PARCHED PROSPECTS 3: USING THE INTERNATIONAL FUTURES MODEL TO FORECAST WATER SUPPLY AND WITHDRAWALS IN SOUTH AFRICA

Zachary Donnenfeld, Steve Hedden, Barry Hughes, Jakkie Cilliers and Courtney Crookes

WATER RESEARCH COMMISSION

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Parched Prospects 3: Using the International Futures model to forecast water supply and withdrawals in South Africa

Report to the
WATER RESEARCH COMMISSION

by

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African Futures Project (AFP), a partnership between the Institute for Security Studies (ISS) and the Frederick S. Pardee Center for International Futures

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EXECUTIVE SUMMARY

Background

South Africa is over-exploiting its freshwater resources and the national level and water could be a major constrain on development going forward. This project improved the water model of the International Futures (IFs) forecasting system, and uses IFs to forecast water demand and supply for South Africa at a national level to 2035, the time horizon for the national water strategy. The research finds that the gap between demand and supply persists over time, and that the solutions proposed by the Departments of Water and Sanitation (DWS) (and previously the Department of Water Affairs) will be insufficient to reconcile that gap. This report offers a comprehensive picture of the state of South Africa's water system, a dynamic representation of how the water sector might unfold over time, and provides a sense of how water interacts with other key aspects of human, social and economic development.

Methodology

The IFs system integrates over 4 000 historical data series across a number of important development systems, including: agriculture, demography, economics, education, energy, the environment, governance, health, infrastructure, international politics and technology, and now also water. These sub-models are also dynamically connected with each other, simulating how changes in one system lead to changes across all other systems.

IFs leverages those historical data series to identify trends and model dynamic relationships to forecast hundreds of variables for 186 countries for every year from 2015 to 2100. The tool helps users understand how the global system may unfold, thereby allowing them to think more systematically about potential futures, as well as development goals and targets. This project uses are three main avenues for analysis in IFs: historical data analysis (cross-sectional and longitudinal), Current Path analysis (where systems seem to be developing), and alternative scenario development (exploring if-then statements about the future).

The IFs tool helps policy makers get a sense of the effects of development interventions, as well as exogenous shifts in the development landscape. Such analyses therefore provide a data- and evidence-based framework to help policymakers and practitioners think more carefully about trade-offs among choices in the face of uncertainty.

The authors complemented the water data within IFs, which comes from the United Nations (UN) Food and Agriculture AQUASTAT database, with water supply and demand information available in various government documents, an analysis of all major reconciliation strategies from DWS and data gleaned from interviews and other outside research.

The project highlights the scope of the challenges facing South Africa's water sector by offering a comprehensive supply forecast along with a sense of how water withdrawals are constrained by water scarcity. But, because IFs uses the country as its unit of analysis, the forecast presented here necessarily glosses over the substantial regional vulnerabilities in the country, the impact of deteriorating water quality on the overall system or many of the other grid-based elements that are common to other hydrological research. The intention is to advance the water debate in policy circles in South Africa with an eye toward implementing sustainable and resilient solutions to water scarcity and human development in the country.

Objectives and aims

- The purpose of this project is to provide an authoritative forecast of water supply and demand in South Africa at the national level
- To achieve that the project also improved the water sub-model of IFs by integrating water supply and demand and more fully developed the drivers of withdrawals
- Based on these model improvements, the project will use IFs to explore the implications of water scarcity on key aspects of human development
- The intention is to disseminate the findings of this research in an accessible format to inform policy-makers in South Africa

Results, discussion and conclusion

South Africa is facing a serious threat to its water security. The country is already over-exploiting its renewable resources and the current plans to rectify that gap, even if completed on time and to specifications, are inadequate. In fact, even if South Africa implements those plans on schedule *and* reduces total withdrawals by 1.2km^3 below a previous forecast (from an early publication in this project), the country still continues to over-exploit its water resources until 2035, with truly unknowable consequences for individuals and communities.

South Africa can only address its water challenges through a combination of supply enhancement *and* demand reduction measures. At present, the vast majority of attention is devoted to increasing supply. However, the interventions proposed to increase supply will not close the gap by 2035. It is possible for South Africa to reconcile its water system by using available technologies, but only if it acts with urgency, by

- Implementing aggressive water conservation and demand reduction measures
- Increasing the amount of wastewater that is treated and reused
- Increasing groundwater extraction, particularly for agriculture
- Exploring new technologies – including renewable energy and desalination
- Create financial incentives for efficiency

This report does outline a path to a sustainable and resilient water sector in South Africa, but the proposed interventions are aggressive and would require a significant political investment and engagement across sectors and communities. To understand the precise policies necessary to close the gap, this report recommends that additional research be focused in the following areas:

- A national study of the country's water infrastructure
- Improve the monitoring and evaluation of wastewater treatment facilities
- Explore options for a tiered pricing system that reflects local water scarcity
- Better understanding of how much groundwater is available
- Improve the monitoring of surface water quality in South Africa
- Explore new technologies (particularly in coastal cities)

Capacity building

For this project the ISS recruited an MA candidate from the University of Pretoria, Ms Courtney Crookes, who is studying hydrology and who will use the project as the basis for her thesis. The ISS also worked closely with DWS, the Agricultural Research Council, and the Department of Agriculture, Forestry and Fisheries to develop the forecast and refine the baseline assumptions presented in this report.

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LIST OF ABBREVIATIONS

AEI – Area equipped for irrigation

AFP – African Futures Project

APAP – Department of Agriculture Forestry and Fisheries. Agricultural Policy Action Plan

CPI – Consumer price index

DWS – Department of Water and Sanitation

DWA – Department of Water Affairs

ERWR – External renewable water resources

FAO – United Nations Food and Agriculture Organization

GDP – Gross Domestic Product

Ha – Hectare

IFs – International Futures forecasting system

IRWR – Internal renewable water resources

ISS – Institute for Security Studies

IPCC – Intergovernmental Panel on Climate Change

Km^3 – Cubic kilometre

kWh – Kilowatt hour

l/c/d – Litres per capita per day

MCWAP - Mokolo Dam Crocodile River Water Augmentation Project

NDP – National Development Plan

NIWIS – National Integrated Water Information System

NWRS – National Water Resource Strategy

NWRS2 – National Water Resource Strategy 2

OECD – Organisation for Economic Cooperation and Development

Pardee Center – Frederick S. Pardee Center for International Futures

PID – proportional-integral-derivate

pH – Potential of hydrogen

PPP – Purchasing Power Parity

SAWS – South African Weather Service

StatsSA – Statistics South Africa

TFR – Total Fertility rates

TRWR – Total renewable water resources

UIA – Utilisation intensity of irrigated land

UN – United Nations

UNESCO – United Nations Educational Scientific and Cultural Organisation

USD – United States Dollars

WCWDM – Water conservation and water demand management

WRC – Water Research Commission

WRCI – Total water requirement of crops per unit

WI – Water demand for irrigation

ZAR – South African Rand

1 INTRODUCTION AND OBJECTIVES

South Africa's water sector sits in a precarious state. The country is already over-exploiting its renewable resources and, according to the International Futures (IFs) model, withdrawals are forecast to increase in all three sectors (agricultural, industrial and municipal) until 2035. Meanwhile, much of South Africa's water infrastructure is in disrepair, and dam levels are dangerously low – particularly in the Western Cape province, where surface water storage levels are at an estimated 31% (considered **very low** for the time of year) in the Breede-Gouritz catchment as of 24 October 2017.[i] Furthermore, the proposed solutions for reconciling the gap between supply and demand put forward by the Department of Water and Sanitation (DWS) appears to be insufficient.

This report provides a national-level forecast of water supply and withdrawals in South Africa until 2035, the time horizon for the National Water Resource Strategy (NWRS2). It then explores some alternative scenarios and their impact on both the water sector and on human and economic development. The research provides a national overview of the current challenges facing the water sector, along with a forecast to illustrate a likely future trajectory.

The goal is to highlight the gap between supply and demand in South Africa's, to explore the evolution of that gap over time, and finally to identify potential solutions that could reconcile South Africa's water system. While South Africa is a water scarce country that is currently over-exploiting its renewable resources, there are extant, affordable technologies that government, business and private individuals could employ to help realign supply and demand while ensuring water security for future generations.

This report is guided by the Institute for Security Studies (ISS) on behalf of the African Futures Project (AFP). The AFP is a collaboration between the ISS and the Frederick S. Pardee Center for International Futures (Pardee Center) at the Josef Korbel School of International Studies at the University of Denver. The AFP is an in-depth, multi-method research endeavour designed to advance practical solutions to some of Africa's most pressing development challenges. Together, the partners represent an unparalleled set of capabilities and produce forward-looking, policy-driven research. ISS is an African organisation with a substantial legacy of policy work on human security, peace, and development across the continent. The Pardee Center, on the other hand, brings decades of quantitative modelling expertise through the IFs platform.

1.1 Background

Water scarcity is rapidly emerging as a critical global issue. From local farmer-herder conflicts in north-eastern Kenya to concerns about city-level sustainability (as is the case with the capital of Yemen, Sana'a), water is increasingly viewed as an authentic security issue.[ii] Water crises can occur locally, nationally and even across entire regions. Water scarcity now ranks as the third most concerning global risk, according to the 2017 World Economic Forum Global Risk Report, although the nature of potential water crises differs from one country to another as well as within individual countries.[iii]

Water scarcity is not the only potential water-related challenge. Too much water can result in catastrophic floods. In August 2017, monsoon rains devastated South Asia – submerging nearly half of Bangladesh and killing more than 1 200 people – and the United States saw the most severe downpour in its history (roughly 150cm over 8 days), all in one month.[iv] In South Africa in October 2017, a storm dropped a record rainfall on the Durban metropolitan area, killing at least 8 people.[v]

Furthermore, water quality can be as serious a problem as water quantity.[vi] Acid mine drainage, often associated with heavy metals like uranium, is a major risk to South Africa in the Witwatersrand goldfields and Mpumalanga coalfields.[vii] Moreover, general over-exploitation of water ecosystems can deteriorate their integrity and ultimately compromise the ability of rivers and wetlands to regenerate themselves.

In short, water is a precious resource that must be managed with great care across all levels of government. The National Development Plan 2030 (NDP) clearly states that food, fuel and water are interconnected, particularly in the context of climate change and their impact on one another.[viii] Given the state of South Africa's water sector however, it is clear that the public and private response has thus far been inadequate to address the scale of the challenge.

1.1.1 South African context

South Africa is characterised by low and variable annual rainfall along with high levels of natural evaporation.[ix] Average annual rainfall in South Africa is only 495 mm (accoding to the World Bank); whereas the world average is 1 033 mm.[x] Evaporation losses are often three times more than rainfall.[xi]

Furthermore, what meagre rainfall there is, is unevenly distributed. The western region of

South Africa is particularly arid, with the driest regions receiving an average of less than 100 mm of rain per annum, while the eastern parts of the country can experience in excess of 1 000 mm per year[xii] Water resources and the environment are particularly under threat in the Mpumalanga Highveld coalfields, upstream of the Vaal and Loskop dams and in the Lephalale-Waterberg area, arising from the mining and combustion of coal. The NDP also calls for the urgent need to revise water allocations in the upper Vaal and Olifants River water-management areas.[xiii]

Not only is South Africa a dry country (with less water per capita than, for example, Namibia and Botswana, which are considered arid), but it also uses more water on a per capita basis than most others. World average water consumption is estimated at 173 litres per person per day (l/c/d); the average per capita water consumption in South Africa is between 235 and 290 litres a day.[xiv] In his 2010 state-of-the-nation address, President Jacob Zuma said, “We are not a water-rich country. Yet we still lose a lot of water through leaking pipes and inadequate infrastructure. We will be putting in place measures to reduce our water loss by half by 2014.”[xv] Moreover, the NDP notes that “since South Africa is already a water-scarce country, greater attention will have to be paid to [the] management and use [of water].”[xvi]

However, little immediate progress has been made to fulfil that commitment. The most recent data on the Department of Water and Sanitation (DWS) website (from 2012) cites that about 36% of municipal water is lost through physical leakages or commercial losses.[xvii] This despite the fact that in 2011 the South African Local Government Association and the Water Research Commission (WRC) re-established the assessment of water services in South Africa through the launch of the national Municipal Benchmarking Initiative for Water Services, which was aimed at improving efficiencies in water management.[xviii] The government has also aggressively promoted the ‘War on Leaks’ campaign, but there has been little in the way of monitoring and evaluation of the program and little publically available information about the current state of non-revenue water in South Africa.

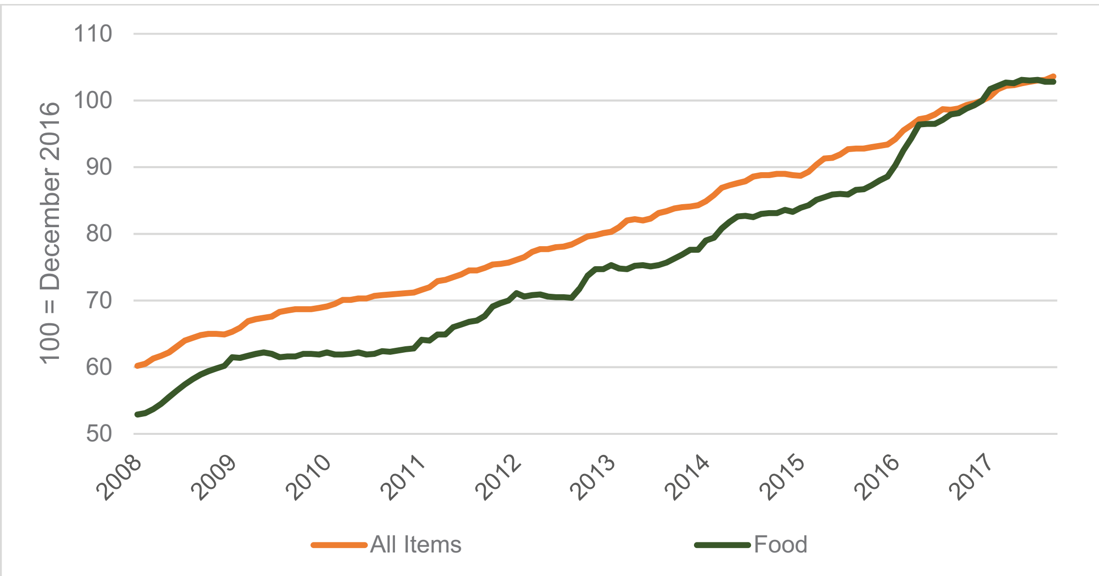
1.1.2 The recent drought and its impact

According to the South Africa Weather Service (SAWS), 2015 was the driest year on record.[xix] Since 1904, when SAWS began keeping track of annual precipitation in South Africa, the 403 mm of rain that the country received in 2015 is the lowest recorded annual total. For context, in the century plus that annual rainfall totals have been tracked, only 13 years have seen rainfall lower than 500 mm, and the average for that entire time period is 608 mm, according to SAWS.[xx] Put another way, South Africa received about one-third less precipitation than its historical average in 2015. Moreover, the 2015 drought followed three consecutive years of lower than average rainfall, making it the most severe and prolonged drought in South Africa since the 1940s.[xxi]

This had enormous implications for a water scarce country such as South Africa and has had especially dire consequences for South Africa's agricultural sector. Cattle farmers were particularly affected, with a 15 percent decline in the number of cattle between 2013 and 2016. This is the result of normal grazing capacity being reduced to around 30 percent of the historical average. Crop production was also affected, with national planting of maize down roughly 30 percent from the previous planting season.[xxii] This forced the South African government to step in, with the Department of Rural Development and Land Reform approving a R286 million drought relief package and the Department of Agriculture, Forestry and Fisheries pledging another R268 million in assistance.[xxiii]

The decline in domestic agricultural production had consequences for local markets. Figure 1 shows the increase in the consumer price index (CPI) from 2008 in food against the total basket of goods, according to Statistics South Africa (StatsSA). There has been a clear increase in food prices relative to other goods since the end of 2015, no doubt related to the effects of the drought. In the year from August 2016-2017, meat prices alone increased by 15%.[xxiv]

Figure 1: CPI increase from 2008-2017 for food and for the entire basket of goods for South Africa



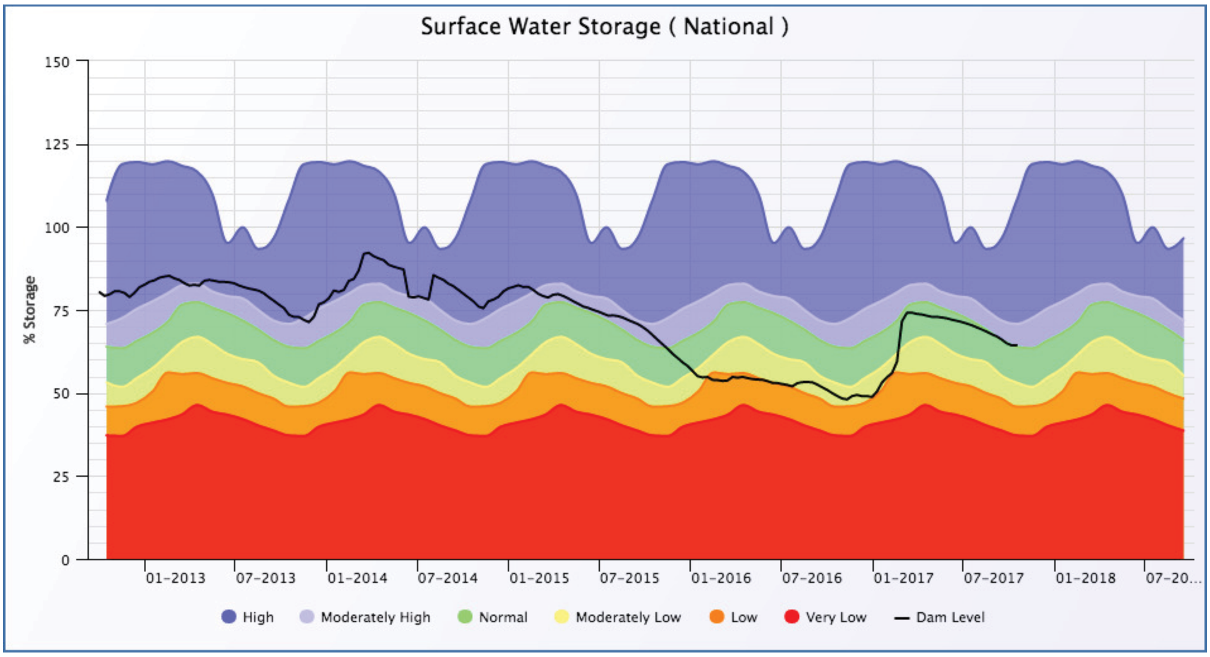
Source: StatsSA

The increase in commodity prices has combined with a depreciating rand to create a significant spike in real food prices nationwide. The brunt of this impact was undoubtedly felt by less affluent South Africans that are already struggling to achieve food security and afford other basic essentials.

The drought also tested the ability of South Africa's physical infrastructure to mitigate the impact of inconsistent rainfall in the country. In early November 2016, the DWS announced that water levels in South Africa's 215 national dams was at 49 percent and dropping.[xxv] Since then, dam levels have recovered somewhat (they stood at about 64% – or normal – in October 2017), largely due to the above average rainfall in January and February 2017, as shown in Figure 2.[xxvi]

From 2013 (the beginning of the time series shown in Figure 2), South Africa's surface water storage was consistently above 75% (either 'high' or moderately high') until a steady decline lasting from July 2014 to January 2017. Figure 2 also illustrates that the storage level has a natural or seasonal fluctuation, so that what would be considered 'normal' levels in some parts of the year could be 'moderately high' or 'moderately low' in others.

Figure 2: Storage water levels over time, and rated in terms of stability for South Africa



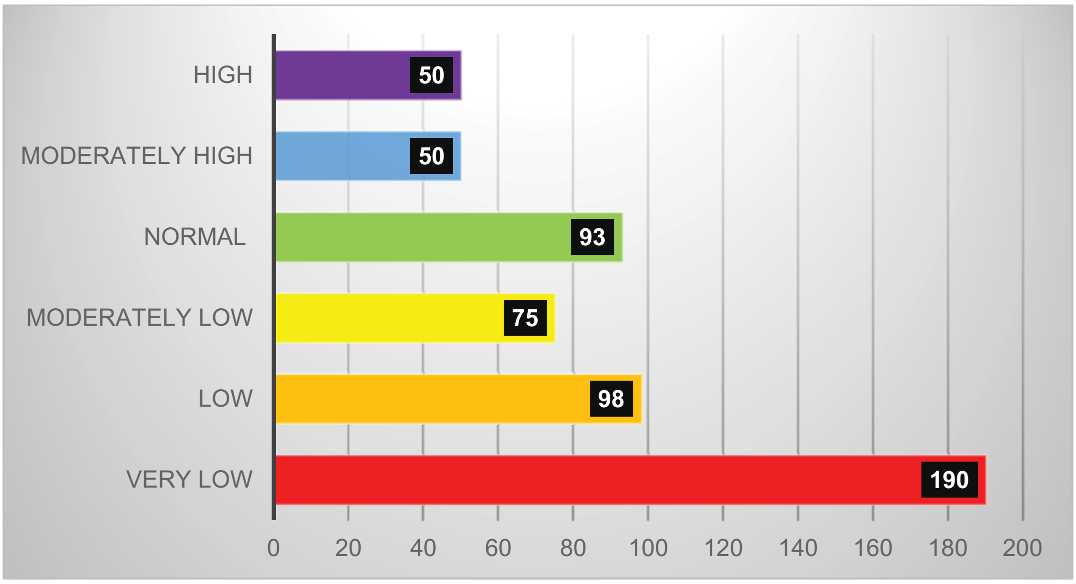
Source: Taken directly from DWS NIWIS website

However, surface water storage levels are only part of the story. Water restrictions are currently in place in most of the major metropolitan areas including Cape Town and Johannesburg.[xxvii] Other municipalities, like Nelson Mandela Bay are implementing tariffs on users who consume more than 400 litres a day.[xxviii] Multiple provinces, including Mpumalanga, Limpopo, KwaZulu-Natal, North West and the Free State, have been declared disaster areas. In May 2017, the Premier of the Western Cape officially declared the entire province a disaster zone as well.[xxix]

Although the 2014 – 2016 drought catalysed a national conversation and, to some extent, brought water scarcity into the policy debate in South Africa, it is not the cause of the current problem. What the drought did do was to highlight the existing vulnerabilities in South Africa's water system and to appropriately frame the magnitude of the challenge of ensuring water security for South Africa at the national level.

According to the DWS National Integrated Water Information System (NIWIS), 190 of South Africa's 565 rivers are categorised as having 'very low' flows, while a further 98 are 'low' and another 75 'moderately low', shown in Figure 3. According to the DWS, the purpose of the categorizations are to show the current flows to 'gauge against historically observed flow thresholds' in order to 'indicate if the current flows are higher than, lower than or similar to average flow conditions observed for the same time of year in the previous years'.[xxx] Put another way, more than 60% of South Africa's rivers are currently being over-exploited relative to historical averages.

Figure 3: Rivers in South Africa categorised by level of flows



Source: DWS NIWIS website (October 24, 2017)

The consequences of over-exploitation may not be evident overnight but, as described by the United Nations, 'the ultimate losers are the exploited aquatic ecosystems and the organisms (including humans) dependent on them for survival and well-being'.[xxxi]

A national level picture necessarily obscures important regional differences. While the national picture has become a bit more stable recently, important areas of South Africa remain in a critical state. The Western Cape is likely the most heavily affected area, with average dam levels in the Breede-Gouritz catchment at 31% and the Berg-Olifants dam levels at 47% (both considered 'very low' for the time of year). Moreover, in the Breede-Gouritz and Berg-Olifants catchments more than 90% of rivers are being over-exploited. The problem is not limited to the Western Cape however. KwaZulu-Natal is over-exploiting nearly 40% of the rivers in its main catchment (Pongola-Mtamvuna), where dam levels are also about 50% (rated as moderately low for this time of year) as of October 2017.

Looking forward, the Intergovernmental Panel on Climate Change (IPCC) forecasts a downward trend in precipitation in western South Africa and that the south-western region will be at increased risk or drought in the years ahead.[xxxii] In addition to lower average annual rainfall in parts of the country, South Africa can also expect a general warming trend of between 0.2^{0}C and 0.5^{0}C per decade.[xxxiii] This increase in surface temperature will likely have negative consequences on water supply in South Africa over the coming years.

Particularly in arid regions, like much of central and western South Africa, increased surface temperatures will reduce soil moisture and cause a reduction in runoff.[xxxiv] Moreover, warmer air temperatures will also increase the evaporation rates in large bodies of water, for instance in many of South Africa's major dams. So, not only will annual rainfall likely be lower in future years, but less will make it to tributaries and streams and even less will survive the enhanced temperatures of dams to eventually be released and available for downstream use.

Evaporation also has effects on water quality. Because the concentrates in water are not evaporated along with the hydrogen and oxygen molecules, the remaining water becomes over saturated with salts and other particulates. This can also happen along streams, affecting the fertility of the soil and ultimately threatening agricultural production.[xxxv]

Although the country's water picture has stabilised somewhat since the African Futures Project (AFP) published the first national level supply and demand forecast for water in South Africa in 2014 – *Parched prospects: the emerging water crisis in South Africa* – the country still has a long way to go to achieve sustainability.[xxxvi] IFs forecasts that demand will increase in all three sectors (agricultural, industrial and municipal), due to a combination of population growth, rising incomes and accompanying shifts in lifestyle preferences.

Taken together with the IPCC forecast of declining precipitation in the western part of the country and increased risk of severe drought for the entire south-western region, the IFs forecast suggests that South Africa must implement aggressive measures to restore stability to its water sector. While the January and February rains of 2017 have offered a brief reprieve from the 2014 – 2016 drought, the fact is that South Africa is still over-exploiting its renewable water resources and, without additional interventions will continue to do so for the foreseeable future.

1.2 Consequences of over-exploitation

When water is extracted from river systems at unsustainable levels, it reduces the overall amount of water flowing downstream, which affects the ability of the river ecosystem to properly absorb the byproducts associated with human activity (e.g. industrial discharge or fertilizer runoff). So, when effluent discharges occur downstream of the point where water is extracted for human consumption, and there is an insufficient volume of water in the river to dilute the chemicals and microbials present in the (raw and treated) effluent discharge, then the ecosystem begins to deteriorate.[xxxvii] This imbalance between effluent discharge and river flows can manifest as temperature increases, higher concentrations of chemicals and microbials or as changes in dissolved oxygen and pH levels.[xxxviii]

When water resources are over-exploited for a prolonged period of time, this interaction between human activity and deteriorating water quality is amplified. Other things being equal, adding more people to a community that is already over-exploiting its renewable resources will not only exacerbate the impact on water levels (i.e. cause the level of over-exploitation to increase), those additional people will also engage in other activities that add more effluent to the hydrological system.[xxxix] In other words, there are more pollutants being added to less water, making it increasingly difficult for the water system to efficiently dilute those particulates and regenerate itself.

When the ability of a river to effectively absorb potentially harmful particulates is diminished, there are substantial consequences for human development – including an increased risk of contracting a waterborne disease.[xl] Contaminated water is a significant driver of diarrheal disease, which alone is responsible for roughly 1 600 dead children per day, according the UNICEF.[xli]

Even when children survive a bout of diarrheal disease, they may suffer from undernutrition or stunting. Stunting has negative consequences for both physical and cognitive development and can hinder people's ability to progress through school and inhibit the productivity of the workforce over the long-term.[xlii] Poor water quality may also result in an increase in vector borne diseases from mosquitoes, tsetse fly's and ticks, particularly when the water is so polluted that it is not disturbed by humans and where the eggs of insects can survive for extended periods in a dormant state.[xliii]

Also important to the South African context is that the consequences of over-exploitation in one area, can have negative impacts in downstream communities that are not over-exploiting their local resources. This is particularly devastating when downstream users live in otherwise disadvantaged communities, further compounding the challenges created by poverty and general underdevelopment.

As shown earlier, certain areas of the country are suffering from far more severe water stress than others, and if any province or municipality were to completely run out of water, it would quickly become a national emergency. The Western Cape is still a drought disaster zone, with the hardest hit areas being the Karoo and the western coast.[xliv] As of August 2017, water restrictions were at level 4b, or the most severe restrictions ever implemented.

In September however, the City of Cape Town was forced to create an entirely new category of water restrictions. That month, the City took the unprecedented step of implementing level 5 water restrictions.[xlv] Moreover, there has been wide fluctuations in dam levels around the Cape Town metro area, and the province is gravely concerned with the loss of their water supply, with the Premier recently warning about Day 0, when the province would potentially run out of water completely.[xlvi] More recent prognostications have suggested that the Western Cape may endure a total collapse of its water system in March 2018.[xlvii] Even without a total collapse, tightly constrained water supplies could result in unmet basic needs, continued deterioration of water quality and negative environmental consequences.[xlviii]

Finally, as has been seen in South Africa over the last three and a half years, water systems that are over-exploited for a substantial period of time become more vulnerable to the impact of external shocks like droughts, floods and other extreme weather events. Although droughts in South Africa are inevitable – and likely to become more prominent in the southwest of the country in the future – the severity of their impact can be mitigated by efficient management of the water system. Droughts cannot be addressed retrospectively, but must be planned for in advance and include a holistic vision of the water ecosystem along with its relationship to human and economic development.

2 THE INTERNATIONAL FUTURES FORECASTING SYSTEM

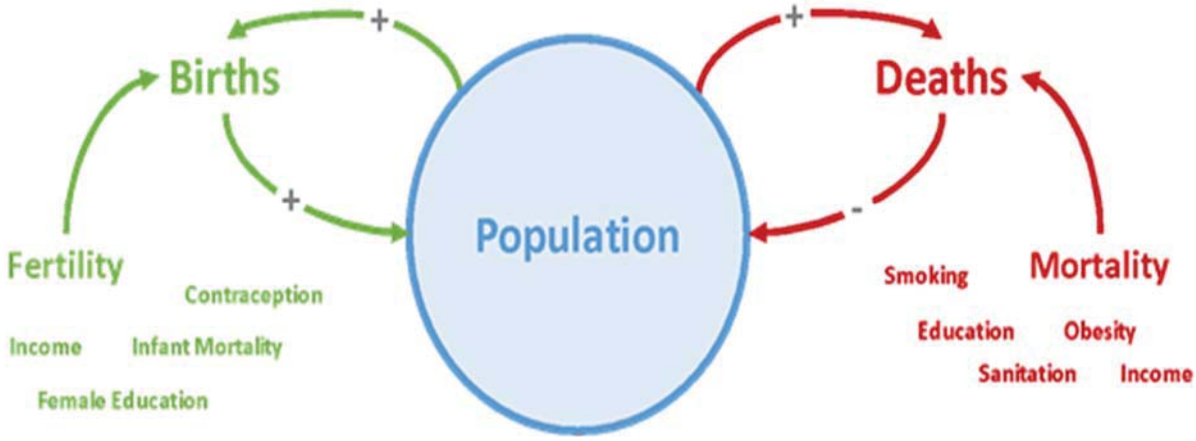
The IFs system is a global model that dynamically integrates data and forecasts across a number of key development systems including; agriculture, demographics, economics, education, energy, the environment, health, governance, infrastructure, international politics and technology. IFs contains over 4 000 variables for 186 different countries and produces long-term forecasts for hundreds of variables for every year between 2015 and 2100. IFs is a dynamic scenario-building tool that allows for the exploration of long-term development futures. IFs forecasts are informed extensions of current trends and are built upon our knowledge of development patterns and can therefore frame alternative outcomes from different policy decisions.

IFs is built on the foundations of 'systems dynamics thinking', pioneered in the 1970s as a way of understand both continuity and change within complex, evolving global systems.[xlix] The core concept of this philosophy is that systems are represented by 2 key elements, stocks and flows. As Meadows puts it' if you understand the dynamics (behavior over time) of stocks and flows, you understand a good deal about the behavior of complex systems'.[l]

Stocks are relatively straightforward. A quantity of natural resources is a stock, the population of a country is a stock and water in a well is an example of a stock. However, while we think of stocks as static, they do change over time due to their relationship with the various flows that affect that particular stock.

Taking population as an example, while the stock (i.e. number of people) is fairly basic, the flows that impact population size are more intricate. Births, deaths and migration are the three immediate (or proximate) drivers, but there are also second- and third-order (or distal) drivers like female education, access to contraceptives, access to clean water and improved sanitation and the prevalence of smoking. All of which effect the overall stock (i.e. number of people) and all of which themselves are impacted by different flows that change independently over time. Figure 4 is a conceptual representation of some of the proximate and distal drivers that affects population size within the IFs model.

Figure 4: Conceptualisation of the population stock and flows in IFs model



Source: Stylised representation of the IFs Population Model Documentation from Porter et al.[li]

From this starting point, IFs lends itself to three broad types of analysis. First, the user can analyse historical data points and relationships to better understand how a country or region has developed over time and across systems. Second, these relationships are formalised within the model to produce a Current Path forecast. These initial forecasts, which are dynamically integrated across all systems within the model, are useful benchmarks from which to begin our analysis. So, the Current Path forecast represents a trajectory of where the country appears to be heading based on historical trends, current circumstances and policies and in the absence of major shocks to the system (e.g. wars, pandemics, etc…).

Third, IFs allows users to conduct scenario analysis, which allows for augmentation of the Current Path forecast to explore alternative futures. This enables policymakers to get a better understanding of how to push systems toward more desirable outcomes, and what the potential trade-offs might be for different areas of human and economic development. This report will use all three types of analysis available in the tool.

Because IFs takes the country as its unit of analysis, this report does not discuss a number of important issues within the water sector. For one, this report will not be able to speak to the regional variability of water security in South Africa. Nor will this report be able to model the impact of deteriorating water quality on the sustainability of the overall water system. Therefore, this report will not contain many of the grid-based elements that are more common in hydrological studies.

That said, taking a macro-level view does have its advantages as well. While the report does miss some granular details (which are critically important), it also offers a comprehensive view of water in South Africa at a national level, which cannot be obtained by using more specific grid-based models. These are eventually not alternative approaches but complement one another and assist in the development of a better understanding of likely future developments in South Africa's water sector.

IFs is an open source tool and uses publicly available data from large international providers such as the World Bank, World Health Organization, UN, FAO, etc. Unless otherwise noted, each data reference in this report can be found in the IFs database or documentation. The IFs tool can be downloaded for free at pardee.du.edu.[lii]

2.1 The IFs water model

For this project, the AFP has refined the methodology for forecasting water withdrawals in the agricultural sector, and connected supply and demand to produce a dynamic future where development priorities are constrained by over-exploitation of a country's renewable water resources. In order to identify gaps in knowledge, supplementary sources of information will be used to complement and compared the data within IFs. ISS will also make use of the various datasets produced by the various government departments of South Africa, in particular the WRC and DWS. In addition, the WRC reference group has helped to identify potential data gaps and emerging issues for subsequent review by the ISS and Pardee researchers.

The new water model of the IFs system forecasts water demand by sector (municipal, industrial, and agricultural) and supply by source (surface water, groundwater, non-renewable groundwater, desalinated water, and treated wastewater) for 186 countries to the year 2100. Water supply and demand are also now equilibrated using a shadow price index, which is determined using a proportional-integral-derivate (PID) controller.[liii]

In this paper, over-exploitation refers to the yield (i.e. volume) of a water resource that can be reliably extracted at a certain rate over a specified period of time. Here, yield is measured in cubic kilometres per year. Since the volume of water in water systems varies throughout the year (demonstrated in Figure 2), the amount of water that can be extracted on a reliable basis ('reliable yield') is the amount that can be extracted at the period of lowest flow. By holding water in dams during periods of high flow and releasing that water during periods of low flow, the volume of water that can be extracted on a regular basis (i.e. the yield) is increased.[liv] So, over-exploitation does not necessarily create a scarcity of water. If the flow of a water system is above average for a given year, then withdrawing more water than the yield may not be a problem. If, however, a drought occurs, over-exploitation increases vulnerability to water shortages.

Further, water scarcity is distinguished from water stress. Scarcity is defined as a higher level of total water demand than available supply.[lv] Water shortages can occur because of a lack of available supply, but also as a result of faults in infrastructure, policy implementation, environmental changes or deteriorating water quality. Water stress can be the symptom of either water scarcity or water shortages. These symptoms could be conflict or competition over scarce water resources, declining standards of reliability and service, harvest failures or food insecurity.[lvi] Low and unpredictable supply, coupled with high (and growing) demand and poor use of existing water resources, combine to make South Africa a water scarce country.

The end result of the modelling improvements and adjusted supply forecast is that – despite the significant changes from previous forecasts outlined below – South Africa continues to see a period of prolonged over-exploitation before supply and demand begin to reconcile in any meaningful way.

2.2 Dominant relations in the water model

[Disclaimer: This model documentation section is largely taken directly from the IFs Water Model Documentation.[lvii]]

Within IFS water demand is modelled as the sum of three sectors — municipal, industrial, and agricultural. The AQUASTAT data differentiates between these three sectors and many other water models that use these same sectors. AQUASTAT refers to these data series as “water withdrawal.” For our purposes, we consider water withdrawal to be equivalent to water demand.

Water supply is defined as the sum of five components: surface water withdrawal, renewable groundwater withdrawal, non-renewable (fossil) water withdrawal, desalinated water, and direct use of treated wastewater.

The size of a country’s urban population and water use per capita for the urban population drive municipal water demand. Water use per capita for the urban population is driven by GDP per capita (at purchasing power parity), the portion of the population with access to piped water, and the portion of the population that lives in urban areas. Non-renewable electricity generation capacity and the overall size of a country's manufacturing sector drive industrial water demand. The area of land under irrigation drives agricultural water demand. The shadow price index impacts all three water demand sectors and will be explained in more detail below.

Surface and (renewable) groundwater withdrawals are driven by the shadow price index and constrained by their country-specific exploitable limits. Estimated stocks constrain fossil water withdrawals. The shadow price index and an initial growth rate (which can be specified by user) drive desalinated water. Direct use of treated wastewater is driven by the shadow price index and the volume of wastewater which is treated.

Total water demand and total water supply are used to adjust the shadow price index. The water price index then impacts each sector of demand and most sources of supply the following year. This algorithmic logic keeps water demand and water supply in approximate equilibrium over time, even though it does not require exact equality in any time step.

2.3 Structure and agent system

Table 1: Structure and agent system

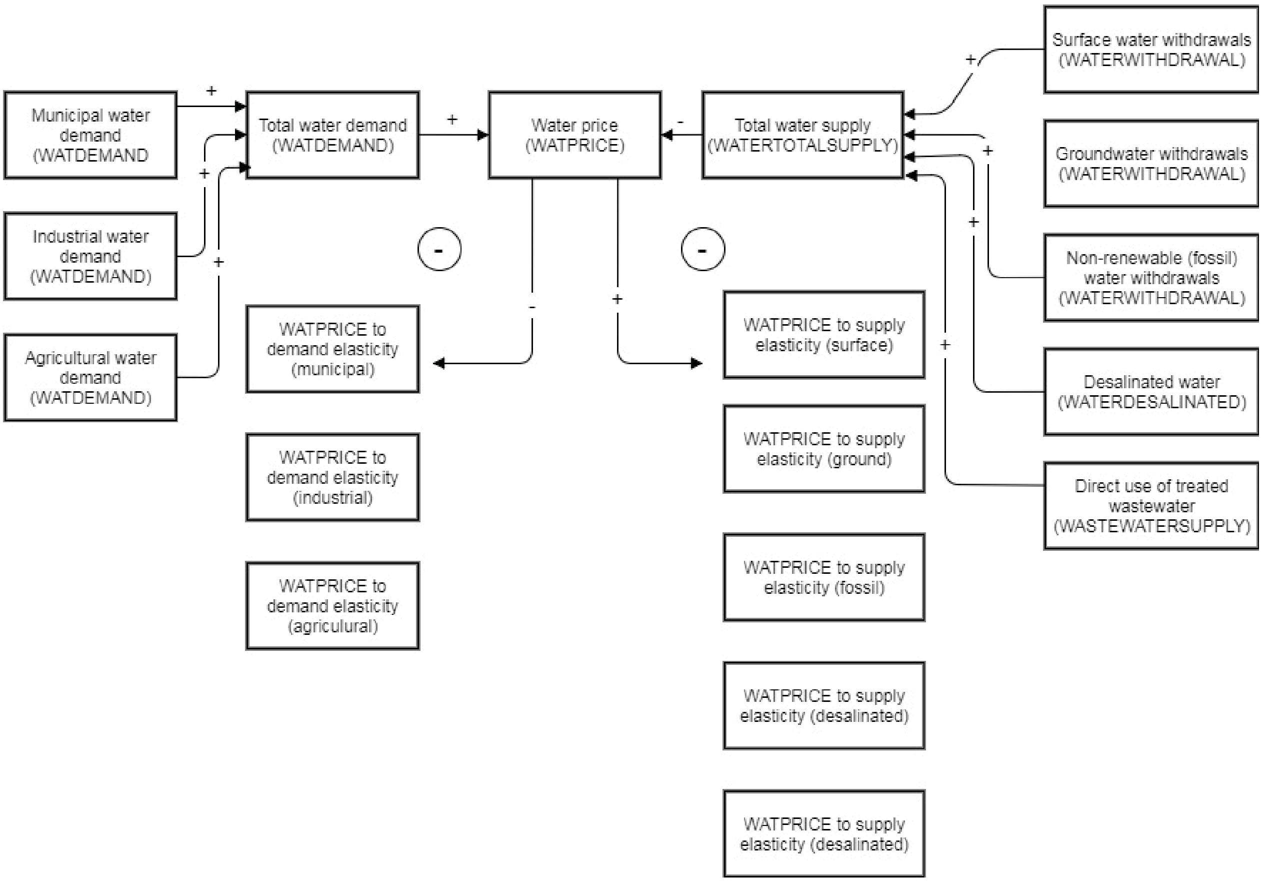
System/Subsystem	Environment (e.g. CO2, water)
Organising Structure	Systemic Accounting
Stocks	Exploitable renewable water resources (surface and ground) Total renewable water resources (surface and ground) Non-renewable (fossil) water Water price index
Flows	Water demand (municipal, industrial, agriculture) Wastewater (produced, treated, treated and reused) Desalinated water Non-renewable (fossil) water withdrawal
Key Aggregate Relationships (illustrative, not comprehensive)	Water withdrawals as a portion of exploitable limit Water price index
Key Agent-Class Behavior Relationships (illustrative, not comprehensive)	Governments and environmental policies regarding exploitable limits Water demand and supply responses to scarcity (elasticities on sectors)

Source: IFs Water Model Documentation

2.4 Water flow charts

2.4.1 Water overview

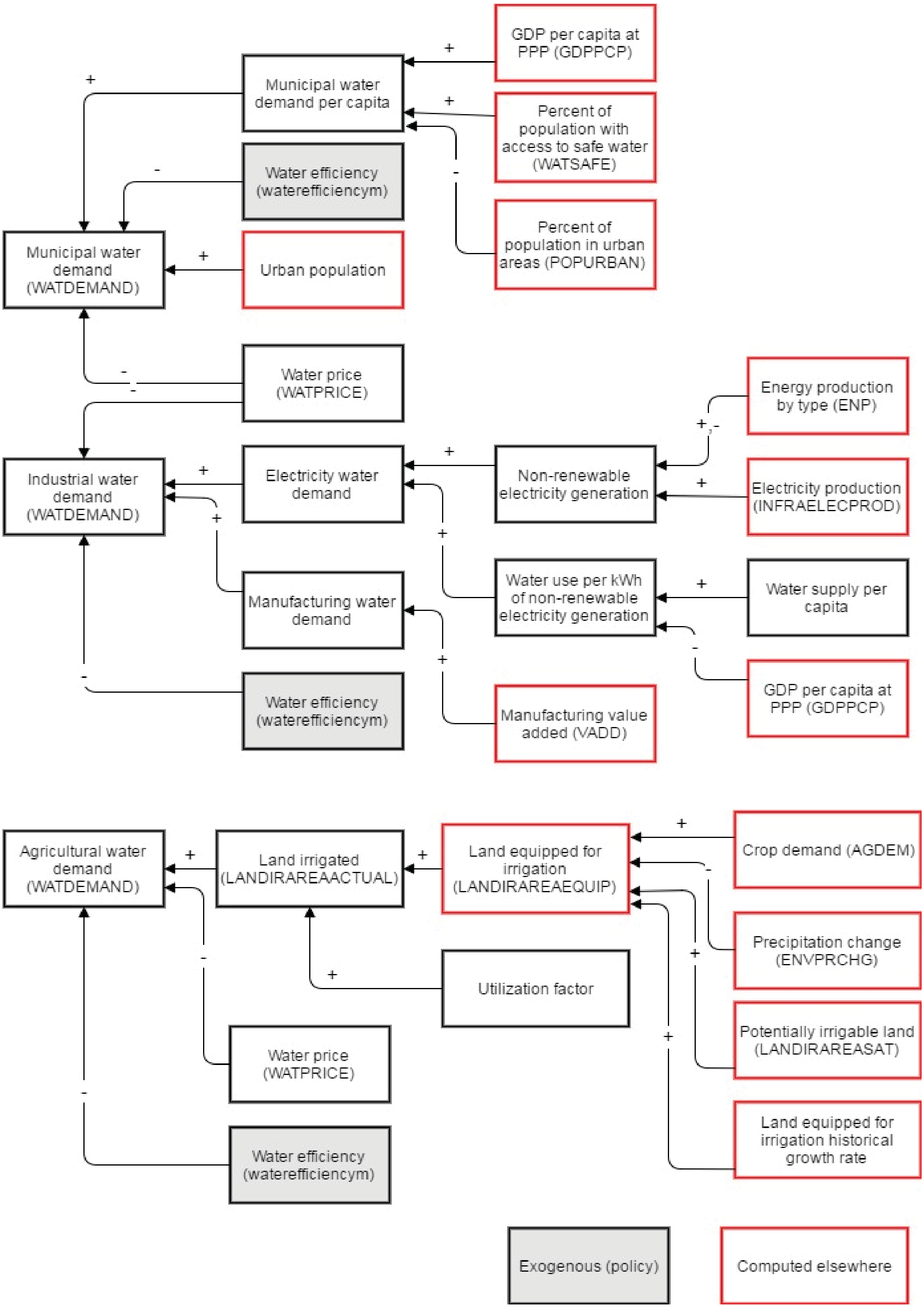
Figure 5: Water supply and demand as equilibrated using a shadow water price index



Source: IFs Water Model Documentation

2.4.2 Water demand overview

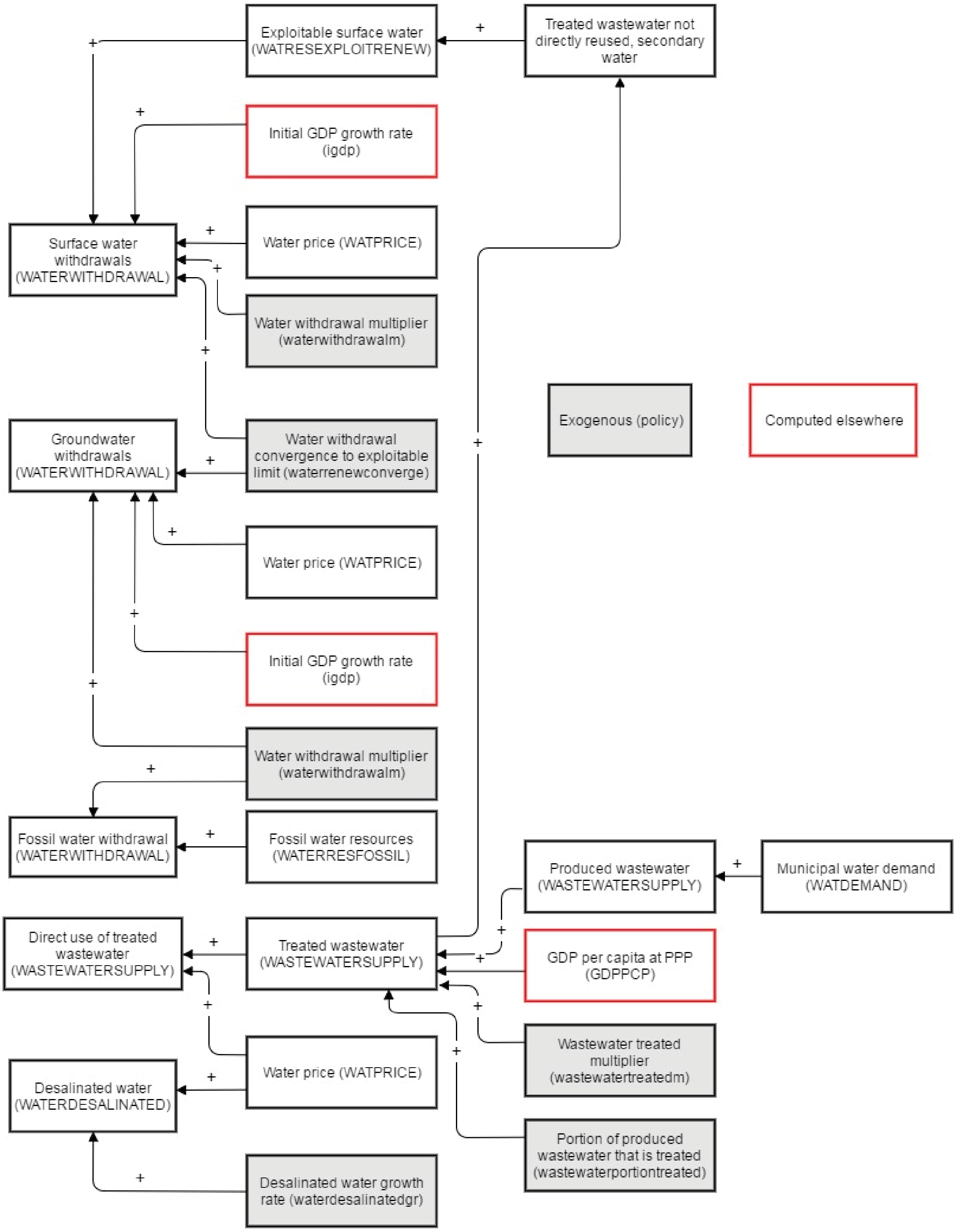
Figure 6: Three components of water demand: agricultural, industrial and municipal



Source: IFs Water Model Documentation

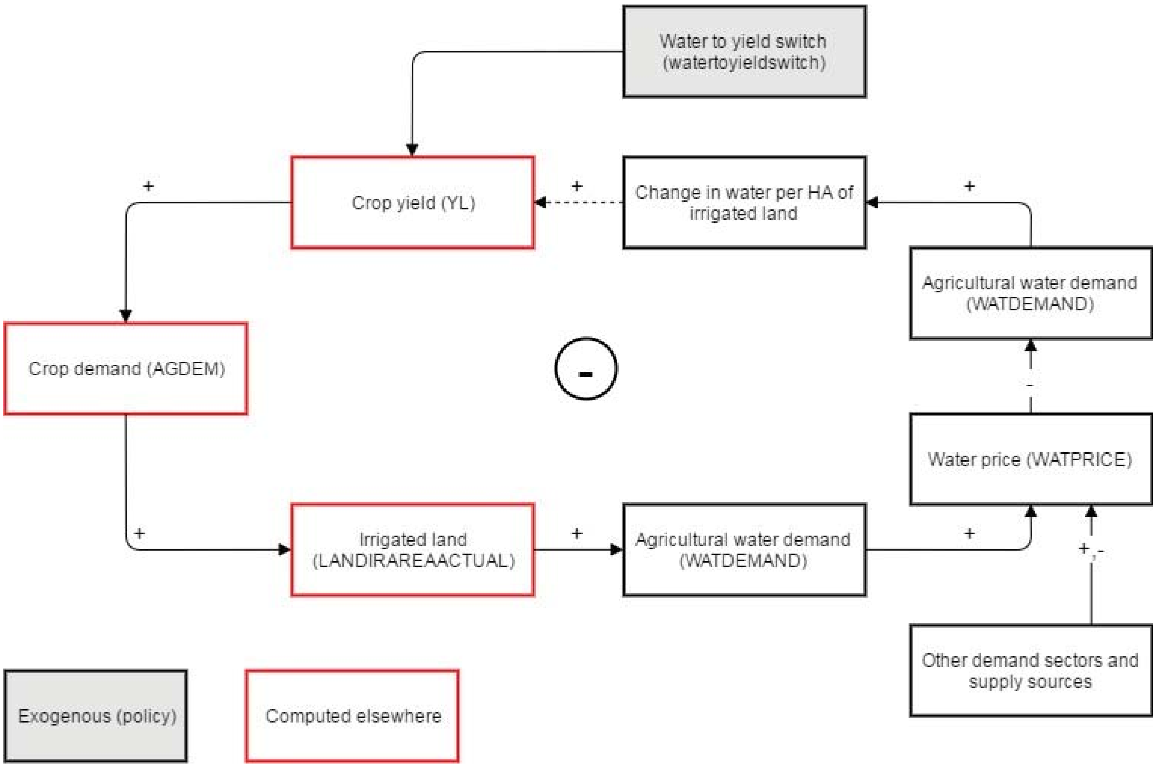
2.4.3 Water supply overview

Figure 7: Five components of water supply and their driving variables



Source: IFs Water Model Documentation

Figure 8: Conceptual framework for water constraints on the agricultural model



Source: IFs Water Model Documentation

2.5 Water Equations

2.5.1 Water Demand

Water demand is disaggregated into three sectors: agricultural, municipal, and industrial. Each of these three sectors have their own driving variables, mainly calculated in other sub-modules of the IFs model. Each of the equations for the three sectors of demand follow roughly the same structure – the first term in each of the equations is a level of water withdrawal intensity (water use per HA of irrigated land, municipal water use per capita, and water use per kWh of non-renewable electricity generation). This term is then multiplied by the overall size of the denominator in each of these intensity calculations (area of irrigated land, urban population, and non-renewable electricity generation).[lviii]

Each sector of water demand is also impacted by changes in the water price index using a -0.1 elasticity (see section on water price index for details on those calculations).

$$WATDEMAND_{r,municipal,t+1} = WATDEMAND_{r,municipal,t} * (1 + (IncreaseInPrice_r * -0.1))$$

$$WATDEMAND_{r,industrial,t+1} = WATDEMAND_{r,industrial,t} * (1 + (IncreaseInPrice_r * -0.1))$$
$$WATDEMAND_{r,agriculture,t+1} = WATDEMAND_{r,agriculture,t} * (1 + (IncreaseInPrice_r * -0.1))$$

2.5.2 Agricultural water demand

Water use for irrigation can be estimated by the following equation:

$$WI = AEI * UIA * WRCI * \frac{1}{IE}$$

Where WI is the water demand for irrigation (m^3), AEI is the area equipped for irrigation (HA), UIA is the utilization intensity of irrigated land, i.e., the ratio of irrigated land actually irrigated over extent of land equipped for irrigation, and WRCI is the total crop water requirement per unit of irrigated area depending on climate, crop type and multi-cropping conditions, and can be affected by specific crop management practices. IE is the efficiency of irrigation that accounts for the losses during water transport and irrigation application, (Wada et al., 2015).

Forecasting irrigation water demand thus requires forecasting these four components.

2.5.2.1 Area equipped for irrigation (AEI)

The area of land equipped for irrigation is driven by sub-national factors (mostly biophysical), and national factors (socio-political and governance related).[lix] Wada et al. identify nine potential drivers for the area of land equipped for irrigation: availability of land and water; reliability of water supply and access to water; irrigation impact (achievable yield increase and/or stabilization of yields and reduced variability); agricultural demand; availability of land with rain-fed potential; existing current yield gaps in rain-fed and/or irrigated land; cost; profitability, economic means available and support policies to invest in irrigation; state food security and self-reliance policies.[lx]

Neumann et al., modelled global irrigation patterns using a multilevel approach, using driving variables at the grid level as well as the national level.[lxi] At the national level, they identified the following variables as significant: corruption, government effectiveness, GDP, political stability, autocracy, democracy. Many of these variables are correlated, so the authors of that paper used the variables, “government_performance” and “government_type” in their final analysis.[lxii] At the grid level, Neumann et al. found the following variables to be significant: slope discharge; humidity; evaporation; evapotranspiration; population density; and access to markets.[lxiii]

Because the IFs system uses countries as the unit of analysis, we are unable to incorporate indicators at the grid level. In an effort to account for these grid-level indicators, we have incorporated data on the area of potentially irrigable land into our model. “Irrigation potential” is defined by AQUASTAT as

> Area of land which is potentially irrigable. Country/regional studies assess this value according to different methods. For example, some consider only land resources, others consider land resources plus water availability, others include economical aspects in their assessments (such as distance and/or difference in elevation between the suitable land and the available water) or environmental aspects, etc. If available, this information is given in the individual country profiles. The figure includes the area already under agricultural water management.[lxiv]

Using this variable (% of potential) as the dependent variable, implicitly includes some of the constraining factors identified above in the analysis. For example, while IFs does not include land availability and the slope of the land as explicit driving variables, those factors limit the area of potentially irrigable land.

For independent variables, we used crop demand and precipitation (see metadata below):

SeriesLandIrAreaEquip

- Definition: Area equipped for irrigation: total (1000 HA)
- Source: AQUASTAT
- Units: 1000 ha

SeriesLandIrPotential

- Definition: Irrigation potential (1000 ha)
- Source: AQUASTAT
- Units: 1000 ha

SeriesEnvPrecipitation

- Definition: Average annual precipitation from 1980 to 1999
- Source: Climate and global dynamics laboratory
- Units: Millimeters

SeriesAGCropDomesticSupplyFAO

- Definition: Domestic supply quantity of crops (tonnes)
- Source: FAOSTAT
- Units: tonnes

Dependent variable:

- LandIrAreaEquip (most recent) / LandIrPot (most recent)

Independent variables:

- EnvPrecipitation (most recent)
- (AGCropDomesticSupplyFAO (most recent) / LandIrPotential (most recent))

We use the most recent data from each series. We logged both independent variables and the dependent variable. Both independent variables are significant and the valences are in the correct direction, shown in Figure 9.

Figure 9: Regression used to forecast land equipped for irrigation

```
Dependent Variable = LandEquipOverPotential (Log)
Independent1 Variable = EnvPrecipitation(MOSTRECENT) (Log)
Independent2 Variable = CropDemandOverPotentialIrrigation (Log)


Coef_of_X1: Independent1 = -.625172812929616
Coef_of_X2: Independent2 =  .388271581940588
Y_Intercept = -1.07413220226835
R-Square =  .216116134340812
Adj R-Square =  .201325872724601
F-Value =  14.6120562265061
Probability of zero coefs =  2.48508620859179E-06


SE_of_Y-Intercept =  1.55628148750049
SE_of_X1: Independent1 =  .155295675578332
SE_of_X2: Independent2 =  .115176271444579
Beta_of_X1: Independent1 = -.346760565819479
Beta_of_X2: Independent2 =  .29037657059235
t-Value_of_Y-Intercept = -.690191466579411
t-Value_of_X1: Independent1 = -4.02569363635806
t-Value_of_X2: Independent2 =  3.37110740841632
Prob_of_Y-Intercept =  .49158221196555
Prob_of_X1: Independent1 =  1.06910274148731E-04
Prob_of_X2: Independent2 =  1.0455469419717E-03
Multiple_R =  .464882925413283
StdError_of_Estimate =  1.38728558983326
Dependent Variable Average =  .515504783397265
Dependent Variable Standard Deviation =  1.10774928567822
Dependent Variable Coefficient of Variation =  2.14886325278684
Ratio SE to mean =  2.69112069279128
```

Source: IFs Water Model Documentation

We use this new regression to estimate the portion of potentially irrigable land that is irrigated in the first year. The residual is then applied in every subsequent year as a multiplier.

Precipitation (EnvPrecipitation) changes each year as average annual precipitation changes due to total carbon in the atmosphere (a function of annual emissions from fossil fuels). Likewise, crop demand changes over time due to changes in demand in the component sectors (food, feed for livestock, food manufacturing/seeds, and industrial), along with changes in agricultural imports and exports, production, and loss. See the agricultural model documentation for a full description of our forecast for crop demand.[lxv]

2.5.3 Utilisation intensity of irrigated land (UIA)

There are four potential drivers of the UIA: increased competitiveness (irrigated land shrinks faster than equipped); land may be equipped to reduce drought risk (as a safeguard in bad years); limited water supply; and under poor economic conditions, areas equipped may not be maintained and become unusable.[lxvi]

We initialise utilisation capacity using data from AQUASTAT. We use the most recent data point from the series described below. If there is no data available for a country, we use the global average of 77%. The utilization capacity remains constant over time. For South Africa, the most recent data point (2014) was 81%.

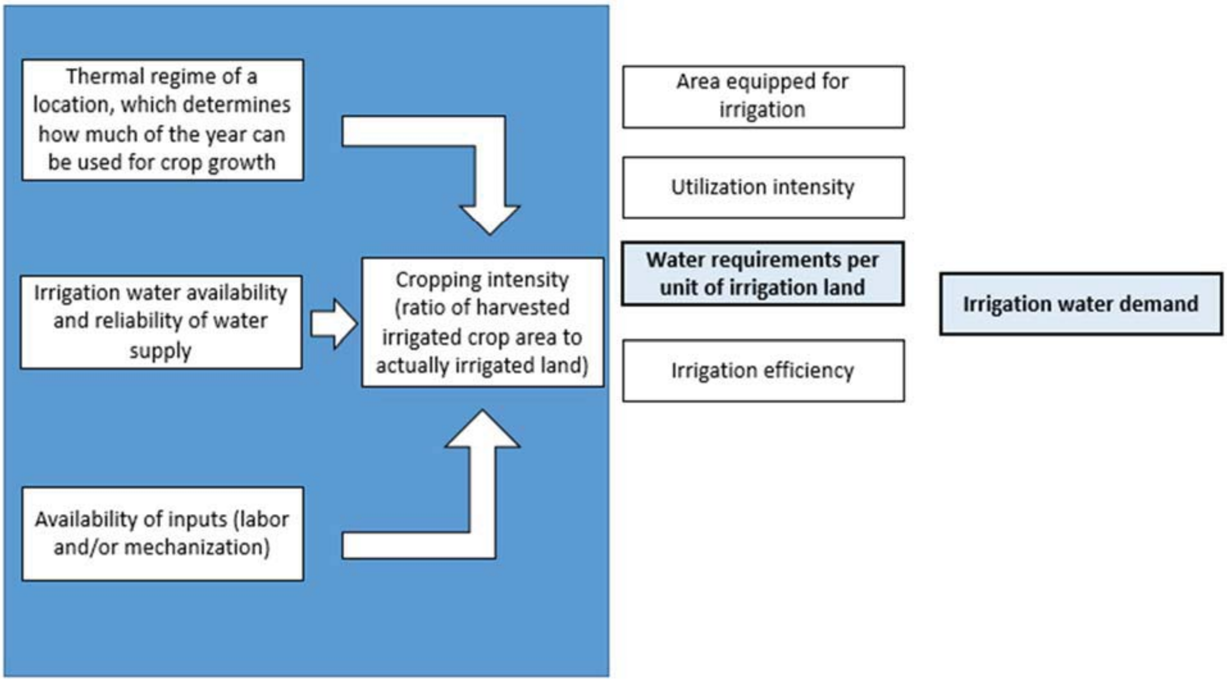
SeriesLandIrActual%Equip

- **Definition:** Area equipped for irrigation: actually irrigated, %
- **Source**: AQUASTAT
- **Units:** Percent

2.5.4 Water requirement per unit of irrigated land (WRCI)

The water requirement per unit of irrigated land is the difference between total crop water requirements and the part supplied by precipitation. This is largely driven by the cropping intensity, or the ratio of harvested irrigated crop area over irrigated crop area.[lxvii]

Figure 10: Drivers of water requirements per unit of irrigated land



Source: IFs Water Model Documentation

Water use per unit of irrigated land in IFs is estimated using a linear regression between agricultural water withdrawals (dependent variable) and irrigated land (independent variable). The details of the regression are shown below.

The regression used to forecast agricultural water demand uses the following data:

SeriesLandIrAreaEquip

- Definition: Area equipped for irrigation: total (1000 ha)
- Source: AQUASTAT
- Units: 1000 ha

SeriesLandIrActual%Equip

- Definition: Area equipped for irrigation: actually irrigated, %
- Source: AQUASTAT
- Units: Percent

SeriesWaterWithdAgriculture

- Definition: Agricultural water withdrawal
- Source: AQUASTAT
- Units: Cubic Km

We use the most recent data from each series. The independent variable is calculated as:

$$LANDIRAREAACTUAL$$

We use a linear formulation for this regression. The results are shown below.

Figure 11: Regression used to forecast agricultural water demand

```
Dependent Variable = WaterWithdAgriculture(MOSTRECENT) (None)
Independent1 Variable = LandActuallyIrrigated (None)

Coef_of_X1: Independent1 =  9.0717393264794E-03
Y_Intercept =  1.64630179154062
R-Square =  .931353570742858
Adj R-Square =  .930876859428572
F-Value =  1953.70561350818
Probability of zero coefs =  1.18500748335757E-85

SE_of_Y-Intercept =  1.48525302636007
SE_of_X1: Independent1 =  2.0523952470481E-04
Beta_of_X1: Independent1 =  .965066614665982
t-Value_of_Y-Intercept =  1.10843187142008
t-Value_of_X1: Independent1 =  44.2007422280236
Prob_of_Y-Intercept =  .26952322018785
Prob_of_X1: Independent1 =  1.18500748335757E-85
Multiple_R =  .965066614665981
StdError_of_Estimate =  17.4891828952643
Dependent Variable Average =  15.5897914285714
Dependent Variable Standard Deviation =  62.4034335637723
Dependent Variable Coefficient of Variation =  4.00283954084244
Ratio SE to mean =  1.12183559192536
```

Source: IFs Water Model Documentation

We use this regression to calculate the expected level of agricultural water demand (given land under irrigation) in the first year. This residual is then applied in every subsequent year as a multiplier.

2.5.5 Irrigation efficiency

The efficiency of irrigation can also change over time depending on the type of irrigation used and the technology behind it.

The model assumes that the efficiency of irrigation remains relatively constant over time for each country. However, a parameter on agricultural water demand is included, that allows the user to adjust the efficiency of irrigation for countries, regions or the world.

2.6 Municipal water demand

Municipal (domestic) water demand is modelled in IFs by multiplying sectoral water intensity (municipal water demand per capita) by the size of the urban population. This is a similar formulation to other global water models like WaterGAP.[lxviii]

Per capita municipal water use increases as household incomes increase. As incomes increase, people adopt a more water-intensive lifestyle, which eventually saturates.[lxix] The water sub-module of IFs uses GDP per capita and levels of access to piped water to forecast per capita municipal water use. To account for increased water use efficiency, the model includes the percent of the population living in urban areas as an additional independent variable.

The dependent variable in the equation used to forecast municipal water demand is municipal water demand per capita:

$$\frac{WATDEMAND_{municipal,r}}{POPURBAN}$$

We multiply this term by the size of the urban population (forecasted elsewhere) to get total municipal water demand.

$$WATDEMAND_{municipal,r} = \frac{WATDEMAND_{municipal,r}}{POPURBAN} \times POPURBAN$$

The independent variables for forecasting municipal water demand per capita are: GDP per capita (PPP); percent of the population living in urban areas; and the percentage of the population served with piped water.

Where municipal water demand per capita (WATDEMANDPC) is calculated using the following equation.

$$\frac{WATDEMAND_{municipal,r}}{POPURBAN} = x_1(\ln(GDPPCP_r)) + x_2(\ln(WATSAFE_{piped,r})) - x_3(\ln(UrbanPercentSmooth_r))$$

Where GDPPCP represents GDP per capita at purchasing power parity (PPP), WATSAFE represents the portion of the population with access to piped water and UrbanPercentSmooth represents the portion of the population living in urban areas but decreased for countries which are rapidly urbanizing. That is why there is a 'smoothing' of that variable for this equation. The coefficients of the first two independent variables ("x_1" and "x_2") are positive—as when GDP per capita and access to piped water increase, water use per capita will also increase. The third coefficient "x_3" is negative because higher levels of urbanization are negatively correlated with water use per capita. All three of these independent variables are statistically significant at the global level.

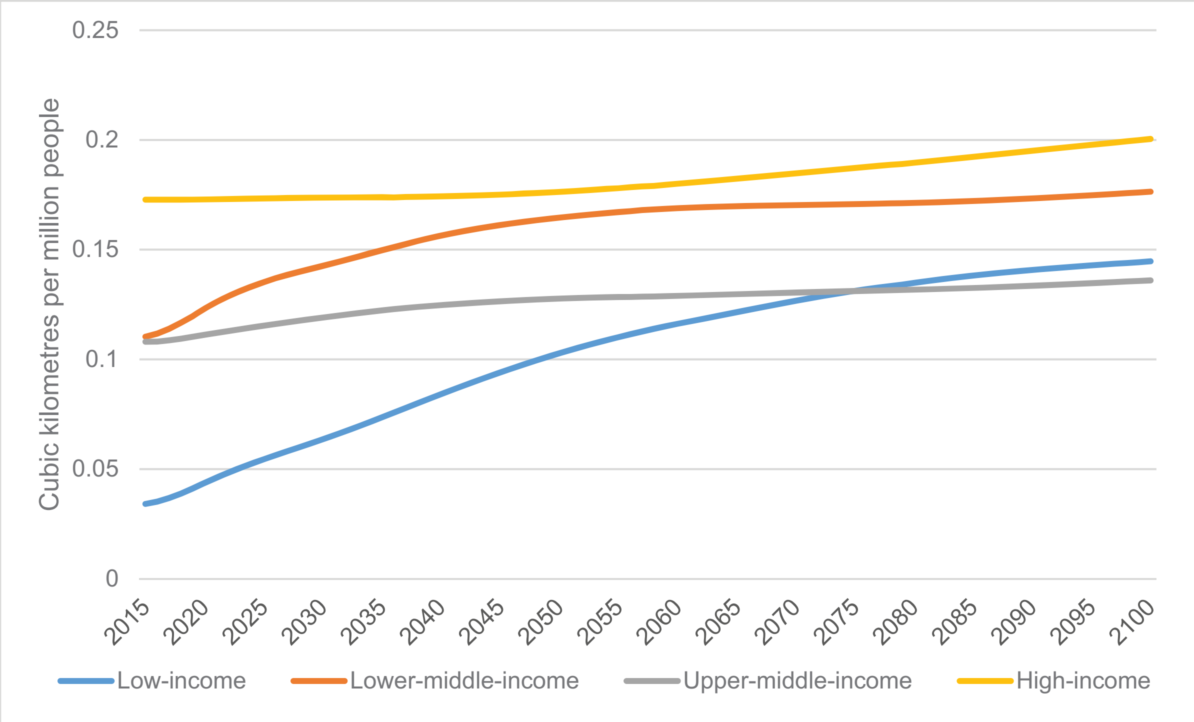
While the portion of a country's population living in urban areas is negatively correlated with water use per capita, the rate of urbanization is not necessarily negatively correlated with water use per capita. Countries with a large portion of their population living in urban areas might have water use efficiency infrastructure and policies in place, explaining the lower water use per capita. It takes time to put these water-conservation measures in place however. South Africa's urban population is forecast to increase by more than 1% throughout the duration of the forecast.

For countries where the urbanization rate is greater than 1%:

$$UrbanPercentSmooth_r = 1.01 \times \frac{(92 - UrbanPercent_r)^{.75}}{92}$$

This ensures that rapid urbanisation does not lead to rapid water conservation. This is of particular concern for China, where IFs forecasts rapid urbanisation over the next decades. Municipal water use per capita (urban) increases in all income groups (see Figure 12).

Figure 12: South African per capita municipal water use in urban areas by World Bank income grouping 2015 - 2100



Source: IFs v. 7.29 initialised from AQUASTAT and UNPD data

2.7 Industrial water demand

Industrial water demand is calculated as the sum of water demand for thermo-electric power generation (cooling) and water demand for the manufacturing sector.

2.7.1 Thermo-electric power generation

To forecast water consumption for thermo-electric power generation, we multiply total non-renewable electricity generation (in kWh) by a calculated value of water consumption per kWh. Water use per kWh is calculated as a function of both water scarcity within a country and the GDP per capita of the country. The more water-scarce a country is, the lower the desired water use per kWh. The actual water use per kWh is determined by this desired value together with the GDP per capita (PPP) of the country.

Water scarcity is calculated as the total water supply divided by the country's population. This water-scarcity figure is then linearly mapped onto the range of [0.4 – 2.0]. This is a reasonable range for water use per kWh in a country (in terms of litres per kWh).[lxx]

GDP per capita (PPP) for each country is linearly mapped onto the range [0-1] to calculate an 'AbilityToAffordEfficiency' variable.

Actual water use per unit of power generation (liters/kWh) is then calculated as:

$$ActualWaterUsePerkWh_{\mathrm{r}} = 2 - (AbilityToAffordElecEfficiency_r \times (2 - DesiredWaterUsePerkWh_r))$$

This water use per kWh variable is then multiplied by non-renewable electricity generation to calculate total water consumption for electricity generation.

$$IndustrialWaterDemandforElectricity_r = ActualWaterUsePerkWh_r \times NonRenewablePowerGeneration_r$$

Where NonRenewablePowerGeneration is calculated as:

$$INFRAELECPROD_r - ElecRenew_r$$

Where ElecRenew' is calculated as

$$\left(ENP_{renew,r} + ENP_{hydro,r}\right) \times 1699.41 \times 1000$$

Renewable energy production is forecast in terms of billion barrels oil equivalent (the standard unit for energy data in the IFs model) so the model must convert to gigawatt hours and then to kWh before it is subtracted from INFRAELECPROD. Industrial water demand for electricity is thus a function of non-renewable electricity generation, water scarcity, and GDP per capita (PPP).

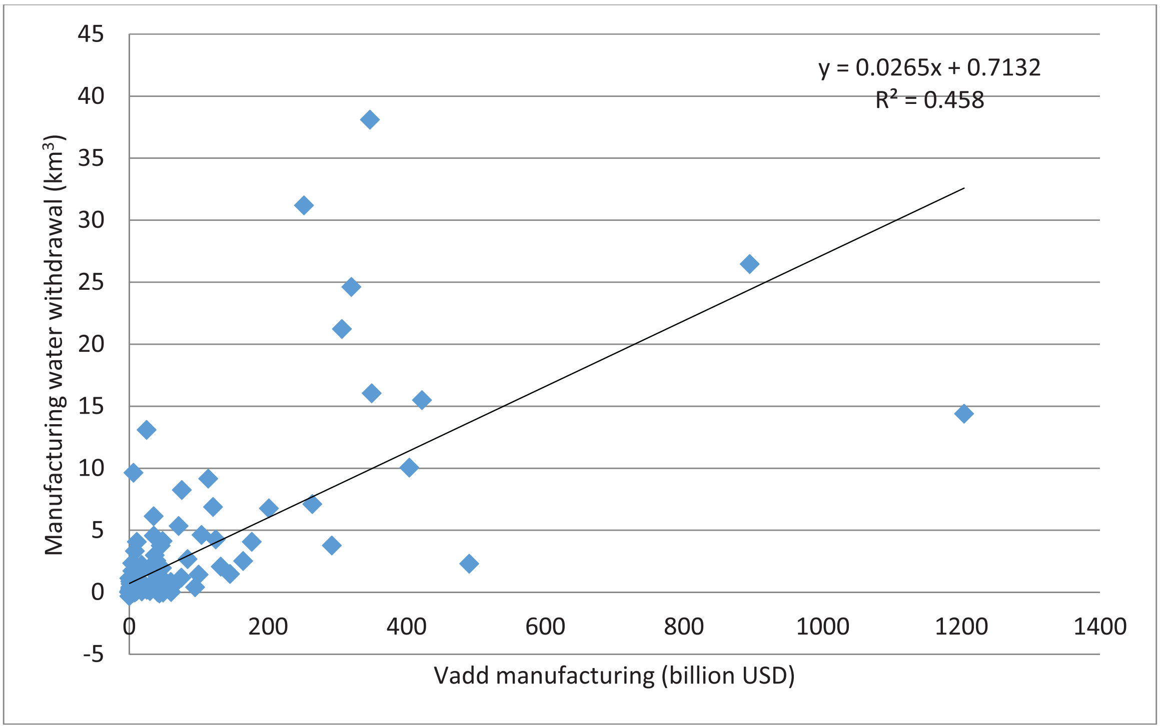
2.7.2 Manufacturing

Although we do not have data on water demand for the manufacturing sector, using the calculations above for industrial water demand for electricity generation, we can estimate the portion of industrial water demand that is required for the manufacturing sector:

$$IndustrialWaterDemand_{manufacturing,r} = WATDEMAND_{industrial,r} - IndustrialWaterDemand_{electricity,r}$$

We use the size of a country's manufacturing sector to drive industrial water demand for manufacturing. There is a correlation between this calculated industrial water demand for manufacturing and the size of the country's manufacturing sector.

Figure 13: Manufacturing water withdrawal (km³) relative to value-added from the manufacturing sector (constant 2011 USD)



Source: IFs v. 7.29 initialized from AQUASTAT and World Bank data

Industrial water demand for manufacturing is calculated by using the annual growth rate in the size of the manufacturing sector, adjusted by an elasticity of 0.45.

$$IndustrialWaterDemand_{manufacturing,r,t} = IndustrialWaterDemand_{manufacturing,r,t-1} \times \left[\frac{VADD_{manufacturing,r,t}}{VADD_{manufacturing,r,t-1}}\right]^{0.45}$$

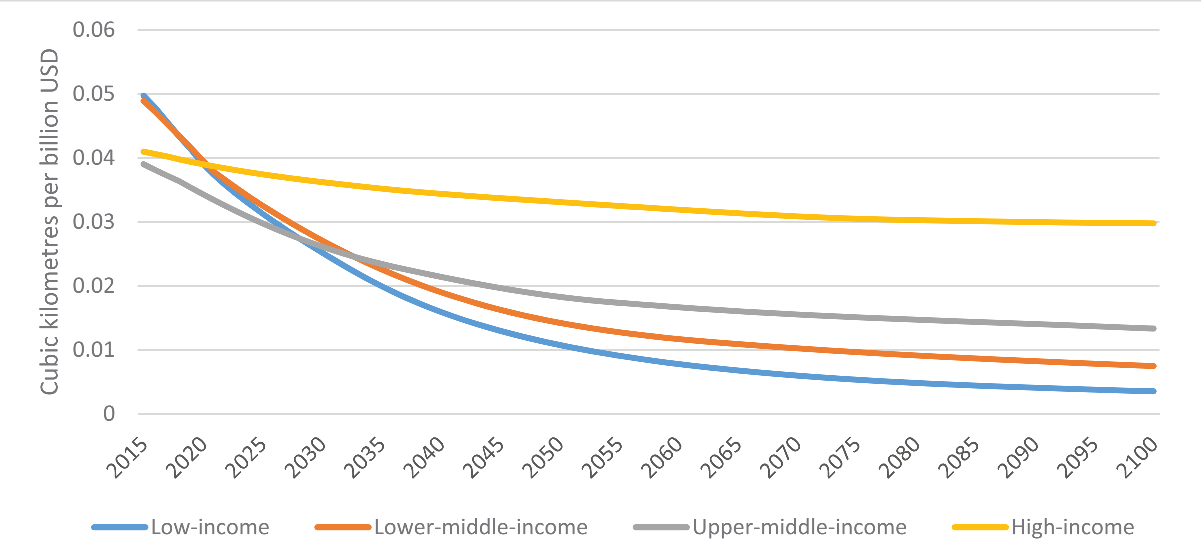
This elasticity figure (0.45) was calculated using country-specific elasticities between manufacturing value added growth rates and manufacturing water demand growth rates weighted by GDP:

$$\frac{\sum_{r}^{All\ Countries}\left[\frac{\log(ManufacturingWaterWithdrawalGR_r)}{\log(ManufacturingValueAddedGR_r)} \times GDP_r\right]}{Global\ GDP}$$

Where ManufacturingWaterWithdrawalGR is the compound annual growth rate for industrial water demand for the manufacturing sector and ManufacturingValueAddedGR is the compound annual growth rate for value added from the manufacturing sector. We log both growth rates because the elasticity is calculated as an exponent rather than a multiplicative factor.

This new formulation means that industrial water use per unit of value added from the manufacturing sector decreases for all income groups (see Figure 14).

Figure 14: Industrial water demand per unit (US$ billions) of value added from the manufacturing sector in different World Bank income group



Source: IFs v. 7.29 initialized from FAO and World Bank data

Using the equations described above, we calculate an "expected" water demand for each sector for each country. Using data from the pre-processor we are able to calculate residuals—the difference between the expected water demand and the actual water demand.

$$Residual_{r,s} = ExpectedWaterDemand_{r,s} - WATDEMAND_{r,s}$$

These residuals do not change over time. We include efficiency parameters (**waterefficiencym**) on each of the water demand variables so that the user may decrease water demand in any sector.

Water demand is calculated the same way in each year. We recalculate the expected level of water demand for each sector for each country using the driving variable, and then apply the residual. We also include the efficiency parameter multipliers in these calculations.

$$WATDEMAND_{r,w} = (ExpectedWatDemand_{r,w} - Residual_{r,w}) * \boldsymbol{waterefficiencym}_{r,s}$$

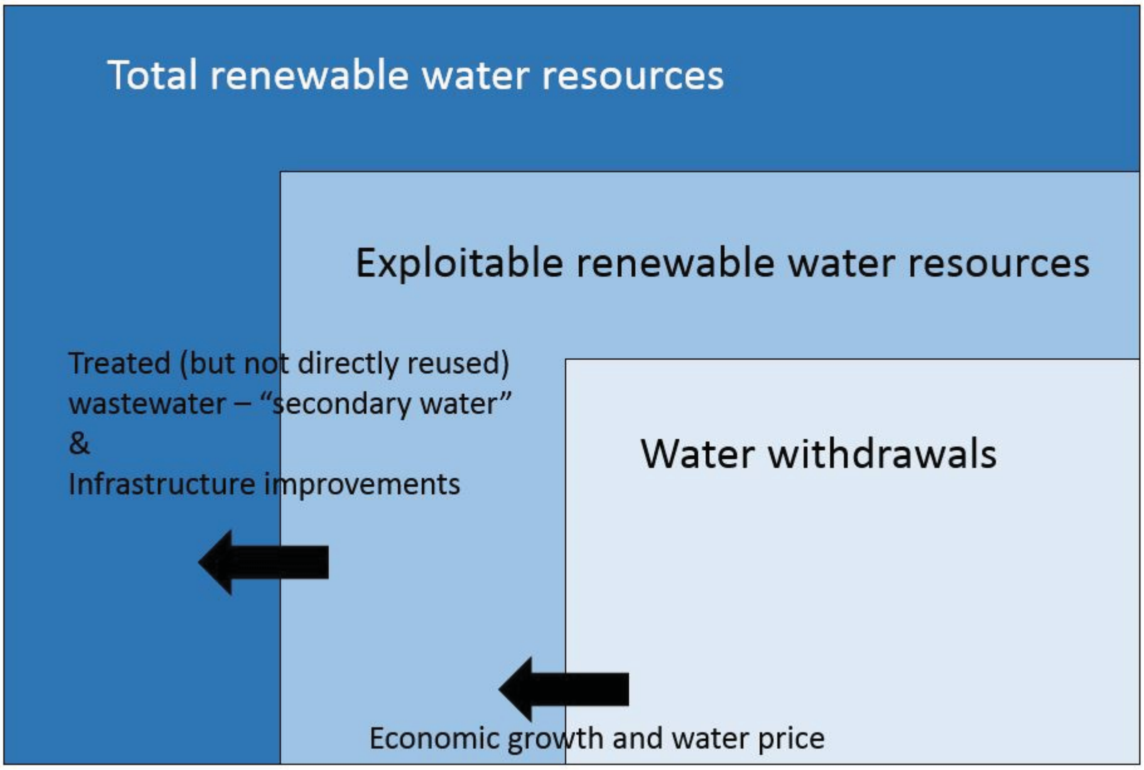
2.8 Water supply

To model water supply in IFs we use the sum of surface water withdrawals, renewable groundwater withdrawals, non-renewable (fossil) groundwater withdrawal, treated and directly reused wastewater, and desalinated water. Treated wastewater that is not directly reused is added to surface water yield. This constitutes secondary water.

2.8.1. Surface water and renewable groundwater

Within IFs total renewable water resources is a constraint on exploitable renewable water resources (separated into surface water and groundwater) and exploitable renewable water resources as a constraint on water withdrawals. Figure 15 shows the conceptual framework for forecasting surface water withdrawals. Withdrawals are driven by economic growth (GDP growth rate) and the water price index (described in section 3.5). Withdrawals are bound however, by the exploitable limit. Exploitable renewable surface water resources can increase due to “secondary water” – water that is treated but not directly reused. Exploitable surface water is limited however, by the total renewable surface water.

Figure 15: Conceptual model for forecasting water withdrawals when withdrawals do not exceed exploitable limit.



Source: IFs water model documentation

The data for total renewable water resources, exploitable water resources, and water withdrawals is taken from AQUASTAT that defines total renewable water resources (TRWR) as, "The sum of internal renewable water resources (IRWR) and external renewable water resources (ERWR). It corresponds to the maximum theoretical yearly amount of water available for a country at a given moment".[lxxi]

We use WATRESTOTALRENEW as a limit on the increase in WATRESEXPLOITRENEW. Exploitable water resources are usually a portion of total resources. This is because exploitable resources consider several restrictions on the use of water resources. The AQUASTAT data handbook defines these restrictions in terms of technical-economic criteria, environmental criteria, and geopolitical criteria.[lxxii]

AQUASTAT defines exploitable water resources as, "Exploitable water resources (also called manageable water resources or water development potential) are considered to be available for development, taking into consideration factors such as: the economic and environmental feasibility of storing floodwater behind dams, extracting groundwater, the physical possibility of storing water that naturally flows out to the sea, and minimum flow requirements (navigation, environmental services, aquatic life, etc). Methods to assess exploitable water resources vary from country to country".[lxxiii]

Exploitable water resources do however include secondary water so it can sometimes exceed total renewable water resources. This is rare but an important factor to keep in mind when forecasting. Thus, when using total renewable resources as a limit on exploitable resources, secondary water must first be subtracted from exploitable water resources.

Since total renewable water resources does not account for the overlap between surface water and groundwater, we must recalculate total renewable water resources by subtracting this overlap. We then recalculate total renewable surface water and total renewable groundwater using this adjusted total.

$$WATRESTOTALRENEW_{r,w} = \left(\frac{WATRESTOTALRENEW_{r,w}}{WATRESTOTALRENEW(Overlap)}\right) * WATRESTOTALRENEW(No\ Overlap)$$

It is not possible, however, for exploitable water resources (excluding secondary water) to reach the TRWR limit. While exploitable water resources can increase, we assume that it cannot grow by more than 20%. We also assume that exploitable water resources cannot grow by more than .5% per year and that only one fortieth of remaining resources can be extracted in any year. Thus, the equation for exploitable water resources is:

$$WATRESEXPLOITRENEW_{t,w} = Min(WATRESEXPLOITRENEW_{t-1,w} * 1.005, \left(\left(\frac{(MaxExploitRenew_{w} - WATRESEXPLOITRENEW_{t-1,w})}{40}\right) + WATRESEXPLOITRENEW_{t-1,w}\right))$$

Where

$$MaxExploitRenew_{w,r} = \boldsymbol{iwatresexploitrenew}_{w,r} * 1.2$$

iwatresexploitrenew is the exploitable renewable water resources in the first year. The subscript "w" represents that the variable is dimensioned in terms of surface and ground water. We also include a parameter, watresexploitrenewm on the total volume of exploitable water resources so that the user may increase or decrease this supply over time. After this growth rate is applied to exploitable surface water resources the secondary component is added to WATRESEXPLOITRENEW (surface). Secondary water is the total volume of treated wastewater that is not directly reused.

To forecast surface and groundwater withdrawals, we separate each country into one of two cases: countries where water withdrawals exceed the exploitable limit, and countries where water withdrawals do not exceed the exploitable limit. Surface water withdrawals and groundwater withdrawals are forecast separately. For example, a country can be over-exploiting their surface water resources while groundwater withdrawals remain below the exploitable limit.

If surface water withdrawals are less than exploitable surface water resources, then surface water withdrawals are driven by a growth rate of 20 percent of the country's latest GDP growth rate. This growth rate however cannot force surface water withdrawals to exceed one seventh of the remaining exploitable surface water (total exploitable surface water minus current surface water withdrawals).

The equation below describes the forecast equation for surface water withdrawals. It is calculated as the minimum of two terms: the previous year's surface water withdrawals multiplied by 20 percent of the GDP growth rate of the country, and one seventh of the remaining exploitable potential plus the current level of withdrawal.

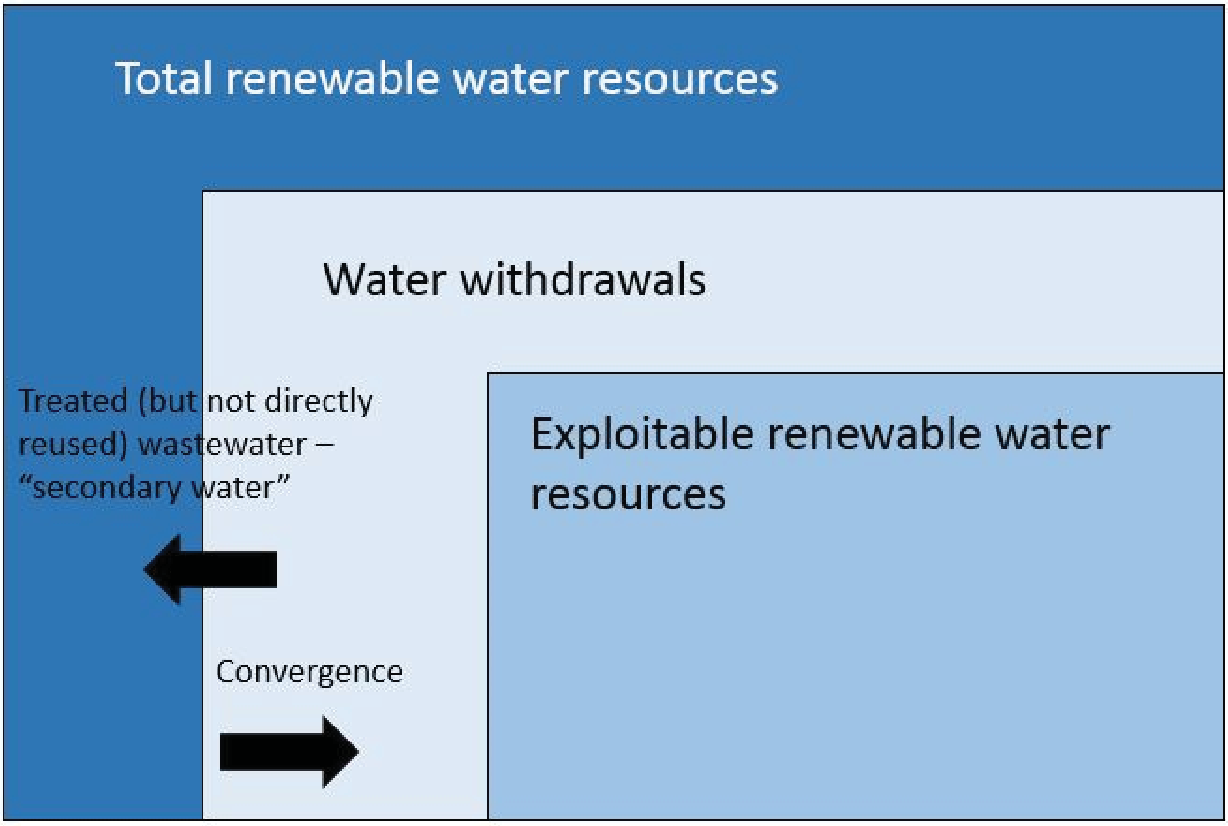
$$WATERWITHDRAWAL_{r,surface,t+1} = Min\,(WATERWITHDRAWAL_{r,surface,t} * (1 + 0.2 * IGDP_r),\ \frac{RemainingPotentialExploitable}{7} + WATERWITHDRAWAL_{r,surface,t}),$$

In the second case, where surface water withdrawals exceed the exploitable surface water limit, they are forced to converge to the exploitable limit over a 50-year time horizon. This time horizon is a parameter in the model (waterrenewconverge) that can be adjusted by the user.

$$WATERWITHDRAWAL_{r,surface,t+1} = WATERWITHDRAWAL_{r,surface,t} - \left(\frac{WATERWITHDRAWAL_{r,surface,t} - WATRESEXPLOITRENEW_{r,surface}}{\boldsymbol{waterrenewconverge}_{r,surface}}\right)$$

Where **waterrenewconverge** is the 50-year default convergence time.

Figure 16: Conceptual model for forecasting water withdrawals when withdrawals exceed exploitable limit.



Source: IFs water model documentation

The exact same logic described above applies to groundwater withdrawals, and the parameter (**waterrenewaconverge**) is dimensioned by surface and groundwater. In the case of groundwater however, secondary water does not increase the exploitable limit – we assume treated wastewater that is not directly reused is released back into the system in the form of surface water.

If groundwater withdrawals are less than the exploitable limit:

$$WATERWITHDRAWAL_{r,ground,t+1} = Min\,(WATERWITHDRAWAL_{r,ground,t} * (1 + 0.2 * IGDP_r), \frac{RemainingPotentialExploitable}{7} + WATERWITHDRAWAL_{r,ground,t}),$$

If groundwater withdrawals exceed the exploitable limit:

$$WATERWITHDRAWAL_{r,ground,t+1} = WATERWITHDRAWAL_{r,ground,t} - \left(\frac{WATERWITHDRAWAL_{r,ground,t} - WATRESEXPLOITRENEW_{r,ground}}{\boldsymbol{waterrenewconverge}_{r,ground}}\right)$$

Both surface and groundwater withdrawals are adjusted based on the change in the water price index. A 0.5 elasticity is applied to the change in the water price index, which is then applied to both surface water withdrawals and groundwater withdrawals. Again, however, neither is permitted to grow faster than one seventh of the remaining exploitable potential.

$$WATERWITHDRAWAL_{r,surface} = Min(WATERWITHDRAWAL_{r,surface} * \big(1 + (IncreaseInPrice * 0.05)\big), \left(\frac{WATRESEXPLOITRENEW_{r,surface} - WATRESEXPLOITRENEW_{r,surface}}{7}\right) + WATERWITHDRAWAL_{r,surface}$$

The same logic and elasticity is applied to groundwater:

$$WATERWITHDRAWAL_{r,ground} = Min(WATERWITHDRAWAL_{r,ground} * \big(1 + (IncreaseInPrice * 0.05)\big), \left(\frac{WATRESEXPLOITRENEW_{r,ground} - WATRESEXPLOITRENEW_{r,ground}}{7}\right) + WATERWITHDRAWAL_{r,ground}$$

2.8.2 Wastewater

WASTEWATERSUPPLY is a multidimensional variable in the IFs model. The three dimensions are Produced, Treated, and TreatedAndReused. Most of our data on wastewater comes from the AQUASTAT database so IFs uses their conceptual framework to model and forecast wastewater.[lxxiv] Total produced wastewater is forecast in IFs as a portion of total municipal water demand. This relies on the assumption that wastewater that is reused *among* sectors comes primarily from collected municipal wastewater. Wastewater that is reused within a sector (for example, reuse of industrial wastewater within the same industrial factory) does not increase the water supply but, rather, decreases water demand in that particular sector.

Since we take the most recent data for each of these series they often do not reconcile. For example, treated wastewater may exceed produced wastewater, which is impossible. If a country's volume of treated wastewater exceeds their supply of produced wastewater we assume that they treat 95% of their produced wastewater.

If we do not have data for a country's volume of produced wastewater, we estimate this value using their municipal water demand. If we do not have data on the volume of treated wastewater, we estimate this value using a portion of their produced wastewater. The portion of a country's produced wastewater that is treated is driven by GDP per capita. If we do not have data on the portion of treated wastewater that is directly reused, we estimate this value using a global average of 66%. Parameters are in IFs on both the portion of wastewater that is treated and the portion of treated wastewater that is directly reused: **wastewaterportiontreated** and **wastewaterportiontreatedreused.**

Since a portion of treated wastewater is directly reused and a portion of treated wastewater is discharged directly back into the water system, this discharge is considered "secondary water" and is added to exploitable surface water resources. Likewise, a portion of non-treated wastewater is directly re-used, usually by the agricultural sector, and a portion is discharged. The portion of non-treated wastewater that is not directly re-used is not added to exploitable surface water resources however. We do not yet have forecasts in IFs for the amount of non-treated wastewater that is directly reused. This is something that needs to be added to the model as some countries, like Mexico, use a large volume of non-treated municipal wastewater to irrigate crops.

Wastewater that is treated but not directly reused is then added to exploitable surface water resources.

$$
\begin{aligned}
WATRESEXPLOITRENEW(Surface) &\\
= WATRESEXPLOITRENEW(Surface) &+ WASTEWATERSUPPLY(Treated) \\
- WASTEWATERSUPPLY(TreatedAndReused) &
\end{aligned}
$$

Wastewater supply is calculated for all years using the same regressions described above for all years. The residuals for each of the equations do not change. The only way to increase supply of wastewater is to adjust municipal demand (which will affect total wastewater produced) or to adjust the wastewaterportiontreated parameter. This parameter is initialized as 1 but can be adjusted by the user. If the user does not change this parameter, the portion of produced wastewater that is treated will be driven by GDP per capita. If the user changes this to a value between 0 and 1 then that is the portion of produced wastewater that is treated.

If **wastewaterportiontreated** != 1 Then

$$WASTEWATERSUPPLY_{treated,r} = WASTEWATERSUPPLY_{produced,r} * \boldsymbol{wastewaterportiontreated_r}$$

Else

$$WASTEWATERSUPPLY_{treated,r} = WASTEWATERSUPPLY_{produced,r} * TF(GDPPCP_r)$$

We use a log function of GDP per capita to forecast the portion of wastewater that is treated.

Treated wastewater is also affected by changes in the water price index, using a 0.5 elasticity. The equation below shows the water price index effect on treated wastewater. Treated wastewater is also bound by produced wastewater – a country cannot treat more wastewater than is produced.

$$WASTEWATERSUPPLY_{r,treated,t+1} = Min\ (WASTEWATERSUPPLY_{r,produced}, WASTEWATERSUPPLY_{r,treated,t} * \left(1 + (IncreaseInPrice * 0.05)\right)$$

2.8.3 Non-renewable (fossil) water withdrawals

We take fossil water resources data from three sources: FAO, UNESCO, and a peer-reviewed journal article from IOPScience.[lxxv] The IOP article however, does not differentiate between renewable groundwater resources and fossil groundwater resources so we subtract renewable groundwater resources from total fossil water resources.

For some countries, we have data on fossil water withdrawals but not fossil water resources. This creates problems in the forecast since future water withdrawals are based on remaining fossil water resources. For these countries, we estimate that their total fossil water resources are 10 times their current fossil water withdrawals.

$$WATERRESFOSSIL = 10 * WATERWITHDRAWAL(Fossil)$$

We model fossil water in IFs using a stock and flow dynamic. Total fossil water resources are used as a stock and fossil water withdrawal is the flow. Fossil water withdrawals increase at a one percent growth rate. This increase is bounded by the total supply of fossil water remaining. A country cannot extract more than one seventh of their remaining fossil water resources in any year. This number is taken from current fossil water extraction rates. The highest rate of extraction globally, occurring in the Nubian Sandstone Aquifer, is about one seventh of remaining resources.[lxxvi]

$$WATERWITHDRAWAL_{t+1,f} = Min(WATERWITHDRAWAL_{t,f} * 1.01, \frac{WATERRESFOSSIL}{7})$$

The subscript f represents fossil water.

2.8.4 Desalinated water

Desalinated water grows at 8% per annum, but this growth rate diminishes over time. Desalinated water cannot decrease by more than 2% per year. Desalinated water increases based on an 8 percent growth rate (**waterdesalinatedgr**) which can be changed by the user. Growth in desalinated water is also endogenously adjusted based on the change in the shadow water price index, using a 0.5 elasticity.

$$\begin{aligned} WATERDESALINATED_{r,t+1} \\ &= Min(WATERDESALINATED_{r,t} \\ &* \left(1 + (IncreaseInPrice * 0.5)\right), WATERDESALINATED_{r,t} \\ &* \left(1 + \left(\frac{\boldsymbol{waterdesalinatedgr_r}}{100}\right)\right)) \end{aligned}$$

Total water supply (WATERTOTALSUPPLY) is then calculated as the sum of these 5 water sources i.e. reused water, desalinated water, surface water, ground water, and fossil water.

$$\begin{aligned} WATERTOTALSUPPLY \\ &= WASTEWATER(TreatedAndReused) + DESALINATEDWATER \\ &+ WATERRESEXPLOITRENEW(Surface) \\ &+ WATERRESEXPLOITRENEW(Ground) \\ &+ WATERWITHDRAWAL(FossilGround) \end{aligned}$$

Because of the way we define water supply, demand can exceed supply of water resources. This usually means that the country is over exploiting their resources. This means that the country is using more surface water then their available yield, or withdrawing groundwater faster than the recharge rate. There are currently 23 countries that are over exploiting their water resources on a national level, however, over-exploitation at the local level is not captured. This is particularly relevant to countries like China and India—countries where over-exploitation is known to occur but not captured in our analysis. The top 5 countries in terms of national water exploitation are: Turkmenistan, Singapore, Egypt, Uzbekistan, and Syria, respectively.[lxxvii]

While we do not forecast water withdrawal by source (surface, ground, and fossil ground), the historical data is available in IFs. Eventually, we hope this will be useful to forecast in the future so that we can determine the type over-exploitation that is occurring in water scarce countries.

We pull in data on surface water withdrawal, groundwater withdrawal, and total water withdrawal from AQUASTAT. Since total water withdrawal is the sum of surface water withdrawal and groundwater withdrawal, it is possible to estimate surface water withdrawal based on total water withdrawal and groundwater withdrawal. Likewise, if data is available for total water withdrawal and groundwater withdrawal it is possible to estimate surface water withdrawal. Since, however, AQUASTAT does not differentiate between renewable groundwater withdrawal and fossil groundwater withdrawal we must first subtract fossil water withdrawal from groundwater withdrawal using other data.

$$WATERWITHDRAWAL(Ground) = WATERWITHDRAWAL(Ground) - WATERWITHDRAWAL(FossilGround)$$

If we have data on total water withdrawals but not surface water withdrawals and groundwater withdrawals, then IFs estimates using global averages, assuming that 67% of a country's water withdrawals come from surface water and 33% come from groundwater. If we do not have data on total water withdrawals IFs assumes that a country's total water withdrawals are equivalent to total water demand. We then use the same global averages to determine which portion of this demand is met by surface water and which portion is met by groundwater. IFs does not currently reconcile total water demand with total water withdrawals, though, theoretically, they should be equivalent.

2.9 Water price index

The water price index is initialised at 100 in the first year of the model and changes year-to-year as a function of differences between supply and demand, using a proportional-integral-derivative controller (PID controller). The PID controller uses two terms to adjust the water price index: the integral or absolute distance of the system from the target, and the derivative, the change in value of the system from the previous year. In this case, the integral term is the absolute difference between the demand to supply ratio and 1 (the demand supply ratio in the first year) and the derivative term is the change in the demand to supply ratio from the previous year.

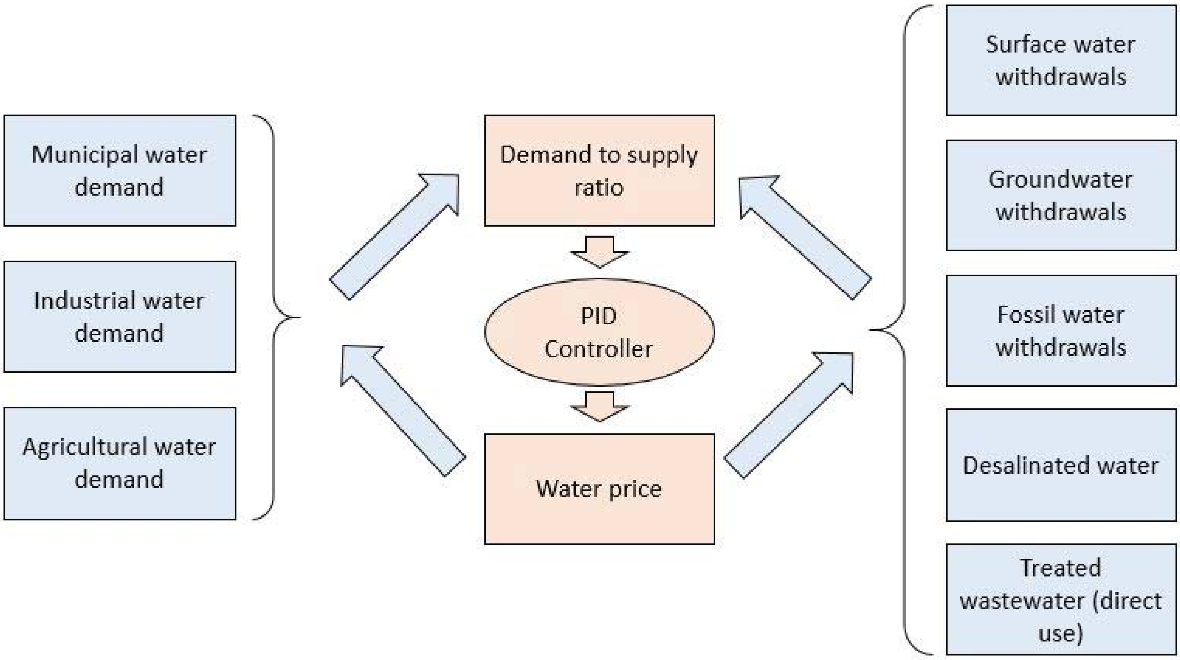
The following equation describes the four terms that are used by the PID controller to calculate the price index adjustment: the first term is the absolute change in the demand-supply ratio (the integral), the second term is the change in the demand-supply ratio from the previous year (the derivative), the third term is the impact that the integral has on the price index (0.3 but adjustable by user), and the fourth term is the impact that the derivative has on the price index (0.6 but adjustable by user).

$$
\begin{aligned}
&PriceAdjustment_{r}\\
&= PID(DemandSupplyRatio_{r,t}\\
&- 1, \big(DemandSupplyRatio_{r,t}\\
&- DemandSupplyRatio_{r,t-1}\big), impactofIntegralonPrice, impactofDerivativeonPrice)
\end{aligned}
$$

The change in the price index is then used to adjust water demand for each sector and water supply from each source. The change in price is then used to adjust water demand for each sector and water supply from each source.

To reiterate, water supply in IFs comes from 5 sources: surface water withdrawal, (renewable) groundwater withdrawal, non-renewable (fossil water) withdrawal, desalinated water, and the direct use of treated wastewater. Water withdrawals in IFs are classified as either agricultural, industrial or municipal. A conceptual representation of how IFs equilibrates supply and demand through the shadow price mechanism is shown in Figure 17.

Figure 17: Water supply and demand as equilibrated using a demand-supply ratio, a PID controller, and a water price.



Source: IFs water model documentation

2.10 Forward linkages

While there are no default forward linkages built into the model, there is a switch (watertoyieldswitch) that can be set to a range of values between 0 and 1. The watertoyieldswitch allows water availability to impact agricultural yields.

$$YL_r = YL_r * \left(1 + \left(\frac{(adjustedWaterPerHA - waterPerHA)}{waterPerHA}\right)\right)^{waterToYieldElasticity}$$

Where YL[lxxviii] is agricultural yield, adjustedWaterPerHA is the agricultural water availability per HA of irrigated land after adjusting for the change in the price index, and waterPerHA is the agricultural water availability per HA of irrigated land before adjusting for the price index.

In this model, the default setting for the waterToYieldElasticity parameter is 0. However, in this paper it is set to 1 so that water scarcity does constrain agricultural yields.

3 APPLICATION AND IMPLEMENTATION OF THE MODEL

Because IFs integrates over 4 000 data series across a diverse basket of development systems, and the water model now has linkages to other systems, over-exploitation in the water sector has consequences for other areas of human and economic development within the model. The most direct impacts are felt in the agricultural sector, as explained in section 2.10. This is also consistent with South African policy where agriculture is given a lower assurance of supply (which is embedded in dam operating rules), so that in times of drought, the supply of agricultural water gets cut in preference to industrial and municipal water supply.

This new modelling allows the latest report to explore the implications of water scarcity on other development goals identified in the NDP, and help get a better understanding of the importance of water stability to South Africa’s future.

In other words, this revised model helps to frame the implications of over-exploitation of renewable water resources in South Africa in a way that more traditional, grid-based water modelling does not allow for. While this approach also has its limitations, it does provide a macro-level picture of the challenges facing South Africa (and other countries) and the potential constraints of that over-exploitation on economic and human development.

Further, as water supply and demand now interact in a dynamic way over time, the model assumes that water demand will be constrained by available supply. Likewise, supply will be affected by changes in demand. In other words, the model has built-in ‘rebound effects’ which constrain water use and overall development. Some of these rebound effects may be in the form of efficiency measures, but some will come at the cost of reduced agricultural yields.

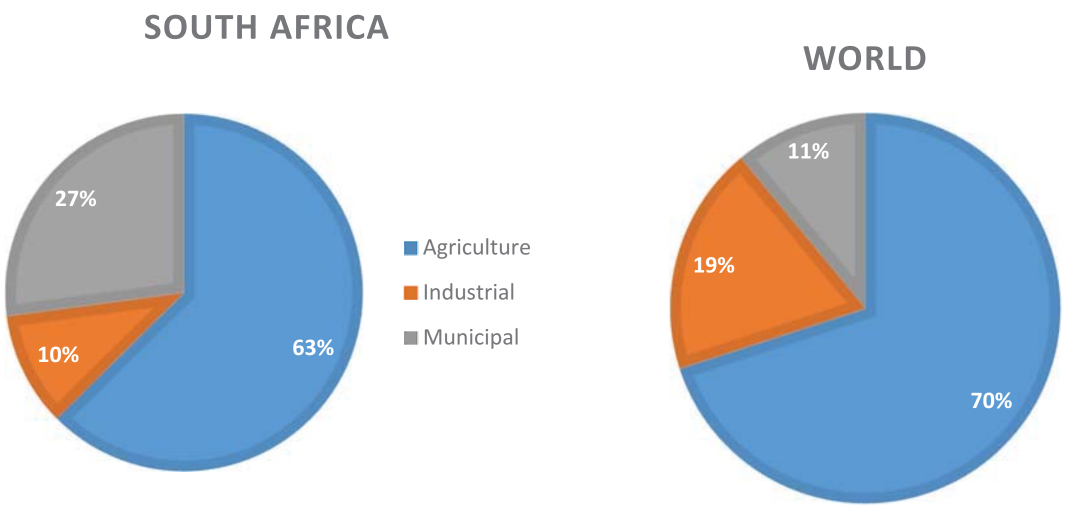
3.1 Current withdrawals and supply

To forecast water withdrawals, IFs relies on data from the United Nations Food and Agriculture Organization’s (FAO) AQUASTAT database, which has data for South Africa until 2013 on withdrawals in all three sectors. IFs uses AQUASTAT data to ensure that data are standardised across countries and also because AQUASTAT withdrawal categories are mutually exclusive, so withdrawals are not either double-counted or underrepresented.

Agricultural withdrawals are defined by the FAO as including 'self-supplied water for irrigation, livestock and aquaculture purposes', while municipal withdrawals consist of the total water withdrawn from the public distribution network.[lxxix] Finally, industrial withdrawals are defined as self-supplied consumers that are not connected to the public distribution network.[lxxx]

In line with global trends, the agricultural sector is estimated to account for the majority of water withdrawals in South Africa, using approximately 9.8 km^3 (63% of total withdrawals) in 2017. The FAO estimates that, globally, about 70% of total available freshwater is used by the agricultural sector, although that figure varies fairly dramatically by region.[lxxxi] The next largest user of water in South Africa is the municipal sector, which used about 4.3 km^3 (or about 27% of total withdrawals) in 2017 according to IFs estimate. Finally, the industrial sector is estimated to account for about 1.6 km^3 (or about 10% of total withdrawals) worth of withdrawals in 2017. Figure 18 below is a graph showing total withdrawals by sector in South Africa, against the global average.

Figure 18: Total withdrawals in South Africa and the world by sector



Source: IFs v. 7.29 and FAO AQUASTAT data

There are a number of reasons for high municipal use in South Africa. A 2012 WRC study found that, at about 300 litres per capita per day (l/c/d), per capita water consumption in South Africa is well above the global average of approximately 175 l/c/d.[lxxxii] But, another component that drives high levels of municipal withdrawals in South Africa is surely the high levels of non-revenue water in the country.

Non-revenue water refers to the ‘difference between the amount of water put into the distribution system and the amount of water billed to consumers’.[lxxxiii] Non-revenue water can generally be categorised as falling into one of three types; real or physical losses that occur because of leakage from poor operation and maintenance, commercial losses caused by meter manipulation or other forms of water theft and unbilled authorized consumption, which includes water used by the utility for emergency purposes like firefighting.[lxxxiv]

According to the latest (2012) DWS data, approximately 36% (or nearly 1.5 km^3) of municipal water consumption in South Africa was non-revenue.[lxxxv] Of that 36%, approximately 70% was from real or physical loses, and another 17% from commercial loses, representing the vast majority (nearly 90%) of that 1.5 km^3. Although the level of non-revenue water in South Africa is relatively on par with the global average, it is significantly higher than in other water stressed countries. For example, Australia has limited its non-revenue water to roughly 10% of total municipal withdrawals. If South Africa were to accomplish a similar feat by 2035, it could reduce municipal withdrawals in the country by 1.1 km^3.

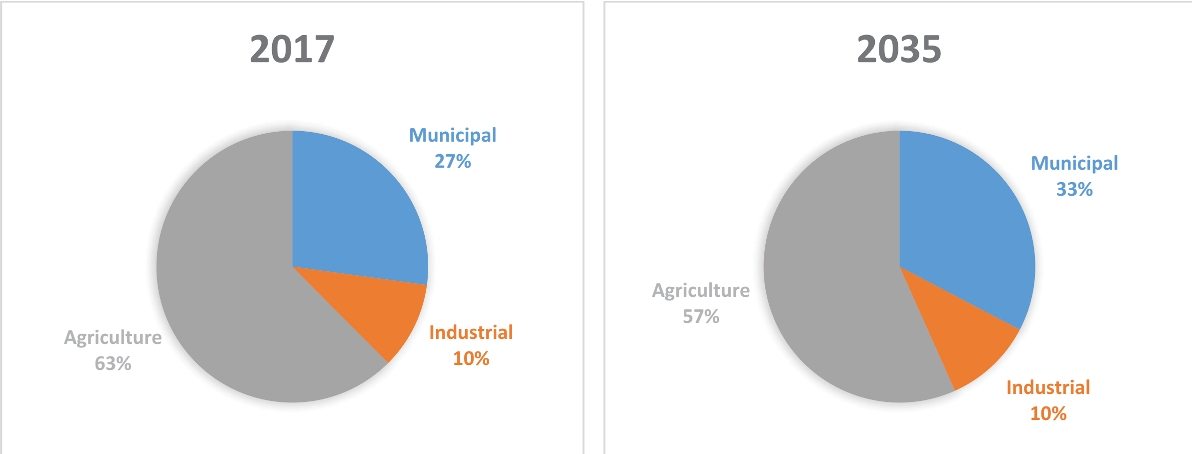
3.2 Forecast of withdrawals and supply

3.2.1 Withdrawals

The agricultural sector is forecast to continue to be responsible for the majority of South Africa’s total water withdrawals, accounting for about 10.1 km^3 of South Africa’s 17.8 km^3 of total withdrawals in 2035. However, the most significant *increase* is expected in the municipal sector. While the agricultural sector is forecast to withdraw about 3% more water in 2035 than it did in 2017, and the industrial sector about 17% more, the municipal sector is forecast to consume about 35% more water in 2035 than it did in 2017.

By 2035, the municipal sector will account for roughly 33% of total withdrawals, against 27% in 2017, whereas the agricultural and industrial sectors will account for about 57% and 10% respectively. The increase in municipal consumption is driven by South Africa’s growing and rapidly urbanizing population, rising incomes in the country and an increase in the percentage of the population with access to piped water, as government prioritizes the rectification of historical imbalances. Figure 19 shows a forecast of the evolution of water withdrawals by sector between 2017 and 2035.

Figure 19: Water withdrawals by sector in South Africa in 2017 and 2035



Source: IFs v. 7.29 initialised from AQUASTAT data

Although the municipal sector is expected to account for the majority of additional withdrawals, water demand is forecast to increase, in an absolute sense, in all three sectors. While municipal consumption is forecast to increase by 1.4 km^3, industrial demand is forecast to increase by 0.2 km^3, and agricultural water demand by about 0.8 km^3 by 2035.

One potential reason for the failure to sufficiently plan for increased water demand, is that there are some fairly significant discrepancies between the assumptions behind the IFs forecast, and the assumptions in South Africa's NDP. The first distinction to highlight is that the IFs population forecast is quite a bit higher than the NDP forecast.

The NDP outlines five potential demographic futures, with a mean population size of about 59.3 million people in 2030 (with a high of 61.5 million and a low of 58.2 million). In contrast, the IFs Current Path population forecast for South Africa is approximately 62.3 million people by 2030.[lxxxvi] Not only will these 3 million additional people require water for personal use, but the enhanced demand for food and electricity caused by this larger population will place further stress on the food, water, energy nexus.

Part of the explanation for this difference is that IFs initialises its population forecast from a higher total fertility rate (TFR) than envisaged in the NDP. While IFs assumes that the average woman in South Africa had roughly had 2.4 children in 2011, the assumption of the NDP is that the TFR was 2.3 births per woman in 2011. That may seem like a trivial distinction, but a 0.1 difference in TFR in a country the size of South Africa would result in about 1.5 million fewer (or additional) children being born.

There are also other incongruities between the IFs forecast and the NDP. For example, IFs forecasts that roughly 85 percent of South Africa's citizens will live in urban spaces by 2035, while the NDP expects that figure to be more like 70 percent.[lxxxvii] A difference of 15 percentage points here would be plus or minus 6 million additional people living in cities – based on the IFs population forecast. The IFs forecast also includes the assumption that South Africa will add an additional 8.2 million new piped water connections between now and 2035, which will drive up per capita water use.

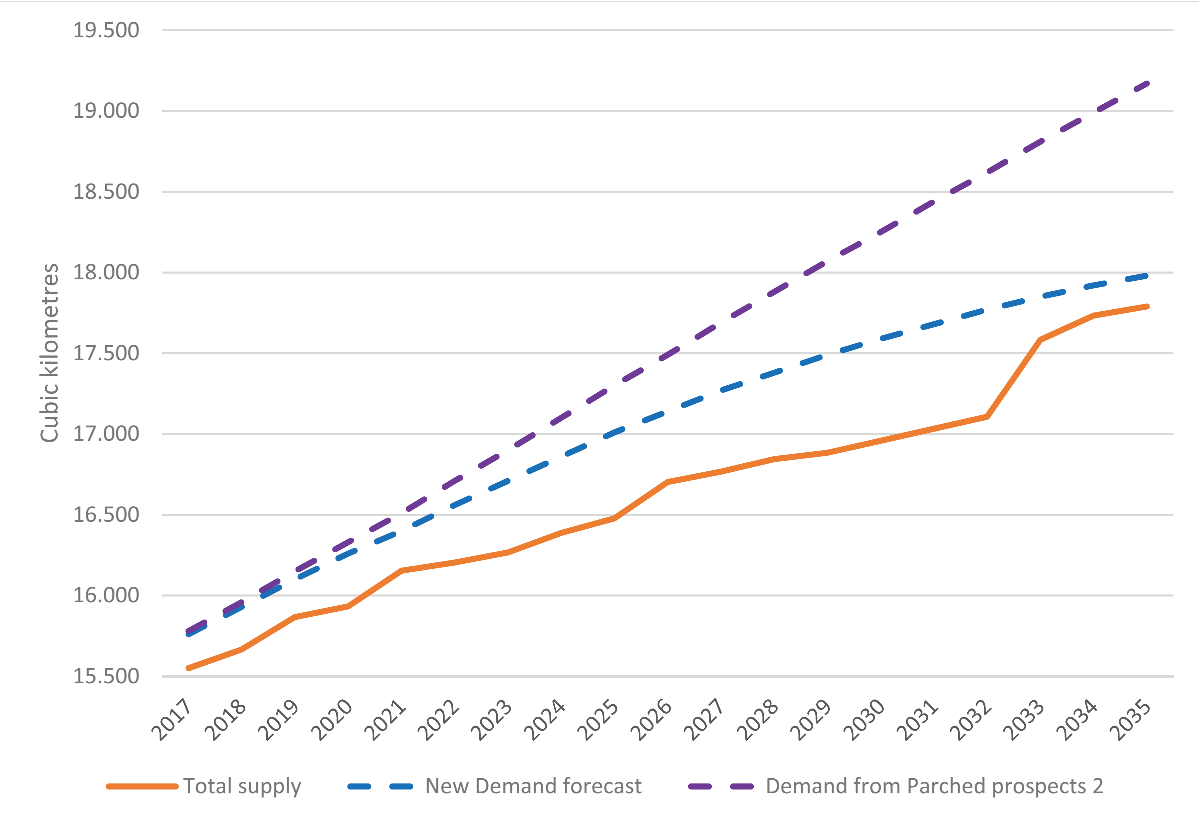
Finally, the IFs forecast expects South Africa to remain heavily dependent on coal for power generation. Thermoelectric power generation is a large driver of industrial water demand (mostly for cooling) and the Current Path forecast is that coal will remain the dominant fuel source for South Africa until 2035. The assumption in IFs is that thermo-electric power generation in South Africa consumes 1.85 litres/kWh (kilowatt-hours), but that this will decrease to 1.78 due to the implementation of dry-cooling technologies by 2035. But, the growing population and continued reliance on thermo-electric power will still drive water demand up in the industrial sector, even as it becomes less water-intensive in a per unit of energy sense.

Another issue with coal in South Africa is that many power stations are situated in catchment areas that are under water stress.[lxxxviii] This makes those catchments even more vulnerable to over-exploitation, as well as highly sensitive to any potential contamination resulting from industrial activity.[lxxxix]

A recent report found that the Mokolo Dam Crocodile River Water Augmentation Project (MCWAP) – which is intended to supply water to the Medupi power station – will divert more than 80% of its water for power generation and mining. Furthermore, the MCWAP could 'pose significant risks to the population's right to food water and health'.[xc] Moving the country away from a coal-based energy profile and increasing the share of renewables will reduce industrial water demand and liberate water for use in other sectors.

The two demand forecasts shown below represent two potential futures for South Africa. The first demand forecast (from *Parched prospects 2*) is a future where South Africa continually over-exploits its water resources with truly unknowable consequences for people, wildlife and the general ecological sustainability of the country's major surface water systems. The second forecast, from the revised water model with equilibrating dynamics, is a future where economic and human development are constrained by water scarcity. This second forecast represents a more plausible future, but also a much more challenging one.

Figure 20: Change in demand forecast after model revisions



Source: IFs v. 7.29 initialised from AQUASTAT data and supply forecast based on authors estimates of planned reconciliation strategies

While it may appear to be 'good news' that South Africa's over-exploitation seems less severe in this revised forecast, that improved water balance will have to be achieved through incredibly aggressive efficiency measures. Further, this New Demand forecast will likely entail some level of decreased agricultural production. These factors could make the country more vulnerable to international commodity shocks and threaten food security over the long-run.

The constraints on economic and human development from water scarcity are most evident on the agricultural sector. In the New Demand forecast, average agricultural yields in South Africa decline by over 9 percent in 2035, and total agricultural production declines by over 7 percent relative to the previous forecast from *Parched prospects 2*. This decline in agricultural production also has effects on economic growth, causing a cumulative ZAR 346 billion reduction in overall economic output over the duration of the forecast.

Another consequence of the constraint that water scarcity places on agricultural production is that South Africa is forecast to become a net food importer in the late 2020s, and is forecast to be importing over 9 percent of its total crops by 2035. Compared to the previous forecast, where South Africa was a consistent net food exporter, this new future could have serious implications for food security and make the country more vulnerable to droughts and other international price shocks going forward.

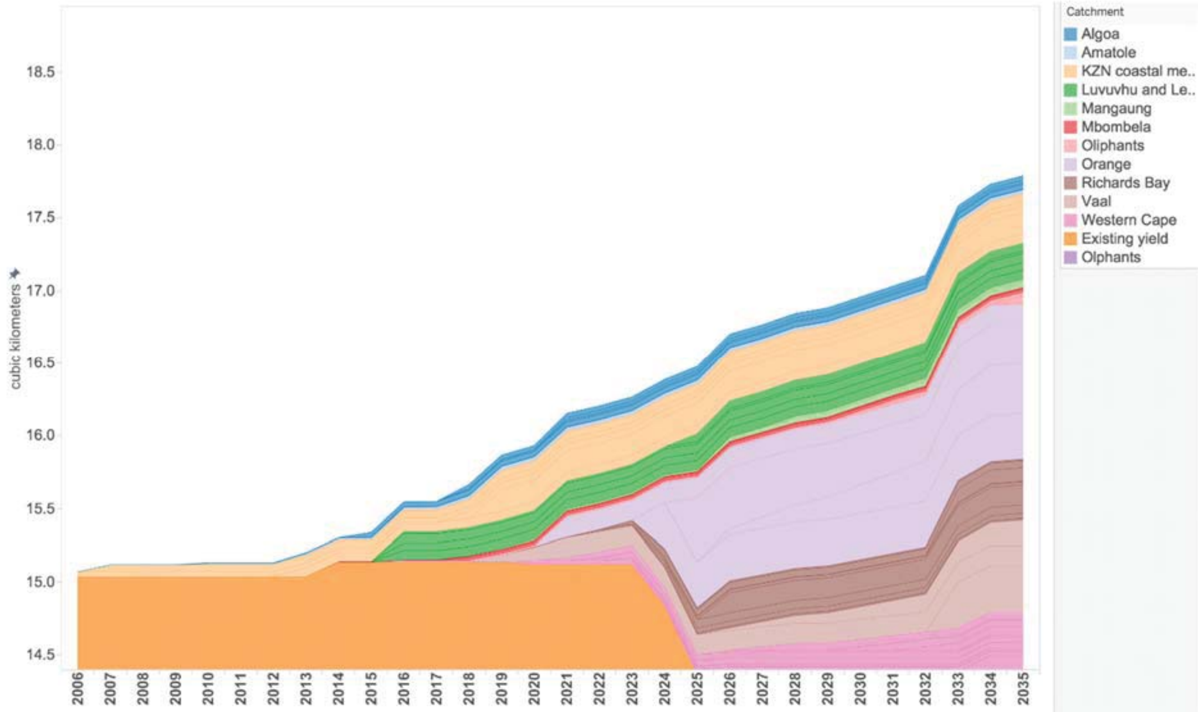
So, IFs now makes an assumption that South Africa will recognize that it is over-exploiting its renewable water resources and will implement measures to reduce demand and force convergence with the exploitable limit over time.[xci] This New Demand forecast assumes that South Africa will have to reduce total withdrawals by about 1.2 km^3 (relative to the previous forecast). This amount is equivalent to nearly three-quarters of the total withdrawals of the industrial sector in 2017. A decrease of this magnitude would not be without historical precedent, but would represent the exception, rather than the rule, for upper-middle-income countries.[xcii]

The key point is that, even with a dynamic model where withdrawals are constrained based on available supply, South Africa is forecast to continue to over-exploit its water resources throughout the duration of the forecast. This can have devastating effects for water ecosystems and could ultimately impact the future of water security throughout the country.[xciii]

3.2.2 Supply

Parched prospects 2 included a water supply forecast that was constructed by combing through the NWRS2 along with every large-scale reconciliation strategy published by DWS.[xciv] The forecast presented in this paper includes all publically available information at the time of writing about any additional plans, delays, or cancellations of those existing reconciliation strategies (for details on these updates see annex A). These revisions have been incorporated into a supply forecast that is slightly different than that from Parched prospects 2, shown below in Figure 21.

Figure 21: Planned increases in yield extracted from all published large-scale reconciliation strategies



Source: All large-scale reconciliation strategies[xcv]

Those strategies do not cover the whole of South Africa, but they do address all the major urban centres and sources of supply (i.e. the country's major rivers). The vast majority of these plans are large-scale infrastructure projects aimed at increasing the supply of water in the country. While increases in supply are certainly necessary to address South Africa's water challenges, they will not be sufficient to bring the system back into alignment within the time horizon presented in this paper.

The outcome of all these interventions is that the total water system is forecast to yield approximately 17.8 km^3 in 2035, against a revised withdrawal forecast of roughly 18 km^3. It is important to emphasize though, that this supply forecast depends on the ability of South Africa to implement – on time and to specifications – every planned reconciliation strategy. Also, this withdrawal forecast assumes that South Africa will reduce withdrawals, *significantly*, by 2035. Finally, even in a forecast where South Africa reduces withdrawals by more than 1 km^3, and where the country implements all planned reconciliation strategies on time and to specification, South Africa continues to over-exploit its water resources beyond 2035.

4 RESULTS AND SCENARIO ANALYSIS

Although South Africa's water challenges seem daunting, there are available and affordable solutions to some of the most pressing problems posed by water scarcity in the country today. So far, the overwhelming majority of proposed solutions in South Africa have focused on increasing the overall level of surface water, mainly through large infrastructure projects like the construction of new dams. However, as previous research from the AFP has indicated, even those strategies, if implemented on time and to scale, are insufficient to meet South Africa's growing water needs in the absence of demand constraints.[xcvi] In other words, without a combination of existing plans, additional strategies to access previously underused water sources and some measure of conservation and demand management, the water sector will constrain the ability of South Africa to meet other development objectives.

4.1 Wastewater treatment

According to the latest AQUASTAT data (from 2009), South Africa only treats about 54% of its municipal wastewater.[xcvii] Furthermore, South Africa's existing wastewater treatment infrastructure requires significant investment. The 2014 Green Drop Report concluded that nearly a quarter of South Africa's wastewater treatment facilities are in a 'critical state', defined as needing urgent intervention, while roughly another quarter of existing facilities are defined as 'high risk'.[xcviii] Although 2014 was the last official Green Drop report, there have been subsequent efforts to identify the scale and scope of the problem.

Between May and June 2017, the non-governmental organization AfriForum tested the water sewage systems in 88 towns and found that two-thirds (59) did not meet national quality standards.[xcix] This is an increase of more than 100% relative to 2016 (when 26 plants did not meet minimum standards). According to AfriForum, this dilapidated water infrastructure could 'pose a threat to human health, food security and the environment'.[c]

This increase in the number of insufficiently operated or maintained water sewage treatment points to some opportunities for municipal water authorities to improve water quality and potentially increase supply. Moreover, the poor quality of water treatment plants is just one indication of the country's deteriorating water infrastructure, in addition to the issue of non-revenue water discussed earlier.

Although seven of the ten reconciliation strategies analysed for this paper set targets for increasing the use of treated wastewater, those interventions amount to roughly 0.22 km^3, or less than one-quarter of the projected gap between supply and demand in 2035. While the proposed interventions are surely a step in the right direction, there is absolutely scope to increase the amount of treated wastewater in South Africa beyond what is currently envisioned in the major reconciliation strategies.

4.2 Groundwater

Parched prospects 2 pointed out that groundwater is likely an underutilized resource in South Africa. Since then, the DWS has published estimates of how much groundwater could potentially be available in the country, and suggests that utilizing groundwater more intensively, particularly in the agricultural sector, could be a fruitful source of additional water.[ci] The DWS has estimated that close to 85% of the country's groundwater aquifers are under allocated and that there could potentially be as much as 4.8 km^3 worth of exploitable groundwater in South Africa.

Box 1: Water conservation

There is misconception that water restrictions are draconian measures reserved for near-emergency situations like those in the Western Cape or in the American southwest in 2013-2014. But, examples from other communities demonstrate that conservation need not compromise quality of life. Tucson, Arizona is a city with a population of about 500 000 that receives about 300 mm of rainfall a year. The municipality began to run out of groundwater in the 1970s and adopted a multifaceted policy response that has enabled the city to reduce per capita consumption by roughly one-third (from just over 700 litres a day in 1989 to less than 500 litres a day in 2015).[1] This multipronged approach involved tiered water pricing (higher rates for larger consumers), the implementation of new building codes (reducing irrigation for landscaping and mandating efficient utilities in commercial spaces), encouraging the collection of rainwater and offering a slew of incentives for private individuals to invest in water efficient appliances.[1] The result is that total consumption in the city is roughly the same as it was in the late 1980s, despite population growing by roughly 40% over the same time period.[1]

Israel is an oft-cited example of a country that has used supply side measures (i.e. desalination technology) to reconcile its national water sector. However, water conservation has been a critical part of Israel's water strategy as well. The Israel Water Authority has said that 'water conservation and efficient usage of it is the cheapest most available source of water' and further that 'savings campaigns carried out in the past have shown, without doubt, that 10-20% of [the] total consumed in the municipal sector may be saved, while making sure not to affect the consumer's welfare'.[1] This last part is perhaps the most important. It is possible to decrease water consumption on a large scale, without significant sacrifices in the day-to-day lives of South Africans.

Nobody can say with any certainty if that groundwater estimate is accurate or not because the kind of in-depth, scientific study necessary to establish a reliable figure has yet to be completed. Further, groundwater is a delicate resource and needs to be managed cautiously. Nonetheless, the DWS estimate does suggest that a modest increase in groundwater use, provided that it was done in a sustainable way, could act as one prong of a strategy to improve water security in South Africa.

4.3 Water Conservation and Water Demand Management (WCWDM)

South Africa must price water more deliberately. In fact, WCWDM strategies may be the most important element of South Africa's effort to ensure stability in its water sector. This research suggests that the price of water must increase in South Africa. But, the legacy of apartheid and the extreme levels of structural inequality require a very delicate and nuanced approach to water pricing that does not further harm previously disadvantaged communities.

Tiered water pricing is a well-established system of water conservation that has proven its effectiveness in other parts of the globe. Tiered pricing works by charging customers a higher per unit cost for water, based on how much water they withdraw. Customers who use more than the level deemed necessary for human consumption, will pay a higher rate. Nelson Mandela Bay has already begun to implement tiered pricing. In that municipality, customers pay R14.57 for the first 1 000 liters per day, R29.46 (per thousand liters) for the next 3 000 liters and R58.92 (per thousand liters) for anything up to 8 000 liters per day.[cii] Customers using more than 8 000 liters per day, pay R196.41 per 1 000 liters.

Santa Fe New Mexico began implementing tiered, or block, pricing more than a decade ago and has seen per capita water use drop by almost 30 percent.[ciii] Total municipal water withdrawals have decreased by about 20%, despite the city's population growing by more than 10%. The advantage of tiered pricing is that it 'offers a balance between fairness and efficiency', according to a 2014 study from the University of California, Riverside.[civ] That same study found that introducing tiered pricing in residential communities reduced demand by at least 18%, in just over three years.[cv] Research from Stanford University further suggests that 'increasing block price schedules provide strong incentives for consumers to conserve water'.[cvi]

Tiered pricing is beneficial because it does not rely on government regulation or forbid anyone from using additional water. The idea is that water meant for basic human consumption be as affordable as possible (perhaps even free in a country like South Africa), while water used to maintain a swimming pool or extravagant landscape is relatively expensive. As Santa Fe's director of public utilities commented, 'for some people a lawn is important, and if they want to spend their money on irrigation, they can'.[cvii]

This has enormous implications for South Africa, which has committed to rolling out universal access to clean water irrespective of the ability to pay for it. Although President Mbeki made universal access to clean water within 5-years a cornerstone of his 2004 State of the Union address, in 2015 roughly 3.7 million South African's still lacked access to safe drinking water.[cviii]

Israel is another example of a country that has used tiered pricing to reflect scarcity.[cix] That country also treats more than 80% of its wastewater and has employed a dynamic approach to water security that has allow the country to move from continually over-exploiting its renewable resources during the 1980-1990s into a space where the National Water Authority is now able to reduce price.[cx] In South Africa, the DWS has been investigating an increase in tariffs and has held public discussions on the introduction of tiered pricing, no national strategy has yet been implemented.[cxi]

Pricing water more responsibly should help create a culture of conservation, and help avoid more onerous regulations like the level 5 water restrictions currently in place in the Cape Town metro area.[cxii] The best way for other areas of South Africa to avoid having to deal with the harsh measures being implemented in the Western Cape, is to start using water more consciously before critical shortages hit.

There are also other demand reduction campaigns being implemented by DWS. In the Northern Cape, the Department has issued 50 000 water saving blocks for users to drop in their toilet cistern to reduce the average flush by about two liters. The department hopes the 'Drop a Block' campaign will save over 100 000 liters of water per year.[cxiii] DWS has also started the Clear Rivers Campaign, which calls on citizens to get involved in their communities and assist with river rehabilitation.[cxiv] These are not national campaigns yet, but could be built upon to encourage a more introspective conversation about water use in South Africa.

4.3.1 Non-revenue water

Non-revenue water is essentially municipal water that is not paid for either through physical losses, theft and other unbilled consumption (see section 3.1 for more details). While the amount of non-revenue water in South Africa is roughly on par with the global average, the country is considered a 'high' water stress country by the World Resources Institute, and cannot afford to let its water infrastructure fall into further disrepair.[cxv]

The South African government has committed to a 'war on leaks' campaign that aims to reduce the level of non-revenue water in South Africa by employing 15 000 South African's as plumbers and artisans by the end of 2018. Although the campaign is being implemented unevenly throughout the country, the majority of the focus seems to be in Kwa-Zulu Natal and the Eastern Cape.[cxvi]

Reducing non-revenue water will be challenging, but could also have a large impact in South Africa and should be a fundamental component of a comprehensive demand management strategy. Reducing non-revenue water from its current level of 36% (according to 2012 DWS data) to 10% by 2035 could reduce municipal withdrawals by more than 1.1km^3, representing the majority of the demand reduction presented in the New Demand forecast.

What is clear is that South Africa must implement a combination of strategies to restore balance to its national water system. This combination will likely involve significant demand reduction strategies, increasing the amount of wastewater that is treated and reused, reducing non-revenue water and increasing the use of groundwater.

4.5 Scenario analysis

South Africa's water sector hangs in the balance. But, as shown, solutions are not out of reach. As other areas of the globe facing severe water stress have demonstrated, there are solutions available to cultivate a more secure water future for South Africa. These include a combination of WCWDM strategies, increasing the amount of treated wastewater and using groundwater more frequently in areas where its longevity can be ensured. This section will explore the likely future of South Africa's water sector and introduce some alternative scenarios. A first scenario (Agricultural Tradeoffs) is intended to highlight the constraints that water scarcity can place on other development priorities. A second scenario (Closing the Gap) is presented to demonstrate how a comprehensive, robust response to the water challenges faced today, could lead to a more secure water future in South Africa.

In line with the time horizon of the NWRS2 the Closing the Gap interventions begin from 2018, occur over 5 years and are then maintained until the end of the forecast. The Agricultural Tradeoffs scenario is calibrated to coincide with the time horizon of the NDP, although the target has been adjusted based on research for this project.

4.5.1 Agricultural tradeoffs

South Africa's National Development Plan 2030 (completed in 2012) envisions a 'substantial investment in irrigation infrastructure' and loosely suggests a 50% increase (at an estimated cost of R40 billion) over a 10-year period as the first pillar of the country's national agriculture strategy.[cxvii] South Africa currently has an estimated 1 670 000 hectares (ha) equipped for irrigation in 2015, of which about 1 365 000 is actually irrigated.[cxviii]

It has subsequently been questioned, by the NWRS2 as well as the Department of Agriculture Forestry and Fisheries, if that increase is possible, or even desirable, given current water constraints.[cxix] The Department of Agriculture, Forestry and Fisheries believes that 145 000 ha could be a more reasonable target, which it has established as its target for the national Agricultural Policy Action Plan.[cxx] This scenario will explore some of the implications of increasing the amount of land under irrigation by roughly 145 000 ha by 2022 (i.e. 10-years after the publication of the NDP).

There are benefits to increasing irrigation. A well-executed expansion of irrigated land in South Africa could increase yields, decrease dependence on erratic rainfall and improve the overall resilience of the agricultural sector. However, like the municipal sector, an expansion of irrigation in South Africa will have to be conducted 'primarily through more efficient use of existing water resources'.[cxxi] If South Africa hopes to efficiently increase the amount of land under irrigation and get 'more crop per drop', it will have to exercise careful water management in the agricultural sector.[cxxii] Indiscriminately increasing the number of hectares equipped for irrigation, could have paradoxical effects.

Put bluntly, 'in conditions of increasing water shortage, further development of irrigated agriculture production is impossible without improving the methods of cultivation of agricultural crops, primarily irrigation technology.'[cxxiii] An expansion of irrigation should be reserved for soils with a higher nutrient content to achieve the desired increase in yield. If this is accomplished, it should increase food production in the country and also leave more water for the municipal and industrial sectors.

In the Agricultural Tradeoffs scenario, the land equipped for irrigation increases from its current (2017) level of 1 690 thousand hectares to 1 867 by 2022 and then 1 967 by 2035. This leads agricultural water demand to increase from 9.8 km^3 (in 2017) to 10.7 km^3 by 2035 (compared to the Current Path of 10.1 km^3 in 2035).

In the absence of other supply enhancement and demand reduction interventions, increasing the amount of land equipped for irrigation in South Africa will be challenging, and will almost certainly have diminishing returns. As South Africa's population continues to grow, as incomes continue to rise and as the country seeks to expand its manufacturing sector, it will be increasingly difficult to allocate additional water to the agricultural sector.[cxxiv]

In the Agricultural Tradeoffs scenario, municipal water demand still increases slightly, to 5.5 km^3 by 2035 compared to 5.8 km^3 in the Current Path. Industrial water demand is constrained as well, growing to just 1.8 km^3 rather than 1.9 km^3 in the Current Path. In this scenario, South Africa has less water to distribute to individuals and less water available to grow its manufacturing sector or increase the supply of thermo-electric power.

Put differently, if the South African government hopes to achieve the irrigation target in the NDP, it will need to offset the additional withdrawals in the agricultural sector by either 1) increasing supply through alternative sources (i.e. large investments in treated wastewater, additional groundwater extraction) or 2) by reducing demand through conservation measures or infrastructure improvements. It will very likely involve some aspects of both supply enhancement and demand reduction.

Additional irrigation schemes will increase agricultural yields and resilience over the short-run, but the amount of water devoted to agriculture is still restricted by the structural constraints of the water sector. Increasing the amount of land equipped for irrigation will mean that, over the long-run, each hectare of farmland in South Africa would then receive less water than it otherwise would have without that additional irrigation. Moreover, as additional land is irrigated and agricultural water demand increases, the municipal and industrial water demand sectors will be even more constrained than in the Current Path.

4.7 Closing the Gap

There are a plethora of policy options available to South Africa to reconcile supply and withdrawals in its water sector. The critical question is, what combination of penalties, incentives, investments and technologies to embrace?

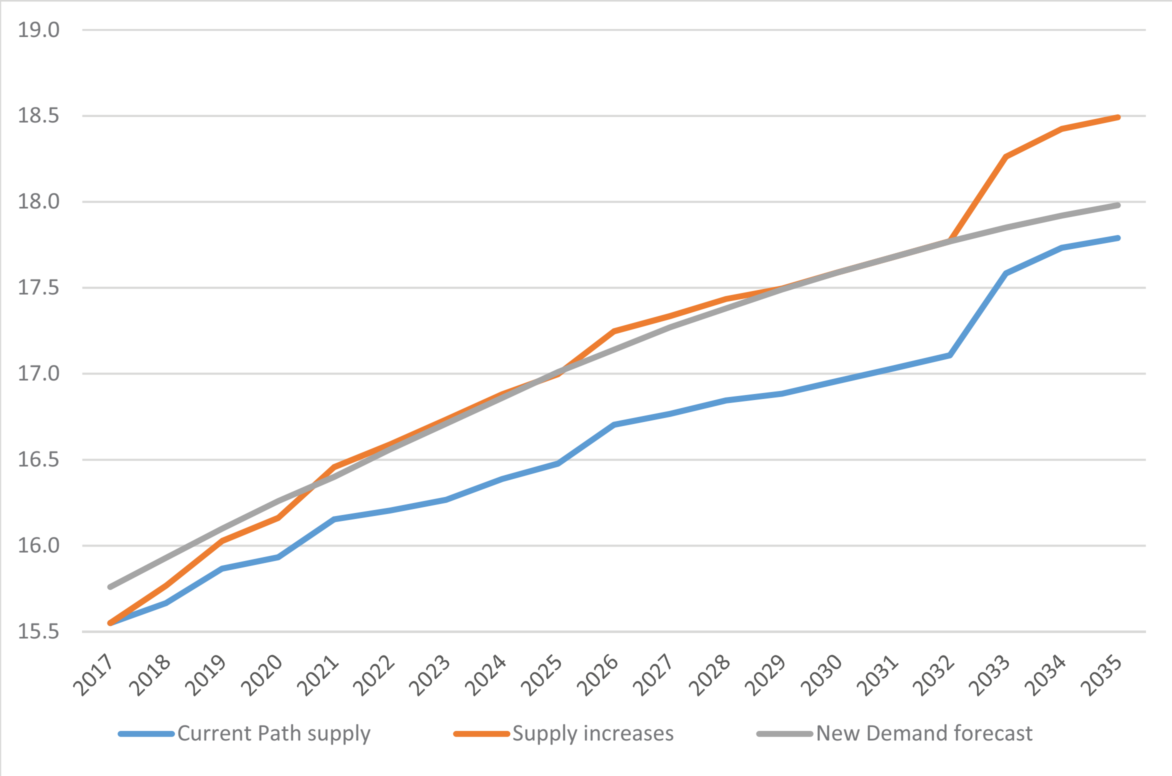
4.7.1 Closing the Gap supply side interventions

There are various combinations of policies that could deliver a sustainable solution to South Africa. But, deciding which set of policies will ultimately provide the largest return on investment requires detailed work at local and catchment level by experts with an intimate knowledge of the relevant conditions and constraints in their respective water systems. At a national level however, this research has pointed to broad areas that the South African government can focus on: increasing the amount of wastewater that is treated and reused, minimizing non-revenue water or otherwise increasing efficiency in the municipal sector, increasing the intensity of groundwater use in areas where it is sustainable and increasing the share of renewable sources in the national energy mix.

This section presents the Closing the Gap supply side interventions where the level of treated wastewater that is recycled through the system is increased by about 0.38 km^3 in 2035, and the amount of groundwater extracted increases by about 0.33 km^3 in that same year. Moreover, in this scenario these interventions occur *in addition* to all of the planned interventions outlined in the major reconciliation strategies. In other words, the Closing the Gap supply side interventions consists of efforts that are above and beyond what the government is currently planning.

In the Closing the Gap scenario, South Africa aggressively implements demand management strategies (reducing withdrawals by nearly 1.2 km^3 relative to the previous forecast), increases the amount of treated wastewater and increases the extraction of groundwater. These interventions begin from 2018, occur over 5 years and are then maintained until the end of the forecast. Figure 22 below shows that if South Africa implements extremely ambitious water policies, it is feasible to bring the water sector back into relative balance in a fairly short period of time. However even in this optimistic scenario, South Africa still toes the line of over-exploitation for the next decade and a half.

Figure 22: Closing the Gap supply side interventions relative to total supply on the Current Path and a revised withdrawal forecast



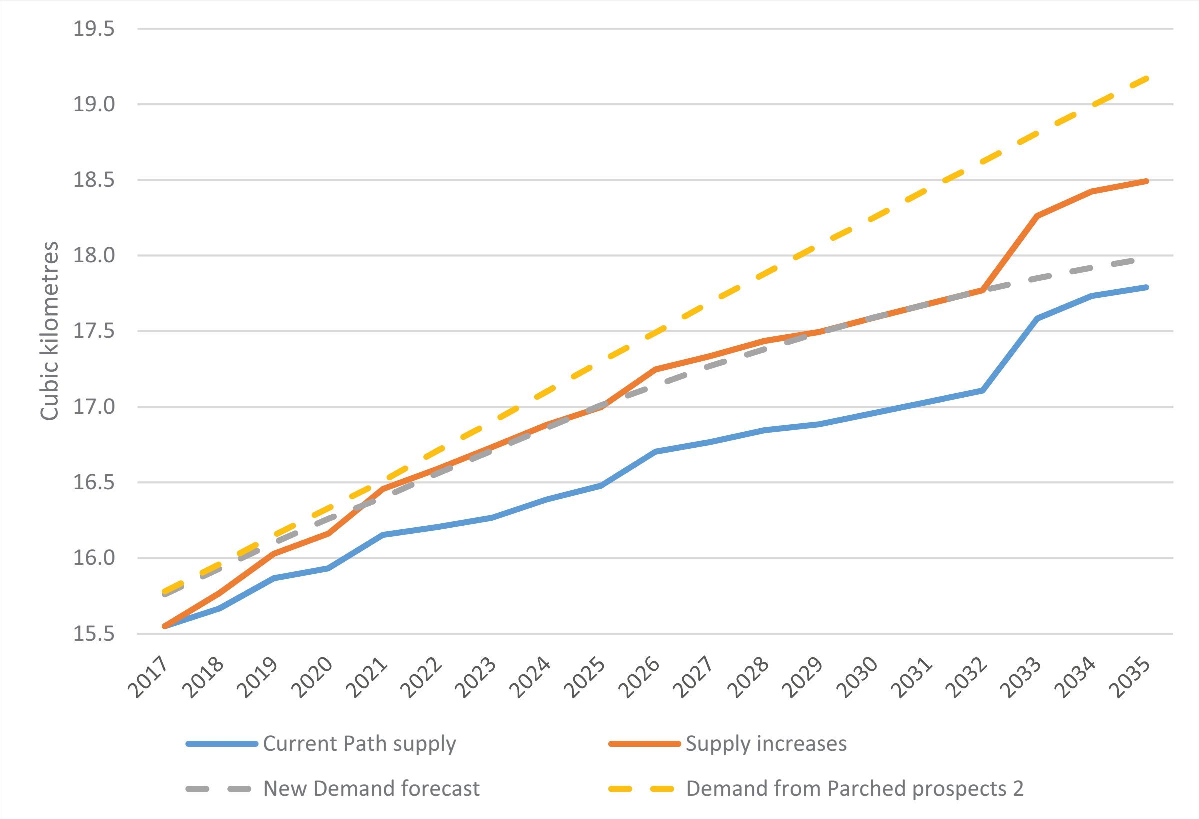
Source: IFs v. 7.29 and authors calculations

It is important to reiterate that this revised demand forecast represents an assumed reduction in withdrawals of 1.2 km^3, compared to the forecast from Parched prospects 2. If South Africa hopes to avoid some of the negative consequences that water scarcity will place on human and economic development, this needs to be taken into consideration.

4.7.2 Closing the Gap demand side intervention

While Figure 22 gives the impression that it will be reasonably straightforward for South Africa to restore balance to its water sector, Figure 23 better illustrates the size of the challenge. Figure 23 shows the Closing the Gap intervention compared to the revised demand forecast, the demand forecast from Parched prospects 2 and a Current Path supply forecast. Again, this new forecast – where water constrains other areas of development – results in a future where South Africa's economy is significantly smaller, and it is much more reliant on imported food than it has been in the past.

Figure 23: Closing the Gap scenario relative to total supply on the Current Path, an updated withdrawal forecast and the withdrawal forecast from Parched prospects 2



Source: IFs v. 7.29 and authors calculations

It is difficult to overstate the magnitude of the demand reduction implicit in this new forecast. This reduction of roughly 1.2 km^3 is almost equivalent to the withdrawals of the entire industrial sector in South Africa today. To frame it using another lens, non-revenue water would have to be reduced from about 36% today to roughly 10% by 2035, and would still fall a bit short of this target.

Perhaps most importantly though, even if all of these things happen on time and to specification, they will not provide South Africa with a water surplus until the 2030s.

This could be achieved in a number of ways. Reducing the level of non-revenue water is essential. Expanding the ‘war on leaks’ – along with other awareness campaigns – is an important part of the problem, but, WCWDM can also be implemented in the agricultural sector, by employing more efficient irrigation technologies or growing less water intensive crops. Most importantly, more conservative use of water must be encouraged by a tiered pricing structure and other incentives for consumers to use more water efficient appliances – tax rebates for purchasing water efficient fixtures is a possible option.

But again, even with a basket of interventions that effectively increase the available supply of water by more than 0.7 km^3 by 2035 – along with a reduction of 1.2 km^3 on the demand side – South Africa does not restore balance to its water sector until after 2030.

Moreover, this scenario comes well short of achieving the withdrawal forecast from *Parched prospects 2*, and will likely still have negative consequences for human and economic development in South Africa.

Together with the supply side recommendations, this scenario represents a comprehensive push from the South African government to stabilize the water sector and would necessarily involve a delicate combination of incentives and deterrents. If the government begins to assertively implement measures to enhance supply and curtail demand, then it is possible to restore sustainability to South Africa's water sector, without resorting to extremely punitive restrictions. If the government fails to respond to the situation, then the country could be forced to endure situation similar to the recent energy crisis, which nearly paralyzed the country's economy.

Based on the research presented in this paper, these targets appear to be within the realm of possibility – at least in terms of South Africa's physical resources. Whether or not it is politically (or financially) feasible to proactively implement these recommendations is an entirely separate question.

5 CONCLUSION AND RECOMMENDATIONS

The predominant takeaway from this report is that it is possible for South Africa to reconcile its national water system by using available technologies. Policies that incentivize efficiency (including tiered pricing and reducing non-revenue water), improve the quality of the country's water infrastructure (including wastewater treatment plants) and increase the amount of groundwater used can bring demand in line with available supply. Moreover, as new technologies (like desalination and renewable energy) become more affordable, there are other solutions beyond what has been outlined in this paper that could help close the gap between supply and demand.

In 2002, UNESCO adopted General Comment No. 15 that states 'the human right to water is indispensable for leading a life in human dignity. It is a prerequisite for the realization of other human rights.'[cxxv] As the forces of climate change, population growth, urbanization and industrialization collide in South Africa it is vital that policymakers take aggressive measures to restore balance to the water sector. However, it is equally critical that those policies are implemented with the understanding that the country is still working to overcome decades of systemic oppression. Finding the right balance between promoting general conservation among those who can afford it, while working to expand access to clean water for those who do not currently have it will be difficult. That said, it is hard to think of a more important or laudable policy goal.

Along with policy action, it is important to underscore that there is still a great deal of information that we do not know about South Africa's water ecosystems. In that vein, this report outlines the following topics, as potentially fruitful avenues of future research:

- **Improve the monitoring and evaluation of wastewater:** The government of South Africa stopped publishing its annual Blue and Green Drop Reports in 2013/2014. These reports used to provide researchers with critical information about the country's water and sanitation infrastructure. While intrepid NGOs like AfriForum have carried on producing updates on the state of South Africa's wastewater treatment centres, a well-funded, national-level assessment of these facilities is sorely needed.
- **A national study of the country's water infrastructure:** Although wastewater treatment facilities are likely the aspect of South Africa's water sector in need of the

most attention, the high per capita use and high rates of non-revenue water suggest that a deeper examination of water use in the country is necessary.

- **Explore options for a national tiered pricing system:** If South Africa is going to successfully address the challenges in its water sector it will have to start pricing water more responsibly. Because of the deep-seated structural inequality left behind by apartheid, increasing the price of water for those who can afford it, while making it more accessible to previously disadvantaged groups will be difficult. An efficient, equitable system of tiered pricing will involve significant coordination between municipal, provincial and national governments and must be implemented with great care.
- **Better understanding of how much groundwater is available:** Although the DWS has information on their website about how much groundwater could potentially be available in South Africa, there is less confidence about how much can safely and reliably be extracted. It is likely that groundwater is an underused resource in South Africa, particularly in the agricultural sector, and should be part of a comprehensive strategy to address the problem. However, it is impossible to know how much groundwater can be relied on with more in-depth research about exactly how much groundwater can be reliably extracted in which communities.
- **Improve the monitoring of water quality in South Africa:** As the country continues to over-exploit its renewable water resources the quality of water could deteriorate across South Africa. Modelling water quality is currently outside the scope of this research, but it is nonetheless an important factor that warrants continued attention from policymakers and civil society.

South Africa cannot afford to forestall the implementation of more aggressive policies in its water sector. In order to avoid a state of national emergency – similar to that which occurred during the energy crisis of 2014-2015 – the government will have to act immediately. In order to align its water sector, South Africa must:

POLICY RECOMMENDATIONS

- **Implement water conservation and demand reduction measures:** South Africa must do more to improve the efficiency of water use in the country. This can be done through a combination of infrastructure repairs (to address non-revenue water), the implementation of new building codes, incentives to install water efficient appliances and a tiered pricing structure. Policy measures should also be supplemented with campaigns to raise awareness about high levels of per capita water use and the inherent value of water conservation in a water scarce country.

- **Increase the amount of wastewater that is treated and reused:** A survey of 88 municipalities found that more than two-thirds of the wastewater treatment facilities surveyed did not meet minimum quality control standards. A failure to efficiently address wastewater treatment and reuse could have devastating consequences for people, the environment and the economy. Increasing the amount of wastewater that is treated and reused will not only improve the quality of South Africa's water, but also increase the supply.
- **Increase groundwater extraction:** Groundwater is likely an under-used resource in South Africa. Although there are no precise estimates of how much groundwater is available where, the DWS estimate suggests that there is potential to significantly expand the amount of groundwater extracted. This could be particularly useful for the agricultural sector, where nearly two-thirds of South Africa's water is allocated.
- **Complete all planned water infrastructure projects** on time and to specification. Additionally, there should be a siltation strategy that guides decision-making on impoundment siltation management at both existing and new dams.
- **Explore new technologies:** This report stresses that there are available, affordable solutions to South Africa's water problems. However, the report has not explored more advanced technologies in as much detail.
    - **Desalination:** Currently, desalination technology is prohibitively expensive for South Africa except in very large, coastal metropolitan areas like Cape Town, Durban and Nelson Mandela Bay (desalination currently accounts for less than 1/10th of 1 percent of South Africa's total water supply). As the cost of desalination decreases, it will likely be an increasingly viable option for these major municipalities. But, desalination will not be able to address water scarcity in South Africa's inland areas and will have a limited impact on the agricultural sector, and so likely will only play a small part in South Africa's water future.
    - **Renewable energy:** South Africa is almost entirely dependent on coal for its electricity needs. These thermoelectric power plants require large amounts of water for cooling and threaten to further harm the country's water ecosystems. Increasing the amount of energy generated from renewable sources will reduce industrial water demand, lower carbon emissions and minimize water contamination from industrial activity related to coal production.

- **Create financial incentives for efficiency:** South Africa must provide a favourable regulatory environment and financial incentives to invest in research and development. Incentives should be provided for the development of renewable energy technology (to reduce dependence on coal) and for the development and production of commercial and residential appliances that promote water efficiency. Further, the government should provide construction companies and homeowners an incentive to buy and use water efficient appliances. It will be difficult for government alone to create a *culture* of water conservation in South Africa, but it is the only one that can provide a financial incentive to take water conservation *seriously* by individuals, businesses and communities.

Stability in South Africa's water sector is feasible, but it will take significant research, ambitious policies and the creation of a culture of water conservation that extends beyond scientists and civil society and permeates everyday life in South Africa.

Annexure A – Updates to large-scale reconciliation strategies

- LHWP Phase II, had slight delays due to the unrest in Lesotho after their national elections and a new government coming into power. That notwithstanding, the project is proposed to be finished in the original timeline by 2025.[cxxvi] The main structures will be the building of the Polihali Dam and the tunnel that would join Polihali to the Katse Dam now in operation.[cxxvii]
- Kalahari East Water Scheme in Northern Cape, construction of a 21million litre storage reservoir, not competed.[cxxviii]
- Greater Mthonjaneni Bulk Water Supply Project in Kwa-Zulu Natal. In Phase 2, goal of eradicating water backlogs by 30 percent with a yield of 14.6milliom m^3/year, expected to be completed by 2018. Includes upgrading booster pumps, refurbishment of raw water reservoirs and pipeline networks, using Lake Phobane as a water source.[cxxix]
- Vaal Gamagara Water Scheme in Northern Cape launched on 23 June 2016. To Augment water supply in the Northern Cape up to 2040. For mining and agricultural activities and six municipalities and 22 villages. Involves pipeline construction and drilling of boreholes.[cxxx]
- Mopani Intervention Project in Limpopo province is set to be completed in June 2017. Project consists of a pipeline network, borehole refurbishment and upgrading Waste Water Treatment Works (WWTW) and construction of a new WWTW that will provide water to 55 villages.[cxxxi]
- Thukela-Goedertrouw Tranfer Scheme upgrade in Kwa-Zulu Natal. Richards Bay area water supply is running low and therefore the upgrade will double current yield from the Tugela River.[cxxxii]
- Mzimvubu Water Project in Eastern Cape is soon to finish the design phase. It consists of 2 dams; Ntabelanga Dam on the Tsitsa River with a storage capacity of 490 million m^3 and the Lanleni Hydropower Dam which will generate between 35 and 180 MW of power. The project will include a distribution pipeline and an irrigation network.[cxxxiii]
- James Kleynhans Bulk Water Supply in the Eastern Cape, Phase 1: augmentation and upgrading has commenced and will increase water treatment works from 3,65million m^3/year to 7,3million m^3/year. Upon completion, the project will help meet water demand requirements till 2035.[cxxxiv]

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[xcii] Examples of countries that have decreased total water demand include Australia (1 km^3 between 2000 and 2013), Belgium (1.6 km^3 between 1997 and 2009), Canada (.9 km^3 between 1996 and 2007) Japan (3 km^3 between 2002 and 2009). Data taken from IFs via FAO AQUASTAT.

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