University of Southern Queensland

Faculty of Engineering and Surveying

Water Budgeting & Urban Water Demand Management in Townsville

A dissertation submitted by

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Abstract

The city of Townsville in northern Queensland, has endured a variety of extreme weather events in recent years from flooding and cyclones to extreme temperatures and drought. All of these issues have stretched the capacity of an already limited water supply system that continues to see the effects of climate change, as are many urban areas throughout the world. Australia's climate continues to be hotter and dryer, placing an increased focus on water security issues. In addition to these supply factors, demand for water continues to climb, particularly for Townsville. These deficits in water supply require a renewed focus on water modelling to ensure that policies adopted to address water security are appropriately targeted to ensure sustainable urban development.

This research project seeks to contribute to this challenge by providing a water modelling study for Townsville out to 2030. In doing so, it seeks to understand the key variables affecting both demand and supply and provide nine scenarios to forecast potential water security within the city. AWBM was utilised to generate run off data and an excel water balance model was constructed to achieve this. Drawing on existing studies of the Townsville area and wider Australia, the study will also provide a contextual understanding of the issues affecting the city.

The study ultimately concludes that Townsville will require long-term investments in supply initiatives while simultaneously incorporating permanent water restrictions to mitigate the projected water deficits facing the city. The planned investment in the Haughton Pipeline duplication was found to be necessary to sustain Townsville's projected growth. Permanent water restrictions to reduce consumption by 30% was also found to be the most optimal water management measure to reduce consumption to an average of 0.32kl p/p, p/day.

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Table of Contents

1 - Introduction

Water security is becoming an increasingly difficult challenge throughout the world. The effects of climate change, compounded by population growth in increasingly urbanised areas is threatening the ability of many global citizens to receive adequate clean drinking water. This issue is only expected to become more exacerbated with global water usage expected to increase by 1% a year while water supply becomes increasingly threatened by the effects of climate change (UNESCO 2020, p. 1). In Australia, this issue continues to be highlighted with water restrictions becoming increasingly common in major population centres due to a prevalence of drought and extreme weather events. In the city of Townsville in north Queensland, this issue has become a core part of the city's daily life due a complex mixture of supply and demand issues.

The Townsville City Council has launched a number of initiatives to address water security in the city, including the support of a review conducted by the Department of Energy and Water Supply (DEWS) in 2014. One of the review's many findings included the increasing likelihood of a deficit in water supply out to 2030 without immediate action (Townsville City Council 2014, p. 15). As a part of the strategy to address this concern, the review recommended an increasing need for water modelling to support effective policies for water supply and demand management. This research project will seek to contribute to this recommendation by providing water balance modelling scenarios out to 2030 and drawing on existing research to aid in the city's development.

1.1 Aim

This project seeks to provide water budgeting and management solutions that contribute to the future sustainability of the city of Townsville by identifying emerging water supply and demand factors.

1.2 Objectives

The purpose of this research project is to provide a meaningful contribution to water budgeting in Townsville and thereby offer sustainable solutions for Australia's future. The purpose of this research project is to validate or challenge existing models for water management by conducting independent modelling of Townsville, QLD. By forecasting consumption patterns and supply factors, this project seeks to improve water management techniques. In doing so, the project will explore existing models and policies across Australia to determine what innovations could be adopted on a wider scale. With a focus on urban water budgeting, the project will also examine the effectiveness of managing domestic consumption through restrictions as well as regulation.

This project had the following key objectives in the pursuit of the above aim:

1. Understand and forecast key demand factors facing the city.
2. Understand and forecast key supply factors facing the city.
3. Review existing modelling for Townsville to determine a baseline of understanding.
4 Review wider research into water budgeting and modelling to determine best practice for the city.
5 Model scenarios for Townsville's water budgeting within the selected timeframe.
6. Provide recommendations for water management within the city.

1.3 Expected Findings

Townsville's water security has become increasingly strained in past years due to a variety of extreme weather events combined with increasing demand. It is expected that this research will further highlight these pressures and the implications for the city without adequate responses. Due to the variety of factors affecting supply and demand, the need for updated modelling to confirm or challenge the assumptions underpinning water management policies will continue to be important. The findings of this research will have broad implications for urban planning and development for the city as well as enabling more informed strategies for water budgeting.

2 - Literature Review

This purpose of this chapter is to provide a review of existing literature on issues affecting water modelling, supply and demand management as well as pertinent factors affecting the targeted area of study, being the city of Townsville. It begins with a background of water security issues and its relevance to Townsville, before going into the challenges of forecasting supply and demand factors. Lastly, a review of similar studies will be undertaken to determine the relevant gap in research that this project will exploit to better our understanding of Townsville's water issues.

2.1 Townsville Background

More than 2 billion people lack access to safe drinking water today. That number is likely to increase with projected population growth within the next 20 years corresponding to an increase in water demand of nearly one-third (UN 2018). The issue of water management is thereby becoming an increasingly important issue for urban development around the globe. Providing a valuable resource to place Townsville's water security in context, UN Water publishes an annual World Water Development Report with a particular focus on the responses required to mitigate the impact of climate change (UNESCO 2020).

Climate change will undoubtedly impact Australia's water supply with a decrease in river flows already being identified in addition to a reduced availability of water for consumption (Australian Academy of Science 2019, UNESCO 2020). For a nation with a large agricultural sector, water scarcity could also have dramatic implications for food production (Heggie 2019). Similarly, the effects of extreme weather conditions will increase the prevalence of flooding and drought which will further exacerbate the stresses on water security as highlighted by Weber (2019). Understanding the projected impacts of climate change will therefore present a continued focus for this research.

The Australian continent has always had an inconsistent water supply, receiving the second lowest level of precipitation behind Antarctica (Heggie 2019). The effects of climate change will continue to threaten that supply with total rainfall in 2018-19 at its lowest level in 50 years (BoM 2020, Meterology 2020). The Bureau of Meteorology (BoM) publishes valuable data on these trends as well as the consumption patterns with one of their more notable publications being an report titled 'Water in Australia' (BoM 2020). These reports highlight the highly variable nature of Australia's water supply that is often impacted by floods and droughts (BoM 2020).

Townsville is particularly vulnerable to these conditions with an unreliable supply, a history of extreme weather conditions and household water demand that is one of the highest in Australia (Townsville City Council 2020). Not surprisingly, Townsville City Council publishes a variety of information on the city's water security with the topic featuring consistently in annual reports as well as within a specific annual report on the issue (Shiels 2018, Townsville City Council 2020a). In addition, the establishment of the intergovernmental taskforce known as the Townsville Water Security Taskforce (the Taskforce) provides regular updates on their work to secure the city's water infrastructure (Townsville Water Security Taskforce 2021).

Following the construction of the Ross River Dam in 1971, it has provided the foundation of Townsville's water supply in addition to flood protection (Hammer 2018). This has been further complemented by Burdekin Haughton Water Supply Scheme as well as the Mount Spec Water System (Department of Energy and Water Supply 2014). Townsville's population has continued to climb over this period though, placing increased pressure on existing supply. With an expected 50% increase in population over the next 10 years, this issue is only expected to become more exacerbated (Department of Energy and Water Supply 2014). In addition, consumption trends in the city have greatly increased the likelihood of critical shortages of water without improved methods of water management (Hamilton 2016).

Water security has become a prominent political and social issue in Townsville following a number of extreme weather events and water shortages. Highlighting the increased focus, the Townsville's City Deal (of December 2016) provided $215 million in investment in water security measures in addition to $10 million on demand management initiatives (Hammer 2018). This has also prompted a number of studies which have been funded by the National Water Infrastructure Development Fund (NWIDF), established in 2017 and of particular importance to the foundation of knowledge for this project.

2.2 Supply Factors

Townsville's water supply is provided by three key sources (Infrastructure Australia 2020). The first is the Ross River Dam (to the south of Townsville) which acts as the primary water source for the city with a catchment area of 750km2 and a capacity of 233,187 ML (DEWS 2014). The second is the Mount Spec water system which transports water from the Paluma Dam and Crystal Creek system to the north of Townsville which has a catchment area of 9.8km2 and a capacity of 11,400 ML (DEWS 2014). The final source is the Sunwater Burdekin Haughton Water Sharing Scheme (BHWSS) which acts as a supplementary water supply system when the Ross River dam is low (DEWS 2014).

Townsville's water supply entitlement from Mount Spec and Ross River Dam equates to 96,571ML per year (Infrastructure Australia 2020). However, subject to the availability of water from those sources, Townsville is often required to seek additional water from the BHWSS and has an allocation of 10,000 ML per year. This placed a greater requirement on the duplication of the Haughton Pipeline which links the BHWSS to the Ross River Dam (Infrastructure Australia 2020). Stage 1 of the Haughton Pipeline Project was completed in June 2020 with stage 2 due for completion in December 2023 (ANZIP 2021).

The Taskforce has provided a number for recommendations in the short (0-3 years), medium (3-15 years) and long (15-50 years) term to address supply. In terms of infrastructure investments, the Taskforce has only recommended improving the Haughton pipeline to enhance the supply from the Burdekin Falls Dam (North Queensland Conservation Council 2020). The Taskforce has not provided a firm commitment to long-term solutions; however, has explored the Hells Gate Dam and the raising of the Burdekin Falls Dam as possible options (North Queensland Conservation Council 2020). Notably, the Taskforce has determined that addressing demand factors will be more economical for sustainable urban development and therefore placed this as its priority.

2.3 Demand Factors

Relative to other Australian towns of similar sizes, Townsville's demand for water is significantly higher. The South East Queensland Water and Sewerage Planning Guidelines (2012) provides a variety of demand data for South East Queensland which provides a noteworthy benchmark. By comparison, Townsville's residential water demand is 170% higher than the Gold Coast, reflecting a variety of unique demand factors (IPWEA). The combination of a dry tropical climate, higher ownership of vehicles requiring cleaning and greater hygiene needs are just some of the varied factors which leads to increased consumption.

Ram Sarker (2018) identifies three approaches to water demand modelling, being the Time Series Approach, Econometric Approach and the End Use Approach. According to Gato et al. (2005) the Time Series Approach is based predominately on historical trends of water consumption which doesn't incorporate external factors. The econometric approach establishes through statistical analysis how water consumption is dependent on independent variables which thereby allows a better understanding of the influence of key factors (Turner 2008). Finally, End Use Approach relates to how water is consumed by the end user to differentiate between household, industrial and commercial use (Schlafrig 2008).

Using the Time Series Approach will be valuable in the Townsville context to understand the historical challenges facing the city. It is also likely to provide trends that can be used to identify likely surplus or shortfalls within a projected timeframe. The downside of this approach, as identified by Roberts (2004) is that historical data can be skewed by irregular data-sets such as drought. Given the extremes of Townsville's climate, any historical data would need to be assessed to understand these irregularities. Similarly, historical data is unable to forecast changes to these variables based on other extreme events or unexpected demand requirements.

An Econometric Approach would be beneficial for Townsville to understand where individual sectors are impacting the aggregate demand for the city over time because of changes in selected variables. An increase in the size of households or a temperature increase resulting from global warming are all potential variables that could significantly affect water demand in the city. A downside of this approach is that it does not consider how water is utilised in each sector or how it could change over time (Sarker 2018). This method can also take longer to complete and is limited by the data available (Sarker 2016).

To get a better understanding of the behavioural factors influencing water demand, the End Use Approach could be utilised to provide a breakdown of water use. By example, the Townsville residents' desire to correct the city's label of 'Brownsville' resulted in a spike in residential water use for gardening with significant implications for aggregate water demand (Hammer 2018). The End Use approach could be utilised to examine the impact of this particular use on total household water consumption to allow for more targeted approaches to water policy (Rathnayaka 2011). Collection of data for this approach often requires personal communication with end users; however, meters can also be used for gathering technical information (Schlafrig 2008).

Noting the prevalence of water restrictions for Townsville residents, it is worth understanding the effectiveness of restrictions in curtailing waste. Due to a high proportion of Australian residential water being used for outdoor purposes such as gardening, the importance of restrictions on otherwise discretionary uses provides an obvious target for planners (Brennan 2007). Researchers such as Cooper (2011) and Haque (2013) contend that such restrictions will need to become more frequent in the future and aligned with Australia's seasons to ensure a reliable water supply. Given the likelihood of this approach continuing in Townsville, it will be important to include water restrictions in any modelling conducted.

2.4 Trends

The above trends indicate an increasing water deficit for Townsville based on a reducing supply and increasing demand. Climate change will provide the clearest trend for supply factors with less reliable wet seasons coupled with higher temperatures which will undoubtedly affect the water flows into Townsville's dams. The capture and storage capacities of those dams are also expected to be increasingly affected by rising temperatures and prolonged drought (Hammer 2018). While there is a large variability in temperature and river flow projections over the next 30 years, the trend is increasingly negative for water demand management within Townsville.

2.5 Studies

Particular feasibility studies of interest to this research (as identified by the Taskforce) include SMEAC Australia's (2018) study into the possibility of raising the Burdekin Falls Dam to improve water supply in the area. While the study found that the project was feasible, it concluded that upstream water supply from other sources may provide a better return on investment (SMEAC Australia 2018). In addition, the study suggested a catchment-wide study to be undertaken to provide a more holistic view of water management in the area; however, at this time there does not appear to be such a study in existence. A different study in the same year by SMEAC Australia (2018a) examined the feasibility of the Hells Gate Dam to support long-term agriculture and hydropower in the region. While the study highlighted the potential for alleviating Townsville's urban water supply issues in the 'extreme long-term', the findings of this study are unlikely to be helpful for this research (SMEAC Australia 2018a).

A study by Greg Munck (2018) for SunWater Limited examined the feasibility of an upgrade to the Burdekin Channel Capacity focused on both support to major mining developments as well as Townsville's urban water supply. Expanding on the studies above, Munck's work explores in more detail the demand and supply factors affecting the region and provides useful recommendations that will aid in the research for this project. Of note, there does not appear to be any Townsville-specific study that examines demand management, although similar demand and supply studies of the Gold Coast (Girard 2007) and Sydney (Coombes 2003) along with climate change studies in Tasmania (Nunez 2007) and the Murray-Darling Basin (Crosbie 2010) will all be of value to this study.

End use studies have been a common method of research for water demand in Australia. The Steward (2009) study of domestic water uses in the Gold Coast, found that water consumption increased in higher socio-economic areas. A Perth study by Loh (2003) found no seasonal changes in indoor water use as well as highlighting a larger domestic consumption amongst single residential housing relative to multi-residential housing. Noting that Townsville comprises of 80% single residential housing, this last finding is of particular interest (ABS 2016).

A multi-year study from Roberts (2004) (2005) examined household usage in Yarra Valley, Victoria and found the largest residential uses of water was from showers (22%) and washing machines (19%). This increased to 32% and 22% respectively during a later study in 2011 by Roberts (2011). Another study by Roberts (2012) found that as household size increases, the daily per capita use of water decreased. Noting Townsville's average of 2.6 residents per household, this may be another factor for a high per capita water usage in the city (ABS 2016).

Using water balance models, the Coombes (1999) study of households in Newcastle demonstrated the importance of rainwater tanks in reducing water extracted from the main supply. Similar studies by Tam (2010) and Huston (2012) also reinforced the value of rainwater harvesting. The findings of this research have supported the Townsville City Council's initiatives to increase rainwater tank usage through generous rebate schemes (Townsville City Council 2020).

The Urban Water Security Research Alliance (or the Alliance), established in 2007, undertook a five-year research program to address urban water issues in South East Queensland. With a $50 million budget, the Alliance delivered 17 projects under three programs focused on reducing water grid demand, water source quality and total water cycle planning and management (Urban Water Security Research Alliance 2014). While Townsville and North Queensland were outside of the scope of programs, the research delivered valuable research findings on water management issues affecting the state.

2.6 Analysis of Research

Existing research in this field provides valuable analysis on supply factors affecting Townsville's dam management whilst also providing analysis of specific demand factors. What has been noticeably missing from the research conducted to date though has been aggregate studies addressing both holistic demand and supply projections to inform better water management policies in the city. The research undertaken by the Alliance on South East Queensland provides a useful framework for this study and has largely informed the approach to this research project. By modelling different scenarios based on key changes in demand and supply, this project will fill a key gap in the research undertaken to date by giving policy makers a mechanism to make informed water management decisions.

3 - Methodology

3.1 Introduction – Overview of process

This project will utilise open-source data on supply and demand factors affecting Townsville's water security. The data will then be modelled to project multiple scenarios. This modelling will be complemented by a review of existing research into Townsville's water security in addition to wider modelling techniques and water budgeting models that provide a worthwhile comparison. Data for demand factors will be extracted from the Australian Bureau of Statistics and Townsville City Council sources with supply factors being drawn from the Australian Bureau of Meteorology and available data from Townsville water sources. Assumptions will then be made on likely changes to demand factors based on population growth and expected consumption patterns as well consideration for known investments in supply initiatives. Finally, modelling will be developed through Microsoft Excel in addition to a confidence test model to produce the projected scenarios.

The project was broken down into the following steps:

1. Project Preparation – Literature review: researched the background information relating to Water management as well as supply and demand factors in Townsville. Researched examples of other water models specifically to regional Australia.

2. Data Collection: collected source data relating to water consumption and water supply including trends and variables in Townsville.

3. Prepared Water Balance Model using Excel, confidence tested the Model and developed scenarios.

4. Evaluation of results from the model.

3.2 Scope & limitations

With a focus on urban development, this analysis will examine water budgeting in the city of Townsville in North Queensland. As such, rural areas and agricultural water budgeting will not be addressed in this project. A model will be developed based on the supply and consumption factors outlined in the methodology and tested against nine scenarios. A water budget will be developed for each of the modelled scenarios with a final recommendation provided based on an average across each of the scenarios.

The most significant limitation for this project will be the availability and reliability of data. I will be largely limited to open-source data that I will be unable to independently verify. Additionally, as there was no funding for this project, I was constrained by the tools available to me. This has also constrained the detail and number of modelling scenarios that I was able to develop to support my findings. Finally, I was limited by time and the due date for the project at the end of Semester 1, 2022.

3.3 Preparing the Model

3.3.1 Generating Inputs

The following inputs have been sourced and generated to prepare the model:

1. **Ross River Dam storage capacity and catchment.** The ross river dam has a catchment area of 747km2 and a capacity of 233,187 ML at 100% capacity (DEWS 2014). Catchment size is sourced from the QLD Water Monitoring Portal, with 100% dam capacity sourced from Department of Energy and Water Supply.

2. **Rainfall.** Historical daily rainfall data is collected through the BoM rainfall stations. There are limited rainfall stations in this area; however, four stations were used to find daily data for the period of 1/1/1950 to 31/12/2021.

3. **Evaporation.** Evapotranspiration data has been sourced for the region through the BoM. This has been converted into a daily value and factored by 0.85.

4. **Runoff.** Runoff was generated using AWBM software. The inputs utilised to determine runoff were rainfall and evapotranspiration, as sourced through the BoM.

5. **Haughton pipeline inflow.** Using the existing contractual agreement, the inflows from the Haughton pipeline were found to be 130ML per day (up to 10,000ML per annum) allowing for 20% losses (DEWS 2014). The inflows from the duplicate pipeline (currently under construction) were generated by allowing for 364ML per day and 120,000ML per annum, with losses of 20% (Townsville City Council 2022).

6. **Seepage.** The average seepage value for the dam of 2.3% was based on seepage results from a report published by the National Water Commission (2011). This was based on the assumption that the Ross River Dam has a medium-heavy clay base.

7. **Climate change**. If emissions remain high, the evaporation will increase by 6% and rainfall will decrease by 7% based on QLD Government reporting (Queensland Government 2022). These projections have been used for the modelling of this project.

8. **Population.** Using data from the Townsville City Council (2016), we know that the current population of Townsville is 185,000 with a projected increase to 300,000 by 2030.

9. **Water Consumption.** Historical water consumption data has been sourced through Townsville City Council (2022). This provided quarterly residential data which was then broken down into monthly and daily figures. Industrial water consumption was averaged and remained as a constant throughout the model.

10. **Water Restrictions**. The above water consumption data was further analysed to account for periods where water restrictions were in use. Over the period FY16-17 and 17-18, water restrictions were in place with the average consumption for each quarter over this period being utilised. Where water restrictions weren't in place from FY12-13, 13-14 and 14-15, quarterly data was extracted and broken down by month and by day to account for seasonal change.

3.3.2 AWBM Runoff Generation

The AWBM is a rainfall-runoff model used for runoff estimation. It requires rainfall and evapotranspiration data as input data to compute the runoff from a catchment. The following steps were taken:

Location and Catchment

Location and catchment size was recorded from Queensland water monitoring portal.

118104A ROSS RIVER AT ROSS RIVER DAM HEADWATER

All data times are Eastern Standard Time

Details | Prepared Outputs | Custom Outputs

Details

Site no.	118104A
Zone	55
Easting/Northing	472207.000/7853593.000
Latitude	19°24'42.0"S
Longitude	146°44'07.0"E
Site commence	01/10/1974
Site ceased	01/08/2007
Zero gauge	0.000
Datum	AHD
Control	Dam Spillway
Cease to flow level	34.600
Maximum gauged level	1.450
Maximum gauge date	22/03/1977
Distance from stream mouth	26.400 km
Catchment area	747 sq. km

-

Figure 3.1 – QLD Water Monitoring portal Ross River Dam catchement and location.

Qtopo was used to draw and measure catchemnt

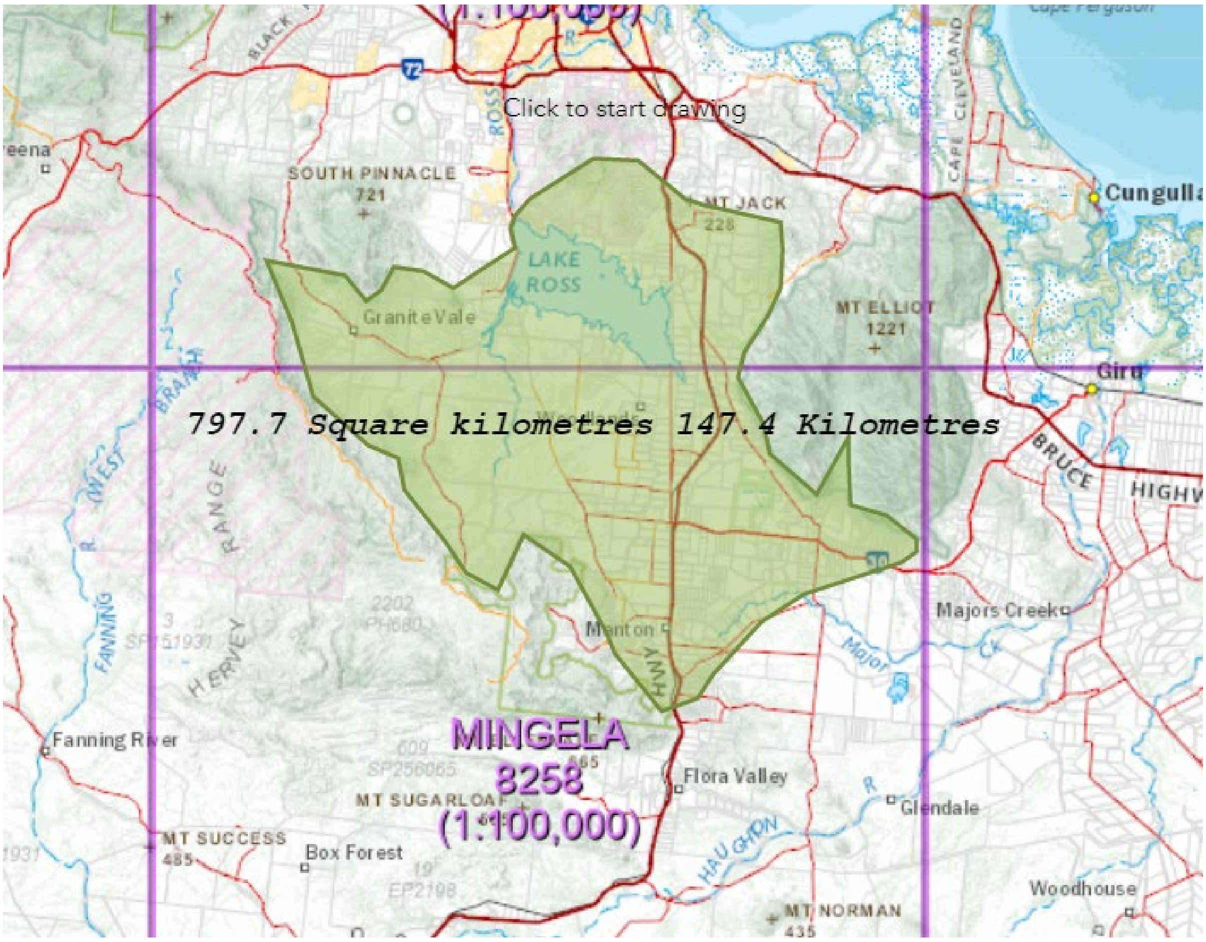

Figure 3.2 – Cathement drawn on Qtopo

ET data

Monthly Average Area Potential Evapotranspiration was extracted from the BoM. Coordinates found from the water monitoring portal used to locate the value for location. This was converted to a daily value and factored by 0.85. These values where then applied to each day of the time period.

Table 3.1 – Evapotranspiration per day by month and factored by 0.85

	Average Areal Potential Evapotranspiration (mm/month)	**Per/day**	**0.85 factored**
JAN	188	6.0645161	5.1548387
FEB	164	5.8571429	4.9785714
MAR	186	6	5.1
APR	136	4.5333333	3.8533333
MAY	111	3.5806452	3.0435484
JUN	97	3.2333333	2.7483333
JUL	97	3.1290323	2.6596774
AUG	117	3.7741935	3.2080645
SEP	142	4.7333333	4.0233333
OCT	186	6	5.1
NOV	202	6.7333333	5.7233333
DEC	191	6.1612903	5.2370968

Rainfall stations

Rainfall stations located on the BoM were cross checked with the catchment map. There are a limited number of rainfall stations in the area that have a significant period of recordings. Based on this poor data availability, the stations chosen are the Townsville airport and Majors creek. Stations used to fill in gaps in the data are Landsdown and Yabulu. All rainfall data was changed to the previous day to allow for recording at 9am following day.

Figure 3.3 – BOM rainfall stations

Spatial Areal average rainfall was calculated using Theisen polygon method. The distance between the two primary rainfall stations was calculated, a perpendicular line was drawn at the half way point. The catchment area that fell in on either side of this perpendicular line was calculated. The percentage of the the overall catchment was calculated and rainfall from each station factored accordingly.

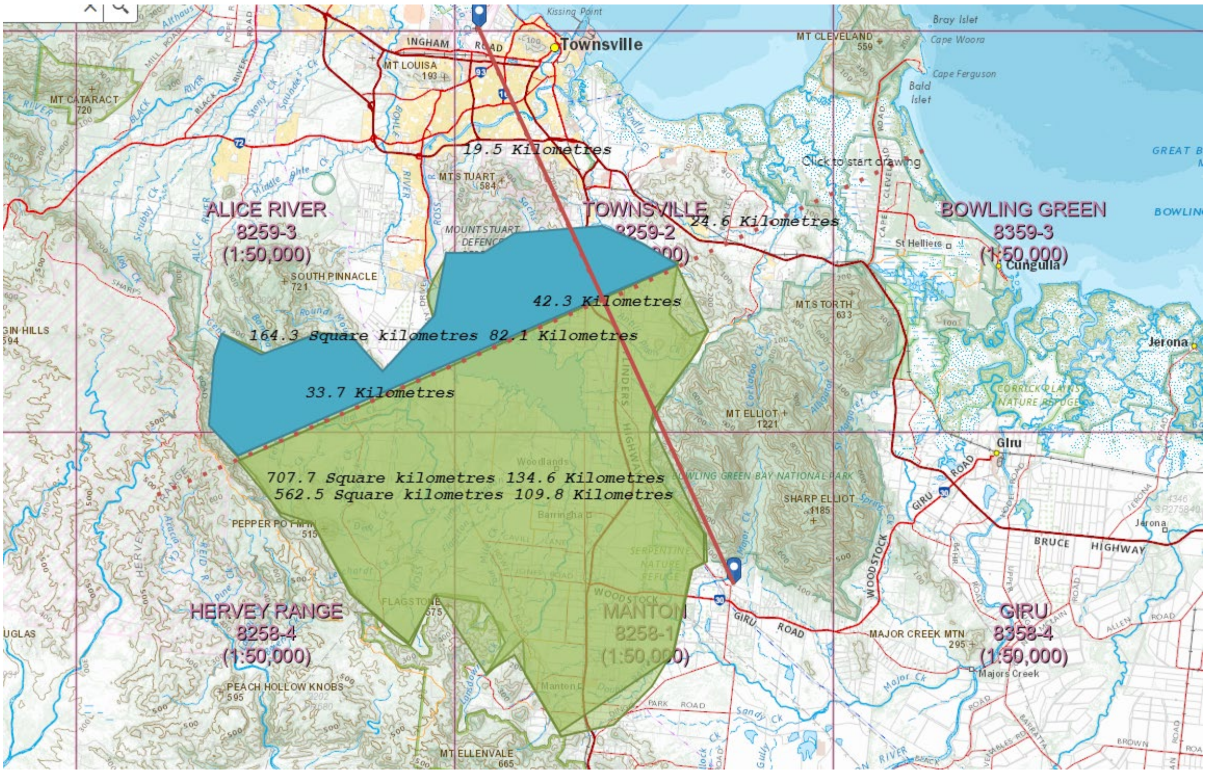

Figure 3.4 - Spatial Areal average rainfall was calculated using Theisen polygon method

Runoff Data

Run off data for the was very limited which resulted in an uncalibrated model needing to be utilised.

Manual input and Verify the AWBM

The following parameters were utilised for manual input:

Table 3.2 – AWBM Manually inputted parameters

Parameters	Input
A1	0.134
A2	0.433
BFI	0.17
C1	13.2
C2	134.11
C3	268.22
Kbase	0.950
Ksurf	0.35

These parameters are as recommend by Boughton and Chiew (2007) based on their research on estimating runoff in ungauged catchments:

$$A_1 = 0.134; \quad A_2 = 0.433;$$

Table 5
Values of baseflow parameters by Drainage Division

Division	BFI			K_{base}		
	90%	Median	10%	90%	Median	10%
I	0.11	0.17	0.45	0.813	0.950	0.987

$$C_1 = 0.075 \times \text{Ave}; \quad C_2 = 0.762 \times \text{Ave}; \quad C_3 = 1.524 \times \text{Ave}.$$

Figure 3.5 – Boughton and Chiew (2007)

C1, C2 and C3 were calculated using the average daily rainfall from rainfall stations in the catchment. As seen in Table 3.3 the average of these stations was taken and found to be 1.146mm. Boughton and Chiew (2007) recommend C average for Queensland to be 190; however, Townsville is in the dry tropics and generally received less rainfall in comparison to other coastal areas of Queensland. C average between 150 and 190 were used to calculate C1, C2 and C3, and these parameters were then run in AWBM. The resulting runoff mean value was compared to the average daily discharge recorded by monitoring stations and the parameters which resulted to the closest value were chosen.

Table 3.3 – Average runoff of nearby stations.

	Average discharge mm
118106A ALLIGATOR CREEK AT ALLENDALE	1.539718837
118004A LITTLE BOHLE RIVER AT MIDDLE BOHLE RIVER JUNCTION.	0.816099129
118003A BOHLE RIVER AT HERVEY RANGE ROAD	1.457579166
118001B BOHLE RIVER AT MOUNT BOHLE	0.768745956
AVERAGE	**1.145535772**

Table 3.4 – C1, C2 and C3 parameter iterations.

Average	150	160	170	172	174	175	176	177	180	190	200
C1	11.25	12	12.75	12.9	13.05	13.125	13.2	13.275	13.5	14.25	15
C2	114.3	121.92	129.54	131.06	132.59	133.35	134.11	134.87	137.16	144.78	152.4
C3	228.6	243.84	259.08	262.13	265.18	266.7	268.22	269.75	274.32	289.56	304.8
Mean mm	1.21	1.185	1.161	1.156	1.151	1.149	1.146	1.144	1.137	1.113	1.09

Generate Monthly Streamflows

Daily runoff values were generated and exported into an excel document. The generated runoff was compared to dam storage levels as a sanity check.

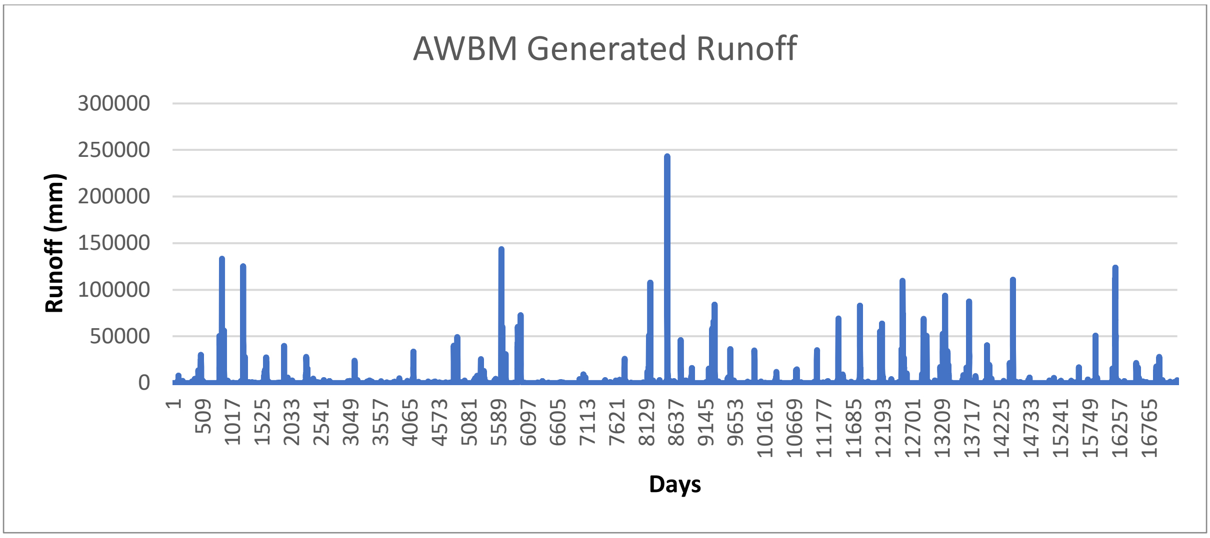

Figure 3.6 – AWBM Generated Runoff plot.

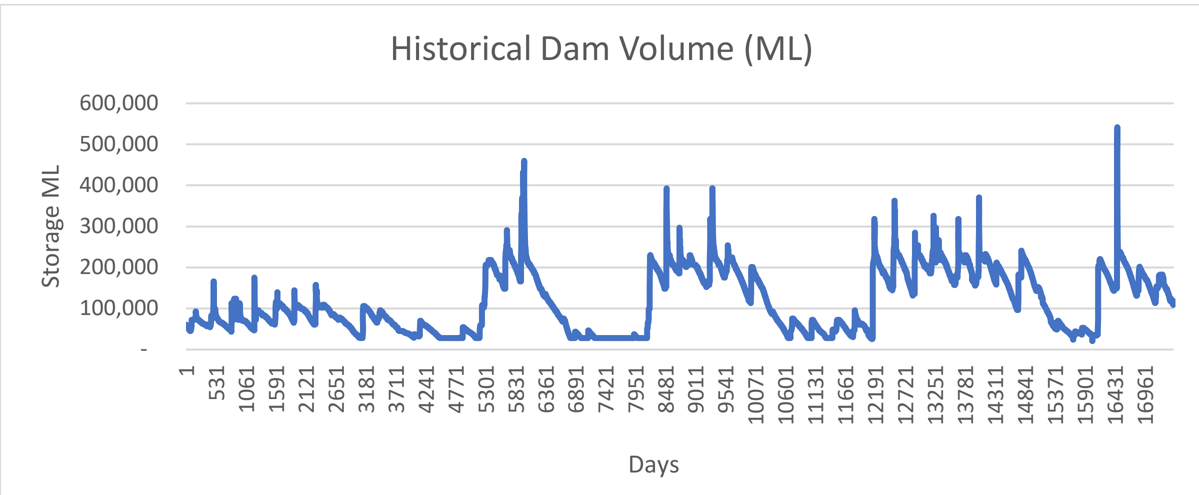

Figure 3.7 – Historal Dam volume in ML plot.

Generate Alternate Monthly Streamflow accounting for climate change

The process was repeated to generate alternate runoff accounting for climate change. Rainfall input was reduced by 7% and evapotranspiration was increased by 6% with all parameters in AWBM being kept constant.

3.3.3 Building water balance model in Excel

The model constructed is based on the water balance equation at a daily timestep:

$Storage_{day\ t} = Storage_{-1} + Runoff_{dayt} - Evapouration_{dayt} - Seepage_{dayt} + Pipeline_{dayt} - Demand_{dayt} - Spill_{dayt}$

$Storage_{dayt}$ is the storage volume on day t,

$Storage_{-1}$ is the storage volume at the end of the previous day

$Runoff_{dayt}$ is the inflow of runoff from the catchment on day t

$Evapouration_{dayt}$ is the evaporation from the open storage surface on day t,

$Seepage_{dayt}$ is the seepage from the storage on day t,

$Pipeline_{dayt}$ is the inflow from the Haughton pipeline pumped into the storage on day t, from the storage (if any) on day t.

Dt is the diversion from the storage to meet the water demand on day t, and Lt is the spill from the storage (if any) on day t.

Rainfall on dam surface has been excluded as it has been included in the runoff.

The model was built with the following steps:

Step 1. Variable inputs have been created to allow for simple adjustments to the model. Columns for the model are altered by amending the variable inputs.

seepage rate	2.3	mm/day	Lake Evapooration factor	1				Water restrictions'		
			Catchment	747	km2	747000000	m2	Level 2	10%	17181634.2
			Storage capacity 100%	221303506.7	Kl			Level 3	5%	8505214.59
			Storage capacity 514%	1200000000	Kl			Level 4	3.50%	5677527.72
			Population	185000						

Figure 3.8 – Inputed variable parameters.

Step 2. Column 1 – Date. The model is using historical data to forecast future scenarios. The date has been included in the model as it assists in confidence testing against known historical rainall events. The rainfall data available determined the date range of 1/01/1950-31/12/2021.

Step 3. Column 2 – Day. A daily timestep has been chosen for this model with future modelling reflected by giving each day a number and run over 26,298 days.

Step 4. Column 3 – Evaporation. Evaporation was calculated to detemine runoff in the AWBM software and has been entered into the spreadsheet in mm.

Step 5. Column 4 – Storage previous day. This cell comprises a forumula to determine the final storage volume of the previous day.

Step 6. Column 5 – Runoff. Runoff has been determined using AWBM entered in ML.

Step 7. Column 6 – Surface area. This cell is a formula linking to a lookup table which is a rating curve. The formula will take the value of column 4, the previous day's storage for that day, and find the closest volume in the lookup table to present the corresponding surface area for that volume.

Table 3.5 – Extract of surface area look up table.

Surface area Look up table			
Level	Volume	Volume	Area
m AHD	%	m^3	m^2
11.4	0.00%	0	0
19	0.00%	25.80271	7.944625726
19.25	0.00%	32.08807	117.1800219
19.5	0.00%	183.4617	1643.357302

```
=INDEX($J$10:$J$132,MATCH(MIN(ABS($I$10:$I$132-Q9)),ABS($I$10:$I$132-Q9),0))
```

Step 8. Column 7 – Seepage. This cell is a forumla. It takes the variable input seepage rate and mulitplies it by the corresponding column 6 value which is the surface area for that day. It is then divided by 1000 to convert to KL.

```
=($G$1*T10)/1000
```

Step 9. Column 8 – Haughton Pipeline. All scenarios other than scenario 1 have the Haughton pipeline as column 8. This cell is a formula which is dependent on the current daily pumping capacity, percentage losses, and the maximum allocation per annum. Haughton pipe pumping commences when the dam reaches 15% capacity. If the storage from the previous day is less than 15% capacity and the sum of supplied water from the pipeline for that year is less than the allocation, the model will include pumping at current capacity minus loses for that day.

```
=IF(Q9<$G$4,IF(SUM($W$8)<$G$5,$G$2-$G$3,0),0)
```

Step 10. Column 9. This cell is taking the storage from the previous day, plus runoff and the haighton pipeline. Evaporation and seepage is then subtracted from this figure.

```
=Q11+R11-U11-S11+W11
```

Step 11. Column 10 – Spill. This cell is a formula that calculates if the dam will spill. If column 9 for that day is greater than the 100% storage capacity, then the excess from 100% volume will be spilled.

```
=IF(X11>$K$3,X11-$K$3,0)
```

Step 12. Column 11 - Residential Demand. This cell is a formula that is dependant on population number and the requisite month as residential demand varies seasonally. The daily demand per person is pulled from a lookup table:

```
=(IF(MONTH(L10)=1,$C$10,IF(MONTH(L10)=2,$C$11,IF(MONTH(L10)=3,$C$12,IF(MONTH(L10)=4,$C$13,IF(MONTH(L10)=5,$C$14,IF(MONTH(L10)=6,$C$15,IF(MONTH(L10)=7,$C$16,IF(MONTH(L10)=8,$C$17,IF(
MONTH(L10)=9,$C$18,IF(MONTH(L10)=10,$C$19,IF(MONTH(L10)=11,$C$20,IF(MONTH(L10)=12,$C$21)))))))))))))*$K$5
```

Table 3.6 -Average daily residential demand

Average daily residential demand per person (KL)	
JAN	0.5919
FEB	0.5919
MAR	0.5919
APR	0.4431
MAY	0.4431
JUN	0.4431
JUL	0.3975
AUG	0.3975
SEP	0.3975
OCT	0.5159
NOV	0.5159
DEC	0.5159

Step 13. Column 12 – Industrial Demand. The average daily demand for industry has been added and remains constant throughout the model.

Table 3.7 -Industrial demand

Industrial water demand KL				
	Q1 20/21	**Q2 20/21**	**Q3 20/21**	**Q4 20/21**
Commercial and Industrial	1426859	1877708	1489598	1758712
TCC Irrigation (Parks)	1064950	1112579	784980	398768
Schools	304927	471412	285320	412868
TCC Facilities and Sites	98104	126013	103962	114399
Churches	59145	96068	70066	73612
Other	5707	2076	1820	1432
Average daily consumption (KL)	33263.24658			

Step 14. Column 13 – Total Demand. Total demand is the sum of residential and industrial demand.

Step 15. Column 14 – Demand Met. This cell is a formula that detemines if the full demand was met, and if not, how much was supplied. It is a function of total demand and Column 9.

```
=IF(X9>AB9,AB9,X9)
```

Step 16. Column 15 – Storage. This cell is a formula that determines the total storage at the end of each day. If Column 9 is less then the total demand, storage will be zero. If it is greater than Column 9 and 100% capacity, then storage will be Column 9 minus demand and spill. If it is not greater than 100% capacity, it will be Column 9 minus demand. Storage on the first day was inputed as zero, it was found due to a major rainfall event occuring within the first year of the model the warm up period on minimal and this had little effect on the overall model.

```
=IF(X9<AB9,0,IF(X9<$K$3,X9-AB9,X9-AB9-Y9))
```

Step 17. Column 16 - Supply Count. This is a results column. It is a forumla that returns a '1' if Column 14 demand met was greater than or equal to total demand. If Column 14 is less than total demand, it will return a zero. This gives clear information on how reliable the water source is.

```
=IF(AC8>=AB8,1,0)
```

Step 18. Column 17 - Water Restrictions Required. This is a results column. It is a forumla that returns a zero if Column 15 (Total Storage) was greater than or equal to 10% of total volume, as this is when level 2 water restrictions are put into place. If it is less than than this, it will return a '1'.

```
=IF(AD8>=$R$2,0,1)
```

Step 19. Column 18 - Pumping Required. This is a results column. It is a forumla that returns a zero if Column 15 (Total Storage) was greater than or equal to 15% of total volume, as that is when pumping from the haughton pipe line commences. If it is less than this, it will return a '1'.

```
=IF(X8>=$G$4,0,1)
```

3.3.4 Confidence Testing

Before using the model to predict future outcomes by varing inputs, it was first confidence tested using historial conditions against historial events. This is called Scenario 1. Historial rainfall, runoff and evaporation data was run in the model with the current population, and historial demand usage from the previous 5 years. The storage results produced by the model over the 71 years was plotted against the historial dam volume data from the Townsville City Council from 10/10/1974 – 31/12/2021.

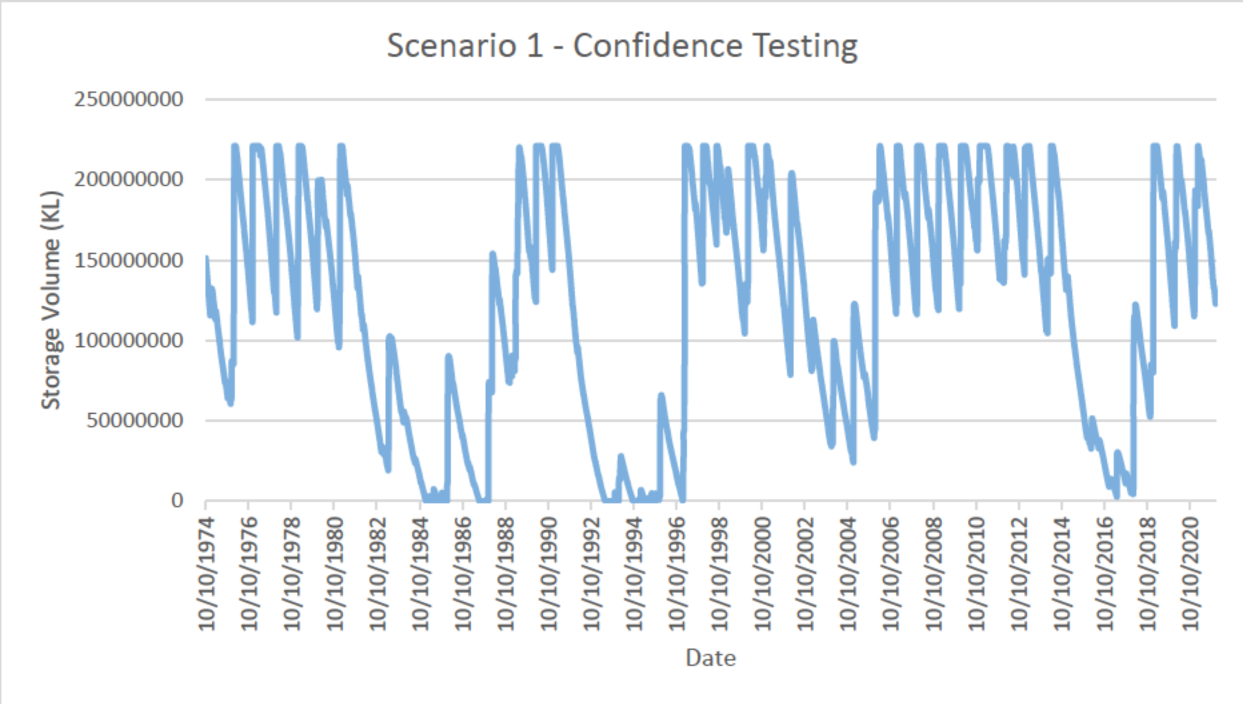

Figure3.9 - Confidence testing, scenario 1 storage volume

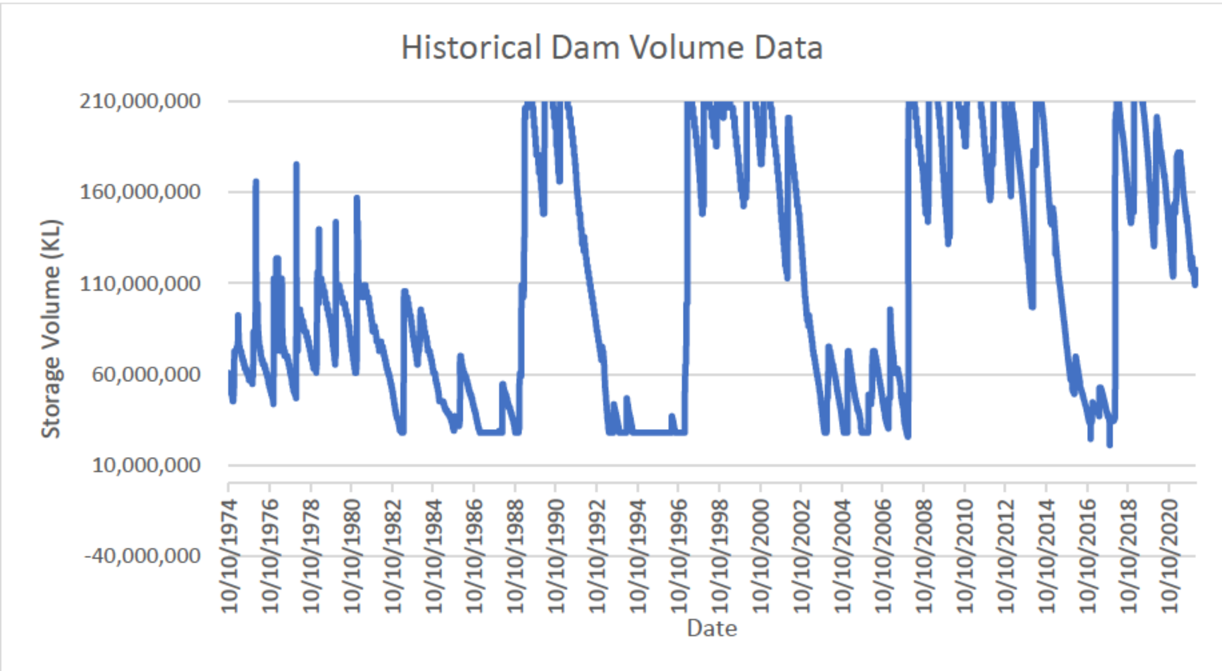

Figure 3.10 - Historical Dam volume data.

3.3.5 Running Scenarios

Scenario 1 – Historial Conditions. This scenario provides a baseline to allow for confidence testing and also allows for quick analysis on the impact of not developing the pipeline or if the pipleine were to become unavailable. It comprises the following parameters:

Haughton Pipeline (Y/N) – N.
Population – Current (185,000).
Water consumption – historical data without restrictions.

Scenario 2 – Haughton Pipeline included. This scenario provides an adjustment for only one variable being the Haughton pipeline (at the current capacity) with all other variables remaining constant:

Haughton Pipeline (Y/N) – Y (130ML p/day).
Population – Current (185,000).
Water consumption – historical data without restrictions.

Scenario 3 – Increased population. Using the same parameters as Scenario 2, the population is now increased to determine the projected impacts on water supply. It comprises the following parameters:

Haughton Pipeline (Y/N) – Y (130ML p/day).
Population – Future (300,000).
Water consumption – historical data without restrictions.

Scenario 4 – Climate change. Here we can evaluate the impact of higher emission resulting in lower rainfall and higher evaporation. Daily rainfall was reduced by 7% with daily evaporation increased by 6% and entered into the AWBM. This produced the adjusted runoff, which allowed for rainfall, runoff and evaporation to be entered into the model. It comprised the following remaining parameters.

Haughton Pipeline (Y/N) – Y (130ML p/day).
Population – Future (300,000).
Water consumption – historical data without restrictions.

Scenario 5 – Water restrictions. By utilising the historical data from periods where water restrictions were in place, this scenario is able to adjust for the reduced demand within the model. It comprised the following parameters:

Haughton Pipeline (Y/N) – Y (130ML p/day).
Population – Future (300,000).
Water consumption – historical data with restrictions.

Scenario 6 – Haughton Pipeline stage 2. Returning to a scenario without restrictions, this scenario models the increased inflows from the future duplication of the Haughton Pipline without considering climate change. It consists of the following parameters.

Haughton Pipeline (Y/N) – Y (364ML p/day, 120,000ML p/a allocation).
Population – Future (300,000).
Water consumption – historical data without restrictions.

Scenario 7 – Haughton Pipeline stage 2, future population, reduced rainfall. This provides the same scenario as above although accounting for the effects of climate change. As with Scenario 4, the rainfall, runoff and evaporation have been adjusted to account for this. It consists of the following remaining parameters:

Haughton Pipeline (Y/N) – Y (364ML p/day, 120,000ML p/a allocation).
Population – Future (300,000).
Water consumption – historical data without restrictions.

Scenario 8 – Haughton Pipeline stage 2, future population, reduced rainfall, water restrictions. Building on Scenario 7, the model now accounts for reduced demand by considering the impact of water restrictions. It consists of the following parameters:

Haughton Pipeline (Y/N) – Y (364ML p/day, 120,000ML p/a allocation).
Population – Future (300,000).
Water consumption – historical data with restrictions.

Scenario 9 – Haughton Pipeline stage 2, future population, reduced rainfall, reduced water usage. The final scenario is a solution scenario taking into account the previous scenario's parameters but with less severe water restrictions. With level 3 restrictions resulting in a reduced consumption of 60%, it was determined to halve these restrictions to achieve a reduced consumption of 30%. This provided the optimal water management solution and comprised the following parameters:

Haughton Pipeline (Y/N) – Y (364ML p/day, 120,000ML p/a allocation).
Population – Future (300,000).
Water consumption – the difference between the average of historical data with restrictions and without (30% reduced consumption).

4 – Results

4.1 Scenario 1- Base line Scenario

Scenario 1 is the Baseline scenario that runs historical data with no variable changes. Figure 4.1 shows the results of storage volume over 71 years when the baseline scenario 1 is run in the Excel water balance model.

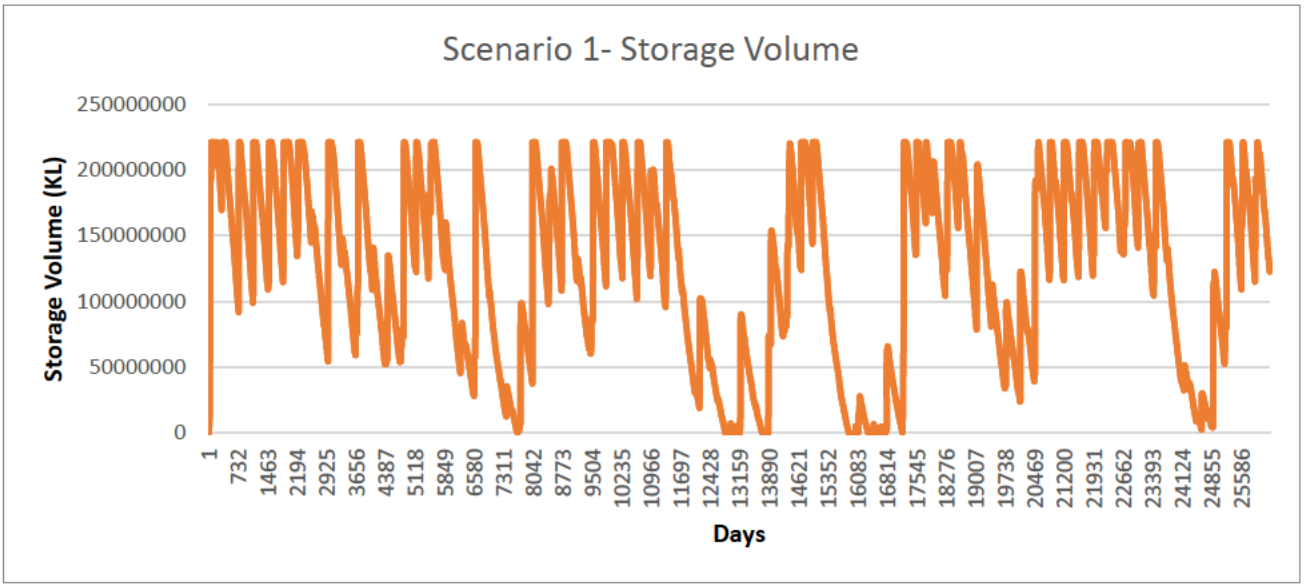

Figure 4.1 – Scenario 1 Storage volume

Figure 4.2 shows the number of days the storage was able to supply the total demand required when scenario 1 was run in the model. Days the demand was met are recorded as one, while days where demand was not met are recorded as zero.

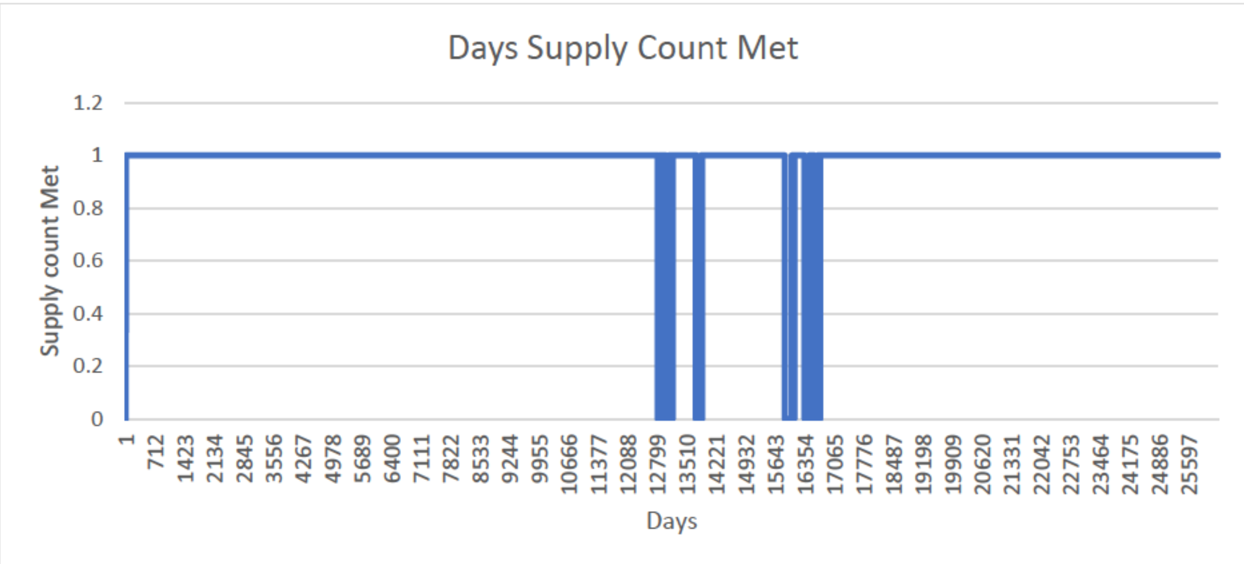

Figure 4.2 – Days Supply met

Figure 13 shows the number of days Water restrictions would be required when scenario 1 was run in the model. Days water restrictions are required are recorded as one, while days where they are not required are recorded as zero.

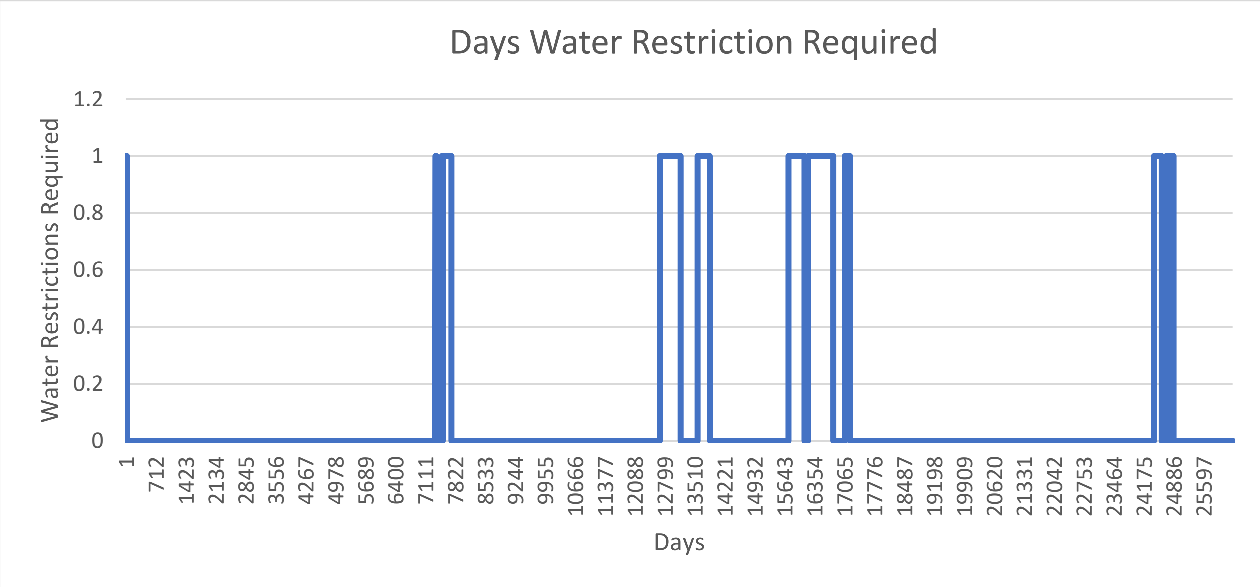

Figure 4.3 – scenario 1 days water restrictions required.

Table 4.1 shows a summary of results from running scenario 1 as percentage of number of days the storage met demand and number of days water restrictions were required.

Table 4.1 – Summary of scenario 1 results

Supply Count Days	Days Water Restrictions Required
25631/26298	2510/26298
97.46%	9.54%

4.2 Scenario 2

Scenario 2 introduced the Haughton pipeline inflow at its current capacity. Figure 4.4 shows the results of storage volume over 71 years when scenario 2 is run in the Excel water balance model.

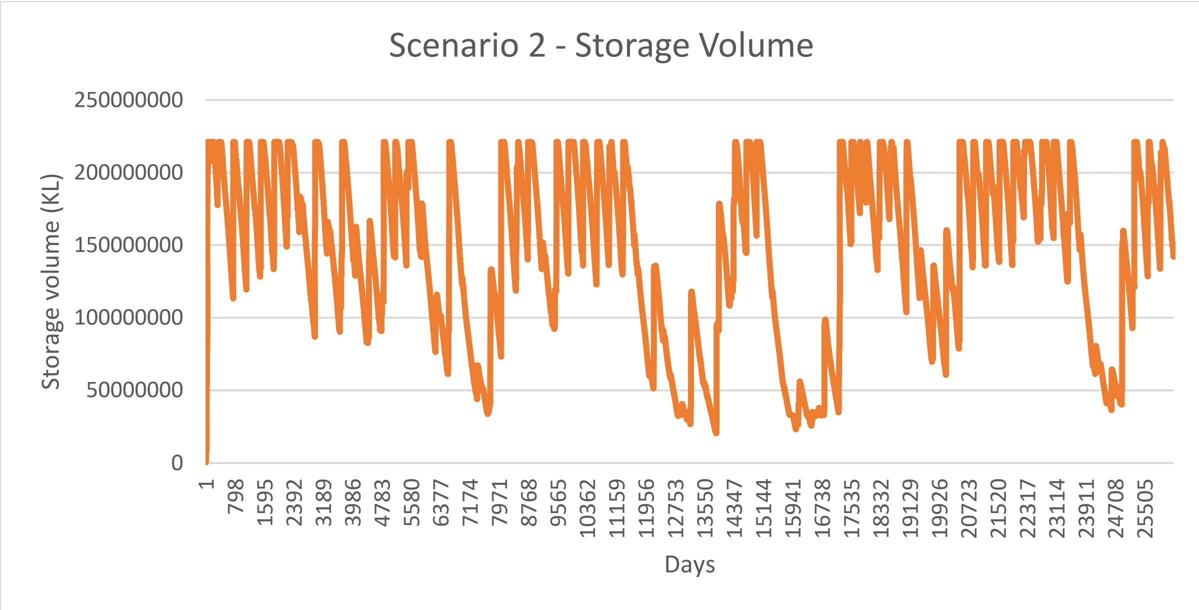

Figure 4.4 - Scenario 2 Storage volume

Figure 4.5 shows the number of days the storage was able to supply the total demand required when scenario 2 was run in the model. Days the demand was met are recorded as one, while days where demand was not met are recorded as zero.

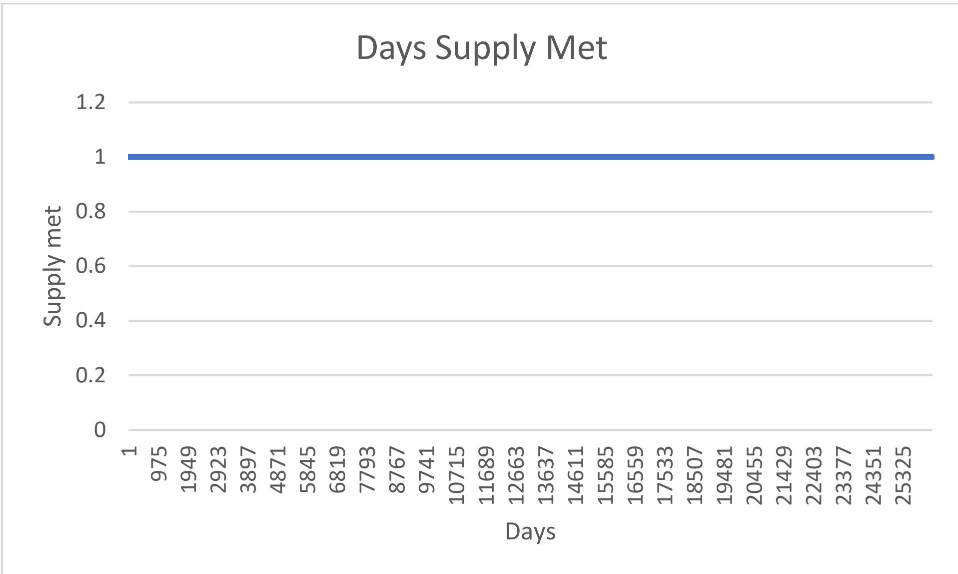

Figure 4.5 – Scenario 2 Days Supply met

Figure 4.6 shows the number of days water restrictions would be required when scenario 1 was run in the model. Days water restrictions are required are recorded as one, while days they are not required are recorded as zero.

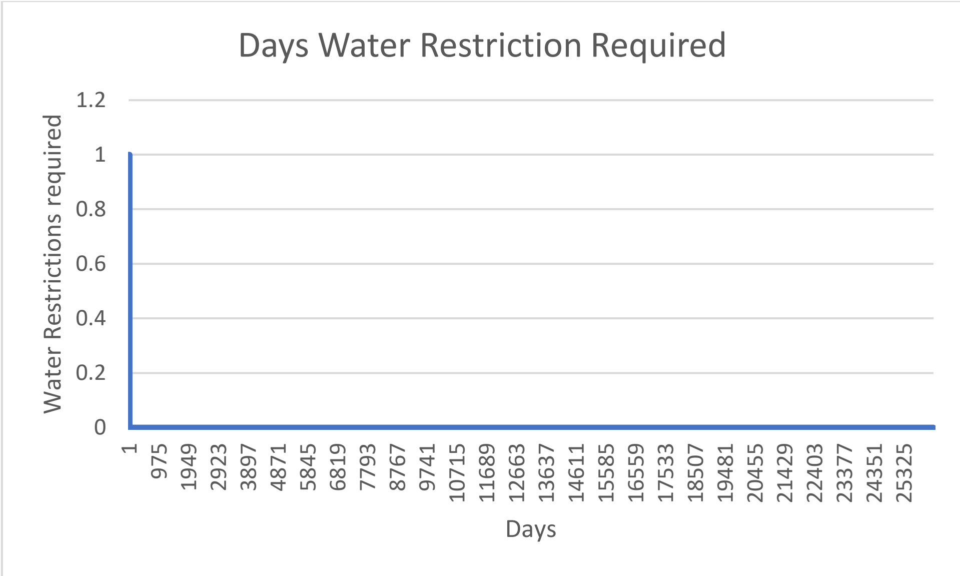

Figure 4.6 - Scenario 2 days water restrictions required.

Figure 4.7 shows the number of days pumping from the Haughton pipeline would be required when scenario 2 was run in the model. Days pumping are required are recorded as one, while days they are not required are recorded as zero.

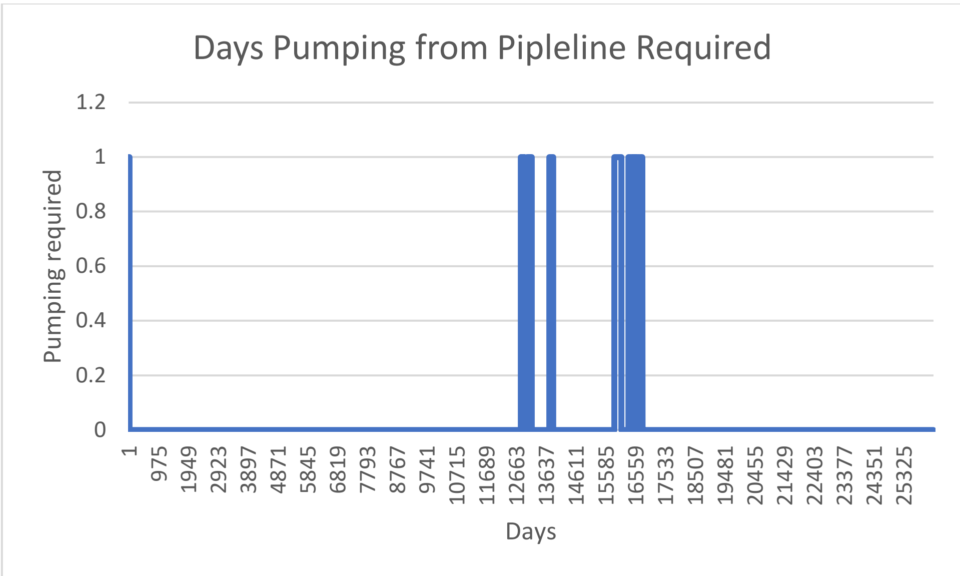

Figure 4.7 - Scenario 2 days Haughton pipeline pumping required.

Table 4.2 shows a summary of results from running scenario 2 as a percentage of the number of days the storage met demand and the number of days water restrictions and pumping from the Haughton pipeline were required.

Table 4.2 - Summary of scenario 2 results

Days Supply Met	Days Water Restrictions Required	Days Pumping Required
26298/26298	28/26298	845/26299
100.00%	0.11%	3.21%

4.3 Scenario 3

Scenario 3 represents an increase in population. Figure 4.8 shows the results of storage volume over the 71 years when scenario 3 is run in the Excel water balance model.

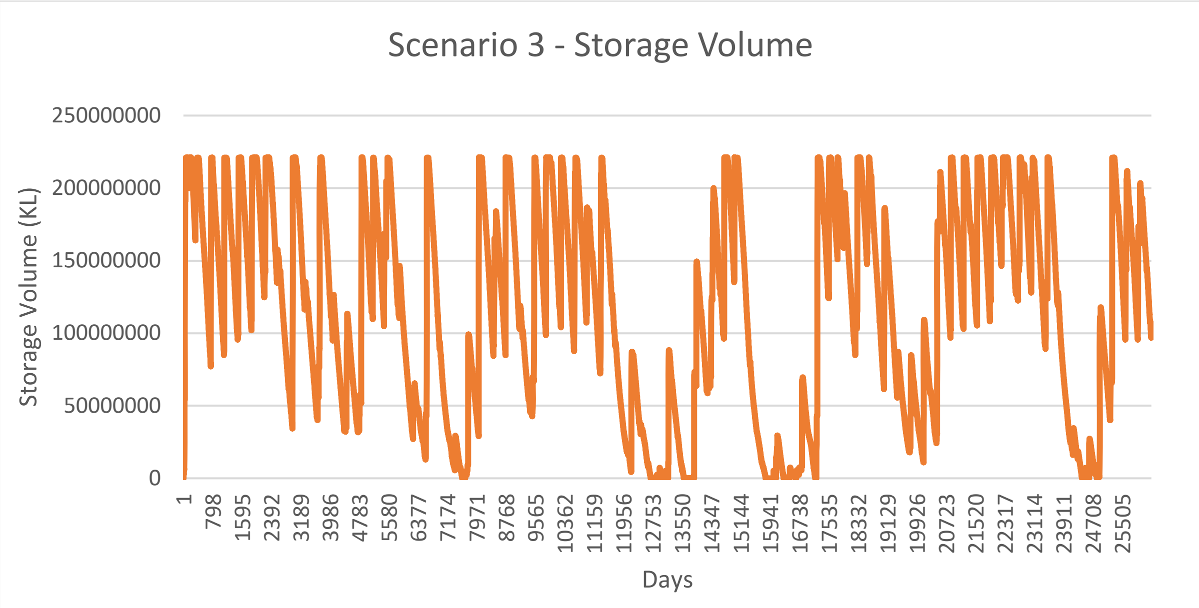

Figure 4.8 - Scenario 3 Storage volume

Figure 4.9 shows the number of days the storage was able to supply the total demand required when scenario 3 was run in the model. Days the demand was met are recorded as one, while days demand was not met are recorded as zero.

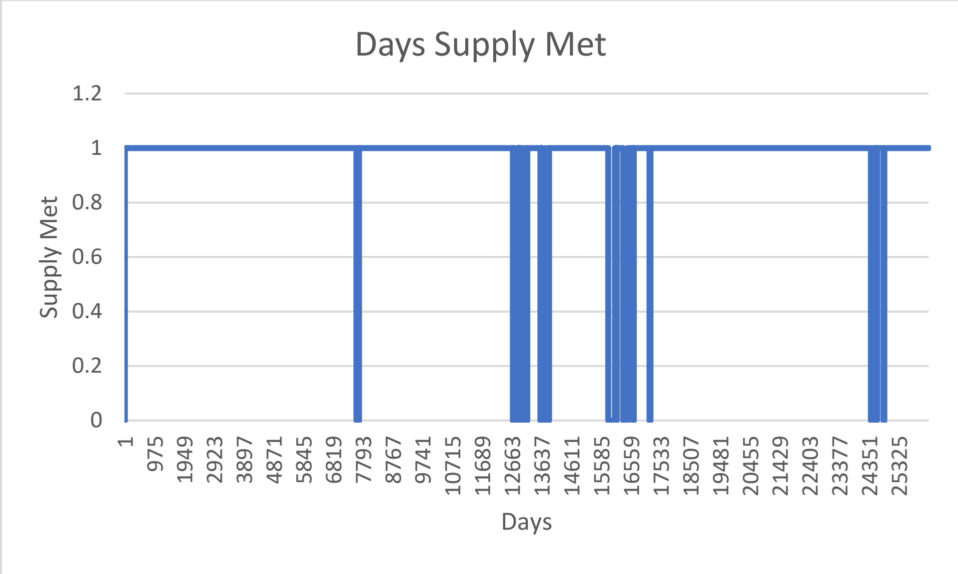

Figure 4.9 – Scenario 3 Days Supply met

Figure 4.10 shows the number of days water restrictions would be required when scenario 3 was run in the model. Days water restrictions are required are recorded as one, while days they are not required are recorded as zero.

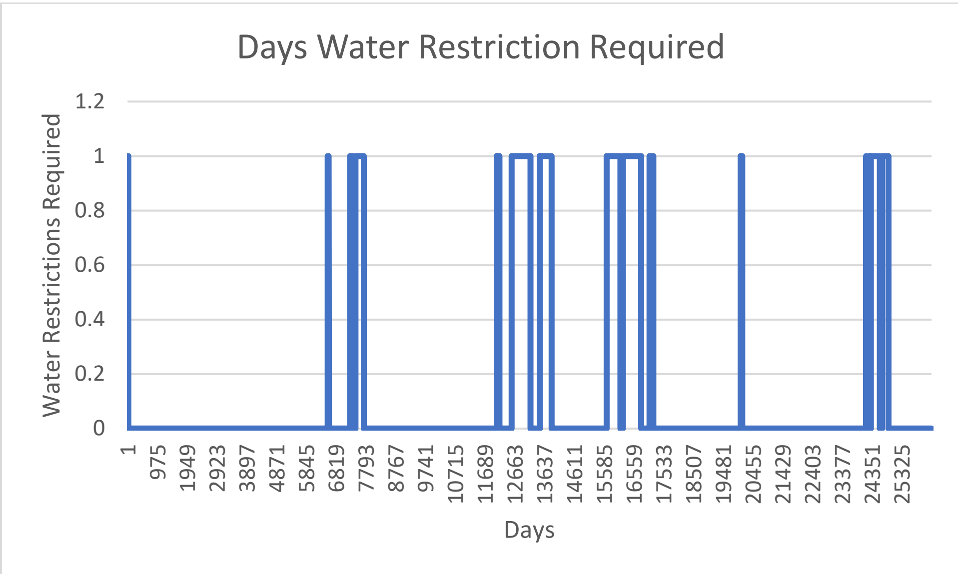

Figure 4.10 - Scenario 3 days water restrictions required.

Figure 4.11 shows the number of days pumping from the Haughton pipeline would be required when scenario 3 was run in the model. Days pumping are required are recorded as one, while days they are not required are recorded as zero

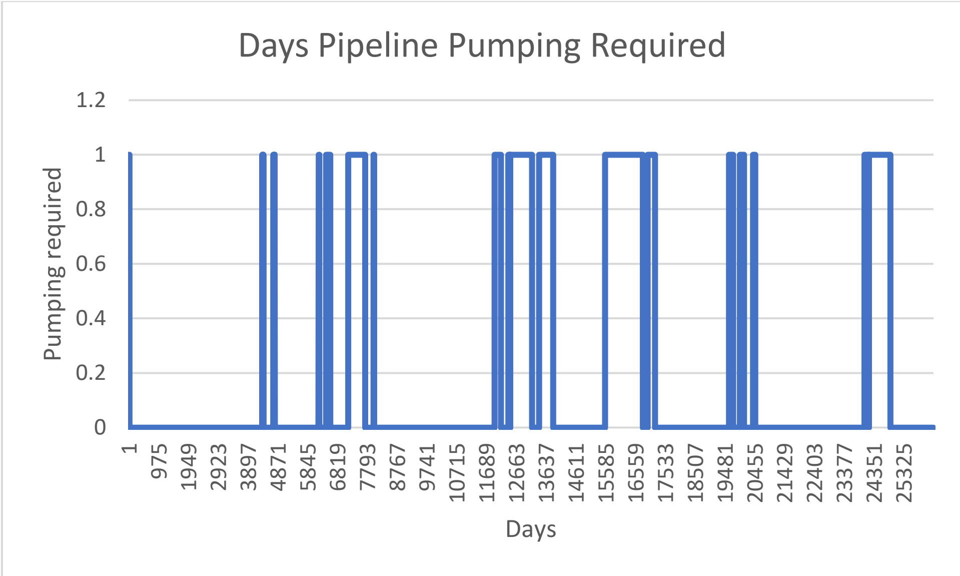

Figure 4.11 - Scenario 3 days Haughton pipeline pumping required.

Table 4.3 shows a summary of results from running scenario 3 as percentage of the number of days the storage met demand and the number of days water restrictions and pumping from the Haughton pipeline were required.

Table 4.3 - Summary of scenario 3 results

Days Supply Met	Days Water Restrictions Required	Days Pumping Required
25092/26298	3246/26298	4862/26299
95.41%	12.34%	18.49%

4.4 Scenario 4

Scenario 4 represents the changes due to climate change. Figure 4.12 shows the results of storage volume over the 71 years when scenario 4 is run in the Excel water balance model.

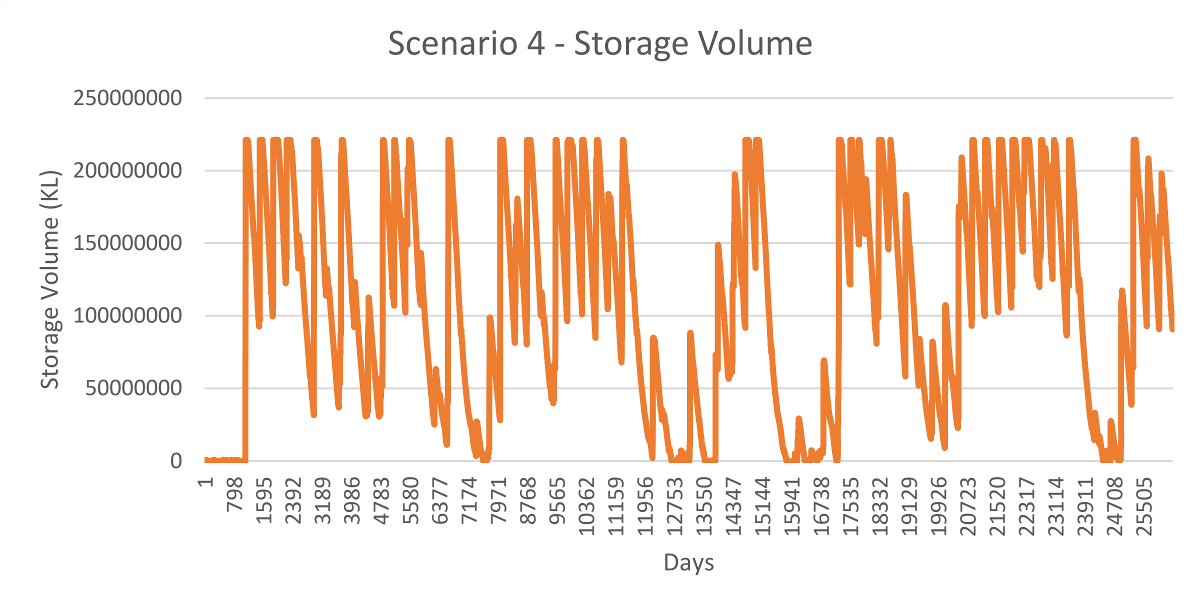

Figure 4.12 - Scenario 4 Storage volume

Figure 4.13 shows the number of days the storage was able to supply the total demand required when scenario 4 was run in the model. Days the demand was met are recorded as one, while days demand was not met are recorded as zero.

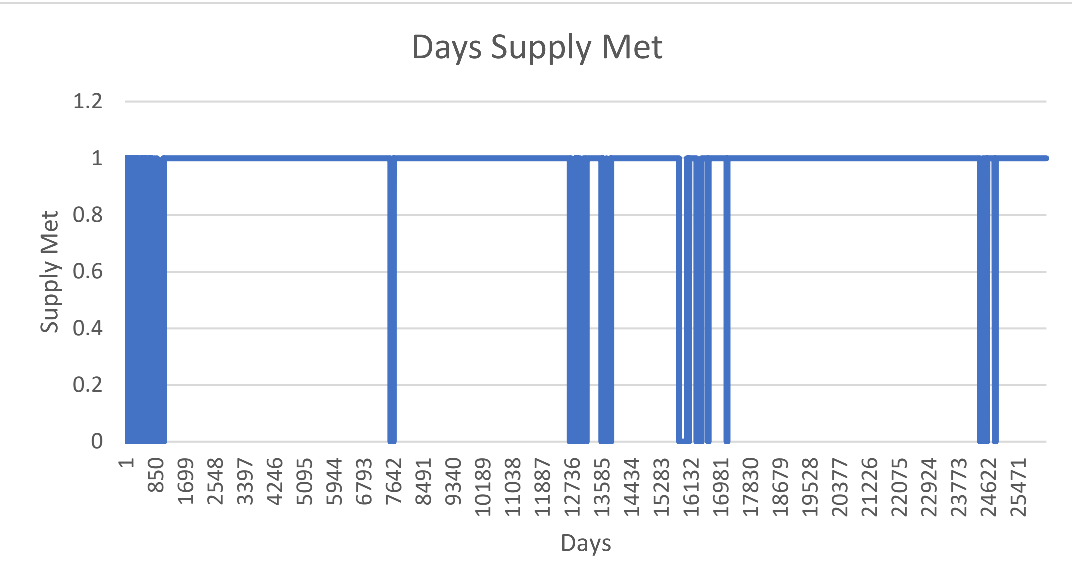

Figure 4.13 - Scenario 4 Days Supply met

Figure 4.14 shows the number of days water restrictions would be required when scenario 4 was run in the model. Days water restrictions are required are recorded as one, while days they are not required are recorded as zero.

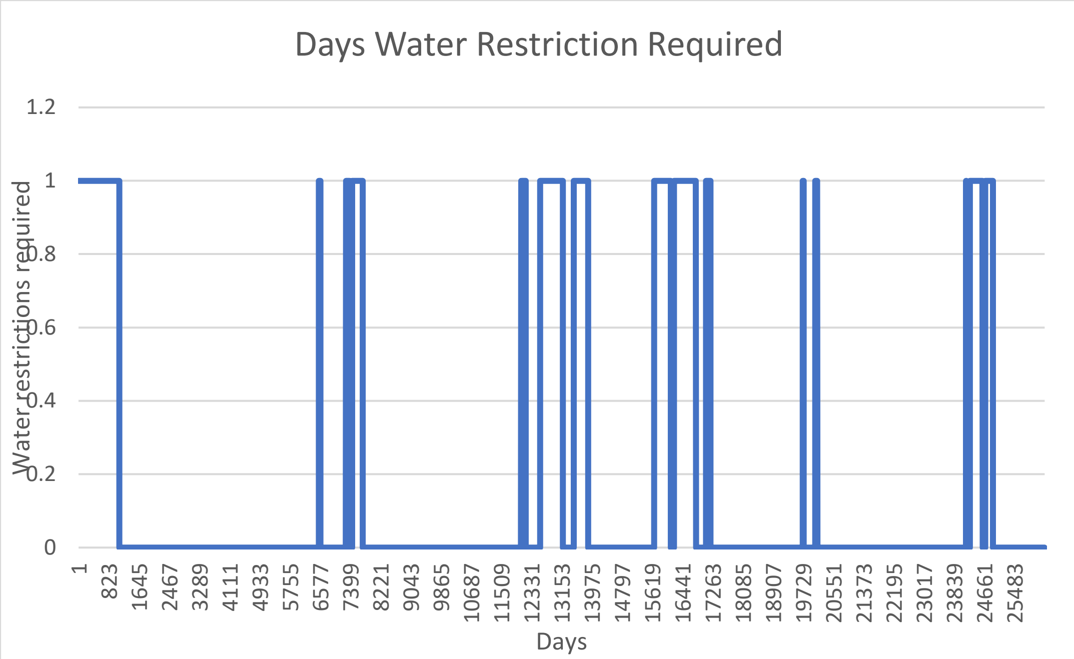

Figure 4.14 - Scenario 4 days water restrictions required.

Figure 4.15 shows the number of days pumping from the Haughton pipeline would be required when scenario 4 was run in the model. Days pumping are required are recorded as one, while days they are not required are recorded as zero.

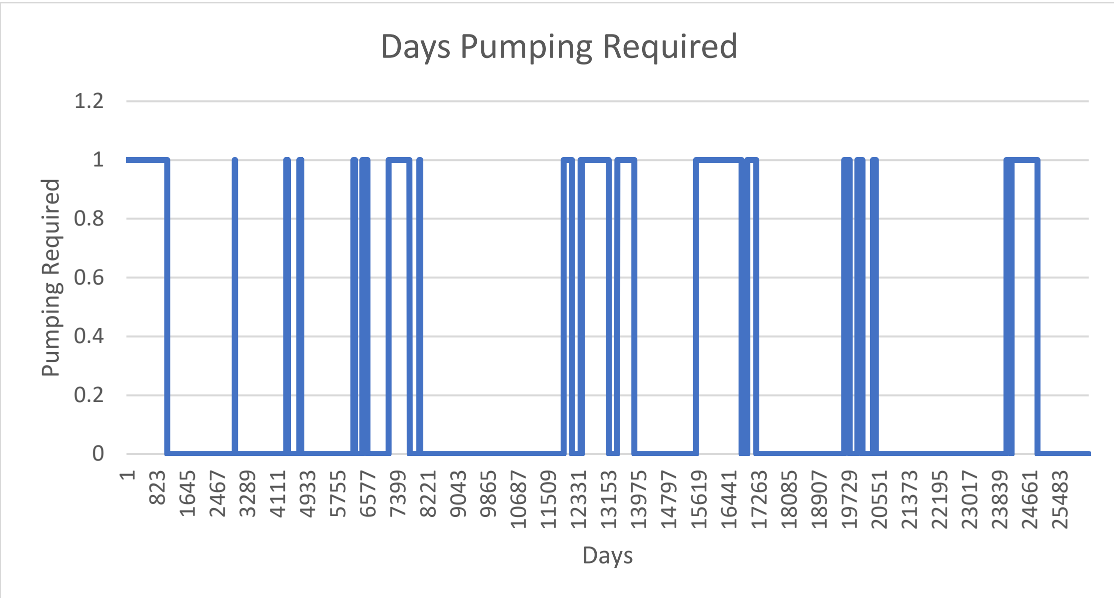

Figure 4.15 - Scenario 4 days Haughton pipeline pumping required.

Table 4.4 shows a summary of results from running scenario 4 as a percentage of the number of days the storage met demand and the number of days water restrictions and pumping from the Haughton pipeline were required.

Table 4.4 - Summary of scenario 4 results

Days Supply Met	Days Water Restrictions Required	Days Pumping Required
24104/26298	4484/26298	6127/26299
91.66%	17.05%	23.30%

4.5 Scenario 5

Scenario 5 represents the effect of water restrictions. Figure 4.16 shows the results of storage volume over the 71 years when scenario 5 is run in the Excel water balance model.

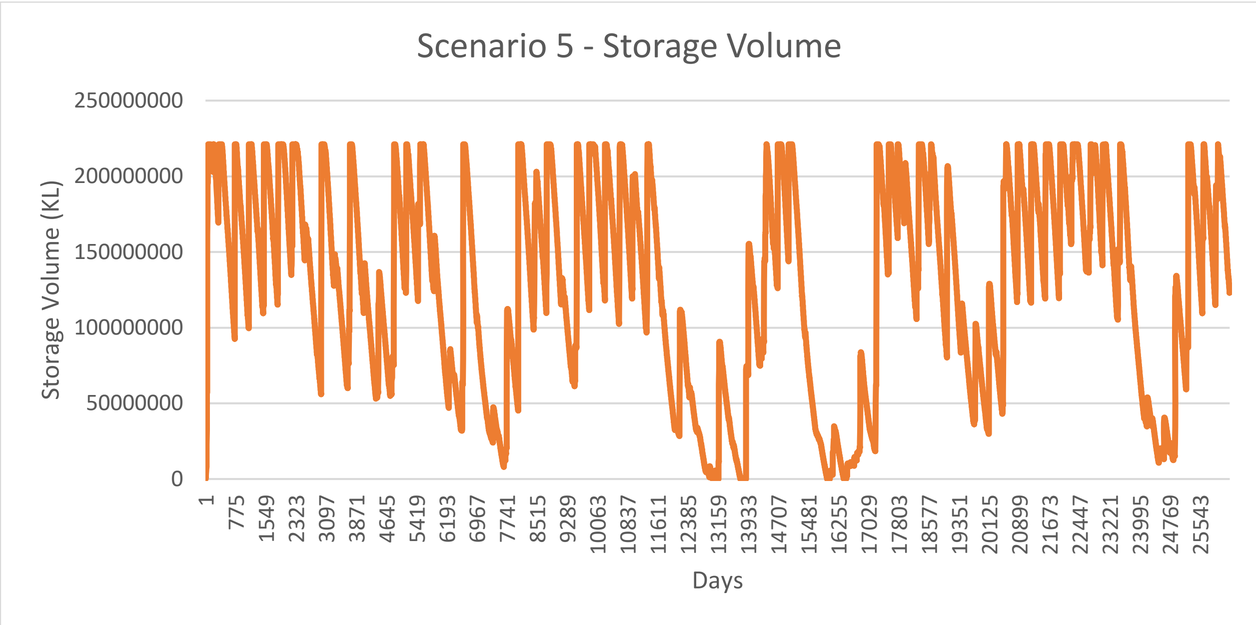

Figure 4.16 - Scenario 5 Storage volume

Figure 4.17 shows the number of days the storage was able to supply the total demand required when scenario 5 was run in the model. Days the demand was met are recorded as one, while days demand was not met are recorded as zero.

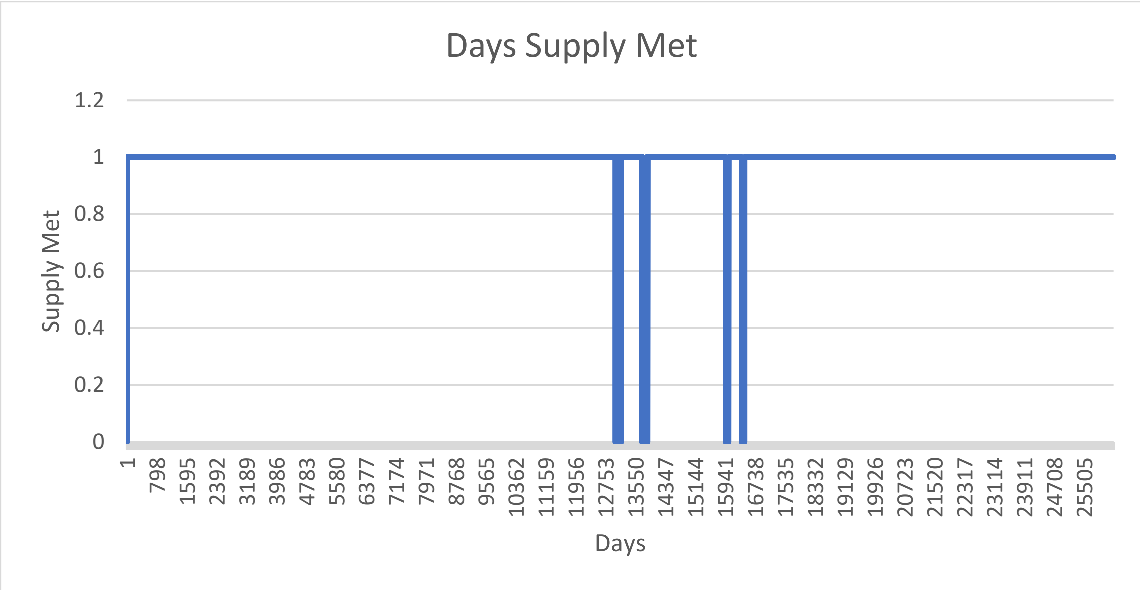

Figure 4.17 – Scenario 5 Days Supply met

Figure 4.18 shows the number of days Water restrictions would be required when scenario 5 was run in the model. Days water restrictions are required are recorded as one, while days they are not required are recorded as zero.

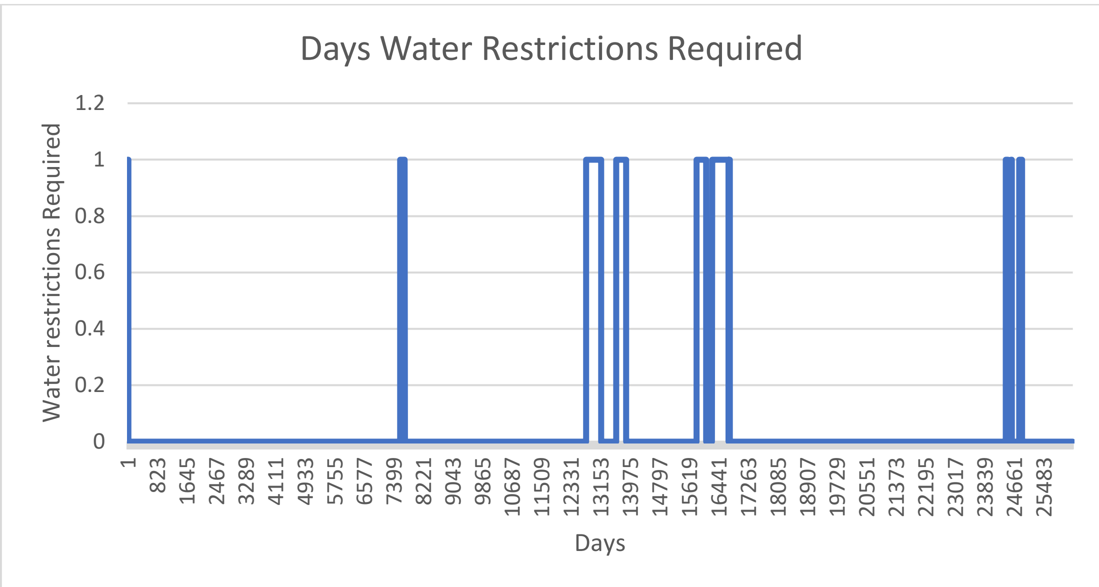

Figure 4.18 - Scenario 4 days water restrictions required.

Figure 4.19 shows the number of days pumping from the Haughton pipeline would be required when scenario 5 was run in the model. Days pumping are required are recorded as one, while days they are not required are recorded as zero.

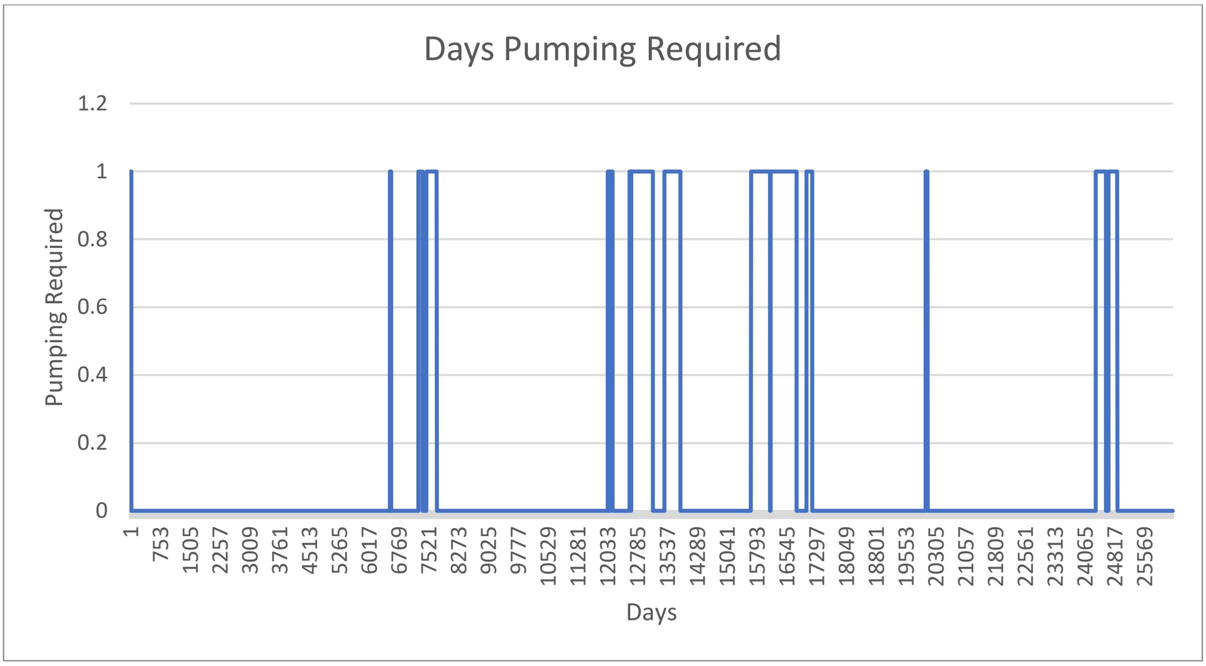

Figure 4.19 - Scenario 5 days Haughton pipeline pumping required.

Table 4.5 shows a summary of results from running scenario 5 as a percentage of the number of days the storage met demand and the number of days water restrictions and pumping from the Haughton pipeline were required.

Table 4.5 - Summary of scenario 5 results

Days Supply Met	Days Water Restrictions Required	Days Pumping Required
25960/26298	1781/26298	3283/26299
98.71%	6.77%	12.48%

4.6 Scenario 6

Scenario 6 represents the duplication of the Haugton pipeline. Figure 4.20 shows the results of storage volume over the 71 years when scenario 6 is run in the Excel water balance model.

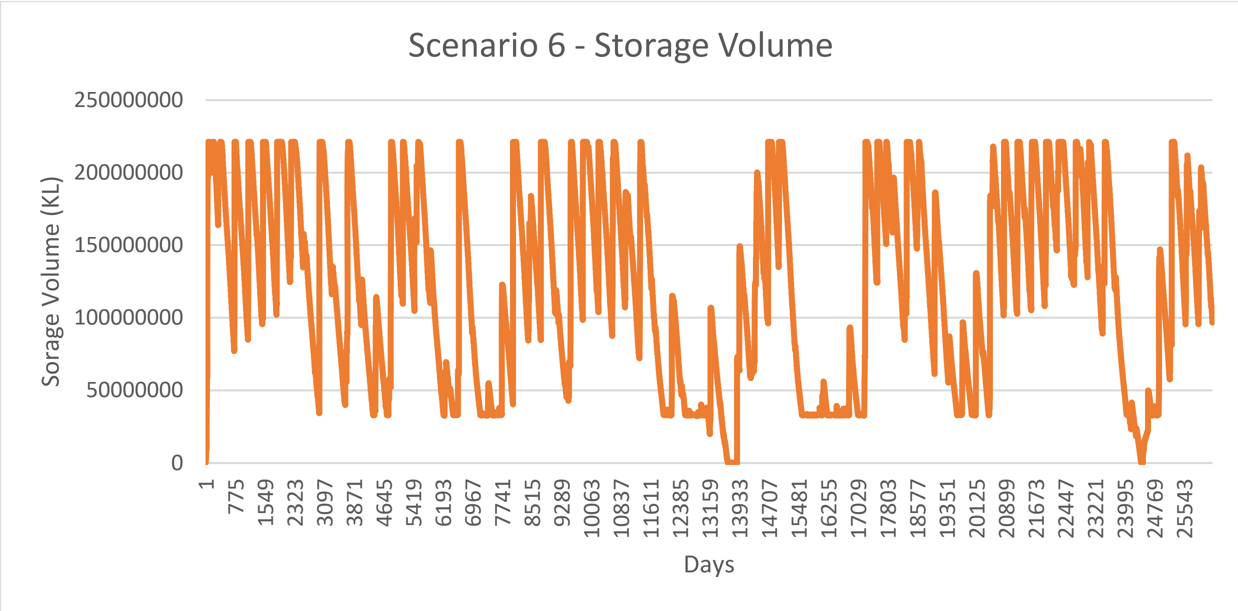

Figure 4.20 - Scenario 6 Storage volume

Figure 4.21 shows the number of days the storage was able to supply the total demand required when scenario 6 was run in the model. Days the demand was met are recorded as one, while days demand was not met are recorded as zero.

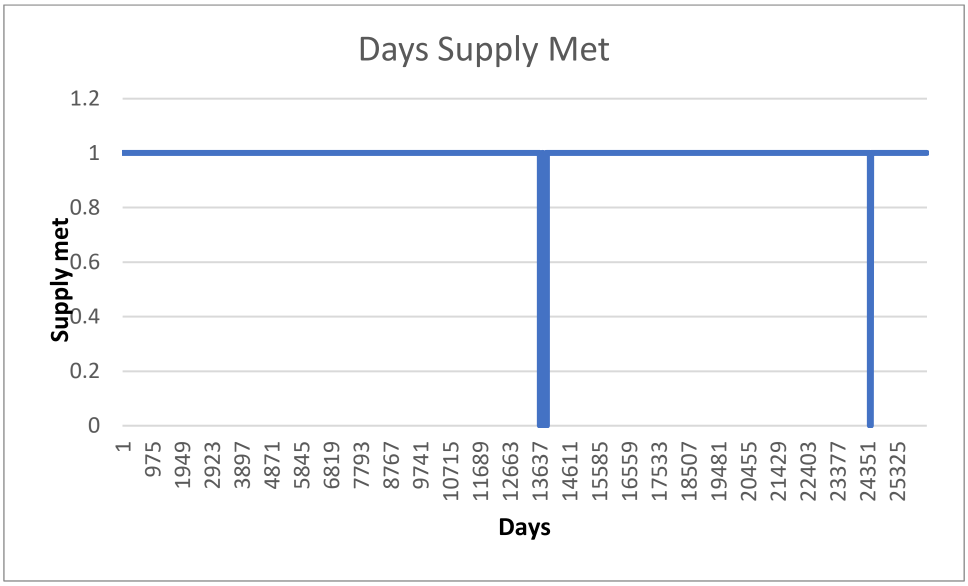

Figure 4.21 - Scenario 6 Days Supply met

Figure 4.22 shows the number of days water restrictions would be required when scenario 6 was run in the model. Days water restrictions are required are recorded as one, days they are not required are recorded as zero.

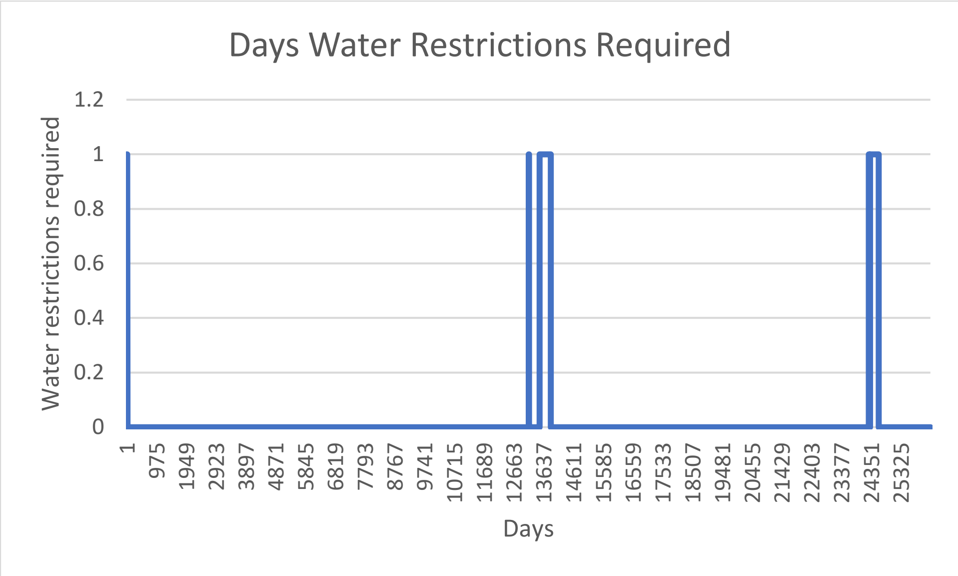

Figure 4.22 - Scenario 6 days water restrictions required.

Figure 4.23 shows the number of days pumping from the Haughton pipeline would be required when scenario 6 was run in the model. Days pumping are required are recorded as one, days they are not required are recorded as zero

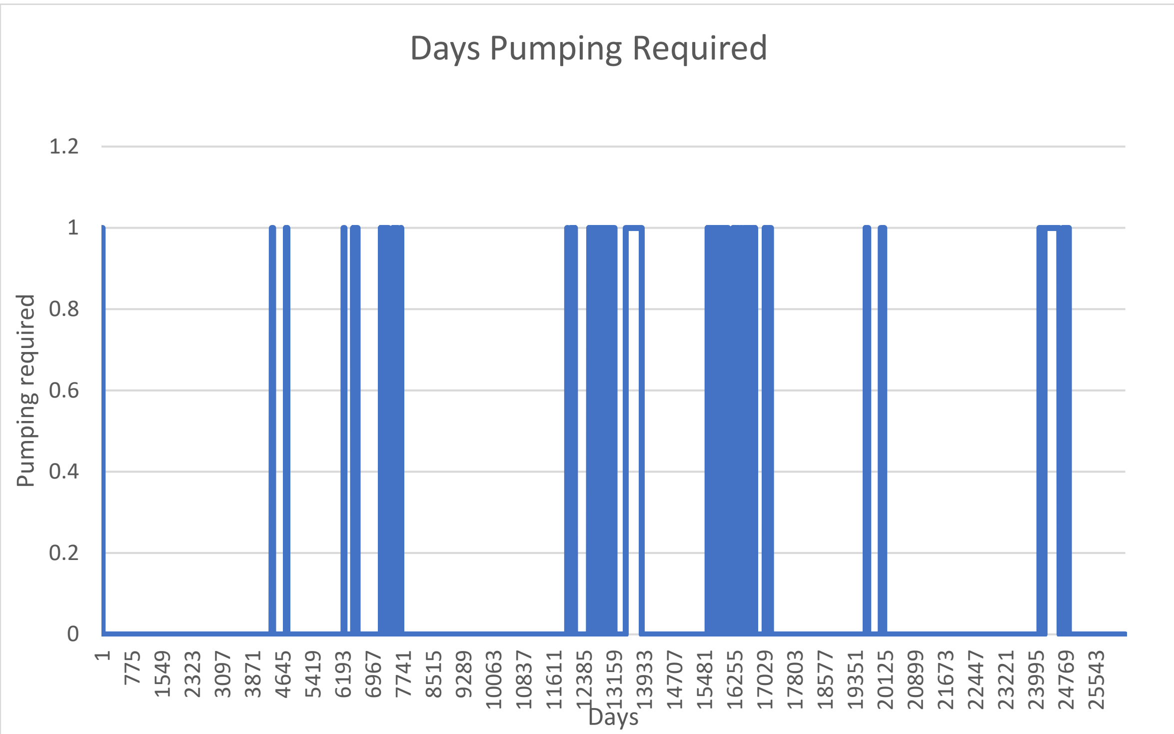

Figure 4.23 - Scenario 6 days Haughton pipeline pumping required.

Table 4.6 shows a summary of results from running scenario 6 as percentage of the number of days the storage met demand and the number of days water restrictions and pumping from the Haughton pipeline were required.

Table 4.6 - Summary of scenario 6 results

Days Supply Met	Days Water Restrictions Required	Days Pumping Required
26042/26298	713/26298	1935/26299
99.03%	2.71%	7.36%

4.7 Scenario 7

Scenario 7 combines the effects of climate change, increased population and the Haughton pipeline duplication. Figure 4.24 shows the results of storage volume over the 71 years when scenario 7 is run in the Excel water balance model.

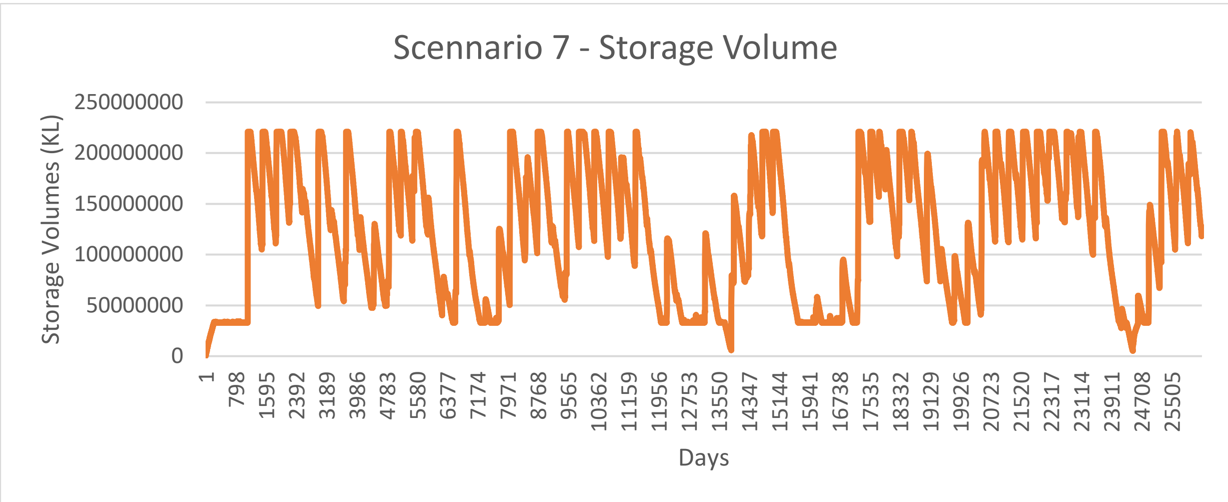

Figure 4.24 - Scenario 7 Storage volume

Figure 4.25 shows the number of days the storage was able to supply the total demand required when scenario 7 was run in the model. Days the demand was met are recorded as one, while days demand was not met are recorded as zero.

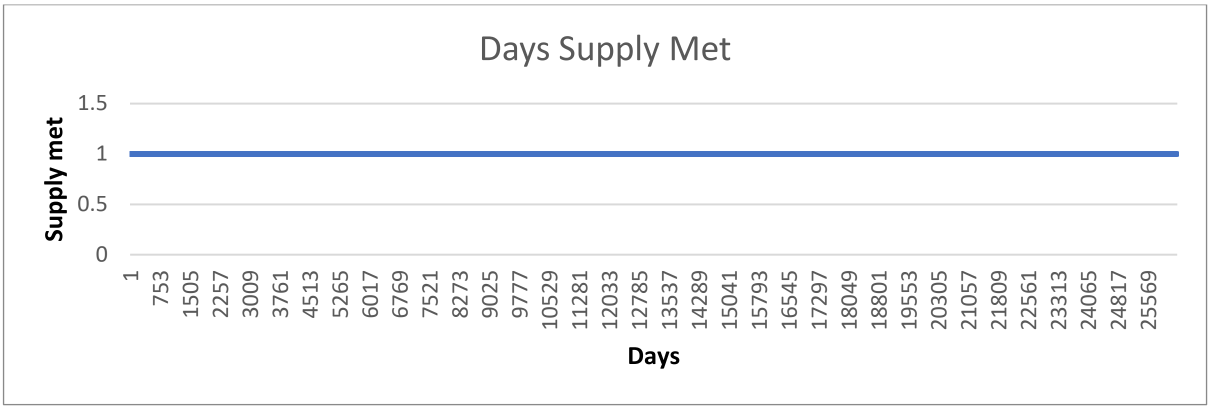

Figure 4.25 - Scenario 7 Days Supply met

Figure 4.26 shows the number of days water restrictions would be required when scenario 7 was run in the model. Days water restrictions are required are recorded as one, days they are not required are recorded as zero.

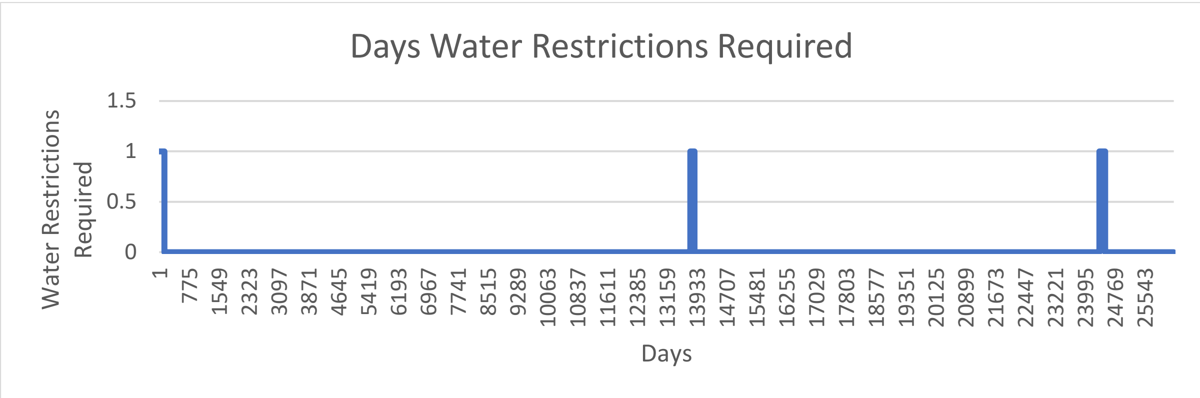

Figure 4.26 - Scenario 7 days water restrictions required.

Figure 4.27 shows the number of days pumping from the Haughton pipeline would be required when scenario 7 was run in the model. Days pumping are required are recorded as one, while days they are not required are recorded as zero.

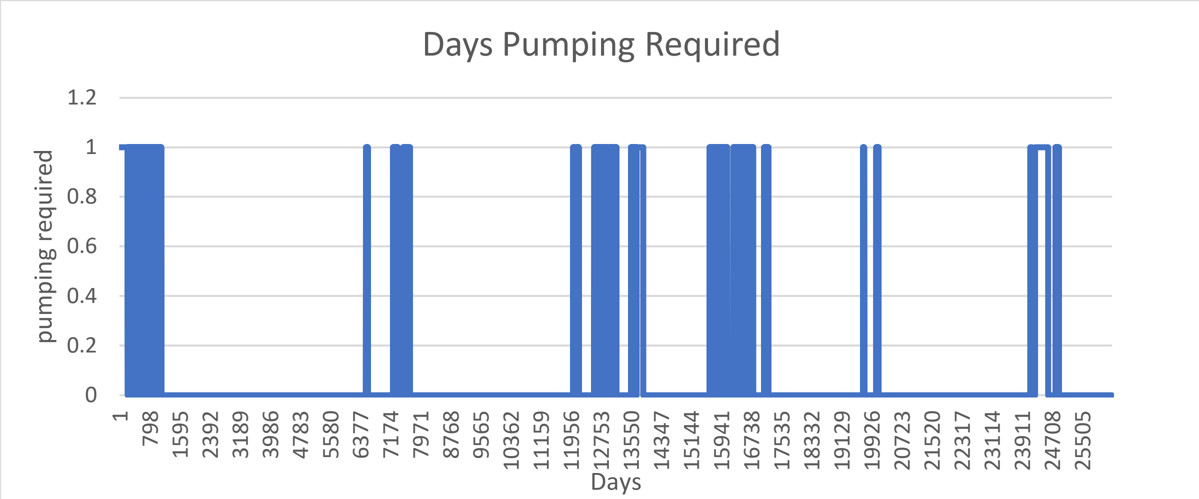

Figure 4.27 - Scenario 7 days Haughton pipeline pumping required.

Table 4.7 shows a summary of results from running scenario 7 as percentage of the number of days the storage met demand and the number of days water restrictions and pumping from the Haughton pipeline were required.

Table 4.7 - Summary of scenario 7 results

Days Supply Met	Days Water Restrictions Required	Days Pumping Required
26025/26298	915/26298	2856/26298
98.96%	3.48%	10.86%

4.8 Scenario 8

Scenario 8 combines the effects of climate change, increased population, the Haughton Pipeline duplication, and water restrictions. Figure 4.28 shows the results of storage volume over the 71 years when scenario 8 is run in the Excel water balance model.

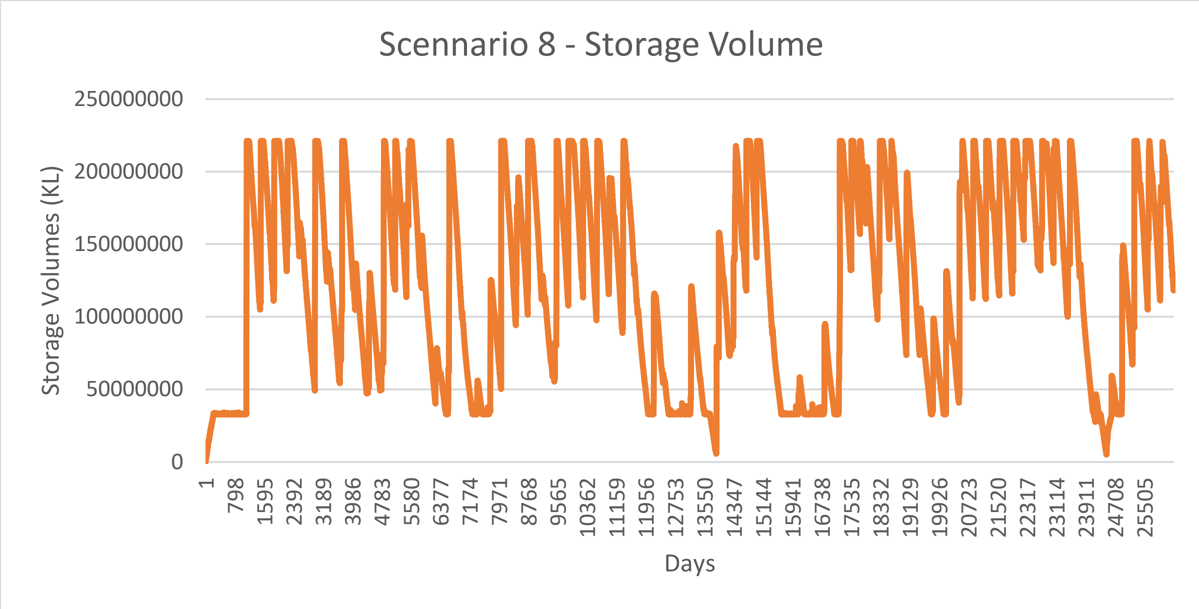

Figure 4.28 - Scenario 8 Storage volume

Figure 4.29 shows the number of days the storage was able to supply the total demand required when scenario 8 was run in the model. Days the demand was met are recorded as one, while days demand was not met are recorded as zero.

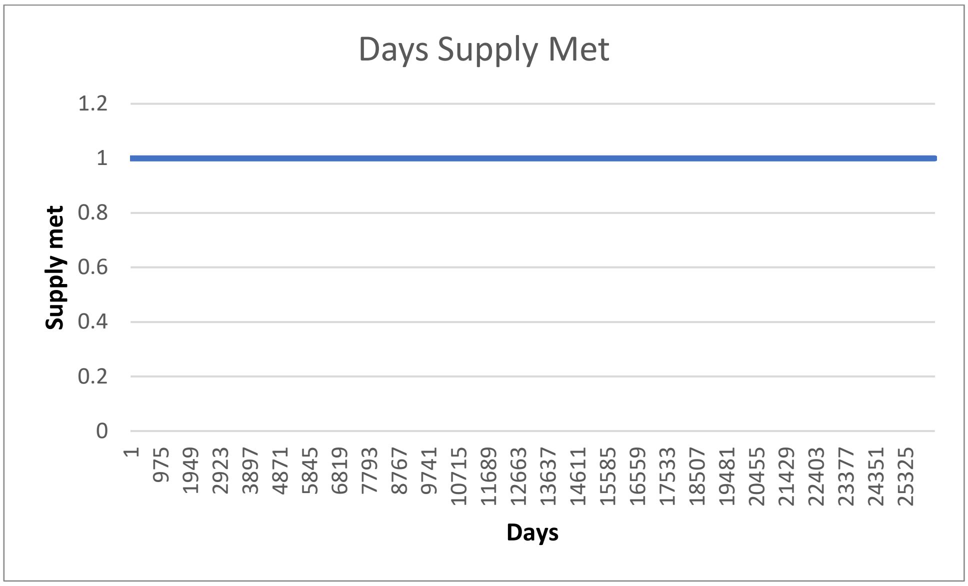

Figure 4.29 - Scenario 8 Days Supply met

Figure 4.30 shows the number of days water restrictions would be required when scenario 8 was run in the model. Days water restrictions are required are recorded as one, while days they are not required are recorded as zero.

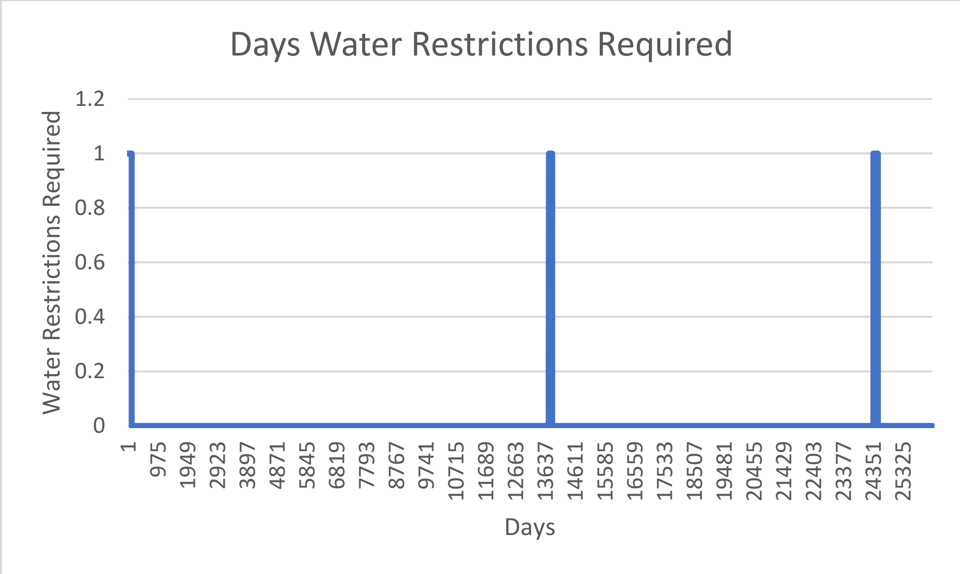

Figure 4.30 - Scenario 8 days water restrictions required.

Figure 4.31 shows the number of days pumping from the Haughton pipeline would be required when scenario 8 was run in the model. Days pumping are required are recorded as one, while days they are not required are recorded as zero.

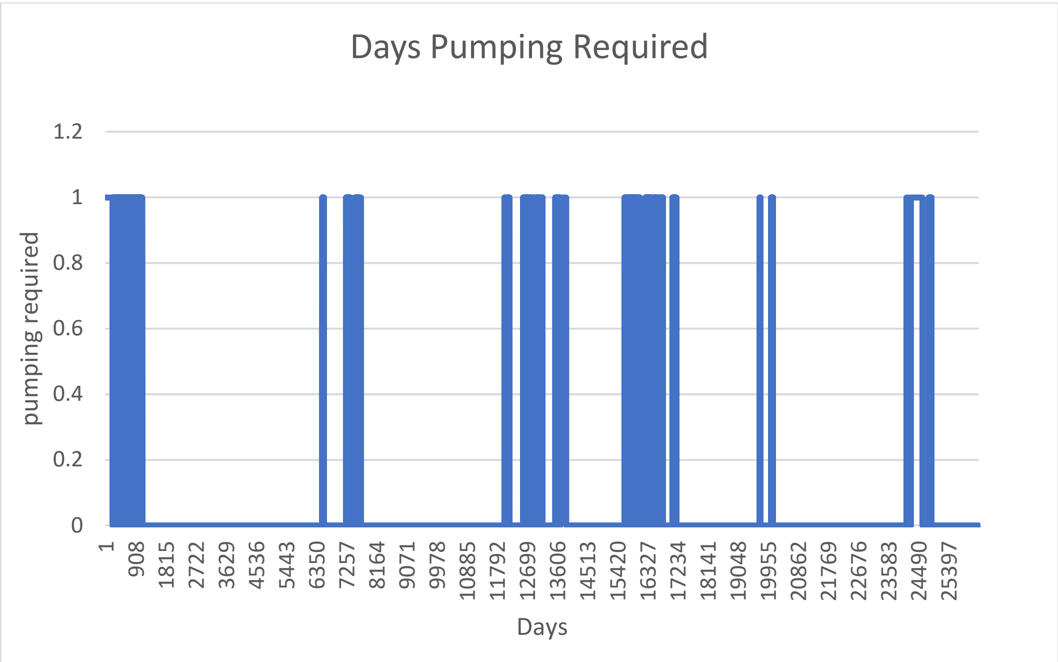

Figure 4.31 - Scenario 8 days Haughton pipeline pumping required.

Table shows a summary of results from running scenario 8 as percentage of number of days the storage met demand, number of days water restrictions and pumping from the Haughton pipeline were required.

Table 4.8 - Summary of scenario 8 results

Days Supply Met	Days Water Restrictions Required	Days Pumping Required
26298/26298	293/26298	1416/26299
100.00%	1.11%	5.38%

4.9 Scenario 9

Scenario 8 combines the effects of climate change, increased population and the Haughton pipeline duplication and reduced water consumption. Figure 4.32 shows the results of storage volume over the 71 years when scenario 9 is run in the Excel water balance model.

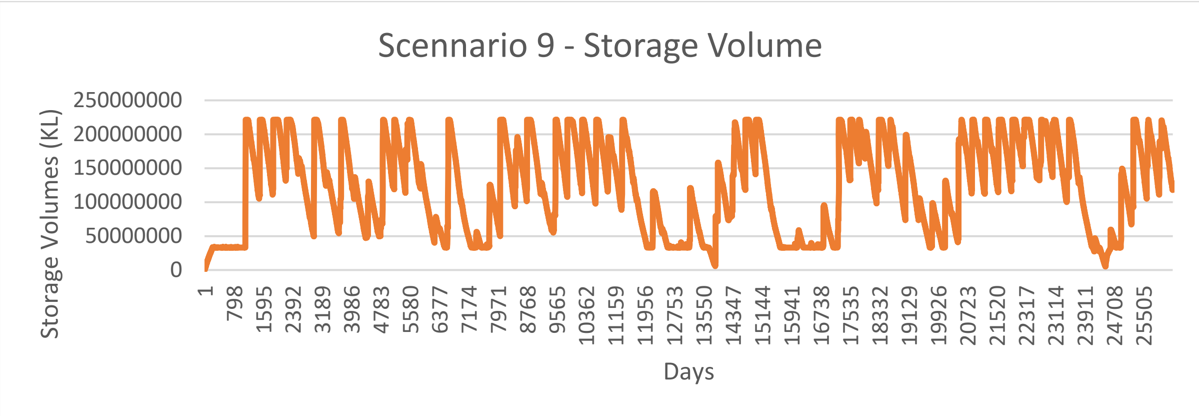

Figure 4.32 - Scenario 9 Storage volume

Figure 4.33 shows the number of days the storage was able to supply the total demand required when scenario 9 was run in the model. Days the demand was met are recorded as one, days demand was not met are recorded as zero.

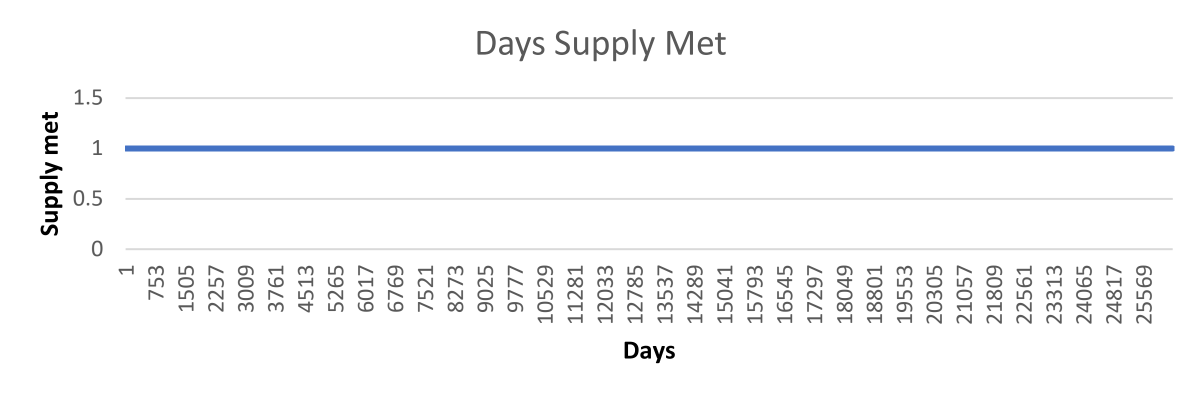

Figure 4.33 - Scenario 9 Days Supply met

Figure 4.34 shows the number of days Water restrictions would be required when scenario 9 was run in the model. Days water restrictions are required are recorded as one, days they are not required was not met are recorded as zero.

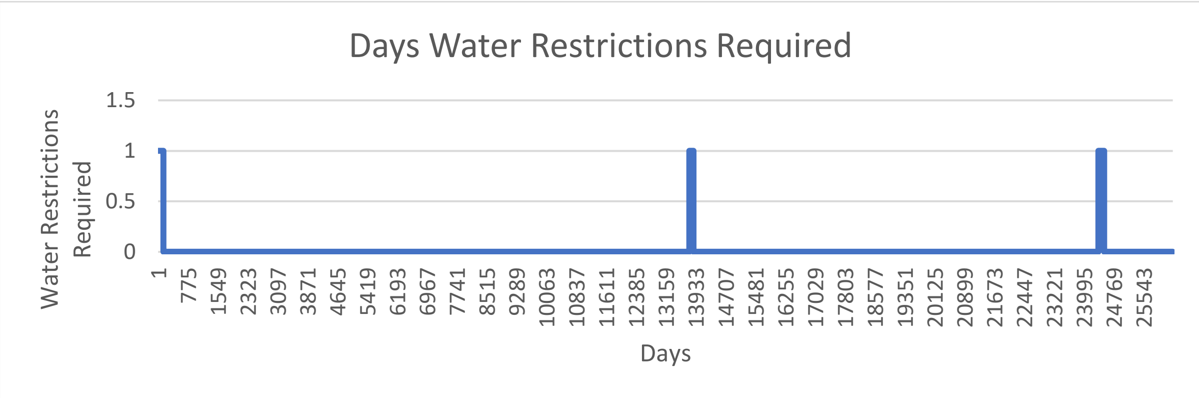

Figure 3.34 - Scenario 9 days water restrictions required.

Figure 3.35 shows the number of days pumping from the Haughton pipeline would be required when scenario 9 was run in the model. Days pumping are required are recorded as one, days they are not required was not met are recorded as zero

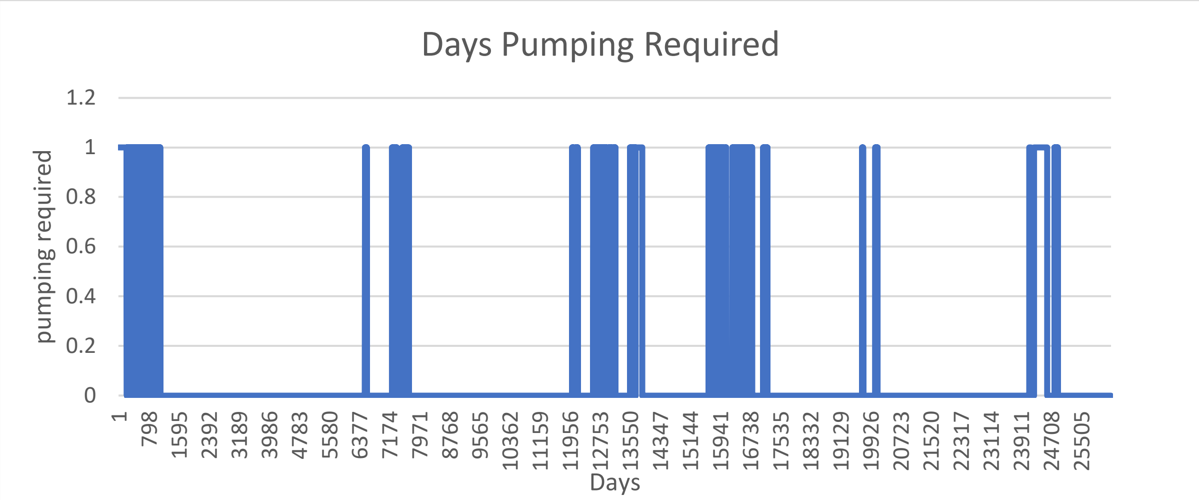

Figure 4.35 - Scenario 9 days Haughton pipeline pumping required.

Table 4.9 shows a summary of results from running scenario 9 as a percentage of the number of days the storage met demand and the number of days water restrictions and pumping from the Haughton pipeline were required.

Table 4.9 - Summary of scenario 9 results

Days Supply Met	Days Water Restrictions Required	Days Pumping Required
26298/26298	388/26298	1600/26298
100.00%	1.48%	6.08%

5 – Discussion

Confidence testing demonstrated that the model worked effectively and accurately reflected historical events. Despite this, there were limitations in the model's approach. Population (as one parameter) did not account for fluctuations over the period and instead utilised a pre-determined forecast. Historical data for rainfall and runoff was limited which affected the reliability of the data and meant that the AWBM could not be calibrated accordingly. Excess storage over 100% was released in the same day within the model; however, this would likely be done over a longer period to avoid downstream flooding. Finally, the model was also unable to account for water releases due to environmental reasons.

Industrial demand within Townsville was kept as a constant for the purposes of this study. While the water demand from this sector has historically not fluctuated significantly, future studies should consider including a more accurate representation of the impact of this sector. This will be particularly important if there is an unexpected growth or decline in industrial demand that alters the assumptions made as the basis for this study.

The effects of climate change for this study were predicated on a moderate estimate of decreases in rainfall. It is, however, important to note that projected changes in rainfall vary significantly. Future studies should explore the impact of more extreme decreases in rainfall of up to 26% based on Queensland Government (2022) forecasts. This will allow for a more rigorous study of Townsville's potential water supply issues when contrasted with the data used for these findings.

There are a number of limitations with AWBM starting with the quality of the data inputted. The AWBM was unable to be calibrated due to the absence of historical runoff data. Further, the same evapotranspiration values for each month were inputted for all 71 years of data and this is unlikely to be an accurate representation. Rainfall monitoring stations in this area had missing data. This required the utilisation of nearby station data making it less of a true representation of the rainfall in that area. There were also a limited number of rainfall stations that had sufficient data and none of them fell directly within the catchment.

Using the existing population and infrastructure as a foundation for projections, the model tested the capacity of Townsville's water supply to meet demand without water restrictions or support from the Haughton pipeline inflow. This analysis also removed from consideration the potential effects of climate change. Under these circumstances, the Ross River Dam was found to be only 97% reliable and requiring water restrictions to be in place for 10% of the time. As the foundation for future modelling, this scenario demonstrates the likely challenges that Townsville will face in the future and the findings of all other models when factoring in the projected trends for supply and demand factors. It also highlights the importance of the Haughton pipeline inflow.

Keeping population stable and including the existing inflows from the Haughton pipeline, the effectiveness of the dam increased to 100% with water restrictions not being required. Pumping from the Haughton pipeline would be required for 3.2% of the time without increases in demand usage. This scenario sees the existing water management solution being sustainable without water restrictions and would likely be considered sustainable for the city due to the limited cost of inflows. However, this model does not include the potential for a decrease in rainfall because of climate change.

Assuming a population growth forecast out to 2030 being 300,000, we can begin to factor in demand changes for the city. With this growth forecast, the dam would only be effective for 95% of the time and would require water restrictions to be in place for 12.3% of the time. Pumping from the Haughton pipeline would also be required for 18.5% of the time. These findings demonstrate the significant impact of population growth alone on the city which would largely see the existing water management solution being unsustainable. In addition, this model also does not include the possibility of decreased rainfall due to climate change.

Keeping the forecasted populated growth stable at 300,000 but accounting for reduced demand allows the modelling to determine the effectiveness of water restrictions. With level 3 restrictions in place, the model demonstrates that the dam reliability increases to 98.7% effectiveness and reduces the requirement of pumping from the Haughton pipeline to 12.5% of the time. While these findings demonstrate an improvement to the previous model and the effectiveness of water restrictions, this scenario is still considered to be unsustainable for the city. In addition, the impacts of climate change have still not been incorporated into the model.

Now that demand factors have been accounted for, the model can begin to address the impacts of reduced supply through climate change. The first model begins by keeping the projected population growth stable and returning to a scenario without water restrictions. The forecast of reduced rainfall based on QLD Government projections now sees the dam effectiveness reduced to 91.7% with the requirement for pumping from the Haughton pipeline increasing to 23.3% of the time. Not surprisingly, such a scenario would be unsustainable for the city and would require water restrictions in place for 17% of the time.

If level 3 water restrictions are introduced to the above scenario, the dam effectiveness is increased slight to 96.1%. Similarly, the pumping required from the Haughton pipeline is only reduced to 17.2% of the time. This scenario is still likely to be unsustainable for the city and demonstrates the challenges facing the region over the coming decade. The key variable missing from this forecast though is the inclusion of planned upgrades to supply infrastructure.

The duplication of the Haughton pipeline (which is currently underway) will increase the pumping capacity to the dam. This project will also coincide with negotiations to increase Townsville's allocation from the pipeline. Factoring in this increase to supply (without reduced rainfall) with the projected population would see the dam's effectiveness increase to 99% with water restrictions only required for 2.7% of the time. It would also see pumping required from the Haughton pipeline decreasing to 7.4% of the time. This infrastructure clearly improves the city's water supply but is still likely to be insufficient to meet the demand. This is further demonstrated when the effects of climate change are introduced which sees the dam at 99% effectiveness, water restrictions in place for 3.5% of the time and inflows required from the Haughton pipeline for 10.9% of the time.

Finally, by incorporating level 3 restrictions into the above scenario (inclusive of reduced rainfall) we can see the dam's effectiveness increasing to 100%. This would also see the pumping required from the Haughton pipeline decreasing to 5.4% of the time. While this now presents a suitable scenario for managing supply and demand, the severity of water restrictions are unlikely to be palatable to the city for long periods of time. Determining a sustainable model for Townsville therefore requires a delicate balance of water management techniques.

5.1 Recommendations

The modelling undertaken for this study highlights the importance of increasing the supply to the Townsville's water system. The duplication of the Haughton pipeline is a necessary project that will make a meaningful contribution to the water deficit facing the city. This project alone though, is unlikely to meet the growing demand and will necessitate further actions. While outside the scope of this study, continued feasibility studies to improve the dam's capacity, or factoring in alternative water supplies should be considered essential for future town planning.

Despite being unpopular to the residents of Townsville, the projections from this study continue to demonstrate the importance of water restrictions in some capacity. The unpredictable nature of Townsville's supply coupled with the increasing demand projections, show that it will be difficult for the city to able to effectively manage its water without these measures. With no restrictions in place, the average residential daily demand per person was found to be 0.49kl based on historical consumption data. With level 3 restrictions, the average daily residential demand per person was found to 0.29kl which equates to a reduction of 40% in consumption. The model shows that with a reduction of the daily residential consumption by 35% or 0.32kl, the dam would maintain 100% effectiveness with inflows required for only 6.1% of the time and level 2 restrictions required for 1.5% of the time.

Lastly, the findings of this study point to water management policies in Townsville that find an effective balance between increasing the reliability of supply while curtailing the consumption of residents. Based on the above analysis, it is difficult to foresee any singular project or policy that would focusing on either demand or supply that would ensure the city's goal of a sustainable water system. The city should therefore plan on long-term water restrictions and an increasing investment in supply initiatives for the foreseeable future.

6 - Conclusion

Townsville provides an excellent case study for water management challenges facing Australia and the region in the coming decades. With demand and supply factors both pointing towards an increasing water deficit, the need for detailed town planning is essential for the sustainable growth of the city. The modelled scenarios presented in this study demonstrated the importance of developing both long-term demand and supply measures that will mitigate the projected increases in consumption and decreases in rainfall. This project provides a meaningful contribution to this aim but also acknowledges that there is significantly more work to be done to secure Townsville's future.

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Appendix A – Project Specification

ENG4111/4112 Research Project

Project Specification

For: Stephanie Wilson

Title: Water budgeting and urban water demand management for Townsville

Major: Civil Engineering

Supervisors: Justine Baillie

Enrolment: ENG4111 – ONLINE S1, 2021

ENG4112 – ONLINE S2, 2021

Project Aim: This project will identify water supply and demand factors in the city of Townsville in order to assess water budgeting and management solutions that contribute to its future sustainability.

The purpose of this research project will be to provide a meaningful contribution to water budgeting in Townsville and thereby offer sustainable solutions for Australia's future. The purpose of this research project is to validate or challenge existing models for water management by conducting independent modelling of Townsville, QLD. By forecasting consumption patterns and supply factors, this project will seek to improve water management techniques. In doing so, the project will explore existing models and policies across Australia to determine what innovations could be adopted on a wider scale. With a focus on urban water budgeting, the project will also examine the effectiveness of managing domestic consumption through cost-pricing models as well as regulation.

Programme: Version 1, 13th March 2021

1. Project Preparation – Literature review: Research the background information relating to Water management as well as supply and demand factors in Townsville. Research examples of other water models specifically to regional Australia.

2. Data Collection: Collect source data relating to water consumption and water supply including trends and variables in Townsville.

3. Prepare Water Balance Model using Excel, confidence test Model and develop scenarios.

4. Evaluation of results from model.

5. Write up final thesis and providing recommendations for Townsville's Future water management and budgeting.

Project Resources

The resources required to complete this project will be:

- Computer and internet access.
- Microsoft Office applications: Excel and Word
- Datasets consisting of:
  - Demand factors relating population and water consumption trends in Townsville. Sourced from Australian Bureau of Statistics and Townsville City Council.
  - Supply Factors relating to rainfall patterns and Ross River Dam management. Sourced from Bureau of Meteorology and Sun water.
  - Examples of Water Balance Models used in regional cities of Australia.

Appendix B – Risk Assessment

Appendix B

ENG4111/4112 Research Project

Risk Assessment

A risk assessment has been developed utilising the USQ Safety Risk Management System under the ID: RMP_2020_4859. The Risk Matrix has been provided as Figure 1 and the Risk Register and Analysis has been provided as Figure 2. The maximum residual risk level was determined to be ‘Low’ and requiring Manager/Supervisor approval.

Risk Matrix

Probability	Consequence				
	Insignificant No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injury $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1,000	L	M	H	H	H
Unlikely 1 in 10,000	L	L	M	M	M
Rare 1 in 1,000,000	L	L	L	L	L

Recommended Action Guide

Extreme:	E= Extreme Risk – Task ***MUST NOT*** proceed
High:	**H** = High Risk – Special Procedures Required (Contact USQSafe) Approval by VC only
Medium:	**M**= Medium Risk - A Risk Management Plan/Safe Work Method Statement is required
Low:	**L**= Low Risk - Manage by routine procedures.

Figure 1.

	Risk Register and Analysis											
	Step 1	Step 2	Step 2a	Step 2b	Step 3			Step 4				
	Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional Controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:*** Has the consequence or probability changed?			
					Probability	*Risk Level*	*ALARP*		*Consequence*	*Probability*	*Risk Level*	*ALARP*
	Example											
	Working in temperatures over 35^0 C	*Heat stress/heat stroke/exhaustion leading to serious personal injury/death*	*catastrophic*	*Regular breaks, chilled water available, loose clothing, fatigue management policy.*	*possible*	*high*	*No*	*temporary shade shelters, essential tasks only, close supervision, buddy system*	*catastrophic*	*unlikely*	*mod*	*Yes*
1	USQ does not approve project.	Project needs to be redefined at short notice causing delays.	Moderate	Early engagement with supervisor.	Rar	Low	☐	Have alternative projects in a related field that will allow quick transition and reduce delays.	Insign	Rar	Low	☑
2	Insufficient resources for project.	Project cannot be completed in its planned form.	Moderate	Early engagement with supervisor to understand project requirements.	Rar	Low	☐	Source external resources to USQ if required.	Insign	Rar	Low	☑
3	Inadequate or insufficient data.	Data will be insufficient to draw the planned outcomes of the project.	Major	Source the available data early in the project development.	Pos	High	☐	Contact Townsville City Council early to determine willingness to share data.	Minor	Unl	Low	☑
4	Errors in data input cause flawed results.	Project is delayed or not suitable for publication.	Moderate	Establish time for reviews of data.	Pos	High	☐	Request time with supervisor throughout the project to validate work.	Minor	Rar	Low	☑
5	Distance from research area results in delays.	Researcher is unable to retrieve required data within timeframe causing delays.	Minor	Early engagement with literature and Townsville City Council.	Unl	Low	☐	Use personal contacts in Townsville if necessary.	Insign	Rar	Low	☑
6	Insufficient time to develop dissertation and present findings.	Unable to deliver dissertation on time.	Minor	Early planning of schedule and anticipated delays.	Rar	Low	☐	'Write early, write often' approach to dissertation development.	Insign	Rar	Low	☑

Figure 2.