Water Security Driven by Industrial Revolution 4.0

A Desktop Study Report
for
The Water Research Commission of South Africa

A Part Contribution
Towards Enhancing Water Security

Department of Mechanical Engineering Science

Faculty of Engineering and the Built Environment

UNIVERSITY OF JOHANNESBURG

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Preface

On 15 September 2020, the University of Johannesburg entered into a Memorandum of Agreement with The Water Research Commission of South Africa for a first pass, exploratory, short duration, desk top study (WRC Project No. C2020/2021-00400).

Field of Interest: Industrial Revolution 4.0 and Water Security

Theme: Towards Developing a Technology Driven Water Pool Model for Bilateral and Competitive Trading of Water Resources.

Duration of Study: The period of study was limited to six months, to conclude on 31 March 2021.

Study Methodology: The Harvard Case Study Approach was adopted as the reference for the investigations into pooling of resources. The Southern African Development Community's Southern African Power Pool and the City of Johannesburg's Joburg Fresh Produce Market were selected as successful local experiences in market models; for case study review, analysis and transfer of learnings to the proposed Water Pool Model.

Given a water pool market model that collates all the water resources in all the available states (virtual, natural, used etc.), the University of Johannesburg's resident Institute for Intelligent Systems were tasked to prepare a conceptual model of an Industrial Revolution 4.0 driven water pool model; such that the end goal of "big data, markets and cash flows" could converge towards an arrangement that delivers strong financial liquidity for all; the market of traders and brokers, the buyers, the sellers and the infrastructure investors.

Real time strong financials from a transparanet and vibrant market, will promote, sustainably and with resilience, capital and operational investments in national and regional infrastructure, thereby ensuring water security to all.

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Klaus Schwab, Founder and Executive Chairman, World Economic Forum, noted that "we stand on the brink of a technological revolution that will fundamentally alter the way we live, work and relate to one another. In its scale, scope, and complexity, the transformation will be unlike anything humankind has experienced before. We do not yet know just how it will unfold, but one thing is clear : the response to it must be integrated and comprehensive, involving all stakeholders of the global polity, from the public and private sectors to academia and civil society." In this chapter, the team explores the state of art in IR4.0 technologies and starts to prepare conceptual designs for a water pool market model as driven by the digital revolution. The emerging picture, supported by the first mathematical equations, confims that it is practical to bring together the physical, digital and biological spheres of the water sector. Much work reamins ahead. A new reset to the thinking on water security is emerging.

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The desk top study has attempted to reset our thinking with respect to water security. The traditional approach would be to depend on the public sector to build more capacity to collect, store, process and distribute rainfall in reponse to increasing demand. The new thinking introduced is to build new capacity in open and transparent markets. Markets will access all the available water resources. Markets will stimulate investments to package, process and distribute the water to all. Market forces, operating freely, will spur on infrastructure investments to excel under longer time horizons and greater economies of scale. The results will emanate; higher volumes at lower unit prices at best quality, demand lags supply and security is assured. This chapter provides some recommendations on how to go about realizing the gains.

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Acknowledgement

The creative idea emanated from the early conversations between the leadership of the University of Johannesburg and The Water Research Commission of South Africa on the concept of virtual water and the role of the emerging industrial revolution 4.0 technologies in contributing to water security. The concept of virtual water was introduced in the mid nineties to describe water used for the production of fresh produce as traded in international markets. The virtual water perspective was initially proposed as a strategy for countries with water-shortage to import fresh produce that consume substantial amounts of water. Imported fresh produce from water abundant countries will contribute to alleviate the existing water stress of a country and enhance the country's water security. This idea remains mostly academic. Economic and political considerations have greater influence than water scarcity in determining national trade strategies.

Building upon the initial idea, the conversation migrated to "markets, big data and cash flows"; to prepare a conceptual model of a "water pool" that could collate the virtual and real states of all the available water resources from a spectrum of sellers and delivered to a spectrum of buyers. A "water pool" market model is envisaged as an open and transparent market that operates in real and future time and that the cash flows between the buyers and sellers provides the liquidy required to promote capital investments and to sustain operating, maintenance and refurbishment activities.

Given past experience at the Southern African Development Community's Southern African Power Pool and at the City of Johannesburg's Municipal Enterprise, Joburg Fresh Produce Market, a case study approach was proposed to understand "markets, big data and cash flows". The Southern African Power Pool and the City of Johannesburg, together with experienced consultants were invited to contribute to the case studies. Building upon the case study experiences, the University of Johannesburg's Institute of Intelligent Systems, was invited to gather the ideas and to produce a first pass conceptual plan for a "water pool model".

The study team met weekly, online, and shared inputs, contributions and prepared the desk top study report. On 17th March 2021, the report was shared, via webinar, with members of SAIEE. The report has received its first professional CPD accreditation from ECSA and SAIEE.

Thank You

Rami Kobela

Specialist : Group Strategy
City of Johannesburg

Rami Kobela holds a B.A in Information Science degree from the University of Johannesburg (UJ), a B.Com Honours in Economics degree from the University of South Africa (UNISA), and a Master of Management degree from the University of the Witwatersrand. He works as a Specialist: Partnerships & Peer Learning; for the City of Joburg' s Group Strategy, Policy Coordination & Relations Department (GSPCR). His role is to provide support in leveraging on the City's partnership with higher education institutions – to enhance service delivery performance through evidence-based policymaking.

Mziyanda Mbuseli

Market Surveillance Manager
Southern African Power Pool

Mziyanda has over 19 years' experience in the electricity industry, mainly at Eskom, the private sector and now the Southern African Power Pool as the Market Surveillance Manager; with the primary responsibility of ensuring that the SAPP markets operate efficiently and provides confidence to all stakeholders that the market outcomes are a true reflection of a fair and competitive interaction between demand and supply forces. He was instrumental as the Chairperson of the SAPP Markets Sub-Committee when the Day-Ahead Market was opened for trading in 2009.

FRANCIS MASAWI

Independent Consultant
Founding Member of the Southern African Power Pool

Francis Masawi is an independent consultant with a Degree in Electronics and Power Engineering from the University of Zimbabwe. Francis has worked, for the past four decades, in electrical power systems in eastern and southern Africa and has consulted widely for the World Bank, USAID, the German Government the European Union as well as being a founder member of the Southern African Power Pool (SAPP).

Francis has acquired some applied knowledge and clarity in information access in energy markets in which energy demand, supply and access and the simultaneous conversion of the energy into electrical energy and work occurs to produce goods and services that society demand and can pay for. His interests are now in the nexus of energy, water and food without which life, as we know it, would be impossible.

JAN MOCKE

Independent Consultant
Former Chairman
Joburg Market SOC Limited
City of Johannesburg

Jan Mocke is a qualified electronic engineer (UP), who has completed a MBL at Unisa. After working as consulting engineer, he joined the IDC for a number of years. He later spent many years in senior management positions in agricultural organizations, including Sapekoe and Mount Carmel Farms. He was also COO at the Joburg Market for 7 years, after which he served on the Joburg Market Board for two terms. He also served as Board Chairman at the Joburg Market. He now works as independent consultant on the development of fresh produce markets and agriculture projects. He is playing an instrumental role in the design and construction of the new Mpumalanga International Fresh Produce Market, introducing various industry leading characteristics.

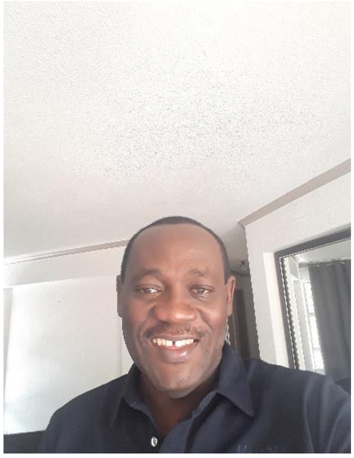
HERMAN MYBURGH

Institute for Intelligent Systems
University of Johannesburg

Dr Herman Myburgh holds a PhD in nutrition from the North-West University, in which he focused on the genetics of inflammation. Being passionate about technology, during his postdoctoral studies, he started investigating how modern technologies – particularly extended reality technologies – can be implemented to solve public health problems on the African continent. As a senior lecturer at the Institute for Intelligent Systems, University of Johannesburg, Herman guides students in public and environmental health – focusing on allowing his students to achieve new academic heights. He is also an active member of the African Nutrition Leadership Programme.

UCHE CHUDE-OKONKWO

Institute for Intelligent Systems
University of Johannesburg



Dr Uche Chude-Okonkwo is currently a Senior Lecturer at the Institute of Intelligent Systems, University of Johannesburg, South Africa, and has over eighty (80) publications in reputable journals and conferences. He serves as a technical program committee member for the prestigious IEEE GLOBECOM, and associate editors for Frontier in Communications and Networks and the SAIEE Africa Research Journal. His current research interests include (but are not limited to) Wireless communication, Molecular communication applied to advanced medicine, Artificial intelligence, Internet of Everything, Blockchain, Extended Reality, Complex systems, Systems Biology, and Signal processing.

Chapter 1

Introduction

A conceptual note, towards developing a water pool market model, "Water Security Driven by IR4.0", is presented in this chapter.

At the 2014 Annual General Meeting of the South African Institute of Electrical Engineers (SAIEE, 2014) , the inaugural address of the incoming President made reference to the world class stature of South Africa and the emerging trend of poor service delivery.

> "South Africa is the sparkling diamond of the world. In the passage of time, South African engineers have delivered world first and world class solutions to the agricultural, industrial and post industrial societies. Relocate yourself to any part of the global community and look at Southfrica. You will see unlimited opportunity for its people. We have a respected and free country with constitutionally embedded human rights. We have a country with the world's best banking and financial systems. We have the best weather conditions with gentle winds, rain, sunshine and storms. We have an open country that thrives with all that nature can offer; from the marine life in our two oceans to the wild game in our natural parks; from the fruits of the valleys of the Cape to the abundant bread basket of Central South Africa; from the rolling sugar cane fields of Kwa Zulu Natal to the gold, diamond, coal and platinum natural resources of the Highveld. We have health, wealth and an abundance of resources with unlimited opportunity for all."

With respect to the emerging trend of poor service delivery;

> "South Africa, two decades into democracy, continues to face challenges with respect to providing a better quality of life for its entire people. The 20th century industrial era public infrastructure, designed, built and operated to world class standards, now requires major maintenance, upgrade and refurbishment. The communities that lacked infrastructure either continue to have no infrastructure or if infrastructure was delivered, in the past twenty years, the quality and affordability of the service remain

> a challenge. South Africans are generally restless with respect to public utility services. This restlessness is directly impacting on the economic productivity of the nation. The nation has all the ingredients for providing for providing its entire people, the best quality of public utility services. South Africa has the political goodwill, the natural resources, the financial resources, the technology, the factories, the machinery, plant and equipment and skilled, energetic and empowered human resources to deliver the required solutions.
>
> What mystery holds us back from serving our citizens? Where is the gap? Which technology requires more research and development before application? What is the barrier to world class service delivery? Why are we not delivering on the basic human rights of communications, of water and sanitation, of energy? The gap is a lack of leadership with a sharp focus on customers. The sharper the focus is on the customer, the greater will be the purpose of business."

Water, a natural resource, is the source of all life. Water, in nexus with the energy, was selected as the service delivery sector for priority study. In joint conversations between the University of Johannesburg and the Water Research Commission of South Africa, a desk top study was promoted to investigate the potential of a market based trading environment that could contribute towards enhancing water security.

1.1 The Desk Top Study Question

How could one collate, promote and sharpen the focus of both the public and private sectors to harness all the available resources of data, information and intelligence plus financial and engineering capacities and capabilities that will drive the sustainability of all investments in providing society with Water Security?

To commence the study, two key references are adopted.

The first study reference is to make a contribution to United Nation's goal number 6, "Transforming our World: The 2030 Agenda for Sustainable Development (UN, 2015),

Goal 6. Ensure availability and sustainable management of water and sanitation for all

6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all

6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations

6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate

6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes

6.a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies

6.b Support and strengthen the participation of local communities in improving water and sanitation management."

The second reference is to embrace the emerging and rapidly evolving space of the 4th Industrial Revoution as promoted the World Economic Forum (WEF, 2016).

The leadership of the University of Johannesburg has strategically adopted the 4th Industrial Revolution as its focal theme for futher study, test, research and investigations. Water Security embraces the physical, biological and technological world's and makes an ideal candidate for further study in the space of 4IR.

> "In contrast to the earlier industrial revolutions, 4IR is based not on a single technology, but on the confluence of multiple developments and technologies. Some of these include artificial intelligence, machine learning, robotics and automation, cryptocurrencies and renewable energy, to name a few. Technologies and processes are each evolving at an exponential pace and are often inter-related, increasingly connecting the digital world with the physical one. Substantial disruptions will impact all industries and entire systems of production, management and governance and will undoubtedly transform all aspects of 21st century life and society. Humans will be affected in many ways through interfaces between humans and technology. The 4IR will 'intrude into the private spaces of our mind', it will affect our identities, and specifically our notions of privacy. This technological revolution will 'fundamentally alter the way we live, work, and relate to one another. In its scale, scope, and complexity, the transformation will be unlike anything humankind has experienced before."

The third reference is to add climate change as a study boundary condition. The United Nations Framework Convention on Climate Change reports that a real risk exists that rising greenhouse gas concentrations in the atmosphere could lead to irreversible interference with the global climate system (UN, 1992). The world is already experiencing changes to average ambient temperatures, shifts in seasonal weather patterns and an increasing frequency of extreme weather events. Water, a natural resource, is openly exposed to the emerging global risk. This real risk requires all to embrace a strategy of adaptation with resilience. In the case of water, there exists the urgency to bring together all the available states and qualities of water in addressing water security.

Given the rapidly changing climate with increasing human activity :

> Can we RESET our thinking in providing water and sanitation security for all ?
>
> Can we deliver water and sanitation services to all;
>
> > Affordably ?
> >
> > With resilience and sustainability ?
> >
> > In synchronism with Nature ?
>
> A potential answer could reside in Industrial Revolution 4.0; in the space of big data, markets and cash flows.

1.2 The Desk Top Study Proposal

Develop an Industrial Revolution 4.0 driven conceptual solution for an independent and self-regulating business market model that can promote and manage competitive and bilateral trading of water between buyers and sellers whilst simultaneously promoting and supporting the required engineering infrastructure that will deliver the physical water between buyers and sellers.

It is envisaged that water will be traded in all its available states and qualities, including virtual water, bulk fresh natural water, bulk ocean water, technology cleaned and purified used water, bulk industrial, mining and commercial wastewater, bulk municipal sanitation water, rainfall harvested and ground stored water.

With machine driven trading of water resources, open to both private and public sector participants, decision making will have the values of transparency, integrity, consistency and repeatability and this will lead to the creation of the required financial liquidity that will support the bankability of infrastructure development, operations and maintenance. Thus by design, long term sustainability and resilience in the delivery of water security for all will be assured.

Emanating from the trading activity, wheeling and delivery infrastructure and systems would be engineered, commissioned, operated and managed for both bulk transfers and last mile service delivery of forward fresh and return waste/used supplies.

The hypothesis is that the trading activities and the results thereof will lead and spur on the growth, development, operations and maintenance of the wheeling and delivery infrastructure and systems.
Three specific deliverables were contracted for the desk top study.

Deliverable 1 : The first deliverable was for a conceptual market model for water security as driven by IR4.0.

Deliverable 2 and 3 : The second and third deliverable was to explore the market models of two existing enterprises; one focused on energy security and the other on food security. Their brief terms of reference was to study the existing market models; their strategy, structure, systems and performance; to extract and transfer the learnings to the proposed "Water Pool Market" that could be developed for South and Southern Africa

1.3 The Three Deliverables for the Desk Top Study

1.31 Ideas for a Conceptual Model for Water Security Driven by IR4.0

The University of Johannesburg's Institute for Intelligent Systems was tasked to investigate the state of art in industrial revolution 4.0 technologies with reference to the conversations of a market based environment for water security. The Institute was provided with a broad terms of reference; namely:

i. IR4.0 builds upon the engineering and technology of earlier revolutions. Trading of water resources, both by bilateral and competitive bidding, takes the activity into the space of Industrial Revolution 4.0; big data, data analytics, transparency of information, integrity of information, machine-based decision making and internet of things.

i. IR4.0 trading activity will consist of a platform of data and analytics that are driven by empowered buyers and sellers. The decision making and delivery of outcomes is technology managed. The integrity of decisions is to be defined by set policy. There is no need for human interference. Sustainability and resilience is to be built into the model; continuity and adaptability is assured for ensuring water security at all times.

ii. IR4.0 will stimulate new business models that will have a sharp focus on set core value to serve infinite customers locally, nationally, regionally; effectively "without borders and global". Satisfied and delighted customers will promote repeatability of transactions and will create the necessary financial liquidity for sustainability, resilience, growth and development of the business.

iii. IR4.0 will promote technologies and people to connect and communicate with each other. With a core capability of data and analytics, the information will be comprehensive, dependable and transparent for decision making, problem solving and infrastructure development.

iv. IR4.0 will stride across the man-made boundaries of private and public sectors, including man-made regulations and policies of the past, creating a virtual self-regulating business environment.

IR4.0 and Big Data has the potential to bring to the forefront the concept of "virtual water".

The concept of "virtual water" was first introduced by Allan (1996) to describe water used for the production of crops traded in international markets (Allan 1996, 2002, 2003). The virtual water perspective was initially proposed as a strategy for countries with water-shortage to import commodities that consume substantial amounts of water and are produced in water abundant countries to alleviate existing water stress. In practice, this strategy remains academic and is not reflected in international trade data or in daily trading of fresh produce. Du Fraiture (2004) notes that economic and political considerations may have more influence than water scarcity in determining national trade strategies (Du Fraiture,2004). Water and politics is like Church and State, inseparable. However, IR4.0 and Big Data has the ability to rise over and to allow market forces to determine the most efficient ouctomes for all.

Although observed trading patterns do often not support this hypothesis, there is a lack of research to explore the reasons why trade patterns often do not support the intuitive virtual water hypothesis. To fill this important gap, Zhao et al (Zhao, 2019) conducted a spatial-temporal analysis of the comparative advantage of land, labor and water in China in their quest to understand the concept of virtual water and the linkages between water availability, water costs, economic productivity, comparative advantages and opportunity costs. They introduced the comparative advantage theory in a quantitative way to track the driving forces of net virtual water export based on the spatial-temporal distribution of resource productivity and opportunity costs of land, labor and water use in agricultural and non-agricultural sectors across Chinese provinces between 1995 and 2015. The results show that regional differences in land productivity be-tween agricultural and non-agricultural sectors are the main forces determining the pattern of virtual water flows across major regions, and other resources such as labor and water have played only a limited role. Their study showed that the current market forces reflect the scarcity of land resources, but does not reflect the water scarcity in the context of interregional trade in China. Their findings suggest that the ongoing efforts to increase land productivity of agriculture in the southern regions would contribute to reducing water scarcity in the North and Northeast China Plain.

For the record, let us accept that “virtual water” has value in promoting that water-deficient regions could alleviate water stress through importing water-intensive products from water-abundant regions; where regions could be national, continental or global. IR4.0 has the strength to transend physical boundaries and as example, a customer in Singapore could order oranges from Citrus Growers in the Nkwaleni Valley of Kwa Zulu Natal. The oranges will be grown in the water abundant Umfolozi River Valley and when ready, be transported to Singapore. Oranges equals water. This effectively means that one is trading in water; global financial resources could be invested year ahead on a market platform and be made available to support the required water infrastructure for the agricultural sector in Kwa Zulu Natal. This investment could be substantial such that cross subsidies could flow on and support neighbouring community required water infrastructure development, operations and maintenance. Using this example in the discussions, the team was challenged to explore and highlight the opportunities associated with “virtual water”; noting that this subject will follow on as part of continued investigations post the desk top study phase.

1.32 The Case Study of City of Johannesburg’s Joburg Market SOC Limited

More than a century ago, the community of Johannesburg promoted the development of a food market as a contribution towards sustainable economic development and food security for all. The market owns no food, it has no farms to produce the food neither does the market own the delivery infrastructure and transport vehicles that moves the food to and from the market. In 1873, the City of Johannesburg started the “market model and co-ordination office” and today boasts an annual turnover in food sales that approaches R10b; realizing an annual commission to the City that now approaches R0,5b.

1.33 The Case Study of the Southern African Power Pool

Three decades ago, a similar “market model and co-ordination office” was set up for the Southern African Power Pool of SADC. The Power Pool owns no electricity; it has no power stations and no power lines. Daily, the “co-ordination office” transacts and connects buyers and sellers of electricity, dispatch purchases and sales and makes a commission on every transaction. Today, the Southern African Power Pool boasts a multi- million US dollar liquid market and continues to grow from strength to strength. It is headquartered in Harare, Zimbabwe and serves the Southern African Region as part contribution to energy security.

Given that the proposed new market model for the co-operative and competitive trading of water resources will be bounded and driven by policy, the policy framework on water security as driven by the National Planning Commission of the Republic of South Africa and SADC’s Water Security Protocols were selected as the study boundary. In conclusion, the desk top study was launced as conversations with stakeholders as an initial roadmap for the start of developing a pilot Water Pool Market Model for South and Southern Africa.

CHAPTER 2

LITERATURE REVIEW

The classic chapter on literature review is limited to provide a very brief reflection on the present day water security in South and Southern Africa. Emanating from the review, salient hypothesis are discussed by the study team. Four hypothesis are adopted as references for the building of the conceptual model.

2.1 Reflections on Water Security in the Southern African Development Community

The SADC Vision encapsulates the pooling of resources to achieve collective self-reliance that directly contributes to improved quality of life for the people of the region. SADC is an expansive region, as shown in figure 2.1, and consists of unevenly-distributed water resources. Southern Africa experiences seasonal precipitation with varying distribution amongst the northern tropical and southern arid regions. The demand for fresh water across the region emanates from the domestic, agricultural, mining and industrial sectors.

Water is a finite resource. Water has an economic and social value.

SADC has the urgency to develop and manage the available water resources efficiently and to optimise the returns that embraces conservation, longevity and sustainability of the resource. SADC has developed three agreements amongst its membership to enhance water security. These are the :

i. Protocol on Shared Water Resources (SADC, 2000)
ii. Regional Water Policy (SADC, 2005)
iii. Regional Water Strategy (SADC, 2006)

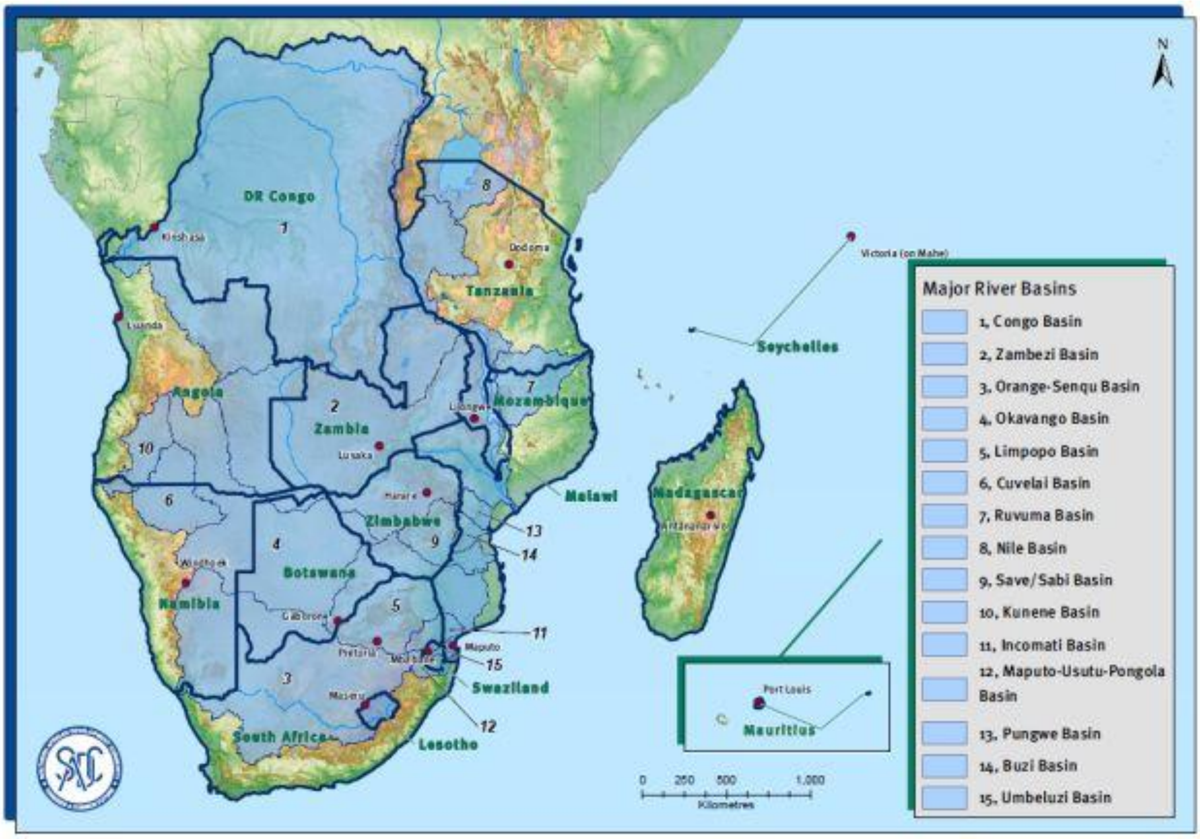


Figure 2.1 : The Major River Basins of SADC

On sharing of regional water resources, the Revised Protocol on Shared Watercourses (SADC, 2000) emphasizes the equitable use of water resources, using the guiding principles of Integrated Water Resources Management. The protocol takes into account the geographic and climatic factors, as well as the socio-economic demands of SADC Member States. The SADC Water Division promotes the sustainable use of water resources through coordinated management, protection and equitable use.

The strategies for investments in water security include those that

i. promote adequate, fiscally efficient and sustainable funding of the water sector;
ii. promote the effective and efficient use of financial resources to achieve the sector goals; and
iii. to facilitate the establishment of stakeholder partnerships in order to share water resource benefits equitably and liabilities fairly.

Water as a resource was taken for granted because it has been perceived as infinitely renewable. However, of late water is increasingly being recognised as a variably available and frequently scarce economic good to which realistic value must be attached. Increasingly it is understood that there is a cost associated with the use and degradation of natural resources.

Natural Resource Accounting is the process of assigning a monetary value to resources that are traditionally not valued in such a way. This helps a government to integrate natural resources into the system of national accounts. SADC has embraced this concept and through extensive project work, has developed and tested methodologies for Economic Accounting of Water Use. Central to the enhancement of water security, SADC promotes and facilitates the acceptance of and accounting for water as a valuable input in socio-economic development programmes; to develop regional guidelines and procedures for economic accounting for water; to develop and promote cost recovery mechanisms and to encourage a culture of responsibility and accountability with policymakers and private sector investors.

There is currently no standard formula to estimate the value of water.

SADC has need for significant investment to achieve the goals of the various development and management projects, but the region has difficulty in mobilising adequate funds for developing and managing the water resources.

2.2 Refections on South Africa's National Water Security

Water security is percolating to the top as the number one risk to national sustainability, growth and development. For many days, in many municipalities and communities, the taps are dry. News 24 South Africa recently reported on the dire water situation in Port Alfred as the taps run dry (NEWS, 2021).

> *"The dire water situation in Ndlambe Municipality, Eastern Cape, has hit Port Alfred, Kenton-on-Sea, Alexandria, Bathurst, Boknes, Cannon Rocks, Boesmansriviermond, and surrounding farms. The local economy is dominated by farming and tourism, both heavily affected.*
> *The municipality blames the crisis on the drought. The drought situation has come a long way since 2018. This drought has caused dam levels to drop drastically especially when rainfall is not available. The Port Alfred community is serviced with bulk water*

from the Sarel Hayward dam, the East Bank dune wellfields, and the Central belt boreholes. These water sources are designed to traditionally produce a combined yield of 6.6 million litres per day, yet the current water demand is 8.2 million litres per day. The reverse osmosis plant is currently under construction and will yield five million litres per day when in operation. In a recent pamphlet, the municipality said the plant was expected to produce water towards the end of March."

For many South Africans, the basic human right to clean and fresh water and managed sanitation is being violated. The Human Rights Commission of South Africa has recently published its report on sanitation overflow into Gauteng's source of natural fresh water, the Vaal (SAHRC, 2021)

"The importance and economic value of the Vaal was made very clear during the Inquiry. National Treasury emphasised that approximately 19 million people depend on the Vaal for water, for drinking and for domestic and commercial use. It also became clear during the Inquiry, that the Vaal is now polluted beyond acceptable standards, and that the cause is the kilolitres of untreated sewage entering the Vaal because of inoperative and dilapidated wastewater treatment plants which have been unable to properly process the sewage and other wastewater produced in Emfuleni as well as the sewage and other wastewater from the City of Johannesburg Metropolitan Municipality as well as the Midvaal Municipality, that is also directed towards the wastewater sewerage systems situated in the Emfuleni Municipality.

The impact of the discharge, occurring over more than five years at the time of writing, violated a number of constitutional rights which includes the rights to: human dignity, freedom and security of the person, an environment that is not harmful to health or well-being, not to be deprived of property, health care, food, water and social security, just administrative action and the rights of children to be protected from maltreatment and degradation."

In June 2020, The National Planning Commission, Presidency of South Africa, published its National Water Security Framework for South Africa (Nepfumbada et al, 2020). The report acknowledges the urgency in national water security and tabled key recommendations for a water secure country.

“Water security has always been an issue of concern in South Africa but, in recent times, it is increasingly under very serious threat in the country. The National Water Security Framework (NWSF) responds to the question of the extent of this threat and the actions required in the short, medium and long term to mitigate or offset the threat.”

SUMARRY RECOMMENDATIONS AND NEXT STEPS

South Africa’s water legislation gives correct and clear guidance on water management, but implementation has been weak. Therefore, a clear understanding of roles and responsibilities and difficulties in implementation is urgently required. In framing and planning the water security journey, cognisance is given to difficulty that comes with disrupting the status quo and the associated need to invest in paradigm shifts, as well as building the necessary momentum for change. Accordingly, the framework is expressed in a manner that allows for a possible phased approach that takes into account the urgency to deal with the low hanging fruits such as urgently implementing the legislation and commitments made through the various strategies. This includes making immediate decisions that do not require any addition resource capacity except delegated authority or other forms of convening capital associated with jurisdictional mandates from government through to private sector and other social partners.

A number of recommendations are summarised below and potential steps required to take the country on the path to water security in the immediate term:

i. *Assessing and taking stock of current difficulty in implementing policies and programmes. If relevant, mitigation measures should be identified for potential difficulties in implementations;*
ii. *Roll-out of the national framework to guide national processes and provide a long-term view of ensuring water security, including immediate process to develop the second edition of the Framework as a living document;*
iii. *Positioning of the effective implementation of the framework by creating a centre of water intelligence, taking into account the importance of water in all aspects of human life, especially for the South African conditions. This will further involve development and refinement of national indicators on*

water security and redirecting the various institutions mandated to carry out the water business, including stakeholders, public and private sectors as well as citizens;

iv. *Creating a planning and monitoring framework that is robust to ensure that water-related risks are avoided or mitigated;*

v. *Setting up a consultation process, during development and execution, taking all role players and stakeholders along through a participatory process without losing focus on the apex priorities espoused in the NDP;*

vi. *An assessment framework is proposed with indicators aimed at addressing the full spectrum of water security considerations that are in line with the identified key apex priorities. Water is seen as cross-cutting in all aspects of human life and the NWSF is set to address this.*

vii. *Aligning local government legislation and national legislation;*

viii. *Unpacking roles and responsibilities of all role players from the line department, institutions, private sector and other social partners;*

ix. *Given the lessons over the past 20 years since the National Water Policy and subsequent individual work done by the Department and researchers from across the country as well as internationally, further detailed assessments need to be done within 12 to 24 months. The key for this would be to consolidate what has been learnt and ensure that the amendments address the shortcomings.*

x. *It is evident that one of the key risks in the sector is the enabling environment for watersecurity. It is therefore important to immediately implement the institutional framework by establishing the institutions for water management without delay, especially those that have been debated and even gazetted.*

xi. *Continuous and managed consultation process both during the development of framework and execution taking all role players.*

This framework is the first of its kind in South Africa and meant to bring a fresh, internationally legitimised, and inclusive approach to assessing and addressing South Africa's challenges and opportunities for managing its water resources and provision of services to harness benefits and mitigate risks.

It is clear that SA is world class with legislation, policy, strategy and planning, but is poor with implementation of these. In fact, it is well accepted that the situation of water management and provision of water and sanitation services have deteriorated instead of improved. It is due to this lack of implementation and emerging challenges like climate change, infrastructure deterioration and massive urbanisation amongst others, that water security is now under threat, and that it requires a systematic and carefully considered intervention not only to stop-gap immediate challenges in the short term, but also to ensure water security in the long term. The framework provides an opportunity to ensure that water takes its rightful place as an enabler to uplift communities, reduce the economic inequality gap, stimulate economic growth and create wealth. It has huge potential to positively influence other sectors of the economy including health, education, crime prevention, mining, industry, tourism, finance, environment, security, etc. in different ways."

In May 2020, the South African Academy of Engineers, concerned on the current state of national water security, sent the first advisory note to the President of South Africa (SAAE, 2020). This was followed by a further three advisory notes (SAAE, 2020, 2021) The South African Academy of Engineering (SAAE) is a voluntary association that, as part of a global system, brings together eminent engineers from all engineering disciplines to serve the nation with independent expert advice.

COVID19 has shown that South Africa's water security is tenuous and declining.

Advisory Note 1 focused on prioritizing strategic investments (SAAE, 2020). The recommendations to the administration of the day were prioritize and implement strategic infrastructure investment programme to create jobs, promote economic activity, and sustain the water security of key urban and industrial centres.

In June 2020, the second advisory note on the state of water services in South African municipalities was delivered to the Presidency (SAAE, 2020). The failing of municipal water services can be attributed to weak management, a lack of competent and experienced professional and technical staff, political interference in day to day operations and poor oversight.

In October 2020, the third advisory note on municipal water losses was delivered to the Presidency (SAAE, 2020). In a highly water stressed country such as South Africa, approximately 41% of municipal water is lost through leaks (burst water pipes) and leakages (as in water accounting). Given lack of internal capacity at the municipalities, it is recommended that the private sector be engaged with performance based contracts.

In February 2021, the third advisory note on the water sector was delivered to the Presidency (SAAE, 2021). The advisory note was titled "The foundation of our water security is eroding – why hydrological information is important." The academy detailed the source, importance and current problems of hydrological information and tabled recommendations for enhancement.

2.3 Selection of Study Hypothesis as Emanating from the Reflections on Regional and National Water Security

2.31 Hypothesis 1 : Pool Water Resources

The SADC Vision of pooling of resources to achieve collective self-reliance is selected as the foundation for hypothesis 1. The idea of a water pool model has merit:

i. to manage unevenly-distributed fresh water resources;
ii. to manage the variations in seasonal precipitation;
iii. the ability to bring all water resources, in all its available states and qualities, such as virtual water, bulk fresh natural water, bulk ocean water, technology cleaned and purified used water, bulk industrial, mining and commercial wastewater, bulk municipal sanitation water, rainfall harvested and ground stored water;
iv. to smooth out imbalances in supply and demand;
v. to strengthen and enhance resilience in dynamic and changing environments; and
vi. to start the process of developing standard formulas for attaching financial value to all the available water resources. Once cash flows, the environment for infrastructure investments will arise and push forward the mobilization of funds for developing and managing the water resources.

2.32 Hypothesis 2 : Flow Data from Source to Decision Making

The flow of data from source to decision making is a necessary condition for monitoring, managing and assuring water security in a dynamic natural environment that has the burden of growing demands on natural resources and erratic behaviours as driven by climate change and global warming.

The image provided in figure 2.2 from Google illustrates the hypothesis.

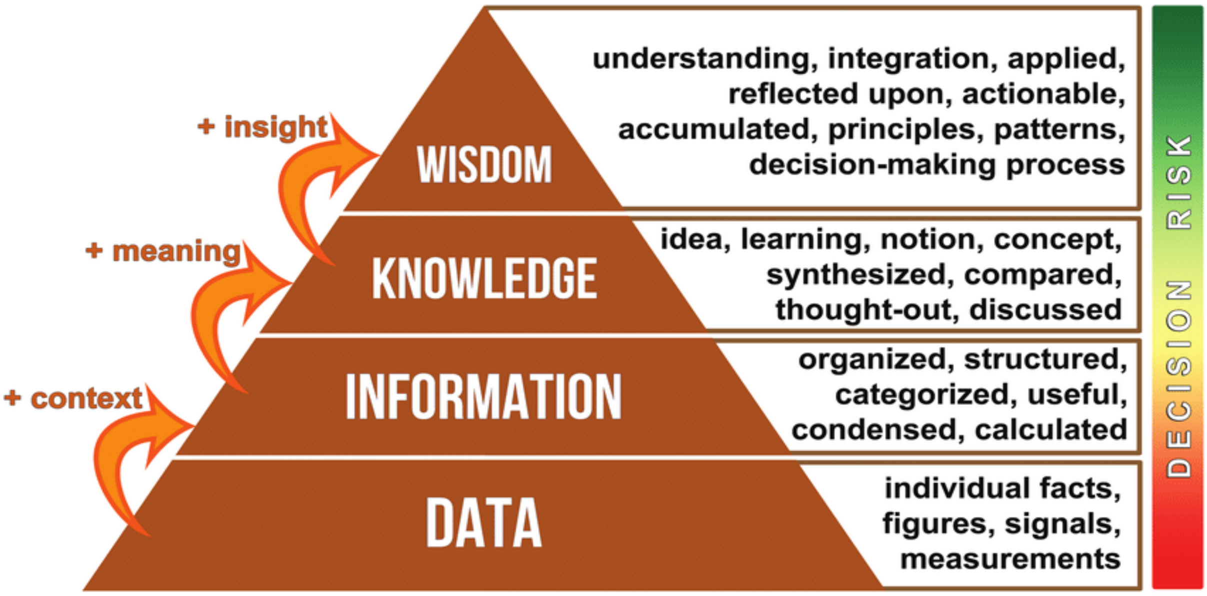


Figure 2.2 : A Google Image Illustrating the Flow from Data to Wisdom

The message conveyed is that data is a public good and the responsibility and authority to collect and manage vests with Government as in Central Administration. Another view could be that the data is a public good and should vest in a public domain; to be transparent and accessible to all stakeholders, for example, a data driven market platform. The latter sets the scene for the Proposed Research Assignment : Water Security Driven by Industrial Revolution 4.0. Internet of Things, Machine Learning, Artificial Intelligence and Robotics, driven and embedded in latest generation 5G cellular technologies of smart phones and computers, are best positioned to capture data, to package data and to process data onto information, intelligence and wisdom for decision making.

2.33 Hypothesis 3 : Competition and Markets Extracts Value

SADC notes that substantial investments are required in managing the region's vast fresh water resources. South Africa clearly has challenges on multiple fronts; lack of infrastructure, lack of maintenance of existing infrastructure, high water losses both in physical and monetary terms, deteriorating water quality and increasing pollution from open sanitation systems.

Without doubt, the private sector needs access into the water space; from project development, to project financing, to project engineering, construction, commissioning, operations and maintenance. The region and the nation has adequate resources of the classic four contributors of "manpower, money, machines and materials" to effect a sustainable and resilient turnaround of the distress in water security. The gap of action resides with leadership; leadership that should have sharp focus on the customer as purpose of business.

To invite private sector participation, the path forward will be to introduce and adopt open and free market competition for water security. Harvard University's Michael Porter (Porter, 1980) promotes that open and free market competition will promote rivalry between participants with the goal of achieving revenue, profits and market share.

Competition is the best practice :

i. for managing resources efficiently;
ii. to excel and to foster innovation;
iii. to diversify supply and enhance resilience;
iv. to yield best prices of affordability and with accessibility to all;
v. to stimulate growth, market development and opportunities for all stakeholders;
vi. to enhance the value of public goods and services for the greater benefits of the community and society;
vii. to spur all to deliver value to customers; to meet and exceed the needs of customers; and
viii. to ensure longer term sustainability.
ix.

2.34 Hypothesis 4 : Competitively Trade Water Resources for Water Security

Competition has the strength to bring new private sector participants into an otherwise public sector dominated environment. This strength will contribute to eroding the operational weaknesses of the public sector whilst enhancing its delivery on regulatory policies and practices. The net result will be enhanced water security for all.

The Southern African Power Pool has demonstrated over time that the two market models of bilateral contracting and competitive bidding can coexist. The Joburg Fresh Produce Market has consistently delivered lowest prices of fresh produce for over a century; the auction platform has served both farmer and consumer and ensured food security for all. At this point in the conversation on water security, the Case Study for both the Southern African Power Pool and the Joburg Fresh Market is considered; the learnings from both are transferred to the proposed Water Pool Market Model Driven by IR4.0.

CHAPTER 3

CASE STUDY MODELS

The Harvard Case Study Model approach is adopted for the two selected case studies in local and regional market experiences. The analysis is based on publicly available information as published in the annual and integrated reports. Experienced consultants were engaged to extract the salient features of each market model, to collate and interrogate the market and performance data and to extract the learnings for transfer to the proposed Water Pool Market Model.

3.1 Case Study 1 : The Southern African Power Pool

The University of Johannesburg decided to study existing and similar trading platforms to establish if lessons could be leant for water that would be of value in designing and establishing a water pool. The Southern African Power Pool (SAPP) was identified as a successful, operational and interconnected electrical power system that also depends on water and water services to be studied in this context. SAPP published reports (SAPP, 2009 -2021) has reference for the discussion that follows.

The Southern African Power Pool operates the world's largest and unique power pool that consists of physical and financial products operating, simultaneously, across monopoly and competitive markets. The power pool serves twelve countries having a combined population of 260 million people. The installed capacity exceeds 50 GW's with energy consumption in excess of 400 TWh per year. The market is liquid, robust and bullish. The energy mix consists mainly of thermal coal in the South (South Africa) and hydro in the North (Congo and Zambezi Waters). The emerging energy opportunities are in natural gas (Mozambique) and renewable energy resources of solar, wind and biofuels. Nuclear energy exists and is limited to the two pressurized water reactors at Koeberg, South Africa.

SAPP is an extraordinarily successful power pool, the first in Africa, operating in 12 countries in the 15-member Southern African Development Community (SADC), with the three unconnected being island states in the Indian Ocean with no power links to the continent. The

SAPP is an interconnected electrical power system that couples the power systems of Botswana, DRC, eSwatini, Lesotho, Mozambique, Namibia, RSA, Zambia and Zimbabwe. The power systems in Angola, Malawi and Tanzania are yet to be interconnected.

In August 1995, the Southern African Power Pool (SAPP) was established. This was at the SADC summit in South Africa. Member governments of the Southern African Development Community (excluding Mauritius) signed an Inter-Governmental Memorandum of Understanding (IGMOU) for the formation of a regional electricity power pool.

SAPP currently has seventeen active members. Twelve members are from the national power utilities, two members are from independent transmission companies and three are from independent power producers. Four agreements govern SAPP; the IGMOU which enabled the establishment of SAPP, the Inter-Utility Memorandum of Understanding (IUMOU) which established SAPP’s management and operating principles, the Agreement Between Operating Members (ABOM) which established the specific rules of operation and pricing and lastly, the Operating Guidelines, which provide the standards and rules for operating the power pool.

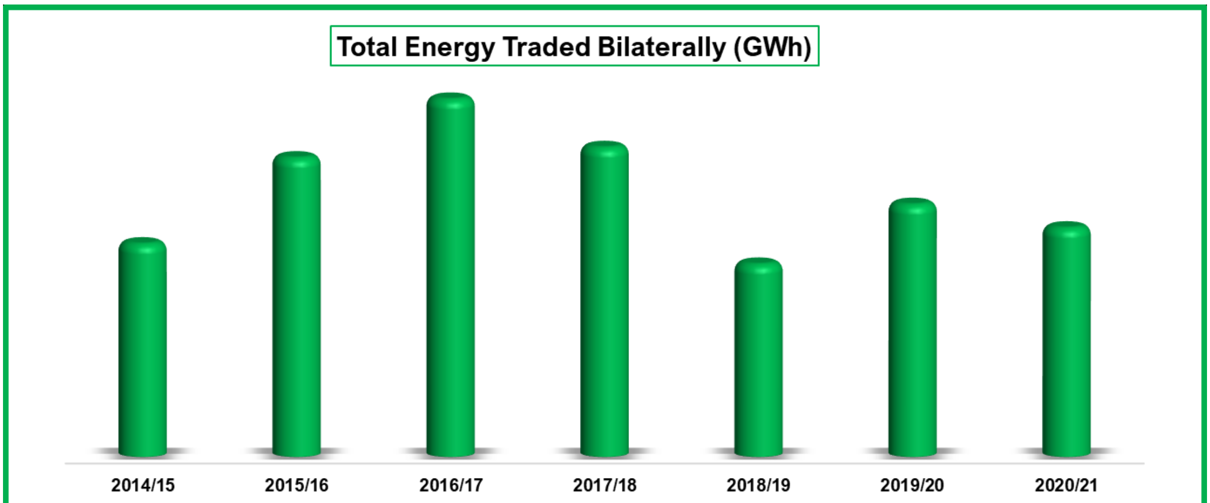
Committees populated by the membership provide non-executive oversight. The committees consists of Executive, Management and working sub - committees of Planning, Operations, Environmental and Markets. A Co-Ordination Centre located in Harare, Zimbabwe manages the day-to-day workings of SAPP. The SAPP operational budget emanates from membership annual subscriptions and trading commissions. SAPP is an independent going concern, financially liquid and having substantial and growing cash reserves.

The vision of SAPP is to facilitate the development of an electricity market in the Southern African region that provides for both bilateral and competitive trade between member states. The expectation is one of choice of electricity supply for end users, to promote the Southern African region as a destination for investment by energy intensive users and to facilitate sharing of energy resources in sustainable development through sound economic, environmental and social practices.

The electricity market consists of two platforms. These are as follows:

I. **The Bilateral Market.** The bilateral market recognises and manages the contractual relationship between member states and independent participants. The contracts are generally long-term in nature as in standard power purchase or standard power wheeling contracts. The trading terms and conditions are mutually agreed between bilateral partners and includes key parameters of volumes, price and transmission security. The energy contracts are generally firm but could include interruptible terms and conditions. A dominant participant in the bilateral market is South Africa which has baseload thermal coal electricity production and the capacity to export surplus energy into SADC. The capacity to export base load electrical energy is dependent on power station performance.

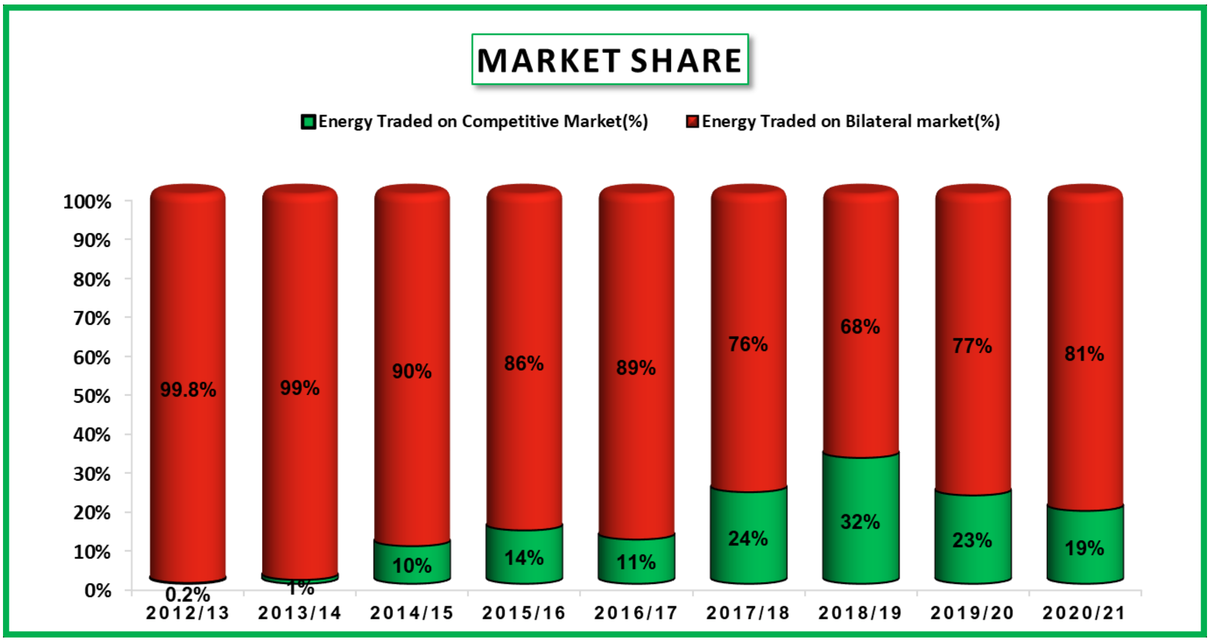
Graph 3.1 presents the volume of bilateral trade for the period 2014 to 2017. The growth in period 2014 to 2017 corresponded directly to the successful recovery of base load thermal electrical energy production from South Africa's Thermal Power Stations. Since 2018, South Africa's baseload thermal electricity production slipped in performance and this is equally reflected in the declining and erratic performance for the period 2018 to 2021.



	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Energy Traded on Bilateral market(GWh)	4,761	6,681	7,992	6,913	4,308	5,642	5,117

Graph 3.1 : Total Energy Traded Bilaterally (GWh)

Graph 3.2 shows the allocation of energy between the two market platforms of bilateral and competitive trading. South Africa's surplus thermal coal generation at the end of 2017 is evident in the growth in bilateral sales during the period 2017 and 2018. The post 2018 collapse in power station performance is equally reflected in the years 2018 to 2021.



Graph 3.2 Market Share of Energy Traded Competitively vs Bilaterally

II. The Forward Physical Market (FPM).

Here the SAPP Coordination Centre manages competitive trading amongst the membership for future time of energy delivery according to the contract specifications. Graph 3.3 presents the profile of energy matched versus energy traded in GWh.

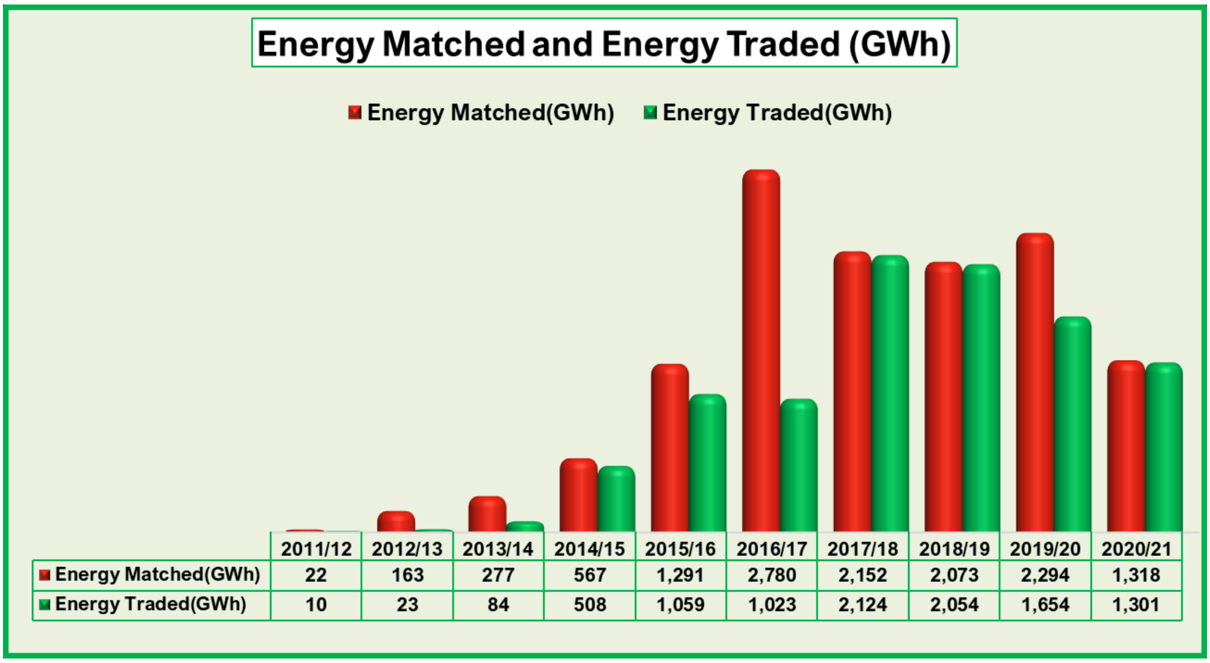
The following energy contracts are available for trade;

FPM-Monthly: This trades hourly energy base-load contracts for each of the 24 hours of all days in the following month. The hourly energy base-load contracts for the following time-of-use contracts with different hourly patterns valid for all days in the following month includes off-peak hours and non-off-peak hours.

FPM-Weekly: This trades hourly energy contracts for the following time-of-use contracts with different hourly patterns valid for all days in the following week; off-peak hours, peak hours and standard hours

Day Ahead Market (DAM)- This is the regional market established within the SAPP with the objectives to trade electricity a day in advance of the delivery of such trades and consists of hourly energy contracts for each of the 24 hours of the following day, or a future day.

Intra Day Market (IDM) - The IDM is a continuous market, and trading takes place every day around the clock until one hour before delivery. Prices are set based on a first-come, first-served principle. The SAPP Market Operator specifies the timing of the hourly energy contracts.



	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Energy Matched(GWh)	22	163	277	567	1,291	2,780	2,152	2,073	2,294	1,318
Energy Traded(GWh)	10	23	84	508	1,059	1,023	2,124	2,054	1,654	1,301

Graph 3.3 Profile of Energy Matched versus Energy Traded for the Last Decade

Table 1 provides the market performance statistics and table 2 shows the market clearing prices in US cents/kWh. The range of standard tariffs across the region varies from 3 to 17 US cents/kWh. Graphs 3.4 to 3.8 demonstrates the liquidity of the market and provides the confidence that price discovery in association with supply and demand will track the fundamentals of economics.

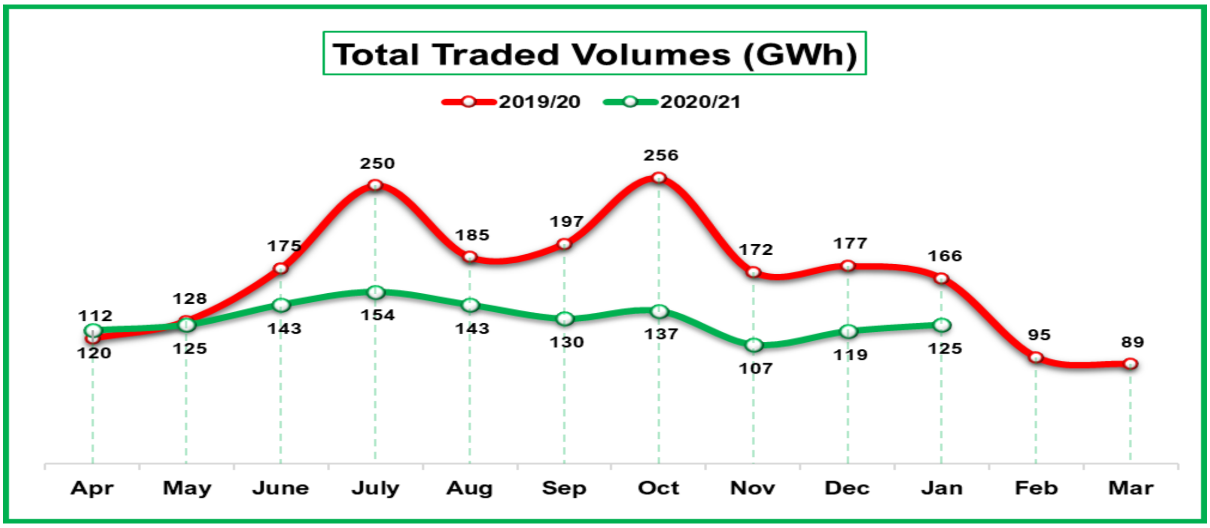
Month	Active Portfolios	Number of Participants	Total Volumes Traded (GWh)	Total Revenue USD million
Nov 2018	11	9 of 17	216,0	11,4
Dec 2018	13	10 of 17	161,0	6,7
Jan 2019	14	9 of 17	122,5	5,1

Table 1: Market Performance for the Period Nov 2018 to Jan 2019

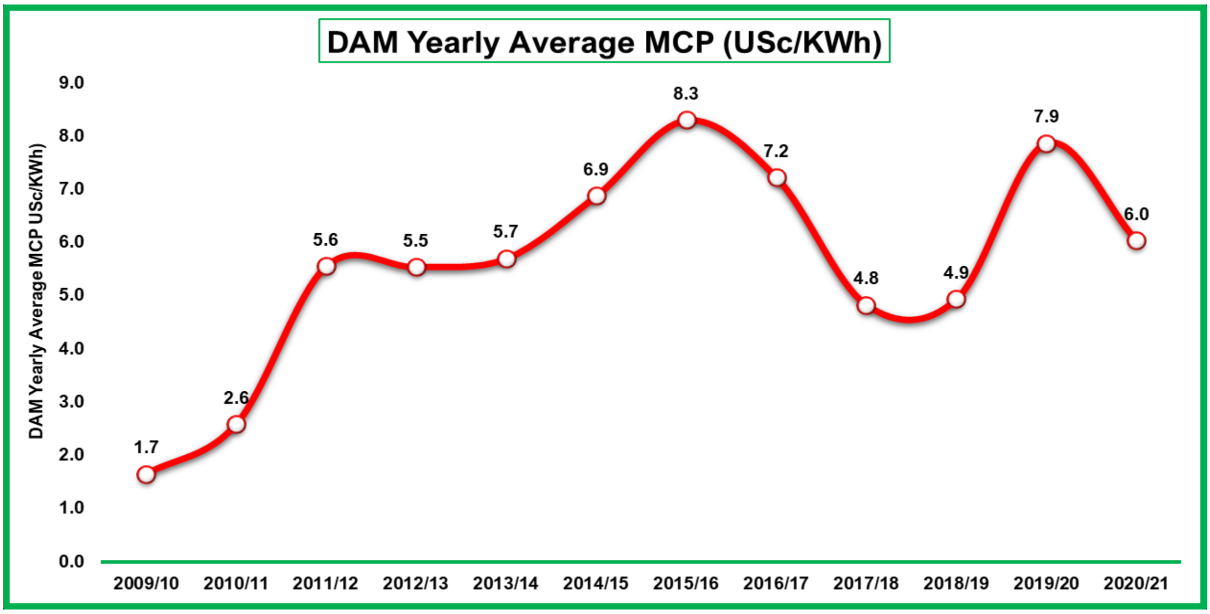
The SAPP 2018 annual report records that 2,154 GWh traded in 2017/18. The competitive market revenue was USD 106.6 m, compared to USD75.6 m in the previous year.

Month	FPM Monthly		FPM Weekly			DAM	IDM		
	Non Off Peak	Off Peak	Peak	Std	Off Peak		Peak	Std	Off Peak
Nov 2018	6,1	2,8	8,6	5,7	2,9	5,7	9,2	6,4	3,3
Dec 2018	7,1	2,7	12,8	5,7	2,7	5,0	8,7	6,2	2,7
Jan 2019	10,9	2,4	13,8	5,2	2,5	4,3	4,7	No Trade	2,1

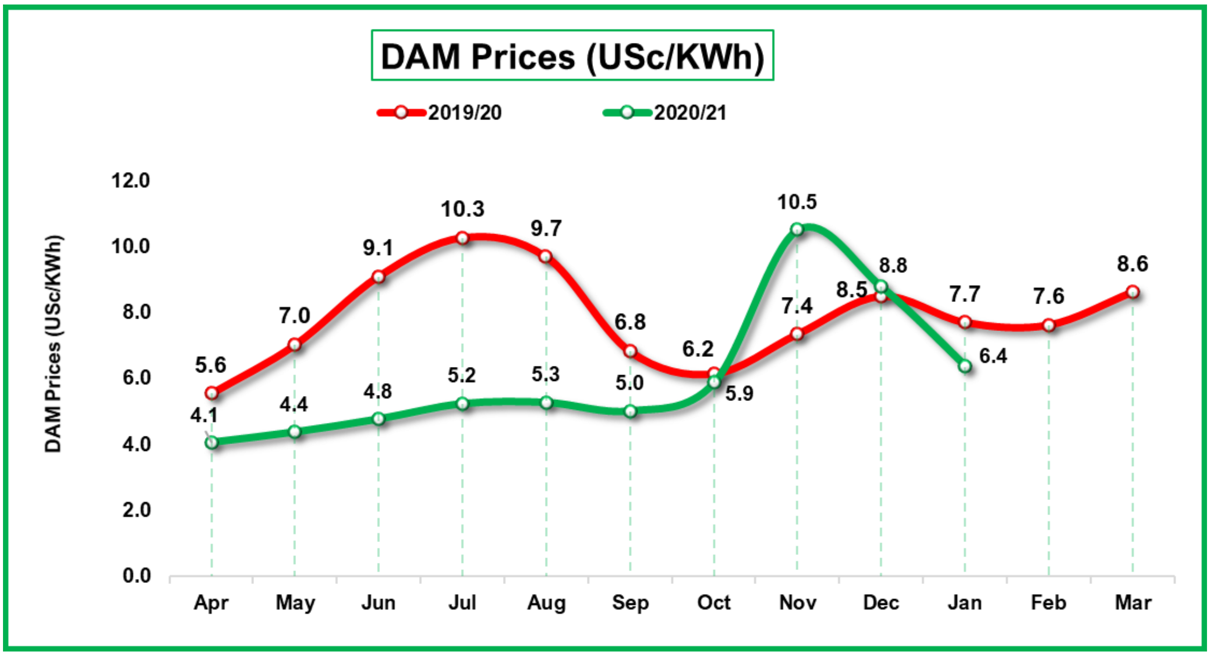
Table 2: Market Clearing Prices for the Period Nov 2018 to Jan 2019 in US cents/kWh



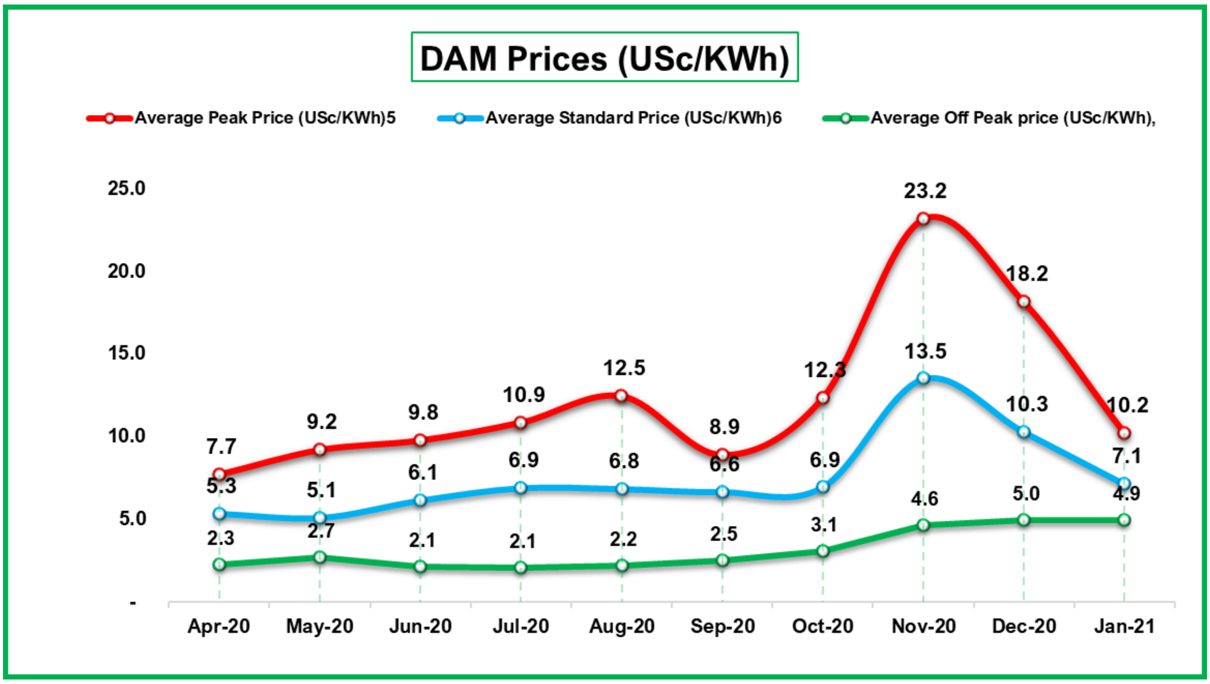
Graph 3.4 Annual Profile of Total Traded Volumes (GWh)



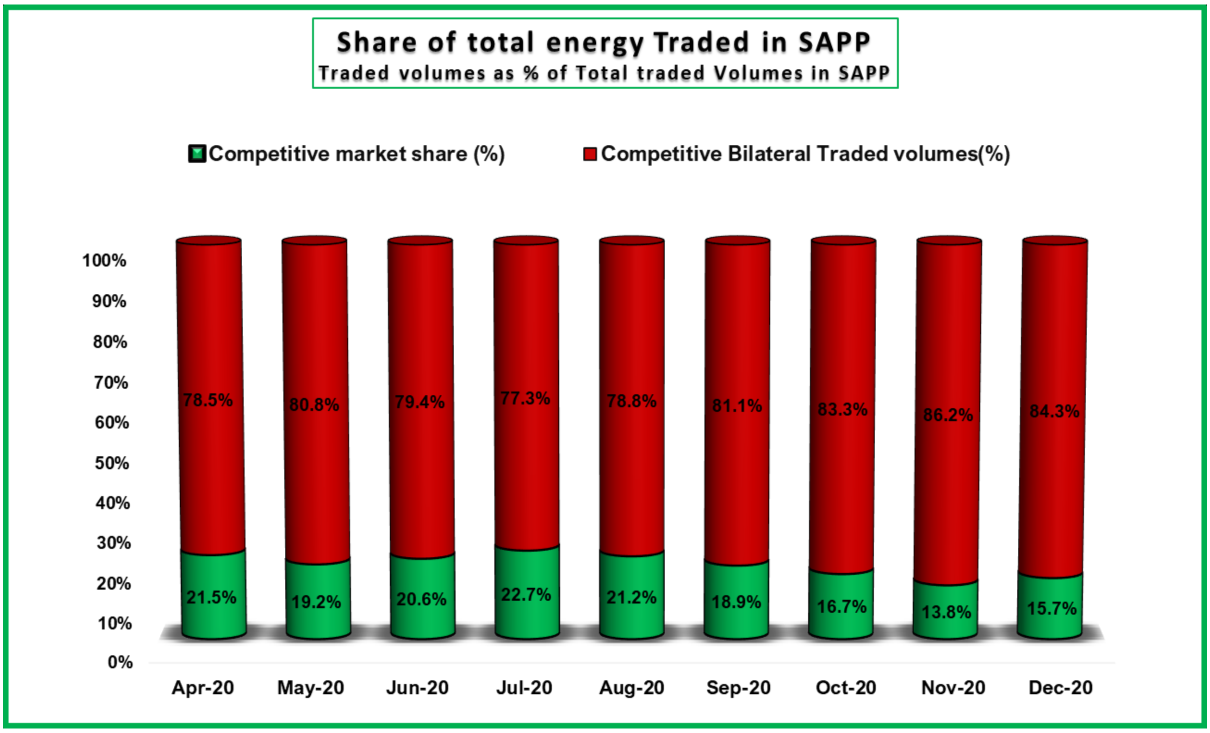
Graph 3.5 DAM Yearly Average MCP (USc/kWh) for a Decade



Graph 3.6 Annual Trends in DAM Prices (USc/kWh)



Graph 3.7 Annual Trends in DAM Prices (USc/kWh) for Peak, Standard and Off Peak Periods



Graph 3.8 Energy Market Share Profiles in Volumes Traded

For performance enhancement, SAPP requires an increase in market participants from the current 9 - 10 of 17 to all 17 of the full SAPP membership and onto unlimited participation from the private sector. Three SAPP members remain not connected to the regional power pool due to the absence of transmission. The countries are Angola, Tanzania and Malawi.

In addition, the introduction of private sector direct customers, both buyers and sellers, as members of the power pool will enhance trade. Private sector direct customers are available and can emanate from the emerging migration of new energy intensive mining and industrial customers deep into Africa. The theme of the SAPP Annual Report of 2018 is "Accelerating development of energy projects to optimize electricity trading". This captures the mood and bullishness of the region to grow volumes, to increase trade and turnover and to achieve lower prices and affordable energy for all.

The SAPP integrated electrical power system is comprised of the following distinct and unique processes that work together to provide the electrical energy used in the production of goods and services society needs and wants and is able to pay for.

a) Primary energy sources supply i.e. nuclear, fossil and non-renewable solar (coal, oil and gas) and contemporary and renewable solar (sunlight, wind, water and biomass). The sun gets its energy from nuclear fusion.
b) Infrastructure for primary energy conversion into electrical energy on the supply side in accordance with demand side signals.
c) Infrastructure, known as transmission and distribution networks, for the delivery of the electrical energy as electron flow (1 Ampere = 6.242×10^{18} electrons past a point in one second) between supply and demand sides and the management of these electron flows.
d) Infrastructure for the simultaneous conversion of the electrical energy into work used to produce goods and services on the demand side.
e) Information and Communication Technologies (ICT) for use in power system and energy markets operations.

The systems in (a), (d) and parts of (e) are predominantly owned and operated by the private sector while the rest of the processes are monopolised by the public sector and regulated. The two sectors seem to have different objectives to meet with respect to electrical power systems which has resulted in the sub-optimal allocation of resources leading to the current low standards of energy access, reliability, security and affordability. The urgent resolution of the energy crisis is overdue for sustainable social and economic development and growth.

The main product of an electrical power system is electrical energy whose source is the primary energy sources and depends on its demand by energy users whose interest is in the production of goods and services that society needs and want. The private sector is predominantly in charge of primary energy supply and electrical energy use. Electrical power systems comprise of the following infrastructure services that complement energy supply and usage; (a) primary energy conversion into electrical energy, (b) electrical energy delivery services from supply to demand, (c) electrical energy conversion into work to produce goods and services, (d) real time power system operations, and (e) energy trading services.

The SAPP consists of the initial bilateral markets for energy trading between power utilities which is now complemented by competitive markets comprising of the Day Ahead Market (DAM), Forward Physical Markets – Monthly and Weekly (FPM-M and FPM-W) and Intra-Day Markets (IDM) markets. The bilateral markets are still the predominant ones, at 68% as at 31 March 2019, while the DAM, FPM and IDM markets are slowly claiming market share albeit at a slower rate due to the many challenges the SAPP faces.

During this study, various Key Success Factors were identified in the SAPP and include:

i. The pooling of resources and the sharing of information resulted in efficiency improvements in governance, system operations, trading of energy and financial performance of the SAPP.
ii. The development of the energy markets guided by the Nord Pool wholesale energy market in Europe, has seen the growth of the DAM, FPM and IDM and market surveillance.
iii. A single Grid Emissions Factor (GEF) for the SAPP exists which, for the first time, can be used in the promotion of renewable energy and energy efficiency interventions in the whole of SAPP grid connected countries.
iv. Demand Side Management (DSM) has resulted in some noticeable energy efficiency improvements.

Challenges facing the SAPP may be summarised in the form of questions that need to be urgently addressed and be also considered in the type of Water Pool model to be adopted.

i. Is the monopoly of the public sector in electrical energy supply not an out-dated business model that needs urgent transformation?
ii. Is the current self-regulation model of the SAPP, which is not good governance practice, not going to present it with problems when it is interconnected with the Eastern African Power Pool (EAPP) which has an autonomous regional regulator?
iii. Is lack of access to finance to extend the electricity infrastructure the reason why the electrical power systems of Angola, Malawi and Tanzania are still not coupled to the SAPP grid 25 years after the creation of the SAPP?
iv. Why are Transmission System Operations (TSO) not given the predominant role they play in the management of electrical power systems as in the Nord Pool or in Australia?
v. Why are barriers to private sector entry into the SAPP, even with revised membership rules, still formidable, couched in legal terms and an outdated power utility business model and governance?
vi. Why are Energy Availability Factors across the SAPP very low, compared international best practices?
vii. Why are there high energy losses in the electrical power systems in SADC?
viii. Can the load shedding occurring in RSA, Zambia and Zimbabwe be due to the energy reliability and security performances which are very poor compared to say Australia or the Nord Pool?
ix. Why are there transfer capacity constraints on regional power interconnectors which are negatively affecting regional energy trading?
x. Why were there only three out of the twelve state owned SAPP power utilities in Eswatini, Lesotho and Namibia that are viable as at end of 2019?

Electrical energy and water are single commodities driven by similar basic infrastructure services of production, delivery and utilisation. Some of the learnings from the SAPP key success factors and challenges for the proposed Water Pool Model might include:

i. The governance of the SAPP and its operations and improvements therein.
ii. The principles of system and market operations in the SAPP can be applicable.
iii. Studies will be needed to see if water can be added to the SAPP power trading platforms.
iv. The participation of the private sector is critical for the proposed Water Pool Model.

The recommendations, for the proposed Water Pool Model, arising from the SAPP case study, on conceptualisation and operational considerations, are as follows:

A Conceptualisation

i. A SADC Water Pool is needed to address water access, reliability and security challenges by member states through the pooling of resources as was the case with the SAPP.

ii. The creation of the SADC Water Pool should be guided by the Protocol on shared watercourses in SADC signed by the Heads of State in Windhoek on 7 August 2000.

iii. The Water Pool may be based on similar governance structures as in the SAPP and utilise appropriate water business models with clarity on the roles of the public and private sector Water Market participants.

iv. The private sector should play a leading role in the Water Pool, which may be based on Water Markets structures right from the beginning.

v. The Water Pool strategy should include a Results-based Management and Learning (RML) system to ensure success. RML systems are non-existent and need to be incorporated at the conceptualisation stage to ensure optimum allocation of resources and the success of the Water Pool.

vi. Risk management, which is the identification, description, evaluation and treatment (control / mitigation, avoidance, transfer, financing, etc.) of externally and internally driven strategic, operational and financial risks should be a must for the success of the Water Pool. The current energy and water crisis in Africa, despite the abundance of natural resources, could be due to the lack of RML and Risk Management.

vii. Clearly identified commodities like information, oil, gas, minerals, electrical energy, food, shelter, water, etc. should ideally use their own unique business models and market platforms so as not to lose focus.

viii. Innovative and novel financing mechanisms will be required to finance the water infrastructure upon which the water market will be built. Financing of the Water Pool and Water Markets should be the key role of the private sector in view of the poor financial position of the public sectors in SADC?

ix. The Water Pool should be extended, like the African Single Electricity Market being implemented by the African Union Commission, with the assistance of the European Union Commission, to include all African countries.

B Operational considerations

i. The Water Pool should include all the rivers whose waters are currently being used and those not being used for electricity generation.

ii. Water production infrastructure such as large and centralised boreholes, desalination plants, etc. and the water pipelines that connect water supply with utilisation should also be part of the Water Pool.

iii. Decentralised boreholes at users' premises should, like self-generation power plants in the SAPP, also be part of the Water Pool since they take pressure off the centralised water plants.

iv. Real-time SCADA and Water Management Systems (SCADA/WMS) using advanced Information and Communication Technologies (ICT) should be mandatory for all National Control Centres (NCC) for national water resources management in the Water Pool.

v. Efficient water production, delivery and utilisation should be the cornerstone of the Water Pool since water is likely to be a scarce resource in future also negatively impacted by climate change.

The example Income Statement for SAPP, given in Table 3, provides confidence that the market model could make a sustainable contribution to water security.

INCOME	Notes	2019 US$	2018 US$
Members contribution:			
Equal share for members	5	585 427	624 146
Imported energy	5	97 571	104 024
Exported energy	5	97 571	104 024
Peak demand	5	48 786	52 012
Thermal rating	5	97 571	104 024
Host member	5	48 786	52 012
Participation fees	5	108 412	115 583
Market trading platform - administration fees	5	4 108 418	4 247 424
Grant income	6	6 043 767	3 523 088
Other income	7	1 138 793	12 045
Total income		12 375 102	8 938 382
EXPENDITURE			
Participation			
Administration costs	8	6 509 258	3 932 080
Communication costs	9	42 739	38 626
Market trading platform expenses	10	267 701	194 661
Depreciation	11.1	52 514	38 269
Amortisation	12	8 983	9 053
Bank charges	13	19 842	8 116
Marketing and publicity	14	10 410	3 665
Motor vehicle expenses	15	6 035	5 804
Occupancy costs	16	41 807	56 730
Staff costs	17	1 118 199	847 086
Travel and subsistence	18	199 544	171 025
Recruitment costs	19	34 846	36 997
Total expenditure		8 311 878	5 342 112
Surplus for the year		4 063 224	3 596 270

Table 3 : Example of the SAPP Income Statement for Year Ending March 2019

3.2 Case Study 2 : The Joburg Fresh Produce Market

The Joburg Market is an extraordinarily successful trading platform for fresh produce, operating in Johannesburg for well over a century. Produce originating from across the country, and even elsewhere in the world, is made available for sale on this platform. Although the platform was developed primarily to serve the Johannesburg area, produce is procured from this platform to be distributed across South Africa, from Cape Town in the South to the Democratic Republic of the Congo in the North. The market has grown from humble beginnings to where 1.4 million tons of produce was traded in 2018/19, at a value of almost R8 billion. This is by far the biggest fresh produce market in Africa, more than double the size of the second biggest market. The published reports from Joburg Market SOC Limited (Joburg Market, 2016 - 2020) has reference for the disucssions that follows.

Over the years, the Joburg Market (the Market) has developed into a key element in the successful development of the fresh produce production industry in the country. Some of the key benefits of the Joburg Market include the following:

i. The Market developed over the years into the price discovery platform for fresh produce in South Africa, which prices are used by other markets and direct traders in concluding transactions.
ii. All produce, irrespective of quality will find a price and a buyer on the Market.
iii. The market has played an important role in the development of an internationally competitive fresh produce industry in South Africa.
iv. The market served, and continues serving, as an effective marketing mechanism in supporting emerging farmers to grow and become successful commercial farmers.

The Joburg Market used various different trading mechanisms over the years, including a bartering system, and auction system and a commission system. The most effective of these in discovering price was the auction system, however, due to the rapid growth of the market, resulting in a huge range of different products, qualities and quantities, this system became impractical, and the Market switched to the commission system. In recent years, due to significant technological developments, the auction system is becoming viable again for fresh produce, and some fresh produce markets internationally have incorporated the auction system on their platforms.

Due to the nature of the product traded at Joburg Market, incredibly capital-intensive infrastructure is required to support a physical trading platform. This platform must be maintained at huge cost and further capital investment is required from time to time as the volumes traded on the market increases.

During this study, various Key Success Factors have been identified at the Joburg Market. This include:

i. That the system works transparently. This includes transparency regarding the cost structures and the margins added by each player who adds value in the process.
ii. Integrity of the platform. All stakeholders have comfort that the transactions on the platform cannot be manipulated to their disadvantage, and if this would happen mechanisms are in place to identify such conduct and correct the situation.
iii. The platform is cost effective and a competitive marketing channel.
iv. There is not be a risk of the seller not receiving his payment. Payment for the product takes place within a week from the sales transaction.
v. The farmers' interests are protected to the extent that they do not need to spend time on the Market and can focus all their attention on their farming activities.

Some of the learnings from the Joburg Market for the proposed water pool include:

i. The principles of operation at the Joburg Market can be applied to the proposed water pool.
ii. It will not be optimal to add water to the Joburg Market product offering – water trading will work better on a much less costly virtual platform, that can be accessible from anywhere in the world.
iii. The trading systems used in fresh produce markets can be used for a water pool, especially the virtual, auction-based trading system.
iv. The Joburg Market faces challenges of its own, which is useful to understand when developing a trading platform for water.
v. Further research is recommended into other auction platforms and available virtual auction technology options.

The Joburg Market Model has consistently and sustainably delivered **FOOD SECURITY** for the community of Johannesburg. The market model is driven by mutual responsibility of the public and private sectors. The public sector embraces “process” whilst the private sector embraces “content”. The public sector provides the policy, regulation and administrative environment for the market. The private sector provides the farms that produce the food and the transport that moves the produced food to and from the market. The operations is continuous, seamless and secure; delivering continuous confidence to all the active participants and stakeholders. Price is discovered daily in a competitive seller – buyer environment. Given continuous downward pressures on prices, volumes have consistently increased. Price and volume have both enhanced turnover over time.

Since 1873, annual turnover now approaches R10b and the average daily cash sales is in the region of R30 to R40 million rands. In its current location, the Joburg Market has grown its turnover from R2.4 million in 1973/74 to R7.9 billion in 2018/19. This translates into an average annual turnover growth of 19.7% per annum, which is quite remarkable and an indication that the industry finds significant value in this trading platform.

In 2018/19, the mass traded at the Joburg market amounted to 1.4 million ton of fresh produce. Of all fresh produce traded in the country, about 50% is traded through the fresh produce markets and the balance through alternative channels from the farms to the consumers. The most significant of these alternative channels is the supermarket groups.

A couple of decades ago, a much higher portion of fresh produce (over 80%) was traded through the fresh produce markets, however, in view of increasing customer demands (necessitating improved food safety systems, cold chain, value chain efficiency, etc.) and a slow response by South African fresh produce markets to this changing environment resulted in the development of marketing channels which bypassed the fresh produce markets.

The role of the fresh produce markets however remains strong, partly due to key role players who are defending the price discovery role of the fresh produce markets (which is used as reference for all fresh produce trading in the country, on and off the market trading floor), as well as farmers who prefer to price discover rather than be price fixed by the supermarket groups. The Joburg Market platform is currently used to trade the produce of about 6 000 farmers, while about 11 000 buyers compete on a regular basis for this produce. Table 4 provides the Joburg Market Income Statement for year ending June 2019, an example of the potential for a market model for water security.

Joburg Market soc Limited
(Registration number 2000/023383/07)
Financial Statements for the year ending 30 June 2019

Statement of Financial Performance

Figures in Rand	Note(s)	2019	2018
Revenue			
Commission		398 729 853	367 793 837
Rental of facilities and equipment		53 608 906	47 991 889
Interest received	16	28 458 379	19 027 199
Storage		5 963 998	7 180 719
Cash handling fees		3 630 960	3 215 574
Banana ripening		1 826 047	3 669 889
Sundry revenue		2 601 078	1 434 850
Miscellaneous other revenue		1 280 193	1 224 960
Discount received		4 997	2 000
Total revenue		**496 104 411**	**451 540 917**
Expenditure			
Employee related costs	17	(141 940 177)	(136 011 858)
Depreciation and amortisation	18	(24 806 344)	(23 438 759)
Impairment loss	19	(5 217 926)	-
Finance costs	20	(3 106 866)	(4 061 997)
Lease rentals on operating lease		(645 784)	(590 678)
Debt Impairment	21	(8 363 733)	(55 880)
General Expenses	22	(133 998 431)	(131 928 620)
Total expenditure		**(318 079 261)**	**(296 087 792)**
Operating surplus		**178 025 150**	**155 453 125**
(Loss) on disposal of assets and liabilities		(4 361 769)	7 311
Surplus before taxation		**173 663 381**	**155 460 436**
Taxation	24	50 457 012	59 622 032
Surplus for the year		**123 206 369**	**95 838 404**

Table 4 : Example of the Joburg Market Income Statement for Financial Year Ending June 2019

3.3 Transfer of Learnings to the Proposed Water Pool Market Model from the CASE STUDY of the Southern African Power Pool Market Model

There are a number of lessons to be learned from the workings of the Southern African Power Pool. These include:

i. All the identified challenges the SAPP is facing must not be allowed to be the Water Pool challenges.
ii. Clarity in identification of products and services in the Water Pool is critical if the problems identified in the SAPP are to be avoided.
iii. The water trading platform must make sure that the Water Pool utilises the most appropriate trading mechanism for this application.
iv. It will be important to make sure that the best technology is used for rolling out the platform.
v. It cannot be expected that today's technology will remain the same. A continuous scanning of the environment will be required to ensure that the water trading platform remains in a position where competitive platforms will find it exceedingly difficult to improve on this platform.
vi. It is of critical importance to remain close to the stakeholders in the industry, to understand their frustrations.
vii. There must be a constant effort to find solutions for frustrations experienced by stakeholders.
viii. The integrity of the platform must be impeccable.
ix. Stakeholders must have comfort that the system cannot be manipulated.
x. The platform must be customer centric and focused on quick problem resolution.
xi. The system must be transparent.
xii. The management team of the platform must be completely independent and have no vested interests.
xiii. Market forces must be allowed to find the "correct" prices for the water on offer.
xiv. Scale is important. The higher the value of water products and services sold through the platform, the more affordable/profitable the platform will be.
xv. There must be a continuous effort to reduce costs, to avoid a situation where it becomes attractive for competitors to enter the industry.

xvi. The trading platform must be reliable, with close to no downtime.

xvii. The platform must be fast and effective. Buyers do not want to waste time.

Note 1 : The addition of water to the SAPP trading platform

It is certainly worthwhile investigating the implications of adding water as a commodity to be traded on the SAPP trading platform in the same way gas is traded in electricity markets in Europe. When considering this option, various positives and negatives surface, of which the most prominent include:

i. Water, like gas, can be stored, which gives plenty of time for timely interventions by humans unlike in the case of electrical energy which has to be used at the same time it is converted from primary energy.

ii. The ICT systems that are used to monitor river water flows and monitoring water levels in dams and for power generation can also be used for managing water resources.

iii. The applications software for water management does not have to be the same as that for electrical energy management but can run in the same computer hardware in Data Centres, which could be in the Cloud.

iv. There is no need to engage a lot of additional people to manage the water as most of the functions can be automated.

v. What might be needed could be reinforcement or expansion of the ICT infrastructure to accommodate the water management and trading.

Note 2 : Opportunities for Water

Some pointers are listed below, regarding the opportunities for water, when making use of a transparent competitive trading platform similar to that of the SAPP:

i. All the rivers in the SADC countries are potential sources of water and energy and should be exploited accordingly for both the Water and Power Pools,

ii. Similar governance structures as in the SAPP could be used for the Water Pool,

iii. Sellers of water will find buyers for the water.

iv. Parties in need of water will have a fair chance to compete for available water.

v. Such system will facilitate a process whereby the parties who are able to add the most value with the water, eventually to the bigger advantage of society, should be able to procure sufficient water.

vi. Such a platform could result in quick, unbiased allocations, in the interest of all in the region.

vii. Other factors can also be introduced in a water trading system.

viii. Such factors may include the following (if required):

a. The contribution of a specific application of the water to energy and food security.

b. The impact of specific applications on the environment.

c. The impact on job creation.

d. The impact on economic development.

Note 3 : Enhanced Workings from Public and Private Sectors

A transparent water trading platform can ensure that stakeholders in the Public and Private Sectors work more effectively and co-operate seamlessly. This can be achieved in various ways, including the following:

i. The allocation process of water via an automated process can be speeded up significantly, avoiding frustrating delays and difficult subjective decision making processes.

ii. Discipline can be enforced in water usage to prevent mismanagement of water as happened on the Kariba Dam complex now being blamed on drought?

iii. A clear and transparent system, where the criteria of operation is known to all, will establish trust amongst the Public and Private Sector.

iv. Such system will reduce uncertainty, a factor which results in reduced investment by the Private Sector.

v. If the Private Sector understands what it has to do to get access to the water, and they know the limitations within which they can bid for the water, it is highly likely that more investment will take place, more projects launched, more job opportunities created and the governments’ tax revenues will increase.

Note 4 : SAPP assistance in water infrastructure development

The similarities between electrical energy and water as single commodities, driven by similar types of infrastructure services, that can be traded on the same market trading platforms should be leveraged in the development of the Water Pool.

Electricity infrastructure, in the form of transmission lines, has been crossing national borders for quite some time now and continue to do so in the planned African Single Electricity Market (AfSEM). This experience can be used in the crossing of national borders by water delivery infrastructure.

Water pipelines from the Congo, Zambezi and Limpopo rivers among many in the north can be installed to supply water in the drier south. Lessons learnt from the use of the Lesotho Highlands project for both energy and water supply will be invaluable. The planned supply of water to Pholokwane in RSA from Zimbabwe is a step in the right direction and so will the Matabeleland Water project in Zimbabwe meant to supply Bulawayo that could easily be extended to Francistown in Botswana

Transportation of coal and gas by pipelines, rail or road networks can easily be used for the transportation of water from sources to demand centres.
A Water Pool Plan can be put together using the same principles as in the SAPP Pool Plan and similar innovative financing mechanisms can be employed.

Note 5 : Water and Energy

Water and energy are single commodities that are driven by similar infrastructure services of production, delivery and utilisation. They all suffer from leakages or losses in the production, delivery and utilisation processes and need to be properly managed.

Water can be seen and touched and is easier to manage from that aspect while electricity cannot be seen and is lethal to touch and is difficult to manage. Adding water management to an energy trading platform may be easier to do than the other way round but there should be other considerations made before the final decision to combine. Energy production is dependent,

directly or indirectly, on water and water cannot be produced without energy and therefore the two are inseparable.
The same ICT infrastructure used to monitor the electrical power system can be extended to include remote monitoring of the water systems.

Energy and water are the two critical and basic ingredients that support life on this planet and therefore need effective and efficient management for sustainable social and economic development and growth and an improvement in the Quality of Life for all.

Recommendations Towards the Development of a Water Pool Market Model

A SADC Water Pool is urgently needed to address water access, reliability and security challenges by member states through the pooling of resources as was the case with the SAPP. The creation of the SADC Water Pool should be guided by the Protocol on shared watercourses in SADC signed by the Heads of State in Windhoek on 7 August 2000.

The Water Pool may be based on similar governance structures as in the SAPP and utilise appropriate water business models with clarity on the roles of the public and private sector Water Market participants.

The private sector should play a leading role in the Water Pool, which may be based on Water Markets structures right from the beginning.

The Water Pool strategy should include a Results-based Management and Learning (RML) system to ensure success. RML systems are non-existent and need to be incorporated at the conceptualisation stage to ensure optimum allocation of resources and the success of the Water Pool.

Risk management, which is the identification, description, evaluation and treatment (control / mitigation, avoidance, transfer, financing, etc.) of externally and internally driven strategic, operational and financial risks should be a must for the success of the Water Pool. The current energy and water crisis in Africa, despite the abundance of natural resources, could be due to the lack of RML and Risk Management.

Clearly identified commodities like information, oil, gas, minerals, electrical energy, food, shelter, water, etc. should ideally use their own unique business models and market platforms so as not to lose focus.

Innovative and novel financing mechanisms will be required to finance the water infrastructure upon which the water market will be built. Financing of the Water Pool and Water Markets should be the key role of the private sector in view of the poor financial position of the public sectors in SADC?

The Water Pool should be extended, like the African Single Electricity Market being implemented by the African Union Commission, with the assistance of the European Union Commission, to include all African countries.

The Water Pool should include all the rivers whose waters are currently being used and those not being used for electricity generation.

Water production infrastructure such as large and centralised boreholes, desalination plants, etc. and the water pipelines that connect water supply with utilisation should also be part of the Water Pool.

Decentralised boreholes at users' premises should, like self-generation power plants in the SAPP, also be part of the Water Pool since they take pressure off the centralised water plants. Real-time SCADA and Water Management Systems (SCADA/WMS) using advanced Information and Communication Technologies (ICT) should be mandatory for all National Control Centres (NCC) for national water resources management in the Water Pool.

Efficient water production, delivery and utilisation should be the cornerstone of the Water Pool since water is likely to be a scarce resource in future also negatively impacted by climate change.

3.4 Transfer of Learnings to the Water Pool Market Model from the CASE STUDY of the The Joburg Fresh Produce Market Model

When considering the Joburg Market and the proposed water platform, there are various similarities between these two platforms. These include:

i. There are several different "suppliers".
ii. There are several different "buyers".
iii. There is a limited amount of the commodity available.
iv. A transparent mechanism is required to establish which "buyer" will get access to how much of the commodity and at what price.
v. The price for the commodity is unclear and must be "discovered".
vi. The price will not remain the same and will change from time to time as supply and demand changes.

Note 1 : The addition of water to Joburg Market platform

It is certainly worthwhile investigating the implications of adding water as a commodity to be traded on the Joburg Market platform. When considering this option, various positives and negatives surface, of which the most prominent include:

i. At the Joburg Market, a physical trading platform is required. This physical infrastructure, the maintenance thereof, the security, cleaning, waste management, consignment control, floor management, etc. represents the bulk of the costs of operating the Joburg Market. A water trading platform would not require a physical platform and would most likely work effectively on a virtual platform. Therefore, using the Joburg Market trading platform for the trading of water, it is likely to make the water trading platform unnecessarily costly.
ii. The commission system used at the Joburg Market is, under current circumstances, the most practical trading mechanism for fresh produce, although an auction mechanism would be better if the practical issues could be resolved. The water platform can work effectively with an auction system and should not be limited by the shortcomings of the commission system. The Joburg Market platform does not

currently have the capacity to accommodate trading by virtual auction, while virtual auction systems have been developed and are available of the shelf.

Note 2 : Opportunities for Water

Some pointers are listed below, regarding the opportunities for water, when making use of a transparent competitive trading platform similar to that of the Joburg Market:

i. Sellers of water will find a buyer for the water.
ii. Parties in need for water will have a fair chance to compete for available water.
iii. Such system will facilitate a process whereby the parties who are able to add the most value with the water, eventually to the bigger advantage of society, should be able to procure sufficient water.
iv. Such platform could result in quick, unbiased allocations, in the interest of all in the region.
v. Other factors can also be introduced in a water trading system. Such factors may include the following (if required):
    a. The contribution of a specific application of the water to food security.
    b. The impact of a specific application on the environment.
    c. The impact on job creation.
    d. The impact on economic development, etc.

Note 3 : Lessons from Joburg Market

There are a number of lessons to be learned from the Joburg Market. These include:

i. The water trading platform must make sure that they utilise the most appropriate trading mechanism for this application.
ii. It will be important to make sure that the best technology is used for rolling out the platform.
iii. It cannot be expected that today's technology will remain the same. A continuous scanning of the environment will be required to ensure that the water platform remains in a position where competitive platforms will find it exceedingly difficult to improve on this platform.
iv. It is of critical importance to remain close to the stakeholders in the industry, to understand their frustrations.

v. There must be a constant effort to find solutions for frustrations experienced by stakeholders.
vi. The integrity of the platform must be impeccable. Stakeholders must have comfort that the system cannot be manipulated.
vii. The platform must be customer centric and focused on quick problem resolution.
viii. The system must be transparent.
ix. The management team of the platform must be completely independent and have no vested interests.
x. Market forces must be allowed to find the "correct" prices for the water on offer.
xi. Scale is important. The higher the value of water products and services sold through the platform, the more affordable/profitable the platform will be.
xii. There must be a continuous effort to reduce costs, to avoid a situation where it becomes attractive for competitors to enter the industry.
xiii. The trading platform must be reliable, with close to no downtime.
xiv. The platform must be fast and effective. Buyers do not want to waste time.

Note 4 : Enhanced Workings from Public and Private Sectors

A transparent water trading platform can ensure that stakeholders in the Public and Private Sectors work more effectively and co-operate seamlessly. This can be achieved in various ways, including the following:

i. The allocation process of water via an automated process can be sped up significantly, avoiding frustrating delays and difficult subjective decision-making processes.
ii. A clear and transparent system, where the criteria of operation is known to all, will establish trust amongst the Public and Private Sector.
iii. Such system will reduce uncertainty, a factor which results in reduced investment by the Private Sector. If the Private Sector understands what it has to do to get access to the water, and they know the limitations within which they can bid for the water, it is highly likely that more investment will take place, more projects launched, more job opportunities created and the governments' tax revenues will increase.

Note 6 : Joburg Market assistance in infrastructure development

The Joburg Market example highlights the potential value that a transparent trading platform can offer the country. Through experience gained over many decades, the Joburg Market can provide input on pitfalls to avoid and important factors to consider in establishing a trading platform for water.

The Joburg Market is an excellent example of how such a platform completes the value chain for a commodity, by establishing a central trading platform and providing a trusted effective trading mechanism, open to all.

This example is even better illustrated when compared to the fresh produce industry in Nigeria. Citrus orchards were visited in Nigeria, where trees produced the most beautiful and sweetest fruit. Tragically, this fruit ended up falling from the trees and rot on the soil, due to the lack of an effective marketing channel. The result of this is that a country, with excellent soil, great agricultural climate, and an abundance of water, end up importing their fresh produce from countries such as South Africa.

Recommendations Towards the Development of a Water Pool Market Model

There are some innovative fresh produce markets elsewhere in a world, where the value of the auction system is recognised and being introduced. There are also the flower markets in Johannesburg and Amsterdam, which make use of an auction system for flowers, which will also be in a position to provide valuable input, advice and assistance in developing an auction based trading platform for water.

The use of auction systems is increasingly being introduced again into fresh produce markets in some new Eastern markets.

The Mechelse Veilingen just outside Brussels has a combined physical and virtual auction platform for fresh produce, which will also offer some useful learning points for the proposed water pool.

The Joburg Market trading platform has been serving the fresh produce industry and the country very well for well over a century.

Despite being a very well-designed platform, close contact with the industry is critical to identify challenges and to use a creative approach to formulate and implement solutions before competitors do it.

The Joburg Market platform, and the different phases in its life cycle serves as an excellent example from which lessons can be learnt to design and implement a water trading system which can serve the region very well in allocating resources, speed up decision making and removing business uncertainty.

The Joburg Market model can be applied to a water trading model, although certain improvements must be considered. A trading platform for water, similar to the Joburg Market platform, can significantly contribute to private sector investment, economic development, job creation and government tax revenue. Well thought through allocation criteria and a well-designed water trading system, based on the Joburg Market model, can significantly shorten decision times, improve transparency, and reduce uncertainty.

A water platform based on the Joburg Market principles, will result in effective price discovery, where the seller will get as high a price as he can hope to get and the buyer will be able to pay as low a price as his competitors allow.

It is recommended that:

i. An auction based virtual trading platform be considered for the water trading platform, and that lessons learned at the Joburg Market be used to refine the water trading model.
ii. The mechanisms and technology used at the Joburg Flower auction should also be investigated to identify differences in operation. This could assist in ending up with a more refined end product.
iii. Similarly, existing virtual trading platforms, such as "Mechelse Veilingen", should also be investigated to identify learning points.
iv. Various available and suitable virtual auction software platforms should also be investigated.

CHAPTER 4

INDUSTRIAL REVOLUTION 4.0 TECHNOLOGIES

Klaus Schwab, Founder and Executive Chairman, World Economic Forum, noted that “we stand on the brink of a technological revolution that will fundamentally alter the way we live, work and relate to one another. In its scale, scope, and complexity, the transformation will be unlike anything humankind has experienced before. We do not yet know just how it will unfold, but one thing is clear : the response to it must be integrated and comprehensive, involving all stakeholders of the global polity, from the public and private sectors to academia and civil society.” In this chapter, the team explores the state of art in IR4.0 technologies and starts to prepare conceptual designs for a water pool market model as driven by the digital revolution. The emerging picture, supported by the first mathematical equations, confims that it is practical to bring together the physical, digital and biological spheres of the water sector. Much work reamins ahead. A new reset to the thinking on water security is emerging.

4.1 Introduction

To address the global and regional water security challenges, the contemporary approach has been a structural one that focuses on augmenting the supply side of the water supply and management system. In this case, dams and reservoirs are built as buffers to take care of the time-space-dependent demand variations (Gleick, 2003). Typically, centralized governmental institutions are responsible for water reallocation and the main suppliers of water. These centralized governmental institutions do not only supply water to the demanding populace (consumers), they also determine the water distribution method and cost based on their forecast of the demand response of the consumers. Over many years, the use of this centralized approach and the augmentation of supply by structural methods to address water security have returned good benefits in terms of water access and services. However, as the global population keeps increasing, the demand for more water is stretching the resources currently available for addressing the consumer needs. More also, the hydrological uncertainties related to climate change, the resultant effect on water availability, and the aging physical infrastructure have put more strain on the contemporary approach to addressing water security.

It is therefore natural to seek a change to the current approach to addressing the challenge of water security. Such change should consider a distributed approach to water production, lossless distribution/supply of water-based on demand, responsible consumption of water, and very efficient treatment and reuse of wastewater.

Currently, an increasing number of public and private entities are becoming involved in the production and supply of water to consumers for specific use and in emergency/scares situations. These entities explore the implementation of alternative production of water, such as stormwater capture and reuse, groundwater extraction, water recycling, and water conservation. Many of these engagements in water production and supply are usually done independent of the infrastructural and non-infrastructural control of the centralized governmental institutions, thereby, limiting the significance of their participation to the boundaries of the structural capacity (capacity of their water conveyance system, and the capacity of the storage system). It is therefore ideal to suggest that considering an integrated approach that attracts larger participation by entities other than the centralized system in the water production and supply chain in a manner that among other alternatives includes the use of the available infrastructure and management system of the centralized governmental institutions like the JW is a great option. This introduces a hybrid infrastructure network that combines centralized and decentralized sources at various scales. The hybrid approach requires an informative and transaction platform where water and services that are related to water access and right will be valued and exchanged in a manner that addresses the needs of diverse stakeholders and takes advantage of possible funding and operational partnerships. Such a platform is commonly termed a water market or trading platform. Explicitly, the water trading platform allows buyers and sellers of water-related goods and access entitlements to interact and facilitate exchange.

Some functional water markets have been implemented in some places in California's Central Valley, United States, the Murray-Darling Basin, Australia, and the National Market in Chile. However, experiences in the established markets have shown that the conventional water trading approach has downsides that inform its non-wide adoption and implementation in many countries. These downsides include market distortions such as insufficient data availability, information asymmetry, and high transaction costs. Insufficient data availability is a very crucial factor that is a huge impediment to water supply, management, and trading in general, and has been given little attention. Naturally, the need for water management and water trading arises from the requirement of even and adequate supply/allocation of water to users based on demand. And the user demand is to be met by the available water resource/production/supply system, which is dependent on dynamics such as environmental (e.g. climate change and seasonal variations) and infrastructural conditions. Hence, a good water market model has to be consumer/environment/infrastructure-centric. In this sense, the impact of factors such as the increase in population per area, predicted water consumption rate per area, condition of infrastructures along space-time axis. Hence, the availability of information about these factors is crucial for ensuring effective water trading. Currently, these data play little or no role in the current model of the water market. On the other hand, even when such data is available, the issue of information asymmetry will surely arise. Information asymmetry orbits around decisions made before and during transactions in regulated trading space. Examples of such information asymmetry include data availability bias (Wilson, 2017), where some participants might have better access to data than others, data tampering (Kotowitz, 2008), and data monopoly. Another issue that impedes participation in water trading is the cost of developing and running the water market. For instance, the cost factors include the infrastructural cost that encompasses the cost of connecting buyers and sellers, monitoring and evaluation of water use and externalities, enforcement mechanisms for penalty and reward. It also factors in the transaction costs for participation fees, data search costs of willing buyers and sellers, negotiation and bargaining costs, cost of registration for an exchange, enforcing contracts, and checking the veracity of the product.

To provide answers to the water supply and water trading challenges enumerated above, it is ideal to turn to technologies to drive the solutions. A key driver to this challenge of efficient implementation of water pool/market/trading is the Fourth Industrial Revolution (4IR). The 4IR is the fusion of the physical, biological, and digital world that is facilitated by the increase in the mastery of enabling technologies such as, big data, Internet of Everything, nanotechnology, advanced sensor network, blockchain, artificial intelligence, robotics, and automation to create solutions. In this chapter, the possibilities and potentials of harnessing some of the enabling technologies of the Fourth Industrial Revolution (4IR) to address the challenges of water security in general, and the development of a 4IR enabled water trading solution in particular are discussed. Firstly, a generalized model of a water resource management system that integrates the 4IR concepts is presented. The discussion considers in a modular fashion how different 4IR enabling technologies can be used to improve the efficiency of the respective sub-systems in the water production-supply chain. The 4IR solutions applied to each module in the build-up of the generalized model form the basis on which a good water trading model is built. Specifically, the 4IR solutions on each module provide the basis to addresses the challenges of developing a consumer/environment/infrastructure-centric water trading model. Finally, the 4IR-driven water trading model is presented to address the challenges of information bias, and the cost of developing and managing the water market.

4.2 Generalized Framework for a 4IR-driven Water Resource Management System

A generalized model of a water resource management system that is defined by the 4IR solution is presented in Fig. 4.1. Typically, the contemporary water resource management system operational components include water production from defined sources, allotment of water right/permission to entities, water treatment and storage, water distribution and loss detection/mitigation, quantification and billing of water consumed by users, wastewater management, and asset/risk management. There are numerous challenges that the components of the water management system face. However, there is no single solution to these challenges, except to explore the application of clusters of technologies to provide alternatives to the current approaches in dealing with the challenges of water production, water treatment, water storage, water distribution, water consumption, and water recycling.

While harnessing the rapid advancements in the 4IR enabling technologies holds great promise for improving the way we manage global water challenges, the question remains, how can this be done in theory, and how do we turn these theoretical promises into reality? In an attempt to address these questions, let us present and discuss the models of each of the components of the water resource management system and proffer solutions that are 4IR driven. The components that will be discussed are water production, water treatment, water storage, water distribution, water consumption, and water recycling.

4.2.1 Water Production

By water production we mean the series of processes that include water softening, microfiltration, reverse osmosis, ultrafiltration, UV-sterilization, and mixed bed ion-exchange that results in the generation of a desired quality and quantity of water from a water source. The water source for water production is typically any of the surface water, groundwater, stormwater, wastewater, and icebergs/glaciers sources as is illustrated in Figure 4.1. Let us present a generalized systemic model of water production and discuss the challenges associated with the process. We shall then consider how the 4IR technologies can provide integrated solutions.

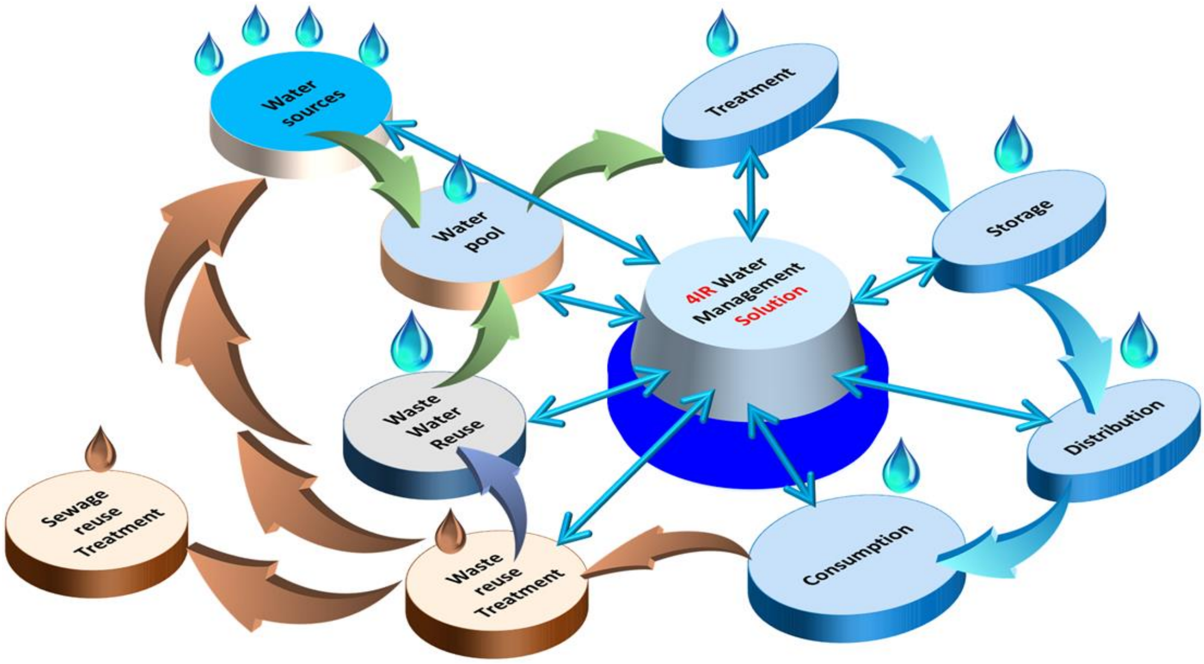


Figure 4.1 Generalized model of a 4IR-driven water resource management system solution.

4.2.1.1 Classic Water Production Model

The classical operational flow diagram of a water production system is shown in Fig. 4.2. The diagrams compose a cluster of entities that are in the business of water production, where each of the entities usually has rights/permission to one or more water sources. The cluster of entities with the right to water production includes participants from both the public and the private sectors. The typical examples of the water sources are surface water, groundwater, stormwater, wastewater, and icebergs/glaciers sources. These sources provide the feed to the water production facility depending on the right/permission a water production participating entity has. And the water output of the production facility is transported to the storage facility.

The major objectives of water production are to (i) maximize the reliability and minimize the uncertainty of water sources in terms of quantity and quality, (ii) minimize the cost of water production in a way that promotes environmental sustainability, ensure the economic viability of the process, and equitably allocate water to users that satisfy their demand. Figure 4.3 represents the model of a water production system that takes into consideration the primary factors in the process.

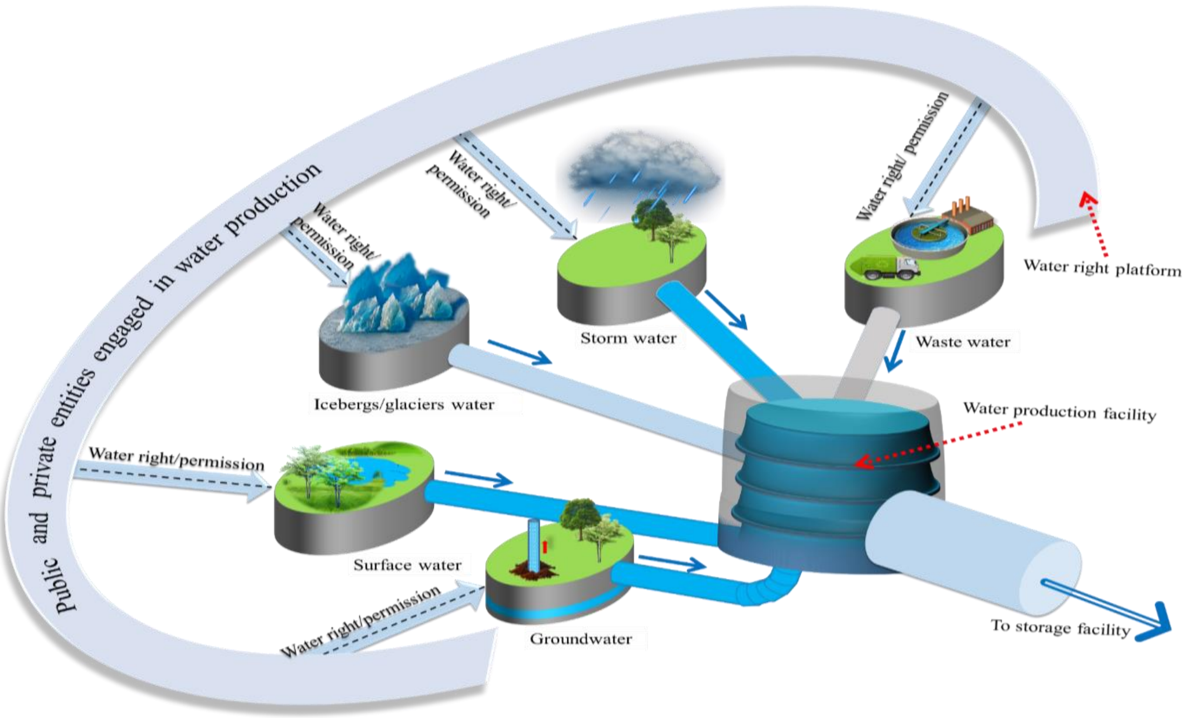


Figure 4-1 The classical operational flow diagram of a water production system

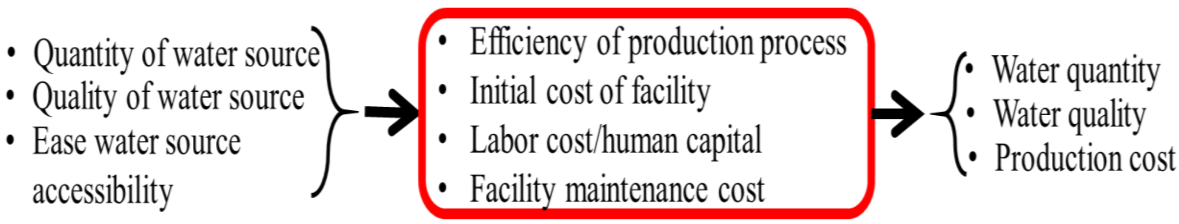


Figure 4-2 Model representation of a water production system

Let us represent the various functions and factors in Figure 4.3 as follows

$g_{quantity}$	Quantity of water source
$g_{quality}$	Quality of water source
g_{access}	Ease of access to a water source
p_{eff}	Efficiency of water production facility
$cost_{in}$	Initial cost of water production facility
$cost_{labor}$	Cost of human labour
$cost_{facility}$	Cost of facility maintenance
$f_{quantity}$	Quantity of water produced
$f_{quality}$	Quality of water produced
f_{cost}	Production cost

The outputs of the water production system, namely, water quantity, water quality, and production cost can be modelled as by the following expressions

$$f_{quantity} = f(g_{quantity}, g_{quality}, p_{eff}) \quad (4.1)$$

$$f_{quality} = f(g_{quality}, p_{eff}) \quad (4.2)$$

$$f_{cost} = f(f_{quantity}, f_{quality}, cost_{in}, cost_{labor}, cost_{fm}) \quad (4.3)$$

respectively. To increase the quantity of water produced implies having the desired quantity and quality of water fed into the production facility. However, our reliability on a water source to provide water of certain quantity and quality is an uncertain function, which is dependent on the time of water access, the reservoir capacity of the water source, the number of available water sources, and the influence of the environment. Let us define the water quantity that is available at a water source by

$$q_{source,i} = f(q_{rate,i}(time, environment), reservoir\ capacity) \quad (4.4)$$

And the total water quantity available Q_{source} at the disposal of the water, the producer depends on the number of sources that the producer has the right/permission to access, such that

$$Q_{source} = \sum q_{source,i} \qquad (4.5)$$

Hence, we can express the reliability of water source available to a water production system as

$$\beta_{rel,q} = Q_{source} - \frac{g_{quantity,Target}}{Q_{source}} \qquad (4.6)$$

where $g_{quantity,Target}$ is the target water source quantity that yields the targeted output water quantity, $f_{quantity,Target}$.

Invariably, given a water quantity target, $f_{quantity,Target}$ that will meet the demand of users at any given time, the reliability of the water source for production purpose should be as close as possible to unity ($\beta_{rel,1} \rightarrow 1$) so that $g_{quantity,Target} = g_{quantity}$ is achievable at all times. This requires reducing the uncertainty in the availability of the water source, Q_{source}. This will help in the more efficient allocation of water production facility resources, and to always meet the demands of the consumers. However, the contemporary water production systems typically have little or no very unswerving way of obtaining information that can reduce the uncertainty in the reliability of water sources.

The discussion around (4.4)-(4.6) can also be extended to the targeted water quality, $f_{quality,Target}$. Let us express the water quality of a water source by

$$qq_{source,i} = f(qq_{rate,i}(time, environment)) \qquad (3.7)$$

The total water quality QQ_{source} when we consider the number of water sources (assuming independence of contaminants from all sources) that are available for access to water production is given by

$$QQ_{source} = \sum qq_{source,i} \qquad (3.8)$$

Hence, we can express the reliability of water source in terms of quality of water production system as

$$\beta_{rel,qq} = \frac{g_{quality,Target}}{QQ_{source}} \quad (3.9)$$

where $g_{quality,Target}$ is the target water source quality that yields the targeted output water quality, $f_{quality,Target}$.

Hence, given a targeted index of water quantity(Kachroud et al., 2019), $f_{quality,Target}$ that will meet the demand of users at any given time, the reliability of the water source for production purpose should be as close as possible to unity ($\beta_{rel,1} \to 1$). This invariably implies that $g_{quantity,Target} = g_{quantity}$ should be obtainable irrespective of the number of water sources involved. This requires knowing the qualities of the water source in real-time before deciding on whether to use the sources or not in water production. Contemporary water production systems typically do not have the capability for real-time ways of obtaining such information. We also note (as is indicated in (4.1)) that the quality of the water source can also influence the quantity of water produces since water contaminants are factored into the quantity of water. Hence, the more contaminants there are in a given water quantity, the lesser the water ratio, hence, the lesser the water quantity output.

Furthermore, the efficiency of the production facility also determines the possibility of obtaining a certain water quantity of the desired quality. The current methods of producing water are not 100% efficient, hence, innovations are required to improve facility efficiency for better output. In the case of the production cost, f_{cost}, (4.3) indicates the dependency of the production cost not only on the quality and quantity of the water source fed into the system, but on the total input cost, namely, the initial cost of the facility, cost of labour, and cost of facility maintenance. Reducing these costs naturally reduces the total cost and makes the system more cost-efficient.

Hence, the primary objective of water production can be summarized by the following optimization expressions.

$$\text{maximize} \quad f(g_{quantity}, g_{quality}, p_{eff}) \quad (4.10)$$

$$\text{subject to} \quad \beta_{rel,q}, \beta_{rel,qq}, p_{eff}$$

$$\text{maximize} \quad f(g_{quality}, p_{eff}) \tag{4.11}$$

$$\text{subject to} \quad \beta_{rel,qq}, p_{eff}$$

$$\text{minimize} \quad f(g_{quantity}, g_{quality}, cost_{in}, cost_{labor}, cost_{fm}) \tag{4.12}$$

$$\text{subject to} \quad g_{quantity}, g_{quality}, cost_{in}, cost_{labor}, cost_{fm}$$

These optimization challenges are impediments to realizing the desired goals of water security with contemporary water production systems. Therefore, by optimizing any or all of the functions in (4.10)-(4.12) in ways that promote environmental sustainability and ensure economic viability, a water production system will be able to equitably allocate water to users satisfactorily.

4.2.1.2 4IR-Solution for the Water Production Model

The goal of any approach that is designed to address the challenges of the contemporary water production system is to optimize (4.10) - (4.12). To this end, we present a 4IR solution that employs its enabling technologies in an attempt to optimize the expressions in (4.10)-(4.12).
To maximize (4.10) and (4.11) implies the real-time (or in some cases offline) acquisition of information relating to the variables that define the reliability of the various water sources that are available for water production. The variables include the rate at which water enters the water sources, $q_{rate,i}$, the rate at which the water sources are contaminated, $qq_{rate,i}$, the capacity of the water source, the weather conditions, the number of water sources available for use, and the operational state of the water production facility, p_{eff}. More also, the operational efficiency of the water production facilities can also be improved by considering matching 4IR technologies and innovative technologies.

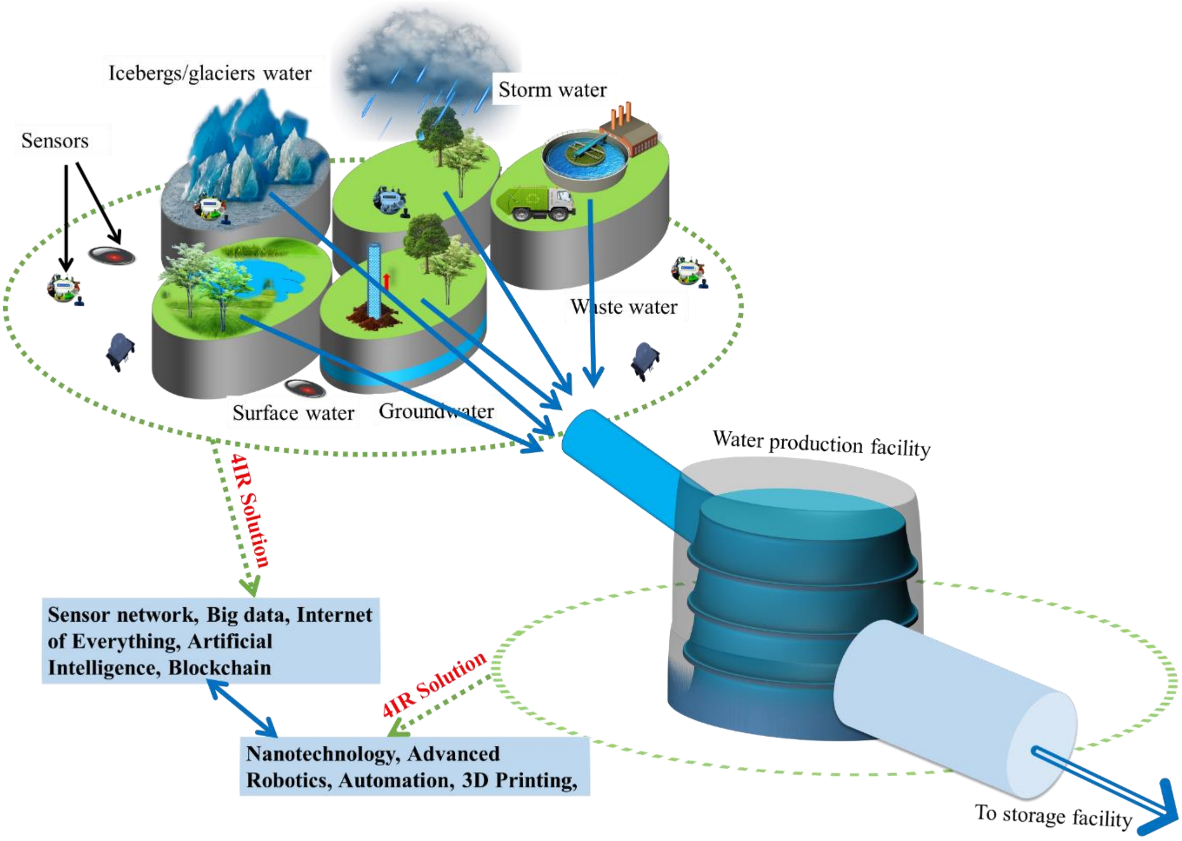


Figure 4-3 4IR-driven water production system solution.

How can the data for computing $q_{rate,i}$, $qq_{rate,i}$, the capacity of the water source and the weather conditions be obtained using 4IR solutions?

By using the 4IR enabling technologies such as ***advanced sensors and sensor network*** deployed at the water source locations and environment (as is depicted in Figure 4.4), real-time geological and hydrological data that represent the water levels and variations at the water sources, the dimension of the water sources, and the weather conditions can be acquired. In locations that are inaccessible for the deployment of physical sensors or where the number of sensors that are required is too large, ***virtual sensors*** can be employed. The acquired data will be transmitted to a remote location or to the cloud over the ***internet of everything*** (IoE) configuration that is within the control of the water production company for onward data analysis using localized or ***cloud computing***. Data analytics require the development and application of machine learning algorithms, which are the ***artificial intelligent system***. Additional data from appropriate ***big data*** resources will information about the water rights/permissions and allocations of water resources that can be used in the data analytics process for better results. In some case where there is financial values, security, and confidentiality attached to the transfer of data, the blockchain technology can be implemented.

How can the data for computing the operational state of the water production facility, p_{eff}, be obtained using 4IR solutions?

Sensors and sensor networks can be used to obtain information on the operation state of the water production facility. These sensors can include sensors that can detect variations in chemicals (such as pH, salinity, contaminants, etc.) and physical variables (such as pressure, temperature, vibrations, noise, etc.). In locations that are inaccessible for the deployment of physical sensors or where the number of sensors that are required is too large, ***virtual sensors*** can be employed. The ***IoT-enabled sensors*** can be used in a configuration that enables the collection of data at a remote location or at the ***cloud***, where ***computing/data analytics*** can be done using ***artificial intelligence*** algorithms. The decision the algorithms arrive at can be used to initiate appropriate responses at the facility in an ***automated*** manner.

Further, not only can 4IR enables the collection of operational data of the water production facility, the design, and fabrication of the facility can benefit from the 4IR initiative. For instance, various materials and innovations that are based on ***nanotechnology*** can be used to design the facility. ***Nanomaterials*** (Gehrke et al., 2015) with excellent properties in terms of resilience to corrosion/degradation by chemicals/contaminants can be used to fabricate the parts of the facility. Also, nanoparticles can be employed as potential heavy metal adsorbents in the production process (Simeonidis et al., 2019).

How can the operational costs be minimized using 4IR solutions?

Then, to minimize (4.12) implies the reduction in the initial cost of the facility, the cost of labor, and the cost of maintenance, in addition to ensuring that good quality of water is fed into the plant. While the initial cost of the facility depends on the choice of the technology, which is a once-off purchase, hence, we do not consider its cost minimization, the cost of maintenance and labor can be minimized. To minimize the cost of maintenance implies using robust materials with excellent properties such as nanomaterials for constructing the facility, and using sensor network to monitor the state of the different operation parts to be able to identify faulty parts in an emergent manner before they cause more problem in the system that will incur more cost. To minimize labor cost/human capital will involve automation and robotics. Robots can be used to do many jobs that humans can do. And robots can even do maintenance jobs that are needed in remote locations like inside high voltage/temperature areas and water pipes where humans cannot access.

4.2.2 Water Storage

Water storage facilities include dams, reservoirs, barrages, structures (above-ground or in-ground), and all systems such as the associated monitoring or gauging equipment that are necessary for collecting and storing water. Such facilities may be publicly owned, privately owned, investor-owned, or cooperatively held with the intent to distribute/allocate the water for consumption/re-allocation when the demand arises.

The primary objectives of water storage are to (i) allow for deferred use of water until the need arises (ii) ensure the guaranteed continuous availability of water when the demand arises, without compromising the quantity and quality of the water. Let us present a generalized systemic model of the water storage system and discuss the challenges associated with its operation. We shall then consider how the 4IR technologies can provide integrated solutions.

4.2.2.1 Classic Water Storage Model

The classical operational flow diagram of a water storage system is shown in Fig. 4.5. To attain these primary objectives of a water storage system enumerated above, it is necessary to adopt measures aimed at preserving the quality and quantity of the stored products overtime at a considerable cost. To place these objectives in a comparative platform, the model of the water storage is shown in Figure 4.6.

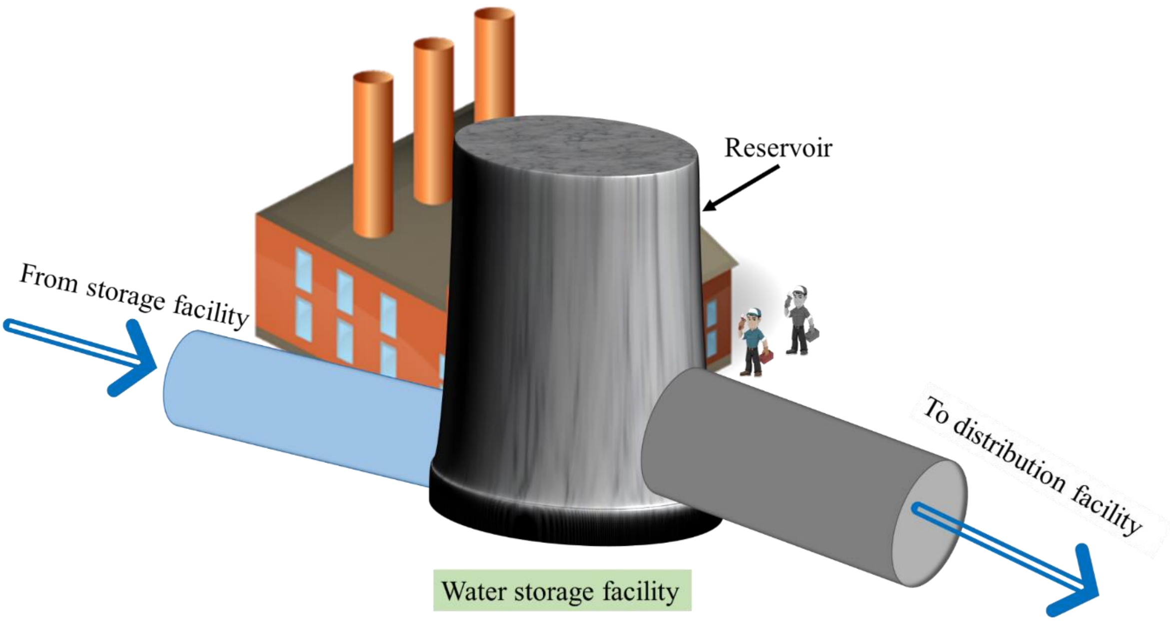


Figure 4-4 Classical operational flow diagram of a water storage system.

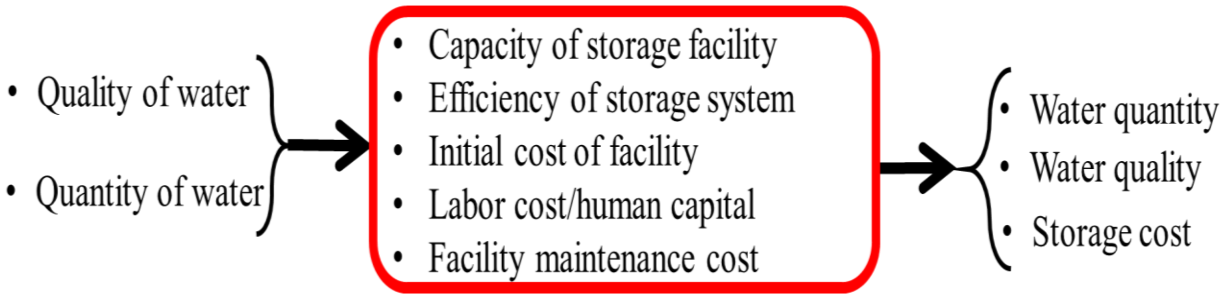


Figure 4-5 Model representation of a water storage system.

Let us represent the various functions and factors in Figure 4.6 as follows

$h_{quantity}$	Total quantity of water fed into the storage
$h_{quality}$	Quality of all the water fed into the storage
$h_{capacity}$	Capacity of the reservior
s_{eff}	Efficiency of water storage facility
$cost_{in,ws}$	Initial cost of water storage facility
$cost_{labor,ws}$	Cost of human labor for water storage process
$cost_{facility,ws}$	Cost of water storage facility maintenance
$ws_{quantity}$	Quantity of water output from the storage

$ws_{quality}$	Quality of water output from the storage
ws_{cost}	Storage cost

The outputs of the water storage system can be modeled by the following expressions

$$ws_{quantity} = f(h_{quantity}, h_{capacity}, s_{eff}) \tag{4.13}$$

$$ws_{quality} = f(h_{quality}, s_{eff}) \tag{4.14}$$

$$ws_{cost} = f(h_{quantity}, h_{quality}, h_{capacity},, cost_{in,ws}, cost_{labor,ws}, cost_{fm,ws}) \tag{4.15}$$

Equation (4.13) indicates that the quantity of the water from the water storage facility is dependent on the capacity of the reservoir, the water in the reservoir, and the efficiency of the storage facility. The target is to ensure that the total quantity of water fed into the facility is equal to the total quantity of water that leaves the facility and is fed into the distribution system. However, in the contemporary water storage facility, loss of water arise from surface evaporation and seepage through the reservoir structure into the surrounding environment. There are contemporary efforts being made to address the challenges, however, the current options have not substantially yielded many results.

The expression for the targeted output quality of the water storage facility that is given in (4.13) specifies that the quality of the water from the water storage facility into the distribution facility is dependent on the quality of the water that goes into the reservoir, and the efficiency of the storage facility. Again the target is to ensure that the quality of water fed into the facility is not better than the total quality of water that leaves the facility and is fed into the distribution system. While this condition is ideal, the unintended introduction of water pollutants into the reservoir often occurs. Hence, the efficiency of the storage facility to shield the water quality from degrading is crucial.

Equation (4.14) is associated with the total cost of the storage operation. The total cost of water storage is dependent on the quantity and quality of water stored, the capacity of the storage system, the cost of labor, the initial cost of the facility, and the cost of maintenance. The more the capacity of the storage system, the larger the quantity of water stored, and this translates to bigger profit in terms of water sales. However, the lower the quality, the lower the value of the water, and possibly a resultant strain on the performance of the storage facility. More also, the various costs in the storage process add to the overall cost. Ideally, high capacity storage, large water quantity and good water quality are desired while keeping the cost of labor, and maintenance low.

4.2.2.2 4IR Solution for the Water Storage Model

The goals of any approach that is designed to address the challenges of contemporary water storage address the following.

i. To ensure that the total quantity of water fed into the facility is approximately equal to the total quantity of water that leaves the facility and fed into the distribution system.
ii. To ensure that the quality of water that leaves the facility and is fed into the distribution system is equal or better than the quality of water that is fed into the facility.
iii. To ensure that the water storage venture is cost-effective given the knowledge of the consumer response.

The conceptualized 4IR-driven water storage system model is shown in Fig. 4.7. The 4IR enabling technologies can be aggregated to achieve the above goals as follows.

How do we ensure that the total quantity of water fed into the facility is approximately equal to the total quantity of water that leaves the facility and fed into the distribution system using 4IR solutions?

This can be achieved by minimizing the loss of water through the storage facility. In this case, the use of the 4IR enabling technology, ***nanotechnology***, comes handy. Since evaporation is a function of temperature, keeping the temperature of the reservoir low will reduce loss through evaporation. Hence, nanotechnology can be used to achieve a sustainable and inexpensive cooling system for the reservoir. This can be achieved by the use of composite nanofluids in cooling systems. Such a system may further be power by graphene-based solar cells, which are reportedly more efficient than conventional solar cells. On the other hand, ***nanomaterials*** with excellent resilient qualities can be fabricated to form the structure of the reservoir and reduce water leakage. And ***sensors*** embedded in the storage system can be used to monitor the system temperature and initiate temperature control, and to monitor the reservoir structure for faults that may lead to seepage, even from a remote location by using ***IoE*** and ***artificial intelligent***

algorithms. More also, nanoparticles can directly be added to the water with no resultant quality degradation to reduce water loss by evaporation (Pour Omolbani et al., 2017).

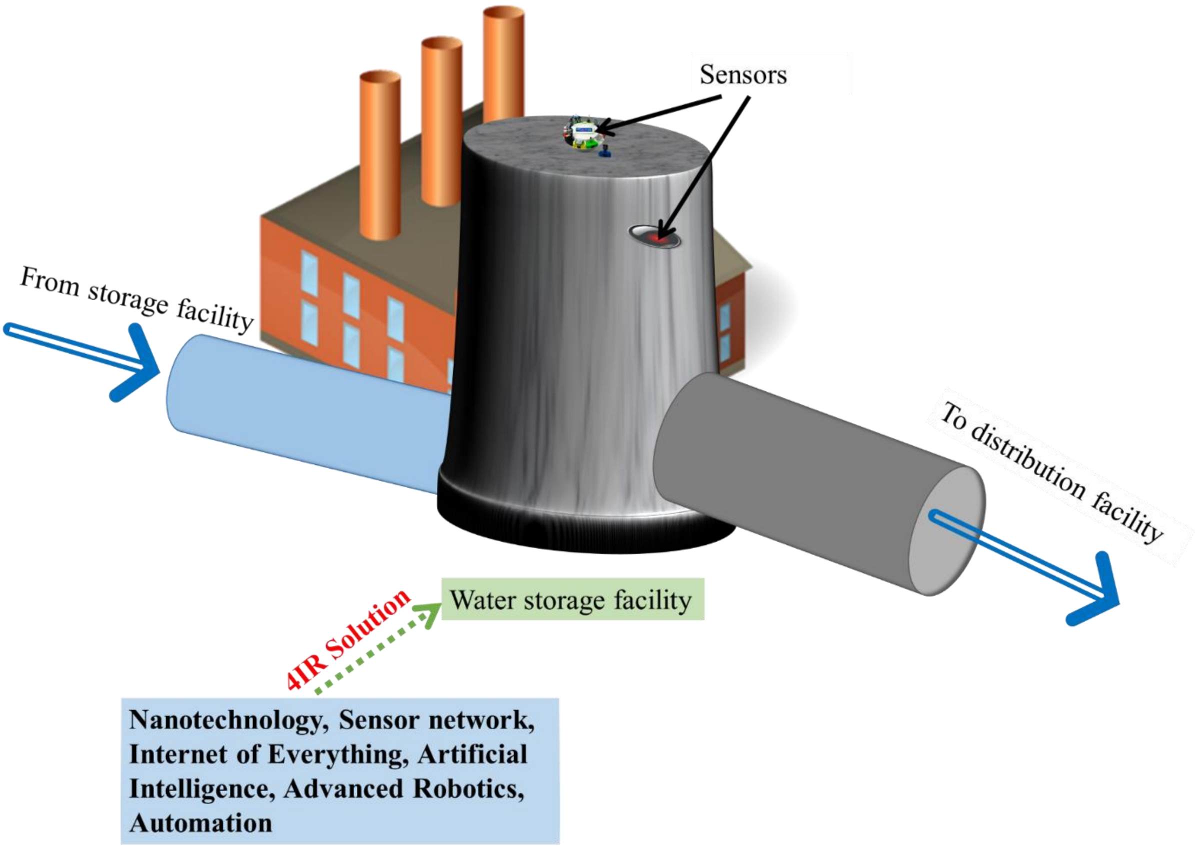


Figure 4-6 4IR-driven water storage system solution.

How do we ensure that the quality of water fed into the facility is equal to the quality of water that leaves the facility and fed into the distribution system using 4IR solutions?

This can be achieved by ensuring that the storage system does not degrade the quality of the water fed into it. Typically, quality degradation can come from the accumulated contaminants that are leftovers from previous water stored in the facility, or/and from the environment of the storage system. ***Nanotechnology*** can be used to keep the quality of the water that is fed into it from degrading by integrating composite and non-composite nanomaterials such as carbon nanotubes and zeolites into the structure and water space of the facility. These nanomaterials have the characteristics of being able to absorb contaminants and degrade organic pollutants. More also, physical and biological sensors can also be deployed (either in real or virtual form) at the storage facility to monitor the system temperature and initiate temperature control, and to monitor the reservoir structure for faults that may lead to seepage, even from a remote location by using ***IoE*** and ***artificial intelligent algorithms***.

How do we employ 4IR solutions to ensure that the water storage venture is cost-effective given the knowledge of the consumer response?

Then, minimizing the operational cost of water storage implies the reduction of the cost of labor and the cost of maintenance. The cost of labor can be minimized by employing 4IR enablers such as ***automation*** and ***robotics***. Robots can be used to do many jobs that humans can do, and automation will ensure real-time response in the storage operation. Also, robots can do maintenance jobs and even access remote locations in the storage facilities to repair and replace parts of the facilities where humans cannot access easily. Additionally, the cost of maintenance can also be minimized by using nanomaterials with robust and resilient/durable properties that can stand the test of time and environment.

4.2.3 Water Distribution

A water distribution network is an interconnected assembly of sources, pipes, and hydraulic control elements for delivering water to consumers in prescribed quantities and qualities. The fundamental objectives of the water distribution system are to (i) deliver water to all customers of the system in sufficient quantity for different purposes with the desired quality (ii) deliver water to customers irrespective of their locations at the appropriate pressure and with minimal loss (iii) ensure that the cost delivery of water to the customers is economical. Let us present a generalized systemic model of the water distribution system and discuss the challenges associated with its operation. We shall then consider how the 4IR technologies can provide integrated solutions.

4.2.3.1 Classic Water Distribution Model

The typical operational flow diagram of a water distribution system is shown in Fig. 4.8. To realize the objectives of a water distribution system enumerated above, it is necessary to adopt measures aimed at ensuring that the quality and quantity of the water fed into the distribution network are preserved. To place these objectives in a system perspective, we present the model shown in Figure 4.9.

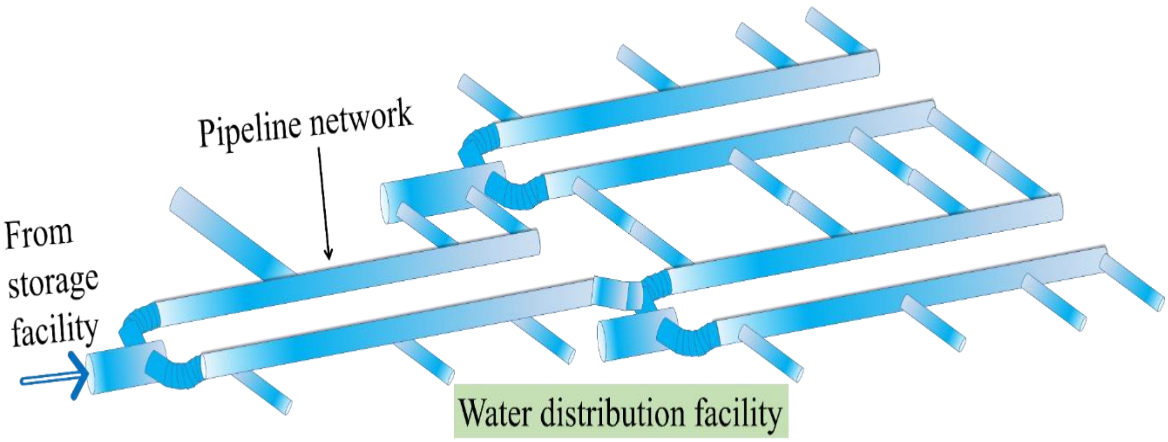


Figure 4-7 Operational flow diagram of a water distribution system.

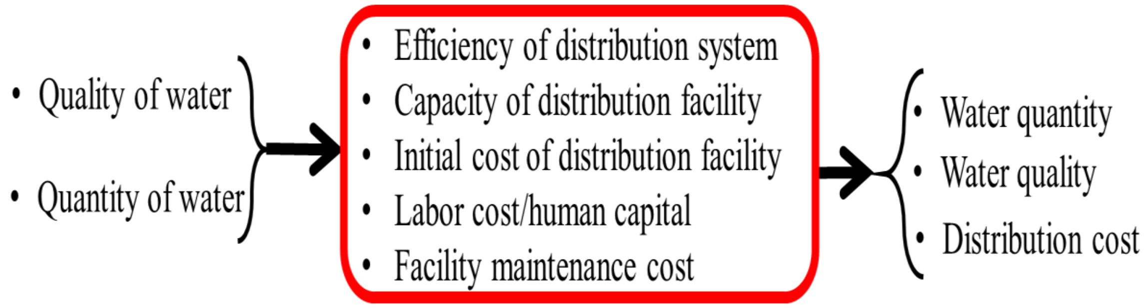


Figure 4-8 Model representation of a water distribution system.

Figure 4.9 shows the dependency of the water quality and quantity, as well as the distribution cost on the efficiency of the water distribution network, the initial cost of installing the water distribution network, the cost of labor, and the cost of maintaining the distribution network. Let us represent the various functions and factors in Figure 4.9 as follows

$m_{quantity}$	Total quantity of water fed into the distribution facility
$m_{quality}$	Quality of all the water fed into the distribution facility
$m_{capacity}$	Capacity of the distribution facility
d_{eff}	Efficiency of water distribution facility
$cost_{in,d}$	Initial cost of water distribution facility
$cost_{labor,d}$	Cost of human labor for water distribution process

$cost_{facility,d}$	Cost of water distribution facility maintenance
$d_{quantity}$	Quantity of water output from the distribution facility
$d_{quality}$	Quality of water output from the distribution facility
d_{cost}	Water distribution process cost

The outputs of the water distribution system can be modeled by the following expressions

$$d_{quantity} = f(m_{quantity}, m_{capacity}, d_{eff}) \quad (4.16)$$

$$d_{quality} = f(m_{quality}, d_{eff}) \quad (4.17)$$

$$d_{cost} = f(m_{quantity}, m_{quality}, m_{capacity}, cost_{in,d}, cost_{labor,d}, cost_{fm,d}) \quad (4.18)$$

Equation (4.16) indicates that the total quantity of the water fed the consumers from the water distribution system over a unit time is dependent on the capacity of the distribution network, the water in the distribution network over the unit time, and the efficiency of the distribution network. The target is to ensure that the total quantity of water fed into the facility is equal to the total quantity of water that leaves the distribution facility. However, in the contemporary water distribution system, loss of water arises from leakages and burst pipes into the surrounding environment. To address the challenge of water loss, contemporary systems rely on reports on leakages by the population. This is inefficient since there must have been losses incurred before the report is obtained and the repair is done.

The expression for the targeted output quality of the water distribution facility that is given in (4.17) specifies that the quality of the water from the water distribution facility into the consumers' facility is dependent on the quality of the water that goes into the distribution network, and the efficiency of the distribution facility. Again the target is to ensure that the quality of water fed into the facility is not better than the total quality of water that leaves the facility and fed into the consumers. While this condition is ideal, the unintended introduction of water pollutants into the distribution network may occur. Hence, the efficiency of the distribution facility to shield the water quality from degradation is crucial.

Equation (4.18) is associated with the total cost of the distribution operation. The total cost of water distribution is dependent on the quantity and quality of water in the distribution system, the capacity of the distribution system, the cost of labor, the initial cost of the facility, and the cost of maintenance. Here, capacity implies how distributed the system is, which interprets to the number of customers that it serves. The more the capacity of the distribution system, the more customers pool, and this translates to bigger profit in terms of water sales. However, the lower the quality, the lower the value of the water, and possibly a resultant strain on the performance of the distribution facility. More also, the various costs in the distribution process add to the overall cost. Ideally, a high capacity distribution network, large water quantity, and good water quality are desired while keeping the cost of labour, and maintenance low.

4.2.3.2 4IR Solution for the Water Distribution Model

The goals of any approach that is designed to address the challenges of contemporary water storage address the following.

i. To ensure that the total quantity of water fed into the distribution facility is approximately equal to the total quantity of water that leaves the facility and fed into the consumer system.
ii. To ensure that the quality of water that leaves the distribution facility and fed into the consumption system is equal or better than the quality of water that is fed into the distribution facility.
iii. To ensure that the water distribution venture is cost-effective given the knowledge of the consumer response.

The conceptualized 4IR-driven water distribution system model is shown in Fig. 4.10. The 4IR enabling technologies can be aggregated to achieve the above goals as follows.

How do we ensure that the total quantity of water fed into the distribution facility is approximately equal to the total quantity of water that leaves the facility and fed into the consumer system using 4IR solutions?

This can be achieved by minimizing the loss of water through the distribution facility. In this case, the use of the 4IR enabling technology, the ***IoE-enabled sensor network***, comes handy.

The type of ***sensor network*** for use in this application should have the capability to provides information on the state of the pipes and connections in the distribution system (emergent leakage detection) in real-time and transmit the data to a remote location where ***artificial intelligence algorithms*** and other related data analysis tools are used to make sense out of the data and take appropriate action. This will allow timely intervention in the event of any possible water leakage. More also, nanomaterials of robust qualities can be used for pipe fabrication.

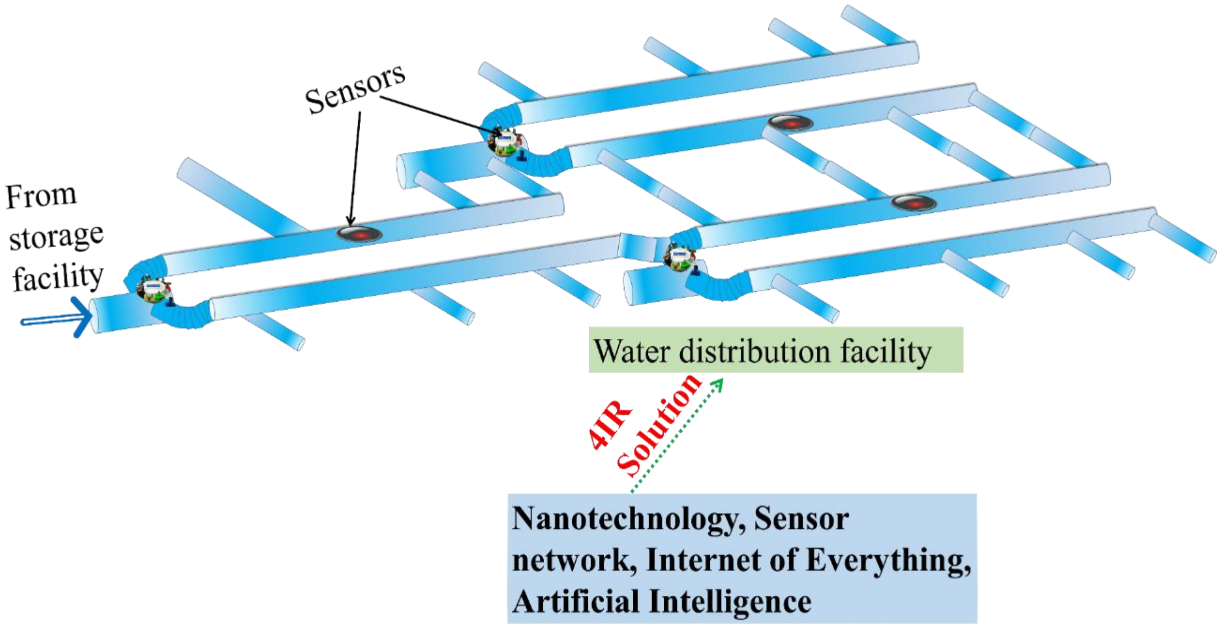


Figure 4-9 4IR-driven water distribution system solution

How do we employ the 4IR solutions to ensure that the quality of water that leaves the distribution facility and fed into the consumption system is equal or better than the quality of water that is fed into the distribution facility?

This can be achieved by ensuring that the distribution system does not degrade the quality of the water fed into it. Typically, quality degradation can come from the accumulated contaminants that are leftovers from previous water volumes that traverse the facility, or/and from the environment of the storage system. ***Nanotechnology*** can be used to keep the quality of the water that is fed into it from degrading by integrating composite and non-composite nanomaterials into the structure and water space of the facility. These nanomaterials have the characteristics of being able to absorb contaminants and degrade organic pollutants. Additionally, ***biosensors*** can also be deployed (either in real or virtual form) at the distribution facility to detect and report the presence of contaminants and organic pollutants. The data from the biosensors can be remotely accessed using ***IoE*** and analyzed with ***artificial intelligence algorithms***.

How do we employ 4IR solutions to ensure that the water distribution scheme is cost-effective?

To minimize the operational cost of water distribution implies the reduction of the cost of labour and the cost of maintenance. The cost of labour is typically incurred when dealing with repairs, facility monitoring, and the customer billing process. Human activities in this area can be replaced with ***automation***. Robots can do maintenance jobs and even can be deployed at locations in the pipeline that are typically inaccessible to humans. For instance, there are robots that can move along the inside of a water pipe, use sensors embedded on it to detect changes in force caused by water leakage, and confirm the location of a leak. Additionally, the cost of maintenance can also be minimized by using nanomaterials with robust and resilient/durable properties that can stand the test of time and environment.

4.2.4 Water Consumption

Water consumption in this report is directly relates to the process of withdrawing water from a distribution system for purposes such as household use, industry use, irrigation, livestock watering, and thermal/nuclear power. In fact, water consumption includes all forms of activities (including the water withdrawal for resell) that involves the authorized withdrawal of water from the water distribution network for whatever purpose. And the entities that consume water are referred to as consumers in this report.

Typically, just like in many ventures, demand drives production and supply. Hence, it is pertinent to say that water consumers and water consumption rate drive the entire water resource management system, and invariably the need for this report. The fundamental objective of the water consumption system is to ensure that the customers are to withdraw water of desired quantity and quality from the distribution system at affordable cost. Let put this objective into an analytical perspective, we present a generalized systemic model of the water consumption system and discuss the challenges associated with its operation. We shall then consider how the 4IR technologies can provide integrated solutions.

4.2.4.1 Classic Water Consumption Model

The typical operational flow diagram of a water consumption system is presented in Fig. 4.11. The diagram typically includes the dispensing device and the billing system (meter reading and bill generation). To realize the goal of a water consumption system, which is best observed from the perspective of a consumer, we present and discuss the model shown in Figure 4.12.

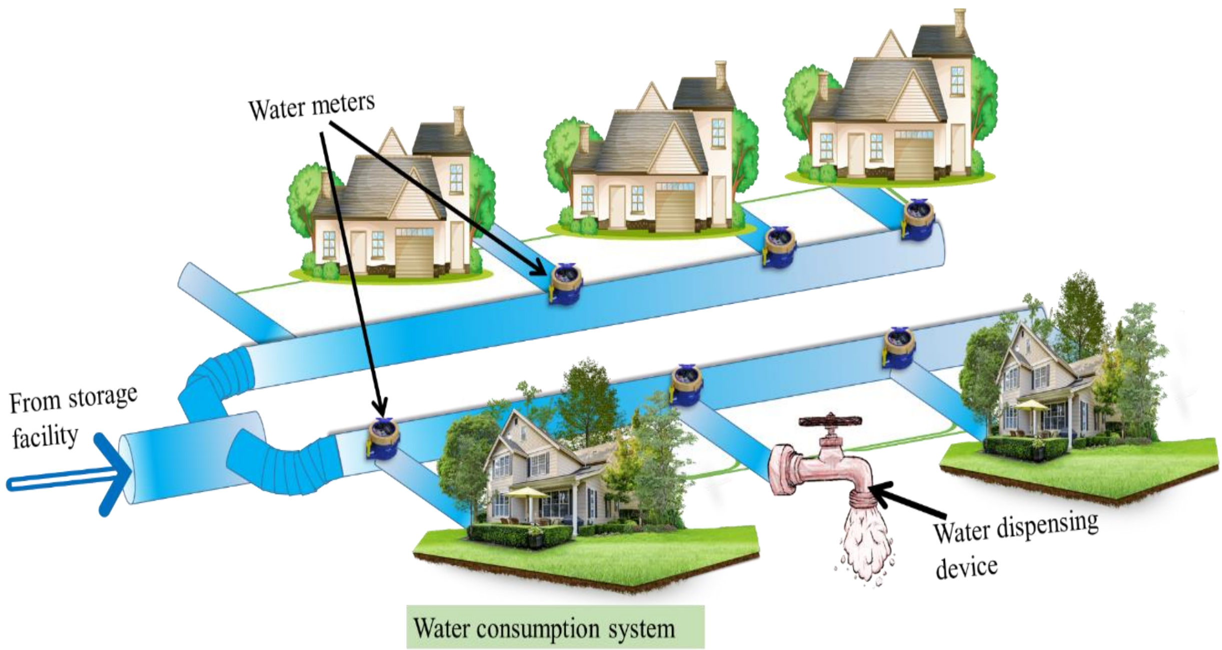


Figure 4-10 Operational flow diagram of water consumption system

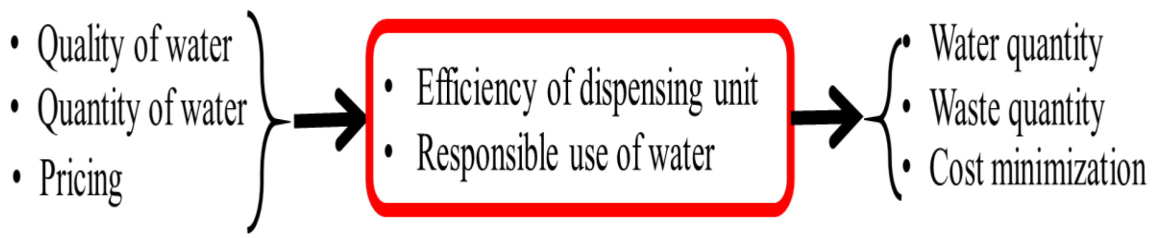


Figure 4-11 Model representation of a water consumption.

Figure 4.12 indicates that the quality and quantity of water dispensed by the water dispensing unit, the tap, for instance, is crucial as the determinant of service delivery by the water supply (production, storage, and distribution) system. These indicators of the service depend on the quantity and quality of water supplied, the pricing regime provided by the supply system, the efficiency of the dispensing unit, and the consumers' attitude towards water usage. Let us represent the various functions and factors in Figure 4.12 as follows

$u_{quantity}$	Total quantity of water fed into the consumption system
$u_{quality}$	Quality of all the water fed into the consumption system
R_{use}	Responsible use of water
b_{eff}	Efficiency of water dispensing unit
$con_{pricing}$	Pricing regime
$b_{quantity}$	Quantity of water output from the distribution facility
$b_{quality}$	Quality of water output from the distribution facility
con_{cost}	Water consumption cost

The outputs of the water distribution system can be modelled by the following expressions

$$u_{quantity} = f(b_{quantity}, b_{quality}, R_{use}, b_{eff}) \tag{4.19}$$

$$u_{quality} = f(b_{eff}) \tag{4.20}$$

$$con_{cost} = f(u_{quantity}, u_{quality}, con_{pricing}) \tag{4.21}$$

Considering (4.19) and (4.20) the target is to ensure that depending on the water use, the desired quantity and quality of the water that is wanted by the consumer is available at the time of need. This implies ensuring that the corresponding quality of water with desired quality is fed into the water consumption system and that the water dispenser dispenses allows the consumer to withdraw the required water quantity/quality, and do so responsibly. In the case of the cost, this typically depends on the accumulated cost of supplying the water name, production cost, storage cost, distribution cost, and logistic cost. So from the standpoint of the consumer, minimizing the cost of the water consumption requires the use of efficient water dispensing unit and ensuring that water is used responsibly (to reduce water loss).

4.2.4.2 4IR Solution for the Water Consumption Model

The conceptualized 4IR-driven solution to water consumption challenges is shown in Fig. 4.13. The 4IR enabling technologies can be aggregated to specifically address the following.

What 4IR solution can ensure that the customers can withdraw water of desired quantity and quality from the consumption system at any desired time?

This can be achieved by ensuring that the required quantity and quality of water is supplied to the consumer at all times. The implementation of 4IR solutions at the production, storage, and distribution facilities can ensure that the above challenge is addressed as we have highlighted previously. The use of a smart metering system at the consumption facility can also play a crucial role in this case. Since water can be scarce sometimes, information about the consumption rate and priorities in water use can help shape the approach of the water supply towards ensuring that the required quantity and quality of water is supplied to the consumers at all times. In this sense, the metering system should have a way of not only obtaining the quantity of water consumed by providing the difference in reading at two instances, but calculate the rate of use over the different times of the day, weeks, and months, and relay such to the water supplier. Such a meter represented in Fig. 4.11 as a smart meter will be **IoT-enabled**. When such information is combined with ***big data*** (which can give personal information about each consumer and his/her activities) and the required data analytics using ***artificial intelligence algorithms***, more insight that can help to shape water supply and even pricing equitably can be obtained.

How do we minimize the cost of consumption of water using 4IR solutions?

To minimize the cost of water consumption implies the reduction of the cost of production, storage, and distribution of water on one hand, and the reduction of water loss at the consumption facility. The implementation of 4IR solutions at the production, storage, and distribution facilities can ensure that the above challenge is addressed as we have highlighted previously. To reduce the cost associated with water loss at the consumption facility, there is the need for the use of an efficient dispensing unit and the responsible use of water. In the case of an efficient dispensing unit, the implementation and use of smart water dispensing units by consumers are important. The smart water dispensing units are faucets that have embedded ***sensors*** that can automatically adjust the rate of water flow based on the consumers' needs. They can automatically go off when not in use and come on when they sense need. This will reduce the waste of water. To help in inculcating responsible water use behaviour in the consumers, the ***blockchain*** can be used to provide a platform that can help to develop a token-based system that provides incentives to anyone in the population that is involved at any level in using water responsibly.

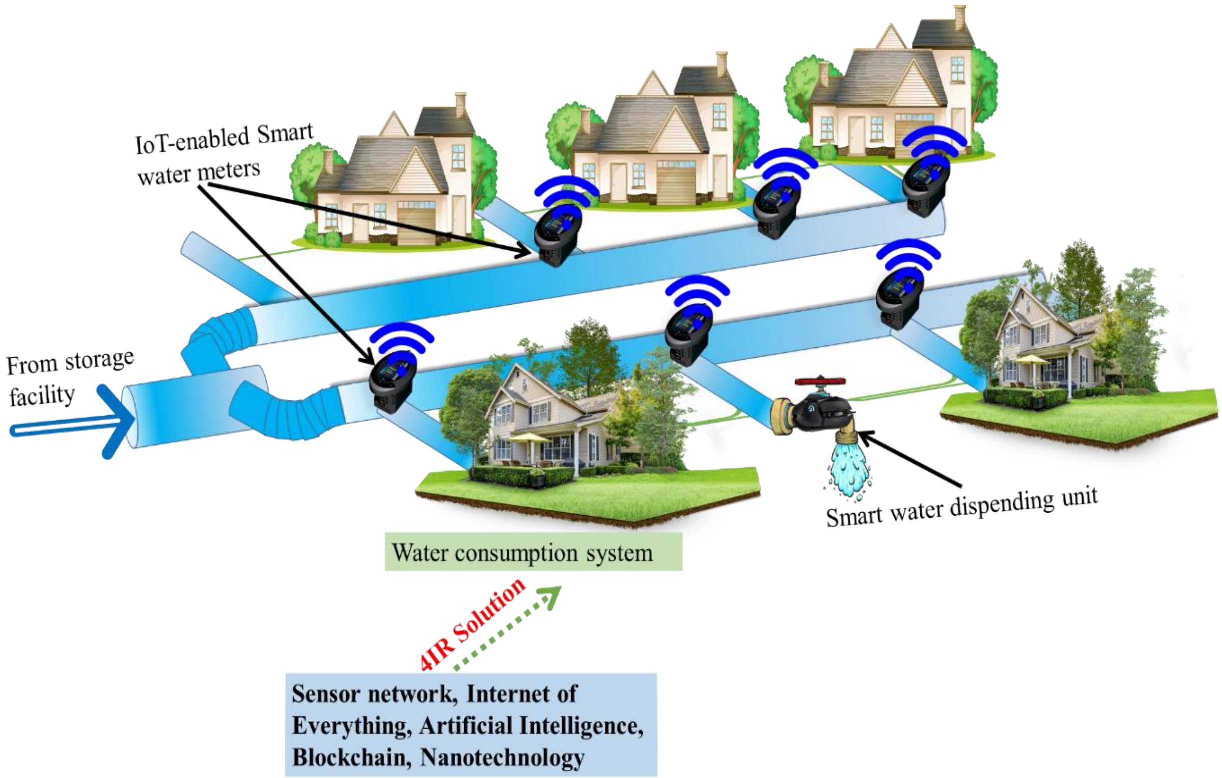


Figure 4-12 4IR-driven water consumption system solution

4.2.5 Wastewater

Wastewater treatment is a process of converting wastewater or sewage from different sources into a more useful reusable state with acceptable impact on the environment by to remove contaminants from it. The operational model of a typical wastewater management system is shown in Fig. 4.14. In the figure, there are the primary treatment, secondary treatment, and tertiary treatment systems. The primary treatment involves temporarily holding the waste in a settling tank where heavier solids sink to the bottom while lighter solids float to the surface. This process is usually done in the screening/pumping and grift removal stages where objects such as wood/plastics fragments, rags, grease, sand, and gravel are removed. At the secondary treatment facility, the biological content of the waste is substantially degraded through aerobic biological processes. The processes used for this process include biofiltration, and aeration, oxidation ponds. After this stage, the water output is safer to be released into the local environment. Depending on the targeted use and the quality of the water output from the secondary treatment facility, a tertiary wastewater treatment facility can be used to raise the quality of the water to domestic and industrial standards, or to meet specific requirements around the safe discharge of water. In the case of water treated by municipalities, the tertiary treatment also involves the removal of pathogens, which ensures that water is safe for drinking purposes.

4.2.5.1 Classic Wastewater Model

The typical operational flow diagram of a wastewater treatment system is presented in Fig. 4.14. The need for wastewater treatment that can result in greywater recycling is obvious given the global water challenge and environmental sustainability concerns. However, the process of water treatment is faced with many challenges that have resulted in the poor management of the wastewater treatment facilities that now require a huge financial commitment to refurbish and maintain. These challenges include energy consumption, staffing, and sludge production.

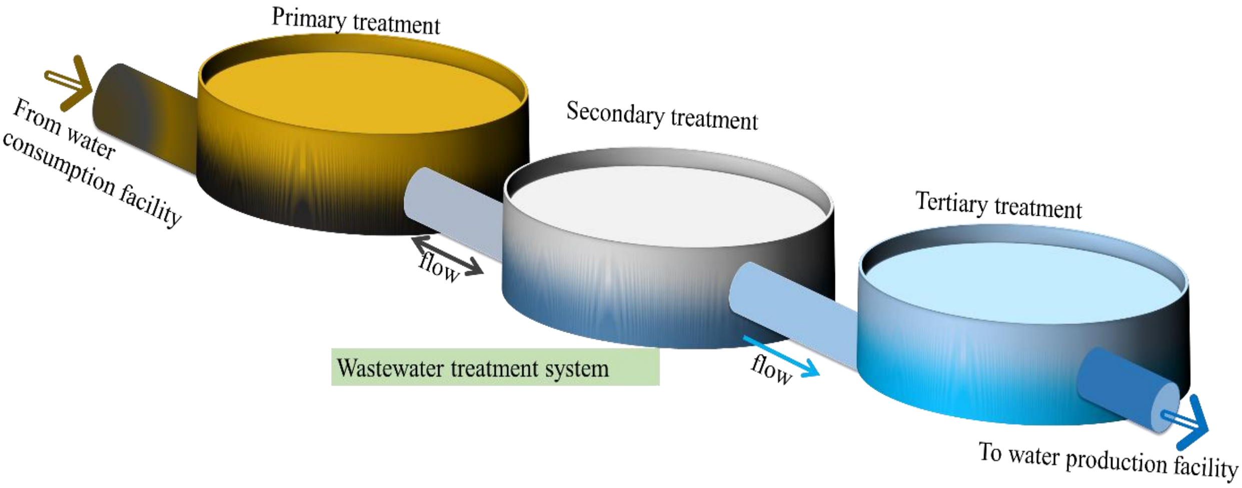


Figure 4-13 Operational flow diagram of wastewater treatment system.

The energy consumption challenge is associated with the amount of energy consumed by the water treatment process. Typically, the process consumes so much energy, especially for biological treatment plants. The staffing concern arises from the need for 24 hours staffing of the facility with trained and certified personnel responsible for overseeing everything from pipe leaks and valves to electrical and instrumentation equipment. Another major challenge is the destination of the sludge produced by the wastewater treatment facility. Typically, the sludge contains large amounts of organic matter and nitrogen, phosphorus, potassium, and other compounds (Tao et al., 2012) (such as organic chemicals, toxic metals, chemical irritants, and pathogens), some of which may be unsafe to the environment, hence, its disposal is a huge problem. Contemporary methods of disposal include activate sludge treatment (which is the extension of the wastewater treatment, and inherits all the challenges of conventional wastewater treatment system enumerated above), disposal in sea, agricultural and non-agricultural lands, and landfilling. These approaches to sludge disposal leave behind adverse environmental footprints that are environmentally non-sustainable.

To consider how to address the challenges highlighted above, let us employ the system model presented in Figure 4.15. Let us represent the various functions and factors in Figure 4.15 as follows.

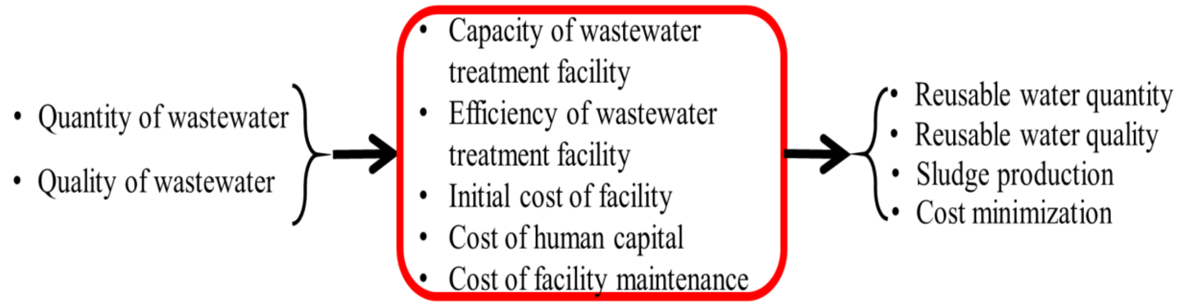


Figure 4-14 Model representation of a wastewater treatment facility.

$l_{uantity}$	Total quantity of waste water fed into the treatment system
$l_{quality}$	Quality of all the wastewater fed into the treatment system
$w_{capacity}$	Capacity of the wastewater treatment facility
w_{eff}	Efficiency of water dispensing unit
$c_{init.waste}$	Initial cost of the wastewater treatment facility

$c_{labor.waste}$	Cost of labour
$c_{fm.waste}$	Cost of facility maintenance
$v_{quantity}$	Quantity of reusable water output from the facility
$v_{quality}$	Quality of reusable water output from the facility
v_{sludge}	Quantity and quality of sludge produced
$cost_{waste}$	Wastewater treatment cost

The outputs of the water distribution system can be modelled by the following expressions

$$v_{quantity} = f(l_{quantity}, l_{quality}, w_{capacity}, w_{eff}) \quad (4.22)$$

$$v_{quality} = f(l_{quality}, w_{eff}) \quad (4.23)$$

$$cost_{waste} = f(v_{quantity}, v_{quality}, c_{init.waste}, c_{labor.waste}, c_{fm.waste}) \quad (4.24)$$

Considering (4.22), the quantity of reusable water output from the wastewater treatment facility is proportional to the quality and quantity of the wastewater fed into the facility, the capacity of the facility, and the efficiency of the water treatment process. Hence, since we do not have to discriminate over the quality of the wastewater, to get a good quantity of reusable water is from the treatment process, we have to ensure that we have a high capacity of the water treatment facility and feed a large quantity of wastewater into a system with very efficient treatment process. Contemporary system approaches this challenge by increasing capacity, however, increase in capacity comes at the cost of an increase in energy consumption. And as the efficiency of the treatment process is much less than 100% (Lu et al., 2016), the increase in capacity will result in more production of sludge.

On the other hand, in (4.23), it is shown that the quality of reusable water output from the wastewater treatment facility is proportional to the quantity of the wastewater fed into the facility, and the efficiency of the water treatment process. Hence, since we do not have to discriminate over the quality of the wastewater, to get a good quality of reusable water from the treatment process, we have to ensure that we employ a very efficient treatment process. However, the efficiency of the contemporary treatment processes is much less than 100% (Lu et al., 2016).

Equation (4.24) is associated with the total cost of the wastewater treatment operation. The total cost of wastewater treatment is dependent on the quantity and quality of water produced from the system, the cost of labour, the initial cost of the facility, and the cost of maintenance. Hence, to minimize the cost of production, we have to maximize reusable water output, increase its quality, reduce the cost of labour, and reduce the cost of facility maintenance. These challenges remain unaddressed.

4.2.5.2 4IR Solution to the Wastewater Model

The conceptualized 4IR-driven solution to wastewater treatment system challenges is shown in Fig. 4.16. The 4IR enabling technologies can be aggregated to specifically address the following.

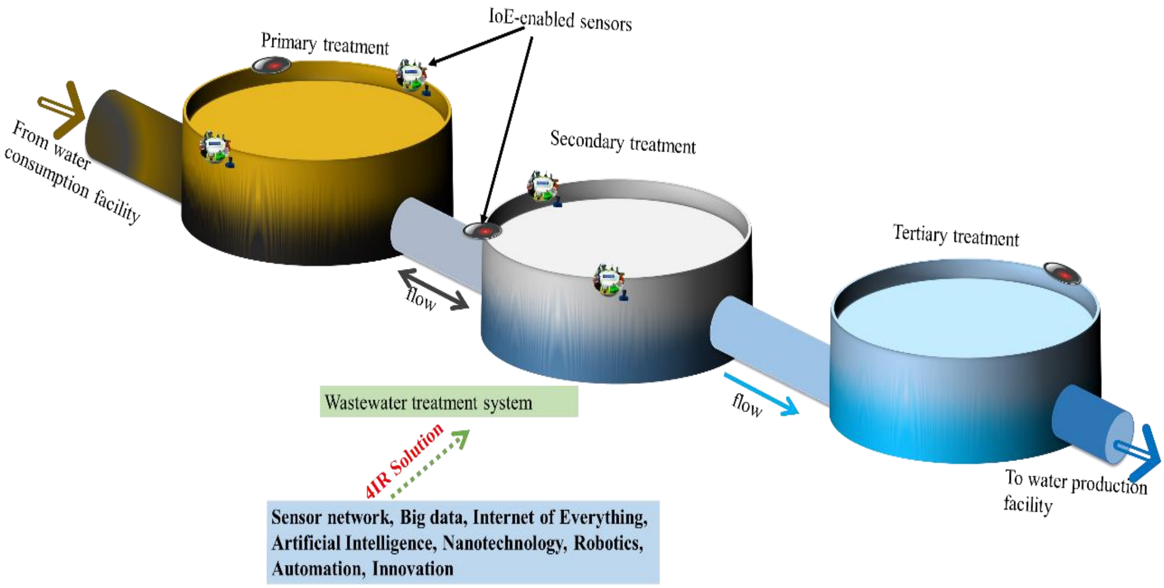


Figure 4-15 4IR-driven wastewater treatment solution.

What 4IR solution can ensure that we produce high quantity and quality of reusable water from a wastewater treatment facility without compromising on the environmental consequence of the process, and reduce sludge output or at least produce conveniently disposable sludge?

To keep the output quantity and quality high without compromising on the energy requirement, there is the need for an efficient wastewater treatment process and the use of low-cost energy sources, and the *innovation* of ideas that can provide more efficient low energy consumption wastewater treatment processes. Nanotechnology Alternative energy sources like solar cell systems can be employed. Here more efficient solar cell systems that are fabricated based on ***nanotechnology*** such as graphene-based solar cells can be used. More also, producing a good quantity and quality of reusable water at low quantity/safe sludge production can be achieved by improving the efficiency of the treatment process. This can be done use ***nanotechnology***. Here, nanotechnology concepts and products such as carbon nanotubes, nanofibers, zeolite filtration membranes, nanoscopic pores in zeolite filtration membranes, nanocatalysts nanoparticles, and magnetic nanoparticles, which are highly effective in removing the contaminants from the wastewater can be employed in nanofiltration, advanced oxidation process, osmosis, sorption (Lu et al., 2016). This reduces the amount of toxic sludge produced. Additionally, ***big data*** and data from ***IoT-enabled sensors*** that are embedded at various points in wastewater treatment systems can be collect data and sent to the monitoring systems (Sundui et al., 2021), where artificial intelligent algorithms can be employed to perform data analysis and predictive analysis. Such data can include water quality, temperature changes, pressure changes, water leak detection, and chemical leakage detection. For instance, the predicted results from the analysis can be used to optimally assign specific production parameters to a generalized treatment process based on the quality of wastewater fed into the system, the available treatment facility resource, and other variables for best output.

How can the operational cost of wastewater treatment system be minimized using 4IR-driven solution?

To minimize the operation cost of wastewater treatment implies the reduction in the initial cost of the facility, the cost of labour, and the cost of maintenance. Again, like in many businesses, the initial cost of the facility depends on the choice of the technology, hence, it is a once-off purchase. Hence, our concerns will be on the minimization of the cost of maintenance and labour. To minimize the cost of maintenance implies using robust materials with excellent properties such as nanomaterials for constructing the facility, and using a sensor network to monitor the state of the different operation parts to be able to identify faulty parts in an emergent manner before they cause more problem in the system that will incur more cost. To minimize labour cost/human capital will involve automation and robotics. For instance, robots can be used to do maintenance jobs that are needed in remote locations like within high-risk areas especially with the treatment of nuclear and industrial wastewaters.

The pattern emerges; the listing of available water resources, in the 4IR model has potentially has no boundaries. For each available water resources such as sea water, virtual water, acid mine drainage water etc. unique solutions can be prepared for each resource.

4.3 Proposed 4IR-Driven Water Market Model

The diagram in Fig. 4.17 shows a comprehensive operational representation of a water supply and management system with integrated 4IR solutions. This systemic representation is the expanded version of Fig. 4.1 that comprises the water sourcing/production system, the water storage system, the water distribution system, the water consumption system, and the wastewater treatment/recycling system. To place the comprehensive operational water supply and management system into the perspective that will technically define the challenges of water security in a way the motivates the need and challenges of implementing water pooling and trading/marking, and how the 4IR-driven solutions can address them, we present a comprehensive systemic model of the system as shown in Fig. 4.18.

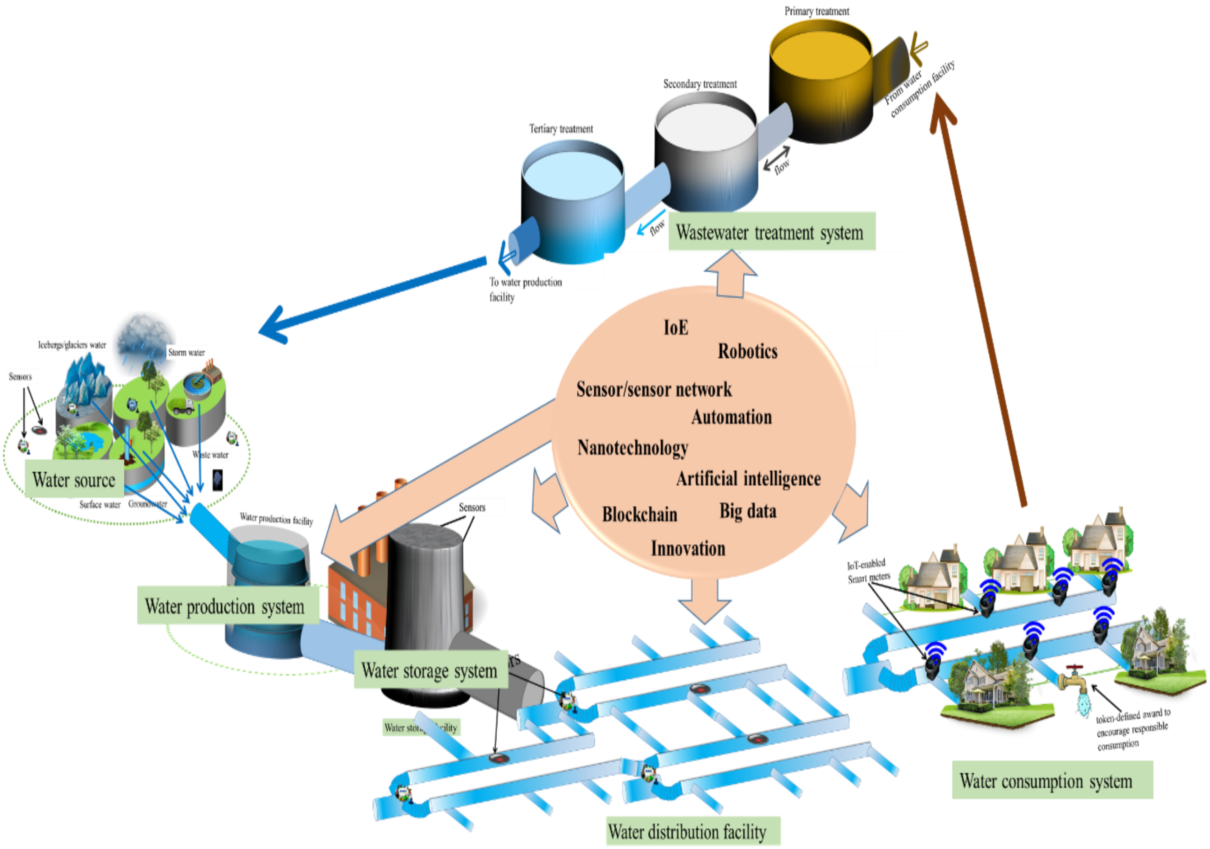


Figure 4-16 Comprehensive 4IR-enabled water supply and management system.

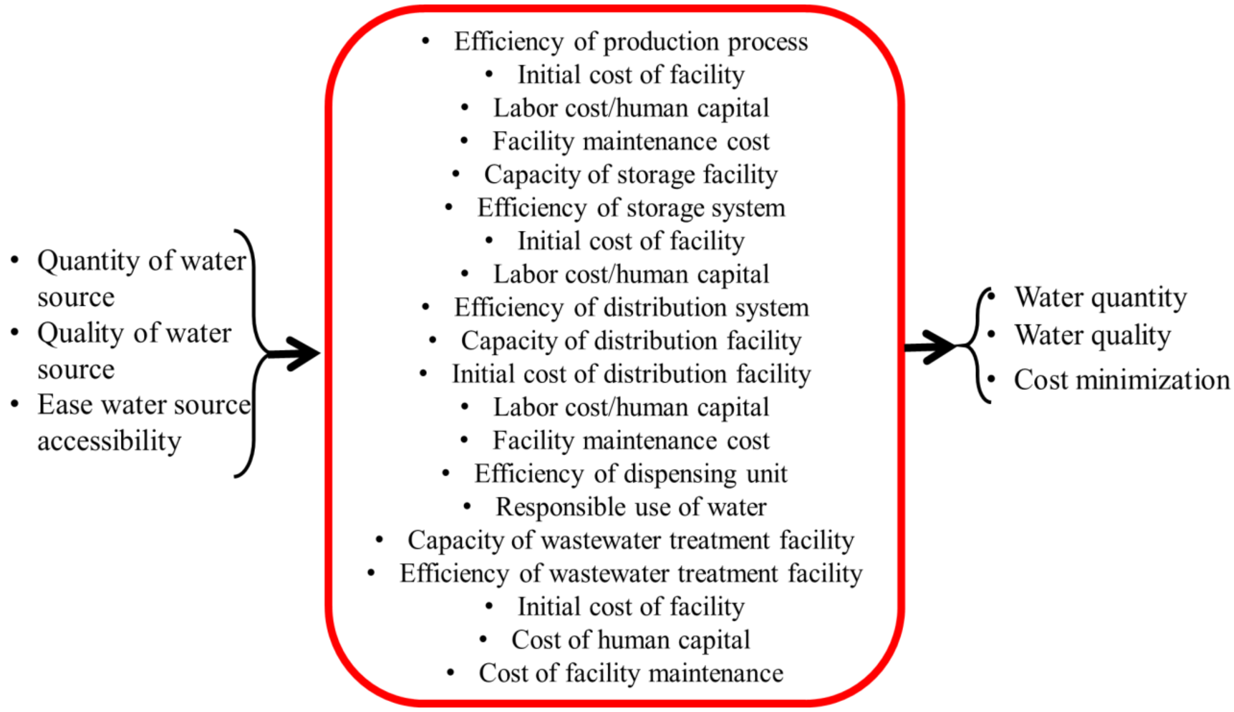


Figure 4-17 A consumer/environment/infrastructure-centric model of a water supply and management system.

Figure 4.18 is a *consumer/environment/infrastructure-centric* model of a water supply and management system that shows the comprehensive factors and variables that are of primary concern in the supply of water resources to consumers in society. In this model, the consumer response drives the process whose dynamics are also dependent on the characteristics of the input to the model, which are the sources of the water to be supplied to the demanding entity, the consumer. The transfer function of this system is dependent on factors such as the efficiency of the system, the capacity of the system, and the operational cost of system processes. In our previous discussion, we have employed different 4IR technologies to provide options that will help in optimizing the efficiency, capacity, and cost-effectiveness of the entire system. This leaves us to ensure that the input to this system is at its optimum level.

The input-output relationship of the model in Fig. 4.18 is compactly expressed as

$$u_{quantity} = f(g_{quantity}, g_{quality}, p_{comp}, R_{comp}) \quad (4.25)$$

$$u_{quality} = f(g_{quality}, p_{comp}) \quad (4.26)$$

$$Con_{cost} = f(u_{quantity}, u_{quality}, cost_{comp}) \quad (4.27)$$

Hence, within the 4IR space, the water quantity demanded by the consumer can be supplied by ensuring that the source of the water is large enough, and this takes us back to (4.6), which defines the reliability of the source of water supply. The equation is restated here

$$\beta_{rel,q} = Q_{source} - \frac{u_{quantity}}{Q_{source}} \quad (4.6)$$

Based on this equation, for a given demand of a water quantity, $u_{quantity}$, by the customer, the demand can be met at all times if $\beta_{rel,1} \to 1$. This implies the requirement of an infinite or large source of water, Q_{source}, given that the 4IR-driven solutions are implemented to optimize the efficiency and capacity of the system as discussed previously. This is where ***water pooling and trading*** come into play. The water pooling and trading system provides a platform that encourages the pooling of water sources ideally into forming an infinite source Q_{source}. Such a platform should also ensure that the quality of water from the sources is on the acceptable level of index.

In developing a water pooling and trading model, the platform must be able to address the challenges enumerated in respect to water trading in general. These challenges include market distortions such as insufficient data availability, information asymmetry, and high transaction costs. Alongside addressing these challenges, the model must be ***consumer/environment/infrastructure-centric*** to ensure that every participant's interest is protected in the trade. To achieve this, this report proposes the implementation of a 4IR solution as is depicted in Fig. 4.19.

The figure shows several entities that have water source rights/permission who can trade water. These can be private or public entities from different locations. The entities are labeled secondary water source 1-7 (SWS 1, SWS 2,…, SWS 7), and are referred to here as ***Sellers***. The primary water source is the centralized governmental institution like the JW, which is referred to as the ***Buyer***. Hence, in this scenario,

$$Q_{source} = SWS\ 1 + SWS\ 2 + SWS\ 3 + SWS\ 4 + SWS\ 5 + SWS\ 6 + SWS\ 7 \quad (4.28)$$

Once an agreement is reached between the buyer and any of the sellers, the seller supplies the desired quantity and quality of water to the buyer through the pool system. The essence of the pool system is to act as an interface system where the quality and quantity of the supplied water are verified and confirmed before being fed into the buyer's water supply facility. For physical pool, 4IR solutions using sensor/sensor networks can be deployed in the pool to automatically obtain water quality and quantity data, which is sent to an ***artificial intelligent*** algorithm through the ***IoE*** connection for analysis and decision (to confirm water exchange contract completion). ***Nanotechnology*** can also be employed in pre-treatment that may take place at the pooling space.

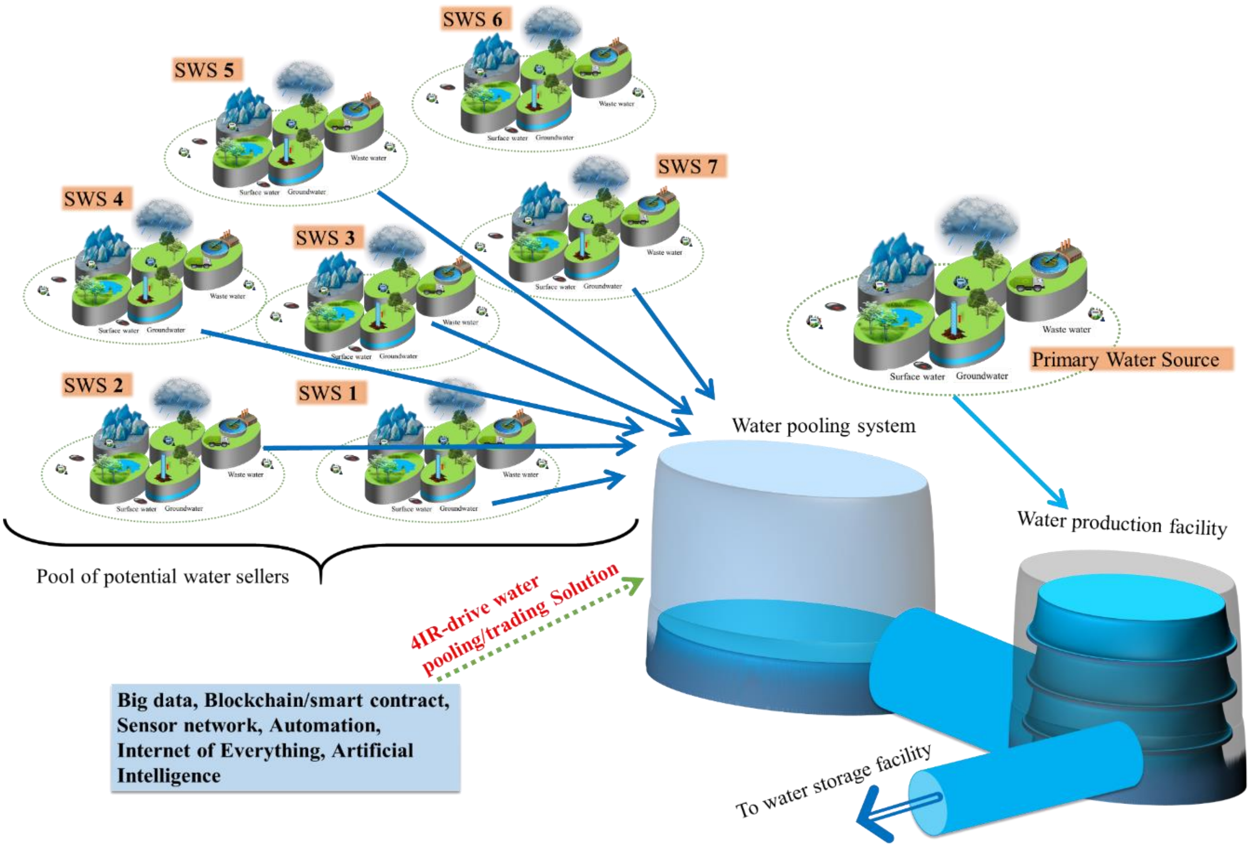


Figure 4-18 Comprehensive 4IR-enabled water resource management system.

To create an even playing field for all the participants in the trade, information exchange, and all forms of transactions between the buyer and the seller is conducted on a **blockchain** platform as is depicted in Fig. 4. 20. Information on the blockchain will include the seller's water quantity potential, seller's water quality potential, seller's water source identification, seller's water production process, seller's water price, seller's water right/permission data buyer's water quantity demand, buyer's water quality demand, buyer's water production demand, buyer's water source demand, and buyer's water price offer.

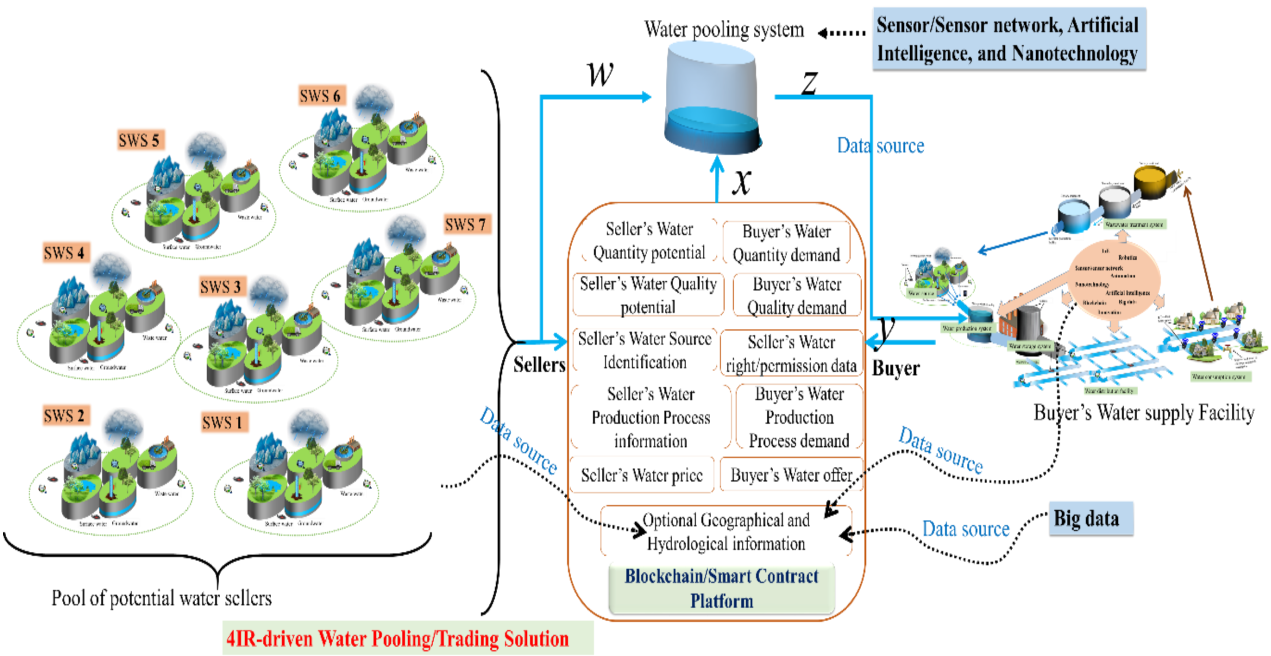


Figure 4-19 Comprehensive 4IR-enabled water resource management system.

Smart contracts will be embedded in the blockchain platform so that once the terms offered by both parties are in agreement, the contract executes and the transaction is completed. In Fig. 4.20, such a process is represented by the ***w***, ***x***, ***y***, ***z*** statements. Here the offer from the seller is represented by ***w***, the conditions presented by the buyer are denoted by ***y***, and the certification operation ***x***. Once, the offer ***w*** from the seller matches the buyer's conditions ***y***, and the certification operation ***x*** is positive, contract ***z*** is executed.

CHAPTER 5
CONCLUSION

The desk top study has attempted to reset our thinking with respect to water security. The traditional approach would be to depend on the public sector to build more capacity to collect, store, process and distribute rainfall in reponse to increasing demand. The new thinking introduced is to build new capacity in open and transparent markets. Markets will access all the available water resources. Markets will stimulate investments to package, process and distribute the water to all. Market forces, operating freely, will spur on infrastructure investments to excel under longer time horizons and greater economies of scale. The results will be read; higher volumes at lower unit prices at best quality, demand lags supply and security is assured. This chapter provides some recommendations on how to go about realizing the gains.

5.1 Stakeholder Engagement

On the 17th March 2021, the completed desk top study was presented to the South African Institute of Electrical Engineers. The meeting was held on line via the Institutes webinar platform. The exercise earned attendees a continuous professional development (CPD) accreditation from the Engineering Council of South Africa. The unaminous feedback was "innovative, creative, well presented and a subject matter that deserves further investment of time, knowledge and contributions from the public, private and academic sectors."

The engagement was hosted by the Technology, Knowledge and Leadership Committee of Council.

The engineers noted :

a. Machines can collect a tremendous volume of data; data will inform investments, maintenance, performance and other issues; data will identify patterns and insights; it is impossible for man or men to deliver similar in defined time frames.

b. Connected supply chains of all available water resources can adjust and adapt when new information is available; it can respond to system dynamics, environmental impacts or demand changes, planned or unplanned.

c. Internet of Things with Cloud Computing is characterized by connected devices and centralized data handing; physically distant and geographically distributed water resources and different types of water resources lose their physical identity and merge into the pool of data, to be merit order stacked against dispatchable criteria, whereby all the decision making is machine driven and actions are excuted automatically.

d. The potential of the model is unlimited and is evolving. The potency vests with its predictability and active positioning to take advantage of gains. Past technologies were more observer based and reactive in response. The Water Sector has opportunity to get ahead of the curve rather than wait for discruptions and disturbances.

e. Building greater connection with revenue providing customers is a strategic advantage. Improving operational performance delivers competitive advantages. IR4.0 will facilitiate and enhance both strategic and competitive advantges for early adopters.

f. IR4.0 is scale friendly. IR4.0 lends itself to a defined and clear strategy with a roadmap to set and manage benefits; to scale and pace investments at affordable rates and time frames.

g. Industrial revolutions has always been about managing demand. The first IR used water and steam to mechanise production to meet demand. The second IR used electricity to mass produce to meet demand. The third IR used electronics and information technology to automate production to meet demand. The fourth IR builds upon the third but it is transforming the entire production and delivery processs to meet demand, including governance and management of the sector and processes. It is evolving at an exponential rather than linear pace so as to keep up with the speed and dynamics of demand; it has to get ahead and ensure that supply leads demand and delivers on long term gains in efficiency and productivity. It is envisaged that the costs of trade will diminish, new investments will arise and economic growth will follow.

h. Regulation, developed in earlier revolutions, generally followed a top to down approach. Public policy and decision makers had the time to study and predict issues and to develop the necessary response or regulatory framework for their sector. In the new era of the fourth IR, the pace of change has intensified. Regulation and policy makers should embrace the change so as to remain relevant in serving customers, the public, and in upholding societal objectives and values.

5.2 Recommended Roadmap Towards Model Development of the Conceptual Note

Based on any engineering project, the process of actualizing a project starts with the virtual actualization of the project through extensive computer-based simulations and software model development. After this, the prototype of the computerized model is developed. The software model experiences and the prototype development stage will provide the required knowledge and risk analysis for the practical implementation of the project on a grand scale. We shall briefly discuss these steps and highlight the critical points in the process of realizing the implementing the 4IR-driven solution for water security.

The development process for realizing the proposed approach to addressing water security challenges is a non-linear process that will begin with the concept initialization and design parameters/variables specification and leads up to the prototype development process and the eventual project realization, as shown in Fig. 5.1.

In this report, we outline the stages of the processes that can be followed sequentially to actualize the integration of the 4IR technologies into the water supply chain and water trading opportunities. Firstly, a generalized model of a water resource management system that integrates the 4IR concepts is presented. The discussion considers in a modular fashion how different 4IR enabling technologies can be used to improve the efficiency of the respective sub-systems in the water production-supply chain. The 4IR solutions applied to each module in the build-up of the generalized model form the basis on which a good water trading model is built.

Specifically, the 4IR solutions on each module provide the basis to addresses the challenges of developing a consumer/environment/infrastructure-centric water trading model. Finally, the 4IR-driven water trading model is presented to address the challenges of information bias and the cost of developing and managing the water market.

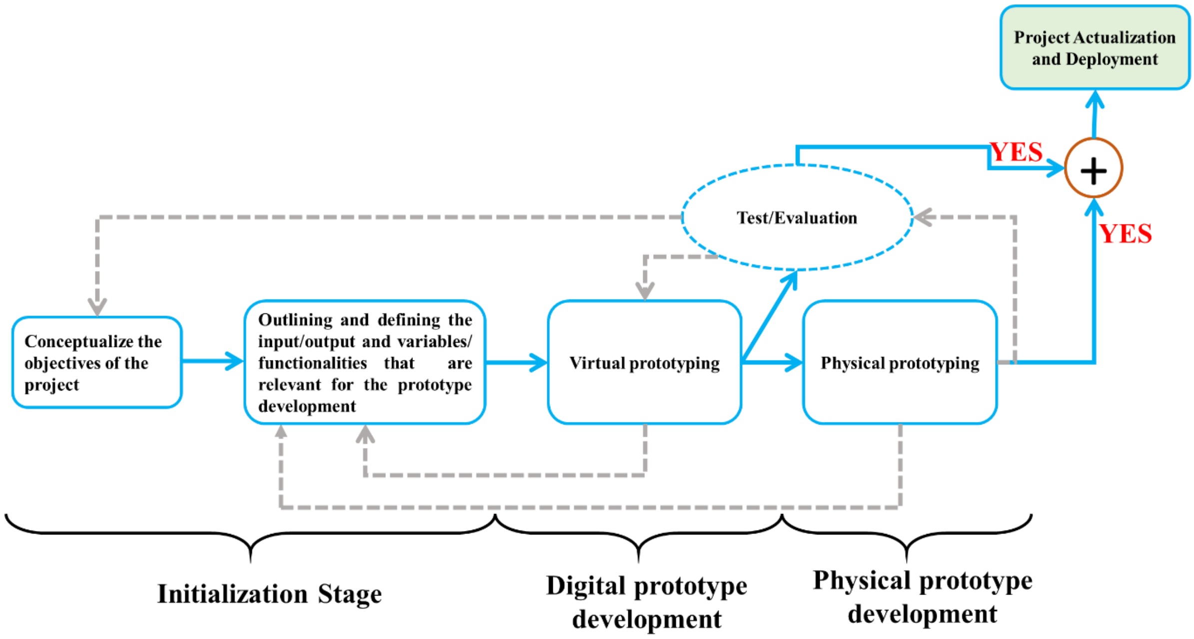


Figure 5-1 The 4IR-driven water resource management system development process.

5.2.1 Initialization Stage and Stakeholder Engagement

In this stage, the aims and objectives of the project in terms of deliverables should be made explicit. In this case, the aim to demonstrate the feasibility and possible gains of implementing the 4IR initiative to solving water security problems. The deliverables will include both physical and virtual prototypes of the project on platforms that will allow for the verification of the possibility and risk factors associated with the deployment of the 4IR solution to actual water supply and management facilities. At this stage, the decision on what inputs and the expected output, as well as other variables/ parameters, are required and indispensable for prototype development. Here, this choice will be defined by whether to go for low-fidelity or high-fidelity prototypes. Each comes at the cost of the prototyping costs, acceleration of the delivery schedule, and model reliability. One may ignore some functionality, such as response time and memory utilization unless they are relevant to the prototype's objective.

5.2.2 Digital Prototype Development Stage

Typically, prototyping, in general, is used in the product development process to verify if a proposed idea or design meets the theoretical gains and performance promises before actual production. This can be achieved by the methods of virtual prototyping and/or physical prototyping. The virtual prototyping stage involves developing a digital/soft/computerized model that serves as a preliminary platform for testing the deliverability of the promises of the product/technology to users. This is commonly an essential step in developing new products or technology given the availability of computerization resources. In the case of this project, the virtual modelling of the entire water production and supply chain will be modelled and a graphical interface provided for users to explore the proposed system in the virtual world. Technologies such as Virtual reality, digital twin, high-performance computing, and the Internet of things will play crucial roles at this stage of the project development. The various aspects of the water supply operation, namely, water sourcing/production, water storage, water distribution, water consumption, wastewater management, and water pooling/trading will be represented in the virtual model in a modular and integrated manner.

To parameterize, calibrate and validate the virtual prototype (and sensors, machine learning algorithms, etc.), many data are needed. These data include data associated with water consumption rates, average user density, water quality and quantity availability per unit time, the efficiency of facilities, maintenance cost/frequency, cost per unit of water over a duration, temperature, and pressure variations across facilities. In designing and running the virtual prototype, repeated test and validation of the system parameters and performance against a benchmark is activated. Any error that arises has to be corrected using a feedback system, where the adjustment will be carried out on some steps of the previous stages of the process.

5.2.3 Physical Prototype Development Stage

While virtual prototyping involves using existing data to produce a model that can perform numerical analysis given some inputs, physical prototyping involves the development of a physical representation of a conceptual design that can provide empirical measurement results for analysis. The success of virtual prototyping sets the stage for the development of the physical prototype. Conceptually, this stage will involve the design and development of a miniature water supply facility, the sourcing of components and equipment for the integration of the 4IR solution to the miniature water supply facility operations. The various aspects of the water supply operation, namely, water sourcing/production, water storage, water distribution, water consumption, wastewater management, water pooling/trading will be represented in the physical prototype, in a modular and integrated manner. The operation of the developed prototype will approximately indicate what the 4IR-driven water supply and management system will look like and work in real-world conditions.

In the course of the prototype design, development, and operation, testing and evaluation are conducted to confirms to the designer and other users the viability of the proposed system and to identify faults and apply corrections to improve the performance of the prototype.

5.2.4 Project Actualization and Market Development Phase

Once, the performance of the physical prototype is confirmed satisfactory, the actual development and deployment of the 4IR-driven solution for the water supply and management system commence.

Technological advances resulted in our world being forever changed. Since the dawn of man and the subsequent technological revolutions, never was there a time in human history where advancement and progress happened at such a tremendous pace as now. It is, therefore, essential that Africa embrace these changes and adopt novel technologies in an ever-more agile manner as to not be left behind.

With increasing water insecurity and the effects of climate change rapidly altering our immediate environments, we are in dire need of new ways of ensuring sustainable practices for managing our water resources. Water may very well be the commodity of the future - as such, we need to now focus on establishing the necessary infrastructure to trade this resource successfully.

5.3 Recommendations

5.3.1 Academic : Market Model Building

It is recommended that:

- Data sources should be obtained to start building a virtual model. These data should include variables pertaining to the whole value chain, from water source to wastewater management.
- Following the acquisition of data and the construction of a virtual representation of the current water management system, optimisation of this digital prototype can occur. During this optimisation process, the effects of implementing novel technological solutions can be investigated, *in silico*, to ensure their effective use.
- Based upon the digital prototype, a physical model should follow. This model can prove the effectiveness of implementing technologies before implementation at a large scale.
- Finally, implementation of the model into current systems, thus ensuring optimal efficiency of existing infrastructure while providing a pathway for further improvements.
- In all the recommendations above, the lessons learnt from the Southern African Power Pool and the Johannesburg Market should be incorporated – minimising the learning curve while speeding up the process from concept to actualisation.

5.3.2 Stakeholder Engagement

There exists four distinct stakeholders for contact, communication and deep conversations on the path forward. The four stakeholders, in order of priority, The Presidential Commission on the 4^{th} Industrial Revolution, The Department of Water and Sanitation, The Southern African Development Community and The National Voluntary Professional Societies. Recommend that we focus our initial reach out to the first two stakehoders. SADC and the National Voluntary Societies can follow.

5.3.2.1 The Presidential Commission on the 4th Industrial Revolution

The Fourth Industrial Revolution South Africa partnership (4IRSA) is the alliance between partners from the public and private sectors, academia and civil society. The 4IRSA partnership is geared to develop a fact based national response to the ideas as promoted in the desk top study report. 4IRSA is governed by a steering committee and a secretariat.

We note that the Vice Chancellor of the University of Johannesburg, Professor Tshilidzi Marwala, is a member of the Steering Committee and he is also the Deputy Chairperson of the Presidential Commission on the 4th Industrial Revolution. We recommend that, via the Office of the Dean, we forward a copy of the desk top report to our Vice Chancellor and follow through with presentations, as shared in the webinar of 17th March 2021. The intent is to seek his guidance and leadership on the next steps in migrating the "initial idea" to the next stage of development.

5.3.2.2 The Department of Water and Sanitation

The National responsibility for Water and Sanitation vests with the Ministry. The Ministry is supported by thirteen reporting entities, of which, the Water Research Commission, is one of the entities. We recommend that, via the Office of the Chief Executive of the Water Research Commission, we forward a copy of the desk top report to the Ministry and on invitation, we follow through with presentations, as shared in the webinar of 17th March 2021.

The intent will be to seek the Ministry's guidance on the next steps in migrating the "initial idea" to the next stage of development.

5.3.2.2 Emerging Questions from 4IRSA in the Drive Towards Water Security

"4IRSA is a platform that creates space for stimulating dialogue, understanding and action to shape a coherent 4IR plan for South Africa."

The following concluding remarks and questions are extracted from the Proceedings of the Inaugural 2019 Summit of 4IRSA, as Chaired by the President of South Africa. The emphasis is transferred to the Water and Sanitation sector.

" The Water and Sanitation service delivery, when unavailable, creates the greatest tension for citizens.

How can we accelerate the adoption of 4IR in the Water and Sanitation sector.
How can 4IR technologies help to accelerate public consultation processes and improve the adoption of 4IR initiatives?
How can the sector enable pockets of excellence to thirve and leverage 4IR? How can all connect into value chains and evolving ecosystems?
What special incentives and structures can South Africa create to drive the adoption of 4IR and new technologies? How will suitable zones be selected?
Which are the critical areas of infrastructure, to monitor, manage and connect all through 4IR?
How does South Africa build knowledge systems to leverage the institutional knowledge, for example, for climate change and its impact on rainfall, to respond better to changes?
What are the local consumption behaviour trends for the future, which will better inform supply side strategies that can be supported locally in a sustainable manner?
What are some of the strategies or enablers to identify opportunities to improve service delivery and to reduce the cost of wastage and environmental impacts?
What are the opportunities to promote digital modernisation of existing water and sanitation infrastructure?

How is South Africa to attract investment in new water production and sanitation processing facilities and digital trade platforms that embrace more connected interactions between consumers and investors?

What are some of the important characteristics we would like to create to grow new digital businesses in the water and sanitation sector?

What data exists to support better AI in the water and sanitation sector and how should they be governed."

END OF DESK STUDY REPORT

ASSOCIATED REPORTS of the THE DESK TOP STUDY

1. Author : Mr Jan Mocke : A Case Study of the Fresh Produce Market at the City of Johannesburg "The Joburg Market Model".
2. Author : Mr. Francis Masawi : A Case Study of the Joint Co-Operative and Competitive Market Model of the Southern African Power Pool of the Southern African Development Community " The SAPP Market Model".
3. Authors : Dr Herman Myburgh and Dr Uche Chude Okonkwo : State of Art in IR4.0 Technologies " First Design of a Conceptual Water Pool Market Model."
4. SAIEE Technology, Knowledge and Leadership Webinar of 17th March 2021 : Collection of Presentations.

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