Further evidence on the debate to shake up the South African pricing system – Implementation and assessment of a dynamic water pricing model in South Africa

Final report to the WRC

by

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Executive Summary

This is the final report for the study entitled *Further Evidence on the Debate to Shake Up the South African Water Pricing System*, a research report commissioned by the Water Research Commission (WRC). The research was undertaken by the Public and Environmental Economics Research Centre (PEERC), based at the University of Johannesburg (UJ). As the title suggests, the overall objective of the research offered a critical evaluation of the current water pricing system in South Africa with a move towards improving its overall design to be more flexible and responsive to current economic, social and environmental circumstances. This is done under the primary premise that the current pricing system might be inconducive to the changing global and national developments impacting on water as a resource, both from the demand and supply side. In economic theory, the price of a good shows the benefit consumers derive from said good and the cost of providing the good. Inefficient pricing systems can result in the poor allocation of the resource i.e., allocative inefficiency, where the pricing system does not provide the good or service to where it is needed the most.

Under this premise, the research attempted to explore innovative pricing strategies and mechanisms that better captured pressures being faced in both the demand and supply of water services. On the demand side, increased population growth, urbanisation and economic growth, and diversification have seen greater demands in the social and economic use of water both at a national and regional level. On the supply side, financing constraints, a lack of investment and poor infrastructure maintenance is applying additional pressure on the supply of water. More importantly, water resources are under increasing pressure due to climate factors and climate change, where the variability and unpredictability of short to medium-term weather patterns have resulted in water resources in traditional catchment areas and resources facing increasing scarcity issues.

Given this background, PEERC has undertaken exploratory research on mechanisms that can be used to improve the incorporation of scarcity and other demand and supply dynamics into the water management system in South Africa, particularly with regard to the allocation of water via the water pricing system. Most water management areas and water service authorities in South Africa suffer from varying degrees of water supply volatility, which is usually accompanied by temporary but frequent water shortages. Such shortages are driven by a combination of long-term and short-term factors related to the supply and demand for water, as argued above.

The incorporation of the scarcity component into the tariff-setting model has become an integral part of cyclical water demand management in some countries around the world. One of the growing mechanisms being implemented is **dynamic water pricing**. Under a dynamic water tariff regime, there are two approaches identified in the literature most commonly used to account for scarcity in the water tariff:

i. **Option 1:** Linking the tariff to the available reservoir capacity/water volume, resulting in the volumetric price increasing by an amount that would capture the increasing value

of water due to scarcity and potentially reduce current water demand to the present (and restricted) water supply

ii. **Option 2 (Seasonal Water Pricing – SWP):** The water tariff is linked to seasonal variations (summer and winter) of water supply within the year. This common strategy links the tariff to exogenous factors such as the temperature and rainfall. In this approach, a tariff adjustment factor is determined by the two climate variables: temperature and rainfall

Essentially, dynamic tariffs adjust to reflect the degree of water scarcity at a given point in time to send the signal of water supply constraints to final consumers. The adjusted tariff is expected to alter consumers behaviour to try and adjust their consumption patterns considering this scarcity in order to better balance water supply and demand. Put differently, scarcity increases the value of an available good or service and the price is the mechanism that reflects this increased value. Consumers would then adjust their usage given the increasing price (value) of water. Such a system has the advantage of embedding scarcity into the water pricing structure to proactively control consumption and ease the demand on current available water resources. This can potentially prevent instances of water authorities implementing drought tariffs and water restrictions and can also potentially avoid "day zero" scenarios driven by normal consumption patterns on a static water price leading to extreme levels of scarcity.

This project explores the possibility of incorporating dynamic water pricing principles into the water pricing model in South Africa, specifically applying the two options mentioned above to specific components of the water value chain in South Africa. The exploratory nature of the project was informed by the complexity and relative limited flexibility of the South African water industry in terms of its institutional configuration, operating practices and pricing structure. Certain practices, designs and complexities in the water sector makes it largely impossible to implement a dynamic water tariff in South Africa with immediate effect. Given this, this study aimed to achieve the following objectives:

i. Provide the theoretical rationale for a dynamic water pricing mechanism to show how scarcity increases the value of water from the supply and demand side
ii. Outline the options for designing dynamic water tariffs and how they could potentially be incorporated into the South African water value chain
iii. Simulate the potential impacts on consumer demand of a dynamic water pricing system
iv. Outline the current constraints in the South African water industry that limits the possibility of implementing dynamic water tariffs
v. Propose potential areas to improve various aspects of the South African water value chain towards the potentially implementation dynamic water pricing in the long term

Given the various objectives of the study, we adopted a suite of qualitative and quantitative methodologies. These are outlined as follows relative to the research objective that needed to be achieved:

i. A critical assessment of the water value chain in South Africa to determine the feasibility of implementing dynamic water tariffs across all or some of its components – The primary method used to achieve this objective was qualitative analysis in the form of focus group discussions with stakeholders across the water value chain
ii. Design and implementation of dynamic water tariffs linked to the volume of available water at the water source for raw water tariffs – Development of a comprehensive *Water Allocation Model* to design and simulate raw water tariffs using the Mdloti River scheme (Hazelmere Dam) as a case study
iii. An assessment of the current pricing model and water demand estimations in order to determine the potential reactions of consumers to dynamic water pricing – Conventional and Stone Geary demand functions using data from the 2014/15 living standards survey
iv. Implementation of the SWP using the City of Tshwane as a case study – a proposed SWP methodology was applied using information sourced directly from the City of Tshwane and climate variables sourced from WeatherSA

In general, the study concluded that it would prove very difficult to fully implement dynamic water pricing in South Africa, given the current configuration, practices, and operations at different levels of the water value chain. Nonetheless, the research achieved the following objectives:

i. Showed the theoretical rationale for a dynamic water pricing system
ii. Outlined the options of implementing a dynamic water pricing system
iii. Critically outlined the water value chain in South Africa and explored the scope of implementing dynamic water pricing within the current configuration of the industry
iv. Undertook simulations to show the potential operation of dynamic water pricing and its potential impact on water supply and demand
v. Proposed amendments to certain aspects of the South African value chain to allow for the implementation of dynamic pricing

Some of the key findings of this report are summarised as follows:

i. Our analysis shows that the current water pricing system in South Africa, be it from a raw, bulk or retail water tariff, does not explicitly or implicitly incorporate issues of scarcity in its design, in terms of either:
    a. Scarcity linked to available water resources at a given location and point in time
    b. Scarcity that is seasonal, i.e., at times of low rainfall (or high temperature)
ii. Econometric analysis showed that consumer water demand is positively impacted by higher temperatures and lower rainfall, thus suggesting a greater demand (and increased pressure on water supply) during these periods of the year
iii. A pricing system that does not incorporate aspects of scarcity can contribute to deviations from the supply and demand of water, putting pressure on water supplies

iv. The prices of raw, bulk and retail water are static, i.e. it does not change during a financial (or calendar) year. This makes it difficult to account for supply and demand changes or shocks during the year

v. Legislation, specifically the Water Services Act, allows for drought and seasonal tariffs, thus empowering water authorities to adjust tariffs to control for demand and supply fluctuations

vi. To date, drought tariffs have been implemented, but these are a short-term "crisis" driven approach to controlling water demand as a last resort. Dynamic water tariffs, whether directly linked to water supply or seasonal, intend to embed the notion of water scarcity in the consumer and create a culture that can ultimately influence short- and long-run water demand and supply

vii. Our analysis shows that embedding a dynamic price into the South African water system is most efficient and accurate using the option that links the price to the actual volume of water available, as opposed to embedding deviations of climate change variables in the price system
    a. However, this option cannot be implemented at the bulk water (water boards) or retail water (municipal) levels
        i. Water boards do not serve all municipalities, as some municipalities treat their own raw water
        ii. Municipalities use several sources for bulk water
        iii. The reservoirs at the municipal level are complex, serving different areas. It will be difficult to monitor these reservoirs without investment in systems and technologies
        iv. One would need to implement dynamic pricing linked to the water source through the use of smart water meters to adjust the price relative to the volume of water available. This will result in significant investments at the municipal level

viii. From our analysis, it is most feasible for dynamic pricing to be implemented at the raw water level. This conclusion was reached based on:
    a. It covers most of the water use in the country. Municipalities only account for 22% of total water use in the country
    b. Raw water sold to municipal customers can make its way to the final customer through the pricing system

ix. However, the current state of raw water allocation and billing makes it difficult to implement dynamic pricing. Some of these issues are:
    a. The current practice of allocating water resources prioritises equity over efficiency. It is difficult to determine whether current allocations are efficient and reaching the customers who need it the most
    b. While there are systems in place to monitor dam levels, linking such levels to the price of raw water can be problematic, as there are currently limited methods to monitor raw water consumption in water users. Currently, there are no meters monitoring raw water use across a large proportion of raw water users
    c. Water billing would need to be done monthly, which is not the case for a certain category of users

d. The inability to register raw water users and monitor raw water usage is a major concern and a major detriment to the efficient allocation of water and the implementation of dynamic pricing. Without such information, it is not possible to determine the value users place on water

x. Our analysis shows that option 2 for implementing dynamic tariffs, i.e., embedding deviations in climate variables in the price, is a feasible and easy-to-implement option. It is also legally allowed and should impact on easing supply during times of potential water supply shortages

   a. This option can be easily implemented at the raw, bulk and retail water levels and can be a feasible option to proactively control water demand during periods of low rainfall and avoid stringent measures such as water restrictions and drought tariffs

Water drought tariffs are currently being implemented in South Africa to curb short-run water shortages in certain parts of the country, driven at the bulk water level by water boards. While there are provisions for water drought tariffs in the legislative and institutional framework of the country, the relative proliferation of its use shows an increasing need to control water consumption on the demand side in the face of water supply constraints driven by climate issues. Given these developments, there is clearly a need for such a dynamic price system to be institutionalised in the South African water sector. However, the current institutional setup in the water market was not fully designed for the implementation of demand side controls using the price mechanism. This is due to the system being designed at a time when there was no imperative need to control water use. Therefore, the finding of this project intends to introduce the concept of dynamic water pricing into the debate on South Africa's water pricing framework.

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iii. Dr Jackie Crafford – Prime Africa
iv. Mr Rajiv Paladh – Bosch Capital

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Contents

1. Introduction

1.1. Background

Defining water as a good or service is complex. Unlike most other goods and services, water is essential for human survival in that all living organisms require a minimum level of water to live. However, water is also an economic good that is used to satisfy human wants and is used in the production of other goods and services. The development of mechanisms for the allocation and pricing of water needs to effectively account for these competing objectives of water use. This economic problem is further exacerbated by water being a scarce resource and, like other goods, such scarcity needs to be reflected in its value.

South Africa's management of water through its allocation and pricing mechanisms has tried to balance these competing needs for water. This is done through its complex water value chain, where raw water resources are managed by national government and the provision of potable water is within the constitutional ambit of local government. The allocation of water resources, which is regulated by the National Water Act (NWA or the Act) 36 of 1998, promotes the equitable access to water towards economic and social development while simultaneously ensuring that the basic human needs for water and protection of water resources are guaranteed through the water reserve. The financing of the management of water resources is implemented through a raw water pricing strategy and is charged retrospectively to all users of raw water. The Water Services Act of 1997 establishes water boards and water services authorities (WSAs), the latter of which are usually municipalities, to treat raw water towards the provision of potable water services. These entities recover the costs of these services through bulk water tariffs and municipal tariffs, which is charged to the final consumers of water services.

1.2. Problem Statement

Given the importance of water for human and economic needs, as highlighted above, the allocation and pricing mechanisms that government attempts to implement essentially balance the goals of social equity and economic efficiency towards the sustainable use and development of water resources. However, such mechanisms also need to be flexible to supply side issues driven by changing natural, social, economic and political circumstances. One such circumstance is climate change and consequent increased pressure on water resources. Many developed and developing countries are facing significant constraints on water supplies that will continue over the coming decades, considering projected climate change impacts (Dharmaratna & Harris, 2010). Climate change and the prevalent water scarcity challenges currently plaguing the world have brought water debates concerning sustainability and efficiency of the pricing (and allocation) model to the forefront (Cole, 2004). Water policymakers are faced with the situation where they need to set cost-reflective tariffs, address equity, meet increasing demand, and manage water supply in the face of these challenges of climate change and the sustainability of water resources.

The nature and impacts of climate change are complex but is usually characterised by a general increase in the Earth's average temperature (Sukhanya and Joseph, 2023). Such rising temperatures can have a significant adverse effect on the short- and long-term availability of water due to extreme and unpredictable weather events such as heavy rains and severe droughts and a general variation in temperatures and rainfall patterns from their long-term averages (Lu *et al*, 2019). The impact of climate change is more pronounced in countries that are naturally water scarce, such as South Africa. Given these challenges emanating from the growing impact of climate change, water decision-makers in the country that are responsible for setting tariffs face the challenge of incorporating climate change and general issues of scarcity into the water pricing model. This now adds an additional dimension to water pricing objectives. Currently, at the raw water level, the water charges tend to recover the costs associated with water resources management and water resource infrastructure, amongst others, (Department of Water Affairs and Sanitation, 2022) while the increasing block tariff (IBT) pricing mechanism has been adopted at the municipal level for potable water to strike a balance between these varied water policy goals (Schreiner, 2015: Anstey, 2013).

The IBT structure, which is also predominantly applied for final water users in many countries around the world, is frequently supported as a good tool for achieving the goals of equity, water conservation and revenue neutrality. The IBT increases the price of water relative to greater use, thus intending to send the signal of greater value of water with higher levels of consumption. This can potentially discourage higher levels of water consumption when the additional cost of a unit of water exceeds the value a consumer places on its use. For this to work, though, the marginal cost of water needs to accurately reflect its scarcity and the concomitant marginal benefit consumers receive at higher levels of consumption. If marginal costs are lower at higher levels of consumption, this can result in over consumption. As a result, the design and the ability of this mechanism to incorporate the climatic change aspect and reflect it into the price to send a water scarcity signal to consumers is currently remains under scrutiny.

Given the discussions above, it is important that the water pricing system effectively accounts for the scarcity of water and sends the appropriate signals to consumers when the water supply is under pressure. While climate change and its consequences are a growing feature of water supply issues, other factors can also impact the short- and long-term availability of water. This can include inadequate investments in new water resources and services infrastructure and poor infrastructure maintenance. In addition, water demand also puts pressure on available water resources. Population growth, urbanisation, economic growth and industrialisation can all change the dynamics of water demand, resulting in a growing imbalance between water demand and available supply. In the face of these challenges, the key to an efficient and effective water pricing system is to contribute to maintaining an appropriate balance between the demand and the supply of water at different time periods across the short, medium and long term.

1.3. Objectives of the Project

Given this background, PEERC has undertaken exploratory research on mechanisms that can be used to improve the incorporation of scarcity into the water management system in South Africa, particularly with regards to the allocation of water via the water pricing system. Most water management areas (WMAs) and WSAs in South Africa suffer from varying degrees of water supply volatility, which is usually accompanied by temporary but frequent water shortages. Such shortages are driven by a combination of long-term and short-term factors related to the supply and demand for water, as argued above. In terms of the former, insufficient planning, infrastructure investment and climate change are some of the long-term factors impacting on water supply, while poor infrastructure maintenance, water leakages and short-term climate variation and extremities can also impact short-term water supply.

In terms of water demand, an embedded culture of excessive water consumption for both domestic and economic purposes in a society, a growing population and varying structural changes (or lack thereof) in the economy can put pressure on the long-term supply of water. In addition, inefficient pricing policies can also promote excessive usage in the short term and can also contribute to a culture of excessive water use in the long term, if domestic and non-domestic water consumers do not adjust their economic decisions to consider the true value of water. Therefore, it is important to consider the possibility of incorporating issues of climate change and general scarcity aspects into the water pricing system in South Africa in order to send the signal of the true value of water to consumers at any given point in time.

The incorporation of the scarcity component into the tariff-setting model has become an integral part of cyclical water demand management in most developed countries. One of the growing mechanisms being implemented internationally (USA, Australia, UK) is what is called dynamic water pricing. Under a dynamic water tariff regime, there are two approaches identified in the literature most commonly used to account for scarcity in the water tariff:

i. **Option 1:** Linking the tariff to the available reservoir capacity/water volume resulting in the volumetric price increasing by an amount that would capture the increasing value of water due to scarcity and potentially reduce current water demand to the present (and restricted) water supply (Quentin and Kopmans, 2007; Grafton, Chu, Kompas, & Ward, 2015; Grafton, Chu & Wyrwoll, 2020; Chu & Grafton; 2021).
ii. **Option 2:** The water tariff is linked to seasonal variations (summer and winter) of water supply within the year. This common strategy links the tariff to exogenous factors such as the temperature and rainfall. In this approach, a tariff adjustment factor is determined by the two climate variables: temperature and rainfall (Ernst and Young, 1994; Griffin, 2006; Herrington, 1999; Munasinghe, 2019; Pesic et al, 2012; Ioslovich and Gutman, 2001).

Essentially, dynamic tariffs adjust to reflect the degree of water scarcity at a given point in time to send the signal of water supply constraints to final consumers. The adjusted tariff is expected to alter consumers' behaviour to try and adjust their consumption patterns, considering this scarcity in order to better balance water supply and demand. Put differently, scarcity increases the value of an available good or service and the price is the mechanism that reflects this increased value. Consumers would then adjust their usage given the increasing price (value) of water. Such a system has the advantage of embedding scarcity into the water pricing structure to proactively control consumption and ease the demand on current available water resources.

This can potentially prevent instances of water authorities implementing drought tariffs and water restrictions and can also potentially avoid "day zero" scenarios driven by normal consumption patterns on a static water price, leading to extreme levels of scarcity.

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i. Provide the theoretical rationale for a dynamic water pricing mechanism to show how scarcity increases the value of water from the supply and demand side
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iv. Outline the current constraints in the South African water industry that limit the possibility of implementing dynamic water tariffs
v. Propose potential areas to improve various aspects of the South African water value chain towards the potential implementation of dynamic water pricing in the long term

1.4. Feedback from Reference Group Meetings and National Workshop

The development of this research occurred through the WRC processes and was evaluated and guided by the Reference Group established for this project. During the course of the project, the research evolved from its initial conception based on the inputs from the Reference Group. Some of the fundamental changes incorporated were as follows:

i. The potential implementation of dynamic water pricing should ideally be considered at the raw water level: Initially, the project intended to look at water services and the exploration of dynamic water pricing at the municipal level. However, the Reference Group suggested that raw water pricing should also be considered
ii. Related to the above, the Reference Group also suggested a brief review of the raw water allocation process in South Africa: The argument was made that the process of raw water allocation and the fundamentals that guide it are possibly not reflective of the contemporary dynamics of supply-side challenges, such as water scarcity driven by climate change. The potential application of dynamic water pricing cannot be implemented without a review of the raw water allocation process
iii. The research should be exploratory and provide a "first step" towards the consideration of dynamic water pricing in the South African water sector. The current institutional and economic configuration of the water industry will likely not support the immediate implementation of dynamic water pricing. However, the research should focus on the

potential benefits of such a concept and the changes that would be required to the current South African water system to potentially effect dynamic water pricing

1.5. Developments from Previous Deliverables

The research was undertaken via eight deliverables. The scope of these deliverables was adjusted from their initial conception in the proposal, given the changes proposed by the Reference group. The revised deliverables and their objectives are outlined as follows:

i. **Deliverable 1: Inception report and study design** – The inception report conceptualised the study by undertaking a comprehensive literature review that provided the theoretical basis for dynamic pricing in the water sector, as well as practical examples of its implementation using international case studies
ii. **Deliverable 2: Data collection** – Deliverable 2 constituted the data collection phase required to undertake a review of the current water pricing system in South Africa and assess its sensitivity to issues of scarcity and environmental factors, such as climate variables.
iii. **Deliverable 3: Review of the current pricing model –** Deliverable 3 undertook a crucial assessment of the current municipal water tariffs to assess their flexibility in dealing with scarcity and issues of climate change. It is important to emphasise here that the focus was primarily on potable (municipal) water tariffs. It was concluded that the current IBT structure[1] that is applied in most municipalities (WSAs) across the country does not send a scarcity signal to water consumers at times of low water supply levels. Furthermore, the results from this analysis showed that water demand is significantly impacted by climate variables that impact water scarcity, such as high temperatures and low precipitation, thus indicating limited variation in the price to show scarcity or to account for climate factors that may impact water supply. This leads to instances where water authorities must be reactive and implement non-price and price (e.g., drought tariffs) to curb water demand.
iv. **Deliverable 4: Options for designing dynamic water tariffs –** This deliverable outlined, in detail, the two options for incorporating dynamic pricing. This was linking the price to existing volumes of available water at a water resource (dam or reservoir) or incorporating variations in scarcity or climate variables (such as temperature and precipitation) in the price mechanism
v. **Deliverable 5: Retail water (municipal) case study/pilot of dynamic pricing** – This deliverable attempted to design dynamic tariffs for the South African water sector and apply such a design to a case study municipality (pilot). It was during this phase of the project that it was concluded that the application of dynamic water tariffs was more feasible at the raw water level, as opposed to the municipal retail tariff. In this phase, the project team engaged with the City of Tshwane and obtained important data regarding the supply of bulk treated water to the municipality, the configuration of the

[1] This refers to the general design of the IBT structure applied in South Africa in normal operating instances and does not refer to special circumstances where prices are hiked to control water demand in the face of severely constrained water supply and droughts.

municipal water distribution network and the municipal retail pricing structure. This deliverable concluded that the implementation of Option 1 of the dynamic water pricing structure (linking the price of water to available capacity at a water resource) is not possible to implement at the municipal level due to a range of complexities. However, Option 2 (the incorporation of climate and scarcity variables into the pricing structure) is possible and should be considered by WSAs.

vi. **Deliverable 6: Raw water pilot of dynamic pricing** – the evolution of the project towards the raw water level saw a change in deliverable 6. In this deliverable, the project team explored the data requirements to test dynamic pricing at the raw water level. The results found that the current inability of the Department of Water and Sanitation to track water users and water use at the raw water level makes it difficult to estimate raw water demand functions and the benefits raw water users derive from water use. One cannot assess the benefit that raw water users attach to water use without actual consumption data. In order to effectively design dynamic water tariffs, one would need to determine the marginal benefit each raw water user attaches to water use in order to adjust the tariff accordingly. Given this, the implementation of dynamic raw water tariffs will be difficult. However, this deliverable critically assesses the theoretical fundamentals of raw water allocation and **develops an exciting new water allocation model** that is able to determine raw water demand functions and the marginal benefit each user attaches to raw water use. This model can be implemented if and when better raw water use data becomes available.

vii. **Deliverable 7: Institutional options for implementation and acceptability of the dynamic water pricing concept** – This deliverable constituted focus group discussions with the Department and municipalities to discuss the merits of dynamic tariffs and some of the institutional constraints to implementing dynamic water tariffs

viii. **Deliverable 8: National workshop** – the results of the deliverables 1-7 were presented at a national workshop to ascertain stakeholder input towards the finalisation of the research. The workshop was attended by over 50 participants from all sectors of the water industry, including the DWS, water boards and the South African Local Government Association (SALGA). Explicit feedback was received from the DWS, the Department of Cooperative Governance (DCoG), National Treasury and SALGA on the dynamic water pricing concept, while valuable feedback was also received from other participants of the workshop. In general, there was support for the dynamic water pricing concept and its benefits were clearly acknowledged. The workshop called for further research towards the potential implementation of the concept in South Africa. A workshop report was submitted to the WRC.

1.6. Objectives and Outline of the Final Report

This report constitutes the final deliverable on the project entitled *Further Evidence on the Debate to Shake Up the South African Water Pricing System*. It is a culmination and summary of the deliverables outlined in 1.5 and is presented as follows:

i. **Section 1** presented the background, problem statement, rationale for the study and the outline of the research process

ii. **Section 2** presents the theoretical framework for dynamic water pricing
iii. **Section 3** offers a brief review of previous empirical literature relating to various applications and assessments of the dynamic water pricing concept
iv. **Section 4** outlines the two options for dynamic water pricing that will be explored for South Africa
v. **Section 5** provides an overview of the methodologies used for the various research questions and objectives, particularly on implementing dynamic water pricing on the respective case studies
vi. **Section 6** briefly discusses the South African water value chain and critically assesses each component of this value chain towards the possible implementation of the two options for dynamic water pricing at each stage
vii. **Section 7** presents the results of the analysis, where we design and simulate dynamic raw water and retail water tariffs and their potential impact on customers
viii. **Section 8** concludes the paper with a summary of the key findings and provides a way forward emanating from the research

1.7. Links to WRC Aims and Research Objectives

This project is intended to assess the performance of the current water pricing model in South Africa in terms of its sensitivity to water supply issues, such as general scarcity and climate-related variables. The primary argument of the research is that a dynamic water tariff applied across or at specific components of the water value chain that embeds scarcity into its design will be a more efficient and effective water pricing model to deal with current demand and supply challenges. This revised water-pricing model would send the right signal for water scarcity and provide significant incentives to consumers to save water and enhance environmental conservation, amongst other benefits. Moreover, the dynamic pricing model should improve the cost-recovery aspect and promote financial sustainability within the sector.

The dynamic water pricing model, relative to the current static pricing model, is proposed to improve the ability to balance short- and long-term water demand and supply. The alternative water pricing system should also contribute to an improved ability to balance the competing needs of water pricing principles. The desired outcomes of this project uphold the WRC Knowledge Tree, which provides the fundamental guiding framework for the outcomes and impacts of WRC research in the policy, social and economic arenas. The project outcome fits several pillars of the WRC Knowledge Tree, such as the transformation and re-dress pillar, as it intends to induce behavioural change in consumers and the water pricing system to promote greater equity and protection of future generations through efficient water use. The sustainable development solutions pillar is at the core of this project, as well, as it is designed to provide solutions to water conservation (environmental sustainability) and cost recovery (financial sustainability). The project and its outputs also result in new products and services for economic development, as we have developed and will disseminate a *Water Allocation Model* that can be used to determine raw water benefit for each water user.

2. Theoretical Fundamentals of Dynamic Water Pricing

Dynamic water pricing is an approach that includes seasonal water scarcity and dynamic connections between present and future consumption of water. It provides an effective tool for conserving water resources and ensures that the water supply is able to satisfy peak-season demand (Molinos-Senante, 2014; Pesic et al., 2012; Sallam, 2015). Dynamic water pricing can encourage investment in water conservation technology in response to increased climate uncertainty (Bhaduri & Manna, 2014). In order to realise such benefits from dynamic water pricing, one is required to equate, as best as possible, the relative marginal benefit each user receives from water consumption to the marginal cost of water, with the latter incorporating scarcity and water supply issues.

The incorporation of the present and future scarcity of water in its price can be achieved and implemented with the determination of the risk-adjusted user cost (RAUC) of water. The RAUC is the component in the cost of water supply that represents the scarcity of water while considering possible realisations of uncertain future outcomes. In other words, it is the implicit and intertemporal (across different time periods) cost of supplying water when water consumption in the present poses a risk of causing water scarcity in the future. Dynamic prices aim to enhance water use efficiency because they reflect real-time variations of water supply costs and incentivise water conservation among customers. Several time-varying factors influence water supply costs, including demand peaks, demand trends, water scarcity, and opportunity costs related to alternative human and ecosystem-related water uses (Brelsford & Abbott, 2017). In principle, dynamic pricing could help better consider these factors and help manage residential water demand (Rougé et al. 2018). In particular, increasing water prices during scarcity scenarios could send end users a signal on water value, leading to a decrease in demand and more efficient water allocation across time and among uses (Pulido-Velazquez et al. 2008). Grafton *et al*. (2020) confirm dynamic water pricing as a key tool to manage the growing uncertainty of future water demand and supply. Essentially, dynamic water pricing extends current water tariffs to account for the long-term interest of water consumers by increasing the water price to account for scarcity of water in different periods, providing signals to efficient water capacity expansion and accounting for the future value of in situ water in current consumption decisions.

2.1. The Economic Value and Opportunity Cost of Water Use

Water, like most economic goods, has a value linked to the demand and supply of the good. This is given by the price of the good that reflects its economic value that economic agents (consumers and producers) place on said good. However, Grafton *et al* (2020) explained the paradox of water pricing, stating that the price of water almost never equals its value and rarely covers its cost. Harou *et al*. (2009) point out that traditional "engineering" models used to determine infrastructure rollout focused on water values that are "fixed" or "static", in other words, the value placed on water by consumers at present. Essentially, the demand for water is defined narrowly based on existing "water rights, priorities and projections of population growth and agricultural and industrial water requirements" (Horou *et al*., 2009: 628). As such, this "static" notion of water has resulted in an oversupply of infrastructure and a water system that is slow to adapt to new conditions, such as climate change or other factors that drive water scarcity.

The economic value of water should capture the rising costs of supplies, new technologies, conflict between users of water and general water scarcity problems, as it changes with concomitant changes in such conditions. The economic monetisation of water use would capture these varying dynamic demands and supply factors and provide a basis to compare the water usage between different water uses and users. Building on the issue of the economic value and monetisation of water, the SmartH2O project (2017) introduces the concept of marginal resource opportunity cost (MROC) of water as a measure of the value of water. This is defined as "the benefit foregone by not allocating an additional unit of water introduced to its most productive use" (SmartH20, 2017: 8). The use of the MROC captures the relationship between scarcity and choice (SmartH2O, 2017). In the face of scarcity, one cannot satisfy all the needs of water in society; as such, the MROC measures the efficiency of the allocation of a scarce resource by ensuring that the user or use that benefits most from water use receives relatively more of the limited water supply. The MROC measure extends the issue of RAUC by applying a cost/price to the use of water. Theoretically, the MROC should be the same across all users of water through the equi-marginal principle. However, this does not apply in reality, given the several, sometimes competing, goals of water pricing (Lopez-Nicolas *et al*, 2018).

The MROC value of water has several defining specifications. It is measured at a specific point in time and space, as water scarcity is both impacted by time and space. The MROC of water is best captured at a reservoir or places where water is stored. This is due to a reservoir being able to determine the best use of water for immediate purposes and for future purposes. For example, it might be more efficient to save water at the current moment for future use, as the future use of the water is deemed more productive. Therefore, pricing water at the MROC will capture all these dynamics and provide the proper value of water relative to scarcity and other demand and supply dynamics. In conclusion, the value of water is likely to change (is dynamic), as the factors that influence its value change. In instances of water scarcity, the value of water increases, as the MROC becomes higher for the amount of water redirected to less productive use. In other words, there is now a higher cost of providing limited water to users or uses that are relatively less productive from both an economic and social perspective.

2.2. The Risk-Adjusted User Cost (RAUC)

A concept linked to the MROC is the RAUC of water. The RAUC looks specifically at the time dimension of current water use by measuring its risk impact on the welfare of future water consumption. In formalising a model for RAUC, one can essentially obtain the variables that one would need to consider when setting water prices. Such a model is given in Equation 1 below:

$$S_{t+1} = \min[I_t + \in_t - h_t - L_t + S_t, S^{cap}] \quad (1)$$

Where:

I_t = expected inflow of (usable) water into storage in time t
$\in_t$ = the uncertainty in future water inflows that is unknown at the time of decision-making in time t
h_t = the volume of water extracted by water users in time t
L_t = water losses
S_t = the storage level in time t
S^{cap} = the storage capacity.

Equation 1 specifies that the change in dam storage (difference between water storage in the future, t+1, with current storage, t) is the difference between inflow and abstraction (with water losses, i.e. L_t e.g. evaporation) and spillover of dams. When setting water prices, one needs to consider the dam level (S_t) and the explicit cost of water supply, such as the costs of catchment management, water distribution, sewage treatment and the cost of pumping. In addition, the price should also include implicit costs, i.e. opportunity costs, such as water abstractions, water quality and water availability (Grafton, Chu & Crawford, 2020).

2.3. Determining the Economic Value of Water

Most authors agree that determining the value of water (through its price or MROC) is difficult, as water markets are usually not fully functional or efficient. As such, the efficient value of water, which captures the dynamics of scarcity, can be determined through hydro-economic modelling. Hydro-economic modelling (HEM) can be defined as "the science of determining the variations of the value of water in space and time" (SmartH20, 2071: 9). Computing the efficient value of water improves the efficient management of water by linking scarcity to the value of water and the demand for water with the price of water. There are essentially two ways of assessing the value of water:

1) Use of an optimisation model to determine the value of water at optimal water management conditions and water use
2) Simulation model looking at current water management conditions

HEMs constitute useful instruments to assess water-resource management and inform water policy. In the last decade, HEMs have achieved significant advances regarding the assessment of the impacts of water-policy instruments at a river basin or catchment level in the context of climate change (Expósito et al., 2020).

Furthermore, integrated HEMs aim to capture the complexity of interactions between water and the economy (Brouwer & Hofkes, 2008). Population growth and economic development constitute the main forces behind processes such as irrigation expansion, urbanisation, and industrialisation, all of which trigger increasing water demands (Vörösmarty et al., 2000; Chapagain et al., 2004; Gerten et al., 2011; D'Odorico et al., 2014). Climate change may act as an amplifier of these impacts on water resources (Berbel et al., 2020). Water scarcity also constitutes an economic problem and has become a serious limitation for socio-economic development worldwide (Damania et al., 2017). The gap between water demand and supply capacity that exists in many parts of the world leads to higher competition between alternative uses (and between economic and social sectors). Water scarcity and extreme climate events exacerbate this competition for water resources and generate negative social and economic impacts, which need to be considered to guarantee the sustainable management of water-resource systems. Understanding the allocation of water in catchments (or river basins) and its impacts in economic and hydrological dimensions is crucial in this context (Olmstead, 2014).

Hydrological and economic tools have been commonly used to model hydrological and socio-economic interactions to assess the impacts of certain policy measures in specific hydrological and climatic contexts (Alamanos et al., 2019). At the policy level, the use of integrated multi-disciplinary methods (e.g., hydrology, engineering, and economics) to support water decision-making has been promoted for the assessment and development of sustainable water-management strategies in integrated water-resource management (IWRM) (Booker, 1995; Booker et al., 2012; Expósito et al., 2020). One example is the paradigm shift represented by the EU Water Framework Directive (WFD) that imposes the use of economic science, including the use of scenarios in the characterisation of water uses (Art 5) and the consideration of economic instruments to reach sustainability goals (Art 4 and Art 9) [EU, 2008]. In line with this reasoning, HEMs have been widely used by academics and policymakers in recent decades.

Moreover, in designing an alternate water-pricing model based on dynamic pricing principles, one needs to represent the first comprehensive life cycle modelling of potable water systems (Sahin, Siems, Stewart and Porter, 2016). This would represent the interconnected feedback loops in tariff structures; demand levels and financing capacity being included in the HEMs model design. Moreover, in designing a dynamic water pricing, a hydro-economic simulation model (HESM) are also considered. HESMs are often based on simulation techniques to predict the water level and, combined with economic models estimating the water demand, are used to predict the price. The HESM links the marginal value of water, which reflects water scarcity given its competing uses, to water supply reservoir levels. Thus, varying reservoir levels trigger variations in the pricing model.

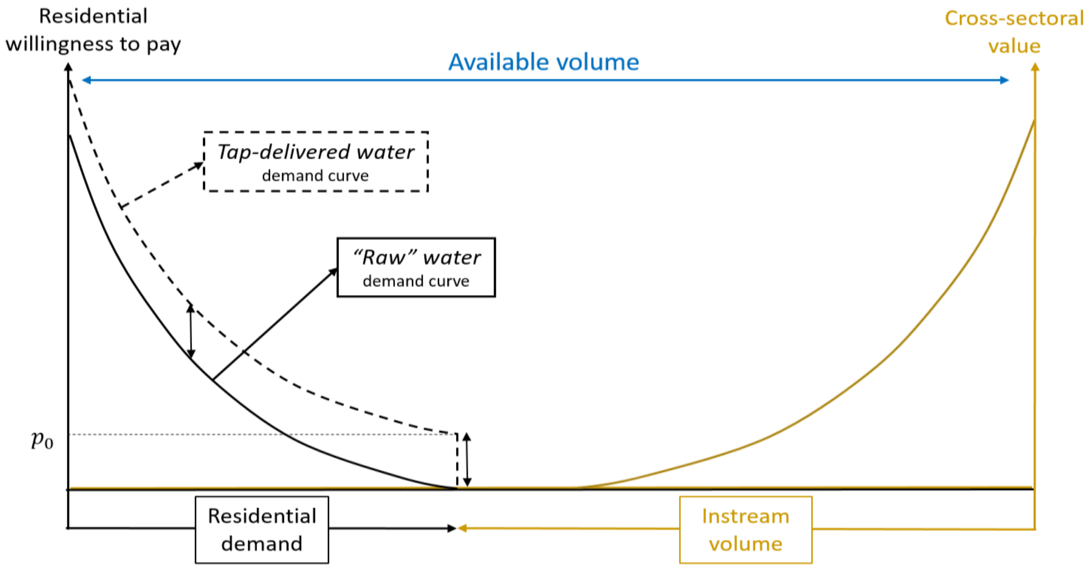
The discussions above confirm that, theoretically, the price of water (the water tariff) is a key mechanism that shows the benefit users derive from water use and the cost of providing such water and the availability of water. Therefore, dynamic water pricing needs to consistently reflect the changing demand and supply factors that reflect water's value at a given point in time and space. This integrated supply-demand system for water value is complex and HEMs, amongst other methods, are required to appropriately estimate key concepts of marginal benefit, willingness to pay, MROC and RAUC, amongst others, to appropriately design dynamic water tariffs.

2.4. The Impact of Dynamic Pricing During Scarcity

The discussions thus far explained the notion of water value that captures the intertemporal use of water and water scarcity and supply factors indicated by available reservoir levels. This is given by the concepts of marginal benefit, marginal cost, willingness to pay, MROC and RAUC, amongst others, that capture these various demand and supply dynamics. The discussions also explained how HESMs and related models could be used to determine the value of water towards a dynamic water pricing structure. This section explains the impact of a proposed dynamic water price on consumer behaviour.

The impact of dynamic pricing on consumer behaviour and water utilities depends on the nature of the demand for water and the price elasticity of water (the sensitivity of consumption to a price change). Figure 1 shows the demand for water from residential customers (left-hand side demand curve) and non-residential customers (right-hand side demand curve), the latter of which would include water use for agricultural, industrial, and other purposes. Residential demand is divided into demand for raw, i.e., untreated water and "tap-delivered" water i.e., treated water, which would include the cost of treating such water. In Figure 1, there is no water scarcity problem. The water price is given as p_0, where the price of water is simply the average cost for a delivering water utility.

Figure 1: Water Pricing with No Scarcity

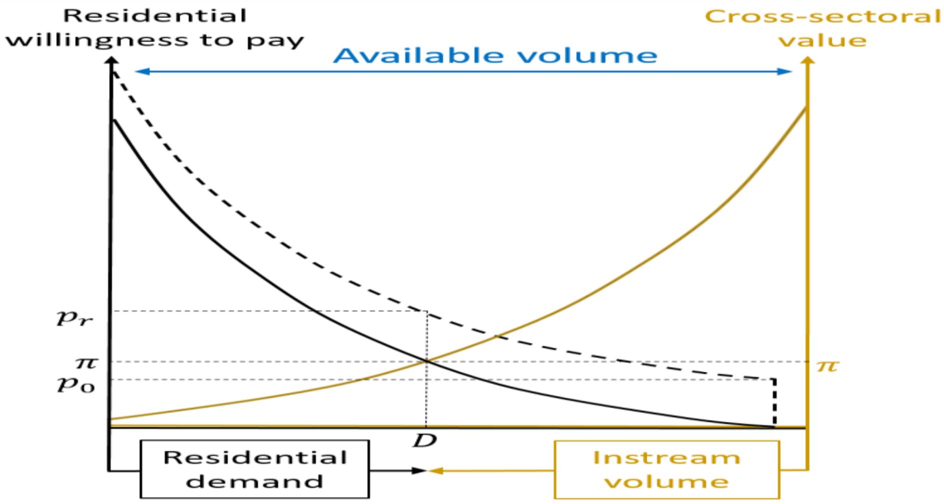


Source: SmartH20 (2017)

Figure 2 introduces water scarcity to the residential and non-residential demand for water scenario in Figure 1. This introduces a competition for water due to water scarcity, which increases the value of water. The optimal allocation is given at price π, where both demand curves intersect. Residential customers will thus pay $p_0 + \pi$ at p_r i.e., the average cost of producing water plus the increase in its value due to scarcity. Dynamic pricing would thus reflect changes in the scarcity level that increase the value of water and would ultimately impact the final price paid.

In Figure 1, the raw water available is meeting the full demand of both the residential and non-residential users. This shows the respective demand curves flattening out and meeting at their end. Every consumer "demanding" on this curve is receiving water. One can contrast this with Figure 2, when the water resource is scarce. In this case, the two demand curves now intersect, showing competition for the good being supplied, in this case, water. Customers below the price line are not receiving water, as the price of the good outweighs the benefit they receive (or it is too expensive to purchase). The efficient allocation of the scarce water between the customers is given by the intersection of both demand curves. At this point, the relative water allocation matches the respective value placed on the good by both types of customers.

Figure 2: Water Pricing with Scarcity



Source: SmartH20 (2017)

Figure 2 is very important for our subsequent analysis of the potential implementation of dynamic water pricing at the raw water level. Indeed, the *Water Allocation Model* developed for the analysis uses the concept described above to determine the “efficient” allocation of water use and the marginal benefit each consumer derives from such water use to design dynamic water tariffs at the raw water level. This is done by estimating demand curves for respective water users within a given water catchment area or using a specific water resource.

2.5. Theoretical Benefits of Dynamic Water Pricing

From the theoretical presentation of dynamic pricing in the preceding sections, the goal of the pricing system to, as instantly as possible, to equate the marginal benefit of users to the marginal cost that is dependent on inflows and water availability at a given time and space has several benefits when it comes to economic efficiency. Some of these benefits include:

i. The key benefit of dynamic pricing is that it greatly reduces the need for water restrictions or rationing (which are estimated to have significant welfare loss, see Grafton & Ward, 2008) and can also provide the revenues needs to fully recover all supply costs when water demand declines (Chu and Grafton, 2019; Grafton, Chu & Wyrwoll, 2020).
ii. With dynamic water pricing defining residential prices according to the marginal cost of supply at a point in time, peak demand for water can be significantly managed through peak pricing at times of high marginal cost. This can contribute to lower costs of a water distribution network's operations, maintenance and expansion, as pressure on the network is better managed. Managing peak water use also has the potential to

reduce the size of new mains during infrastructure expansion, as water flows are better managed, and can also ease the replacement of leaky mains in network maintenance operations; both of which translate into financial savings (Carragher et al. 2012; Lucas et al. 2010).

iii. The management of peak pricing can help delay investment in new mains by postponing the date at which existing mains will no longer be able to handle a rising demand and by lowering the risk of pipe bursts caused by high pressure. As such, reducing peak demand is expected to reduce operational costs.

iv. Dynamic water pricing can also lower peak-hour energy consumption because the daily morning and evening water use peaks often correspond to times of peak-hour electricity tariffs. Therefore, if a utility does not have enough in-network water storage, it must incur higher energy costs to deliver water during peak time. Optimal pumping scheduling then becomes a significant source of savings (McCormick and Powell 2003; Martínez et al. 2007) and reducing peak use can add substantially to these operational savings. Alternatively, if a utility has enough in-network storage but expects peak demand to grow, reducing peak use delays the investment in new in-network storage.

The theoretical discussions above presented the general concept of dynamic water pricing, how it works and its potential benefits in terms of economic efficiency, revenue enhancement and conservation, amongst other objectives of the water pricing system. While the benefits of dynamic pricing are clear, particularly from an economic efficiency perspective, the issue of equity is not directly addressed. Equity is an important goal for the South African water pricing context, given the historical and current economic issues of high levels of inequality in income, resources and access to goods and services. This aspect will be explicitly addressed in our design and analysis of the potential of implementing dynamic water pricing in South Africa. Thus, the dynamic pricing model should address issues within the unique socio-economic setup of South Africa.

Another important conclusion from the discussions is that the implementation of dynamic water pricing can be complex from an operational perspective. As will be discussed in Section 3, the use of various technologies, such as smart metering, is key to the successful implementation of dynamic pricing, depending on the time periods for a dynamic tariff. The time dimension of dynamic pricing can range from hourly, daily and monthly changes in the water price, depending on the available technology to monitor water use and implement real-time or time-of-use pricing. This, already, will be a challenge for potential implementation in the South African context, where issues remain around the metering and monitoring of raw and retail water use. Furthermore, large capital outlays relating to investments in new technologies and metering infrastructure will also be a challenge from a financing perspective.

3. Review Previous Empirical Literature

This section presents a review of previous empirical literature on the rather broad issue of dynamic pricing. As outlined in the theoretical review, dynamic pricing aims to equate the marginal benefit of water use across users to the true marginal cost of water. Ideally, the price of water should adjust (be dynamic) to changing variables that impact the short-term demand and supply for water, such as issues of scarcity. One of the important factors required to implement dynamic water pricing is the estimation of the marginal benefit users receive from water use.

This section commences with a review of literature that applied methodologies, predominantly in the form of HEMs, to calculate the marginal benefit of water use. The review then looks at studies that have designed and simulated the impact of dynamic water tariffs on customers. This component of the literature is important in determining the potential success of such tariffing structures in achieving the goals of a water pricing strategy. We then look at the practicality of implementing dynamic water tariffs in various contexts. The section concludes with a review of some of the existing literature in South Africa that estimated price elasticities for water demand, in order to determine the potential reaction of different South African consumers to dynamic water pricing.

3.1. Use of Hydro-Economic Models to Estimate Marginal Benefit

This section provides a brief review of previous work done regarding the implementation of dynamic water tariffs. The literature review looks at methods used, such as HEMs, to determine water value. As discussed above, determining the relative value users place on water consumption assists in the appropriate design of tariffs that align with the cost and benefit of water use. The literature review also focuses on the demand for water and how customers are likely to react to dynamic pricing and price increases.

The recent bibliometric review by Bekchanov et al. (2017) shows that the largest number of studies using HEMs in recent years have focused on the impact of climate on water-resource systems and the assessment of adaptation policies to decreasing water availability. As mentioned above, HEMs are appropriate in determining the economic value of water and thus play an important role in simulating a dynamic water-pricing model.

Pulido-Velazquez et al (2008) applied the HEM to estimate the economic values for water use in Spain. Economic values for water use were defined according to the marginal residual value of water for production (for agricultural and industrial uses) or the aggregated willingness to pay (WTP) for urban supply and other final water uses in the Adra river system in Spain. Total and marginal opportunity costs of capacity and operation constraints were also determined, using the primary methodology was the use of a holistic conjunctive optimisation model.

The study by Kragt et al, (2011) used the HEM to describe a model development process where biophysical modelling is integrated with economic information on the non-market environmental costs and benefits of catchment management changes for a study of the George

Catchment in northeast Tasmania, Australia (Kragt et al., 2011). Ward & Pulido (2009) applied a HEM using data from the Rio Grande Basin of North America on an analysis of a two-tiered water pricing system that sets a low price for subsistence needs, while charging a price equal to marginal cost, including environmental cost, for discretionary uses. This approach attempted to balance the needs of equity and the efficiency of water use.

Riegels et al. (2011) applied a HEM in estimating the ecological status in northern Greece using metrics that relate average monthly river flow volumes to the natural hydrologic regime. The decision variable in the optimisation is the price of water, which is used to vary demands using consumer and producer water demand functions (Riegels et al., 2011). The study by Varela-Ortega et al., (2011) used the HEM to analyse the spatial and temporal effects of different water and agricultural policies under different climate scenarios in Spain's central arid region (Varela-Ortega et al, 2011).

As is evident from the brief review of previous work above, HEM is a comprehensive methodology that allows one to determine water prices under several scenarios. This includes spatial effects, temporal effects, climate issues and river flow volume. One approach to optimally invest in water supply augmentation is for the volumetric price to increase by an amount that would reduce current water demand to the present (and restricted) water supply. When this price premium equals the marginal cost of supply augmentation, or “marginal capacity cost,” it is optimal for the next supply-side investment to occur (for applications, Grafton, Chu, Kompas, & Ward, 2015; Grafton, Chu & Wyrwoll, 2020).

3.2. Feasibility and Impact of Dynamic Pricing on Consumers and Supply

Dynamic prices aim to enhance water use efficiency because they reflect real-time variations of water supply costs and incentivise water conservation among customers. Several time-varying factors influence water supply costs, including demand peaks, demand trends, water scarcity, and opportunity costs related to alternative human and ecosystem-related water uses (Brelsford and Abbott, 2017). In principle, dynamic pricing could help better consider these factors and help manage residential water demand (Rougé et al., 2018). In particular, increasing water prices during scarcity scenarios could send end users a signal on water value, leading to a decrease in demand and more efficient water allocation across time and among uses (Pulido-Velazquez et al., 2008; Pulido-Velazquez et al., 2013; Macian-Sorribes et al., 2015). Recent work has demonstrated it is possible to design such tariffs for residential users in drought-prone Valencia, Spain, while balancing economic efficiency with other tariff objectives such as cost recovery and equity (Lopez-Nicolas et al., 2018). Frequent price variations over time are commonplace in many industries, from travel to online and traditional retail. In recent years, electricity utilities also experimented with dynamic pricing policies, linking the unit price charged to end users with variations in the marginal costs of electricity supply (Faruqui and Sergici, 2010; Ito et al., 2018; Joskow and Wolfram, 2012; Wolak, 2010).

Several empirical studies have assessed the feasibility of implementing dynamic pricing and its impacts on water consumption and economic efficiency. Hughes et al. (2009) assessed scarcity pricing as a potential alternative to the predominant demand management policy of water restrictions in the Australian Capital Territory (ACT). Their study concluded that dynamic pricing is a better strategy for long-term water demand management as opposed to traditional pricing models and other methods to curb demand. However, they did highlight that the implementation of dynamic pricing can face regulatory, political, and social acceptance challenges.

Marzano et al. (2020) used an online experiment that measures end-users' water consumption decisions when confronted with time-varying (dynamic) prices and investigated the interaction between pricing and water scarcity awareness. Similar to the Hughes et al. (2009) study, Marzano et al. (2009) also found that dynamic pricing can incentivise economic efficiency in the use of resources, but will be more effective if it is complemented by proper communication, accessible pricing information and proper systems.

The Smart H_2O project (2017) used London and Valencia as case studies to explore the possibility of introducing dynamic pricing in these two cities. The project used HEM to compute the marginal value of water in order to determine the impact of scarcity pricing in the face of uncertain factors, in the case of London, and to develop scarcity-based tariffs, in the case of Valencia. Both case studies confirm that the use of dynamic water pricing can play a key role in reducing consumption in times of water scarcity. In the case of London, the analysis showed that dynamic water pricing is limited when applied to cases of extreme drought. In such cases, dynamic water pricing models need to be complemented with other non-price methods of regulating water use. In the Valencia case study, scarcity water tariffs were designed and indexed on reservoir levels in a river basin. The analysis confirmed that dynamic tariffs greatly assist water utilities in protecting revenues during periods of water scarcity.

Political resistance to time-varying prices and the unavailability of cheap enabling technologies (Dutta and Mitra, 2017) have proved to be important hurdles to the implementation and diffusion of dynamic pricing in the electricity sector. These barriers may prove even higher in the water sector, where time-varying prices could be considered as an infringement on the essential right to water. What is more, the impacts of dynamic pricing on water use are uncertain due to contrasting evidence from economic literature. Established wisdom suggests that price elasticity of demand should be lower in the short run than in the long run (Hicks, 1939). The common rationale for this is that it takes time for consumers to become fully aware of a price increase and adapt their choices. This is true for goods as varied as gasoline (Espey, 1998; Sterner, 2007; Brons et al., 2008; Havranek et al., 2012) and electricity (Holtedahl and Joutz, 2004; Halicioglu, 2007) or cigarettes (Becker et al., 1994).

For residential water use, short-term price elasticity may be even lower because end users may find it difficult to fully adjust to the new price if price variations are sudden or expected to be frequent. That being said, different mechanisms can lead end users to respond to dynamic pricing. First, end users may overreact to sudden changes in water prices. Adaptation-level theory holds that agents judge a stimulus relative to the level to which they have become adapted (Helson 1964). Consumers immediately compare a new price to the past reference price (Mizutani et al., 2018), i.e., to a predictive price expectation that is shaped by past purchasing experiences and the current context (Briesch et al., 1997; Kalyanaram and Winer, 1995; O'Donoghue and Sprenger, 2018). Second, water consumers may become more sensitive if prices were to change more frequently. Agents incrementally react to repeated stimulation because a sensitisation process drives the behavioural outcome of a sequence of stimuli (Groves and Thompson, 1973). Empirical evidence for price elasticity of residential water demand upholds the intuitive idea that demand is more elastic in the long run (e.g., Espey, 1997; Marzano et al., 2018; Nauges and Thomas, 2003).

In some studies, the price-driven reduction of consumption has been estimated in the short run by exploiting the introduction of increasing block rates (Wichman, 2014) or an additional price block (Nataraj and Hanemann, 2011). However, there were once-off price shocks, perceived by customers as persistent. Accordingly, the estimated price responses can hardly be conceived as dynamic pricing effects. Besides, a recent study (Schleich and Hillenbrand, 2019) has provided evidence that the short-term effect of a price increase was stronger than that of a price decrease and showed that computing a unique short-run elasticity for both types of price changes amounted to underestimating the short-term impacts of tariff hikes. This contrasting evidence suggests the possible impacts of dynamic pricing on demand are not a foregone conclusion and require further investigation.

3.3. Practical Applications of Dynamic Water Pricing

Typically, water supply pricing policies are aimed at meeting costs incurred through system operation and expected infrastructure expansion. Such pricing does not reflect the climate change impacts that have occurred at any particular point in time. This means energy availability, current water demand and water supply (i.e., scarcity) and the environmental damage incurred through water abstraction are not typically represented in water pricing. In most cases, water consumption and supply are not measured with sufficient frequency to allow incorporating these realities into water pricing policies. As a consequence, users cannot be provided with pricing signals that incentivise the conservation of water in response to the scarcity the water system is incurring at any point in time (SmartH20, 2017).

Currently, there is a growing trend in introducing a dynamic pricing model for water. There are two types of approaches that have emerged in introducing dynamic pricing.

i. The first trend is focused on time-varying prices. Supported by recent technological advances such as “smart” meters (Smart meters gather a household’s water consumption data on sub-daily basis, i.e. a few minutes to an hour) make it possible to manage water demand by moving from time-invariant to time-varying volumetric prices, known as dynamic pricing (Marzano et el, 2020; Lopez-Nicolas et al., 2018; Rougé et al., 2018; Vesal et al., 2018; SmartH20, 2017, Pérez-Urdiales and García-Valiñas, 2016) Examples of cities that have deployed smart meters on a large scale include San Francisco and London (Marzano et al, 2020). In this approach, to optimally invest in water supply augmentation, the volumetric price is increased by an amount that would reduce current water demand to the present (and restricted) water supply. When this price premium equals the marginal cost of supply augmentation, or "marginal capacity cost," it is optimal for the next supply-side investment to occur (for applications see Grafton, Chu, Kompas, & Ward, 2015; Grafton, Chu & Wyrwoll, 2020).

ii. The second approach focuses on the seasonal/climate variations linked into pricing model by dynamically changing prices to reflect water scarcity and supply cost variability linked to changes in climate variables such as temperature and precipitation (Grafton, Chu, Kompas, & Ward, 2015; Grafton, Chu & Wyrwoll, 2020).

3.4. Previous Studies of Demand Elasticities in South Africa

In South Africa, aside from a few studies, there is not much evidence pertaining to the known effects of water prices on household consumption behaviour and the affordability of water for households. Bailey and Buckley (2005) estimated water demand in Durban between 1996 and 2003, using monthly average household water consumption data for low-, middle- and high-income group samples. Using both linear and log-linear regression models, the study revealed the price elasticity of water demand to be -0.55 (log-linear) and -0.52 (linear) for the low-income group, -0.14 (both linear and log-linear) for the middle-income group, and -0.10 (both linear and log-linear) for the high-income group. These results suggest a higher response to price increases in lower income groups as opposed to the middle- and higher-income groups. IN a country like South Africa, where issues of equity are significant policy priorities, such results complicate the potential impact of dynamic water pricing.

The general price inelastic behaviour in households with regard to water consumption is confirmed in the results from Van Vuuren et al. (2004), which revealed the price elasticity of water demand in eThekwini to be -0.13 (low income), -0.13 (middle income) and -0.14 (high income). Van Vuuren et al. (2004) used the participative payment strategy testing (PPST) and contingent valuation (CV) methodologies to determine the price elasticity of water demand for low-, middle- and high-income groups, and to compare different water payment strategies in the Tshwane, Cape Town and eThekwini metropoles. Coupled with similar results from Dockel (1973), Veck and Bill (2000) and Jansen and Schulz (2006), it can be assumed that the responsiveness of water demand to changes in price is inelastic in South Africa. However, it is worth observing that the -0.55- elasticity figure for low-income earners produced by Bailey and Buckley, suggesting higher elasticity among the poor, contradicts the results of Veck and Bill (2000) and those from Jansen and Schulz (2006), who suggest the opposite. These inconsistencies inspire the need for further research on the nature and form of the responsiveness of water demand to water price changes in South Africa.

The Van Vuuren *et al* (2004) study tested the hypotheses that price does influence the amount of water demanded by all classes of water consumers, and that the perception of water consumers about water consumption may be changed by appropriate water payment strategies. Surveys were conducted through face-to-face interviews among low-income, middle-income and high-income population groups of residential water users in the three metropolitan areas. Results confirmed the hypotheses of the study to be true. The results revealed that the price elasticity of demand for low-income groups was -0.37 (Tshwane), -0.11 (Cape Town) and -0.13 (eThekwini). The price elasticity of water demand for middle-income groups was -0.17

(Tshwane), -0.10 (Cape Town) and -0.13 (eThekwini). High-income groups were shown to have price elasticity of water demand of -0.12 (Tshwane), -0.09 (Cape Town), and -0.14 (eThekwini). These results suggest inelastic water demand in all three metropolitan areas, and for all income groups, because the absolute price elasticity of water demand was less than -1. Findings from this study are compatible with those of Dockel (1973), Veck and Bill (2000) and Jansen and Schulz (2006), as they all have elasticities of less than 1. Jansen and Schulz (2006) used a panel data analysis and the two-stage least squares method in a model that aimed to demonstrate how different factors influence water consumption, among them the price of water in Cape Town. However, the work of Veck and Bill and that of Jansen and Schulz suggested that the demand for water services in South Africa is more elastic among the rich and inelastic among the poor – something that was not observed by Van Vuuren et al and Bailey and Buckley (2006).

The primary aim of the studies for South Africa described above was to determine how different groups of consumers reacted to water price increases. Price and income elasticities were determined across various income groups in these studies. While these studies shed light on a key aspect of dynamic water pricing in the form of how consumers could potentially react to price changes, the primary focus of these studies was more from a social perspective. Such studies did not go into detail on the pricing regime in place and how such pricing regimes impact on price and income elasticities of demand. Specifically, previous studies have not considered whether the current IBT, implemented primarily by WSAs for retail water, would still be efficient when issues of scarcity and climate variation is considered.

With that said, one study that stands out in assessing the efficiency of IBT considering climate price variation through an estimation of residential water demand is study by Monteiro & Roseta-Palma (2011). The study applied to Portuguese water utilities and found that, when both demand and costs react to climate factors, increasing marginal prices may come about as a response to a combination of water scarcity and customer heterogeneity. In other words, if climate variables are statistically significant in explaining water demand and water costs, then the pricing mechanism should ideally account for these factors to pass on the signal to customers of climate related demand and supply variations. The best way to allocate water when scarcity occurs is to raise its price in accordance with its true marginal cost, which includes the scarcity cost driven by climate factors.

4. Overview of the approaches to dynamic water pricing

This section builds from the theoretical and empirical literature review to provide details into the two options of dynamic water pricing emanating from the literature on incorporating dynamic factors into the water pricing system. In this section, we present two options given as:

i. **Option 1:** Linking the tariff to the available reservoir capacity/water volume resulting in the volumetric price increasing by an amount that would capture the increasing value of water due to scarcity and potentially reduce current water demand to the present (and restricted) water supply (Quentin and Kopmans, 2007; Grafton, Chu, Kompas, & Ward, 2015; Grafton, Chu & Wyrwoll, 2020; Chu & Grafton; 2021).
ii. **Option 2:** The water tariff is linked to seasonal variations (summer and winter) of water supply within the year. This common strategy links the tariff to exogenous factors such as the temperature and rainfall. In this approach, a tariff adjustment factor is determined by the two climate variables: temperature and rainfall (Ernst and Young, 1994, Griffin, 2006, Herrington, 1999, Munasinghe, 2019: Pesic et al (2012), Ioslovich and Gutman, 2001).

4.1. Linking Price Variations to Level of Water Storage

The theoretical review above clearly confirmed that a dynamic pricing system needs to explicitly account for factors that impact on the current supply of water such that the true marginal cost (or value) of water is communicated through the market. This then sends the signal that the value of water is increasing (and thus the price) due to scarcity, so that consumers can adjust their consumption patterns accordingly. The most effective method of achieving this scarcity component in the price of water is through linking the water price to the current available water level at a dam, reservoir, river or any acceptable water resource. In this approach, to optimally invest in water supply augmentation is for the volumetric price to increase by an amount that would reduce current water demand to the present (and restricted) water supply.

Table 1 below provides an example of a water pricing scheme that responds to water scarcity (dynamic water pricing). When the storage is 85% of the dam capacity or above, the volumetric price is $0.03/L and the water quantity demanded is 1,700,000 L. When the storage reduces to 80% of the dam capacity, the volumetric price would be increased to reflect an increase in the value of water, due to scarcity, and potentially reduce the water demand. Assuming the price elasticity is -0.5, that is, water consumers would reduce consumption by 0.5% in response to a 1% increase in the water price, a premium of $0.004/L could be added to the volumetric price to reduce the water quantity extracted from 1,700,000 L to 1,600,000 L. Lower storage levels would require higher premiums that reflect water scarcity and to subsequently manage water demand.

To reiterate, consumer reactions to price increases are complex, particularly when it comes to water. Unlike most normal economic goods, a component of water consumption is required for human survival and basic needs i.e. there is a subsistence use of water that individual consumers and households are unlikely to consume below, regardless of the price of water. This is considered a price-inelastic level of water demand i.e. no matter the price, consumers will likely still maintain this basic level of water consumption. Furthermore, one cannot assume that consumers react instantaneously to water price changes. There is likely to be a lag in an increase in the price of water and the consumer demand response. This will be touched in our subsequent analysis.

Table 1: Volumetric Charge and Storage

Storage	Water quantity (L)	Scarcity premium	Total volumetric price
85%	1,700,000	$0.00	$0.03
80%	1,600,000	$0.004	$0.034
75%	1,500,000	$0.007	$0.037
70%	1,400,000	$0.011	$0.041
65%	1,300,000	$0.014	$0.044
60%	1,200,000	$0.018	$0.048
55%	1,100,000	$0.021	$0.051
50%	1,000,000	$0.025	$0.055

Source; Grafton, Chu & Wyrwoll, (2020)

The successful implementation of this method depends on the ability to instantaneously, consistently and accurately determine the levels of water available at a given time and water resource. The time dimension can be hourly, daily, weekly or monthly and the determination of this time variable impacts on the nature of the dynamic water tariff being implemented. As noted in the literature review above, dynamic water tariffs can be implemented on an hourly basis, with the prices adjusting to higher levels at peak times when water availability at the reservoir is under pressure through the use of smart meters. On the other hand, dynamic tariffs can also occur monthly with an adjust of a monthly tariffs (if billing is done monthly) when reservoir levels are lower than average (or a sustainable level) in a given month.

This approach was applied in South Africa during drought intensification in 2017/2018 in Cape Town. This approach, in combination with other non-pricing mechanisms, was effective in reducing the demand to address the water supply situation in the short-run. However, it has been criticized by Pesic et al (2012) on the basis that it is only effective if the water is supplied from surface reservoirs. This is not the case for South Africa, as surface water accounts for 68% of all water supplied. Moreover, while this approach might be effective in the short-run it might be difficult to predict the price in the long-run.

4.2. Seasonal Water Pricing (SWP) Approach

In this approach, water pricing is linked to seasonal variations within the year through the incorporation of climate related variables that impact on water demand and water scarcity. Although used infrequently, applied in fewer than 3% of the largest US cities (Ernst and Young, 1994), seasonal water pricing is not unknown to policy makers. Modern metering systems with monthly meter readings allow water prices to vary by month (Griffin, 2006). Although the so-called time of the year pricing has not gained full favour yet, it appears to be more efficient than keeping uniform prices for an entire year. Summer prices can significantly flatten water consumption peaks. There are reported cases, such as in New York, where the imposition of a premium summer tariff was responsible for the reduction of the day peak ratio by 14% (Herrington, 1999).

Rationales for the introduction of seasonal pricing can also be found on the supply side. Literature reports that marginal costs during peak summer months are double those observed during off-peak periods (Munasinghe, 2019). These high marginal costs may be related to higher pumping costs which are, in turn, due to electric power utilities' use of peak load pricing. This could also occur if peak periods of water use are driven by lower precipitation levels. Lower levels of rainfall is likely to put pressure on existing water resources, especially if demand remains consistent or even increases in low precipitation seasons.

The basic concept of the SWP model is to introduce water prices that are sensitive to the temperature and precipitation. One way of implemented such variables into the water pricing system would be to adjust seasonal water prices when there are significant deviations from the normal monthly average temperatures and the monthly precipitation totals (Pesic et al., 2012). For example, when the average monthly temperatures are higher than thirty years' average (temperature normal), and simultaneously, the total monthly precipitations are lower than thirty years' average (precipitation normal), are seasonal prices higher than regular, the water price would adjust to account for the potential impact on these deviations on water demand and supply. The incorporation of two climate determinants (temperature and precipitation) is vital for long-run policy. Another feature of the model lies in an ex-post price determination, which means that prices are to be calculated for the previous months using the official meteorological data. Potential benefits of the model implementation should be a) pushing consumers towards rational behaviour by sending the signal of an increase in the value (scarcity) of a good, b) contributes to the conservation of a valuable resource to ensure short-run availability and long-run protection c) ensuring a better balance of water demand with water supply and, d) enabling the water utility to cover peaked season costs.

Compared to the other water pricing models (Ioslovich and Gutman, 2001; Zhao and Chen, 2008), the proposed model may be characterised as a very simple one, with a low demand for information inputs. Rather than complex shadow price calculations and marginal opportunity cost models, such as those required for Option 1 through HEM and other methods, SWP methods require less complex meteorological data that can show the state of the climate for a given point in time. It does not need any assumptions on efficiency functions for various types of consumers and it does not depend on complex calculation procedures. Therefore, this model may be useful for developing economies characterised by a low level of information availability and a low level of managerial skills in water supply authorities or providers.

An example of a SWP model is that proposed by Pesic et al (2012) to the costs of raw water. Such a model can also be be applied to any form of water tariffs, including bulk and retail tariffs. Such a model can also complement existing pricing structures, such as the IBT, where certain blocks of the IBT can be subject to seasonal pricing and others not. This can be important for issues of equity, if one assumes resource constrained households would likely consume at lower blocks within the IBT system.

In the SWP model. water prices during the dry season, from May to September[2], are to be multiplied by a correction factor τ, where τ is larger than 1 ("increasing rate" condition, $\tau > 1$). If τ is equal or lower than 1, regular water prices are used, without seasonal adjustments. The model is algebraically expressed in Equation 2.

$$SWP = wP.\ \tau \qquad (2)$$

Whereby:

SWP- seasonally adjusted water price (summer price)

wP - regular water price determined by WSAs

τ- correction factor applied from May to September ("dry" months)

Factor τ is calculated according to the following formula:

$$\tau = 1 + [(MAt - LRAt)/LRAt + (LRTp - MTp)/LRTp]/2 \qquad (3)$$

whereby:

MAt -average temperature for a certain month, in ^{0}C

LRAt - long run average temperature (normal temperature) for WSAs

MTp - total precipitation for a certain month, in mm

LRTp -long run total precipitation (normal precipitation) for WSAs

Monthly values of the average temperature and total precipitation obtained from the official climatology observations are used to calculate the SWP for the previous months. Although SWPs are determined for the previous months, on an ex-post basis, it is assumed that the consumers are aware of the price-setting rule and are expected to act rationally. This means that, on days when the air temperatures are higher than usual, and/or precipitation lower than normal, consumers will try to save water due to not knowing how high the water price will be for the current month. Without ex ante knowledge about the full impact of the high seasonal prices, consumers are expected to diminish consumption, particularly for irrigation purposes in suburban agriculture. By not knowing the exact nominal increase in their monthly bill, consumers will be forced to rationalise public supply-system water usage and try to find other water sources for irrigation and recreation purposes.

The SWP presented here is one of the simplest forms of dynamic pricing models created for the electricity supply (Faruqui and George, 2002; Faruqui and George, 2005), and it belongs to a group of models where price levels are unknown, but application time is known in advance (summer season). Besides rational consumption and resource conservation, the SWP model is expected to improve financial performances of the WSAs. Higher summer prices will force consumers to consume less water for non-essential purposes thereby enabling the WSAs to

[2] Seasonal tariffs will depend on the climate of a specific location where water is supplied. In this case, we use Gauteng as an example, where the dry month are usually between May and September of each year.

collect more revenues for less water sold and phase out the need for unpopular water restrictions. For the SWP model to be effective, it is essential that water consumers have a full understanding of the price-setting rule in order to react rationally to them.

The SWP model presented here is but one example of implementing climate variables that can have an impact on short-term water demand and supply into the pricing system. For example, one does not need to specify an ex-ante "dry" season in the water tariff model but can apply dynamic tariffs throughout the year. This will assist in instances where even unexpected variations in precipitation in so-called "wet" months, where rainfall can be less than what is expected (the average), can be incorporated into the price. This can be important given the growing impact of climate change that results in unpredictable and extreme weather conditions at unexpected times of the year. Other variations to an SWP model can exclude short-term climate change variations from its long-term average and simply apply a climate factor that reflects temperature and precipitation levels that are deemed likely to impact water demand and supply. As per the aim of dynamic water pricing, the overall goal here is to ensure that the price of water accurately accounts for the changing benefit and cost of water at different times of the year in order to ensure an appropriate balance between water demand and supply. The incorporation of variables that can impact on water demand and water scarcity into the pricing system can better achieve this goal.

5. Methodology

Given the various objectives of the study, we adopted a suite of qualitative and quantitative methodologies that were implemented. These are outlined as follows relative to the research objective that needed to be achieved:

i. A critical assessment of the water value chain in South Africa to determine the feasibility of implementing dynamic water tariffs across all or some of its components – The primary method used to achieve this objective was qualitative analysis in the form of focus group discussions with stakeholders across the water value chain
ii. Design and implementation of dynamic water tariffs linked to the volume of available water at the water source for raw water tariffs – Development of a comprehensive water allocation model based on the demand side principles of hydro-economic models outlined in Figure 2
iii. An assessment of the current pricing model and water demand estimations in order to determine the potential reactions of consumers to dynamic water pricing – Conventional and Stone Geary demand functions using data from the 2014/15 living standards survey
iv. Implementation of the SWP using the City of Tshwane as a case study – the methodology outlined in Section 4.2 was applied using information sourced directly from the City of Tshwane and climate variables sourced from WeatherSA

Each of these methods are briefly explained below.

5.1. Critical Assessment of the South African Water Value Chain – Focus Group Discussions

The South African water value chain is complex and constitutes various components from raw water management and extraction, bulk water purification and potable water provision by WSAs to final consumers. As a result, there are various costs and charges applied across the value chain, including various raw water charges (operating and capital), bulk water charges (for bulk purification) and retail water tariffs for the provision of potable water. Furthermore, there are different players and institutions across this value chain, with the National Department of Water and Sanitation being the custodians of raw water management, water boards predominantly involved in bulk water purification and municipalities, constitutionally, serving as WSAs towards the provision of potable water services to final consumers.

Given the above, the configuration of these various components of the water industry is complex and diverse and the design of the various pricing structures across this value chain are also complex. In order to determine the possibility, practicality and feasibility of incorporating dynamic water prices across this value chain, one would need to comprehensive assess and critically analyse these various components. In this research, we use a qualitative methodology in the form of focus group discussions with various stakeholders across this value chain. We undertook comprehensive interviews with the respective divisions within the DWS, water boards and a WSA, in the form of the City of Tshwane metropolitan municipality. Our primary goal was to break down the configuration of the raw water, bulk water and retail water components of the water value chain, understand the intricate operations of each component and, more importantly, the design of the pricing structures and their application across these various components. In terms of the latter, the analysis dissected the cost drivers of the different tariffs, how they are determined, how they are applied across customers and how they are billed and collected. The important goal of this analysis is to determine if the current configuration of the water value chain can accommodate the different methods of dynamic pricing and whether the current pricing system could possibly be amended to implement a dynamic pricing structure or component into the pricing regime.

5.2. Assessment of the Current Pricing Model and Demand Estimations

The aim of this aspect of the analysis is two-fold. Firstly, we estimate conventional demand functions to calculate how water consumption at households at different income levels react to changes in the price. This would allow us to predict the potential consumption changes with the introduction of dynamic prices. Secondly, we include climate variables in the form of temperature and precipitation to see how water demand reacts to these variables. This would indicate whether such variables apply pressure on the demand for water. It will also show us whether the current municipal water tariffs, being IBT, incorporates changes in dynamic variables in the form of temperature and precipitation that impact on customer demand. From an a priori perspective, we do know that the current IBT system does not adjust for short-term changes in demand and scarcity issues, be it related to actual supply of water or climate variables that impact on supply. As a result, we do not expect the price to play a role in controlling demand with changes in temperature or precipitation.

In estimating the water demand, the standard literature primarily uses two function forms:

i. The Cobb-Douglas function and
ii. Stone-Geary functional form.

The elasticity estimations in empirical studies differ depending on the functional form specified and other factors. Some studies have found highly elastic (sensitive) changes in consumption with changes in price, while most studies deem water demand to be relatively price inelastic i.e. there are small changes in consumption patterns with changes in the price. Such trends in price elasticities differ considerably when the analysis is applied to households within different income groups. Several factors contribute to the weak sensitivity of water consumption to price changes identified in empirical literature: the intrinsic nature of water as a necessity to life; water bills constitute a small proportion of overall household budget and; imperfect price information (Gaudin, 2006). However, water demand will exhibit different elasticities at different levels of use, levels of income and in different price ranges, which is an inherent characteristic of the IBT (Nauges, and Martinez-Espineira, 2004). Moreover, the water volume required for the necessities of life, such as drinking and cooking, will be extremely inelastic. This portion is deemed as the "subsistent" or price-inelastic portion of water use and, for this reason, the Stone-Geary functional form has two main advantages over Cobb-Douglas:

i. It allows for non-constant price elasticities

ii. It considers that water consumption includes two components: a fixed quantity that cannot be adjusted immediately after a price increase (the subsistence portion of water use) and a residual that can adapt instantaneously.

To reiterate, the Stone-Geary estimation method allows us to establish a minimum water use threshold below which water consumption is insensitive to price changes. In this context, a Stone-Geary utility function has twin objectives. Firstly, it enables the calculation of a portion of the inelastic level of water use. Secondly, there is a derivation of the equity index of the water utility bill components through the estimation of a water demand function.

The Stone-Geary model underlying our assumptions is that consumers have a given level of income and face a set of prices for water supply and other goods. Consumers must satisfy their basic needs first, so they purchase a subsistence level of goods and services, then allocate the remainder of their income in fixed proportions to each of the other goods and services according to their preference parameters. Using the Stone-Geary utility function (assumption of implicit separability, which justifies the water demand function with only a single price), the demand model for water can be given as (Gaudin, Griffin and Sickles, 2001):

$$Q_w = (1 - \beta_w)\gamma_w + \beta_w \frac{I}{P_w} + Z + \mu \tag{4}$$

One of the advantages of the Stone-Geary function is that it is theoretically consistent and uses only two parameters for each type of good or service, while considering non-constant elasticities that may increase with price. Moreover, both parameters have an intuitive economic meaning: γ_w can be deemed a threshold below which consumption is not affected by changes in either price or income, while β_w represents the marginal budget share allocated to the good or service considered, Z is a set of variables that describe the water utility, and μ is the usual idiosyncratic error term.

Climatic effects in residential water demand models can be introduced in different ways. Generally, climate exerts the following influences on water demand: high temperatures increase water demand, while high rainfalls decrease water demand. Outdoor water use depends on climatic conditions that are represented by weather variables. To capture the influence of climate, annual average temperature and rainfall data are used in the demand estimation. The coefficient of temperature with respect to water use is expected to be positive, while the coefficient of rainfall is expected to be negative. The empirical demand function is specified as:

$$Q_{it} = (1 - \beta_w)\gamma_w + \beta_w \frac{I_{it}}{MP_{it}} + \alpha_1 Temp_{it} + \alpha_2 Rain_{it} + \varepsilon_t \tag{5}$$

Where, Q_{it} is a average annually water consumption, β_w and γ_w are structural parameters representing respectively the share of water expenditure in the supernumerary income and the fixed component of annual consumption; *Temp* is annual temperature; *Rain* is annual rainfall and ε_t is the usual error term. Implicitly we assume a threshold (γ_w) that does not vary over time. Price and income elasticities can be derived from these estimates. In this particular case, the two elasticities have the same magnitude but opposite signs, as depicted in Equation 6.

$$\xi_P = -\beta_w \frac{I}{PQ} = -\xi_I \tag{6}$$

We estimate both the Cobb-Douglas and Stone-Geary estimations using information from the 2014/15 Living Conditions Survey undertaken by Statistics South Africa. This was the last comprehensive survey that looked at the expenditure and income trends for households in the country. Like most income and expenditure surveys, the data we received constituted household expenditure on water across income groups, but only for metropolitan areas. We then sourced the retail water tariffs charged for all metropolitan municipalities for the 2014/15 municipal financial year and aligned them with the expenditure data. Consumption levels were then estimated using this approach. While the approach is crude, we are limited on household water consumption data and would need to improvise to achieve such information. The Living Conditions Survey also provided us with the income variable and a range of control variables that impact water use, including household items and general living conditions, such as household size and household structures. We then aligned temperature and rainfall information, sourced from WeatherSA, to each household within each municipality to determine the impact of climate variables on water demand.

5.3. Implementation of the SWP – City of Tshwane Case Study

The third component of the analysis constituted the implementation of the SWP method to simulate the design and potential impact of a dynamic water price using the City of Tshwane metropolitan municipality as a case study. This component of the analysis shows how climate variables that impact the availability of water (scarcity on the supply side) and the change in consumer behaviour (overuse on the demand side) can be incorporated into a tariff. While this assessment will occur using a municipality at the potable water level, such a concept can easily be applied to the raw water sector or bulk water sector, with the former being preferable from a water value chain perspective to ensure all water users in the country are exposed to such tariffs.

We use equations 2 and 3 to develop a dynamic tariff for the City of Tshwane. The municipality provided the research team with water consumption data for 10 years. We undertake the analysis for the 2014/15 financial year to align with the demand estimations outlined in Section 5.2 using the Statistics South Africa 2014/15 Living Conditions Survey. We sourced rainfall and temperature data from WeatherSA to allow us to look at current weather patterns and deviations from the long-run trend. Water tariffs for the City of Tshwane were sourced directly from their budget documents for 2014/15. As presented in the theoretical discussion above, dynamic tariffs improve economic efficiency in the pricing of water. However, in general and specifically for a country like South Africa, equity in the water pricing structure is equally as important as issues of economic efficiency. Embedding a dynamic pricing structure within an IBT can best balance efficiency and equity if the lowest or lower blocks of the IBT, usually aligned to protect a subsistent use of water, are not subjected to dynamic water pricing. Dynamic water pricing should ideally be applied to higher consumption bands in the IBT. In our analysis, we use the fourth block for our illustration purposes to show the potential design of dynamic water pricing, using the SWP, for the City of Tshwane.

5.4. Development of the Water Allocation Model

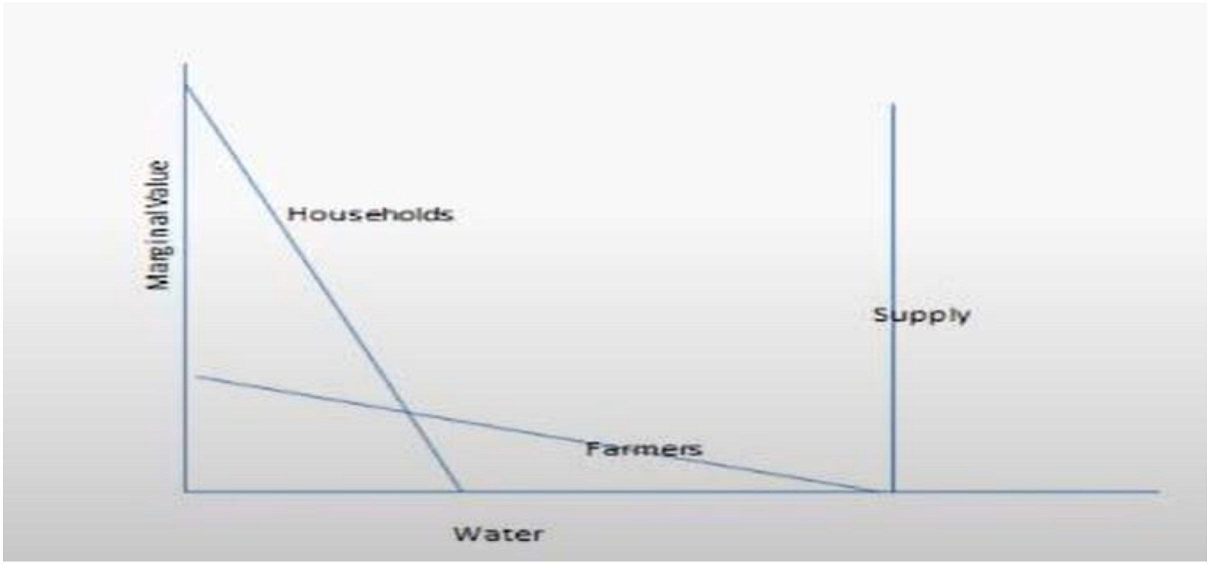
The final component of our analysis is the design and potential implementation of Option 1 of the dynamic water pricing methodology on raw water tariffs in South Africa. As will be seen in this report, the configuration of the raw water sector and the subsequent raw water pricing in the country are complex and not applied uniformly across different catchments and regions. In applying this methodology, the study also briefly reviewed the water allocation model in South Africa, both from a theoretical and practical perspective. This review was not meant to be comprehensive, but rather to inform the appropriate design of dynamic water tariffs.

As per theory, dynamic water tariffs would need to reflect the marginal benefit that each water user places on the good and the determination of the marginal cost for said good. In order to develop dynamic water prices at the raw water level, one would need to undertake the following in sequential order:

i. Estimate raw water user demand functions
ii. Calculate the marginal benefit each user derives
iii. Maximise the consumer surplus of each user
iv. Find out the efficient allocation of water amongst users
v. Determine the increase in the marginal cost of water driven by scarcity
vi. Determine the change in the price of the good that would induce a demand response.

This is shown graphically in Figure 3, which is an adaptation of Figure 2.

Figure 3: Efficient Allocation of Water between Users



Source: ECCA Hydro Economic Model Webinar

In order to undertake this component of the methodology, the project team innovated with the development of a *Water Allocation Model*, built in Microsoft Excel. This model allows one to input demand estimations for each water user within a scheme and explicitly calculate the efficient water allocation based on the description in Figure 3. In other words, the model can use water consumption and price data to estimate demand functions for different water users, calculate the respective marginal benefit derived from such water use per water user, equate this marginal benefit across water users and subsequently determine the economically efficient allocation of water across users within a scheme. The model then calculates the increase in the value (and cost) of water in the scheme at various levels of water supply scenarios, i.e. various levels of scarcity. Dynamic raw water tariffs are then determined using this information.

Figure 4 shows the general inputs required in the model. On this configuration page of the model, the user is allowed to specify the water resource in question, for example, a specific catchment area, river, or dam. The user is then required to input the total water volume available for the water resource, the time dimension for dynamic pricing and the specifications in terms of the number of years for the simulation of the impact of the dynamic tariff. Finally, the user can determine the number of raw water users in the resource by category, as per the category of users in the Revised Raw Water Pricing Strategy currently out for public comment.

Figure 4: General Inputs in the Water Allocation Model

Water Resource Information	
Name of Water Resource	Ngagane River
Total Water Volume	22.8328
Time Variable	Monthly
Number of Years	30
Starting Year/Year of Analysis	2001

Customer Information	
Municipal	Yes
Agriculture	Yes
Mining	No
Industry	No
Hydropower	No
Strategic Users	No
Stream Flow Reduction	No

Source: Water Allocation Model

Figure 5 shows the detailed demand and supply inputs required to estimate the marginal benefit, the efficient water allocations across users and the scarcity premiums on the price in the *Water Allocation Model*. In terms of Figure 5, users are required to input the price elasticity of raw water demand by user group, the constant of the demand specification, the raw water charge currently applied to each user group and their current, predetermined by the DWS, allocation within the scheme. Based on these assumptions, the model then determines the marginal benefit of each user and the scarcity premium to be applied to the raw water tariff. It is important to point out that the allocation model requires demand and supply inputs for user groups as per the current Revised Raw Water Pricing Strategy. Therefore, if there are more than one Municipal or Agricultural user within the scheme, one would need to estimate the aggregate demand function for all these users, as per the specific category of use. The *Water Allocation Model* determines marginal benefits and raw water tariffs per water user group in general, which is exactly how the raw water tariffs are currently determined and applied by the Department.

Figure 5: Demand and Supply Assumptions for the Water Allocation Model

Customer Demand Functions	Municipal	Agriculture
Price Elasticity	-0.193858604	-0.286377895
Constant	20.8583155	13.19230582
Raw Water Charge (c/kl)	103.98	38.20
Current Allocation (kl)	18.05	4.78

Dynamic Pricing Assumptions	Scarcity Premium
100% Capacity	0%
95% Capacity	0%
90% Capacity	0%
85% Capacity	0%
80% Capacity	5%
75% Capacity	10%
70% Capacity	12%
65% Capacity	14%
60% Capacity	16%
55% Capacity	18%
50% Capacity	20%
45% Capacity	22%
40% Capacity	24%

Source: Water Allocation Model

The *Water Allocation Model* is a user-friendly model that can be applied to any water scheme across the country. While the model was designed to simulate raw water tariffs by user within a scheme, the model also has other important outputs, such as determining the benefits users within a scheme get from water use and the economic efficient allocation of water within a scheme. The latter component is important, as it allows a user to determine what is the economically efficient allocation of water within a scheme based on demand behaviour of water users. This can then ensure a comparison between the current allocation of water within a scheme, as determined by the Department, with the economically efficient allocation.

While this model is fully functional to calculate the various demand and supply calculations and coefficients necessary to determine dynamic raw water prices, one would require actual raw water consumption data, per user, to calculate raw water demand functions. As will be discussed in Section 6, raw water allocations to users within schemes in South Africa is predetermined. Furthermore, raw water tariffs are not applied based on actual raw water use, as the Department does not monitor raw water use through the use of metering or related technology. In other words, the raw water tariff is applied to the volume of allocated water and not actual raw water use. Currently, the Department is still in the process of collating a database of licensed raw water users in the country. These issues result in the unavailability of actual raw water consumption by raw water users.

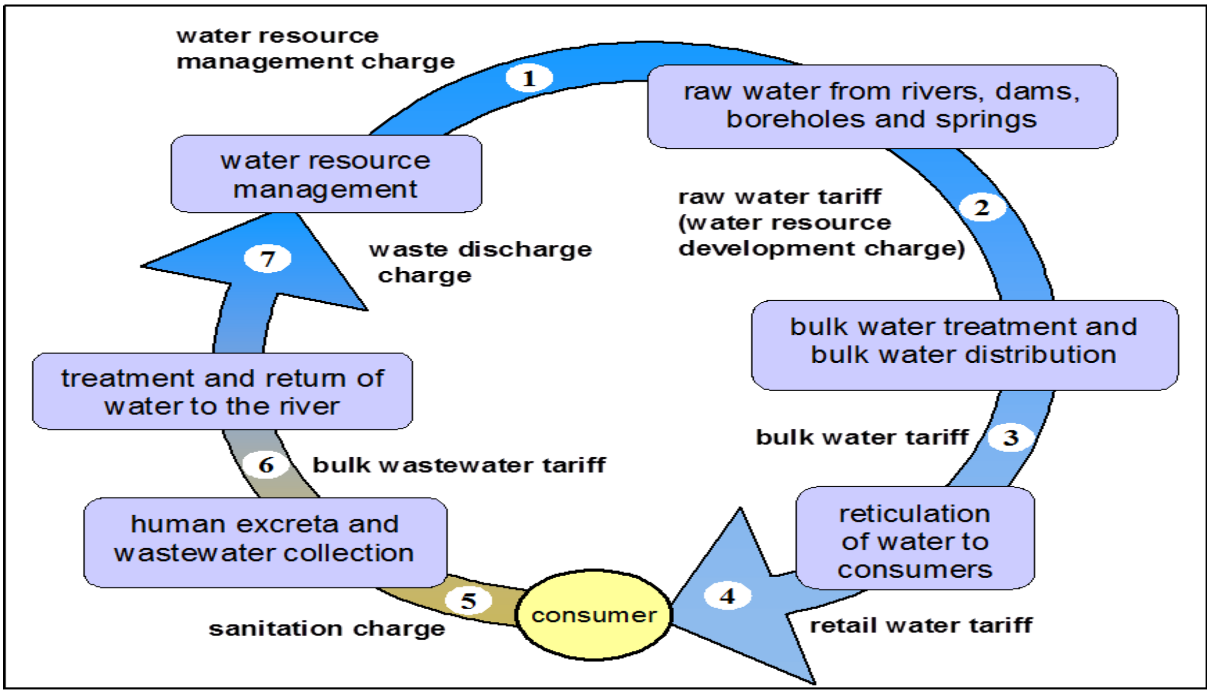
Without such data, one cannot determine accurate raw water demand functions for the application of the *Water Allocation Model* and to determine raw water dynamic tariffs. Indeed, one also cannot scrutinise current raw water allocations from an economic efficiency perspective, as one cannot determine the value placed on raw water by these users. Given these challenges, the project team did not have the required data to estimate raw water demand functions and to simulate raw water tariffs for a specific scheme. However, in order to at least show the concept of dynamic raw water tariffs and their design, the project team used demand assumptions, based on previous literature, and applied them to the Mdloti River Scheme (Hazlemere dam) in KwaZulu-Natal. While these demand assumptions and the subsequent demand and supply results from the model do not accurately reflect the actual consumption and behaviour of the users in the Mdloti River Scheme, these assumptions allow us to illustrate the concept of dynamic raw water pricing applied to a raw water scheme in South Africa. The *Water Allocation Model* will accompany this report and can be used in the future, as and when better information becomes available.

6. Critically Assessing the Water Value Chain in South Africa for Implementing Dynamic Water Tariffs

The discussions thus far outlined the theoretical fundamentals and rationale for dynamic water pricing, an empirical literature review of how dynamic pricing is implemented internationally, two options of implementing dynamic pricing and an overview of the methodology used in this paper. This section applies our qualitative study and presents the results of our focus group discussions with the Department, water boards and the City of Tshwane to critically analyse the South African water value chain and assess the feasibility of implementing dynamic water tariffs across its various components.

The Section commences with an outline of the water value chain in South Africa and a brief description of each of its components. Figure 6 shows the water value chain in the country and the different water charges per component from raw water abstraction to waste water treatment and management.

Figure 6: The Water Sector Value Chain in South Africa



Source: Draft Water Pricing Strategy (2022)

Figure 6 shows the different tariffs applied at different levels of the value chain, including the water resource management charge (operation cost of raw water) (1), raw water resource development charge (infrastructure requirements of raw water) (2), bulk water tariff (bulk purification of water) (3) and the retail water tariff (4). Theoretically, dynamic tariffs can be applied to any of the above-mentioned charges applied across the water value chain in order to send a scarcity signal to the consumer. This section outlines each of these components of the value chain and outlines the benefits and drawbacks of applying dynamic water pricing at each of these components.

6.1. Raw Water Allocation and Charges in South Africa

6.1.1. General Overview of Water Allocation Mechanisms

Allocation of water resources is a key component of political, social and economic policy, given the fundamental role water plays in society and the economy. In addition to its fundamental role in sustaining human and organic life, water is a key input in economic processes, including agriculture, industry, hydropower, recreational and domestic use. Given increased competition for water resources driven by progressively growing demand and constraints on the supply side, the efficient and effective allocation of water resources is pivotal in contemporary society.

As with most goods and services, the allocation process tends to combine and balance the principles of equity and economic efficiency. In terms of the latter, economic efficiency is essentially the allocation of goods and services to where the benefit is the most substantial. Essentially, this is the basis of the market system, where the price mechanism is essentially the source of the efficient allocation of resources. The price mechanism is seen as an efficient mechanism for allocation as it is determined by an equilibrium between the demand and supply sides of a market. Costing water at marginal cost is seen as an economically efficient price of water due to this price allocation mechanism.

Equity, on the other hand, assesses allocation based on fairness i.e., whether the allocation of resources is fair based on criteria of need across society. While the price mechanism allocates resources to areas of the economy where there is more benefit, it is debatable whether the use of resources in these areas is fair, especially when certain members of society are excluded due to issues of affordability. Therefore, an economically efficient allocation of resources is not necessarily an equitable or fair allocation of resources. As a result, there is a need to balance equity and efficiency in the allocation of water.

Balancing the equity and efficiency principles in the allocation of goods and services is most apparent in a good such as water, where there is a minimum sustainable level that is required by all living organisms to sustain life. In this case, ensuring equity is life-sustaining, as a good portion of society requires access to a specific portion of water to survive, regardless of the economic efficiency or price of the water. As a result, policymakers need to ensure the most equitable distribution of water with a limited impact on the efficiency of the production and distribution of water. As a result, there are certain principles that can guide the appropriate allocation of water in trying to achieve the optimum balance between the efficiency and equity principles (Howe *et al*, 1986 and Winpenny, 1994. These are:

i. Flexibility – is the allocation of a resource that equates marginal benefits with minimized cost across various sectors as and when demand changes
ii. Security – is the security of supply for established users of the good.
iii. Real opportunity cost – is the cost of using the good links fully with the user. All other demand and external effects of the good are therefore internalised in the price and consumption of the good. This allows the allocation mechanism to account for uses of the good with a non-market value, such as environmental uses

iv. Predictability – is materialising the best allocation and minimising uncertainty of the allocation process, such as unforeseen transaction costs
v. Equity – is the providing of equal opportunity gains to every potential user of the resource
vi. Political and public acceptability – ensures that the allocation is serving the values and objectives that are accepted by several sectors in society
vii. Efficacy – ensures that the allocation discourages or changes an existing undesirable situation, such as depletion of water or water pollution. The allocation should support the attainment of anticipated policy goals
viii. Administrative feasibility and sustainability – implementing the allocation mechanism at minimal administrative costs and ensuring the continued and growing ability to maintain the policy

Dinar *et al*. (n.d.) identify four water allocation mechanisms, namely, marginal price costing (MCP), water markets, user-based allocation and public allocation. MCP prices water at its marginal cost of supply i.e., the economic value placed on water by its users. Essentially, using the price mechanism of allocating water treats water as essentially an economic good. It can be argued that, using the price as an allocation mechanism, in its most general terms, tends to promote economic efficiency over equity. While allocating water using a price that is equivalent to marginal cost is theoretically economically efficient, water utilities and water service providers tend to find it difficult to price water at marginal cost, due to several social, political and economic reasons.

A market-based allocation of water is an exchange of water use rights. Put simply, lower users of water can "sell" their rights to water to higher users of water. The exchange is totally voluntary and can improve the efficiency of water allocation. Such a market would require initial government intervention to establish the institutional and legal framework for such a market, define the original water allocations and ensure that the technology and infrastructure is in place to allow for water trading between market sellers and buyers. Again, while this method of allocation is theoretically sound, it faces several practical challenges.

The third method used to allocate water is the "user-based" allocation system. In this system, water rights and the allocation of water are determined by a collective action group. Essentially, water resources are managed, and their allocation is determined collectively by all water users. User-based allocation systems are deemed to be more flexible and easily respond to the needs of water users. In terms of the latter, the tastes, preferences and requirements of all water users are transparent, therefore water need can be easily determined, and water allocated accordingly. Such a system is also politically and socially acceptable. However, such a system of allocation is easily implemented on a smaller scale or in specific water use markets. Its operation does get complicated when there are competing sectors negotiating for water use and some groups cannot identify with the needs of other groups, particularly in larger schemes and at more aggregate levels of society.

Lastly, the public (administrative) water allocation method is essentially a centralised "command and control" system where the management and allocation of water resources lies with the government. While there are many ways to implement such a model, many water authorities tend to issue licences or permits to water users or adopt other ways to regulate their use. Having a central authority, such as the state, to allocate water resources is deemed beneficial for inter-sectoral allocation of water, since the state has jurisdiction over all water users. The state is also best placed to determine the social needs and norms, given that it is usually a popularly elected government and can thus allocate resources that align with the social desires and equity principles of a country. It can be argued that this public water allocation method tends to promote equity over efficiency, as the methods used to recover the costs of raw water management and infrastructure development do not necessarily reflect the true cost of such operations. As a result, the true benefit of water is not valued, and the water might not be allocated to areas of greater economic benefit. Public water allocation can thus promote misuse and waste in sectors that value water relatively less than other sectors on the demand side and can result in fragmented investment in water resources on the supply side.

The application of these four general methods of allocating water varies across countries, with some countries even using a combination of these methods across various sectors. While there are several advantages and disadvantages to each of these methods, which will not be elaborated on in this report, it is important to understand these theoretical methods in the context of this study. Raw water allocation in South Africa tends to follow the public water allocation method due to the promotion of equity in water allocation and for historical reasons. However, these methods have several drawbacks, including allocative inefficiency, potential overuse of water, and a price that does not reflect the true value of water. Furthermore, given that the value of water is likely underestimated, it is difficult to build in scarcity of the resource on the demand side of the market. In other words, scarcity is determined at the point of allocation, but users of raw water and potable water are unlikely to change their water consumption behaviour, as the price of water would not reflect current levels of scarcity.

6.1.2. Overview of Raw Water Allocation in South Africa

In general, national government, in the form of the DWS, water boards and local government (municipalities) are the key players in the South African water sector. The primary role of national government is to formulate and implement policies governing water resource management. The Department is also the custodian of South Africa's water resources and allocates raw water to agriculture, mines, industries, water boards and municipalities. The water boards (which are state-owned) provide bulk treated water, primarily offer some retail water services, and sometimes provide technical assistance to municipalities (WSAs). Although WSAs also own some of the bulk water-supply infrastructure, their main role is to provide retail water services. Water provision in each area of South Africa is the responsibility of the area municipality, either in the form of a metropolitan, local or district municipality. A WSA may carry out the functions of a water services provider (WSP) itself, or it may subcontract the delivery to a third party.

In terms of raw water, which is managed and allocated by national government through the DWS, the 2005 draft position paper on water allocation reform outlines seven guidelines to guide the appropriate allocation of water resources. These are:

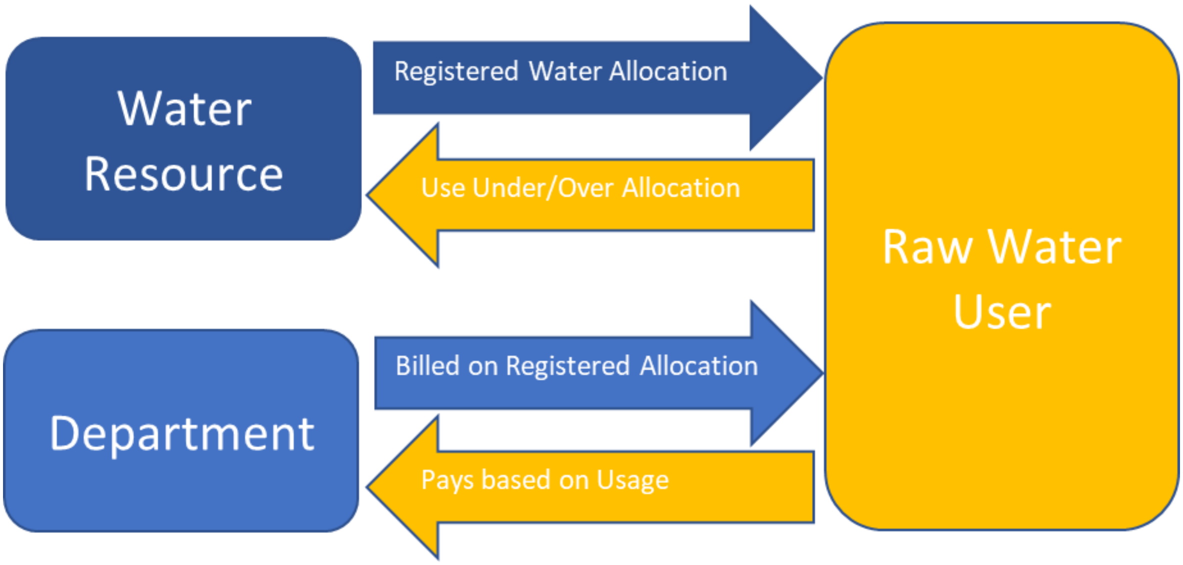
i. Redress past imbalances in water allocations to historically disadvantaged individuals
ii. Water allocations should be accompanied by capacity-building programmes to support the productive use of water
iii. Water allocations should contribute to broad-based black economic empowerment
iv. The water allocation process should respond to local, provincial, national and regional initiatives, including South Africa's international obligations
v. The water allocation process should be fair, reasonable, and consistent
vi. The water allocation process should give effect to the protection of water resources
vii. Ensure the development of innovative mechanisms to reduce the administrative burden of authorising water use

As mentioned, South Africa uses the administrative method of allocating water in a centralised way. While these guidelines inform this allocation process, it is not clear how the actual allocation is determined. Indeed, the Department is currently struggling with registering raw water users and monitoring raw water usage in the country.

6.1.3. Raw Water Pricing in South Africa

The charging of raw water tariffs to users occurs *after* the water has been allocated. Raw water users are given licences to abstract their allocated amount from the raw water resource and are then charged after use. Figure 7 provides a simple illustration of the allocation and billing process for raw water use.

Figure 7: Simple Illustration of Raw Water Allocation and Billing



Source: Focus Group Discussions with DWS

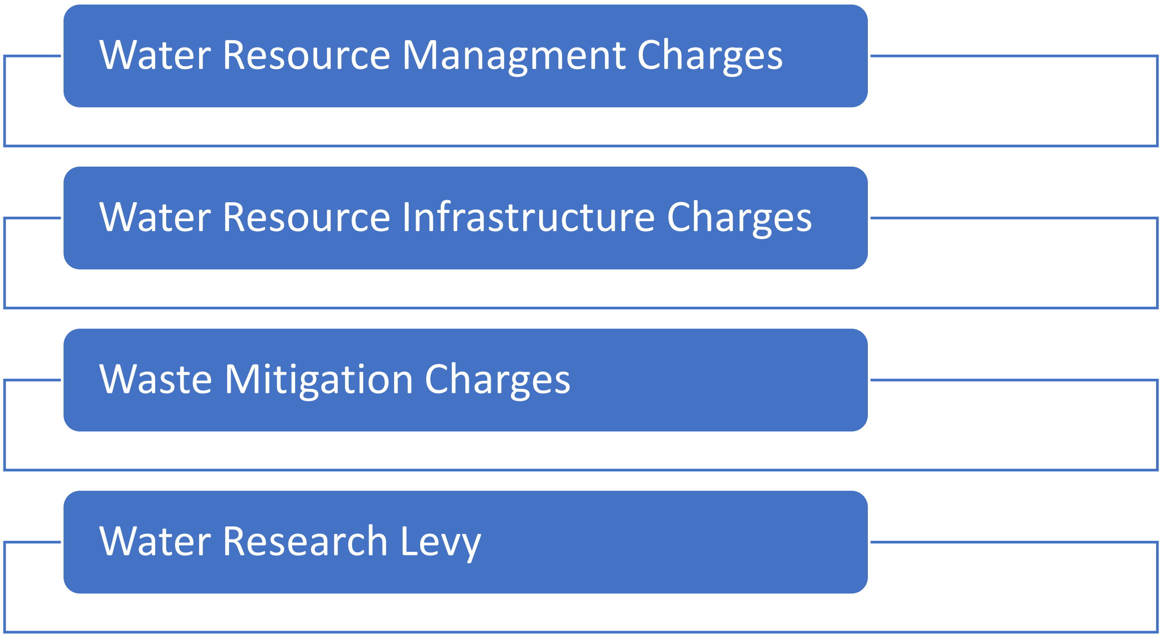
Water is allocated from a water resource (water catchment area) to a raw water user. The basis for the allocation is an application received by the potential raw water user, usually via a licence (although there are other lawful water users and generally authorised water users that do not need a licence). The department then determines this allocation based on this application to the raw water users. This is the registered water use. The raw water user can use more or less of this amount, but the department bills the user based on the registered amount. This is currently due to the lack of meters to measure consumption. However, the raw water user usually reports its use and then this charge is adjusted accordingly.

There are guidelines in place for instances where a catchment area cannot meet the water demand at a given moment in time. Furthermore, in instances of drought or a perceived lack of water supply, the department can temporarily adjust downwards the allocation given to a raw water user.

6.1.4. Current Raw Water Tariffs

Section 56 of the NWA promotes the imposition of a raw water pricing strategy to charge for the use, maintenance and extension of raw water resources in South Africa. As a result, the DWS has formulated and implemented a national water pricing to charge for the use of raw water. The initial strategy was designed in 1999, with a revision of this version undertaken in 2007. In 2015, the Department released a draft revised pricing strategy for public consultation. Following comments received and extensive research to address some of these comments, the department released a revised strategy for public consultation in 2022. During the intervening period between 2015 and 2022, the provisions of the 2007 strategy informed the charging of raw water use. Figure 8 shows the categories of charges as proposed in the 2022 raw water pricing strategy.

Figure 8: Categories of Raw Water Charges



Source: Draft Water Pricing Strategy (2022)

While these charges are proposed in the 2022 strategy, most of these charges are currently applied in the raw water pricing system. Of the charges listed in Figure 8, water resource management charges capture the costs of abstraction of water and related costs in managing the operations of raw water allocations. Included in these potential operational charges is the water resource management programme, which includes water conservation and water demand management efforts. This provides a potential avenue of building in a link between the availability of the water resource and the raw water charge. Water resource infrastructure charges consists of various components that support the maintenance and development of new water resource infrastructure. Dynamic pricing would like to be possible in these two charges.

6.1.5. Potential Application of Dynamic Water Tariffs at the Raw Water Level

Implementing dynamic water tariffs at the raw water level has the advantage of inclusiveness, which means that all water users in the country will be forced to adjust their water consumption/usage due to price changes. This is due to all water users in the country, including those users that just use raw water, being subject to dynamic pricing. Therefore, the main objective of water demand management in the face of scarcity, especially accounting for climate change issues, will be broadly achieved. However, the study identified three areas in raw water sector of the value chain that deserve necessary attention as far as the dynamic water pricing is concerned: 1) raw water allocation 2) raw water billing system and 3) current raw water pricing arrangements.

The DWS issue licenses to raw water users and subsequently determine the allocation of raw water to the respective water user categories by ensuring that there is fair distribution of water resources amongst all categories of users in the country. Once the allocation is set, the DWS does not change the allocations on the WARMS system, even in the event of severe drought. Once the license and allocation process are completed, the data is uploaded to the WARMS system. The WARMS system registers all the raw water authorisations for the purpose of billing or water resource management charges generation as prescribed by the water pricing strategy. Raw water charges are then applied on the reported use of the water by the specific user categories, as per their respective allocation.

While such allocations do not change, instances of climate extreme events, such as drought, obligates the Department to restrict raw water users to use below a certain amount of water. This is communicated via gazetted limits and restrictions applied to the water user and results in the user getting access to less water than what they are registered for or allocated initially. This fact suggests that the allocation of raw water to users is static throughout the year. While this may not result in a major challenge to institutionalise raw water dynamic prices, it has significant implications on the billing generation which forms an important component of dynamic pricing system.

In terms of the billing for raw water use, rates determined by the raw water pricing strategy are applied to the initial allocation level but are likely contested in instances of drought or low water supply when water users would have used less water than their allocated amounts. During times of drought, the Department issues communication (gazetted) to restrict the raw user to use below a certain amount of water. This restriction affects the collections, because, due to the drought, the user gets access to less water than what they are registered or allocated. Thus, users contest the bill referring to the gazette as motivation for the discounts. The DWS will be obliged by Treasury Regulation 11 under Public Finance Management Act compliance to review such complains. When the discounts are granted, the user will therefore end up not paying the full amount. It can be noted that the policies are flexible to account for quantity changes on account of climate issues, such as a drought, but the raw water tariffs itself are not impacted in anyway in such issues of scarcity. This current system of operations in raw water allocation, use and billing means that water use is controlled from the allocation and administrative side and not from the pricing side. Indeed, the raw water tariffs seem to play an insignificant role in raw water allocation, use and management, but is merely a cost recovery tool for managing raw water and to fund raw water resource infrastructure.

Moreover, the frequency of billing of raw water provides another drawback in implementing a dynamic pricing system at raw water tariffs. As per the Raw Water Pricing Strategy, raw water charges are applied per raw water user category. Industrial and municipal users of raw water are being billed monthly for their water use, while the irrigation farmers and forest growers are billed every 6 months (DWA, 2021). Raw water billing would need to be uniform in order to implement a dynamic water pricing structure, as the dynamic price intends to send an instant signal to water consumers to adjust the consumption immediately due to changes in the supply of water and scarcity.

In conclusion, the allocation and billing process of raw water raises challenges to implementing a dynamic water tariff at this level of the water value chain. This makes it difficult to implement both Option 1 and Option 2 of the dynamic pricing options. In order to allow a dynamic pricing system at this value chain level, the water allocation estimation can still be done annually for the purposes of issuing licenses, but the water use should be calibrated monthly to allow for monthly charges. The proposed amendments to the raw water industry to potentially incorporate dynamic pricing is summarised as follows:

i. Licenced raw water users need to be tracked and registered. Furthermore, it is imperative that raw water use is monitored, and metering is put in place to track such use
ii. Raw water bills should be provided on monthly bases to all users
iii. All raw water users must be included in the dynamic water pricing except for those defined in the National Water Act as Schedule 1 user
iv. Without the above fundamental issues being addressed, implementing dynamic water tariffs at the raw water level will remain a challenge. With that said, we propose that, if a dynamic tariff is implemented, it should apply to all components of the raw water charge, as per Figure 8

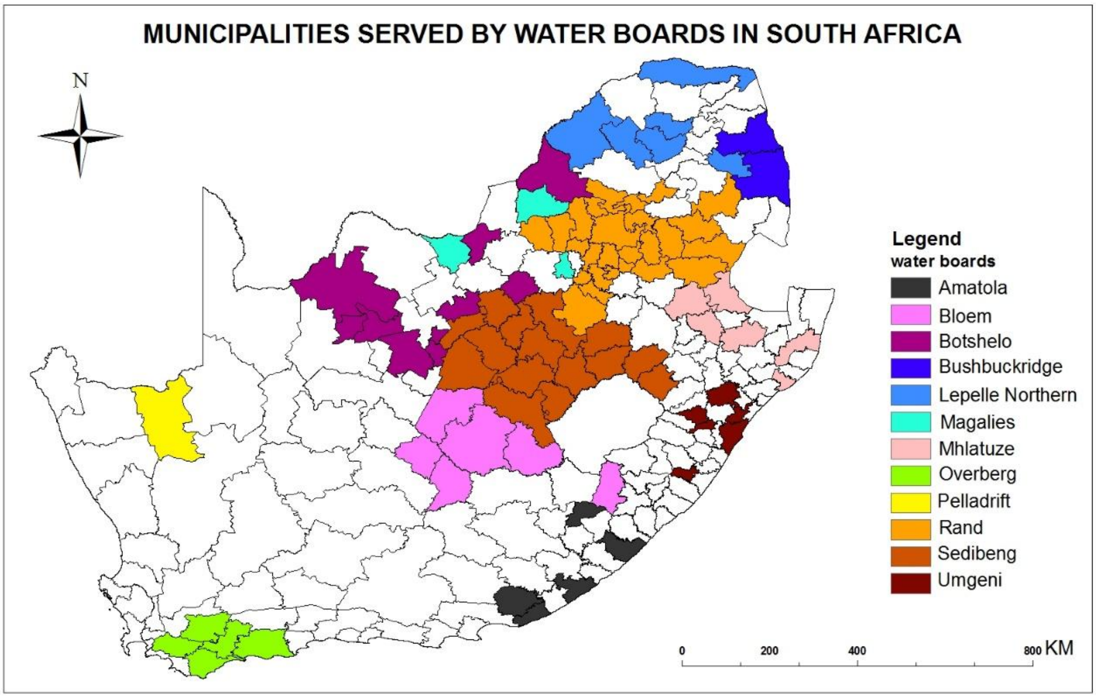
6.2. Bulk and Retail Water Pricing

6.2.1. Overview of Bulk Water Tariffs

Schedule 4B of the South African Constitution assigns the potable water function (retail water services) to local government. South African local government consists of 257 municipalities of which 144 are WSAs. As per Section 155(1) of the Constitution, metropolitan municipalities have exclusive legislative and executive authority within their jurisdictions while such power is shared amongst local municipalities and district municipalities in non-metropolitan areas of the country. As such, the authority to bestow the authorisation to provide water services to either a district or local municipality lies with the Minister of Cooperative Governance and Traditional Affairs, as per Section 84 and 85 of the Municipal Structure Act (Act 117 of 1998).

Of the 144 WSAs, only 90 purchase bulk water from Water Boards[3]. The Water Services Act of 1997 provides for the establishment of Water Boards. As per Chapter 6 of the Water Services Act, Water Boards are established to provide water services to WSAs within their areas of jurisdiction in the form of treated bulk water. Water Boards recover the costs of their operations through the imposition of the bulk water tariff. The bulk water tariff covers the operating and institutional costs of providing bulk water services to WSAs such as labour costs, chemicals, raw water charges and the costs of investment in new and existing infrastructure. Figure 9 shows the areas of the country that are supplied by the seven Water Boards in the country. Figure 9 is based on data from 2016. Since then, several Water Boards have been combined and others have ceased existing. Regardless, all areas highlighted on the map are still areas where a water board remains active.

Figure 9: WSAs served by Water Boards in South Africa



Source: Authors' visualization using data from DWS (2016)

6.2.2. Overview of Retail Water Tariffs

WSAs provide potable water services to final customers and charge a retail water tariff. This retail water tariff covers the municipal costs of providing such services and includes bulk water purchases from Water Boards, labour costs, infrastructure maintenance costs and the costs of investing in new municipal water infrastructure. The provision of sufficient and quality water services has significant social, health and economic benefits, especially for poorer households.

[3] The research team received several pieces of information from the Department of Water and Sanitation regarding the exact number of municipalities served by Water Boards. This number ranges from 79 to 90. The Department also confirmed that WSAs not on these lists sourced raw water directly from the source.

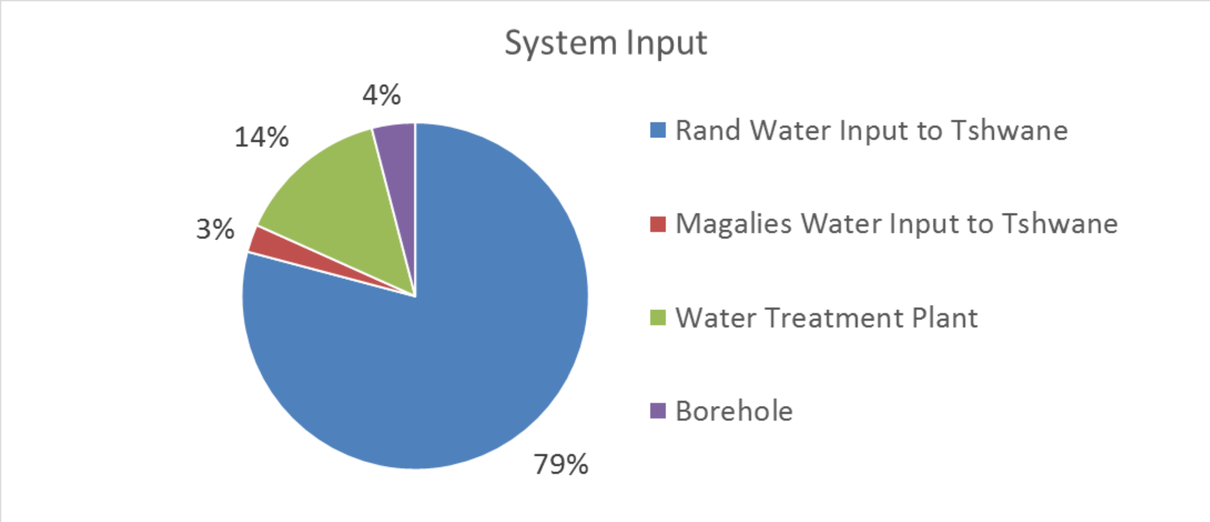
Providing such water services in the context of water scarcity, high poverty and high inequality, as is the case in South Africa, is a difficult balancing task for water policy makers and managers. In pursuit of the objectives of water management, it is widely agreed that setting an appropriate price for a natural resource, such as water, can be an effective mechanism to achieve its efficient and productive use (DWA, 2013). The DWS has several guidelines for setting appropriate tariff structures and water packages aimed at ensuring good-quality water provision, equity in access, affordability, and long-term sustainability. As stated in the legilsation, WSAs can use water tariffs as a cost-recovery tool in their provision of potable water services to their customers. Although they need to recoup water-provision costs, they are obliged by the Free Basic Water Policy of 2002 to provide free basic water to indigent households (DWA, 2002).

For retail water services, the IBT structure is prescribed by regulations under the Water Services Act and the Municipal Systems Act (MSA) (Act 32 of 2000), to address the problems of unequal income distribution and to provide fair access to water (Bailey and Buckley, 2005). Most WSAs in South Africa use the IBT structure. In general, the tariff system consists of two types of charges: fixed and volumetric charges. The volumetric charge varies and is subject to increasing block pricing with a varying number of blocks. A look at the water tariff schedules of WSAs reveals that the number of blocks ranges from 2 blocks to 10. The size of the blocks and prices charged within each block also varies considerably across WSAs. Retail water-service tariffs also vary between user categories (residential, commercial, industrial or public buildings) and consumption (the higher the consumption, the higher the tariff). Non-residential users of water are charged higher tariffs than residential users, on average. Section 28(6) of the Municipal Finance Management Act (MFMA, 2003) provide the legal constraint that must be abided when setting tariffs at the municipality level, the act states that "*Municipal tax and tariffs may not be increased during the financial year except required in terms of a financial recovery plan*". This clause has significant implications for introducing dynamic water tariffs.

6.2.3. Potential Application of Dynamic Water Tariffs at the Bulk Water Level

The second option proposed to introduce the dynamic water pricing system is at the Water Board level i.e. the bulk water tariff. This constitutes the water treatment process of bulk water. Both Option 1 and Option 2 can be implemented at the bulk water tariff component of the value chain. The disadvantage of this approach is that not all municipalities receive their bulk water from Water Boards. As per Figure 9, around 63% (90 out of 144 municipalities authorised to provide water) are served by one or many Water Boards. This suggests that, if the dynamic pricing system is introduced at Water Boards, then it may not be applicable to some municipalities. Moreover, the complication is further driven by the fact that some municipalities are served by more than one Water Board, and, in addition, they have other sources of water to complement the bulk water they purchase from Water Boards. Figure 10 confirms this observation for the City of Tshwane.

Figure 10: The sources of bulk water inputs for the City of Tshwane



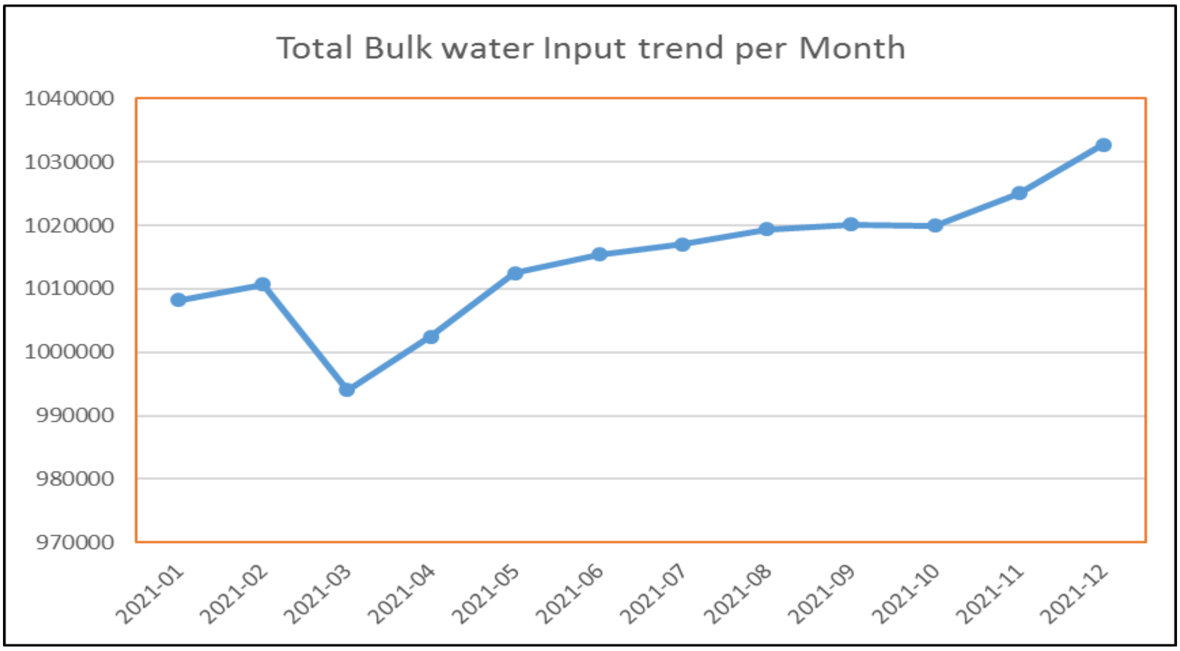
Source: City of Tshwane (June 2022)

Figure 10 shows the different sources of bulk water (system input volume) for the City of Tshwane. While the City receives 70% of its bulk water from Rand Water, a considerable share is sourced from other sources, including its own water treatment and another Water Board, in the form of Magalies Water. This may complicate the potential introduction of dynamic tariffs at the Water Board level, as each Water Board has its own tariff and the scarcity component would depend on its sources of raw water. This will result in the municipality facing several different tariffs and there would be a need to harmonise them for implementation across the municipality.

6.2.4. Potential Application of Dynamic Water Tariffs at the Retail Water Level

The third option for the proper fit of the dynamic pricing in the value chain is at the retail tariff level. Both Option 1 and Option 2, outlined in Section 4, can be implemented at this level. In this discussion, we look at the implementation of Option 1 at a retail tariff level. The discussions in Section 7.2 looks at the implementation of Option 2 i.e. SWP at the municipal level. The discussions in the preceding section confirmed that municipalities source their bulk water from several sources, including more than one Water Board and even from their own water treatment sources. Due to this complexity, this section of the paper explores the possibility of using the total bulk water system input volume available at a given time to a municipality to service as the scarcity measure to link the dynamic water tariff system at municipality level.

Figure 11: Bulk water input trend in the City of Tshwane



Source: City of Tshwane (2022)

Figure 11 shows that the fluctuation of the bulk water input within the 2021 year. An important note to Figure 11 is that the trend does not necessarily correspond to the actual monthly fluctuations experienced in the City. The dry months in the interior of the country is usually in the winter period beginning in May and ending in September. However, Figure 11 contradicts this, as the graph captures a moving average of the water supply for the entire year. With actual bulk water input fluctuation being determined ex-ante, the dynamic pricing system can be anchored against it at a municipality level.

The bulk water input in Figure 11 is the sum of all sourced monthly meter readings processed by Swift to calculate total input in the last 12 months in kl/y. Table 2 shows the details:

Table 2: The total bulk water input calculation

Source	**Data source**	**Detail**
Rand Water	Rand Water monthly meter readings processed by Swift to calculate total input in the last 12 months	Bulk input from Rand Water
WTP	CoT monthly meter readings processed by Swift to calculate total input in the last 12 months	Bulk input from CoT's water treatment plants
Boreholes/Fountains	CoT monthly meter readings processed by Swift to calculate total input in the last 12 months	Bulk input from CoT's fountains & boreholes
Magalies Water	Magalies Water monthly meter readings processed by Swift to calculate total input in the last 12 months.	Bulk input from Magalies Water
Total Bulk Input	Calculated in Swift	Total Bulk Input. Sum of the above inputs

Source: City of Tshwane (2022)

Implementing the dynamic pricing system at the municipal (and Water Board) level excludes most (68%) water users. Municipalities only account for 22% of raw water use in the country (DWS, 2022). Therefore, a disadvantage of placing the system at this level of the value chain will have a lower net benefit as opposed to implementing the system at raw water level. In addition, implementing Option 1 of the dynamic pricing methodology at the retail tariff level is faced with many challenges. These and other challenges were determined through the focus group discussions with the City of Tshwane municipality and are outlined below:

i. Municipal provision of potable water only accounts for approximately 22% of total water use in the country thus excluding the bulk of water use at the raw water level
ii. Municipalities have several sources of bulk water, including water boards and buying raw water directly from the Department
iii. The reservoirs that serve municipalities are numerous and complex systems. As a result, it is difficult for a municipality to track reservoir levels across its systems. Furthermore, the systems are integrated, with some reservoirs feeding others. Therefore, it is difficult to link prices to reservoir levels
iv. Given the complex and integrated system, at some stages of the year, certain reservoirs in a municipality has more water than others. Linking prices to reservoir levels could create several different tariffs for areas across the municipality. Further, some reservoirs serve predominantly poor areas, where increasing prices to reflect scarcity might not have the desired impact on lowering consumption and is likely to have a negative impact on indigent households

Any potential implementation of dynamic water tariffs at the municipal (retail) water tariff level, be it Option 1 or Option 2, should note the following:

1) That the dynamic tariff should be imbedded in the current IBT tariff structure to balance the water policy objectives of equity, affordability, financial and environmental sustainability.
2) The dynamic price should not compromise the municipality's mandate to provide free basic water to indigent households. As a result, the FBW policies of the municipality and/or the first block of the IBT should be exempt from a dynamic tariff.

The discussions above briefly discussed various components of the water management value chain in South Africa and assessed the possibility of introducing a dynamic pricing structure at each of these levels. The discussions confirmed that there are institutional and operational challenges at each of these levels that complicates the implementation of dynamic water tariffs in theory.

7. Analysis and Results

This section presents the analysis of the research project. It constitutes the design, application and simulation of both options for dynamic water pricing i.e. linking water tariffs to temperature variations (SWP) and linking water prices to the available volume of water available in the water resource. In terms of the former, we use the City of Tshwane metropolitan municipality as a case study to illustrate the potential implementation of Option 2 of the dynamic water pricing structure and its potential impact on water demand. In terms of the latter, we use the Mdloti River raw water scheme to illustrate the potential implementation of Option 1 dynamic water pricing option and its potential impact on raw water demand.

As argued in Section 4, linking water prices to temperature and precipitation variations does not necessarily or, more accurately, explicitly show the current scarcity of the water sources and the "increased value" being placed on the resource by users. However, the short-term variations of these variables are linked to availability of water and large variations from these levels can apply pressure on available water resources and water demand behaviour. Furthermore, the application of this option for dynamic pricing is relatively simpler, with very little institutionally or structural changes, and no need for significant investments in technology, such as smart meters. Section 7.2 applies the SWP method using the City of Tshwane as a case study.

Section 7.3 applies Option 1 to a raw water scheme in the form of the Mdloti River. As mentioned, monitoring the level of a dam or water resource is currently being done. As shown in the theoretical analysis and the methodology, users value water given their respective needs and wants. When water becomes relatively scarce, the respective value such users places on water would increase. Section 7.3 applies the *Water Allocation Model* to estimate the demand functions of different water users in the scheme. However, data and institutional challenges limited the scope of this analysis and the project team had to input assumed demand and supply inputs, based on previous literature, to design and simulate dynamic raw water tariffs for the Mdloti River scheme. To reiterate, the results and simulations presented in Section 7.3 do not represent the true demand and supply circumstances at the Mdloti River scheme and the behaviour of its raw water customers.

Prior to presenting the results of our simulations on both options for dynamic pricing, we first present results from our demand functions estimations. This is presented in Section 7.1. Here, we present both the conventional and Stone Geary demand function estimations for each income decile group using information from the 2024/15 living standards survey. The aim of Section 7.1 is two-fold. Firstly, we include climate change variables into the demand estimations to test the impact of these variables on demand. Secondly, we estimate demand functions to allow us to simulate the potential impact dynamic water tariffs for the City of Tshwane simulation in 7.2.

It is important to note that the results presented in this Section are selected results for the presentation of this final report. Previous deliverables submitted to the WRC contain more detailed analysis. The results presented here are succient yet sufficient for the presentation and finalisation of this report.

7.1. Metropolitan Demand Estimations

We commence the analysis by presenting the demand estimations for five income quintiles. Recall from the discussion in the methodology that the data was sourced for metropolitan municipalities using the 2014/15 Living Conditions Survey. All metropolitan municipalities during this period implemented IBT for water. Therefore, this assessment shows the reaction of water consumers in different income categories to changes in water prices. Table 3 shows the demand estimation results for quintile 5 households. The results for quintile 1 to 4 forms part of Annexure A of this report. The key component of the analysis is the price elasticities that were estimated. As indicated, the price elasticities for quintile 1- and 2-income households are statistically insignificant. This suggests that, regardless of the increase in price, demand is unlikely to be impacted. Such price elasticities for lower income households are theoretically supported, as these households tend to use water for largely subsistence reasons and would thus struggle to adjust water use in the face of higher prices.

The price elasticities for income quintile 3 and 5 are statistically significant, suggesting that these types of households are sensitive to price changes. For income quintile 3 households, we estimated a price elasticity of demand of -0.25. This suggests that a 1% increase in the price results in a 0.25% decrease in water consumption. On the other end of the income spectrum with quintile 5 households, we estimated a price elasticity of demand at -0.85. This is a very high price elasticity and theoretically unexpected. However, one can argue such a finding can suggest that higher income households in South Africa seem to benefit from lower water prices and consume water to largely meet their wants, such as for use on luxury items, such as pools and irrigation for gardens. In other words, these households can adjust their consumption with higher increases in price, suggesting a lower marginal benefit derived from water use compared to other households i.e. a flatter demand curve.

Table 3: Demand Estimation for Quintile 5 Households

Variables	Natural Log of Water Consumption
Natural Log of Price	-0.878***
	(0.256)
Natural Log of Income	-0.00343
	(0.0142)
Natual Log of Household Size	0.0956***
	(0.0233)
Natural Log of Number of Bathrooms	0.0533***
	(0.0172)
Natural Log of Rainfall	-0.352***
	(0.0646)
Natural Log of Temperature	0.135***
	(0.0302)
Formal House - Dummy Variable	0.120***
	(0.0442)
Flush Toilet - Dummy Variable	0.166***
	(0.0528)
Receives FBW - Dummy Variable	-0.248***
	(0.0306)
Pool - Dummy Variable	0.417***
	(0.0582)
Constant	6.842***
	(1.046)
Observations	2398
R-Squared	0.103
Robust standard errors in parentheses	
*** p<0.01, ** p<0.05, * p<0.1	

Source: Authors

One of the proposed theoretical benefits of the IBT is that the scarcity of the resource, in this case water, is considered to be incorporated in the price by increasing with higher levels of consumption (Monteiroi and Roseta-Palma (2011). In other words, the more you value the resource the more you pay for it. However, the incorporation of weather variables into the demand functions shows that demand adjusts to changes in these variables. In Table 3, a 1% increase in average temperature increases consumption by 0.135%. In other words, income quintile 5 consumers consume more water (and thus would have a greater marginal willingness to pay for water) with higher temperatures. This suggests that these customers value water more when temperature raises.

In terms of precipitation, a 1% increase in annual precipitation levels decreases quintile 5 household consumption levels by 0.352%. In this case, due to higher levels of rainfall, customers in this quintile group consume less water. The findings on the weather variables are very important, as it shows that consumer value for water is impacted by changes in these variables. In other words, consumers are likely willing to pay more for water when temperatures are higher or when precipitation is lower. However, the IBT is not usually linked to changes in these climate variables. Therefore, the increased value placed on water is not considered in the price. This also has implications for water scarcity. Usually, water levels are compromised when temperatures are higher, or precipitation is lower. The results show that higher temperatures and lower precipitation levels will result in greater levels of consumption when water supply is likely to be simultaneously under pressure.

The results from the demand estimations are important in our assessment of the potential impacts of dynamic water pricing on water consumers. Firstly, the results do show that higher income households are relatively sensitive to price increases and can adjust their consumption downwards. Secondly, it also shows that such households are sensitive to climate factors, with increasing demand during higher temperatures and lower precipitation. This confirms that, when the design of the IBT does not explicitly adjust to climate variables, the marginal cost of water does not increase in the face of these scarcity driving factors. Under the assumption that higher temperatures and lower precipitation levels decrease the supply of water, this should result in the value of water increasing. However, if the price of water does not adjust to incorporate this scarcity, consumption levels are likely to reflect the increased value of water.

Such results clearly support the rationale for dynamic water pricing where the marginal price of water explicitly adjusts for factors that impact on water scarcity and increased water demand (Option 2 – SWP) or actual scarcity at the water resource (Option 1). It is likely that higher income households would adjust their consumption downwards in the face of increasing marginal cost of water. Therefore, dynamic pricing at higher consumption blocks of the IBT would likely have an impact in decreasing consumption. The results also show that lower income households are less sensitive to increasing prices, given their largely subsistence use of water. Such households and their consumption levels should be exempt from dynamic pricing. The first block of the IBT, which is essentially the subsistence level of water use, should be exempt from dynamic pricing to protect lower income water users. This is under the assumption that lower income households consume less than higher income households.
Related to the preceding point, Table 4 below shows the Stone Geary demand estimation of water for all households i.e. not disaggregated by income quintiles. Recall that the Stone Geary estimation generates a price inelastic portion of water demand and a variable consumption component that adjusts with price increases. Our analysis estimates a minimum consumption level of 9.85kl i.e. households will not consume less than this amount, regardless of the price of water. Alternatively, this consumption level is the price inelastic portion i.e. this level of consumption is not sensitive to price changes.

Table 4: Stone Geary Estimation

Variables	Monthly Water Consumption
Income/Average Water Price	0.000727**
	(0.000)
Household Size	0.105
	(0.097)
Number of Toilets in House	1.906***
	(0.462)
Annual Rainfall	0.00256
	(0.002)
Household has a Garden	1.228*
	(0.653)
Household has a Flush Toilet	1.583***
	(0.570)
Formal Household	1.200*
	(0.719)
Household receives Free Basic Water	-4.470***
	(0.579)
Household in an Urban Area	0.796
	(0.705)
Household has a Pool	7.007***
	(2.049)
Constant	9.844***
	(1.125)
Observations	3,168
R-squared	0.09
Robust standard errors in parentheses	
*** p<0.01, ** p<0.05, * p<0.1	
Lifeline Level	**9.85**

Source: Authors

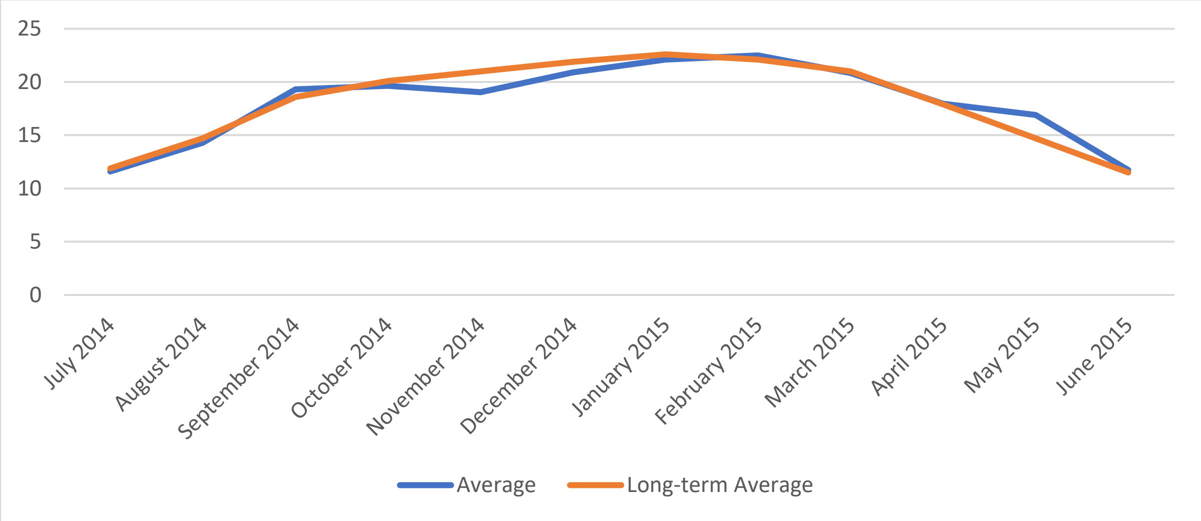
7.2. Application of the SWP Method – City of Tshwane Case Study

The analysis in Section 7.1 undertook conventional and Stone Geary demand estimations to ascertain how consumers react to climate variables and to price increases in the IBTs applied in their demand for water. We concluded that the IBT does not increase the marginal cost of water with changes in climate variables. It also shows that increasing the marginal cost of water in the face of scarcity can result in downward consumption in higher income households.

Given the results above, this section explores the implementation of one of the options of introducing dynamic water pricing i.e. the SWP option, using the City of Tshwane as a case study. Recall, the SWP option incorporates deviations of climate variables from their long run trends into the pricing system. This is under the assumption that such deviations from long run trends results in an unexpected pressure on water supply. As per the demand estimations in Section 7.1, temperature and precipitation variables impacts on demand, as our estimations show that water use increases at high temperatures and low levels of precipitation. Both effects results in an increasing marginal value of water use. As such, the goal of dynamic water pricing is to ensure that the increased value attached to water is incorporated into the cost towards supporting an appropriate balance between water demand and supply.

From the description of the SWP in Section 4.2 above, the incorporation of climate change variables into the pricing mechanisms would see variations in temperature and precipitation as the key variable of analysis. Figure 12 below shows the deviation of the monthly average temperatures from July 2014 to June 2015 (2014/15 municipal financial year) to its long run average per month over 20 years for the City of Tshwane region. This is aligned to the information received from the 2014/15 Living Conditions Survey, which covers the 2014/15 municipal financial year. As it can be seen, there are clear deviations in temperatures in the summer months (November 2014 to January 2015), where average temperatures are lower than long term averages, and the winter months (April 2015 to June 2015), where temperatures are higher than long term averages. In terms of the latter, our demand estimations would suggest that demand in winter during this period would have been higher than expected, as temperatures are higher than the general average. This is likely to apply pressure on water supply.

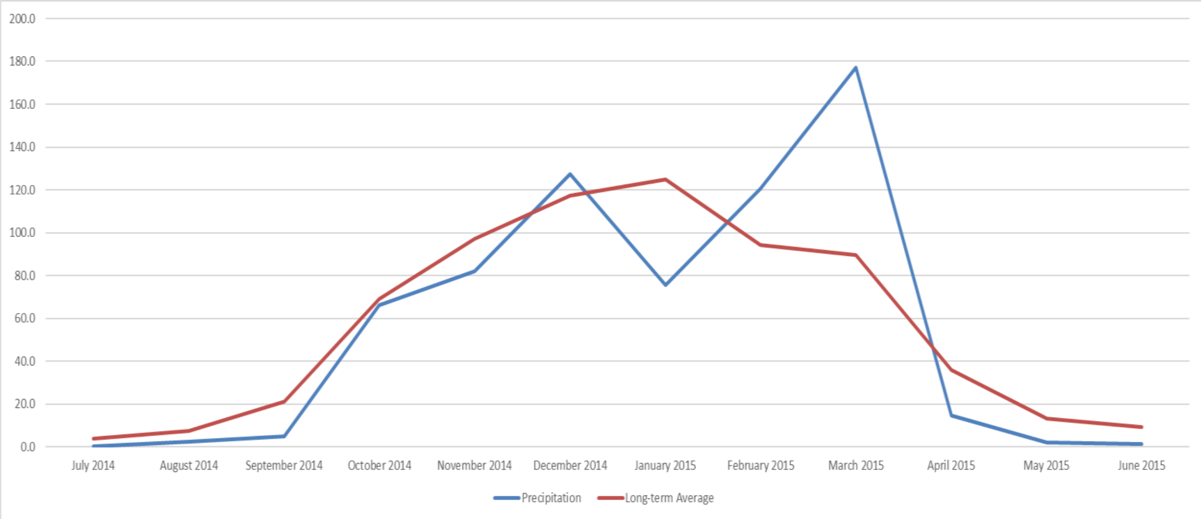
Figure 12: Variation in Monthly Temperatures from Long Run Averages – Tshwane



Source: WeatherSA

Figure 13 undertakes a similar analysis for the City of Tshwane for the same period but looking at deviations in precipitation. Immediately, one can clearly see distinct volatility in the precipitation for the 2014/15 financial year relative to the long-term trend. Such a trend is one of the consequences of climate change i.e. volatility in usual weather patterns. In general, precipitation was lower than its long-term average during the period, including a significant fall in precipitation levels in January 2015, one of the hottest months, and a large increase in precipitation in March 2015. The incorporation of dynamic tariffs can also play a role in smoothing consumption levels in the face of large deviations in climate factors that impact on water demand and supply.

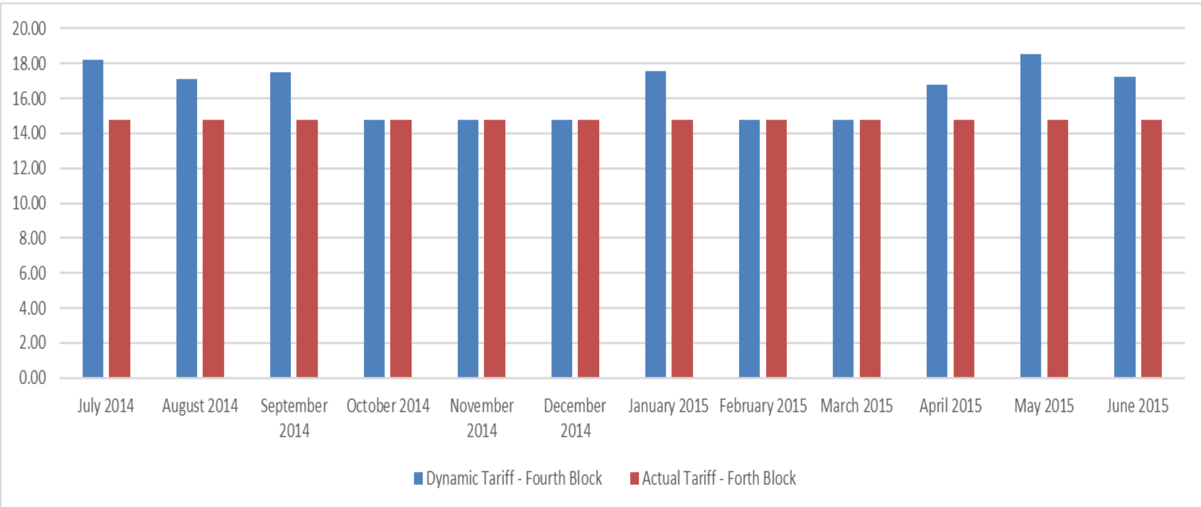
Figure 13: Variation in Monthly Precipitation from Long Run Averages – Tshwane



Source: WeatherSA

Figure 14 implements the SWP option for the City of Tshwane block 4 water tariff. As mentioned, it incorporates the deviations of temperature and precipitation into the price of water, thus sending the signal of potential scarcity and greater value of water being placed during these times. The City of Tshwane block 4 water tariff for the 2014/15 financial year was R14.77 for consumption between 19-24kl. Implementing the SWP option sees a price increase in July 2014 to September 2014, during the winter months when demand is high, but supply is constrained due to a lack of precipitation. There is also a price increase in January 2015, due to a large fall in precipitation in January for the year, and price increases in April 2015 to June 2015, due here to lower deviations in precipitation levels and higher temperatures during this period.

Figure 14: SWP on Water Block 4 – Tshwane



Source: Authors

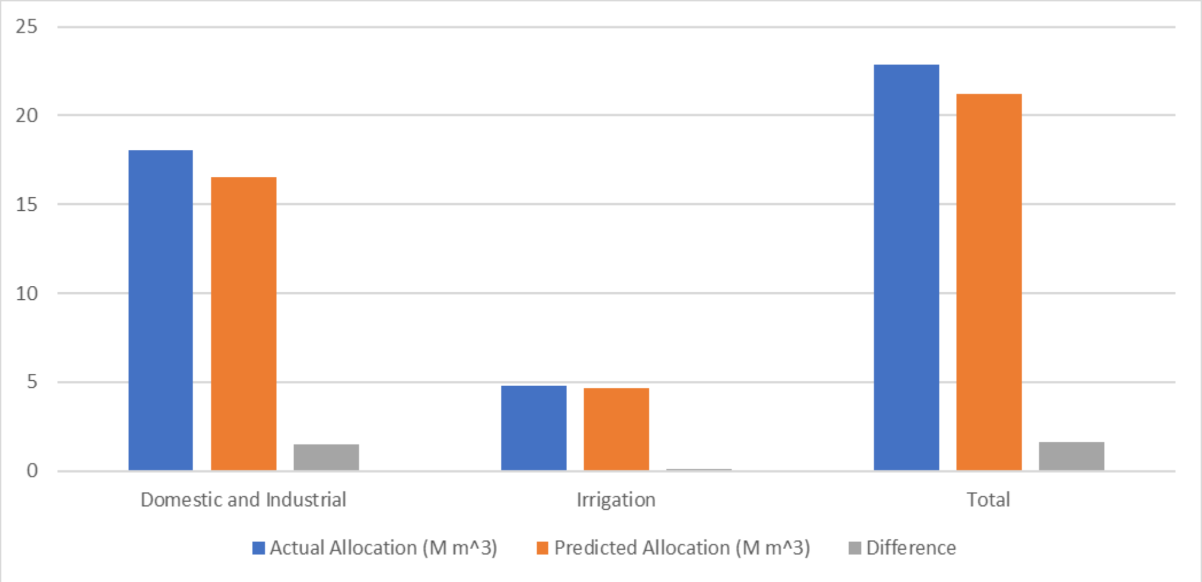
Information on monthly precipitation and temperatures are readily available but with a month's lag. If there are large deviations in precipitation and temperature levels in the previous month, one can assume, from our analysis, that water use would have increased. The municipality can then use the preceding (current) month to adjust consumption and lower levels on demand and supply.

7.3. Application of Dynamic Pricing at the Raw Water Level – Mdloti River Case Study

This section attempts to design and simulate dynamic raw water tariffs in the Mdloti River water scheme (Hazlemere dam) in the form of Option 1 for dynamic water prices i.e. linking the tariff to the available volume of water at a water resource. The assessment was undertaken against raw water charges in the scheme in the 2023/24 financial year . The recently developed *Water Allocation Model* was used to determine this marginal benefit and efficient allocation of water relative to what is actually allocated by the Department. In order to determine the marginal benefit of water use, one needs to estimate raw water demand functions for each user. However, it is important to note that the lack of data on **actual** raw water use made this assessment impossible. As a result, these actual demand functions cannot be estimated. Therefore, the project team inputted demand and supply assumptions for the Mdloti River scheme using coefficients garnered from previous literature. While not an accurate depiction of water use benefit and efficient allocation of water across water users in the Mdloti River scheme, the assumptions applied allowed the team to design and illustrate raw water tariffs for the scheme. This lack of data due to the inability of monitoring raw water use is a major detriment to assessing raw water allocation for economic efficiency, improving water allocation and implementing dynamic prices.

Given the above, the actual application of the *Water Allocation Model* on an actual scheme is not fully possible. However, we show the value and application of the *Water Allocation Model* using simulated demand functions to show how water allocation can be done using demand functions, how such demand functions can be used to determine the marginal benefit each user attaches to water use and how such information can be used to design dynamic raw water tariffs. Figure 15 shows the differences in the actual raw water allocation and the predicted water allocation with our simulated demand functions. From Figure 15, the analysis suggests that the irrigation customer values water more in the scheme relative to domestic users. In fact, demand from both customers is actually lower than the actual allocation given to both customers.

Figure 15: Actual Water Allocation vs Modelled Water Allocation – Mdloti River

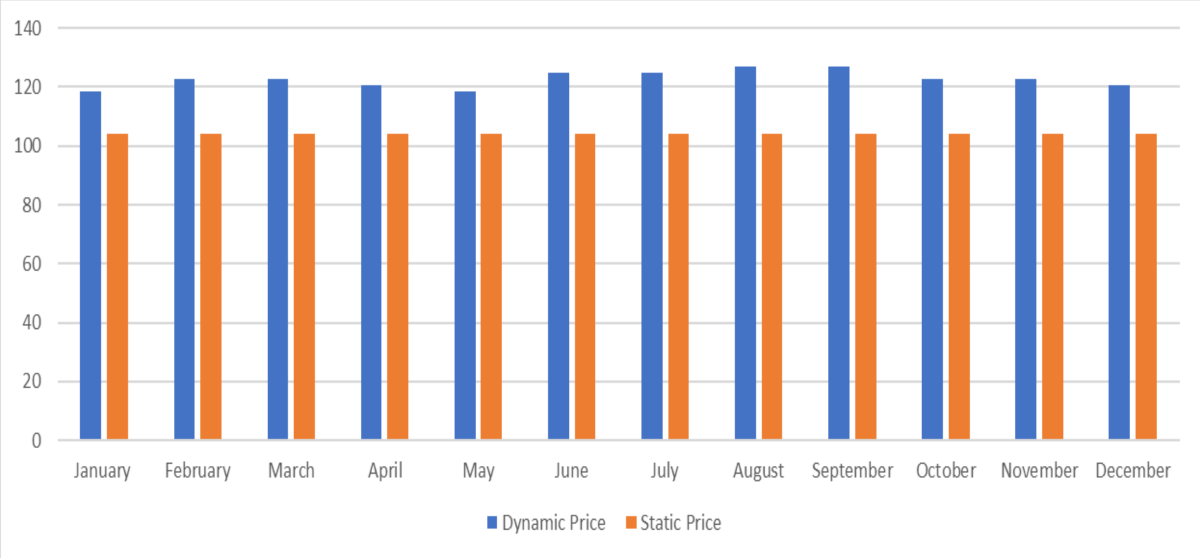


Source: Authors

To reiterate, the results predicted above by the *Water Allocation Model* is not based on actual demand functions estimated from raw water consumption data from users at the Mdloti River scheme. It is based on price elasticity assumptions garnered from previous literature. This was done to generate the marginal benefit each customer places on water in order to assist us in developing accurate dynamic tariffs relative to the marginal benefit placed on the demand side by customers and the increase in the value of water due to scarcity. Figure 16 shows the changes in the raw water price at the scheme level relative to the available water in the water resource compared to the current "static" raw water price applied to domestic and industrial customers at the Mdloti River Scheme. This was applied over a calendar year (January to December), but the price aligns to the financial year of April to March of the following year.

During the period of analysis, the Mdloti River scheme was never at full capacity. The *Water Allocation Model*, using the simulated marginal benefit, estimated the impact of the levels of water scarcity on the raw water tariff. Section 6.1.4 showed that the raw water tariff in South Africa has several components. In our analysis, we applied the dynamic pricing mechanism to the consolidated raw water tariff. Figure 16 shows that the dynamic raw water tariff was consistently higher than the actual raw water tariff, as devised by the Department, during the period of analysis. Under the assumption that the raw water tariff formulated by the Department for this scheme reflects the true cost of providing raw water in the absence of scarcity, then the dynamic raw water tariffs simulated shows the increased in the cost of water (or value placed on water) due to scarcity in this scheme. Over the period, the scheme never operated at 100% capacity. Interestingly, there is a hike in the prices around June to September, which is the drier parts of the year at this scheme.

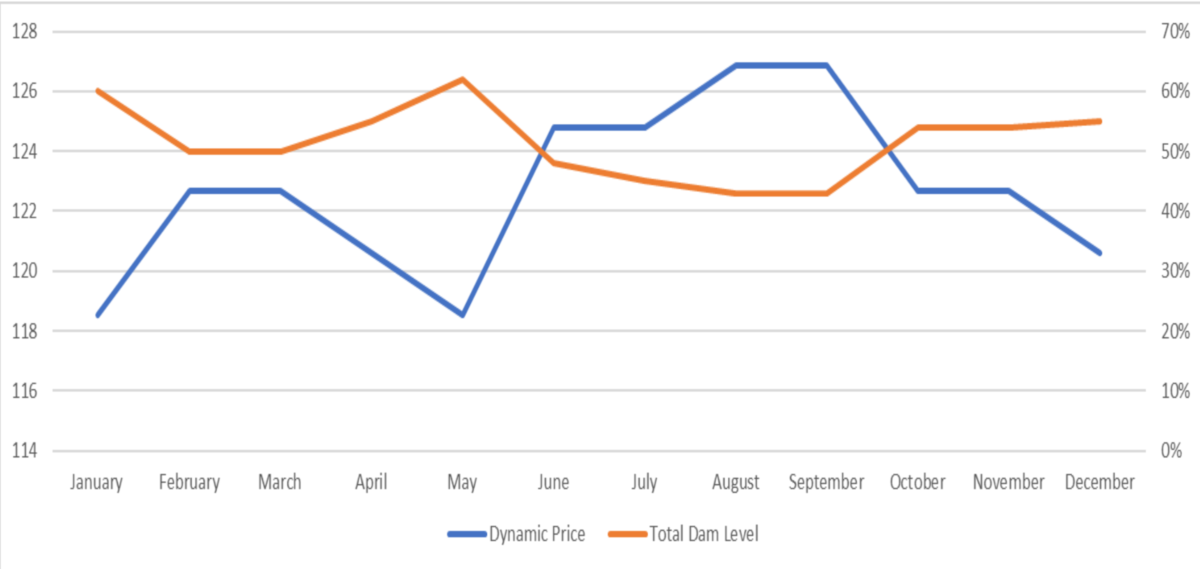
Figure 16: Dynamic Pricing – Mdloti River – 2023/24



Source: Authors

Figure 17 extends the analysis above to show the movement of the dam levels and the relative raw water price. During this period, the available water at the scheme ranged from the low 40% to a peak of above 60%. By being below full capacity, this alone increased the raw water tariff relative to the static tariff applied at this scheme. Additionally, one can then see how the price fluctuated with fluctuations in the available water volume, with the dynamic price reaching a maximum in August to September, when available water capacity was at its lowest. It is important to reiterate that the value at which the dynamic raw water price increases is based on the calculated marginal value users place on water and the impact on raw water costs of increased scarcity.

Figure 17: Dynamic Pricing and Dam Levels – Mdloti River



Source: Authors

8. Conclusions and Summary of Key Findings

Like any economic good, the efficient allocation of water, via the market, can be achieved through efficient pricing. However, water is no normal economic good. A component of water consumption is necessary for the sustaining of human life. Indeed, a portion of water is necessary for all forms of life, for vegetation and for the sustaining of most environments. Water is also an economic good, used for consumption purposes other than drinking, such as cooking and bathing. It is also used for productive (commercial) purposes such as in agriculture or as inputs in many industries.

The management of raw water resources and the delivery of potable water for social and economic needs is also a complex contemporary problem and a delicate balancing act of these various competing needs for water. Governments across the world are faced with the need to bridge the gap between the demand for water and the supply for water. While the demand and supply for water is complicated by the very nature of water as an economic and social good, these factors are further complicated by contemporary social, economic, political and natural issues. On the demand side, modern day spatial patterns, dynamics of economic activities, urbanisation, changing technology and a host of other factors impact on the demand for water. Water availability, planning and infrastructure, abstraction and purification technologies and climate change are but some of the factors that impact on the supply of water.

One of the key mechanisms used to promote the equitable and efficient allocation of water is the pricing mechanism. The appropriate pricing of water, both in the raw form and potable form, is key in this regard. There is substantial work done on water pricing, both from the academic and policy side. In South Africa, the allocation of raw water and the overall pricing of both untreated and treated water across the water value chain intends to achieve a balance of these various competing goals. In terms of raw water, the pricing intends to protect the water resource, improve efficiency and cover operating costs and future water resource investment needs. On the potable water side, municipalities generally use the IBT methodology, attempting to ensure the protection of the poor, the sustainability of the service and the promotion of efficient water allocation and use.

The design of a pricing mechanism that balances these objectives is complex. Pricing structures should be continuously innovating and evolving, particularly when it comes to being sensitive to the changing political, economic, social and natural changes. Given this, this study constituted exploratory research to assess the merits and possibilities of introducing dynamic water pricing in the South African water sector. Dynamic water pricing essentially adjusts the price of water for a change in the marginal cost or marginal benefit of the use of the good, thus sending the signal of an increased value of water at time of water scarcity or changes in demand behaviour. On the supply side, the issue of water scarcity is a growing concern in contemporary society, given the impact of climate change. Climate change results in an increased volatility in weather patterns and a greater occurrence of extreme weather events, such as droughts and floods. Ideally, dynamic factors that impact on the supply and demand of prices need to be incorporated into the price.

There are two largely accepted methods to implement dynamic water pricing, namely, (1) link the water tariff to available water volumes at a water resource (reservoir) or (2) link the water tariff to exogenous climate variables, such as temperature and rainfall. These two methods were explored and simulated for the South African water sector. At the inception of the project, the intended focus was on exploring dynamic pricing at the potable water (municipal) level. However, this position evolved through the guidance of the Reference Group and the project explored the merits of dynamic water pricing across the value chain.

In general, the study concluded that it would prove very difficult to full implement dynamic water pricing in South Africa, given the current configuration, practices and operations at different levels of the water value chain. Nonetheless, the research achieved the following objectives:

i. Showed the theoretical rationale for a dynamic water pricing system
ii. Outlined the options of implementing a dynamic water pricing system
iii. Critically outlined the water value chain in South Africa and explored the scope of implementing dynamic water pricing within the current configuration of the industry
iv. Undertook simulations to show the potential operation of dynamic water pricing and its potential impact on water supply and demand
v. Proposed amendments to certain aspects of the South African value chain to allow for the implementation of dynamic pricing

8.1. Key Findings

Some of the key findings of this report are summarised as follows:

i. Our analysis shows that the current water pricing system in South Africa, be it from a raw, bulk or retail water tariff, does not explicitly or implicitly incorporate issues of scarcity in its design, in terms of either:
    a. Scarcity linked to available water resources at a given location and point in time
    b. Scarcity that is seasonal i.e. at times of the with low rainfall (or high temperature)
ii. Econometric analysis showed that consumer water demand is positively impacted by higher temperatures and lower rainfall, thus suggesting a greater demand (and increased pressure on water supply) during these periods of the year
iii. A pricing system that does not incorporate aspects of scarcity can contribute to deviations from the supply and demand of water, putting pressure on water supplies
iv. The prices of raw, bulk and retail water are static i.e. it does not change during a financial (or calendar) year. This makes it difficult to account for supply and demand changes or shocks during the year
v. Legislation, in specific the Water Services Act, allows for drought and seasonal tariffs, thus empowering water authorities to adjust tariffs to control for demand and supply fluctuations

vi. To date, drought tariffs have been implemented, but these are a short term "crisis" driven approach to controlling water demand as a last resort. Dynamic water tariffs, be it directly linked to water supply or seasonal, intends to embed the notion of water scarcity on the consumer and create a culture that can ultimate influence short and long run water demand and supply

vii. Our analysis shows that embedding a dynamic price into the South Africa water system is most efficient and accurate using the option that links the price to the actual volume of water available as opposed to embedding deviations of climate change variables in the price system
    a. However, this option cannot be implemented at the bulk water (water boards) or retail water (municipal) levels
        i. Water boards do not serve all municipalities, as some municipalities treat their own raw water
        ii. Municipalities use several sources for bulk water
        iii. The reservoirs at the municipal level is complex, serving different areas. It will be difficult to monitor these reservoirs without investment in systems and technologies
        iv. One would need to implement dynamic pricing linked to the water source through the use of smart water meters to adjust the price relative to the volume of water available. This will result in significant investments at the municipal level

viii. From our analysis, it is most feasible for dynamic pricing to be implemented at the raw water level. This conclusion was reached based on:
    a. It covers most of the water use in the country. Municipalities only account for 22% of total water use in the country
    b. Raw water sold to municipal customers can make its way to the final customer through the pricing system

ix. However, the current state of raw water allocation and billing makes it difficult to implement dynamic pricing. Some of these issues are:
    a. The current practice of allocating water resources prioritises equity over efficiency. It is difficult to determine whether current allocations are efficient and reaching the customers that need it the most
    b. While there are systems in place to monitor dam levels, linking such levels to the price of raw water can be problematic as there are currently limited methods to monitor raw water consumption in water users. Currently, there are no meters monitoring raw water use across a large proportion of raw water users
    c. Water billing would need to be done monthly, which is not the case for certain category of users
    d. The inability to register raw water users and monitor raw water usage is a major concern and a major detriment towards the efficient allocation of water and the implementation of dynamic pricing. Without such information, it is not possible to determine the value users place on water

x. Our analysis shows that option 2 for implementing dynamic tariffs i.e. embedding deviations in climate variables in the price is a feasible and easy to implement option.

It is also legally allowed and should impact on easing supply during times of potential water supply shortages

a. This option can be easily implemented at the raw, bulk and retail water levels and can be a feasible option to proactively control water demand during periods of low rainfall and avoid stringent measures such as water restrictions and drought tariffs

Water drought tariffs are currently being implemented in South Africa to curb short-run water shortages in certain parts of the country, driven at the bulk water level by water boards. While there are provisions for water drought tariffs in the legislative and institutional framework of the country, the relative proliferation of its use shows an increasing need to control water consumption on the demand side in the face of water supply constraints driven by climate issues. Given these developments, there is clearly a need for such a dynamic price system to be institutionalise in the South African water sector. However, the current institutional set up in the water market was not fully designed for the implementation of demand side controls using the price mechanism. This is due to the system being designed at a time when there was not an imperative need to control water use. Therefore, the finding of this project intends to introduce the concept of dynamic water pricing into the debate on South Africa's water pricing framework.

8.2. Limitations of the Study and Future Work

It is important to emphasise that this research and the concept of dynamic water pricing in South Africa was exploratory i.e. the concept of dynamic water pricing was introduced, and its potential benefits highlighted. However, substantial changes to the current institutional configuration of raw water management and allocation is required. These proposed changes are highlighted in this report. Furthermore, we propose the following projects to further support the role of dynamic water pricing in South Africa:

i. Detailed case study at a scheme where actual consumption data can be collected to determine water use and efficient water allocation
ii. Development of more complex hydro-economic models that take into consideration both supply and demand side factors to obtain a proper assessment of climate and demand dynamics at the scheme level

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