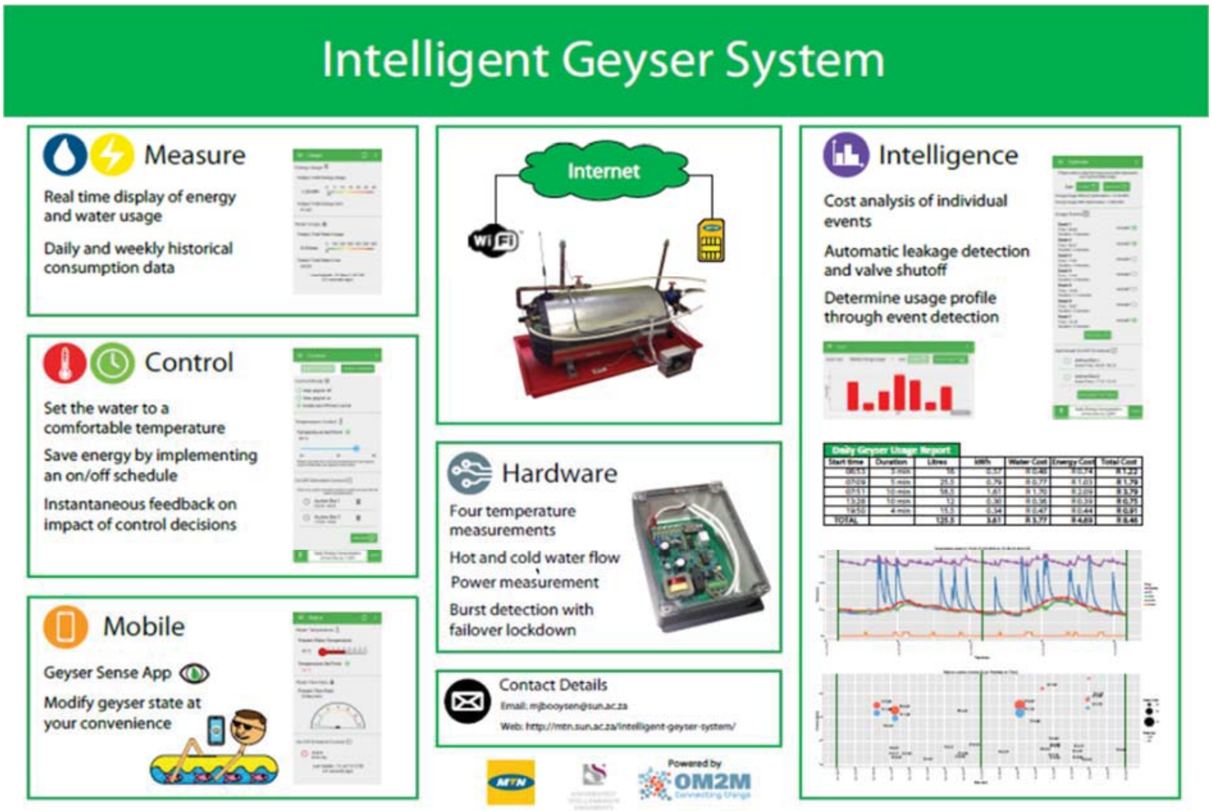

Figure 24: The process of the Geasy technology (source: MTN Mobile Intelligence Lab, n.d.)

The Geasy is commercialised by Bridgiot at the University of Stellenbosch. Bridgiot was developed through the support and help of Innovus. The water controller costs approximately R1000 and the energy device approximately R2000. The Geasy is an example of a water innovation that has successfully reached the deployment stage through the assistance of structures that have been developed within universities to drive innovation deployment.

4.4.2 Case study 8: Aquatrip

The Aquatrip innovation was co-developed between South Africa and Australia. Chris de Wet Steyn, who is a local expert on water wastage, brought the innovation to South Africa. The innovation was first introduced in South Africa in 2011. The main aim was to address the issues of water wastage through leakages. De Wet Steyn has engaged with both private sector and public sector since its introduction in South Africa working with his Australian development partners to provide the mechanism to save water wastage. The Aquatrip innovation has received much support from South African politicians, government officials and local authorities who have shown much interest in adopting the innovation. The Aquatrip is available in both South Africa and Australia and patents for the innovation have been finalised.

Figure 25: Aquatrip (source: source: Chris De Wet Steyn, Aquatrip)

The Aquatrip is a permanently installed and patented leak detection system with a built-in control valve. It monitors the flow of water in commercial, industrial, domestic and retail properties. The Aquatrip automatically shuts the water supply off if the tap is left running, if it leaks or if a burst pipe is detected. It offers users cost-saving benefits in water bills, monitors property damage in case of unexpected burst pipes while also saving water by preventing wastage.

The core product was commercialised a few years ago and ever since the company has been adding to the product. Since its introduction in South Africa, it has reduced water bills for users – it is estimated that the Aquatrip system can save between 30% and 80% of water bills. As a result of its acceptance in South Africa, the company is also considering relocating its manufacturing operation to South Africa to create local employment. To contribute to job creation and community upliftment, during the installation of the Aquatrip innovation in selected schools in Johannesburg, six graduates from the South West Gauteng college were brought in to help with plumbing and installation work of the Aquatrip.

Figure 26 : Image of an installed Aquatrip (source: Splash Plumbing, n.d.)

Several challenges were encountered during the development of the innovation. The first struggle was funding the business in the early days when the brand was relatively new, and the partners of the innovation had to convince the clients to purchase a new and unique technology. The innovators of the innovation highlighted that at first it was challenging to convince the market that the innovation is easy to install, and is a cost-effective water saving system. There were also challenges on getting government departments to buy into the new technology and roll it out through their facilities.

Chris de Wet Steyn highlights that:

> *"The problem has been convincing our customers of the need to save water in an environment where water was inexpensive relative to other utilities, water was not top of the mind of our customers but that is changing."*
> *[Mr de Wet Steyn, Director Aquatrip Water Services (Pty) Ltd interview with The African Centre for a Green Economy, 2017]*

The greatest challenge experienced was changing the people's mindsets about the effectiveness of the innovation. Despite the setbacks, the innovators of Aquatrip were very persistent and determined entrepreneurs and the innovation was deployed successfully. The members of Aquatrip continue to show confidence in the performance of their product and thus the business received quick returns on investment in their innovation.

The innovation has been deployed across South Africa and is considered commercialised. Currently the company is expanding into Namibia and Botswana and have a small presence in

East Africa. Chris de Wet Steyn highlighted that the success of the innovation in terms of deployment has been driven by the buy-in of companies that have invested in the Aquatrip.

The innovation has been installed in several schools in South Africa. Growth Point Properties installed the innovation in their properties, while Vodacom installed the Aquatrip system in their offices in Johannesburg. Mining giant Anglo American have installed the Aquatrip system in their mines in the Free State, Limpopo, Mpumalanga, Northern Cape, and North West. Other major companies that have installed the Aquatrip innovation include Investec, Barloworld, Sasol and Virgin Active. The innovation has also been deployed in several community centres, civic centres and schools across South Africa. For example, it has been installed in community centres in Lentegeur and Manneburg in Cape Town.

The innovation targets a variety of customers such as homeowners, property owners, municipalities and government departments. The Aquatrip system is sold between R1400 and R4500 per unit. To date, over 6000 Aquatrip systems have been sold in South Africa.

4.5 Water Recovery and Energy: The Challenge

Water and energy are interconnected, and this translates to the interdependence between these resources. At the heart of the relationship is the interdependence of resources – how demand for the one can drive the demand for the other, similarly, how the cost of one resource can determine the efficiency of production of the other. Put simply, water is needed to produce energy and energy is required to process, treat and transport water. As demand for water and energy increase and is expected to increase even further in the next coming decades due to the increasing population and the fast-growing economy, alternative sources of water and energy are needed urgently. Therefore, reliable and sustainable solutions for water and energy are necessary.

South Africa is leading in piped water and electricity access in sub-Saharan Africa, but the country relies mostly on coal-fired electricity that requires large amounts of water. South Africa’s electricity-generation activities and large industries account for 6–8% of water resources and are located within moderately and severely constrained water management areas (Pouris & Thopil, 2015). Therefore, the current electricity generation presents a direct threat to the country’s water resources, thus reliable and sustainable water and energy alternatives sources are required. Mabhaudhi et al. (2016) articulate that promoting water efficient energy generation would produce more energy while consuming less water. Conversely, improving efficiencies in water use and distribution could result in less energy consumption.

Despite the available opportunities for exploring alternative water and energy sources in South Africa, developing countries are criticised for lagging behind in the development of policies that will help enhance the exploration of alternative sources of water and energy (Mabhaudhi et al., 2016). Unlocking alternative sources of water and energy present a huge opportunity for addressing water quality challenges faced by South Africa. Innovations such as the Wave Energy Reverse Osmosis Pump (WEROP) and eutectic freeze crystallization (EFC) have emerged in South Africa to recover water and energy from alternative sources in a sustainable manner. These innovations are discussed in this section.

4.5.1 Case study 9: WEROP

The development of the WEROP emanated from an MSc project by Simon Wijnberg in 2002 at the UCT. The aim of his research was to design and develop a system that could capture wave energy and force seawater through a purifying reverse osmosis filter to support the rural coastal communities where he had been doing oceanographic work. The development received substantial support from the Department of Oceanography and Mechanical Engineering at the UCT.

During the R&D of the WEROP, it received substantial support in terms of funding and technical support from the WRC, TIA and the Institute of Maritime Technology (IMT). The NRF provided funding to develop the first model of the innovation, with employees and researchers from the IMT providing much-needed help to construct and test the first prototype. The WRC came on board in 2007 and provided funding for a full-scale prototype that has since been deployed offshore of IMT since 2009.

WEROP is a local technology that has the potential to provide clean, safe drinking water and electricity from renewable resources. WEROP is a patented locally built unit that sits on the seabed anywhere between 500 m and 1.5 km out to sea. The pump uses wave power to push water through an undersea pipe to a land unit that can be configured to run either through a reverse osmosis unit to produce fresh drinking water or through a turbine to produce electricity or both. The water can also be pumped at high volume for land-based seawater mariculture.

The technology is the first of its kind to be designed and built in South Africa. The innovation offers a sustainable, cost-effective and environmentally friendly option compared to current desalination technology. It is significantly cheaper to run than conventional desalination plants because it does not need electricity. The innovation can provide 1.5 megalitres of fresh water per day at R2.96 per kilolitre excluding finance charges and 9c/kWh for electricity once the water treatment unit has been installed.

Potential clients are coastal municipalities or private businesses, especially abalone farms located on South African coastal areas. The WEROP is flexible and modular so it has the capacity to produce seawater, fresh water and electricity in whatever quantities the client requires. The innovation is arguably one of the most environmentally friendly desalination options around as the sea units forms an artificial reef that is beneficial to marine life.

Impact-Free Water, which is the commercial company marketing the product, still needs funding for scale-up and further testing. Despite the successful proof of concept, Impact-Free Water is struggling to sell WEROP as clients are scared of being the first site. Impact-Free Water has already applied for funding from WADER and TIA to help scale up the innovation.

Currently, there is one possible client from the Cape South Coast who has shown some serious interest in adopting the innovation, but it wants to see the innovation operating to specification in a full-scale demonstration site before buying in. Currently, funding is the main constraint blocking the innovation from moving from R&D to deployment stage. The clients are given a choice when deciding to make use of the WEROP technology; they can either purchase the unit outright, or purchase an off-take agreement, i.e. a guaranteed amount of output over a set period of years.

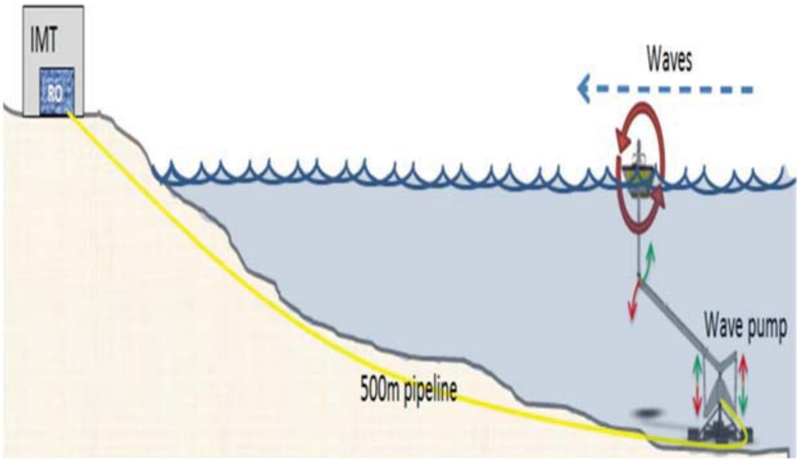

Figure 27: Extracting water and energy using the WEROP (source: Wijnberg, 2015)

Despite the successful trials at the Simon's Town coast from 2009–2016, the innovation has not been deployed commercially yet. The first prototype was deployed to sea in 2009 to test whether the innovation would achieve the desired results. The first prototype achieved the desired results, although there were some improvements made when deploying the full-scale prototype that was deployed offshore of IMT in 2009. The innovation is currently in the final R&D stage, which is aimed at testing scale-up and feasibility.

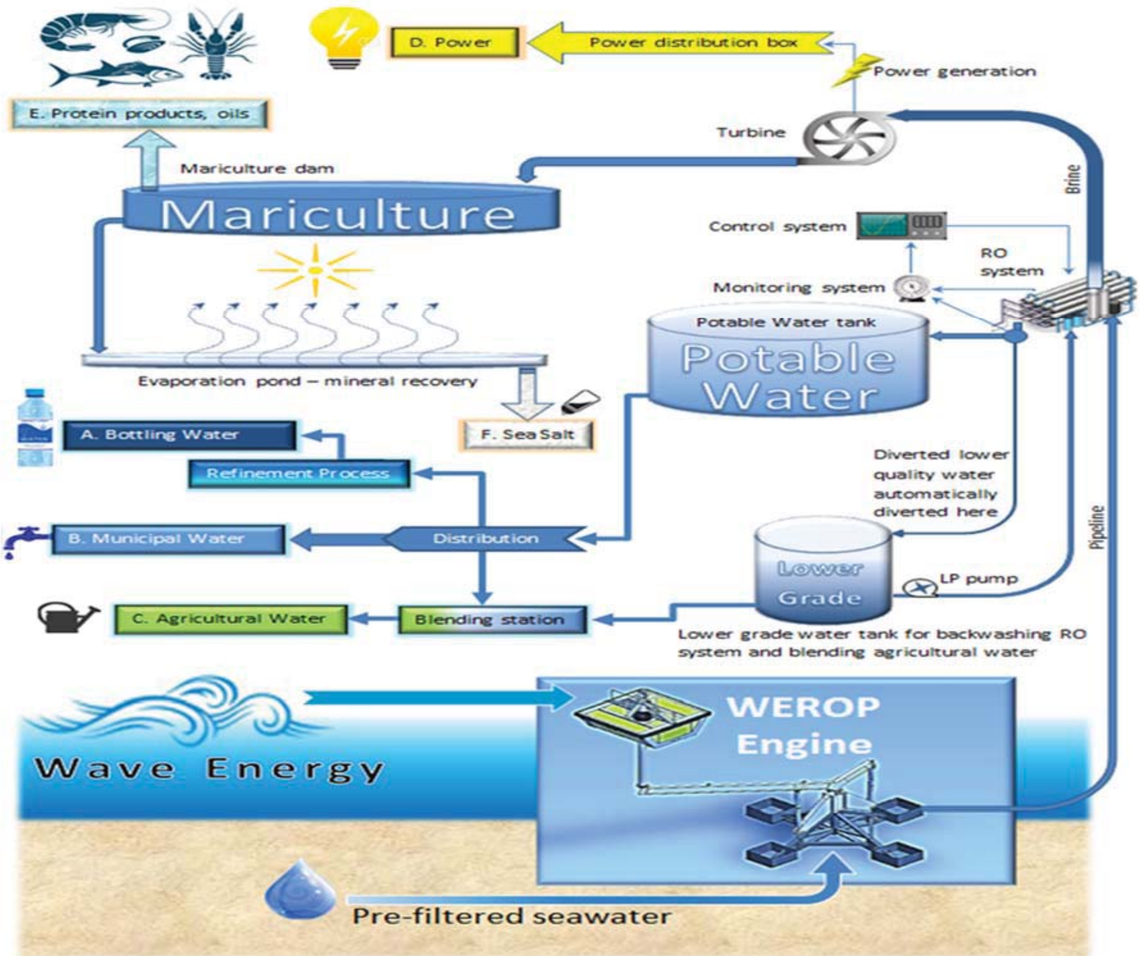

Figure 28: WEROP process schematic (source: Impact-Free Water, n.d.)

4.5.2 Case study 10: EFC

The EFC innovation was based on research carried out at the Tu Delft (Netherlands) and further developed through the research conducted by the Crystallization and Precipitation Unit under the Department of Chemical Engineering at the UCT. The research team was led by Prof. Alison Lewis, who is the dean of the Faculty of Engineering and Build Environment and has vast experience in R&D that leads to cleaner products made by cost-efficient processes. During R&D, the innovation received both public and private sector backing in terms of funding and technical support. The WRC has been supporting the R&D of EFC innovation since 2007.

> *"The WRC has been the major contributor to the development of the eutectic freeze crystallization (EFC) innovation as has been the industry, for example Sasol, Impala, Lonmin and so on. There has been enough support from the private sector, but the lack of support has been mainly on some of the government bodies." (Prof. Lewis, UCT, Interview with The African Centre for a Green Economy, 2017)*

EFC is an innovation offering a waste management solution for saline brines that result from using desalination technologies such as reverse osmosis, especially in the mining industry. EFC offers a novel, sustainable method for treating brines and concentrates previously regarded as difficult to treat due their complex nature. Consequently, they were discharged to evaporation ponds. The innovation is cost-effective to implement (a sixth of the cost of thermal evaporation) and offers a sustainable solution to waste water treatment.

EFC presents major economic benefits. It has been proven that EFC is between 20% and 70% cheaper than evaporative crystallization, which is a competitive process (Lewis et al., 2010). With EFC, pure water and pure individual salts can be recovered, thereby making a significant leap towards achieving zero effluent discharge. Because the heat of fusion of ice (6.01 kJ/mol) is six times less than the heat of the evaporation of water (40.65 kJ/mol) – the energy required to separate the water as ice is significantly less than that required to separate it by evaporation. EFC has been shown to be effective in separating multiple salts from water at full scale at Optimum Colliery from 2016 to 2017.

The EFC innovation in South Africa still requires extensive adoption since it can be used in mines, large industries and in the agricultural industry, but so far it has only been used by certain industries. The innovation is considered to be energy efficient and economically beneficial compared to other techniques that recover pure salts and clean water.

The EFC innovation has been commercialised and deployed in South Africa, although it has not yet been widely used. Research Contracts and Intellectual Property Services acts as the liaison between UCT's research community and the private sector regarding intellectual property, commercialisation and business development activities to develop EFC were signed in 2008 to help transfer EFC from the university laboratory to potential customers. To move EFC from lab-based research to full scale, the Coaltech Research Association comprising coal mining and processing companies, and various research organisations led by the WRC contracted Prentec in 2015 to design and build a full-scale demonstration plant at Optimum Colliery. Eskom commissioned its pilot EFC plant in 2016. It was designed and built by Proxa to test whether the innovation would be suitable for recycling water used in the electricity-generation process and treatment of acid mine drainage (AMD) so that it can be used at power stations. Currently, the Eskom plant can treat 40 000 litres of water every 20-day cycle.

4.6 Water Quality Management

Water is one of the key drivers supporting development and the elimination of poverty and inequality. Therefore, when the quality of water is not up to standard, the development progress suffers. Hence, water quality in rivers, dams and groundwater sources should be well managed to ensure development progresses. The economy, human population and ecosystems suffer from the decreasing water quality in South Africa. The decline in water quality result in a decrease in water that is available for drinking and for different economy sectors, thus directly affecting the country's economic growth. To grow the economy, create jobs, reduce inequality and poverty, water quality challenges in South Africa need to be addressed urgently.

Figure 29: Poor water quality in rural South Africa (source: Gelvenor Textiles, n.d.)

Water quality in South Africa is affected by different anthropogenic factors, including urbanisation, agricultural activities and extractive operations such as mining. The agricultural sector in South Africa is the backbone of the economy and it is one of the sectors that consume the most water and contributes to water pollution in rivers and dams. Rivers located close to or on agricultural land often suffer from water pollution resulting from the construction of canal rivers to direct water supply. The use of fertilisers, sediments and harmful pesticides poses a huge threat to the water quality of rivers when entering watercourses.

The mining industry is also a major contributor to water pollution. AMD is one such effect on the quality of water. Joubert and Pocock (2016) argue that the South African government requires a sustainable long-term solution to AMD, not only in the Witwatersrand, where up to 250 000 m^3/d of AMD must be treated, but also in the coalfields of Mpumalanga and KwaZulu-Natal. Innovations such as the VitaSOFT process and alternative reverse osmosis are some of the innovations that have been identified by the DWS as potential long-term treatment technology solutions for AMD in South Africa.

Due to the contribution of the mining sector to the country's economy, AMD has almost been ignored. In response to the research study Prof. Rose of Rhodes University noted that the government and mining companies in South Africa have known for years that AMD is a serious threat to water quality in South Africa yet support for innovative ideas to address the AMD challenges has not been prioritised.

Despite its danger to water sources, AMD requires treatment and cleaning with appropriate technologies to prevent damage to property and contamination of land and water. Although these technologies exist in South Africa, AMD treatment technologies tend to be expensive to develop, purchase and operate, hence the AMD challenge has not been addressed accordingly in South Africa.

Figure 30: Impact of AMD on water quality in a river (source: Environment News, 2015)

This section will first discuss water innovations that have been developed to treat AMD. However, it should be noted that water quality in South Africa is not only threatened by AMD, but there are also water quality and environmental health issues in general that are a direct threat to water quality in South African rivers and dams. To address these challenges, innovations such as the miniSASS and radio telemetry system have been developed in South Africa. These two innovations will be discussed after AMD-related innovations.

4.6.1 Case study 11: VitaSOFT

The VitaSOFT technology was developed by Dr Gina Pocock and Mr Hannes Joubert, owners and directors of VitaOne8 (Pty) Ltd. VitaOne8 is a water treatment consulting company that has been in operation since 2011. The VitaSOFT process was developed through both laboratory scale and pilot scale testing in response to further research needs identified when the BioSURE technology was piloted in the past. The development of the VitaSOFT process was funded by the WRC. A provisional patent application was filed in July 2014, with full international patents pending to allow for exploitation of the process on a global scale, while retaining the rights and expertise within South Africa. The VitaSOFT research team was nominated for the National Science and Technology Forum award in 2015 for research leading to the development of the innovation by a team in an SMME.

The VitaSOFT process is an active biological process to treat AMD. It integrates four active biological processes, including biological sulphate reduction, with various chemical processes to achieve water quality of potable standard, converting an environmental threat into a valuable water resource for domestic and irrigation purposes while producing valuable by-products (secondary resources). Biological processes tend to be more sustainable in terms of lower chemical usage and reduced electrical power requirements.

The process is unique in its design compared to other AMD solutions developed in South Africa. The VitaSOFT process can effectively replace high-density sludge (HDS) processes by removing heavy metals using the alkalinity and sulphides generated in the biological sulphate-reducing reactors, greatly reducing the amount of sludge produced when compared with the HDS process (Joubert & Pocock, 2016). Sulphate, calcium and magnesium salts are removed, thus eliminating the need to implement downstream reverse osmosis to remove salts from the water, except for the removal of monovalent ions such as sodium, potassium and chloride in some cases.

The potential advantages of VitaSOFT is that it:

- Eliminates the need for HDS neutralisation.
- Reduces the volume of solid waste.
- Reduces the amount of lime required (reduced cost).
- Has the potential to recover valuable by-products.
- Has flexibility to select for the final water quality depending on the requirements.
- Supplements the reserve through environmental discharge.
- Provides industrial quality water to save on potable water use.
- Supplies high-quality potable water directly.

The capex and opex costs of the VitaSOFT process compare favourably with other popular technologies, especially when viewed over an expected life of more than five years (Joubert & Pocock, 2016). The estimated capex of the plant is comparable to that of a biological nutrient removal waste water treatment plant. The opex is much lower than that of an HDS/reverse osmosis process due to the lower quantities of waste produced and the independence of large-scale lime or limestone dosing.

The potential for the co-disposal of industrial biodegradable organic waste offers an opportunity to recover some of the operating costs by charging industries for disposal of solids that may otherwise require costly and risky disposal in landfill. Some of the by-products of the process can be recycled within the process as input chemicals, further minimising waste and lowering cost, and others can be sold to generate additional income.

The main challenge encountered in the VitaSOFT journey has been accessing funding to demonstrate the technology at a larger scale. Various local and international funding avenues have been explored without success. The team continues to pursue potential commercial applications that offer the opportunity to demonstrate the process. They have recently put forward a proposal to the Trans Caledon Tunnel Authority (TCTA) via the WRC for funding to demonstrate the technology as part of the group of technology demonstrators who will test alternative technologies to the proposed long-term solution of HDS/reverse osmosis.

> *"Securing funding for the demonstration plant has been the biggest challenge, which we are still trying to overcome." (Dr Gina Pocock, 2017, Interview with The African Centre for a Green Economy)*

Because the R&D of the VitaSOFT was fully funded by the WRC, they are the owners of the intellectual property and resulting patents. However, VitaOne8 has negotiated a licence agreement with WRC to commercialise the innovation for the benefit of South Africa.

The fundamental science of the VitaSOFT process in terms of the microbiological, chemical and physical processes was researched in the laboratory and demonstrated on a small-scale pilot plant of 1 m^3/d. The pilot plant was constructed and operated at VitaOne8's R&D facilities in Pretoria using synthetic water resembling that of the Witwatersrand Western Basin. The information emerging from the small-scale demonstration will be applied to the design of a demonstration plant of at least 500 m^3/d. The demonstration plant will likely be located adjacent to the decanting AMD source at the Western Basin Water Treatment Plant, west of Johannesburg. Here, the water is currently being neutralised in an HDS process by adding lime and limestone as part of an initiative to select a long-term solution for a fully integrated treatment facility and service for AMD.

The objective is to design, build, operate and optimise this plant, with the goal of building confidence in the technology, training human resources, demonstrating the new research principles and refining the kinetic parameters required for large-scale plant design. The larger scale of the demonstration plant will allow for fundamental research into two specific value-add processes that will greatly reduce the chemical requirements on a large scale. The technology will enter the commercialisation phase upon conclusion of the demonstration phase.

4.6.2 Case study 12: Alternative Reverse Osmosis

Alternative reverse osmosis was developed by Mine Water Treatment Technologies (Miwatek). Miwatek is one of the leading companies in South Africa committed to developing AMD treatment solutions that allow for the production of reusable waste and that are cost-effective.

Since its inception, Miwatek has developed unique and cost-effective solutions to treat mine impacted water and industrial impacted water. There is a great need in South Africa for the treatment solutions to AMD because if it remains untreated, it could potentially decrease the country's water supply quality. The development of alternative reverse osmosis emerged at a time when AMD in South Africa first came into public awareness. The technology was developed by the founders of Miwatek and it was further refined by their own internal resources. The innovation was privately funded.

The alternative reverse osmosis is a treatment technology for primary treatment (desalination) of AMD and it offers a medium to long-term solution for desalination of AMD to water quality to meet water supply and demand. The DWS investigation into the feasibility of various options for the long-term management of mine water on the Witwatersrand has identified the alternative reverse osmosis process as a treatment method that has potential for mitigating mine water situation in that region.

Alternative reverse osmosis is a unique and exclusive South African technology that produces rapid and complete chemical reactions resulting in a dramatically reduced plant footprint and capital costs (Engineering News, 2013). The innovation does not require lime for neutralisation, so it offers no negative downstream effects. Also, it requires no pretreatment other than the pH adjustment. It can remove uranium from the final product; the removed uranium is concentrated in the brine. The alternative reverse osmosis technology uses various chemicals such as sulphuric acid, coagulant, anti-scalant, lime etc. in the process to desalinate AMD.

The unavailability of funds to demonstrate the innovation on a larger public scale to prove the efficacy of the technology has been reported as the major hindrance for its wider uptake. Currently, the development has been put on hold since there is no funding for larger public sector demonstration. Various technology funding events have been conducted by Miwatek, private equity and the United States Agency for International Development have been approached for funding. There has also been funding that has been sought by the WRC through DWS and TCTA to scale up demonstration. However, the funding allocation has been delayed.

The innovation is still a new technology that has not yet been fully tested and is still undergoing intense R&D. The alternative reverse osmosis innovation was piloted and demonstrated on the Western Basin by Miwatek in partnership with other various stakeholders such as the WRC. The technology was designed and demonstrated successfully on a small scale. To date, Miwatek has deployed a simpler version of the technology in Ghana, but the real innovation has not been proven on a larger scale due to a lack of funding. Miwatek is currently looking for investment partners to commercialise the technology.

4.6.3 Case study 13: miniSASS

The development of the miniSASS methodology emanated from the South African Scoring System (SASS), which was developed by the aquatic ecologist, Mark Chutter, in 1998. The SASS is a relatively simple technique developed for trained practitioners. It is generally beyond the reach of the general community because of the need to identify up to 90 invertebrate families that form the backbone of the technique (Graham et al., 2004).

The SASS system was widely used in South Africa before the development of the miniSASS. The SASS was used by institutions such as Umgeni Water, Umlaas Irrigation Board and the Department of Water Affairs and Forestry among others. With the rising concerns of river health, the availability of this resource as a source of clean water and community of species in a river showing signs of stress as a result of pollution, aquatic ecologists Graham, Dickens, Taylor and others (2004) saw the need to develop a simplified version of the SASS, the miniSASS, which is simplified and reduced in complexity.

The miniSASS was developed with the support of the WRC, the Wildlife and Environment Society of South Africa and GroundTruth Consulting. The miniSASS reduced the >90 traditional SASS aquatic invertebrate taxa used to derive river health classes into 13 simple groups to produce citizen science data and provide an indication of the health of rivers.

The miniSASS is a simplified version of the SASS suitable to non-scientists and scientists. It offers an opportunity for local communities to have a voice on the governance of their water resources. Although the innovation is not developed for scientists, it is scientifically reliable, and it is an inexpensive participatory technique to monitor water quality in rivers and streams. miniSASS allows for understanding of the successful, but technically complex, macro-invertebrate bioassessment technique to monitor the SASS (Graham et al., 2004).

Figure 31: Tools used for conducting the miniSASS methodology (source: WRC)

Participants who participate in the miniSASS innovation are provided with a chart showing pictures of different organisms inhabiting streams or rivers. The participants are expected to visit the rivers nearest to them, collect the organisms in water, identify them with the help of a chart provided (data can also be uploaded using the miniSASS application) and upload the type of organisms and their scores to the miniSASS website database.

The website provides a response immediately whereby the colour of the symbolic crab icon changes to show the quality of water in the river or a stream where results are collected. The colour range is from green or unmodified (natural condition) to seriously modified or purple crab (see Table 2). After the results assessment process, the participants are expected to spearhead corrective action to make sure the colour of the crab on the website remains green where possible, which symbolises a lack of pollution in the water. No river should be allowed to go beyond the moderately modified or yellow crab as it starts to lose the ability to provide ecosystem services. The participants are also encouraged to plan other local initiatives to restore and sustain the health of their rivers. These efforts must involve government, particularly the DWS, catchment management agencies, forums, water user associations, local authorities, etc.

Table 2: The colour range of ecological category (condition) (source: Minisass.org)

Ecological category (Condition)	River category	
	Sandy Type	Rocky Type
Unmodified (NATURAL condition)	> 6.9	> 7.9
Largely natural/few modifications (GOOD condition)	5.8 to 6.9	6.8 to 7.9
Moderately modified (FAIR condition)	4.9 to 5.8	6.1 to 6.8
Largely modified (POOR condition)	4.3 to 4.9	5.1 to 6.1
Seriously/critically modified (VERY POOR condition)	< 4.3	< 5.1

The miniSASS technique can be undertaken by anyone – it is a low cost, low technological environmental education tool. It has been used in South Africa over 15 years by environmental educators, general public and the South Africa River Health Programme. The innovation promotes the level of environment understanding and it has also enriched environment knowledge of many rural and urban school children including community groups across the country. The growing interest in the use of the innovation of the miniSASS technique provides a huge opportunity to transform how people look and manage their river water resources. Studying the efficiency of the miniSASS in uMngeni and Msunduzi catchments in KwaZulu-Natal, Cele (2016) observed that the miniSASS has been a valuable community-based education tool that had led to local government authorities responding quickly to resolve incidents of industrial water pollution.

Despite the miniSASS being demonstrated in schools and communities across South Africa, using the innovation in some communities and schools remains a challenge. This is largely because many schools and communities in South Africa still lack the necessary resources or commitment to water resources monitoring to use the miniSASS. In some cases, they need an incentive or preferable stipend. Sithole et al. (2013) argue that ICT access by the rural population compared to the urban population of South Africa is very low, and there is a shortfall in the implementation of the country's strategies for ICT spread in rural areas.

The information about the application process of the miniSASS app requires the use of a smart phone, computer and Internet connection, something that is still a dream in some rural areas in South Africa, contributing to low deployment of innovations like the miniSASS app in rural schools. In addition, in many rural communities, people rely mostly on rivers for livelihoods (irrigation water supply, domestic use). Thus, this innovation could be crucial in addressing the water quality challenges in rural areas of South Africa. It should be noted that miniSASS is the key monitoring tool incorporated in the DWS Adopt a River Programme since its design and launch in 2010. Currently the Adopt a River Programme was redesigned at the request of DWS to provide implementation scenarios and sustainability. Options include collaboration with the DEA branch called Natural Resource Management (Working for Water Programme).

The miniSASS model has been deployed across South Africa. But, the innovation does not lend itself to commercialisation since it is an innovation aimed at promoting citizen science in monitoring the health of rivers and streams and contributing to environmental education across South Africa. The model it uses for dissemination is similar to the Hippo Roller.

The innovation also informs participants about possible water pollution sources that contribute to the decrease of the water quality in rivers where the samples have been collected. The use of the miniSASS has also expanded beyond South African borders. Currently, it is being used in some African countries and beyond African borders. Figure 32 shows places where miniSASS has been used globally.

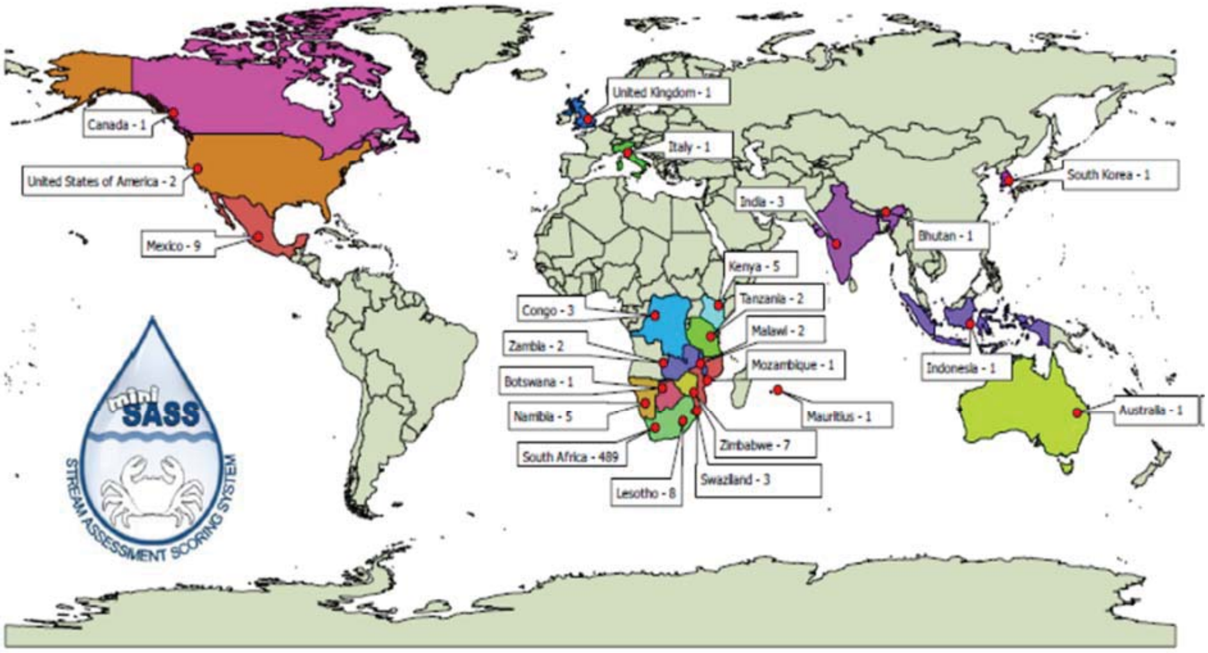

Figure 32: miniSASS studies in various countries around the world (source: miniSASS.org; n.d.)

4.6.4 Case study 14: Local Fish Radio Telemetry System

The development of the Local Fish Biotelemetry System emerged from a series of studies funded by the WRC for four years before the innovation was finally developed and tested in 2012. The successful development and testing of the biotelemetry system in the field was made possible by the collaborative efforts between the Water Research Group and the North-West University, the Centre for Aquatic Research at the University of Johannesburg, Scientific Services at the South African National Parks, E Oppenheimer and Son, and the biotelemetry system specialist Wireless Wildlife International.

It is understood that the overuse of aquatic ecosystem services in South Africa is depleting fish stocks. As a result, this poses a direct threat to social and economic well-being of South

Africans. Thus, the WRC saw the need to fund studies that led to the development of the Local Fish Biotelemetry System.

The biotelemetry system uses transmitting devices to monitor the behaviour and the physiology of animals in their natural environment. Biotelemetry systems are used internationally as the most effective way of acquiring behavioural information of aquatic animals over extended periods within their natural environments. The innovation is a combination of a remote and manual tracking or monitoring systems (monitoring systems include the use of listening stations deployed in the study area) as well as smart tags or transceivers. The tags are attached to the aquatic organisms being monitored. After animals have been tagged, they are released back to their natural environment to re-establish their normal behavioural patterns. The remote monitoring systems can record and transmit the information from the tags from far away to an Internet-based data management system.

The researchers are then able to monitor the continuous behaviour of the aquatic animals (for example, fish) for longer periods using the remote and monitoring systems. The data from the tagged animal can be accessed any time by logging on to a data management system from any computer that has Internet access. Researchers can download real-time behavioural data from any tagged aquatic organism in the field, which allows researchers to document for a long uninterrupted period the difference between how disturbed and undisturbed organisms interact with each other in real time in their natural environment.

The type of behavioural aspects that are monitored for aquatic organisms include the location of the animal, its movement, its activity, environmental variables, the depth of the animal in the water, and the temperature of the water. This enables the team of researchers to evaluate the response of the monitored aquatic organisms to changing habitat variables, flows, water quality components and weather variables. The innovation also allows the authorities to react quickly when they observe the change in behaviour of the monitored aquatic organisms because of things such as reduced flows or a chemical spill into a river. The authorities stand a better chance to deal with the polluters and the technology will allow managers to deal with the polluters accordingly. The technology also allows authorities to make better decisions when it comes to managing and conserving the ecosystems. The fish biotelemetry can be used on strategic catchments, especially where conflicts on water allocation (reserve determination) are of great concern as well as in biodiversity sensitive spots.

The technology has been developed and tested successfully in the field (Figure 33). Tests have been conducted on yellow fish, tiger fish and one Nile crocodile. These animals were tagged, released and monitored for eight months in the Crocodile River. The results of the behavioural data, daily activity patterns and the response displayed by the animals monitored were described and statistically analysed, and the technology was proven to be effective in the field.

After initial successful refinement and production of the manual, training on monitoring methods and analyses techniques were continued, as the technology is envisaged to contribute immensely towards the conservation of South Africa’s aquatic water and biodiversity in future.

Despite the progress that was achieved in developing the technology in 2014, there is no conclusive evidence about the innovation being moved towards deployment after it was successfully developed and tested in the field. Contacting the people involved with developing the innovation proved to be difficult as they could not commit to the scheduled interviews and did not respond to emails that were sent to them.

Figure 33: Water Research Group MSc student holding a tiger fish carrying a transmitter (source: wrc.org)

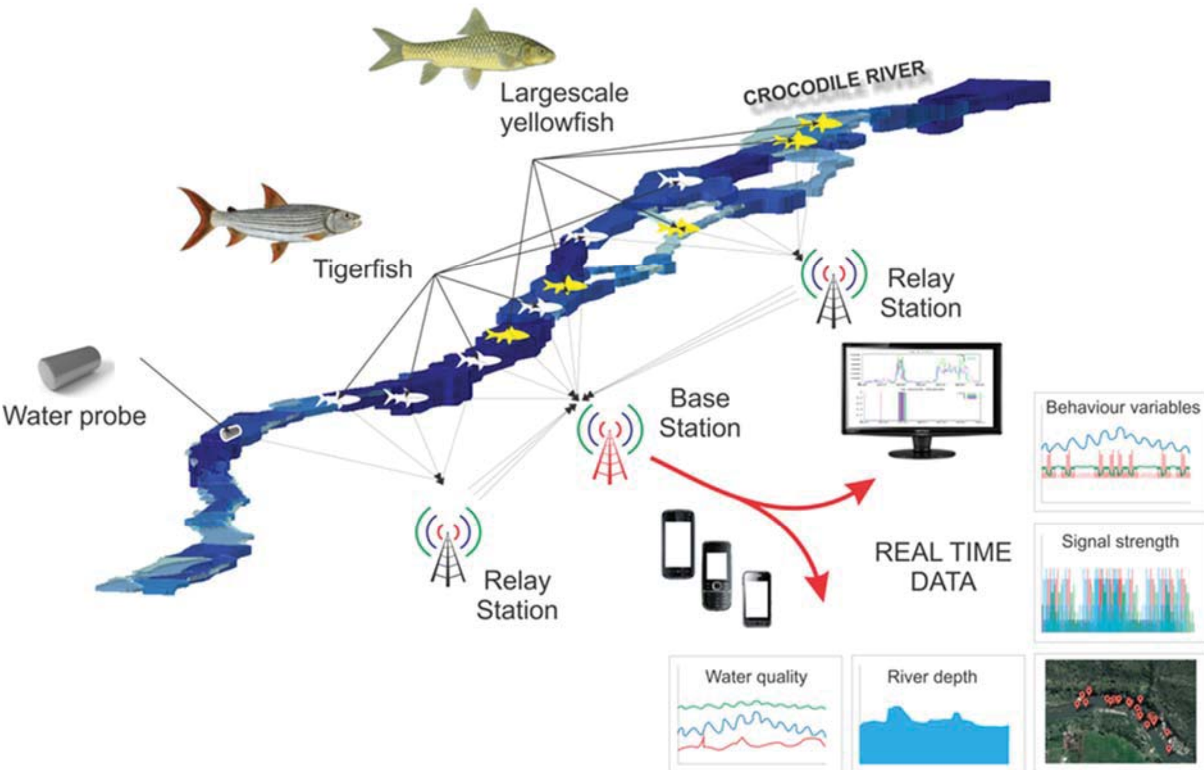

Figure 34: Testing and generating real-time data through fish biotelemetry. Transmitters can be left placed in water without being attached to a fish and still provide most of water quality data at speed (source: WRC)

Although in this innovation cycle, the conservation authorities and DWS were involved in testing the tool, the general problem with moving innovations such as the Local Fish Biotelemetry System forward mainly emanate from the fact that they are developed by academics for academic research papers and that there are no business people involved in the development processes. The incentives that exist in universities are mainly for publication, there are no incentives for deploying innovations. The main problem emanates from the fact that researchers are likely to abandon the innovation once they have completed their studies. The tool therefore needs partnership and strong marketing effort, not only in government departments, but also from individual farmers in game farming, etc.

4.7 The Need for Improved DSSs to Address Water Challenges

DSSs include frameworks, protocols, processes, methods, tools, and models for integrated water resource management to improve decision-making (Stewart et al., 2000 in CPH Water, 2001). A DSS can assist water service providers to improve their water management, water and waste water treatment operations, water distribution and infrastructure asset management. In addition, DSSs help water stakeholders with critical issues such as managing budgets for water treatment, managing water services efficiently, and providing municipalities with crucial information and knowledge about budget allocations. This information is crucial for making decisions about which water services should be prioritised in municipal budgets.

In South Africa, DSSs were used initially to address water quantity issues although they evolved over the years to also address the issues related to water quality challenges. Under the South African Municipal Structures Act (Act No. 117 of 1998), municipalities are given the sole mandate to provide water services within their own jurisdictions. Therefore, DSSs for water management systems in South Africa are mainly aimed at municipal level, where municipal managers are responsible for supplying and managing water services.

A poor DSS is a cross-cutting issue that is required to address all the challenges discussed in this book. Small urban municipalities and rural communities are most likely to be affected by these challenges because of low capacity and poor resources. Therefore, the adoption of decision support tools and guidelines is necessary. The information and knowledge carried out in the DSS will enable the efficient provision of cost-effective potable water and management of water resources and services. The ability of municipalities and other entities to install, manage and maintain new waste water infrastructure has been constrained by large deficits in engineering and technical skills, inadequate capital and operating funds, and skewed compliance incentives (Smith, 2009).

Water authorities and drinking water companies are often challenged with how and where to abate water contaminants of emerging concern in the urban water cycle; therefore, it is often unclear to stakeholders how to deal with several aspects of the contaminants such as sources, properties and mitigation measures (Fischer, et al., 2015). DSSs such as the Downstream Response to Imposed Flow Transformations (DRIFT) Flow Methodology, WATCOST, Waste Water Risk Abatement Plant (W_2RAP) and the Mine Water Atlas (MWA) are some of the many decision support tools that have emerged in South Africa and are crucial for providing water resource managers with the necessary information and knowledge to inform their decision-making. These decision support tools are discussed further in this section.

4.7.1 Case study 15: DRIFT Flow Methodology

Southern Water Ecological Research and Consulting developed the DRIFT methodology. Its development began in 1998 and to date it is still being developed further. Southern Waters is an ecological research and consulting company based in Cape Town. The company provides specialist skills in aquatic ecosystem assessment throughout South Africa and overseas. Within Southern Waters, the DRIFT was developed by Prof. Cate Brown, Dr Alison Joubert and Prof. Jackie King.

The development of the DRIFT was funded by Southern Waters Ecological Research and Consulting with some consolidation funding provided by the WRC. The first funding from the WRC was used to consolidate the early development and write the DRIFT manual, while the second funding was used to programme DRIFT DSS software. However, despite the support from the WRC, Southern Waters spearheaded the development of the DRIFT.

The DRIFT was developed to provide detailed and transparent predictions on how ecosystems could change over time as a result of water resource developments such as dams. These predictions are based on a range of client-selected water development scenarios for discussions and negotiations among governments and other stakeholders.

The development of the DRIFT drew its inspiration from the relatively new science of environmental flow (EFlow) assessments that have evolved in the last 30 years (King et al., 2008). Water stakeholders now recognise EFlow assessments as a central part of integrated water resource management and sustainability planning. Thus, the DRIFT is increasingly being used and specified internationally.

The DRIFT is a process and computer program for managing knowledge on the links between river flow and ecosystem functioning. It does this by using a combination of data, knowledge and experience of the scientist and local people to predict how the river ecosystem will change in future if there is a water resource development.

The DRIFT also predicts the social and economic impacts that water developments have on river ecosystems. It includes a custom-built Microsoft Excel DSS software program to generate summary flow categories from daily hydrological data and to provide a graphic relationship between flow volumes/distributions and river condition (Seaman et al., 2013).

The DRIFT provides government, donors and other stakeholders with clear guidance on the benefits and costs of proposed water resource developments. The use of the innovation is very important for developing countries, where many of people rely heavily on natural resources of rivers for their livelihoods and well-being and where most dam developments are planned for the next few decades.

Main challenges that emerged from developing the DRIFT were related to limited support for patenting and launching the DRIFT. Since the development of the DRIFT, Southern Waters has approached various organisations for assistance with marketing the DRIFT methodology.

The company has had many of its requests for guidance, marketing and assistance with launching the DRIFT turned down. However, through the support of the company and some assistance from the WRC, the innovators showed resilience and worked very hard until the DRIFT was developed and well-known across the country and other in parts of the world.

"We have approached numerous people and organisations for assistance with marketing the DRIFT over the years – all to absolutely no avail and so we continue doing what we can on our own. The single exception was the WRC that provided us with two tranches of funding." (Prof. Cate Brown, Southern Waters, 2017, Interview with The African Centre for a Green Economy)

One of the challenges currently facing further scale-up of the DRIFT is the limitation in the present non-user-friendly state of the software and its associated user manuals. Other prevailing concerns include the need to start marketing the DRIFT, offering training workshops, working out how to make it accessible to other users while maintaining the intellectual property rights and the master copy of the software, keeping other users of it up to date with modifications, and generally developing its overall appeal and ease of application.

There is significant competition facing the innovation, coming from other similar methodologies developed in other countries, which is a threat to upscaling. Hence, the company being in competition for 19 years has realised the need to control and market its intellectual property, but the lack of support to market the DRIFT is seen as a challenge that could hamper the progress of the innovation. The application of the DRIFT is seen as an opportunity for further development of the approach and software. The DRIFT was awarded funds by the WRC in 2009 for the first transition of DRIFT from Excel software to Delphi programming language.

"We continue to adjust this version as and when time and funds are available but recognise that the kind of development now needed is beyond that available through the average South African research project or water resource contract." (Prof. Cate Brown, Southern Waters, 2017, Interview with The African Centre for a Green Economy)

There has been growing emphasis on sustainability across the world and this has increased the demand for the DRIFT applications, which has put a strain to Southern Waters because it has become difficult to develop the tool by itself to meet the high demand and make the concepts more broadly used and marketable. Thus, the company has seen the need to start offering licences to other companies to apply the DRIFT. To date, the company has sold two licenses to two separate companies (one in Pakistan and the other in India).

Since its development, the DRIFT has been deployed in South Africa and other countries, and the innovation is considered commercialised. The innovation was first deployed successfully in the Lesotho Highlands Water Projects in 1998. Since then it has received much attention and seen major uptake outside South African borders. The DRIFT is one of the innovations in South Africa that has enjoyed tremendous success in terms of deployment. As a result, it has been recognised by major organisations as a good practice methodology including the World Bank, International Finance Corporation, Asian Development Bank, International Union for Conservation of Nature, World Wide Fund for Nature, Okavango River Basin Commission, the South African, Pakistani and Tanzanian governments, the Permanent Court of Arbitration in The Hague, and more.

To make profit for the application of the DRIFT, the company charges a nominal USD1000.00 "DRIFT development" fee per application on top of their consulting fees to use DRIFT in a project. A fully comprehensive EFlow assessment ranges in cost from USD100 000.00 to USD1 million and this is a substantial proportion for any planning budget. The money is used to cover the cost of the consultants' time.

The DRIFT is run by a core team of three developers plus other local professionals in the field of hydrology, hydraulics, geomorphology, water quality and biology. The DRIFT has brought millions of rands to South Africa. To further the commercialisation of the DRIFT, Southern Waters is planning to launch DRIFT-EFlows.com, of which the deadline was March 2017, but the company is running late as the team is currently busy running projects to fund the DRIFT development.

4.7.2 Case study 16: MWA

As a result of the persistent and documented AMD challenges in South Africa and the impacts of mining activities on water, the WRC responded in 2014 by putting out a call for proposals to produce a MWA that would map the environmental vulnerability and mining activity for all the water management areas in South Africa, and then overlay them with a risk assessment of ecological status. Golder Associates was awarded the contract by the WRC to develop the MWA.

According to the WRC, the innovation is meant to introduce mine water and its geological, hydrological and legal context, while at the same time examining geographical foundations of water quality, quantity and distribution. It is hoped that the innovation will also provide insights into the challenges and opportunities facing South Africa regarding the quantity, quality, protection and use of its water resources. The MWA is the first of its kind to be developed; there is no other country that has ever developed such innovation.

The MWA was launched in 2017. The areas in the MWA are colour-coded: the areas that are coded red depict that there is a high mine water threat in those areas; the areas that are coded blue show that there is lower risk in those areas; and the areas that are coded yellow show that there is a moderate risk. Therefore, areas that are coded red should not be damaged any further as the damage to them will put more strain on humans and the environment. The areas that are coded blue also show that in those areas ecological status is very good, and the rivers located in those areas are important for both humans and biodiversity, thus new mining activities should not be explored in those areas.

The main reason behind the development of the MWA was to serve as an educational reference for legislators and universities. It is also geared towards raising public awareness about the critical linkages between water and mining activities. The innovation is intended for various stakeholders in the mining and water sector to understand the impacts of mining on the water resources in South Africa. The targeted stakeholders include mining companies, investors, government departments and students. However, it is cautioned that the innovation does not replace the Environment Impact Assessment; therefore, it cannot inform users where to mine and where not to mine. The MWA can only assist with the decision-making process regarding the possible impacts of mining activity in a given area.

"Decision-makers will be able to look to the Atlas for background information and tools to assist in fulfilling commitments made in other recent events and declarations." (Dr Burgess, WRC, 2017 in WRC.org)

The MWA is regarded as a useful decision support tool for banks and investors. When a business is seeking investment for a mining activity, the bank or the investor can check the MWA if the place of proposed mining activity is classified as a vulnerable area or not. If the place is vulnerable and is flagged red in the MWA, the investor/the bank will know that although mining activity can happen in that area, the cost will be high, and this might mean that the return on investments will be low or it will take time to receive it. According to Dr Burgess, the MWA will help guide and prioritise investment in mitigation and remediation activity for sites already damaged by mining activities or other impacts related to the mining activity.

The innovation does not follow a commercial pathway; therefore, it can be accessed from the WRC free of charge. Anyone who is interested in using the innovation can request a hard copy from the WRC or it can be retrieved online as a PDF from the WRC website. The WRC will also distribute the MWA as a fully interactive digital database of spatial information for geographic information system users. Furthermore, there is an online web map portal for people to browse the data sets. There will be large printouts for people that need details on a particular water management area so that they can display them on their walls.

4.7.3 Case study 17: Manual for a costing model for Drinking Water Supply Systems: WATCOST

The WATCOST costing model was developed by Swartz Water Utilisation Engineers. The innovation was developed with WRC funding support. The WATCOST manual is intended for various stakeholders in the water sector. The targeted stakeholders include but are not limited to decision makers, consultants, engineers, planners, water supply authorities, and the DWS. The innovation provides users with instructions on how to use the tool, input component for users to enter the required information, software for cost calculations, output component for providing tables and graphic costing results, and a database of information for doing cost calculations (Swartz et al., 2013).

WATCOST is a costing manual for predicting the cost of water supply systems. The manual estimates the cost for operation, maintenance, and management of water supply services. It estimates all the cost for all stages of drinking water supply process (raw water, water treatment plants, clean water storage and the distribution of water). Both municipalities and consultants have limited comparative costing information for drinking water treatment system options on which to base their decisions for new water treatment schemes, resulting in incomplete planning and inadequate budgeting for these systems. In the light of this, this innovation seeks to bridge the gap by specifically determining the costs of different water treatment systems, technologies and options to be considered for implementation in water supply schemes.

The costing model also provides the users with estimated costs for orders and operation costs of water supply systems, while also providing estimates on the cost of maintenance and the value of the existing water supply systems. Also, it should be noted that although the innovation provides first-order estimates to be used for planning, budgeting and comparing alternative options on a financial basis, it should not be used for tender purposes or for a detailed costing as it does not provide accurate estimation for such costing.

Development involved various water stakeholders with different expertise. No major challenges were encountered during development. The only challenge that emerged from developing the WATCOST manual was insufficient and outdated data from similar projects that have been conducted in the past. The data was needed to produce an effective costing model that would be able to help the users overcome the challenges presented by the lack of adequate costing manuals available in the sector.

Since the innovation has been developed and completed in 2013, it has been used by various stakeholders in the water sector including engineers, water consultants and municipalities. The innovation is not intended for commercial purposes: it is freely available as an electronic copy from the WRC website. The innovation available from the WRC website contains the following information to assist the user (Swartz et al., 2013):

- User instructions.
- Input component (where the user will enter required information).
- Software that will do the cost calculations – the model component.
- Output component (that will provide the tables and graphic costing results).
- Database of costing information (not accessible to the user, only for doing cost calculations).

The costing model can be used by the different targeted stakeholders to estimate first-order capital and operating costs of water supply systems, estimate costs for upgrading existing systems and to determine the approximate value of the existing water treatment systems.

4.7.4 Case study 18: Investigation into the cost and operational aspects of South African municipal desalination and water reuse plants

The investigation into the cost and operational aspects of South African municipal desalination and water reuse plants research was undertaken by Royal HaskoningDHV (Pty) Ltd in collaboration with Stellenbosch University, Umgeni Water, City of Cape Town, GO Water Management and Chris Swartz Water Utilisation Engineers.

The research commenced in 2012 and was finalised in 2015 with the full funding support of the WRC. The research was undertaken because of the drought that hit the coastal areas of South Africa in 2009/2010. The purpose was to understand the O&M cost of water reuse and desalination plants located in the coastal areas of South Africa. The aim of the project was to create awareness at local and regional level about developing reuse and desalination plants as viable options for addressing water challenges.

Figure 35: Image of Mossel Bay seawater reverse osmosis plant (source: Turner et al., 2015)

It is reported that from 2009/2010, the Southern and Eastern Cape regions of South Africa experienced the worst drought in history. To prevent the risk of complete water supply failure, some desalination and water reuse projects were undertaken. It is predicted that many coastal cities in South Africa are outgrowing the natural freshwater resources available to them; therefore, there is a great need to investigate and exploit alternative sources of new water to enhance existing supplies of water. With South Africa reaching a stage where freshwater resources are nearly fully utilised, this project aimed to contribute within the South African water community and provide information relevant to the South African situation and context. It entailed gathering of cost, operational, maintenance and other data associated with local desalination and water reuse plants that have been implemented and were planned for implementation in South Africa.

There is substantial amount of literature available in the public domain with respect to cost and water quality aspects for desalination and reuse plants in South Africa; however, none of these provide real information on the cost and water quality obtained from actual desalination plants constructed in South Africa (Turner et al., 2015). Thus, this particular research was deemed necessary. The information gathered was expected to benefit municipal engineers and the water community at large to define the actual costs for desalination and water reuse plants. This can be used for more effective future planning and comparison of different water supply options. To enhance the findings from this research project, seven desalination and water reuse plants were used, which were selected based on their location and importance with respect to augmenting water supply in the associated regions. All the plants investigated were developed as emergency solutions to water scarcity that hit the concerned regions from 2009. Since the initiation of this study, some of these plants have had a zero-production mode, for example, the Mossel Bay and Sedgefield seawater reverse osmosis plants (Turner et al., 2015).

There have been major discussions at local/regional level in the integrated development plans of city councils and municipalities as well as in national strategies by the DWS to fully exploit desalination options (Turner et al., 2015). This particular project aimed to conduct a literature search on the topic of water reuse and desalination to put it in to context and inform relevant stakeholders on the treatment processes used in desalination plants and how they relate to the technologies used at the studied plants. The data was collected from existing literature and through contacts with collaborating parties. The data was also collected through site visits and communication with project managers, plant designers and other various sources.

It is widely understood that without adequate freshwater resources, municipalities will have no choice but to consider desalination and water reuse to gain access to alternative, but as yet less exploited water sources. (Turner et al., 2015). Undertaking this research, the team experienced some minor challenges that mainly emanated from the absence of data, or from insufficient data being available. For example, there was an absence of more accurate data, some of the plants experienced operational problems such as unavailability of equipment spares and turbidity levels of populate incorrect readings. The lack of accurate power consumption data and a lack of data in respect to monitoring the results during actual/normal production operation were also recorded as some of the setbacks that were encountered during the research.

The completion of the research saw a database being developed, which contributed largely to decision support tools as it shed light on the cost, O&M of existing water reuse and desalination plants in South Africa. This information is crucial for municipalities and other water stakeholders considering building desalination plants. The project was successfully completed in 2015 and the report was submitted to the WRC who provided funding.

To ensure that the database was accessible, it was made a stand-alone package application. A CD was also developed containing data. The CD can be installed on a computer to view the database generated from the seven plants investigated for the study. The database is available for review only; therefore, its functionality is restricted to read only. The database has record input sheets grouped into four sections, namely, plant information, geographical profile, technical specification and financial data. However, the database needs to be operationalised into an interactive platform where a user can obtain information and contribute as a number of desalination plants have been constructed since the completion of this project.

4.7.5 Case study 19: W$_2$RAP Guideline

The W$_2$RAP innovation was developed by Dr Marlene van der Merwe–Botha. The W$_2$RAP emerged at a time when the then Department of Water Affairs (now DWS) contemplated how to best develop a programme to turn around waste water treatment services in South Africa. This arose because of the poor state of the water industry. It was reported that many municipalities did not prioritise, understand or monitor their waste water treatment works. Therefore, the DWS under the leadership of Mr Leonardo Manus developed the Green Drop Incentive-based regulation, comprising a set of audit criteria to audit municipalities annually to determine their performance and compliance with waste water legislation and best practice.

The W$_2$RAP was developed in support of having a risk-based and prioritised plan to effectively move municipalities from high to lower risk by targeting the various risk and addressing them via mitigation measures. The development of the W$_2$RAP was supported by the DWS and the WRC. To develop a more detailed risk abatement approach and ensure that the guideline found practical application and buy-in from the sector, municipalities such as the City of Cape Town, eThekwini Municipality, Nelson Mandela Bay Municipality and Steve Tshwete Local Municipality contributed their typical risk plans as examples to develop the W_2RAP.

The W_2RAP is a means of managing and identifying risks. With many municipalities in South Africa confronted with the challenge of water resource management, this innovation offers a valuable solution to enhance municipal water and waste water service delivery. The W_2RAP includes all the steps in the waste water value chain from the production of water to discharge or reuse in particular catchment. W_2RAP is regarded as one of the first worldwide initiatives that aimed to provide a guideline to plan and undertake a risk-based approach so that waste water service performance can be improved and sustained. The W_2RAP draws many of its principles and concepts from other existing risk management approaches – more especially from Water Safety Planning Process, Hazard and Operability Study Hazard Analysis and Critical Control Points (Van der Merwe–Botha & Manus, 2011).

The W_2RAP when combined with the Green Drop programme brings communities and schools and the public within direct reach of the impact of waste water services on their lives. Having cleaner and safer effluents discharged to rivers and dams and qualified persons employed and enough support in terms of DSS tools to execute waste water management have direct financial cost on the municipal budgets. The innovation is viewed as a critical tool for advancing safe discharge of final effluent stabilised sewage sludge. It has added advantages, for example, the sludge can be used as compost and produce energy from biogas; therefore, it also presents positive environmental impacts.

There were no major challenges reported by the developers of the innovation. It is reported that the DWS Water Services Regulation Unit responsible for the leadership and the ownership of the W_2RAP showed outstanding support for the innovation and the unit geared to effect implementation of the W_2RAP through their regulatory processes.

Minor challenges experienced during the development included finding fit on-site sanitation to implement the innovation, because although the W_2RAP has this, it is not the focus area. It was also acknowledged that the developers should have spent more time and content on waste water reticulation systems rather than focusing on the treatment elements. Despite the success of adopting the W_2RAPs innovation by water service authorities (WSAs), challenges for undertaking effective risk management process were encountered. The lack of a key system and water quality information to inform risk identification and prioritisation were identified. There was also a limited commitment of the senior staff in some WSAs that proved to be a challenge. Budget constraints, capacity and team dynamics were also reported as some minor challenges encountered during the deployment of the innovation in some WSAs. Understanding energy consumption and sludge management was also found to be limited in some municipalities.

From the R&D to the deployment of the innovation, there was a huge uptake in the sector. The innovation became the legislation and best practice. To date, it assists water sector institutions to plan and think in a risk-focused manner. The innovator reports that over the years in South Africa, it has been quite challenging to bridge the gap between engineers, scientists, and financial people or chief financial officers of municipalities.

"For a long time, we battled to bridge the gap between the waste water scientist and engineer, and the finance person or CFO of municipalities. They just spoke different languages! The word 'risk' united them and clarified objectives and targets and assisted technical managers to motivate for resources." (Van der Merwe–Botha, 2017, Interview with The African Centre for a Green Economy)

The innovation has received significant support in South Africa from both the private and public sector. Private-owned institutions such as Nedbank, Sasol and Sun City have also requested to participate in Green Drop audits and develop their own W_2RAPs. This is proof that since the innovation has been developed, there has been progress, it has found its value and it has become self-driven in the industry.

The public sector drives the deployment of the innovation. It is highlighted that everyone who is serious about waste water and management has already adopted the innovation. For example, the DST funded a project with the aim of deploying the W_2RAP innovation to municipalities in the KwaZulu-Natal and Eastern Cape provinces. The WRC was appointed as the implementing agent of the project. The aim of the project was to use the existing WRC tools to engage with selected district municipalities (KwaZulu-Natal and Eastern Cape) and build capacity on risk-based planning for water and waste water systems. The project targeted 15 WSAs in both provinces and 12 WSAs committed to the process. Workshops were conducted with all the participating WSAs and actions for W_2RAP were developed for implementation (Moorgas et al., 2016).

The W_2RAPs achieved some success. In a follow-up survey, the WSAs that participated in the project reported improved risk management for both water and waste water. The success in the deployment of the W_2RAP relies on the willingness of the municipal officials to understand risk management in both water and waste water for the improvement of Blue and Green Drop and as good business practice in supporting service delivery.

"On behalf of the team, I would like to thank you guys for equipping us with the necessary skill to do our own Water Safety Plans and Risk Abatement Plans, with the information that you imparted on us. It will help us a lot moving forward in our operational and compliance monitoring. Most of all we would like to thank you for selecting our municipality to be our one of your beneficiaries." (Ms Luyanda Simelane: Amajuba District Municipality Engineering and Technical Services in Moorgas et al., 2016)

The most recent example of the deployment of the innovation was during 2016 and 2017, when the Department of Public Works initiated a countrywide project based on W_2RAPs to turn around their waste water treatment works. As proof of the success of the W_2RAP innovation in South Africa, the country has received a major award by the American Environmental Engineers for its work on Green Drop and the W_2RAP approach. Thus, many countries and visitors have asked about the W_2RAP; however, it is not known whether other countries have adopted the innovation or not since the innovators of the W_2RAP do not monitor the use of the approach outside South African borders.

5 EMERGING TRENDS IN THE WATER INNOVATION ECOSYSTEM IN SOUTH AFRICA

South Africa faces significant water challenges, ranging from poor water quality attributed to various factors such as mining activities (AMD), agricultural run-off and poor waste water management infrastructure. Most of the key economic hubs, such as Cape Town and Johannesburg, are in water management areas where water demand has outstripped supply. Access to adequate water supplies of good quality in rural areas of South Africa has also been a challenge, whereby in some rural areas people are forced to consume raw untreated water, with no sanitation facilities as well.

Many people in rural areas still have no access to flushing toilets despite many measures being taken by government to provide proper sanitation. A lack of sanitation infrastructure also means that there is poor infrastructure to treat waste water. In many instances, waste water is discharged untreated into the environment, which put communities and the environment at risk.

South Africa has the capacity to develop water innovations as shown by the technologies that have emerged in the sector. The country has a strong scientific community; however, it is very challenging for innovators to deploy their inventions effectively. The main challenges as highlighted by the innovators include significant bureaucratic processes associated with setting up small businesses and poor linkages to industry that have hindered potential innovations that could have been deployed successfully for the benefit of the country. Lack of adequate finance to support innovations all the way from R&D to commercialisation and global scale-up, is also a constraint.

Despite the growing awareness towards building R&D policies, the current innovation policies are not effective in changing practices and outcomes of the knowledge economy, and meeting the development agenda (Rose & Winter, 2015). However, it must also be noted that a significant number of innovations that have been deployed successfully are those that have been driven by the public sector, which is a clear indication that some policies have been effective.

It has been extremely challenging for water innovations that require large amounts of funding for demonstration and scale-up. This is evident in water innovations such as the WEROP, VitaSOFT and alternative reverse osmosis that have been discussed in this book. Despite these water innovations receiving large sums of money for R&D, it has been difficult for them to raise additional funding for large-scale demonstration, which is key for their successful deployment. The challenge of raising funding is associated with the fact that most investors are interested in post-revenue innovations. Therefore, it becomes challenging for start-up companies to attract funding despite their innovations having the potential to succeed.

Other factors that have influenced the acceleration and deployment of water innovations in South Africa include limited links between the various actors and institutions, intellectual property related issues, effectiveness of engaging with the public sector and community involvement.

5.1 Limited Links between the Various Actors and Institutions

South African universities have spearheaded water innovations with several centres of excellence and research chairs located in various universities across the country. However, the linkages between the universities and other spheres of the economy that are key to the commercialisation of water innovations are often not sufficiently strong enough despite the recently established technology transfer offices. As a result of these and other factors, a number of innovations that could have been commercialised or widely deployed have not made it to market beyond the stage of demonstration.

Key actors in the innovation ecosystem such as public sector institutions, for example, the WRC and TIA, work closely with universities in bilateral arrangements, but not in tripartite arrangements, which would have been more effective. Universities also engage quite effectively with the private sector, but public sector promoters of innovations are often not part of those conversations. This disjointed effort results in poor use of the limited resources that could be channelled towards supporting innovators. More strategic alliances are required between public sector institutions, universities and the private sector to ensure that innovators understand national priorities and market opportunities to deploy their innovations effectively.

Even though collaborative efforts in the innovation ecosystem are not very effective at the moment, there are instances where bilateral arrangements with universities have yielded good results. For example, the WRC is regarded as the most important funder of water research in South Africa, and more specifically, its emphasis on capacity building has significantly affected the sector. The TIA on the other hand has been working with various universities to encourage researchers and students to apply to the Seed Fund to fund innovation-oriented projects, in order to push for commercialisation of innovations developed within universities.

Partnerships between educational institutions and the private sector have seen innovation solutions developed for critical water challenges, such as the AMD, while other sectors such as food and beverage, and pharmaceuticals have pushed innovations that have to do with water efficiency and alternative sources of water. The shortfall with private sector partnerships with educational institutions is because often companies approach universities to solve a specific problem they face. Once a solution has been developed, such an innovation might not necessarily be availed to the general public, therefore reducing its potential for wider uptake.

There is a need to strengthen collaboration between businesses and the public sector innovation agencies. Strong linkages between these two actors in the innovation ecosystem have the potential to accelerate the deployment of water innovation. A good example of such a collaborative effort was the CSIR that partnered with the WRC and Amanz' abantu Services, which led to the development of a social franchising model for water management with a strong focus on local community empowerment. Another example of a multi-stakeholder collaborative effort involved the DST, the Bill and Melinda Gates Foundation and the WRC meeting with industry in an attempt to encourage business to partner with the government. This effort led to the establishment of the South African Sanitation Technology Demonstration Programme in 2014, with the purpose of testing the latest cutting-edge sanitation innovations to assess their feasibility for wider uptake and commercialisation.

Such initiatives show that the public sector is starting to realise the importance of industry in driving innovation in South Africa. The Deputy Director General of DST (Socio-Economic Innovation Partnerships), Mr Imraan Patel, acknowledged the significant role that strong linkages between the government, the private sector and research institutions could play in driving growth. He highlighted that:

> *"One other important objective is to build stronger links between government, the private sector and research institutions, where we can all take collective responsibility for creating growth."*
> *(Mr Patel, Deputy Director General, DST, 2016)*

5.2 Intellectual Property Related Challenges

South Africa has adequate intellectual property rights and policies to promote innovations, R&D and technology transfer to support a growing sustainable economy. However, despite South Africa having adequate intellectual property policies, the country still ranks low in terms of patents, copyrights, trademarks, trade secrets, enforcements and international treaties according to a recent report published by the US Chamber of Commerce's Global IP Center (2016). This threatens the success of deploying innovations because it restricts innovators' access to international markets and foreign investments among other things.

During engagements with the relevant stakeholders and innovators, it emerged that there is a lack of understanding and awareness around intellectual property policies in South Africa. This has had significant negative effects on the transfer of innovations. In many cases, companies and innovators fail to adequately protect their intellectual property, which could result in a loss of assets and competitive advantage thus affecting their ability to raise capital from potential investors. For instance, in some cases companies fail to process all the intellectual property rights needed to operate their businesses, thus leaving them vulnerable to violation of intellectual property and putting them at risk of violation claims. The lack of awareness and understanding of intellectual property laws is especially low among emerging innovators at community levels who may have not been exposed to education at higher level. Furthermore, some academic researchers are not necessarily aware about the processes of intellectual property rights, thus leaving their innovative ideas vulnerable to exploitation.

Another major concern regarding intellectual property in South Africa is that the process has been described or viewed by some people as being too bureaucratic. The application for intellectual property rights normally requires significant time, which is discouraging to some innovators. Currently in South Africa there is a huge backlog with processing trademarks and that is also a huge hindrance to the R&D and deployment of innovations. Business Day reported on 30 June 2017 that there is a backlog of 18 months in the Trademarks Division of the Companies and Intellectual Property Commission. Such challenges are a direct hindrance to successful deployment of innovations in South Africa. There is a need for improved communication and information sharing between the actors in the innovation ecosystem about how intellectual property registration process works.

5.3 Inadequate Support for Uptake of New Innovations by the Public Sector

It has been reported that water innovators find it difficult to work with some local authorities due to vested interests. Municipalities work closely with their appointed consultants and in some cases, they resist the introduction of new radical innovations, largely because of vested interests in specific technologies they are promoting and are conversant with its application. However, some municipalities in South Africa have been key in driving certain innovations, for example, the Makana Municipality of Grahamstown in the Eastern Cape has provided significant support for the IAPS innovation developed by Rhodes University.

Most municipalities are not proactive in building partnerships with public institutions such as universities and research institutes in seeking solutions to their water challenges. They wait for researchers and innovators to come to them and seek assistance for developing and deploying water innovations. Collaboration between municipalities, universities and other research institutions is insufficient to optimise the water innovation pipeline being developed in order to improve services and efficiencies. Ruiters & Matji (2016) highlight that:

> *"Water services authority should find creative and innovative models that can assist in responding to water services infrastructure delivery".*

This can be critical since most municipalities face various challenges such as lack of technical, planning and management skills, limited financial resources, and lack of O&M resulting in dilapidating and aging water and sanitation services infrastructure (Ruiters & Matji, 2016).

5.4 Need for Improved Support for Commercialisation of Innovations at Universities

Being part of the public sector, universities have a key role in driving innovation in South Africa. Universities in South Africa need to clearly articulate and share, with relevant stakeholders, the role of universities in promoting innovation. They should provide evidence of the value that universities create in the innovation ecosystem, the economy and society (Pouris, 2016). The organisation should also consider monitoring technology transfer from universities to the private sector.

Universities are ideally placed to be at the forefront of innovation because they possess enough capacity and the ability to draw enough attention to attract investments and sponsorships for emerging innovations. South African universities have set up structures and systems to drive R&D and deployment of innovations. For example, the University of Stellenbosch set up Innovus to accelerate innovations; innovators at the University of Pretoria are supported by the Department of Research and Innovation Support; the UCT provides support through the Research Hub. These structures are set up to help researchers with access to funding, contracts and protection of intellectual property, providing support for technology transfer, entrepreneurial support and development of innovation and promote commercialisation of innovations. Through these supporting structures, innovations such as the Geasy innovation led to setting up a company, Bridgiot, to pursue commercialisation of the Geasy technology.

Pertinent challenges that universities still face include lack of funding to accelerate deployment of water innovations in universities. Although there might be some funding available for R&D, the main challenge is accessing funding to demonstrate and deploy the innovation once a viable product has been developed. This is particularly dire for innovations that require substantial amounts of money for demonstration and deployment at large scale. To effectively transition from the university to the market, partnerships have to be developed between the innovators and investors. For such partnerships to take effect, universities should improve their communication with innovators and provide clarity about issues concerning availability of support to researchers and innovators within universities. It appears that not all academic researchers in universities are aware of the available opportunities for developing businesses out of their research. The focus for most researchers is to excel in their research work and produce outputs like publications without realising the potential to develop their innovations into a viable business with the support of the university. Students who are also involved in doing research are often just pursuing good academic research and move on after completion of their studies without pursuing further opportunities based on their innovations.

5.5 Lack of Information on Funding Sources and Challenges for Funding Water-related Innovations in South Africa

There is limited funding available for supporting water-related innovations in South Africa, with most of the available resources channelled to R&D. Institutions such as the WRC and NRF have been at the forefront of driving R&D in South Africa. Other government departments such as DST also play an important role in accelerating innovations. For example, the establishment of WADER, one of the flagship initiatives of the WRC was through a partnership with DST to demonstrate water technologies. This helps promote market access for innovations, attract investments and build consumer awareness. Private sector funding is also available for water innovations in South Africa; however, there are pertinent challenges that hinder innovators to access funding for water innovations. Discussions with private equity financiers show that there is strong interest in funding water-related innovations, but the main challenge is the poor quality of deal flow. In other words, there are very few water innovations that are investment ready and have the potential to yield the kind of return on investment that is acceptable to private equity investors and venture capitalists.

Lack of information and knowledge by innovators regarding existing funding sources is also a major constraint in accessing such funds. The success of innovations relies on innovators or researchers being able to seek the right avenues for the support they require. The support for innovators and researchers is available but the communication/information flow between the support providers and innovators/researchers is lacking. Prof. Rivett of the UCT states that:

> *"The support that is given by the government to the researchers and innovators is enough, but you must know who to approach in order to get the necessary support." (Prof. Rivett, UCT, 2017, Interview with The African Centre for a Green Economy)*

There is a need to create linkages between innovators, researchers, incubators, businesses and government institutions and to improve the communication channels between them. Universities should position themselves as intermediaries between researchers and funders of the water innovations. The key institutions championing the NSI should also ensure effective communication between the actors in the innovation ecosystem. Effective communication between the above-mentioned role players in the innovation ecosystem will help to unlock the barriers to information flow on funding and other scale-up opportunities available to innovators and entrepreneurs.

Innovative financing mechanisms are required to scale up innovations. Considering that most funding support is for R&D in the water sector, many innovations are trapped between the demonstration stage and commercialisation where they do not qualify for R&D funding and are not investment ready. This is evident in some of the innovations that have been discussed, such as the WEROP, alternative reverse osmosis and VitaSOFT. It is difficult for these water innovations to attract funding because most investors are interested in post-revenue innovations. To unlock this predicament, a form of blended finance is required, which is mix of grant-type instruments and non-grant financing mechanisms such as soft loans and even equity.

Blended finance is a strategic use of public funds, including concessional tools, to mobilise additional capital flows (public and private) to emerging and frontier markets (OECD et al., 2017). Blended finance will help to guarantee financial support for emerging water innovations that are unable to attract investment because they are in early stage of development (R&D). Pouris (2016) also suggests that using levies and small special taxes can provide funds for R&D of science, technology and innovation in South Africa. Such an arrangement could significantly improve the pipeline of investment-ready innovations that could prove to be attractive to investors.

5.6 Engagement with Key Communities to Ensure Relevance

There is a great need for researchers and innovators to engage with community members and industry to determine the most pressing problems where solutions are required. This includes the nuanced social contexts to embed enablers for successful transfer at a later stage. Innovations should not be imposed on key communities due to their real perceived lack of knowledge. Due to the push approach, communities have been reluctant to try out emerging innovations that seek to address water challenges. A good example of key communities showing reluctance to new technologies was prevalent during the pilot stage of the Geasy in Mkhondo Local Municipality, Mpumalanga, where community members showed distrust towards the municipality and were not eager to try out the new technology (Geasy) in their homes.

Therefore, there is a great need to build trust between communities, innovators/researchers, and government especially at a local level. Water innovations that have involved communities have proven to have a significant impact on the people in communities and people have shown great acceptance towards adopting them. A good example of an innovation that has succeeded through acceptance of the communities is the miniSASS innovation. Also, the targeted customers or users of the innovation being developed should be engaged to fast-track the wider uptake of the innovation. Innovations such as the W_2RAP have proven this by engaging the potential users of the innovation through the R&D stage to ensure that the targeted users are welcoming of the innovation being developed.

There needs to be a collaboration between innovators and people who work on the ground to engage with locals, which can include consultancies and NGOs that work with local communities or the targeted users by the emerging water innovation. Due to the challenges of engaging with local people, it has been highlighted by many stakeholders and innovators that it is much easier to provide funds than engaging with locals. Prof. Booysen highlights:

"People need to be found to use the product. If you really want to help a community, either you going to spend time with them or hand out the cash" (Prof. Booysen, Stellenbosch University, 2017, Interview with The African Centre for a Green Economy)

This highlights that an innovation cannot be successful based on funding or technical support being provided. It is crucial that the targeted users support the innovation.

6 CONCLUDING REMARKS AND RECOMMENDATIONS

South Africa's water sector is faced with a plethora of challenges due to natural and anthropogenic causes. These complex and often interrelated issues provide an opportunity to develop innovations that are crucial for sustainable water management and socio-economic development. A wide range of technological and non-technological innovations have emerged in the water sector to address the water challenges facing South Africa. However, engagements with the innovators and some agencies in the innovation ecosystem have shown that despite the robust R&D of water innovations in South Africa, many water innovations have struggled to go beyond the R&D stage due to pertinent challenges encountered by the actors involved in the innovation ecosystem. Institutions such as the WRC have shown great commitment in supporting R&D of water innovations that have emerged in South Africa. There have been efforts and initiatives across the entire water sector to encourage innovators to develop water innovations that will help address the water challenges the country.

In the past few years, emphasis has been on encouraging innovators to come up with ideas that will address the country's water crisis. The development of approaches such as the Water RDI of South Africa (which aims to elevate the key priority areas that all water sector institutions should focus on by supporting innovation, building human capital and commissioning research by co-ordinating and aligning resources) indicates the commitment that has been placed on the development of innovative solutions to address the water challenges facing the country.

Initiatives and campaigns such as Hack4Water launched by the DWS in 2016 to encourage innovators to develop innovative technologies, stories and ideas that could provide solutions, commercial products, inventions etc., also reaffirm the country's position in driving the R&D of water innovations. However, despite the concentrated efforts shown by different public institutions supporting water innovation in South Africa, there is still a lack of coordination between various actors in the innovation ecosystem. There is a need to build more exclusive collaborative efforts across enabling partners to facilitate opportunities provided by water challenges in South Africa. The role of SMMEs looking to innovate, create jobs and drive the country's economic growth is crucial for accelerating innovation; therefore, there should be strategies and policies that will ensure that SMMEs receive the necessary support they require to drive innovation.

Limited linkages between the actors in the innovation ecosystem and funding access for innovations remain the main challenges hindering the success of water innovations in South Africa. Engagement with the actors in the innovation ecosystem in South Africa shows that there are limited linkages between the various actors involved in the innovation ecosystem. Despite the challenges documented in this book, it should be acknowledged that the water sector in South Africa is arguably one of the most robust in terms of innovation activity. A very strong legislative framework has also ensured that water is given a high priority in terms of research.

Ideologically, this is well framed and structured; however, the implementation is not a reflection of this. There is a need to ensure that innovation receives the necessary support from R&D to commercialisation stage of development. South Africa's innovation ecosystem is beset with challenges and hindrances despite the country having well-established water research institutions, such as the WRC, who have developed excellent relationships with researchers in institutions of higher learning who have the capacity to develop cutting-edge innovations and the policy to support it. As a way forward, the following needs to be considered:

In South Africa, there are numerous water innovations that have emerged from universities, start-up companies, entrepreneurs/innovators in communities; however, there is a need to build more linkages between the various actors involved in the innovation ecosystem to solidify the linkages between these actors. Students need to be incentivised to not merely publish their work, which then remains on the shelves of universities, but rather to take the research and develop it beyond commercialisation. To achieve this, the government (through its departments mandated to drive innovation) should drive this coordination by developing enabling policies and providing the necessary support.

Funding is a significant constraint preventing innovative ideas from reaching their full potential. Hence, partnerships are important as a way of making an idea commercially viable to benefit both established businesses and innovators. Collaborating with incubators and investors who have the capacity and financial muscle to drive the development and deployment of water innovations, and developing partnerships between researchers, public institutions and businesses can play a critical role. Creating partnerships with innovators will also benefit businesses because the escalating water challenges also pose risk to the sustainability of businesses. Therefore, pushing for water innovations can also enable businesses to run more effectively despite having to be affected by water challenges. Thus, the innovators should not only look at government institutions for funding support. Incubators play an important role for enterprise development, so they should position themselves as the channel between the innovators and investors/business to help drive the deployment of water innovations. However, to build healthy partnerships between businesses and innovators will require the government to develop strong policies that will ensure that neither party is exploited in the process.

Effective communication and engagement between innovators and the communities are necessary – especially if the innovation is designed to be used by people. A lack of engagement often acts as a major resistance for successful deployment innovations. An innovation cannot simply be imposed on users. Therefore, key communities should be regarded as essential role players in the NSI.

Importantly, all innovations do not have a success story. For innovations that are not successful, it is also necessary for institutions and universities to document their failures. Writing case studies about failed innovations is a learning curve and will provide an opportunity for other innovators to not make the same mistake.

Being the major funder of most water-related research in South Africa, the WRC should ensure that there are mechanisms in place to trace the progress of water innovations they have funded. This will help with accelerating the deployment of water innovations in the country. South Africa's innovation system is to a large extent fragmented as actors are not working together efficiently as many are competing. Strong integration should begin from public institutions such as the WRC and TIA who are mandated to develop and support water innovation in the country. The ideals of a South African innovation system can only be achieved if the system operates as a whole and all actors and enabling conditions are well integrated.

REFERENCES

Ahluwalia, P. (2012). Centralised vs. decentralised wastewater systems. *Journal of Indian Water Works,* January–March 2012, 53–58.

Alfranseder, E and Dzhamalova, V. (2014). The impact of the financial crisis on innovation and growth: Evidence from technology research and development. Knut Wicksell Working Paper Series. Knut Wicksell Centre for Financial Studies, Lund University.

Amanz' abantu Services. (n.d.). Available online: http://www.aserve.co.za/gallery.html

Ansa, E, Lubberding, HJ, Ampofo, JA, Amegbe, GB and Gijzen, HJ. (2012). Attachment of faecal coliform and macro-invertebrate activity in the removal of faecal coliform in domestic wastewater treatment pond systems. *Ecological Engineering,* 42, 35–41.

Aphane, V and Vermeulen, PD. (n.d.). Acid mine drainage and its potential impact on the water resources in the Waterberg coalfield. Available online: http://gwd.org.za/sites/gwd.org.za/files/05_V%20Aphane_Acid%20Mine%20drainage%20and%20its%20potential%20impact.pdf

Asia Pacific Centre and Transfer of Technology (APCTT). (n.d.). Available online: http://apctt.org/nis/what-is-nis

Bdoura, AN, Hamdib, MR and Tarawneh, R. (2009). Perspectives on sustainable wastewater treatment technologies and reuse options in the urban areas of the Mediterranean region. *Desalination* 237, 162–174.

Bridgiot. (2017). Remote intelligence and control. Available online: https://www.bridgiot.co.za/

Business Day. (30 June 2017). Available online: https://www.businesslive.co.za/bd/national/2017-06-30-storage-dispute-stalls-processing-of-trademarks/

Business Tech. (18 November 2015). Who is using all the water in South Africa? Available online: https://businesstech.co.za/news/general/104441/who-is-using-all-the-water-in-south-africa/.

Cele, H. (2016). Citizen science for water quality monitoring and management in KwaZulu-Natal. Wiredspace. Available online: http://wiredspace.wits.ac.za/handle/10539/20845

Cessford, F and Burke, J. (2005). National state of the environment project: Inland water. Background research paper produced for the South Africa Environment Outlook Report on behalf of the Department of Environmental Affairs and Tourism. Available online: http://www.dwa.gov.za/Dir_WQM/wqmFrame.htm

Chapagain, A and Orr, S. (2008). UK water footprint: The impact of the UK's food and fibre consumption on global water resources, v. 1. WWF-UK, 46 p.

Clarke, R and King, J. (2004). The atlas of water. Mapping the world's most critical resource. Earthscan, 8–12 Camden High Street, London, UK.

Corcoran, E, Nellemann, C, Baker, E, Bos, R, Osborn, D and Savelli, H (eds.). (2010). Sick water? The central role of wastewater management in sustainable development. A rapid response assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal. www.grida.no

CPH Water. (2001). Design of a decision support system and scenario generator for the assessment of land use impacts on water resources within a water management area. Report for DWAF/DFID Strategic Environmental Assessment.

Department of Science and Technology (DST). (2014). Annual report: 2013/2014 financial year.

Department of Science and Technology (DST), (1996). White Paper on Science and Technology. Preparing for the 21st Century. Available online: http://www.esastap.org.za/download/st_whitepaper_sep1996.pdf

Department of Water Affairs (DWA). (n.d.). Overview of the South African Water Sections. Available online: http://www.dwa.gov.za/IO/Docs/CMA/CMA%20GB%20Training%20 Manuals/gbtrainingmanualchapter1.pdf

Department of Water Affairs (DWA). (2012). Feasibility study for a long-term solution to address the acid mine drainage associated with the East, Central and West Rand underground mining basins. Study report no. 5.4: Treatment Technology Options: DWA Report No. P RSA 000/00/16512/4.

Department of Water Affairs (DWA). (2014). Annual National State of Water Report for the Hydrological Year 2012/2013. Available online: http://www.dwa.gov.za/Groundwater/documents/Annual%20National%20State%20Water%20Report%20for%20Hudrological%20Year%202012-13_Final.pdf

Department of Water and Environmental Affairs. (n.d.). Water Quality Management in South Africa. Available online: http://www.dwa.gov.za/Dir_WQM/wqm.asp

Dinar, A. (2003). The potential economy context of water-pricing reforms. In: P Koundouri, P Pashardes, TM Swanson and A Xepapadeas. The Economics of Water Management in Developing Countries (pp. 15–40). UK: Edwards Elgar Publishing.

Dispatch Live. (28 February 2015). ANC faces behind toilet tender scandal. Available online: http://www.dispatchlive.co.za/news/2015/02/28/anc-faces-behind-toilet-tender-scandal/

Domènech, L. (2011). Rethinking water management: From centralised to decentralised water supply and sanitation models. *Documents Danalisi Geografica* 57/2, 293–310.

Engineering News. (11 June 2013). Fraser Alexander, Miwatek launch new AMD treatment technology Available online: http://www.engineeringnews.co.za/article/fraser-alexander-miwatek-launch-new-amd-treatment-technology-2013-06-11/rep_id:4136

Environment News. (29 April 2015). Disused mines South Africa: What's being done? Available online: https://www.environment.co.za/acid-mine-drainage-amd/disused-mines-whats-being-done.html

Fischer, A, Ter Laak, T, Bronders J, Desmet, N, Christoffels, E, Van Wezel, A and Van Der Hoek, JP. (2015). Decision support for water quality management of contaminants of emerging concern. *Journal of Environmental Economics and Management* 193, 360–372.

Gelvenor Textiles. (n.d.). Gelvenor Scoops International IFF Innovation Award. Available online: http://gelvenor.com/gelvenor-scoops-international-iff-innovation-award-2/

Gonzalez, R, Garcia-Balboa, C, Rouco, M, Lopez-Rodas, V and Costas, E. (2012). Adaptation of microalgae to lindane: A new approach for bioremediation. *Aquatic Toxicology* 109, 25–32.

Graham, PM, Dickens, CWS and Taylor, J. (2004). MiniSASS: A novel technique for community participation in river health monitoring and management. *African Journal Aquatic Science* 29, 1.

GreenCape. (2016). GreenCape 2016 Water Market Intelligence Report. Available online: http://greencape.co.za/assets/GreenCape-Water-Economy-MIR-2016.pdf

GroundTruth. (n.d.). Available online: http://www.groundtruth.co.za/

Hart, TGB, Ramoroka, KH, Jacobs, PT and Letty, BA. (2015). Revealing the social face of innovation. *South African Journal of Science*. Available online: http://www.scielo.org.za/pdf/sajs/v111n9-10/14.pdf

Henderson, R and Parker, NR. (2012). The blue economy: Risks and opportunities in addressing the global water crisis. In Bigas, H. (Ed.) The Global Water Crisis: Addressing an Urgent Security Issue. Papers for the InterAction Council, 2011–2012. Hamilton, Canada: UNU-INWEH.

Hippo Roller. (n.d.). Available online: https://www.hipporoller.org/

House of Commons Science and Technology Committee. (2013). Bridging the valley of death: Improving the commercialisation of research. Eighth Report of Session 2012–13. The Stationery Office, London.

Hultman, N, Sierra, K, Eis, J and Shapiro, A. (2012). Green growth innovation: New pathways for international cooperation. Brookings Institution, Washington, DC.

Human Science Research Council. (n.d.). South African National Survey of Research and Experimental Development. Main Analysis Report 2013/14.

Human Science Research Council (HSRC). (2014). Research and development in South Africa is improving but not yet at the country’s full potential. Available online: http://www.hsrc.ac.za/en/media-briefs/cestii/research-and-development-survey-released

Impact-Free Water (Pty) Ltd. (n.d.). Available online: http://www.impactfreewater.com/

Infrastructure News. (2014). Eastern Cape working to eradicate bucket system. Available online. http://www.infrastructurene.ws/2014/09/15/eastern-cape-working-to-eradicate-bucket-system/

Infrastructure News. (10 May 2016). SA's waste water treatment works in bad shape. Available online: http://www.infrastructurene.ws/2016/05/10/sas-waste-water-treatment-works-in-bad-shape/

Infrastructure News. (06 March 2017). Here's how much water SA loses through water leaks. Available online: http://www.infrastructurene.ws/2017/03/06/heres-how-much-water-sa-loses-through-water-leaks/

Inhabitat News. (16 April 2008). Hippo rollers delivered! Available online: http://inhabitat.com/project-h-design-in-south-africa-hippo-rollers-delivered/9473

Isidima Design and Development (IDD). (n.d.). Arumloo. Available online: https://www.isidima.net/arumloo

Izsak, K, Markianidou, P, Lukach, R and Wastyn, A. (2013). The impact of the crisis on research and innovation policies. Study for the European Commission DG Research by Technopolis Group Belgium and Idea Consult.

Jackson, DJ. (2011). What is an innovation ecosystem? Available online: http://www.erc-assoc.org/docs/innovation_ecosystem

Joubert, H and Pocock, G. (2016). The VitaSOFT process: A sustainable, long term treatment option for mining impacted water. Water Research Commission, Report No. 2232/1/16.

Katukiza, AY, Ronteltap, M, Niwagaba, CB, Foppen, JWA, Kansiime, F and Lens, PNL. (2012). Sustainable sanitation technology options for urban slums. *Biotechnology Advances* 30(5), 964–978.

King, JM, Brown, CA, Paxton, BR and February, RJ. (2004). Development of DRIFT: A scenario based methodology for environmental flow assessment. Water Research Commission, Report No. 1159/04.

Lawyers for Human Rights. (2009). Water supply and sanitation in South Africa: Environmental rights and municipal accountability. LHR Publication Series (1/2009).

Leadership Magazine. (08 March 2016). War on SA's water shortage. Available online: http://www.leadershiponline.co.za/articles/war-on-sas-water-shortage-17213.html

Lewis, A, E., Nathoo, J., Thomsen, K., Kramer H. J., Witkamp, G.J., Reddy, S.T., and Randall, D.G. (2010). Design of a Eutectic Freeze Crystallization process for multicomponent waste water stream. *Chemical Engineering Research and Design, 88 (9),* 1290-1296

Mabhaudhi, T., Mpandeli, S., Madhlopa, A., Modi, A.T., Backeberg, G., and Nhamo, L. (2016). Southern Africa's Water–Energy Nexus: Towards Regional Integration and Development. Water 2016, *8*(6), 235; doi:10.3390/w8060235

Mackintosh, G and Colvin, C. (2002). Failure of rural schemes in South Africa to provide potable water. *Environmental Geology* 1–9.

Mail & Guardian. (26 September 2014). Buckets, pits and poverty: How the other half defecates. Available online: https://mg.co.za/article/2014-09-25-buckets-pits-and-poverty-how-the-other-half-defecates

Makana Environews. (2014). Landfill fires and citizen science. Available online: https://minisassblog.wordpress.com/2014/08/06/makana-environews-landfill-fires-and-citizen-science/

Manzini, ST. (2015). Measurement of innovation in South Africa: An analysis of survey metrics and recommendations. *South African Journal of Science*. Available online: http://www.scielo.org.za/pdf/sajs/v111n11-12/18.pdf

Marais, HC and Pienaar, M. (2010). Evolution of the South African Science, Technology and Innovation System 1994–2010: An exploration. *African Journal of Science, Technology, Innovation and Development* 2(3) 82–109.

Martins, G, Brito, AG, Nogueira, R, Ureña, M, Fernández, D, Luque, FJ and Alcácer, C. (2013). Water resources management in southern Europe: Clues for a research and innovation based regional hypercluster. *Journal of Environmental Management* 119.

Mckenzie, R, Siqalaba, ZN and Wegelin, WA. (2012). The state of non-revenue water in South Africa. Water Research Commission, Report No. TT 522/12.

MiniSASS. (n.d.). Welcome to MiniSASS. Available online: http://www.minisass.org/en/

Moore, M-L, Von der Porten, S, Plummer, R, Brandes, O and Baird, J. (2014). Water policy reform and innovation: A systematic review. *Environmental Science & Policy* 38.

Moorgas, S, Jack, U and Manxodidi, T. (2016). Case study for building capacity to support implementation of risk management in district municipalities in KwaZulu-Natal and Eastern Cape. Water Research Commission, Report No. TT 693/16.

MTN Intelligence Lab. (n.d.). Welcome to the MTN Mobile Intelligence Lab. Available online: http://mtn.sun.ac.za/

Muga, HE and Mihelcic, JR. (2008). Sustainability of wastewater treatment technologies. *Journal of Environmental Management* 88, 437–447.

National Academics of Science, Engineering and Medicine. (2016). The Power of Change: Innovation for Development and Deployment of Increasingly Clean Electric Power Technologies. Washington, DC: The National Academics Press. DOI:10.17226/21712.

Ninhoskinson. (2011). Research Draft 2: Water Pollution: Humans Contributing to Their Downfall. Available at: envirowriters.wordpress.com/2011/../

O'Brien, GC and Wepener V. (2012). Regional-scale risk assessment methodology using the Relative Risk Model (RRM) for surface freshwater aquatic ecosystems in South Africa. *African Journals Online* 153–166.

Organisation for Economic Co-operation and Development (OECD). (n.d.). Blended finance. Available online: http://www.oecd.org/dac/financing-sustainable-development/development-finance-topics/blended-finance.htm

Organisation for Economic Co-operation and Development (OECD). (1997). National Innovation Systems. OECD Publications, France. Available online: https://www.oecd.org/science/inno/2101733.pdf

Organisation for Economic Co-operation and Development (OECD). (2007). OECD Reviews on Innovation Policy. South Africa, OECD Publishing.

Organisation for Economic Co-operation and Development (OECD). (2010). Nominate Examples of Radical and Systematic Ecoinnovation. OECD Project on Green Growth and Eco-Innovation. South Africa, OECD Publishing.

Organisation for Economic Co-operation and Development (OECD). (2012). OECD Science, Technology and Industry Outlook 2012. South Africa, OECD Publishing.

Organisation for Economic Co-operation and Development (OECD), European Commission and The European Development Finance Institutions. (2017). FX Risk in Development: Managing Currency Risk through Blended Finance, Brussels, 1 February 2017. Available online: http://www.oecd.org/fr/cad/financementpourledeveloppementdurable/themes-financement-developpement/blended-finance.htm

Parliamentary Monitoring Group. (2015). Report of the Portfolio Committee on Water and Sanitation on Public Hearings on Theft and Vandalism of Water Infrastructure, dated 19 August 2015. Available online: https://pmg.org.za/tabled-committee-report/2489/

Pillay, VL. (2009). The development of an immersed membrane microfiltration system for the treatment of rural waters and industrial waters. Water Research Commission, Report No. 1598/1/09.

Pouris, A. (2013). A pulse study on the state of water research and development in South Africa. WRC Report No. 2199/1/12. Water Research Commission, Pretoria. ISBN 987-1-4312-0370-3.

Pouris, A. (2015). State of the water research in South Africa. Water Research Commission. Available online: http://www.wrc.org.za/Knowledge%20Hub%20Documents/Special%20(ad hoc)%20Publications/WRC_StateOfWaterBooklet_Final.pdf

Pouris, A. (2016). Research and innovation funding instruments to raise South Africa's competitiveness in science and technology: Lessons from other developing countries. Research and Innovation Dialogue, Johannesburg from 7–8 April. Available online: http://www.usaf.ac.za/wp-content/uploads/2016/11/Discussion-document-Research-and-innovation-funding-instruments-to-raise-south-africans-competitiveness-in-science-and-technology.pdf

Pouris, A and Thopil, GA. (2015). Long term forecasts of water usage for electricity generation: South Africa 2030. Water Research Commission, Report No. 2383/1/14.

Property24. (05 September 2012). SA looks to curb water wastage. Available online: https://www.property24.com/articles/sa-looks-to-curb-water-wastage/16175

RIIS and the Embassy of Switzerland and South Africa. (05 December 2016). A perspective on innovation in South Africa. Available online: http://www.riis.co.za/templates/assets/PDF/A%20Perspective%20on%20Innovation%20in%20South%20Africa.pdf

Ringler, C. (2001). Optimal water allocation in the Mekong River Basin. Bonn: Center for Development Research (ZEF), Discussion Paper No. 38.

Roma, E., Philp, K., Buckley, C., Xulu, S., and Scott, D. (2013). User perceptions of urine diversion. dehydration toilets: Experiences from a cross-sectional study in eThekwini Municipality. South African Water Research Commission. Water SA, Volume.39, No. 2. Available onlinetp://www.wrc.org.za

Rose, J and Winter, K. (2015). A gap analysis of the South African innovation system for water. *Water SA* 41(3).

Rose, PD. (2013). Long-term sustainability in the management of acid mine drainage wastewaters: Development of the Rhodes BioSURE process. *Water SA* 39, 583–592.

Rosegrant, MW, Ringler, C, McKinney, D.C, Cai, X, Keller, A and Donoso, G. (2000). Integrated economic-hydrologic water modeling at the basin scale: The Maipo River Basin. Washington: International Food Policy Research Institute (IFPRI).

Ruiters, C and Matji, M.P. (2016). Public-private partnership conceptual framework and models for the funding and financing of water services infrastructure in municipalities from selected provinces in South Africa. *Water SA* 42(2).

Seaman, M.T., Watson, M., Avenant, M.F., Joubert, A.R., King, J.M., Barker, C.H., Esterhuyse, S., Graham, D., Kemp, M.E., le Roux, P.A., Prucha, B., Redelinghuys, N., Rossouw, L., Rowntree, K., Sokolic, F., van Rensburg, L., van der Waal, B., van Tol, J., & Vos, A.T. (2013). Testing a Methodology for Environmental Water Requirements in Non-perennial Rivers - THE MOKOLO RIVER CASE STUDY. Centre for Environmental Management, University of the Free State. Available online: https://www.researchgate.net/profile/Marie_Watson2/publication/271211161_Testing_a_methodology_for_Environmental_Water_Requirements_in_Non-perennial_Rivers_The_Mokolo_River_Case_Study/links/54c245270cf256ed5a8c8b6d.pdf

Sekomo C.B, Nkuranga E, Rousseau D.P and Lens PN. (2011). Fate of heavy metals in an urban natural wetland: The Nyabugogo Swamp (Rwanda). *Water Air Soil Pollution* 214, 321–333.

Sithole, M. M., Moses, C. Davids, Y.D., Parker, S., Rumbelow, J., and Molotja, S. (2013). Extent of Access to Information and Communications Technology by the Rural Population of South Africa. African Journal of Science, Technology, Innovation and Development, 5, (1). https://doi.org/10.1080/20421338.2013.782144

Smith, L. (2009). Municipal compliance with water services policy: A challenge for water security. Development Planning Division. Working Paper Series No. 10, DBSA: Midrand.

South African Government. (2016). Science and technology urges businesses to develop innovative sanitation technologies. Available online: http://www.gov.za/speeches/innovative-sanitation-technologies-16-sep-2016-0000

South African Human Rights Commission (SAHRC). (2014). Report on the right to access sufficient water and decent sanitation in South Africa 2014. Available online: https://www.sahrc.org.za/home/21/files/FINAL%204th%20Proof%204%20March%20-%20Water%20%20Sanitation%20low%20res%20(2).pdf

Southern Waters Ecological Research & Consulting (Pty) Ltd. (n.d.). Available online: http://www.southernwaters.co.za/

Splash Plumbing. (n.d.). Aqua Trip installed. Available online: http://www.plumber-capetown.co.za/portfolio/plumber-cape-town-aqua-trip-installed/

Statistics South Africa (Stats SA). (2016). Community survey 2016 statistical release. Statistics South Africa, Pretoria.

Statistics South Africa (Stats SA). (2017). The state of basic service delivery in South Africa: In-depth analysis of the community survey 2016 data. Statistics South Africa, Pretoria. Report No. 03-01-22 2016.

Still, D. (2015). A note on pour-flush pedestal and P-trap design. Unpublished Report.

Still, DA and Louton, B. (2012). Piloting and testing the pour-flush latrine technology for its applicability in South Africa. Water Research Commission, Report No. 1887/1/12.

Swartz, CD, Thompson, P, Maduray, P, Offringe, G and Mwinga, G. (2013). WATCOST: Manual for a costing model for drinking water supply systems. Water Research Commission, Report No. TT552/13.

The Innovation Hub. (31 May 2016). Thought leadership article. Available online: http://www.theinnovationhub.com/press-room-media/thought-leadership-articles/innovation-articles/thought-leadership-state-of-innovation-in-sa-nws439

The Water Project. (n.d.). Why water? Dirty water causes needless suffering. Available online: https://thewaterproject.org/why-water/

Thomson Reuters Foundation News. (24 October 2011). South African municipality tackles water wastage. Available online: http://news.trust.org//item/?map=s-african-municipality-tackles-water-wastage

Thomson Reuters Foundation News. (31 July 2014). Darfur conflict. Available online: http://news.trust.org//spotlight/Darfur-conflict

Tissington, K. (2011). Basic sanitation in South Africa: A guide to legislation, policy and practice. Socio-economic Rights Institute of South Africa.

Tomar, P and Suthar, S. (2011). Urban wastewater treatment using vermi-biofiltration system. *Desalination* 282, 95–103.

Turner, KN, Naidoo, K, Theron, JG and Broodryk, J. (2015). Investigation into the cost and operation of Southern African desalination and water reuse plants: Volume III: Best practices on cost and operation of desalination and water reuse plants. Water Research Commission, Report No. TT 638/15.

United Nations Development Programme (UNDP). (2004). Ideas, innovation, impact: How Human development reports influence change. New York, NY.

United Nations Development Programme (UNDP). (2016). Human development report 2016: Human development programme for everyone. New York, NY.

University of Cape Town (UCT). (29 May 2016). Removing pollution from water. Available online: http://www.ebe.uct.ac.za/ebenews%20-%20removing%20pollution%20from%20 water

Urbach, J. (2015). Intellectual property rights: Where to South Africa? Available online: http://www.freemarketfoundation.com/issues/intellectual-property-rights-where-to-south-africa

US Chamber International IP Index. (2017) The Roots of Innovation. Fifth edition, Global Intellectual Property Center.

Van der Merwe–Botha, M and Manus, L. (2011). Wastewater risk abatement plan: A W2RAP guideline. Water Research Commission, Report No. TT489/11.

Wall, K, Ive, O, Bhagwan, J, Kirwan, F, Birkholtz, W, Lupuwana, N and Shaylor, E. (2012). Demonstrating the effectiveness of social franchising principles: The emptying of household VIPs: A case study from Goven Mbeki Village. Partners in Development, South Africa.

Wallos, MJ, Ambrose, MR and Chan, CC. (2008). Climate change: Charting a water course in an uncertain future. *Journal – American Water Works Association* 10(6), 70–79.

Wang, H, Omosa, IB, Keller, AA and Fengting, L. (2012). Ecosystem protection, integrated management and infrastructure are vital for improving water quality in Africa. *Environmental Science & Technology* 4 (9), 4699–4700.

Water Research Commission (WRC). (n.d.). Available online: http://www.wrc.org.za/

Water Research Commission, Department of Science and Technology, and Department of Water and Sanitation (WRC, DST and DWS). (2015). South Africa's Water Research, Development and Innovation (RDI) Roadmap: 2015-2025. Water Research Commission, Report No. 2305/1/15.

Water Research Commission. (2016). Available online: http://www.wrc.org.za/SiteCollectionDocuments/Dialogues/Khuluma%20Sizwe%20dialogue/Youth/GeyserSense.pdf

Wells, CD, Dekker, LG, Clark, S, Hart, OO, Neba, A and Rose, PD. (n.d.). Integrated algal ponding systems (IAPS) in the treatment of domestic wastewater: A nine-year performance evaluation. Environmental Biotechnology Research Unit, Rhodes University.

Wijnberg, S. (2015). The WEROP: Wave Energy Reverse Osmosis Pump: Development status 2015 (D&I). Water Research Commission Research Development and Innovation Symposium & Water-tech Summit 16–18 September 2015, Birchwood Hotel.

World Economic Forum. (2016). The Global Risks Report 2016, 11th Edition. World Economic Forum, Geneva.

World Health Organisation (WHO). (2003). The right to water. Health and human rights publication series; no. 3. Available online: http://www.who.int/water_sanitation_health/en/righttowater.pdf

World Health Organisation (WHO). (2016). Putting household water treatment products to the test. Available online: http://www.who.int/features/2016/household-water-treatment-test/en/

World Health Organization (WHO), Office of the High Commissioner for Human Rights (OHCHR), Centre on Housing Rights and Evictions (COHRE), Water Aid, Centre on Economic, Social and Cultural Rights. (2003). The right to Water. http://www2.ohchr.org/english/issues/water/docs/Right_to_Water.pdf

World Wide Fund for Nature (WWF). (2015). Innovations in water in the South African water sector: Danish investment into water management in South Africa. (n.d.). Danish Water Report, Available online: http://awsassets.wwf.org.za/downloads/danish_water_report_v10_dps_lo.pdf

World Wide Fund for Nature South Africa (WWF SA). (2017). Water: Facts and futures rethinking South Africa's water future. Available online: http://awsassets.wwf.org.za/downloads/wwf009_waterfactsandfutures_report_web__lowres_.pdf

Zhang, H. (2012). National Innovation System: South Africa and China compared. Department of Industrial Engineering, University of Stellenbosch.

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