University of Southern Queensland

Faculty of Health, Engineering and Science

Effluent Water Reuse for Townsville

A dissertation submitted by

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In fulfilment of the requirements of

ENG4111 and 4112 Research Project

Towards the degree of

Bachelor of Engineering (Honours) (Civil)

Submitted October. 2017

ABSTRACT

The Townsville region is currently (2017) experiencing a drought period where by the regions water supply is reduced to reliance on the Burdekin river water supply through the Burdekin Haughton Water Supply Scheme (BHWSS). The BHWSS requires pumping to move the water and is currently a cost of $27,000 a day to the rate payers. Water supply security is an issue for Townsville and the dry tropics with low rainfall, arid climate and high-water demand. A water security issue of this nature warrants alternative solutions to be investigated. One such solution is effluent water reuse, that this research project investigates specifically for Townsville.

Regional water supply security has previously been investigated by Townsville City Council (TCC). The proposed solution was to duplicate the BHWSS pipeline increase the supply capacity to Townsville from 130ML/day to 328ML/day. The investigation also flagged effluent water reuse as a possible future consideration for the region and the point at which this dissertation picks up and develops.

A Water Balance Model (WBM) was developed for the Ross River Dam (RRD) and validated against historical dam levels. The WBM was used to investigate various scenarios of effluent water supply timing to test for bulk storage changes. The key outcomes addressed by this dissertation are:

- The water restriction influence of non-potable effluent water reuse for Townsville.
- Burdekin Haughton Water Supply Scheme (BHWSS) reliance reduction resulted from non-potable effluent water reuse for Townsville.

The literature review process identified a large volume of effluent water that was largely unusable for neither potable or non-potable reuse without the implementation of reverse osmosis (RO) thus restricting the potential reusable volume. This was due to the low-lying nature of Townsville and the high infiltration inflow of salt water into the waste water system.

Conclusions drawn from the work suggest that whilst effluent water reuse does have a positive effect on Townsville water restriction and a reduced reliance on the BHWSS, the volumes being considered are too small to have any large implications for the region.

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Limitation of Use

CERTIFICATION

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Student Number: [redacted]

ACKNOWLEDGEMENTS

I would like to first and foremost give special appreciations to Lecturer Justine Baillie. Her support and guidance throughout my research project has been without flaw.

Secondly, I would like to make mention of the Townsville City Council water team; Janice Moody, Ricky Bligh & Erin Le Feuvre. The information and data provided has underpinned this project.

Finally, I would like to thank two special family members. My Grandfather Graham Govan for his guidance, support and inspiration for this topic. My wife Melissa Govan for support and commitment to me throughout my studies.

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CHAPTER 1 INTRODUCTION

1.1 Problem Statement

The Townsville region is currently (2017) experiencing a drought period where by the regions water supply is reduced to reliance on the Burdekin river water supply through the Burdekin Haughton Water Supply Scheme (BHWSS). The BHWSS requires pumping to move the water and is currently a cost of $27,000 a day to the rate payers. The city of Townsville itself is presently on level 3 restrictions and has been on water restrictions for the last 2 years. Water supply security is an issue for Townsville and the dry tropics with low rainfall, arid climate and high-water demand. A water security issue of this kind warrants alternative solutions to be investigated. One such solution is effluent water reuse, that this project investigates specifically for Townsville.

1.2 Project Objectives

The aim of this project is to determine the viability of Townsville effluent water for regional potable and non-potable reuse. The project can be broken down into subsection for an objectively analytical approach:

1. Develop a water balance model that can simulate Townsville's water supply and demand.
2. Identify suitable Townsville effluent water supply sources based on volume and quality.
3. Model Effluent water reuse.
4. Determine the effect Effluent water reuse can have based on cost estimation & comparison with BHWSS.

Each of the objectives flow onto each other and amount to final recommendations & Conclusions. The First section establishes the backbone of the Townsville Region water supply. Investigating both supply and demand capabilities. The second section reviews the water treatment processes and evaluates effluent water discharge quality and volume. The sub conclusions from analysis of this objective provides the data required for Effluent water modelling.

The third section of Water Balance Modelling (WBM), emulates the current water storage trend with historical data and runs alternative scenarios with the inclusion of Effluent water. The Final objective is cost estimation and analysis which looks at cost implications of various reuse strategies in comparison to the BHWSS.

1.3 Research Objectives

The objectives of this research project is underpinned by a simple question:

1	**Can an Effluent water reuse scheme have a supply influence on the Townsville region water restrictions?**

Further development of the project lead to another equally valid question:

2	**Can an Effluent water reuse scheme reduce the reliance on pumping from the Burdekin Dam?**

These two questions are developed fully in the proceeding dissertation.

1.4 Dissertation Outline

Chapter 2 – Literature Review

The literature review discusses issues surrounding Townsville water supply and demand and seeks to paint a picture for the reader of the system as a whole. The literature review also presents the foundations for the work undertaken in the preceding chapters.

Chapter 3 – Methodology

The methodology chapter presents to the reader the approach undertaken for analysis and identifies the key parameters and scenarios that have been analysed. This chapter also reviews the model from a sensitivity point of view to illustration confidence in the parameter selection.

Chapter 4 – Model Development

The model development chapter is the technical chapter that delves into fundamentals of the water balance model. The key elements of discussion are, the data management and validation, critical decision-making functions and variables that are embedded in the model and calculations.

Chapter 5 - Results

The results chapter fundamentally presents the results in a raw format with some general discussion to the reader.

Chapter 6 – Discussion

The discussion chapter elaborates on the results and provides engineering discussion to the reader. The discussion will preliminarily conclude and answer the research objectives.

Chapter 7 - Conclusion

Conclusion of the dissertation will outline the finding is a concise and complete model support answer to the research objects. This chapter also summarises the findings and makes recommendations to the reader.

CHAPTER 2 LITERATURE REVIEW

2.1 Background

2.1.1 The Study Area

The coastal city of Townsville is central to the Townsville City Council (TCC). This region of North Queensland, Australia is part of the dry tropics. The Townville City Council more specifically extends from the northern reaches of Mutarnee/Paluma all the way south inland to Reid River. The Council also provide service to Magnetic Island a 20-minute boat ferry ride away. The geography of the region is primarily flat with a gradual elevation increase from the coast heading west. The Council is bordered by three adjacent councils; Hinchinbrook Shire Council to the north, Charters Towers Regional Council to the West & Burdekin Shire Council to the south Figure 2.1.

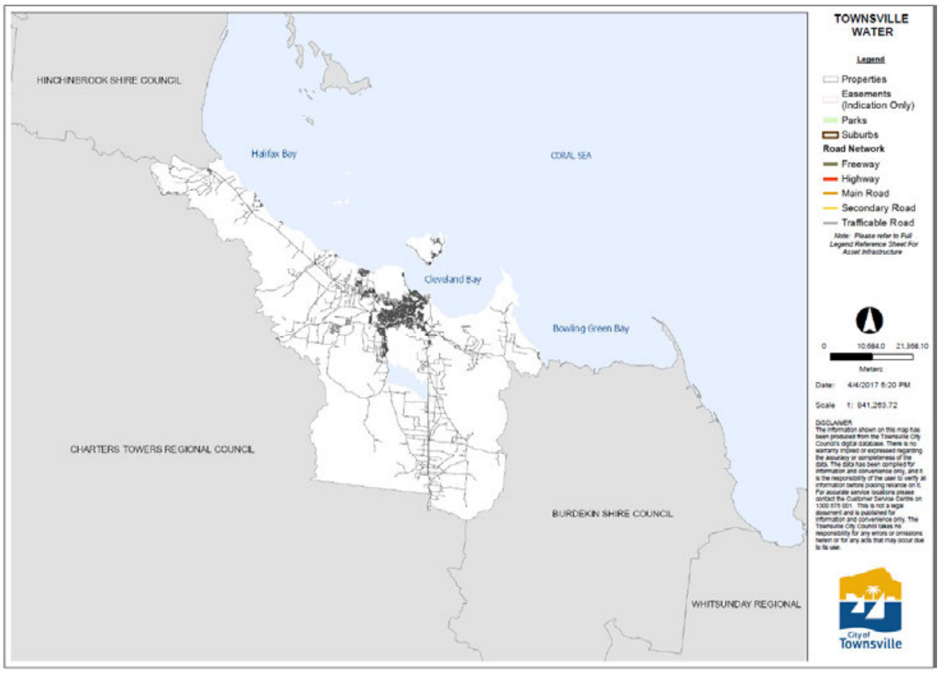


Figure 2.1 - Map of Townsville (Townsville City Council, 2017)

Rainfall is seasonally intense in summer and restrictive in winter. Typically, a monsoon period will occur between the months of December through to March. On occasional years, these periods have been known to fluctuate with heavy rainfall occurring both earlier and later. Historical data has shown that the average rainfall for the Townsville region is 1069.7 ML/Annum (Meterology, 2017).

Townsville is considered the capital of North Queensland with a large government presence in the town through government agencies, military base's as well as being a business hub that extends itself through the international airport to the broad business world. In 2013 the Queensland Government Statistician's Office (QGSO) estimated the Population of Townsville to be 190 000 with and expected average growth to 300 000 by the early 2030's (Department of Energy and Water supply, 2014).

Townsville's water supply demands are serviced primarily by the Ross River Dam (RRD) and Paluma Dam. The region also has a pipeline of bulk water supply from the Burdekin that it can access as a backup.

2.1.2 Key Issues

In recent years, the Townsville region has experience below average rainfall (1069.7 mm). The previous four years of rainfall data all falling below the average with the current year (2017) also projecting a similar forecast. Notably in 2015 the lowest ever rainfall was recorded since records began, registering 397.6 mm (Figure 2.2)

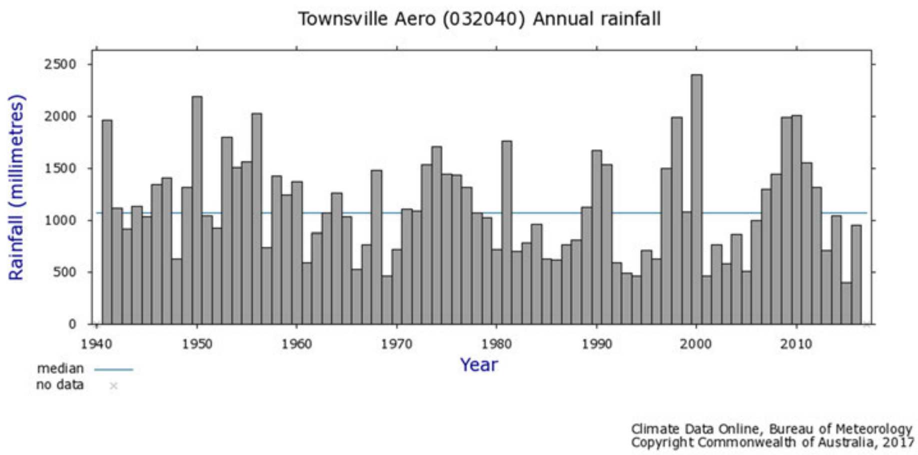


Figure 2.2 - Townsville Annual Rainfall (Meteorology, 2017)

It is documented that Townsville residence generally use more water in dry years and less water in wet years (Department of Energy and Water supply, 2014). This fluctuation is a resultant of residential lawn and garden water usage. This human affect exacerbates the reduced rainfall issue as residents attempt to supplement the rainfall with irrigation and hand watering.

The primary bulk water supply source for Townsville, Ross River Dam also has a role to play in the regions water shortage. The dam itself is wide and shallow with a central channel being a limited point of deep water. Shallow dams like Ross River Dam with large surface areas are subjected to significant evaporation and seepage effects. The relationship of seepage and evaporation loss in a bulk water storage system is related to both surface area and ground contact area. The larger the surface area the greater the evaporation losses. The greater the ground contact area the greater the potential seepage losses. Ross River Dam is an example of an inefficient bulk water storage system in relation to these parameters.

In addition to evaporation and seepage losses, thriving tropical high-water demand plants like hyacinth extract and constrict waterways. Plants and weeds are an issue for all bulk water storage systems, however they are a manageable environmental factor unlike that of evaporation.

Ross River Dam and Paluma Dam can service the Townsville Region water demand through 2 to 3 low inflow/ failed wet seasons (Department of Energy and Water supply, 2014). Once the Ross River Dam hits 20% capacity, where water storage is restricted to the deep channel section of the dam, water is secured through pumping from the Burdekin Haughton water supply scheme (BHWSS) at which point the region is reliant on this source. The cost of pumping bulk water is a burden worn by the rate payers.

In summary, the key issues for the bulk water system of Townsville are identified as:

1. Consecutive years of reduced rainfall in the dry tropics.
2. High water demand from residential consumers.
3. Ross River Dam Topography (Seepage & Evaporation).
4. BHWSS Pumping reliance.

2.2 Townsville Bulk Water Supply System

The Townsville regions bulk water supply service area is divided into three areas:

1. Townsville – Service by Ross River Dam, Paluma Dam & Burdekin Haughton Water Supply Scheme (BHWSS).
2. Paluma Township & Northern suburbs – Serviced by Paluma Dam.
3. Cungulla – Serviced by the Giru Water Treatment plant from the Haughton River. (Independent stand Along System).

Townsville bulk water supply being the largest supply area is serviced primary via the Ross River Dam (RRD) with top up supply from Paluma Dam and emergency supply allocation from the Burdekin Haughton Water Supply Scheme (BHWSS).

2.2.1 Ross River Dam (RRD)

Ross River Dam is the largest of the Bulk water supply systems within the Townsville Council boundary and the primary source. It has a catchment of 750km^2 and a capacity of 233 187 ML. The council has an allocation of 75 000 ML/annum (Department of Energy and Water supply, 2014). The dam is located south west of the town centre (Figure 2.3) with a gravity feed to the Douglas water treatment plant.

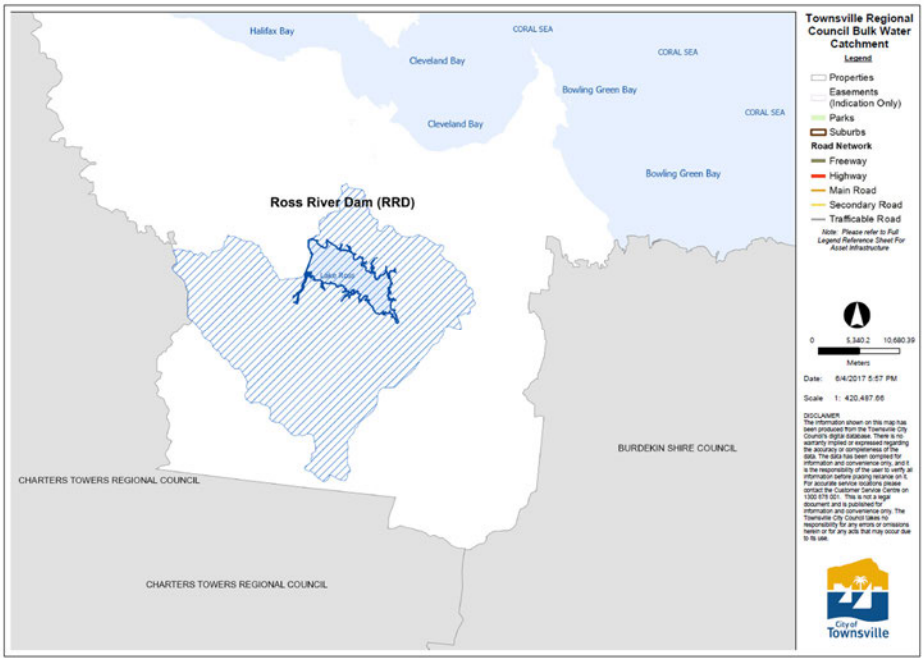


Figure 2.3 - Ross River Dam Catchment (Townsville City Council, 2017)

The topology of the dam is shallow and wide with the channel (Deep section) of the dam capable of total 20% capacity. The relationship of storage volume to water level (Hydrographic Survey) can be seen in Figure 2.4. Graphically it shows that depth and surface area are unfavourably disproportionate for surface and seepage losses.

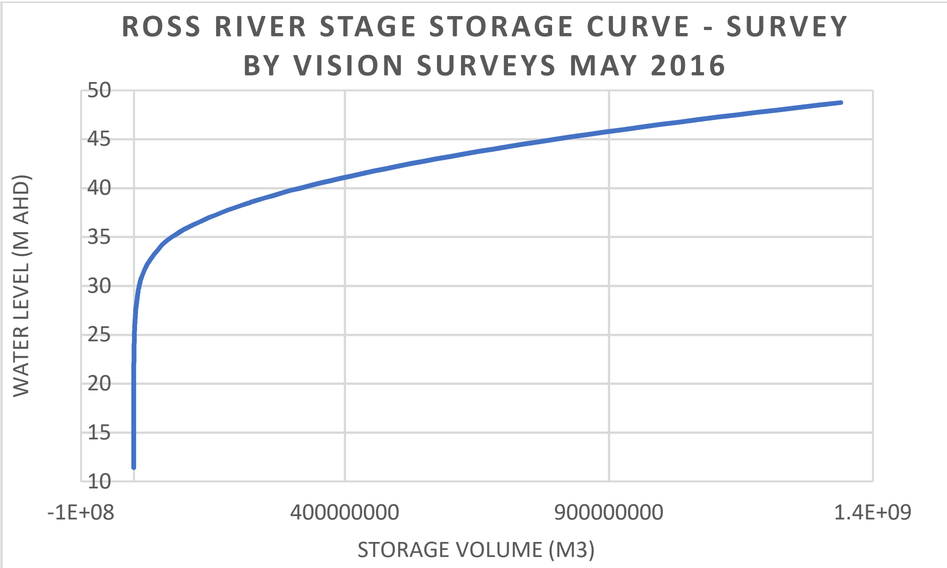


Figure 2.4 - Ross River Stage Storage Curve (Vision Surveys, 2016)

The BHWSS has previously published data in relation to seepage and evaporation losses that are used in water balance models for the region. This data is represented of both the Burdekin Dam and Ross River Dam given the vicinity and climate comparison of the two bulk water storage systems. Figure 2.5 - Evaporation and Seepage Losses is a tabulated form of the monthly loss values.

Month	Evaporation & Seepage Loss (mm/Month/m^2)
January	203
February	180
March	178
April	142
May	118
June	100
July	104
August	129
September	157
October	193
November	211
December	210

Figure 2.5 - Evaporation and Seepage Losses (Department of Environment and Resource Management, 2010)

2.2.2 Paluma Dam

Paluma Dam, is a significantly smaller bulk water source compared to Ross River Dam with a storage capacity of 11 400ML and a catchment area of 9.8km^2. this represents 4.9% of the Ross River Dam storage capacity for 1.2% of the catchment area of Paluma Dam. A more efficient bulk supply source but restrictive in total capacity. Townsville city council holds a 21 571 ML/annum entitlement to this system (Department of Energy and Water supply, 2014).

The Paluma bulk water supply system is treated at the Northern Water Treatment Plant and forms part of the service line for the northern reaches of the council. From a supply analysis point of view the Paluma Dam can be simplified and viewed as having a 31ML/day supply capacity.

2.2.3 Burdekin Haughton Water Supply Scheme (BHWSS)

The supplementary water supply from the Burdekin Haughton Water Supply Scheme (BHWSS) provides water security to the Townsville region during periods of extended drought. TCC owns 10 000ML/annum of High priority (HP) bulk water supply and has an agreement with Sun Water for 110 000 ML/annum of Medium priority (MP) bulk water supply until 2020 (Department of Energy and Water supply, 2014).

Townsville's BHWSS Bulk Water Supply Annual Allocation	
High Priority	10, 000 ML
Medium Priority	110, 000 ML

Table 2.1 - Townsville's BHWSS Bulk Water Supply Annual Allocation

The BHWSS has a total allocation of 99 998 ML HP bulk water and 979 594 ML of MP Bulk water. Currently there is 44 000 ML of uncommitted HP and MP bulk water owned by Sun Water. This unallocated water is available for lease (Department of Energy and Water supply, 2014).

The water allocation from the BHWSS is pumped from the Haughton Balancing Storage via the Haughton pipeline and discharged into the upper catchments of the Ross River Dam at Toonpan Creek. The water supplied is then stream fed through 16km of natural streams until it reaches the storage area of Ross River Dam. A 30% loss due to evaporation and seepage during this stream flow is estimated to occur. Existing studies of this evaporation have concluded that a new Water Purification Plant at Toonpan would resolve the natural stream flow loss. (Townsville City Council, 2012). The treatment plant at Toonpan would treat the water and directly supply Townsville Reserviors eliminating the environmental losses altogether.

The BHWSS pipeline and pumping system is currently capable of supplying 130ML/day. The Council also has planned to increase the supply capacity to 328ML/day through the Haughton Pipeline Duplication project sent to commence in 2019 with a 3-year build time. (Townsville City Council, 2016). The Current pumping cost has previously been reported as $27 000/day (Rooney, 2016). The cost equates to $208/ML un evaporated cost (130ML) or $297/ML evaporated cost (91ML 30% Evaporation).

The Trigger point for pumping has previously been set to 10% total Ross River Dam volume but in recent years has been altered to 20% total Ross River Dam volume. The low percentage Ross River Dam trigger value is a water conservation meassure. If pumping is triggered any earlier, the bulk water will be distributed to the wide shollow portion of the Ross Dam where it will experience major losses through evaporation and seepage. Pumping any earlier will result in longer pumping periods and wastefull management practices.

2.3 Townsville Water Usage

2.3.1 Water Usage and major areas of consumption

The 3 key areas of water usage for any bulk water system are; Agriculture, Urban & Industry/Mining. The Townsville bulk water supply system currently does not support major Agriculture and in previous modelling has been an exclusion. Industry/Mining accounts for 17ML/Day (6200ML/Annum). Which leaves the remaining allocation for Urban Residential use. Townsville residents water usage is a function of rainfall and varies dependant on annual precipitation. The lower the annual rainfall the higher the consumption rate (Figure 2.6). This function is attributed to additional water being used on gardens and lawns to substitute the lack of rain. It has also been reported that more than 70% of Townsville Urban water usage is currently being supplied for Garden and Lawn use (Townsville City Council, n.d.). Previous modelling of the bulk water supply system has used an average liters per person per day of 745L/c/day (51666ML/Annum at 190 000ppl) (Department of Energy and Water supply, 2014) or 88% of the bulk water supply capacity.

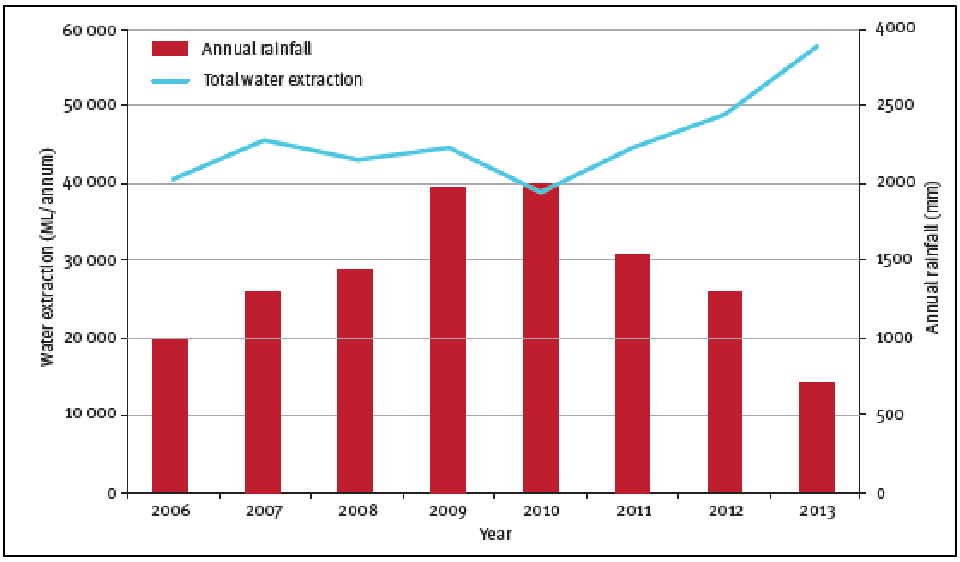


Figure 2.6 - Rainfall vs Water Extraction (Department of Energy and Water supply, 2014)

745L/c/day has been reported as being among the highest residential water demand in the country (Townsville City Council, n.d.) (Figure 2.7). Townsville City Council has provided a level 3 water restriction comparison for 3 major centres (Mackay, Brisbane & Melbourne) (Figure 2.7). Notable, the Townsville demand is nearly double that of the state capital (Brisbane).

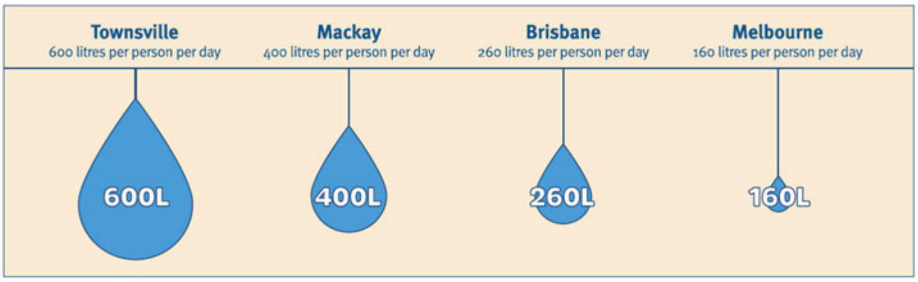


Figure 2.7 - Level 3 Water Comparison (Townsville City Council, n.d.)

Townsville in recent years has played host to the Yabulu Nickle Refinery which is a high water demanding industrial plant. The water used in the refining processes is secured through the Black River sub-artesian lease via 30 bore pumps. The refinery although not currently in operation still maintains the rights to this water source up to the year 2111 (Raggatt, 2016). This water is a standalone system and has no impact on Townsville water supply capacity. Its only restriction is on the Black River residents who are unable to access bore pumping, however this potential demand relief on the system is negligible.

2.3.2 Level of Service (LOS)

The Level of service (LOS) is the criteria used to establish:

- How much water the bulk supply system will be required to supply.
- How often and for how long water restrictions might occur.
- The possibility of needing an emergency water supply due to a prolonged drought.

The Department of Energy and Water Supply (DEWS) encourages local councils outside south-east Queensland (SEQ) to develop their own LOS objectives (Department of Energy and Water Supply, 2016). The Townsville City Council has developed the following LOS:

- Level 3 restriction not to occur more frequent than 1 in 10 year time period (10% of the time), for a duration of no longer than 2 months. Which translates roughly to 2:120 months or 1.7% of the time.

- Level 4 restrictions are not to occur more frequent than 1 in 25 year time period (4% of the time), for a duration no longer than 4 months. Which translates roughly to 4:300 months or 1.3% of the time.

Given that this LOS requirements can be amended from region to region it is not a great tool for assessing a system capability in conjunction with another system capability. The control over the level of service and management can have a major cost implication to the end users and shall be established with due consideration.

2.3.3 Water Restriction

Water restrictions for the Townsville service area are tiered into 4 levels and are presented in Figure 2.8, Figure 2.9, Figure 2.10, Figure 2.11 below for reference to the reader.

LEVEL 1 WATER RESTRICTIONS	**Residential, rural and commercial lawns and gardens** ***(including school grounds/gardens)*** » Sprinklers only to be used between 5am to 7am and 6pm to 8pm (odd and evens system applies) » Handheld watering at any time on any day **Even houses** – Tuesday and Saturday **Odd houses** – Wednesday and Sunday
	Council » 14% reduction in irrigation
	Sports fields (including school sports fields) » Sprinklers only to e used 5-7am and 6-8pm » Handheld watering any time
	Commercial nurseries and market gardens » No watering between 9am and 4pm watering outside of that time by: - Water efficient sprinkler - Handheld trigger or twist nozzle - Irrigation systems - Watering can or bucket
	Washing vehicles and boats (other than flushing boat motors) » No restriction **Washing hard surfaces** » No restriction

Figure 2.8 - Townsville Level 1 water restrictions (Townsville City Council, 2017)

LEVEL 2 WATER RESTRICTIONS	**Residential, rural and commercial lawns and gardens** ***(including school grounds/gardens)*** » Sprinklers only to be used 6pm to 8pm (odd and evens system applies) » Handheld watering at any time on any day **Even houses:** Tuesday and Saturday **Odd houses:** Wednesday and Sunday
	Council » 24% reduction in irrigation » No watering between 9am and 4pm
	Sports fields (including school sports fields) » Sprinklers only to be used 6pm-8pm » Handheld watering any time
	Commercial nurseries and market gardens » No watering between 9am and 4pm. Watering outside of that time by: - Water efficient sprinkler - Handheld trigger or twist nozzle - Irrigation systems - Watering can or bucket
	Washing vehicles and boats (other than flushing boat motors) » Bucket or water efficient car wash **Washing hard surfaces** » Pressure washers only

Figure 2.9 - Townsville Level 2 water restrictions (Townsville City Council, 2017)

LEVEL 3 WATER RESTRICTIONS	**Residential, rural and commercial lawns and gardens** ***(including school grounds/gardens)*** » Sprinklers not to be used » Handheld watering 6-7am & 6-7pm only (odds and evens system applies) **Even houses:** Tuesday and Saturday **Odd houses:** Wednesday and Sunday
	Council » 44% reduction in irrigation » No watering between 9am and 4pm
	Sports fields (including school sports fields) » No sprinklers to be used » Handheld watering - odds and evens system applies
	Commercial nurseries and market gardens » No watering between 9am and 4pm. Watering outside that time by: - Water efficient sprinkler - Handheld trigger or twist nozzle - Irrigation systems - Watering can or bucket
	Washing vehicles and boats (other than flushing boat motors) » Bucket or water efficient car wash **Washing hard surfaces** » Not permitted

Figure 2.10 - Townsville Level 3 water restrictions (Townsville City Council, 2017)

LEVEL 4 WATER RESTRICTIONS	**Residential, rural and commercial lawns and gardens** **(including school grounds/gardens)** » Sprinklers not to be used » No handheld watering allowed » Watering cans and buckets only (odds and evens system applies) **Even houses:** Tuesday and Saturday **Odd houses:** Wednesday and Sunday
	Council » 84% reduction in irrigation » No watering between 9am and 4pm
	Sports fields (including school sports fields) » No watering permitted
	Commercial nurseries and market gardens » No watering between 9am and 4pm. Watering outside of that time by: - Irrigation system - Watering can or bucket
	Washing vehicles and boats (other than flushing boat motors) » Water efficient car wash only **Washing hard surfaces** » Not permitted

Figure 2.11 - Townsville Level 4 water restrictions (Townsville City Council, 2017)

The triggers associated with Ross River Dam % (Table 2.2) total Volume and Operation Conditions (Table 2.3).

Restriction level	***Ross Dam Level***
Level 1	40%
Level 2	30%
Level 3	20%
Level 4	10%

Table 2.2 – Townsville Water Supply Drought Based Restrictions (Townsville City Council, 2015)

Restriction Level	***Restriction Condition***
Level 2	Average daily consumption approaching maximum production
Level 3	Average daily consumption equals maximum production
Level 4	Average daily consumption exceeds maximum production OR an emergency situation exists

Table 2.3 - Townsville Water Supply Operational Restrictions (Townsville City Council, 2015)

Restrictions for the Paluma Township service area also works on a 4-tier draught based restriction triggering system (Table 2.4).

Restriction Level	***Restriction Condition***
Level 1	Weir level takes >2 hours to recover after pumping
Level 2	Weir level takes > 4 hours to recover after pumping
Level 3	Water level is below the weir for > 1 day
Level 4	Trucking Water has commenced

Table 2.4 - Paluma Township Drought Based Restrictions (Townsville City Council, 2015)

Cungulla Township restrictions are both Drought (Table 2.5) and Operation based (Table 2.6)

Restriction Level	***Restriction Condition***
Level 2	Consumption approaching quarterly allocation
Level 3	Quarterly Allocation exceeded
Level 4	Risk of exceeding annual allocation

Table 2.5 - Cungulla Township Drought Based Restrictions (Department of Energy and Water supply, 2014)

Restriction Level	***Restriction Condition***
Level 2	Consumption = Plant capacity
Level 3	Consumption > Plant Capacity
Level 4	Trucking Water has commenced

Table 2.6 - Cungulla Township Operational Restrictions (Department of Energy and Water supply, 2014)

Townsville City Council has reported the expected percentage reduction in residential water usage based on the restrictions to be as per Table 2.7 (Townsville City Council, 2015).

Restriction Level	***Percentage Water Usage Reduction***
Level 1	0 %
Level 2	10 %
Level 3	17%
Level 4	25%

Table 2.7 - Residential Water Reduction (%)

In 2014 the BHWSS pumping trigger was set to 10% of Ross River Dam which lined up with Level 4 water restrictions. The Regional water supply council conducted a report and one of the outcomes was a recommendation to change the trigger to 20% of the Ross River Dam and line up with Level 3 restrictions (Department of Energy and Water supply, 2014).

A plot of the historic dam percentage (%) as recorded by BOM initially and Townsville City Council continuing is presented in Figure 2.12. The years of 1987 & 1995 show extended periods of essentially 0% full. This is due to no recorded data for this time. Graphically the plot generally shows a cyclic history of full and empty dam which is representative of the rain fall for the region as shown in Figure 2.13.

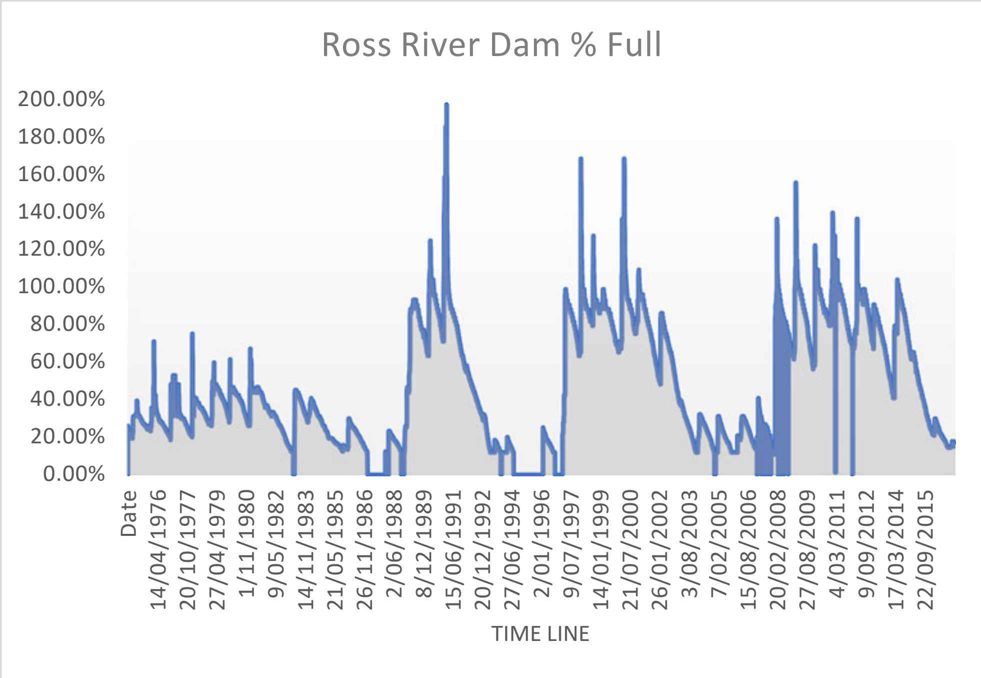


Figure 2.12 - Ross River Dam % Full

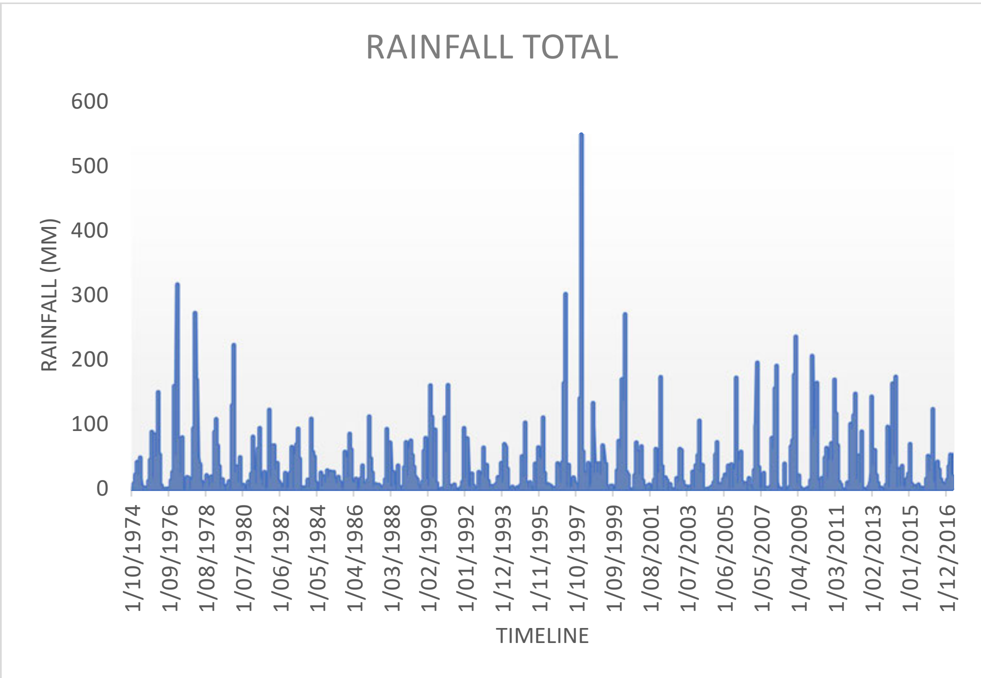


Figure 2.13 - Ross River Dam Rainfall

2.3.4 Water payment scheme and the associated issues

There are two water pricing schemes available for Townsville residential water consumers. A “Standard Plan” and a “Water Watcher Plan”. For all non-residential users, there is only one option. (Table 2.8)

	Standard Plan	***Water Watcher Plan***	***Non-Residential***
Fixed Annual Access Fee	$739/yr.	$337/yr.	$351/yr.
Water Allocation	772kL/yr.	N/A	N/A
Excess Water Charge	$2.83/kL	N/A	N/A
Water Consumption Charge	N/A	$1.35/kL	$2.76

Table 2.8 - Townsville Water Pricing Schemes (Townsville City Council, 2016)

The respective plans have been plotted (Figure 2.14Figure 2.14) to show graphically how they compare Cost vs Usage. Initially for residential consumers up to approximately 300kL (820L/day) the Water Watcher plan is the cheaper option. At which point here after the standard plan is cheaper up to approximately 1200kL (3287L/day) where it flips back in favour of the Water Watcher. Non-residential users are devoid of options and are expected to pay the most for water.

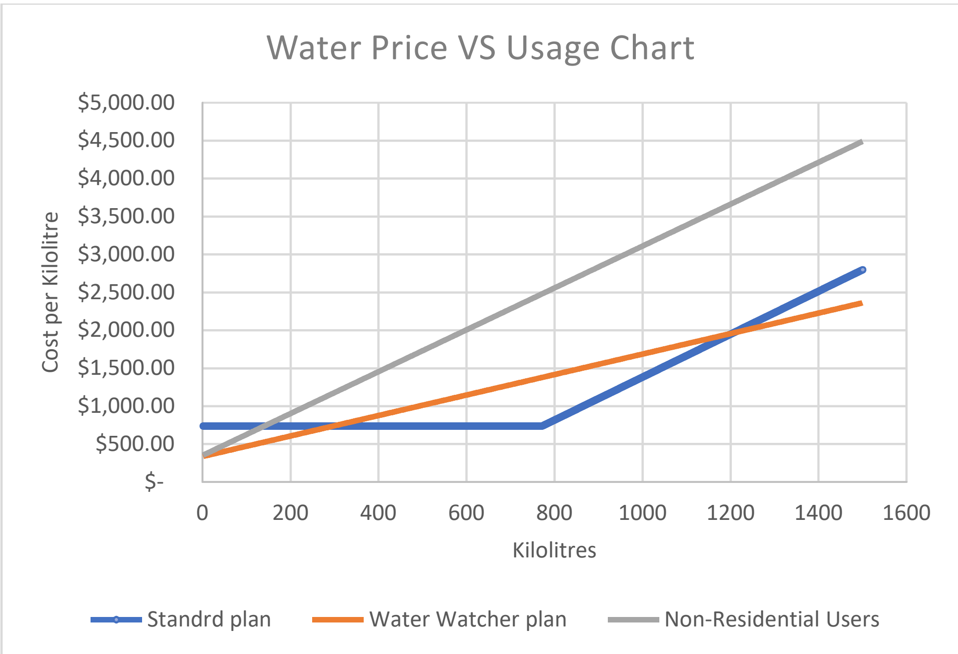


Figure 2.14 - Water Price vs Usage Chart

With an average house hold consisting of 2.6 people and the allocated 745L/c/day, If the annual design allocation is used (707kL/annum) it is cheaper to use the standard plan. This indicates limited finacial based incentive for water conscious living. For a single resident with the same annual allocation but a reduced consumption rate (272kL/annum) the Water Watcher plan is cheaper.

2.4 Townsville Water Treatment Plants
(Effluent water re-use source)

Townsville City has 6 waste water treatment plants. Two (2) of which are located on Magnetic Island with the remaining four (4) on the main land.

2.4.1 Cleveland Bay Water Purification Plant (CBWPP)

Cleveland Bay water purification plant was established in 1988 and upgraded in 2006. By volume this treatment plant has the largest water treatment capacity.

Cleveland Bay Water Purification Plant - Statistics	
Population Service	126, 000 ppl
Current Treatment Volume	25.23 ML/day
Total Treatment Capacity	29 ML/day
Colinta Livestock watering (Average)	0.16 ML/day
On-site reuse (Average)	1.92 ML/day
Effluent Discharge (Average)	23.15 ML/day

Table 2.9 - Cleveland Bay Water Purification Plant – Statistics

Currently this site has very limited re-use of effluent being employed. This is due to high electroconductivity in the effluent (salinity). Infiltration inflow from low lying suburbs in Townsville (South Townsville, Oonoonba & some parts of Fairfield Waters) are the cause. The plant on average has an electroconductivity of 1636 µS/cm. Whilst the plant discharges the effluent back into the ocean there is no further treatment of the salt water required. If effluent re-use is to be considered for potable or non-potable reuse additional energy absorbent process like Reverse Osmosis (RO) will need to be employed to remove or limit the large amounts of salinity in the water. It could be argued that the benefit of treating effluent is outweighed by the benefit of treating ocean water which is locally abundant as Townsville is a coastal city.

2.4.2 Condon Water Purification Plant (CWPP)

Condon water purification plant was constructed in 1986 and upgrade in 1994 where the operation capacity was doubled. This particular plant is the third largest mainland plant.

Condon Water Purification Plant - Statistics	
Population Service	22, 000 ppl
Current Treatment Volume	4.17 ML/day
Total Treatment Capacity	5 ML/day
Townsville Golf Course Effluent use (Average)	1.45 ML/day
On-site reuse (Average)	0.02 ML/day
Effluent Discharge (Average)	2.70 ML/day

Table 2.10 - Condon Water Purification Plant – Statistics

Effluent re-use is already being used from this site with Townsville Golf course being the main beneficiary accepting the effluent as irrigation for the greens and fairways. Some effluent is used on site whilst the majority of it is discharged into the Bohle River.

2.4.3 Toomulla Water Purification Plant (TWPP)

Toomulla Water purification plant is the smallest mainland water treatment plant servicing an isolated portion of the community in the Toomulla suburb.

Toomulla Water Purification Plant - Statistics	
Population Service	160 ppl
Current Treatment Volume	0.04 ML/day
Total Treatment Capacity	0.1035 ML/day
Effluent Discharge (Average)	0.04 ML/day

Table 2.11 - Toomulla Water Purification Plant – Statistics

The low service volume of effluent is discharged to evaporation ponds most of the time, with the exception of high rainfall periods where the overflow is discharged to a nearby creek. Currently no effluent re-use has been considered as the volumes are too small to be considered.

2.4.4 Mount St Johns Wastewater Treatment Plant (MSJTP)

Mount St. Johns Wastewater Treatment Plant is the second largest plant by current treatment volumes. This plant was commissioned in 1972 and upgraded in 2011. MSJTP is Townsville's oldest wastewater treatment plant.

Mount St. Johns Wastewater Treatment Plant - Statistics	
Population Service	106, 000 ppl
Current Treatment Volume	16 ML/day
Total Treatment Capacity	25 ML/day
Rowes Bay Golf Course Effluent use (Average)	2.08 ML/day
On-site reuse (Average)	1.76 ML/day
DAF reuse (Average)	3.84 ML/day
Effluent Discharge (Average)	8.32 ML/day

Table 2.12 - Mount St. Johns Wastewater Treatment Plant – Statistics

The re-use strategy for the effluent of this plant has 50% usage rate. The highest of the four mainland wastewater treatment plants. The strategy includes Rowes Bay golf course irrigation, On-site reuse and Defence and Airforce (DAF) reuse at the adjacent airfields. The remaining effluent is discharged into Snaggy creek which flows into the Bohle River and out to the ocean.

2.4.5 Magnetic Island Water Recycling Facility (MIWRF)

Magnetic Island water recycling plant was established in 2002 and upgraded in 2006. It is thought to treat the largest volume of waste water of the two island based plants however the reuse volumes have not been able to be sourced. (Townsville City Concil, n.d.)

Magnetic Island Water Recycling Facility - Statistics	
Population Service	1,260 ppl
Current Treatment Volume	0.34 ML/day
Total Treatment Capacity	0.54 ML/day
Magnetic Island Golf Course Effluent use (Average)	Unknown
On-site reuse (Average)	Unknown
Effluent Discharge (Average)	Unknown

Table 2.13 - Magnetic Island Water Recycling Facility - Statistics

Effluent re-use is currently employed in picnic bay where effluent is discharged onto the golf course for green keeping. Onsite re-use is also actively used. Any surplus effluent is distributed into adjacent wetlands.

2.4.6 Horseshoe Bay Water Recycling Facility

Horseshoe Bay is the smallest of the Island based plants that only services the Horseshoe Bay community. The plant was commissioned in 2006 with a 100% reuse of waste water capacity. Once again actual volumes have not been reported or recorded. (Townsville City Concil, n.d.)

Horseshoe Bay Water Recycling Facility - Statistics	
Population Service	700 ppl
Current Treatment Volume	0.145 ML/day
Total Treatment Capacity	0.643 ML/day
Dry Tropics Irrigation (Average)	Unknown
Sports Field Irrigation (Average)	Unknown
On-site reuse (Average)	Unknown
Effluent Groundwater Infiltration (Average)	Unknown

Table 2.14 -Horseshoe Bay Water Recycling Facility - Statistics

Currently the re-use of the effluent water is mainly irrigation of reserves and sporting grounds. Although this is the case the volumes available are low.

2.4.7 Townsville Effluent Reuse Summary

Whilst most of the residential waste water is treated in the 6 waste water treatment plants across the town, not all catchments are serviced by a sewage system. Some outer reach suburbs have individual onsite septic systems employed.

It can be said, "Across the Townsville water treatment board, there is an effluent reuse strategy in place". Most of the current applications are in the form of irrigation. Nevertheless, the utilisation rate is not at a 100%. This suggests further reuse potential of effluent water.

In addition to the volumetric effluent potential, the Integrated Water Supply Strategy (IWSS) had previously identified Effluent reuse as a non-effective solution for providing addition water security, but may be worthy of more consideration once the 1st stage of the Toonpan Treatment plant is installed (Townsville City Council, 2012).

Total Mainland Water Recycling - Statistics	
Population Service	254160 ppl
Current Treatment Volume	45.44 ML/day
Total Treatment Capacity	59.1035 ML/day
Reuse (Average)	11.23 ML/day
Effluent Discharge (Average)	34.21 ML/day
Effluent Discharge – Excluding CBWPP (Average)	11.06 ML/day
Effluent Discharge Capacity – Excluding CBWPP (Average)	30.1035 ML/day

Table 2.15 -Total Mainland Water Recycling – Statistics

The exclusion of Cleveland bay water purification plant (CBWPP) volumes is to ascertain the volume of effluent viable for reuse. CBWTP volumes may be considered if measure can be undertaken to reduce the salinity of the effluent.

Total Magnetic Water Recycling - Statistics	
Population Service	1950 ppl
Current Treatment Volume	0.485 ML/day
Total Treatment Capacity	1.183 ML/day
Reuse (Average)	Unknown
Effluent Discharge (Average)	Unknown

Table 2.16 - Total Magnetic Water Recycling – Statistics

Low treatment volumes and high utilisation rates of Magnetic Island effluent indicate that the further effluent reuse is not an option from these sources.

2.5 General Review of Effluent Water Reuse

2.5.1 Effluent Water

Effluent (Flowing out, (University, 2004)) water is the final liquid product of a waste water treatment process that is discharged back to the environment. At this point in the water treatment process it is the discharge license holder's responsibility to meet the defined treatment standards for discharge. The key indicators are: BOD_5 (Biochemical Oxygen Demand), Suspended solids, Nitrogen, Ammonia, Phosphorus, Dissolved Oxygen and Faecal Coliform. Each of these parameters are used to assess, monitor and achieve environmental standards and limit the impact on the natural habitat.

2.5.2 Townsville Effluent Water Discharge and Standard

The standard adopted for Townsville's four (4) mainland waste water treatment plants are list in (Table 2.17 - Townsville Effluent Water Release Standard). Whilst in most cases it is reported that this standard is achieved, for a design consideration in the future the worst scenario (Minimum/Maximum) needs to be considered.

Townsville Effluent Water Release Standard				
	Treatment plant abbreviate names			
Quality Characteristic	CBWPP	MSJTP	CWWTP	TWPP
BOD_5 (mg/L)	20	20	45	45
Total Suspended Sloid (mg/L)	30	30	60	60
Total Nitrogen (mg/L as N)	15	15	-	-
Ammonia (mg/L as N)	3	3	-	-
Total Phosphorus (mg/L as P)	3	3	-	-
PH (PH Units)	6.5 - 8.5	6.5 – 8.5	6.5 – 8.5	6.5 – 8.5
Min Dissolved Oxygen (mg/L)	2.0	2.0	2.0	2.0
Mean Faecal Coliform (cfu/100mL)	1000	1000	1000	1000
max Faecal Coliform (cfu/100mL)	4000	4000	4000	4000

Table 2.17 - Townsville Effluent Water Release Standard (Stevenson, 2016)

From Table 2.17 above, notably both Condon and Toomulla have no Nitrogen, Ammonia or Phosphorus standard. This is due to neither of the plants having advanced water treatment capabilities. Markedly, both plants have a lower quality discharge standard for BOD_5 and Total Suspended Solids as well. Both plants service low volumes of influent which is likely the reason for the exclusion of the additional Advanced Waste Water Treatment infrastructure.

The two (2) main waste water treatment plants in Townsville (MSJTP & CBWPP) both have a higher discharge standard. This higher standard is a result of larger treated volumes and better plant equipment available. Industrial waste is treated at these plants.

2.5.3 Recycling Effluent

An illustration of the purified recycled water process is presented in Figure 2.15. It identifies the treatment barriers and potential uses at the hold point of each barrier. The barriers are defined by hold points in the water cycle that may or may not exist in a specific system. Effluent water is the discharge of varying standards between barrier 2 to 6. Townsville water treatment currently employs barriers 1 and 2 and is typical of regional coastal towns of Queensland.

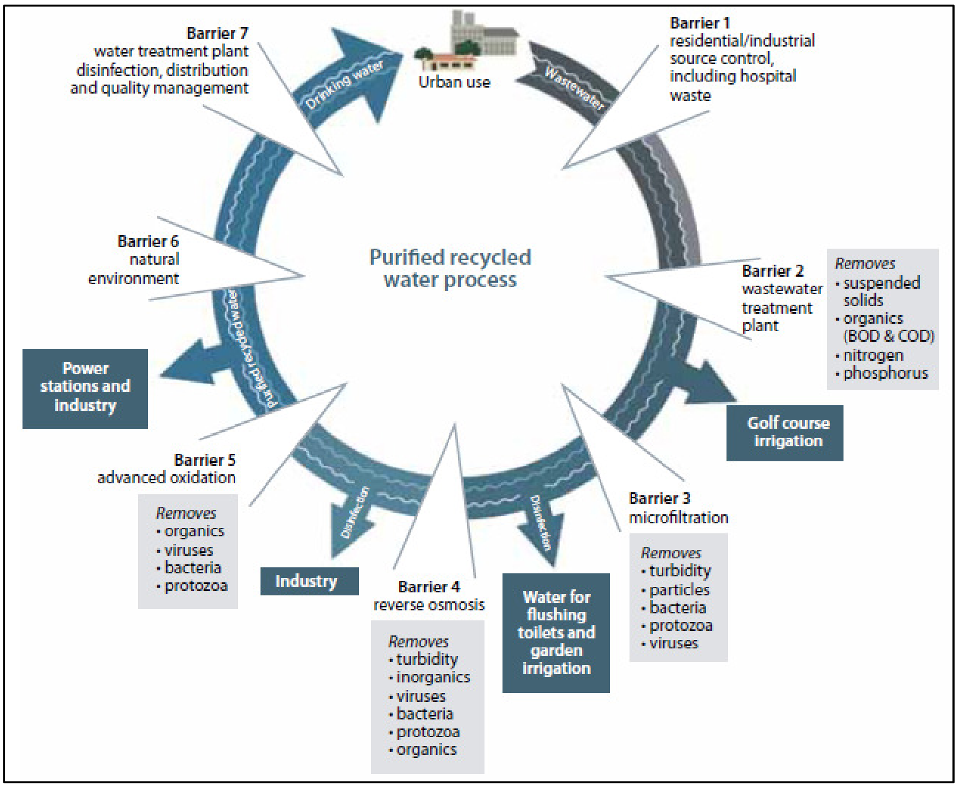


Figure 2.15 - Purified recycled water process (Khan, 2013)

Currently the Townsville water cycle is limited by Barrier 3. Traditional wastewater treatment with some golf course irrigation. In order for non-potable community effluent reuse to be considered a microfiltration process (Barrier 3) needs to be employed.

For Direct Potable Reuse Barrier 4,5 & 7 need to be employed and with the consideration of barrier 6 we would have Indirect Potable Reuse.

2.5.4 Effluent Reuse - Non-Potable Water

Non-potable effluent reuse schemes for public use are typically (but limited) in the form of a dual reticulation system where the water is used for gardens, toilet flushing and washing cars. This type of recycling scheme has previously been implemented in Australia with varying degrees of reported operation cost and in turn success. The system has two distict water supply lines and has in the past relied on developer initative or incentives to install the required piping infastructure.

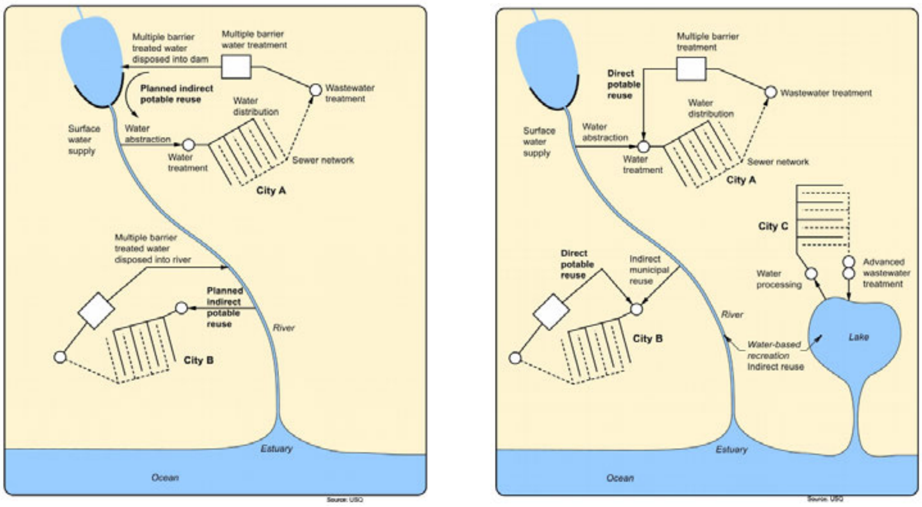
The main reported public concern (West, et al., 2015) is the cross contamination of effluent and potable water, though trial schemes have yeilded no public safety issues.

It was also suggested (West, et al., 2015) that the schemes that had been implimented had all experienced high operational cost and many had been condemend based on this paramater.

2.5.5 Effluent Reuse – Potable Water

Effluent water whilst treated to a high level for environmental discharge is not suitable for human consumption in its current state. The Effluent needs to be treated to a Potable standard as defined by (National Resource Management Ministerial Council, 2011) before it is fit for purpose. Though this standard of drinking water is achievable from the Effluent, Khan, 2013 suggested that these schemes have critical issues to overcome, namely public resistance & cost implications.

Currently in Australia there is no 'Planned *Direct* Potable Reuse' water schemes (Figure 2.16 - B). Althought there are instances of 'Planned *Indirect* Potable Reuse' water schemes (Figure 2.16 – A). The key difference being the effluent is "mixed" (Barrier 6) with nature surface water between the barriers 5 & 7. This mixing of the water has no chemical benefit but is reported by (Khan, 2013) as having a positive public perception and some dilution effect. Planned Direct Potable Reuse scheme are currently employed to many comunities within Australia.



(A) - Planned Indirect Potable Reuse (B) – Planned Direct Potable Reuse

Figure 2.16 - Potable Reuse Schemes (Aravinthan & Yoong, 2015)

2.5.6 Effluent Water Reuse Financial Considerations

The cost of bulk water supply for a community is ideally optimised to reduce the cost to the community. Effluent water as a bulk water source generally comes with a higher price tag for consumers when compared to dams as reported by (West, et al., 2015) With an average of $6 per kL more. Refer Figure 2.17.

Barrier Number	*Treatment*	*Operation Cost per kilolitre*	*Citation*
1	Source Control	$0.00	-
2	Wastewater treatment	Constant	-
3	Membrane Treatment	$0.18 - $1.5	(Water Research Foundation, 2016)
4	Reverse Osmosis	$0.2 - $1.76	(Water Research Foundation, 2016)
5	Advance Oxidation	$0.04 - $ 4.00	(Anon., n.d.)
6	Natural environment	$0.00	-
7	Water purification	Constant	TCC
Non-potabale total	1,2,3	$0.18 - $1.5	
Potable total	1,2,3,4,5,6,7	$0.42 - $7.26	

Table 2.18 - Waste Water Treatment $/Barrier

Note: US source obtained for $/kL conversion of 0.75 to Australian dollars has been used.

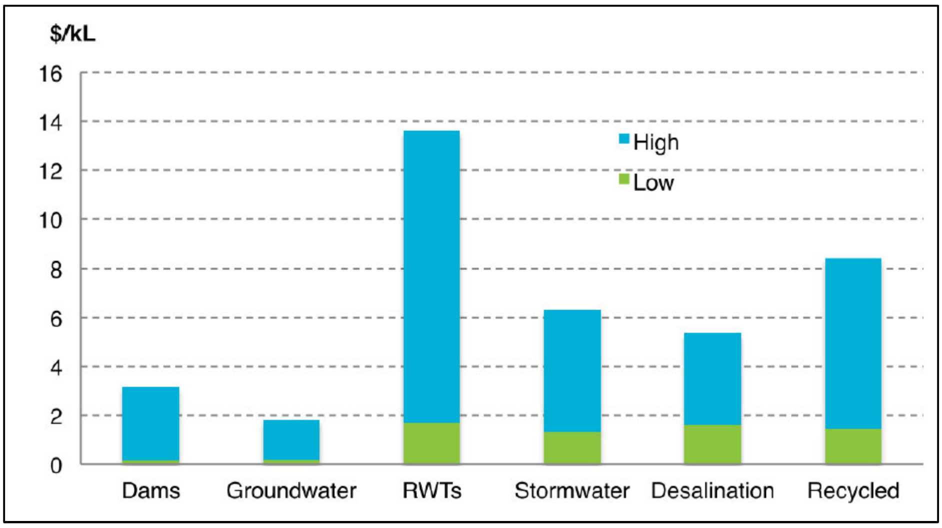


Figure 2.17 - Estimated Levelised cost of water supply ($2012) (West, et al., 2015)

The data presented in Figure 2.17 and Table 2.18 have been rationalised in Table 2.19 to show a relative cost comparison of BHWSS pumping and Effluent reuse treatment cost. This comparison excludes the cost of barrier 1, 2 & 7 as these costs are consistent across the Townsville water supply and treatment system irrespective of the source water. What can be derived from this comparison is that there is a cost benefit to Non-Potable Effluent water reuse when compared to pumping provided a highly efficient, low cost treatment process is employed.

	BHWSS Pumping ($/ML)	BHWSS Pumping, Toonpan Considered ($/ML)	Non-Potable Effluent Water Reuse ($/ML)	Potable Effluent Water Reuse ($/ML)	Recycled Water Estimates ($/ML)
Estimates/ Calculation	$208	$297	$180 - $1500	$420 - $7260	$1600 - $8900
Average	$208	$297	$840	$3840	$5250

Table 2.19 - Pumping & Effluent reuse ($/ML)

Whilst the cost of water is an obvious consideration it is not the only factor for the region. Supply capabilities and system resilience is also an area of consideration.

2.5.7 Effluent Water Reuse Social Considerations

It has been reported by West, et al., (2015) that the availability of unrestricted effluent non-potable water for use in greenspace has an aesthetic value to the public. Whilst seasonal potable water from dam sources may influence water restriciton, the volumes of Effluent will remain rather constant. This annomaly provides for a constant water supply during drought periods and has the ability to enhance public acceptance of such schemes.

Additional research by Nancarrow, et al., (2007) concluded that 74% of a survey population are accepting of 'Indirect Potable reuse' schemes, however the support lessens when environmental harm is a factor or sufficient surface water is available. Conclusion of these findings present some public educational restraints around the subject.

Whilst generally a high acceptance of effluent reuse scheme has been reported, a case study of the Toowoomba regional council water crisis provides a contrast to these statistics. Consultation with the Toowoomba community on the implementation of an Indirect potable reuse scheme resulted in the public rejection (Aravinthan & Yoong, 2015). Indicating that comminty engagement on region specific schemes is required to determine acceptance of any direct or indirect potable reuse proposals. Consumer choice was also reported by (Nancarrow, et al., 2007) as a social issue and appears to be evident in the case of Toowoomba as residents prefered to be on constant water restrictions.

2.5.8 Effluent Water Reuse Environmental Considerations

Environmentally, effluent reuse is beneficial in terms of discharge. Lower quality effluent entering the water course can result in higher quality ecosystems with better fish stock and bird life which ties back into the social benefits.

Potable & Non-Potable effluent re-use schemes previously implemented treat the effluent to a higher standard again from the discharge licence standard. In doing so a higher energy requirement is drawn upon to support the schemes Table 2.20.

Water Treatment Type	***Power Consumption (kilowatts per kilolitre)***
Potable Water	0.3 - 0.6
Effluent Reuse Schemes	1.1 – 1.8
Seawater (Desalination)	4.0 – 5.5

Table 2.20 - Water Treatment Power Usage (West, et al., 2015)

In terms of energy consumption, effluent re-use schemes are considerably more energy efficient then desalination schemes.

2.5.9 Effluent Water Potable Reuse – Global View

On the global scale potable effluent reuse schemes are implemented. Most of these schemes are implemented as a final resort when water supply cannot meet restricted demand.

- ❖ Japan recycles waste water because land is a premium and water catchment and storage areas take up too much of this precious commodity. (Radcliffe, 2004)

- ❖ Singapore is a small island city that has almost zero catchment. Singapore is reliant on water importation from Malaysia and has no independent water security. As a result, alterative water supply from waste water recycling and desalination are implemented. (Radcliffe, 2004)

- ❖ Namibia's capital city Windhoek has a Direct Potable reuse scheme currently in use. Low rainfall, high evaporation and limited catchment has seen the city exhaust the supply of surface water with a 500km radius. (Radcliffe, 2004)

- USA has a guideline for water reuse (The United States Environment Protection Guideline for Water Reuse) that provides guidance on water reuse. The document cites indirect potable reuse as a last resort option to be considered after all other water supply solutions are considered, that including non-potable reuse. (Radcliffe, 2004)

On inspection of the global water reuse as a scheme, it is seen that typically, any other measure available is preferred to that of potable reuses schemes. This being said it is still a considered water supply solution for communities.

2.5.10 Long Term Viability.

The Long-term viability of effluent water schemes have been previously reported by (West, et al., 2015) citing few public health impacts. The challenges surrounding the schemes are reported as; Politic, Economic, Social, Technical, Legal and Underlying all of these operational Financial impacts. Many of the schemes that have been implemented have been decommissioned as a result of one or more of the operational challenges.

This would suggest that long term viability has previously not been achieved and presents a major hurdle for the implementation of any future schemes in Australia.

2.6 Literature Summary

After consideration of the regional water supply and treatment system, several summaries can be drawn about the system and justify the undertaking of this work. Firstly, the water usage for the region is extremely high when compared to other regional centres. Secondly the supply and climate conditions are extreme and unrelenting. These two factors alone present some significant water supply challenges for the community in the future.

Thirdly, there is a volume of effluent water that is currently un used that is discharged back into the natural environment that could be sourced for an effluent reuse scheme. Whilst the volume of this effluent is low and the average cost of treating effluent is high there is a small window of viability for a low cost highly efficient non-potable effluent reuses scheme that is cost efficient when compared with pumping from the Burdekin dam.

Whilst the research objectives are partially answered with the initial consideration of low volumes of effluent water and high cost of effluent reuse schemes, the future community challenges surrounding the issue warrant a detailed consideration. Thus, the small window of viability is what the water balance modelling and dissertation reporting has focused on.

The key points identified have been representing in bullet point format for quick reference to the reader.

Demand Summary:

- Industry uses 17ML/day.
- Estimated current population (2017) 190000.
- Estimated future population (2030's) 300000.
- Average Daily Demand ADD is 745L/c/day.

Supply Summary:

- Ross River Dam storage capacity is 221,304 ML.
- The Paluma Dam storage capacity is 11,400 ML or 31ML/day.
- The BHWSS is trigger when Ross River Dam is at 20%.
- The BHWSS Current capacity is 130 ML/day.
- The BHWSS Future capacity is 328 ML/day.

Effluent Water Supply Summary:

- ❖ Average Effluent discharge free from salt water is 11.06 ML/day (Excluding CBWTP).
- ❖ Maximum serviceable population is 254160 people.
- ❖ Maximum Effluent water discharge 59.1035ML/day.
- ❖ Maximum Effluent water discharge free from salt water is 30.1035ML/day (Excluding CBWTP).

Water Cost Summary:

- ❖ The unevaporated cost of water pumping from the BHWSS is $208/ML.
- ❖ The average cost of non-potable water reuse is $840/ML.
- ❖ The average cost of potable water reuse is $3840/ML.

Viability Summary:

- ❖ Various viability issues surrounding effluent reuse schemes exists, however the underpinning primary issue is the long term operational cost.

The summaries drawn here are used in the water balance modelling aspect of the project which is developed fully in the proceeding chapter.

CHAPTER 3 METHODOLOGY

3.1 Methodology Introduction

The process of analysing the Townsville bulk water supply for the purpose of assessing the viability of an effluent reuses scheme can be broken down into six (6) key steps:

1. Develop a water balance model with the use of modelling software. (Excel) – (Chapter 4)
2. Validate the model. – (Chapter 4)
   (Compare historical data with modelled/ simulated data.)
3. Model base line scenarios
   (3 scenarios representative of 3 known conditions both future and current included.)
4. Model the effluent inclusion scenarios as various management practices.
5. Determine and compare cost implications of the various effluent management practices.
6. Assess the sensitivity of the modelling to present to the reader the model and in turn results reliability.

Water balance modelling is a numerical system of calculations and variables coupled together to express and predict various water storage scenarios. In this dissertation a water balance model is developed for the Townsville region to provide volumetric answers to the research objectives outlined in section 1.3.

Research objectives	
1	Can an Effluent water reuse scheme have a supply influence on the Townsville region water restrictions?
2	Can an Effluent water reuse scheme reduce the reliance on pumping from the Burdekin Dam?

System constants and variables are iterated to represent different effluent usage scenarios which provide the reader a complete picture of effluent reuse as a system inflow for Townsville.

3.2 Water Balance Model

The water balance model in summary has system constants and system variables. System constants do not change whereas system variable are used to run different scenarios. This water balance model has modelling capability to amend all of the system constants and use them as system variables. However, this project has adopted the model constants as per Table 3.1 - Water Balance Modelling Constants.

Water Balance Modelling Constants	
Paluma Dam Supply Capability	31 ML/day
Time Step	1 day
Ross River Dam Storage Capacity	221303.51 ML
Industry Usage	17 ML/day
Average Daily Demand (ADD)	745 L/c/day
BHWSS Pumping Trigger	20%
Level 1 water restrictions trigger	100%
Level 2 water restrictions trigger	40%
Level 3 water restrictions trigger	20%
Level 4 water restrictions trigger	10%
Level 1 water restrictions reduction	0%
Level 2 water restrictions reduction	10%
Level 3 water restrictions reduction	17%
Level 4 water restrictions reduction	25%
BHWSS Pumping Cost	$208/ML
Cost of Non-Potable Effluent water	$180/ML
January Evaporation & Seepage	203mm
February Evaporation & Seepage	180mm
March Evaporation & Seepage	178mm
April Evaporation & Seepage	142mm
May Evaporation & Seepage	118mm
June Evaporation & Seepage	100mm
July Evaporation & Seepage	104mm
August Evaporation & Seepage	129mm
September Evaporation & Seepage	157mm
October Evaporation & Seepage	193mm
November Evaporation & Seepage	211mm
December Evaporation & Seepage	210mm

Table 3.1 - Water Balance Modelling Constants

The water balance modelling variables for this project are as per Table 3.2 -Water Balance Modelling Variables. These modelling variables will be used to represent the various scenarios in varying combinations.

Water Balance Modelling Variables					
Variable Name	1	2	3	4	5
Population	190,000 ppl	300,000 ppl	-	-	-
BHWSS Capability	130 ML/day	328 ML/day	-	-	-
Effluent Supply Capability	11.06 ML/day	30.1035 ML/day	-	-	-
Effluent Trigger based on Ross River Dam Percentage	0%	20%	40%	60%	100%

Table 3.2 -Water Balance Modelling Variables

A full detailed explanation of the calculations and model functionality refer to CHAPTER 4.

3.3 Water Balance Scenarios

Scenarios that have been used in the modelling phase of this project are relative to three (3) baseline states:

Scenario 1: - The current (2017) water supply system.

Scenario 2: - The future (2017) water supply system with the BHWSS pipeline duplication.

Scenario 3: - The future (2030) water supply system with the BHWSS pipeline duplication and increased population.

	Population	BHWSS	Effluent Available
Scenario 1	190,000	130 ML/day	11.06 ML/day
Scenario 2	190,000	328 ML/day	11.06 ML/day
Scenario 3	300,000	328 ML/day	30.1035 ML/day

Table 3.3 – Scenario variables

These baseline scenarios set the major system variables that will stay relative as effluent trigger percentages increase. The results section presents the reader with volumetric outputs

Scenario explanation and representation:

Scenario 1:
The first of three considered scenarios represent the Townsville water supply in its current state as of 2017. The current system supports 190,000 people and has a backup water supply from the BHWSS of 130ML/day capability. The current volume of effluent water available for reuse is 11.06 ML/day.

Scenario 2:
Townsville has a planned project for a BHWSS pipeline duplication. Scenario two represents the current population of 190,000 people with the increase BHWSS capability of 328ML/day. This scenario also has 11.06 ML/day of available effluent water for reuse.

Scenario 3:
The final scenario is representative of future projected population growth. By the year 2030 the serviceable population of Townsville is expected to reach 300,000 people. This population will be supported by the upgraded BHWSS pipeline supply of 328ML/day. Considering the population growth it is considerable to expect the amount of available effluent to increase. For this scenario 30.1035 ML/day of effluent is considered for reuse.

Each of the three (3) baseline scenarios are run as a starting point for and then rerun with different triggers for effluent (20%, 40%, 60%, 100%)

3.4 Sensitivity

Sensitivity is a modelling test used to provide the reader with a level of model reliability. In many modelling aspects assumptions and educated guesses may be used to represent a given situation. However, the human factor involved with assumptions of modelling nature have an inevitable degree of unpredictability. This section of the project presents the primary modelling inputs of sensitive nature and test the reliability of the model to build a degree of confidence and an understanding of the limitations. The key indicator for model sensitivity is the number of BHWSS pumping days, with all three (3) sensitivity test in Table 3.4 run for base line scenario 1.

Sensitivity test number	Sensitivity	Value used	Range	Percentage Change
1	Average Daily Demand ADD	745 L/c/day	+/- 100 L/c/day	13.4%
2	Level 2 water restriction percentage reduction	10 %	+/- 5%	50%
3	Level 3 water restriction percentage reduction	17 %	+/- 5%	29%

Table 3.4 - Sensitivity Test

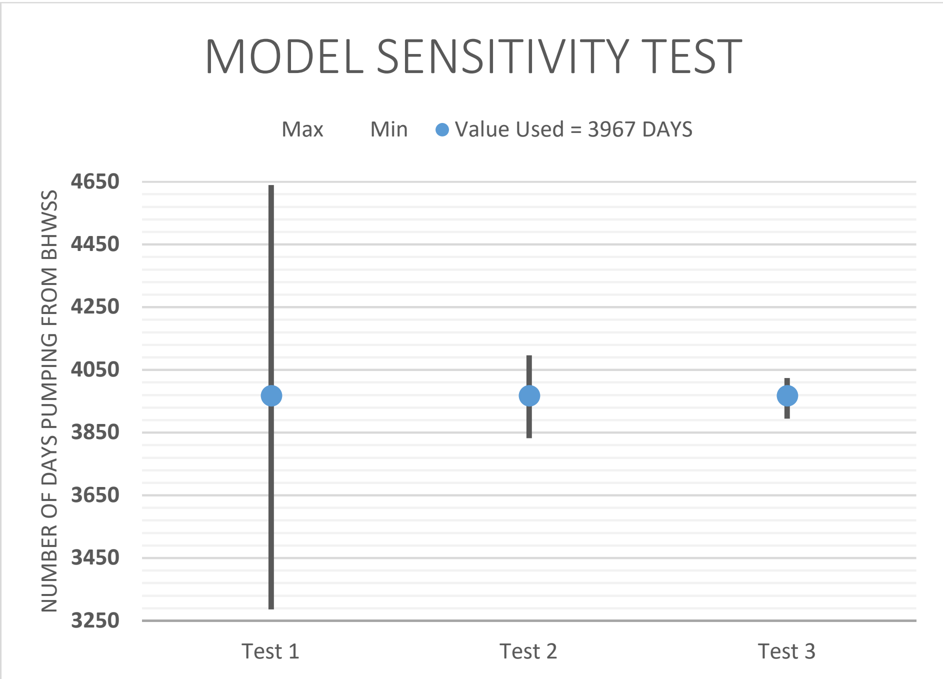


Figure 3.1 - Water Balance Model Sensitivity Test

Sensitivity test number	Max days	Min days	Modelling value
1	4640	3286	3967
2	4096	3832	3967
3	4024	3894	3967

Table 3.5 - Sensitivity Results

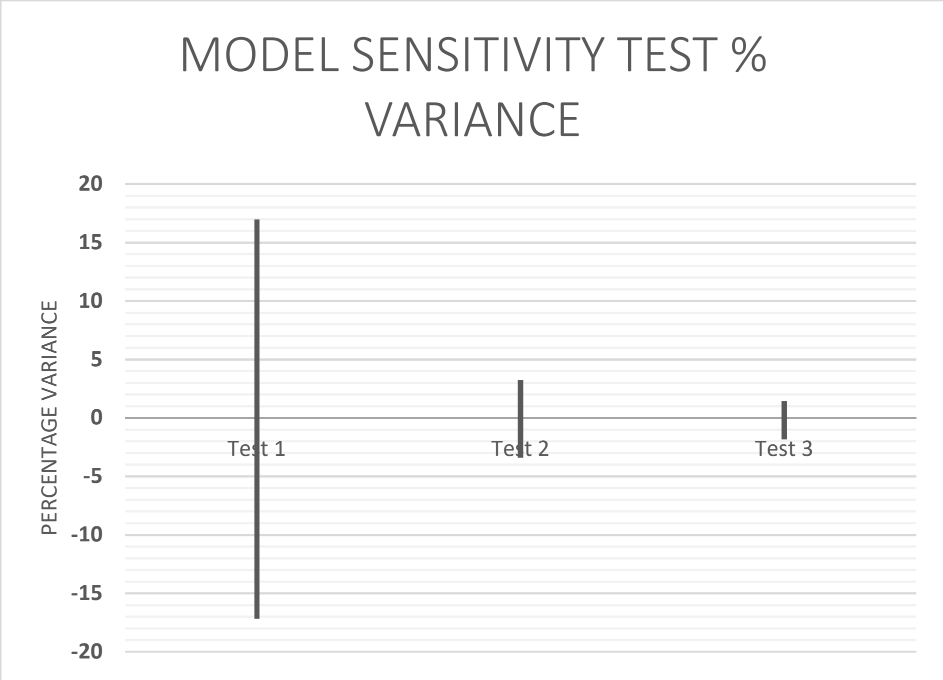


Figure 3.2 - Model Sensitivity Percent Variance

Sensitivity test number	Min % Variance	Max % Variance
1	-17.17 %	+16.96 %
2	-3.40 %	3.25 %
3	-1.84 %	1.44 %

Table 3.6 - Model Variance percentage results

Sensitivity Summary statements:

- ❖ Test 1, tested a +/- percentage range of 13.4 % and returned a variance of approximately +/-17%. Suggesting that the model is sensitive to Average Daily Demand (ADD).

- ❖ Test 2, tested a +/- percentage range of 50% and returned and variance of approximately +/-3.3%. Suggesting that the model is not sensitive to level 2 demand percentage reduction.

- ❖ Test 3, tested a +/- percentage range of 29% and returned and variance of approximately +/-1.6%. Suggesting that the model is not sensitive to level 3 demand percentage reduction.

CHAPTER 4 MODEL DEVELOPMENT

4.1 Water Balance Model Introduction

Water balance modelling in its purest form is a simple summation of inflow and outflow iteratively over a period. Specifically, the water balance model developed as part of this project for the Ross River Dam has been developed for approximately a 42.5-year period or 15,503 iterations.

A high-quality water balance model will have a high number of iterations. Just as a low-quality water balance model with have a low number of iterations.

4.2 Water Balance Model Platform

There are many water balance modelling software products available that are widely used in practice; Music, ewater Source & even MATLab. The modelling platform chosen for this project is Microsoft Excel. Excel is simple to use with inbuilt functions and graphing tools which make data representation user and reader friendly.

4.3 Water Balance Model Inflow Data

Inflow data for this water balance model comprises of four (4) separate sources:

1. Primary data set, Ross River Dam catchment.
2. Paluma dam simplification of daily inflow 31ML/day.
3. BHWSS 130ML/day & 328ML/day.
4. Effluent Reuse 11.06ML/day & 30.1035ML/day.

The primary data set used for this model was historical dam Level/Percentage/Volume data as provided by Townsville City Council. This data set comprises both gauging station data (118104A – Ross Dam) and Townsville City Council recordings. The gauging station data runs from 09/10/1974 to 01/08/2007 at which point Townsville city council readings take over and run up to 22/03/2017. This data was received from Townsville City Council as a complete data set for the entire period 09/10/1974 to 22/03/2017.

The data received was then used to extract inflow volumes by looking at daily changes in dam level. In most cases the volume changes extracted were up 2 weeks separation which does present some level of inaccuracy. However given that this model is a bulk storage model the data is sufficient for the precision required.

Evaluation of the extract volumes presented additional issues with gaps in the history. For the most part the gaps in readings were less than 2 weeks which aligns with the volumes change calculations but some larger month to year length gaps exist.

4.3.1 Data Treatment & Estimation

The gaps in the data require intervention and estimation to compile a complete data set for the entire 42.5 year period. Without a complete data set the quality of the modelling will be low with only a short period of time being continuously assessable. Thus, there must be some form of data estimation. Ensuring that a scientific approach was some estimation criteria need to be established:

Criteria Number	Missing Data Range	Treatment
1	Less than 2 weeks	Estimation from each side of the period
2	Greater than 2 weeks	Historical transposing

Criteria Number 1:

When a data set was missing for a period less the 2 weeks the volumes were reviewed on each side of the gap and an estimation was made based on the change. If the dam volume was presenting a decreasing trend on both sides of the gap that data was estimated to have no inflow. If a volume increased from one side of the gap to the other occurred then a calculation of change was made and used as the inflow estimation.

Criteria Number 2:

Historical transposing of data is an evaluation method developed for the purpose of estimating missing inflow volumes via review of historical inflow trends in reference to rainfall.

The process:

1. Review rainfall data for the missing period and establish major events.
2. Establish whether the major event proceeded a wet or dry period.
3. Establish the month of the event.
4. Review historical rainfall events of similar volumes for the established month and extract the coupling volume change.
5. Tabulate the range of volume change.

Note: There is an obvious difference in the dam volume change from a wet period and a dry period and these values stand out.

6. Use the tabulated historical volumes to average separately the wet period volumes and dry period volumes.
7. Accept and select either the dry average or wet average volume based on the missing data period established major event weather conditions.

The Criteria:

1. A major event is deemed to be 25mm or more.
2. A wet period is when >50mm of rain fell in the previous 3 weeks.
3. A dry period is when <50mm of rain fell in the previous 3 weeks.
4. Similar volumes are considered +/- 10mm for rainfall < 100mm.
5. Similar volumes are considered +/- 20mm for rainfall > 100mm.

A table of all the historically transposed volumes can be found in APPENDIX B

4.3.2 Data Validation

To validate the inflow data generated an annual approach was adopted. A simple plot of the annual rainfall vs annual inflow (Figure 4.1) shows that the two sets of data matched graphically displaying similar trends in the major events. The one questionable section of data is 1981. The plot visibly shows the trends peaking in opposite direction. However, the data still around the years 1980 to 1982 still shows a peak and trough for both rain and inflow concluding that the data is validated.

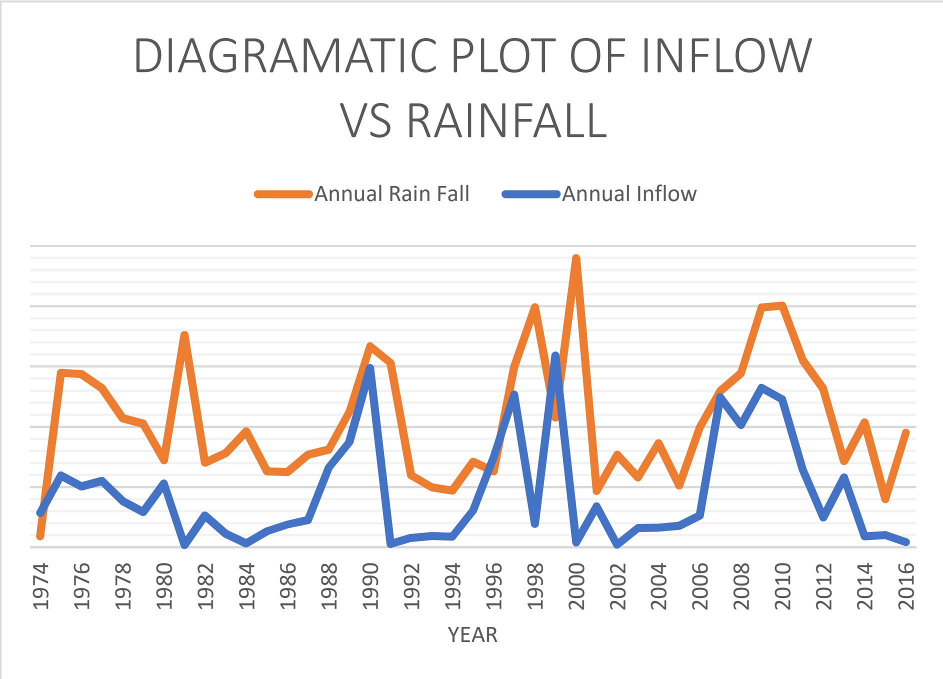


Figure 4.1 - Diagrammatic Plot of Inflow vs Rainfall

4.4 Water Balance Model Variables

Model variables are used to represent scenarios that exist within the system. For this model, the variables have been split into four (4) sub sections:

1. Supply Variables
2. Demand Variables
3. Triggers Variables
4. Projected Losses Variables

4.4.1 Supply Variables

The supply variables are used to represent the water supply and the changes that may occur within the system. The two (2) existing system supply variables are:

- ❖ BHt - BHWSS (ML/day)
- ❖ PDt - Paluma Dam (ML/day)

The BHWSS is a variable because the system has a current capacity and a future project capacity once the duplication project is complete. This model was developed to enable this supply change to be modelled accurately. The Paluma Dam is a bulk storage system on the northern reaches of the region. The capacity of the system is relatively small in comparison to that of the Ross River Dam. For this reason, a simplification has been used by means of developing a ML/day inflow to the system from the bulk storage capacity ML.

Other supply variable that have been established in the model are:

- Starting % - Ross River Dam starting percentage (%)
- EFt - Effluent reuse volume (ML/day)

The Ross River Dam starting percentage has been pre-set to 26%. Historical dam level data available begins at this percentage and is a reasonable value to be adopted. However, it is set as a variable for use in a sensitivity analysis which allows for various starting volumes to be modelled and checked for large variations.

Effluent reuse volume is the primary inflow of interest for this model. The volume of available effluent can be adjusted in this model to simulate different supply capabilities.

4.4.2 Demand Variables

Demand estimation is a vital part of water balance modelling. This system is comprised of two demand components, industry and residential with three (3) variables:

- Population - Estimated Population of the Region.
- ADD - Average Daily demand (L/c/day).
- IDt - Industry Usage (ML/day)

The population for the region is a variable that allows the model to analyse the current scenario as well as the future scenario of a greater population.

Residential usage is a scaled volume tied to both population and restriction. As restrictions are triggered a demand reduction is applied to the residential usage which is in line with data available for Townsville. This allows for usage to be modelled as decreasing in line with dam levels. The ADD value can be modified to simulate changes in water usage allowance.

The industry demand is a constant that for this model is a constant that does not change.

4.4.3 Trigger Variables

Trigger variables are all tied to the percentage (%) full of the dam. There are two types of triggers, pumping triggers that are used to time the pumping of supply water. Restriction triggers used to simulate demand reductions.

Supply Triggers/ Pumping triggers:

- ❖ BH Pump Trigger
- ❖ EF Pump Trigger

Pumping of supply water is tied to the dam levels which allows for adjustment to be made to simulate various supply scenarios. This model is primarily interested in the trigger timing of effluent water pumping.

Demand Triggers/ Restriction triggers:

- ❖ Level 1 restrictions
- ❖ Level 2 restrictions
- ❖ Level 3 restrictions
- ❖ Level 4 restrictions

4.4.4 Project Loss Variables

Project loss variables are estimates used to simulate evaporation and seepage. Given that these are seasonal variables this model has allowed for a month variation. As the model iterates a loss is applied at the daily time step in reference to the month of the individual iteration.

4.5 Water Balance Model Calculations

The water balance model Equation 4.1 iterates at a daily time step and solves for storage.

$$S_t = S_{t-1} + SF_t + PD_t + BH_t + EF_t - D_t - ID_t - ET_t \qquad \textbf{Equation 4.1}$$

$S_t = Storage$

$S_{t-1} = Storage\ from\ Previous\ time\ Step$

$SF_t = Stream\ flow$

$PD_t = Paluma\ Dam\ Inflow$

$BH_t = BHWSS\ Inflow$

$EF_t = Effluent\ Water\ Inflow$

$D_t = Residential\ Demand$

$ID_t = Industry\ Demand$

$ET_t = Losses\ (Seepage\ \&\ Evaporation)$

$t = time\ step\ (Daily)$

$S\%_{t-1} = Dam\ percentage\ full\ at\ previous\ time\ step$

$$if\ S\%_{t-1} < 20\%\ BH_t = 130\ ML/dayor\ 328\ ML/day \qquad \textbf{Equation 4.2}$$

$$if\ S\%_{t-1} < 100\%\ \mathrm{D}_t = \text{No Restrictions} \qquad \textbf{Equation 4.3}$$

$$if\ 40\% < S\%_{t-1} < 100\%\ \mathrm{D}_t = \text{Level 1 Restriction Demand} \qquad \textbf{Equation 4.4}$$

$$if\ 20\% < S\%_{t-1} < 40\%\ \mathrm{D}_t = \text{Level 2 Restriction Demand} \qquad \textbf{Equation 4.5}$$

$$if\ 10\% < S\%_{t-1} < 20\%\ \mathrm{D}_t = \text{Level 3 Restriction Demand} \qquad \textbf{Equation 4.6}$$

$$if\ S\%_{t-1} < 10\%\ \mathrm{D}_t = \text{Level 4 Restriction Demand} \qquad \textbf{Equation 4.7}$$

4.6 Water Balance Model Validation

Validation of the water balance model has been carried out in two simplistic steps:

1. Evaluation of current dam levels in comparison with the water balance model level.
2. Historical visually evaluation of major peaks and troughs.

The historical dam percentage graph is quite crude and is missing some information as discussed in section 4.3. Though visually both data sets (WBM and historical dam %) can be seen to peak and trough at the same periods in history. This suggest that the water balance model is trending correctly. Further more it is accurate and known that the Ross River Dam is currently sitting around the 20% mark and being propped up by the BHWSS. Looking at the WBM calculations, this known scenario is proven as the developed model has BHWSS pumping triggered as a supply inflow starting on the 4/8/2016 and continuing until the end of the model.

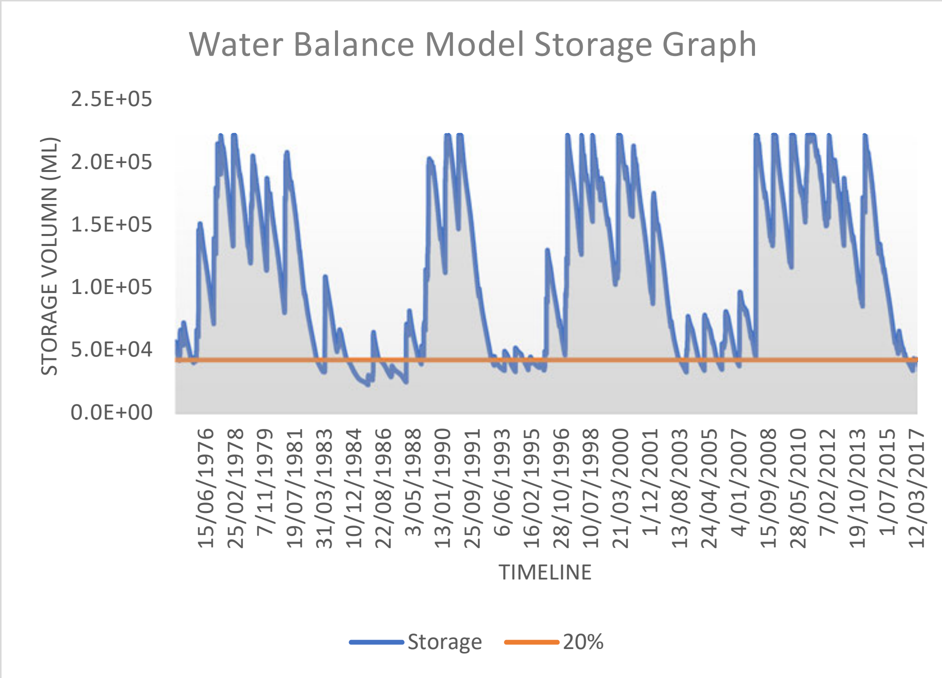


Figure 4.2 - Water Balance Model Storage Graph

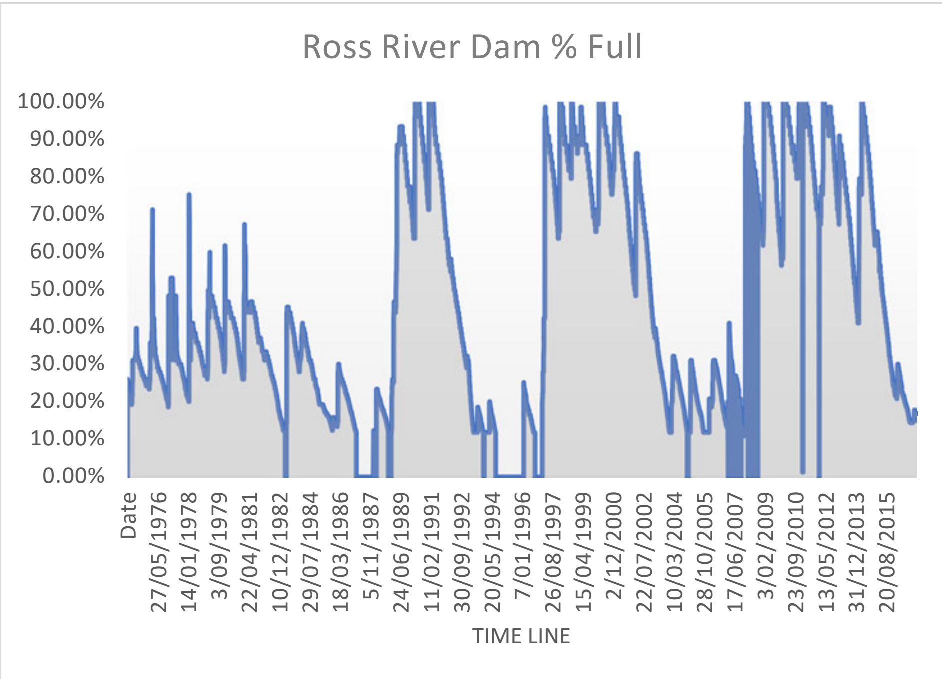


Figure 4.3 - Historical Dam % Graph

CHAPTER 5 RESULTS

5.1 Results Introduction

This chapter presents the result in a bulk but refined volumetric format. The reader will gain an understanding of the exact values of each scenario and management practice. The volumetrics provided are the tools used to answer the research objects:

Research objectives	
1	Can an Effluent water reuse scheme have a supply influence on the Townsville region water restrictions?
2	Can an Effluent water reuse scheme reduce the reliance on pumping from the Burdekin Dam?

5.2 Evaluation Criteria/ Volumetrics

In order to answer the questions established in section 1.3, a set of volumetrics needed to be established. The volumetrics are quantifiable values that are extracted from the water balance model and used in comparison of the various scenarios. The volumetrics provide the evidence that supports conclusions drawn in this dissertation.

General Volumetrics

1. Percentage (%) of days pumping from the BHWSS.
2. Average cost of BHWSS pumping per year based on Percentage (%) of days applied to a single year.
3. Percentage (%) of days on Level 2 restrictions.
4. Percentage (%) of days on Level 3 restrictions.
5. Percentage (%) of days on Level 4 restrictions.

Effluent Volumetrics

6. Percentage (%) of days reusing Effluent.
7. Percentage (%) of available effluent reused.
8. Average cost of BHWSS pumping per year based + Non-potable Effluent reuse on Percentage (%) of days applied to a single year.

5.3 Townsville Existing System Review

5.3.1 Current day (2017)

The two current/ baseline scenarios that represent Townsville are varied by the BHWSS duplication. The current 130ML/day capacity and the future duplication capacity 328ML/day.

	Volumetric	130ML/day BHWSS	328ML/day BHWSS	Affect
1	% days pumping BHWSS	26 %	12%	14%
2	Cost of BHWSS pumping/ year	$2,525,492.05	$3,006,908.00	$481,415.95
3	% Level 2 restriction	26 %	37 %	11 %
4	% Level 3 restriction	20 %	9 %	11 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	0 %	-
7	% of available effluent used	0 %	0 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$0.00	-

Table 5.1 - Townsville Baseline Volumetrics 2017

The duplication of the pipeline has a 14% reduction in pumping but an estimated $481,415.95 increase in cost. The additional benefits are a reduction in Level 3 water restriction by 11% the same percentage that Level 2 restrictions has increased by.

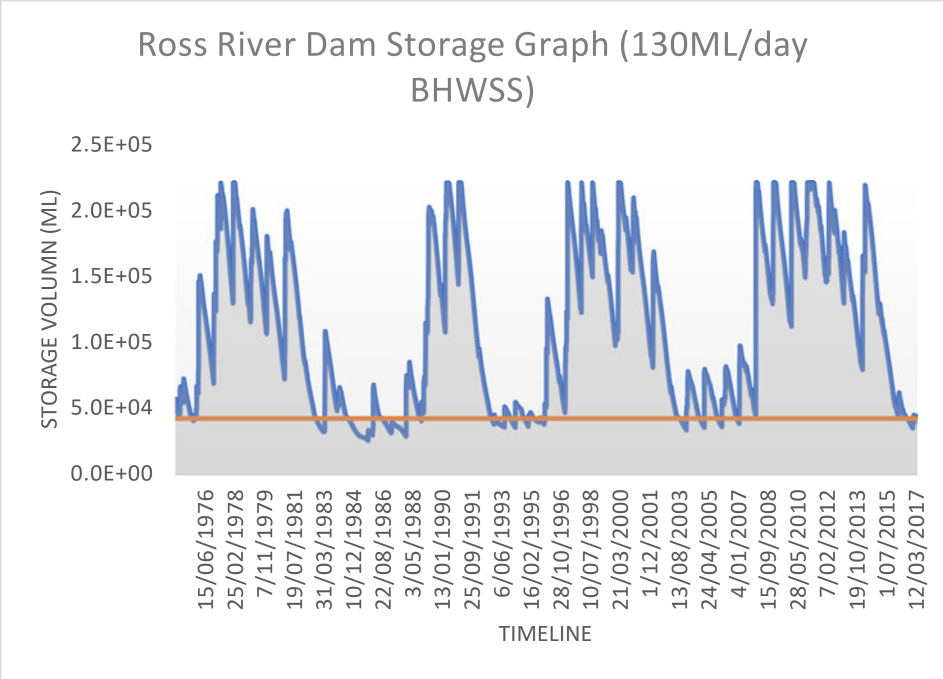


Figure 5.1 - Ross River Dam Storage Graph (130ML/day BHWSS)

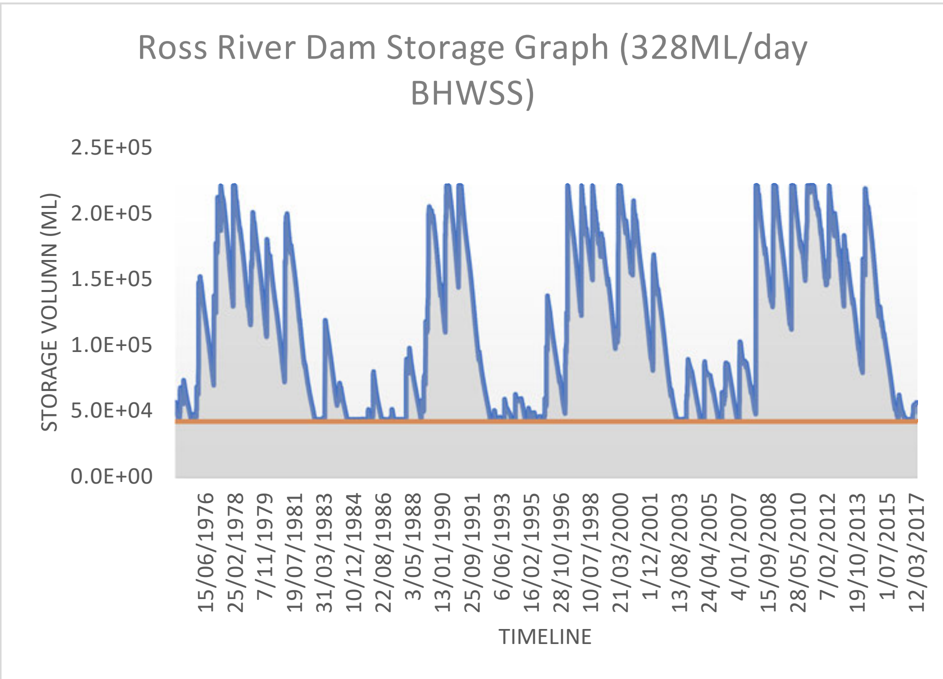


Figure 5.2 - Ross River Dam Storage Graph (328ML/day BHWSS)

5.3.2 Future Scenario (Early 2030's)

The project growth by the early 2030's is expected to be approximately 110,000 topping the total population of Townsville as 300,000 people. This growth is accounted for and is represented in Table 5.2.

	Volumetric	2017	2030	Affect
1	% days pumping BHWSS	12%	24%	12%
2	Cost of BHWSS pumping/ year	$3,006,908.00	$6,062,003.63	$3,055,095.63
3	% Level 2 restriction	37 %	36 %	1 %
4	% Level 3 restriction	9 %	17 %	8 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	0 %	-
7	% of available effluent used	0 %	0 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$0.00	-

Table 5.2 - Townsville Baseline Volumetrics 2030

The increase in population is serviceable by the system however the cost is notably more expensive with a project increase of $3,055,095.63 Net present value. This increase in cost is a result of the additional pumping that is required to meet the defined level of service and management practices. In addition, the percentage time on both Level 3 restrictions will increase by 8% and level two restrictions by 1%.

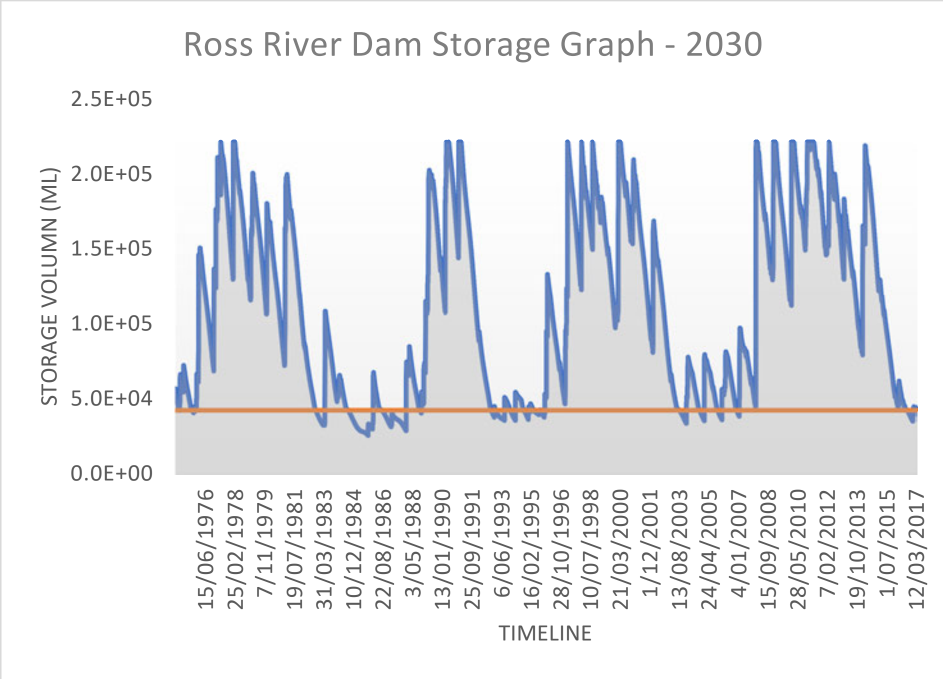


Figure 5.3 - Ross River Dam Storage Graph - 2030

Note: Historical data plotted to simulate a future scenario.

5.4 2017 With Effluent Usage & 130ML/day BHWSS

The results in this section represent the present-day scenario. The present-day scenario is represented by two key parameters. A population of 190 000 people and a Burdekin Haughton Water Supply Scheme (BHWSS) pumping capacity of 130ML/day. The results below show the volumetrics for various effluent supply timing.

5.4.1 2017 - 20% Trigger for Effluent reuse (130ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 20% of the Ross River Dam.

	Volumetric	(2017) 130ML/day BHWSS	(2017) 20% Effluent	Affect
1	% days pumping BHWSS	26 %	24%	2%
2	Cost of BHWSS pumping/ year	$2,525,492.05	$2,413,446.02	$112,046.03
3	% Level 2 restriction	26 %	27 %	1 %
4	% Level 3 restriction	20 %	19 %	1 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	24 %	-
7	% of available effluent used	0 %	24 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$2,591,134.19	-$65,642.15

Table 5.3 – 2017 - 20% Trigger for Effluent reuse (135ML/day BHWSS)

The results of 20% effluent supply timing show that there is a 2% reduction in days pumping and a 1% change in water restrictions from level 3 to 2. Thus, a positive affect when considering the research objectives. However, this affect comes at a cost of $65,642.

5.4.2 2014 - 40% Trigger for Effluent reuse (130ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 40% of the Ross River Dam.

	Volumetric	(2017) 130ML/day BHWSS	(2017) 40% Effluent	Affect
1	% days pumping BHWSS	26 %	23%	3%
2	Cost of BHWSS pumping/ year	$2,525,492.05	$2,303,309.86	$222,182.18
3	% Level 2 restriction	26 %	28 %	2 %
4	% Level 3 restriction	20 %	18 %	2 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	49%	-
7	% of available effluent used	0 %	49 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$2,659,904.87	- $134,412.82

Table 5.4 – 2017 - 40% Trigger for Effluent (130ML/day BHWSS)

40% effluent supply timing continues to present a positive effect in consideration to the research objects showing a 3% reduction in pumping from the BHWSS and a 2% shift in water restrictions from 3 to 2. However, the cost of this affect is continuing to grow which is an undesirable outcome of the scheme.

5.4.3 2017 - 60% Trigger for Effluent reuse (130ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 60% of the Ross River Dam.

	Volumetric	(2017) 130ML/day BHWSS	(2017) 60% Effluent	Affect
1	% days pumping BHWSS	26 %	23%	3%
2	Cost of BHWSS pumping/ year	$2,525,492.05	$2,275,298.36	$250,193.69
3	% Level 2 restriction	26 %	28 %	2 %
4	% Level 3 restriction	20 %	18 %	2 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	65%	-
7	% of available effluent used	0 %	65 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$2,750,570.88	- $225,078.83

Table 5.5 – 2017 - 60% Trigger for Effluent reuse (130ML/day BHWSS)

60% effluent supply timing shows that the effect of the effluent supply is not running linear to that of the cost. With no measurable change in restrictions of pumping reductions. The only change is the increasing cost of the scheme, suggesting that any further increase in supply timing is of no benefit.

5.4.4 2017 - 100% Trigger for Effluent reuse (130ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 100% of the Ross River Dam.

	Volumetric	(2017) 130ML/day BHWSS	(2017) 100% Effluent	Affect
1	% days pumping BHWSS	26 %	23%	3%
2	Cost of BHWSS pumping/ year	$2,525,492.05	$2,250,469.97	$275,022.07
3	% Level 2 restriction	26 %	28 %	3 %
4	% Level 3 restriction	20 %	17 %	3 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	100%	-
7	% of available effluent used	0 %	100 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$2,976,877.62	- $451,385.57

Table 5.6 – 2017 - 100% Trigger for Effluent reuse (130ML/day BHWSS)

A scheme that supplies effluent 100% of the time offers no further reduction in reliance on the BHWSS but another 1% in restriction shift from level 3 to 2. The cost of this type of supply timing is now nearing an additional $500,000 per year for a very small benefit.

5.5 2017 With Effluent Usage & 328ML/day BHWSS

The results in this section represent the present-day scenario with an upgraded Burdekin Haughton Water Supply Pipeline. This scenario is represented by two key parameters. A population of 190 000 people and a Burdekin Haughton Water Supply Scheme (BHWSS) pumping capacity of 328ML/day. The results below show the volumetrics for various effluent supply timing.

5.5.1 2017 - 20% Trigger for Effluent reuse (328ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 20% of the Ross River Dam.

	Volumetric	(2017) 328ML/day BHWSS	(2017) 20% Effluent	Affect
1	% days pumping BHWSS	12%	12%	-
2	Cost of BHWSS pumping/ year	$3,006,908.00	$2,912,139.00	$94,769.00
3	% Level 2 restriction	37 %	37 %	-
4	% Level 3 restriction	9 %	8 %	1 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	12%	-
7	% of available effluent used	0 %	12 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$2,997,116.22	$9,791.78

Table 5.7 - 2017 - 20% Trigger for Effluent reuse (328ML/day BHWSS)

A 20% supply timing trigger has a marginal affect on the water restrictions. In fact the results show that the restriction are right on the limit if having an influence. The reliance of the BHWSS has not change at all. The only change noted is the reduction in total. This type of system shows a $10,000 per year reduction in overall cost. Whilst this is a good outcome as a whole $10,000 benefit per year is not significant.

5.5.2 2017 – 40% Trigger for Effluent reuse (328ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 40% of the Ross River Dam.

	Volumetric	(2017) 328ML/day BHWSS	(2017) 40% Effluent	Affect
1	% days pumping BHWSS	12%	11%	1%
2	Cost of BHWSS pumping/ year	$3,006,908.00	$2,687,263.40	$319,644.60
3	% Level 2 restriction	37 %	37 %	-
4	% Level 3 restriction	9 %	8 %	1 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	49%	-
7	% of available effluent used	0 %	49 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$3,039,874.36	-$32,966.36

Table 5.8 - 2017 - 40% Trigger for Effluent reuse (328ML/day BHWSS)

Increasing the trigger timing for this scenario to 40% shows the financial benefit diminish. This increased cost comes with a reduced reliance on the Burdekin Haughton Water Supply Scheme of 1%.

5.5.3 2017 - 60% Trigger for Effluent reuse (328ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 60% of the Ross River Dam.

	Volumetric	(2017) 328ML/day BHWSS	(2017) 60% Effluent	Affect
1	% days pumping BHWSS	12%	11%	1%
2	Cost of BHWSS pumping/ year	$3,006,908.00	$2,658,350.82	$348,557.18
3	% Level 2 restriction	37 %	37 %	-
4	% Level 3 restriction	9 %	8 %	1 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	65%	-
7	% of available effluent used	0 %	65 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$3,132,357.82	- $125,449.82

Table 5.9 - 2017 - 60% Trigger for Effluent reuse (328ML/day BHWSS)

A 60% trigger to represents a similar trend that of 40%. Increased cost and little to no reduction in BHWSS reliance of shift in water restrictions.

5.5.4 2017 - 100% Trigger for Effluent reuse (328ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 100% of the Ross River Dam.

	Volumetric	(2017) 328ML/day BHWSS	(2017) 100% Effluent	Affect
1	% days pumping BHWSS	12%	11%	1%
2	Cost of BHWSS pumping/ year	$3,006,908.00	$26,629,438.25	$377,469.75
3	% Level 2 restriction	37 %	37 %	-
4	% Level 3 restriction	9 %	8 %	1 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	100%	-
7	% of available effluent used	0 %	100 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$3,355,845.89	- $348,937.89

Table 5.10 - 2017 - 100% Trigger for Effluent reuse (328ML/day BHWSS)

100% supply timing or 100% of the time reusing effluent continues to trend as per 60% and 40%. Higher cost and no affect. Suggesting that increasing the supply timing trigger does not result in reduced water restrictions or reliance of the BHWSS for this scenario.

5.6 2030 With Effluent Usage & 328ML/day BHWSS

The results in this section represent a 30-year future projected scenario with an upgraded Burdekin Haughton Water Supply Pipeline. This scenario is represented by two key parameters. A population of 300 000 people and a Burdekin Haughton Water Supply Scheme (BHWSS) pumping capacity of 328ML/day. The results below show the volumetrics for various effluent supply timing.

5.6.1 2030 - 20% Trigger for Effluent reuse (328ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 20% of the Ross River Dam.

	Volumetric	**(2030) 328ML/day BHWSS**	**(2030) 20% Effluent**	**Affect**
1	% days pumping BHWSS	24%	22%	2 %
2	Cost of BHWSS pumping/ year	$6,062,003.63	$5,564,064.80	$497,938,8.
3	% Level 2 restriction	36 %	37 %	1 %
4	% Level 3 restriction	17 %	16 %	1 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	22%	-
7	% of available effluent used	0 %	22 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$6,005,985.66	$56,017.97

Table 5.11 - 2030 - 20% Trigger for Effluent reuse (328ML/day BHWSS)

The 20% supply timing for the future scenario of 300,000 people and 328 ML/day BHWSS capacity presents similar to the present, upgraded BHWSS scenario in section 5.5 showing a benefit in all key areas, cost, reliance on BHWSS reduction and water restriction shift. The only change being the degree of the affect being greater. Initially indicating that an increased population amplifies the benefit of a scheme.

5.6.2 2030 - 40% Trigger for Effluent reuse (328ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 40% of the Ross River Dam.

	Volumetric	(2030) 328ML/day BHWSS	(2030) 40% Effluent	Affect
1	% days pumping BHWSS	24%	20%	4 %
2	Cost of BHWSS pumping/ year	$6,062,003.63	$4,919,956.84	$1,142,046.79
3	% Level 2 restriction	36 %	39 %	3 %
4	% Level 3 restriction	17 %	14 %	3 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	58%	-
7	% of available effluent used	0 %	58 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$6,074,768.50	-$12,764.87

Table 5.12 - 2030 - 40% Trigger for Effluent reuse (328ML/day BHWSS)

With a 40% supply timing trigger the benefit and affect continues to increase showing a 4% decrease in reliance of the BHWSS and a 3% level 3 to 2 water restriction shift. Whilst the cost may increase slightly by $13,000 for a 40% supply timing trigger, the affect is high in comparison.

5.6.3 2030 - 60% Trigger for Effluent reuse (328ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 60% of the Ross River Dam.

	Volumetric	(2030) 328ML/day BHWSS	(2030) 60% Effluent	Affect
1	% days pumping BHWSS	24%	19%	5 %
2	Cost of BHWSS pumping/ year	$6,062,003.63	$4,834,825.36	$1,227,178.27
3	% Level 2 restriction	36 %	38 %	2 %
4	% Level 3 restriction	17 %	14 %	3 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	75%	-
7	% of available effluent used	0 %	75 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$6,321,460.39	-$259.456.76

Table 5.13 - 2030 - 60% Trigger for Effluent reuse (328ML/day BHWSS)

The effect of a 60% supply timing trigger continues to improve the volumetrics of BHWSS reliance and restriction reductions. The affect is large enough to have a positive restriction shift of 3% from level 3 shifting 2% to level 2 and 1% to level 1. The cost of this affect is not increasing quickly and is in the range of $250,000 per year. Suggesting that the affect is expensive.

5.6.4 2030 - 100% Trigger for Effluent reuse (328ML/day BHWSS)

The results below are representative of an effluent supply timing trigger of 100% of the Ross River Dam.

	Volumetric	(2030) 328ML/day BHWSS	(2030) 100% Effluent	Affect
1	% days pumping BHWSS	24%	19%	5 %
2	Cost of BHWSS pumping/ year	$6,062,003.63	$4,754,512.65	$1,307,490.98
3	% Level 2 restriction	36 %	37 %	1 %
4	% Level 3 restriction	17 %	14 %	3 %
5	% Level 4 restriction	0 %	0 %	-
6	% of days reusing effluent water	0 %	100%	-
7	% of available effluent used	0 %	100 %	-
8	Cost of BHWSS + Non potable water/ year	$0.00	$6,731,802.30	-$669,798.67

Table 5.14 - 2030 - 100% Trigger for Effluent reuse (328**ML/day BHWSS)**

100% supply of effluent in the future scenario has the biggest effect on water restrictions. Showing a 3% reduction in level 3 restrictions with a further 2% shift from level 2 to level 1. All the while this affect is increasing in cost estimated to be around $670,000 per year.

5.7 Effluent Cost Benefit Results

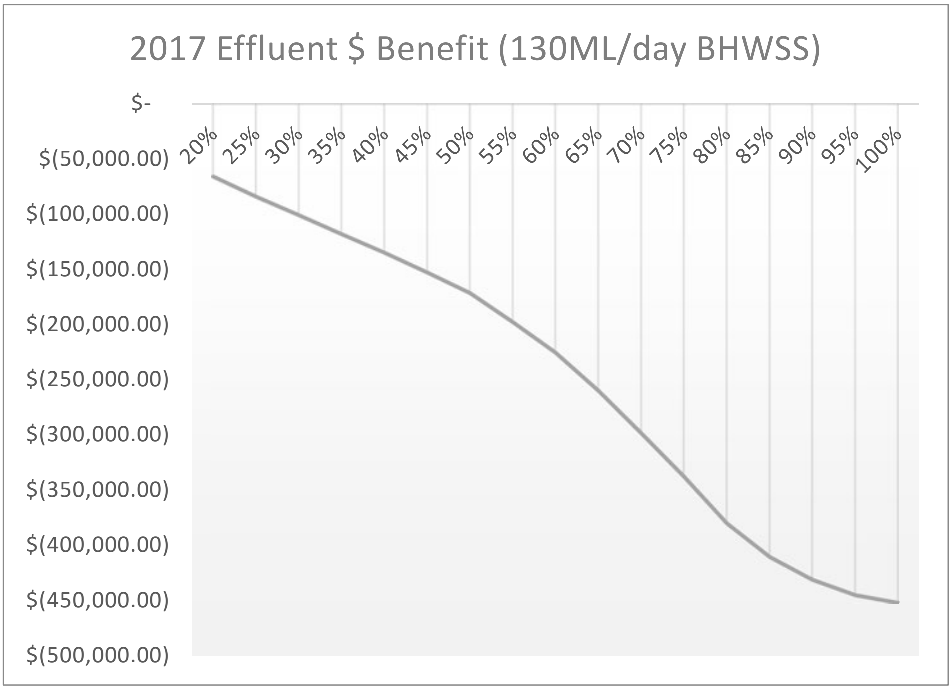


Figure 5.4 - 2017 Effluent $ Benefit (130ML/day BHWSS)

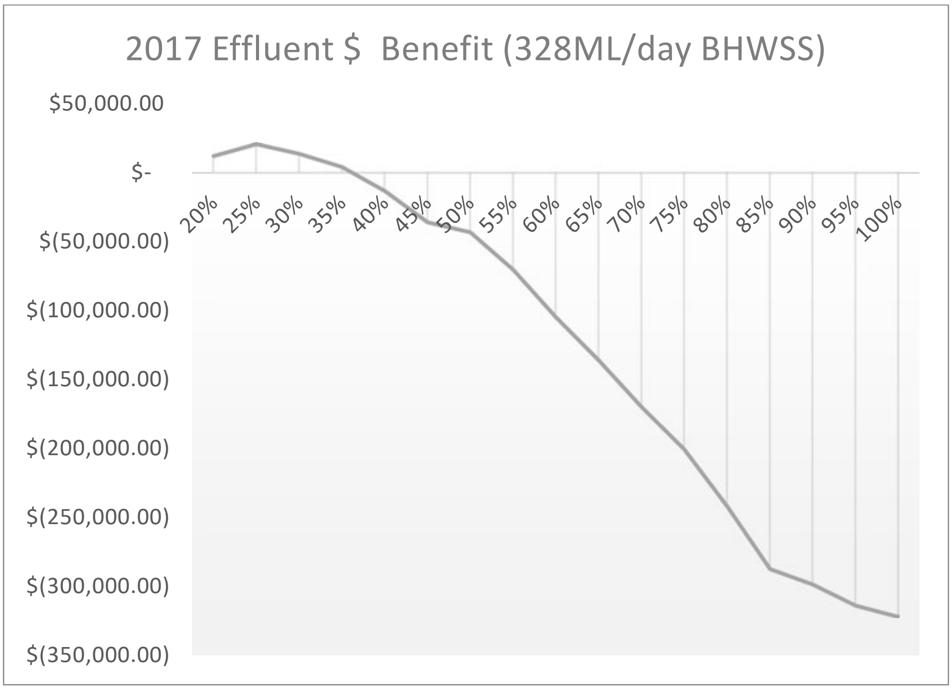


Figure 5.5 - 2017 Effluent $ Benefit (328ML/day BHWSS)

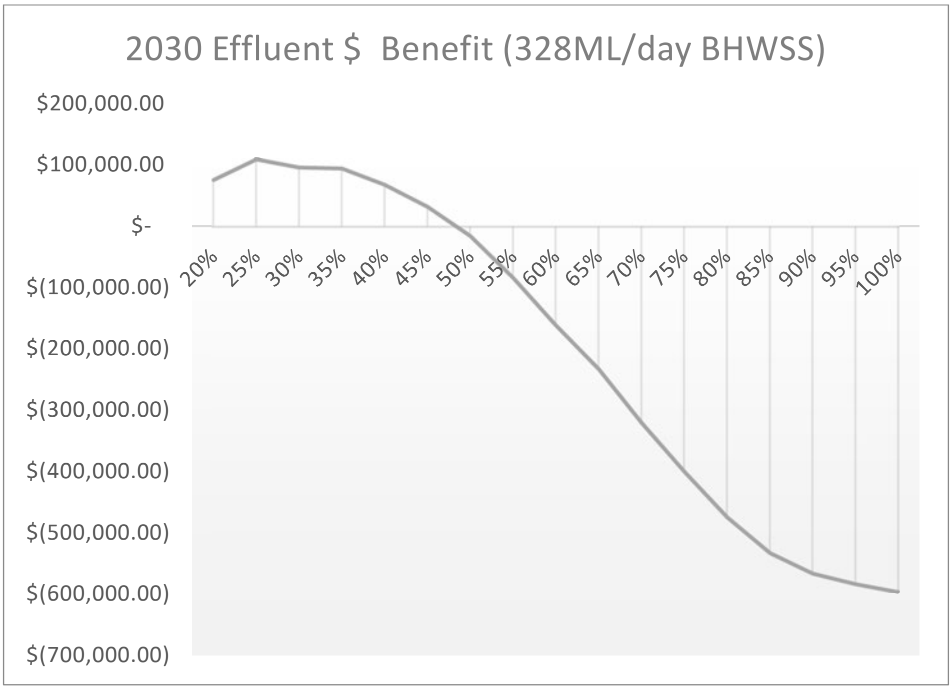


Figure 5.6 - 2030 Effluent $ Benefit (328ML/day BHWSS)

The cost benefit charts in Figure 5.4, Figure 5.5, Figure 5.6 all show that the more effluent is used the greater the cost. However, there is a window of viability in the low percentage supply timing trigger regions for both scenarios modelled with the upgraded BHWSS pipeline. This affect is a result of the cost per ML ($/ML) of pumping and the fact that the water balance model works assumes that the BHWSS pump utilises the full capacity of the pipeline on the days required. Management of the scheme may result in a reduction in this affect. This considered, the greater the volume of water that is required to be pumped by the BHWSS the greater the daily cost. A non-potable effluent water supply scheme cost will be relatively constant and not greatly influenced by the changing power cost. The cost benefit can be considered meaningful and a possible future consideration on this basis.

5.8 Effluent Reuse Percentage Benefit

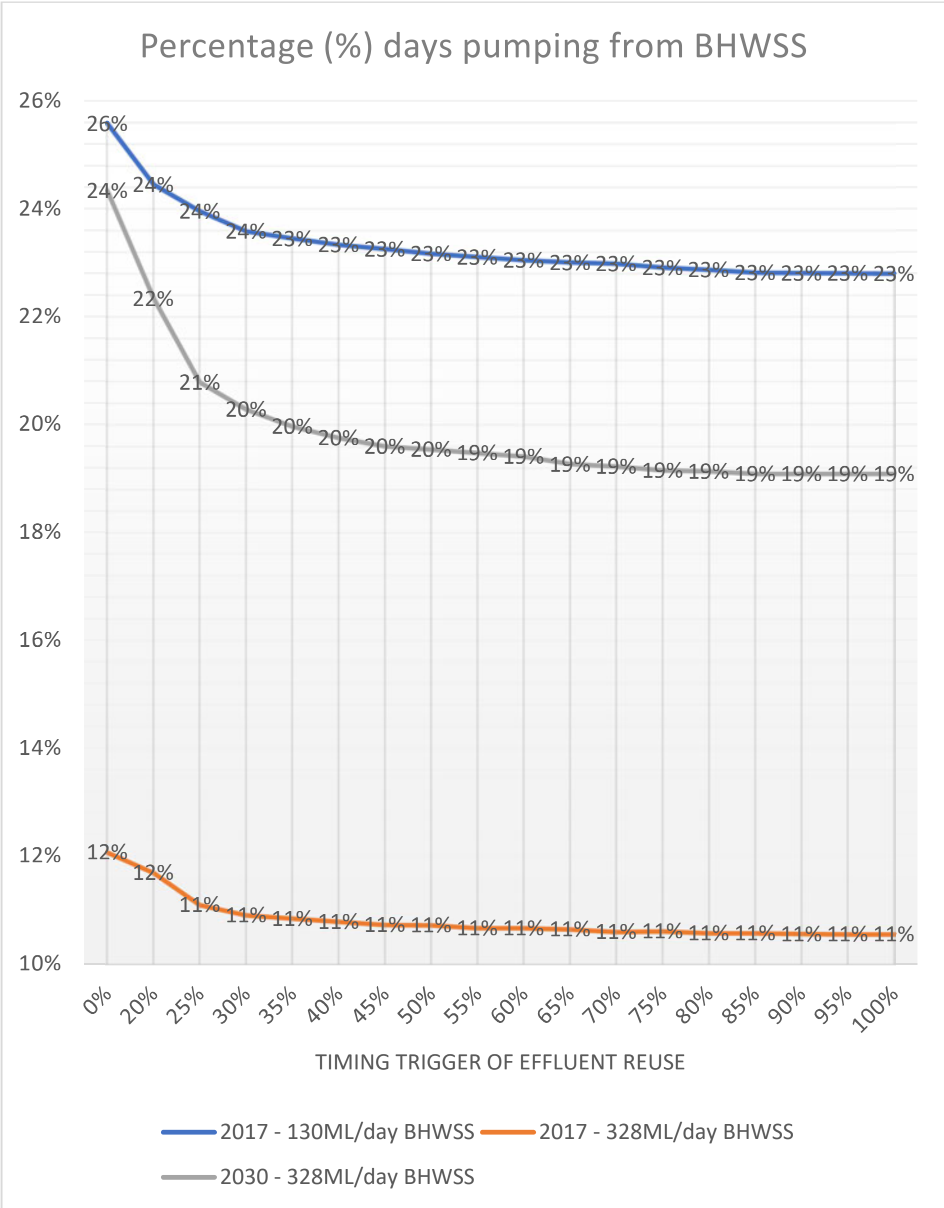


Figure 5.7 - Percentage (%) days pumping from BHWSS

The % reliance on the BHWSS was discussed in the previous sections of this dissertation but are graphically represented again to illustrate to the reader that the reliance on the BHWSS does decrease with the inclusion of effluent water into the bulk water supply for Townsville. The benefit is greatest initially at the low percentage supply timing and flattens out with greater supply. Suggesting that supply timing should be considered for low Ross River Dam levels only as the benefit to cost is negligible for greater supply timing triggers.

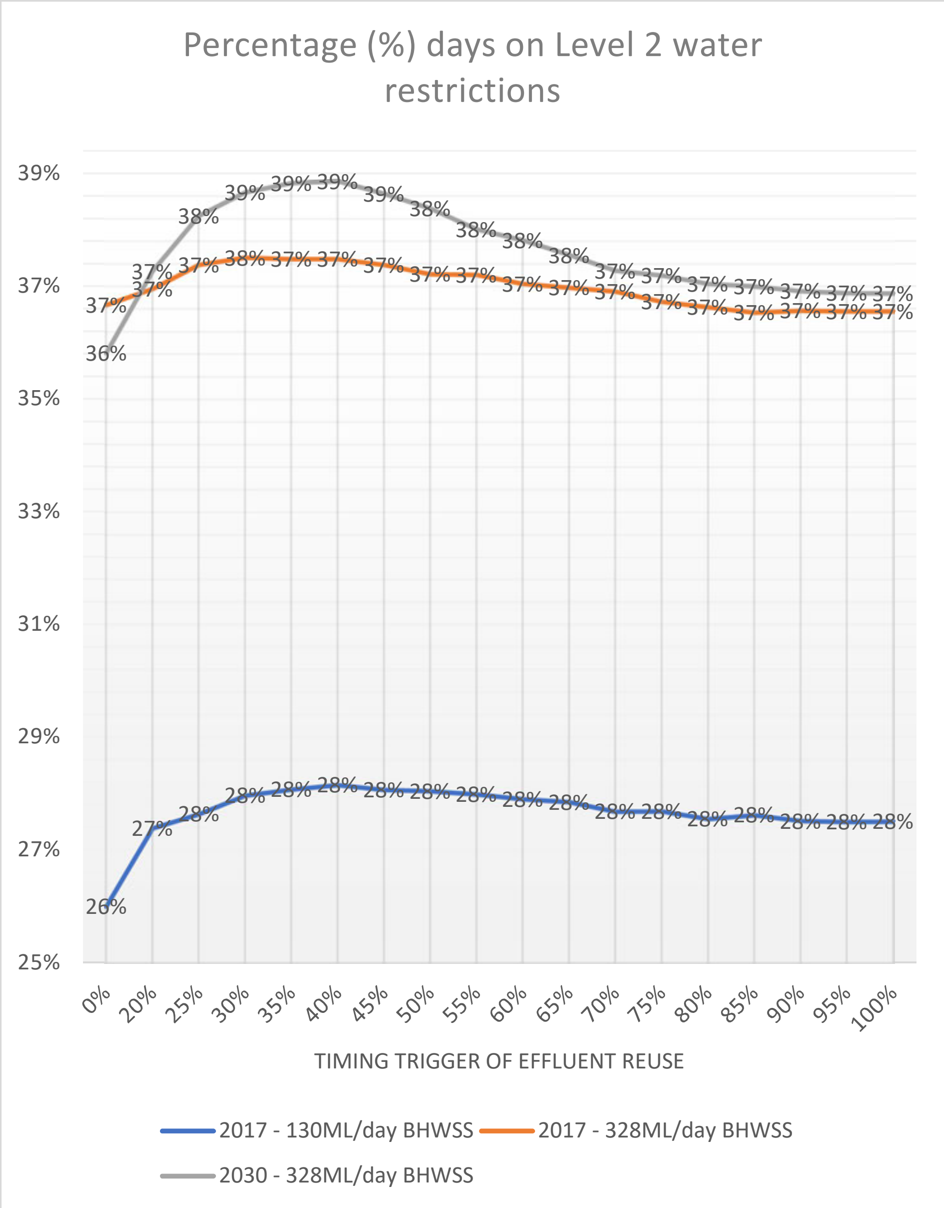


Figure 5.8 - Percentage (%) days on level 2 water restrictions

Level 2 water restrictions for all scenarios shows an increase in % days. This is due to a restriction shift from level 3 to level 2. For this restriction level there is a peak around the 40% supply timing which is the point at which there is a further water restriction shift to level 1. This shows that the greater the volume of water into the system the level days on each water restriction.

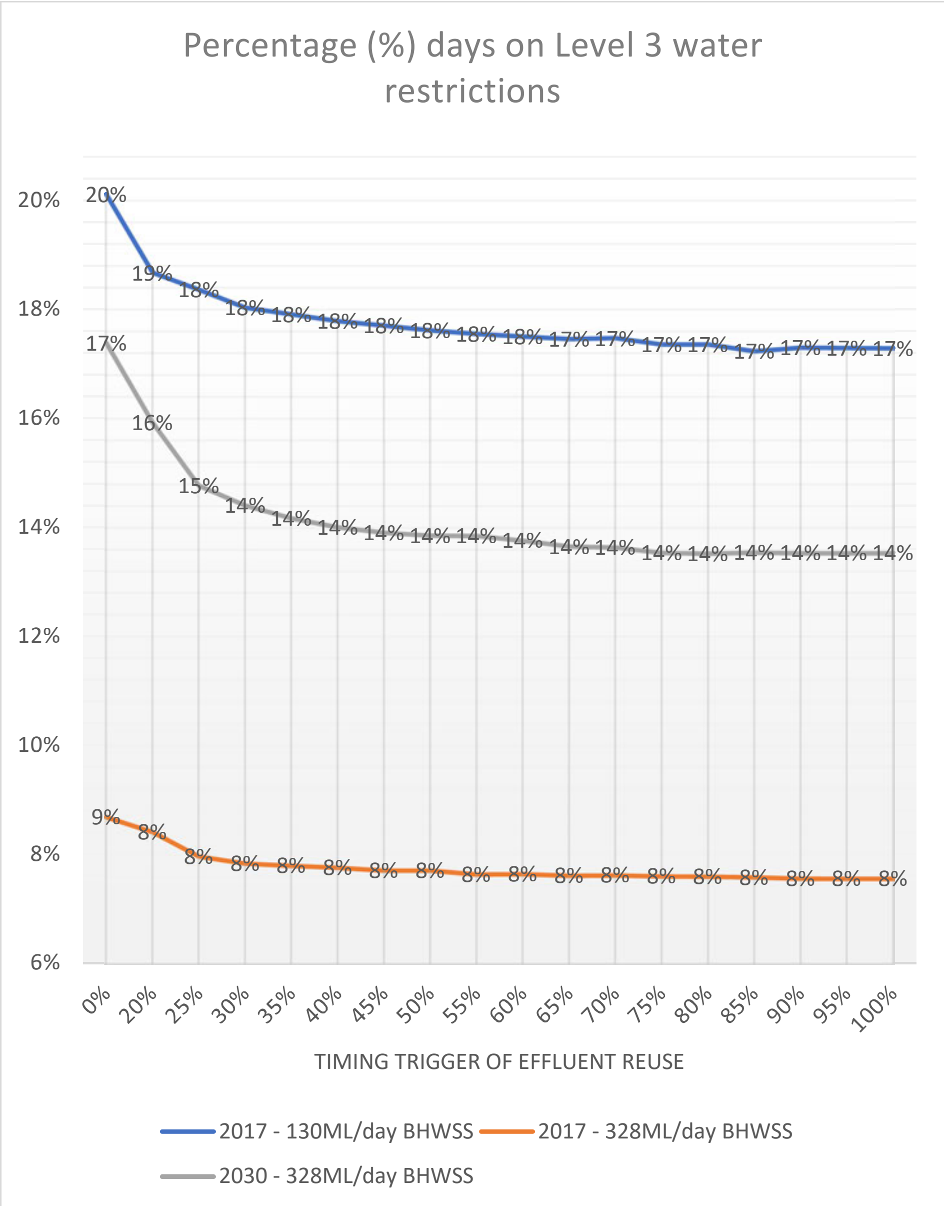


Figure 5.9 - Percentage (%) days on level 3 water restrictions

Level 3 water restrictions all show a reduction, trending downwards with the increase in effluent water to the system. Similar to that of level 2 water restrictions the greater the bulk water supply to the system the greater the reduction in water restrictions.

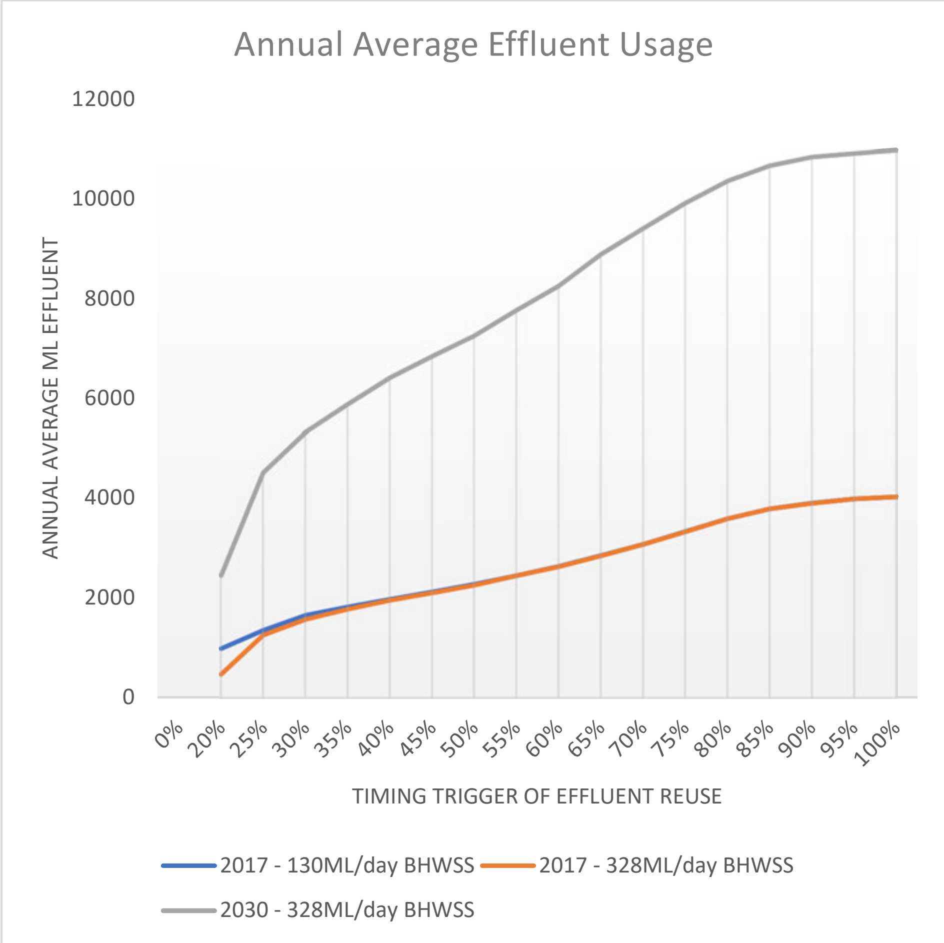


Figure 5.10 - Annual Average Effluent Usage

Figure 5.10 shows the effluent reuse to effluent supply timing. The trend is not linear because the affect and usage of effluent is greatest at the low supply timing. The gradual decrease of annual usage is representative of a redundant supply. This figure reconfirms the discussion that the greatest supply effect of effluent water is for low supply timing triggers.

CHAPTER 6 DISSCUSSION

6.1 Discussion Introduction

This chapter further develops the results and presents to the reader key discussion topics of relevance to the research objectives. These key discussion topics are:

1. Water Restrictions.
2. Burdekin Haughton Water Supply Scheme.
3. Effluent utilisation.
4. Cost implications.

These key topics continue to develop the discussion around the modelling outcomes and direct the reader to the conclusions being drawn from the work.

6.2 Water Restriction Discussion

Water restriction levels are relatable and can be expressed graphically with the bucket storage diagram Figure 6.1. Restriction levels are not linear to % volume, as level 3 restrictions decrease, this reduction will result in an increase in level 2 restrictions. The key point to note is, in order to trigger a restriction reduction or shift from level 3 to level 2 the maximum positive percentage volume required is 10%. Where as to trigger a restriction reduction or shift from level 2 to level 1 a 20% volume increase is required. In simple terms, twice the amount of water is required to trigger a change from restriction 2 to 1, then that of 3 to 2. This anomaly will inevitably mean the period of time on level 2 restrictions will always be more than level 3 restrictions.

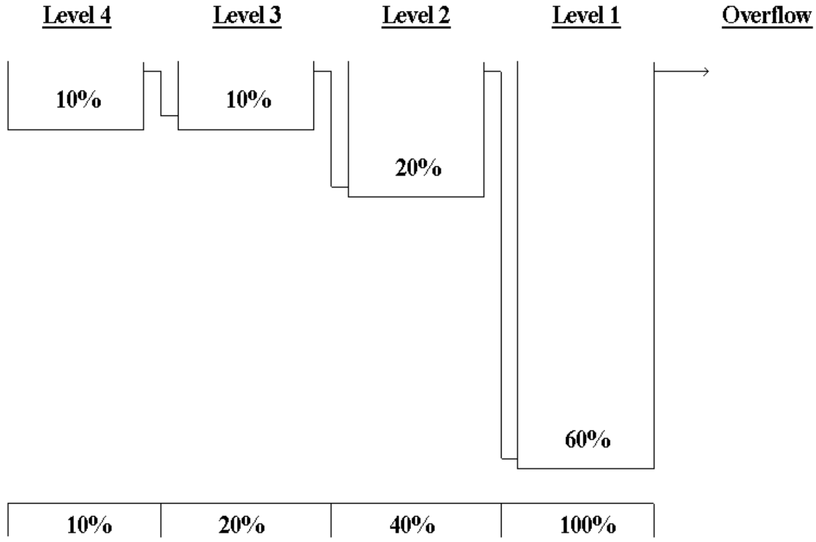


Figure 6.1 - Ross River Dam Storage Diagram

Figure 5.8 & Figure 5.9 graphically show the influence of effluent water reuse on the restriction levels of each scenario. All of the scenarios experience a positive affect which is generally expected. Additional bulk water supply should reduce restrictions. The interesting point to note is insignificant amount of reduction. Figure 5.8, Figure 5.9 both show percentage reductions less the 5%.

Figure 5.8 - Percentage (%) days on level 2 water restrictions trends slightly different to Figure 5.9 - Percentage (%) days on level 3 water restrictions. Figure 5.8 present a parabolic type expression which is most visible for the future scenario. What is visible here is an increase in days on level 2 restrictions until the level 2 restriction is alleviated in the form of the Ross River Dam total percentage increasing above the 40%. Figure 6.2 shows a graphical explanation.

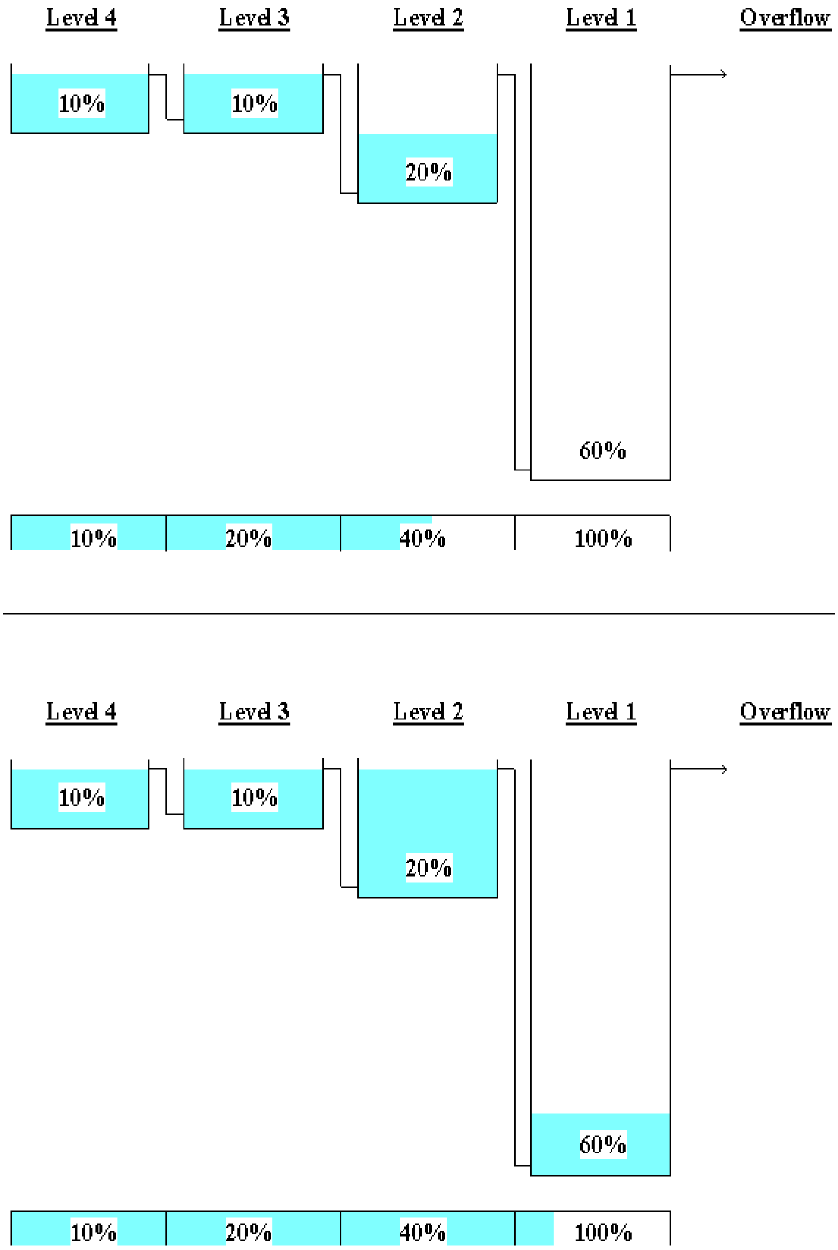


Figure 6.2 - Level 2 Water Restriction curve explanation

6.3 BHWSS Pumping Discussion

The Townsville region is always going to have a reliance on the BHWSS. The entire bulk water supply is structured around this system. From the water balance model, the Average Annual BHWSS pumping is established. Table 6.1 shows the ML/Annum required based on the 3 baseline scenarios.

Average Annual BHWSS Pumping			
ML/day	(2017) 26%	(2017) 24%	(2030) 12%
130ML/day	12337 ML/Annum	-	-
328ML/day	-	28732.8 ML/Annum	14366.4 ML/Annum

Table 6.1 - Average Annual BHWSS Pumping

These volumes are low in comparison to the BHWSS allocations as per Table 2.1. The volumes both current and future project are considered serviceable.

The Inclusion of effluent water as a bulk water supply does have a reducing influence on the number of BHWSS pumping days and is visually represented in Figure 5.7. All of the considered scenario's show a reduce percentage of pumping days as the volume of effluent water is increase.

The current 2017 scenario shows a 3% reduction in total days pumping. This reduction trend is representative for both 2017 considerations: 130ML/day BHWSS & 328ML/day BHWSS. However the effluent has less of a reduction benefit on the 2017 328ML/day BHWSS with only 1% reduction.

The biggest positive influence on pumping reduction in percentage days is for the future projected population. There is a calculated reduction of 5%.

These trends suggest that as population grows the influence of effluent water on pumping increase.

6.4 Effluent Utilisation Discussion

Consideration of effluent reuse costs, resulted in initial conclusions that a potable reuse system would be far too expensive to utilise. A potable reuse system would on average cost $3632/ML more than that of pumping from the Burdekin Haughton Water Supply Scheme (BHWSS). The only time a Potable reuse system would be considered is when the BHWSS supply capabilities could not support the restricted demands.

Non- potable reuse on the other hand is identified as having some benefit when looking at low cost highly efficient systems. It is estimated that on average a non-potable reuse scheme will cost $632/ML more than pumping from the BHWSS. However, on the low end of the scale non- potable effluent reuse has a $28/ML benefit. To further investigate this benefit analysis and further discussion is based around non-potable highly efficient effluent reuse systems.

From an environmental point of view discharge of effluent back into natural water courses is a necessary evil. The concentration and quality of the effluent are controllable variables. A non-potable effluent reuse scheme will improve the quality of the inevitable environmental discharge through a microfiltration process. A reuse distribution network will reduce the concentration of effluent as it is applicated in varying non-potable situations across the region (Irrigation/ Toilet flushing/ etc). Figure 5.10 - Annual Average Effluent Usage presents to the reader the projected average volumes of effluent reused each year based on a 20% trigger.

6.5 Cost Implication Discussion

Previously the reader was introduced to the small window of financial viability of effluent reuse schemes. It is calculated that $28/ML benefit exists for effluent reuse over BHWSS pumping. Figure 5.4, Figure 5.5, Figure 5.6 present the various financial benefits in graphical form. From these figures the following points of discussion can be summaries:

- In 2017 with 130ML/day BHWSS capability there is no financial benefit to non-potable effluent reuse.
- In 2017 with 328ML/day BHWSS capability there is a small financial benefit up to the 32% effluent pumping trigger.
- In 2030 with 328ML/day BHWSS capability there is approximately $100,000 benefit up to the 37% effluent pumping trigger.

These summaries conclude:

- The more effluent available the greater the financial benefit for Townsville.
- The higher the demand the greater the financial benefit Townsville.
- Generally the financial benefit is small.

CHAPTER 7 CONCLUSION

The concluding chapter of this dissertation summarises the result and finalises the discussion. The reader will also have a concise and detailed explanation to the research question outline in section 1.3. The final portion of this chapter will make future study recommendations.

7.1 Research Objective 1

"Can a Effluent water reuse scheme have a supply influence on the Townsville region water restrictions?"

The answer to this question is simply, yes. A non-potable effluent reuse scheme does have the ability to influence and reduce the water restrictions for Townsville. This statement can be concluded on the basis that with the inclusion of effluent water as a bulk water supply source the percentage of time on each water restriction does reduce by a maximum of 5%. The significance of this reduction is where the value of this dissertation lies. Further development of the question would ask "How significant is the reduction?". A 10% reduction is a reasonable amount to consider significant whereas the analysis conducted and discussed above suggest a maximum reduction of 5% is possibly achieved with the inclusion of effluent water. Thus, there is little significance and value in non-potable effluent reuse for the purpose of reducing water restrictions for Townsville.

7.2 Research Objective 2

"Can an Effluent water reuse scheme reduce the reliance on pumping from the Burdekin Dam?"

The answer to the second research objective is, no. Effluent water reuse schemes have the ability to reduce the volume of water required to be supplied from the BHWSS by a maximum of 5%, but the reliance on the system will remain. As per research objective 1 it is considered a reasonable reduction to be in the region of 10%. Whereas the largest reduction is calculated was 5%. This indicates that the reduction value is limited. Reliance on the BHWSS is an integral bulk water supply component for the Townsville region. Without the BHWSS, the Townsville bulk water supplies would not have the capability to supply the region through prolonged drought.

7.3 Effluent Reuse Significance

Many different factors are considered for bulk water supply solutions for a region. The four (4) major factors that are considered in order of significance are:

1. Cost of bulk water supply
2. Volume of bulk water supply
3. Environmental impact of bulk water supply
4. Public perception of bulk water supply.

A non-potable effluent water supply strikes out in three (3) of the four (4) major significance factors. A system of this nature is, not cost effective, low in supply capability & poorly perceived publicly. The only factor that a effluent system scores positively in is environmental. As a significant bulk water source, effluent reuse is poor.

Whilst Townsville and all bulk water supply systems are unique in nature it is safe to say that effluent reuse as a bulk water supply source for coastal communities is seemingly unviable and other alternatives are preferable. The outcome of this research agrees and confirms the Townsville City Council choice to pump water from the BHWSS.

7.4 Future Research

Effluent water reuse as a bulk water supply is not a viable consideration for easing water restrictions for Townsville. Options that may be considerable are:

"Optimisation of supply triggers and Average Daily demand."

This type of research could result in better utilisation of existing supply capabilities and optimise the amount of time on level 1 & 2 restrictions as opposed to level 3 & 4.

"Ross River Dam excavation and topographical manipulation"

The shape of Ross River Dam is poor in design and leads to major losses through surface evaporation. Any improvement on the volume to surface area ratio of Ross River Dam will reduce the amount of evaporation loss. A cost benefit analysis of this type of earthworks in comparison to long term pumping cost make the works viable.

CHAPTER 8 BIBLIOGRAPHY

- Anon., n.d. *4.44 Advance Oxidation Processess.* [Online]
  Available at: https://frtr.gov/matrix2/section4/4-45.html
  [Accessed 04 May 2017].
- Aravinthan, V. & Yoong, E., 2015. Study Book. In: *Public Health Engineering.* Toowoomba: University of Souther Queensland, pp. 23-24.
- Department of Energy and Water supply, 2014. *Regional Water Supply Security Assessment,* Townsville: State of Queensland.
- Department of Energy and Water Supply, 2016. *Water Supply Levels of Service.* [Online]
  Available at: https://www.dews.qld.gov.au/water/supply/security/los
  [Accessed 10 04 2016].
- Department of Environment and Resource Management, 2010. *Burdekin Basin Resource Operations Plan,* Townsville: Water Planning (North) Department of Environment and Resource Management.
- Khan, S., 2013. *Drinking Water Through Recycling,* Melbourne: Australian Academy of Technological Sciences and Engineering.
- Meteorology, B. o., 2017. *www.bom.gov.au.* [Online]
  Available at:
  http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_display_type=dataGraph&p_stn_num=032040&p_nccObsCode=139&p_month=13
  [Accessed Friday April 2017].
- Nancarrow, B. E. et al., 2007. *Community Acceptability of the Indirect,* s.l.: The Urban Water Security Research Alliance .
- National Resource Management Ministerial Council, 2011. *Australian Drinking Water Guidelines 6 National Water Quality Management Strategy,* Canberra: 2016.
- Radcliffe, J., 2004. *Water Recycling in Australia,* Parkiville: Australian Academy of Technological Sciences and Engineering.
- Raggatt, T., 2016. *Townsville Bulletin.* [Online]
  Available at: http://www.townsvillebulletin.com.au/news/state-government-says-yabulu-will-retain-water-rights-out-to-2111/news-

story/b9ecd3a1f32793f3a41522d1d3b36285
[Accessed Saturday 8 April 2017].

- Rooney, K., 2016. *Townsville Bulletin.* [Online]
Available at: http://www.townsvillebulletin.com.au/news/pumping-from-burdekin-starts-as-townsville-water-levels-dip-below-trigger-point/news-story/35860117c4642319ac871b4b56d85450
[Accessed Friday April 2017].
- Stevenson, S., 2016. *Cleveland Bay Purification Plant Annual Return Report 2015/16.* Townsville: Townsville Water And Waste, Townsville City Council.
- Stevenson, S., 2016. *Mt St JOhn Sewage Treatment Plant Annual Return Report 2015/16.* Townsville: Townsville Water and Waste, Townsville City Council.
- Stevenson, S., 2016. *Toomulla Water Purification Plant Annual Return Report 2014/15.* Townsville: Townsville Water and Waste, Townsville City Council 2014.
- Stevenson, S., 2017. *Condon Water Purification Plant Annual Return Report 2015/16.* Townsville: Townsville Water and Waste, Townsville City Council.
- Townsville City Concil, n.d. Horseshoe Bay Water REcycling Facility.
- Townsville City Concil, n.d. Magnetic Island Water Recycling Facility.
- Townsville City Council, 2012. *Integrated Water Supply Strategy,* Townsville: Townsville City Council.
- Townsville City Council, 2015. *Townsville Restriction Policy - Version No.3.* Townsville: Townsville City Council.
- Townsville City Council, 2016. *Haughton Pipeline Duplication Project Update #2 May 2016,* Townsville: Townsville City Council.
- Townsville City Council, 2016. *Schedule of Rates and Charges 2016/2017.* Townsville: Townsville City Council.
- Townsville City Council, 2017. *Townsville City Plan Web Mapping Service,* Townsville: Townsville City Council.
- Townsville City Council, 2017. *Water Restrictions - Information Sheet.* Townsville: Townsville City Council.
- Townsville City Council, n.d. *Our water - Lover Every Drop Fact Sheet,* Townsville: Townsville City Council.

- University, M., 2004. Macquarie Dictionary. In: *Australia's National Dictionary Third Addition.* s.l.:The Macquarie Library.
- Vision Sruveys, 2016. *Ross Dam Stage Storage,* Townsville: Vision Survey.
- Water Research Foundation, 2016. Membrane Treatment Fact sheet. *Advanced Treatment,* Issue October 2016, pp. 1 - 4.
- West, C., Kenway, S. & Yuan, Z., 2015. *Risk to long-term viability of residential non-potable water schemse: a review,* Clayton: Cooperative Research Centre for Water Sensitivity Cities.

APPENDIX A

ENG4111/4112 Research Project

Project Specification

For: Joel Govan

Title: Townsville effluent water re-use, A supply analysis.

Major: Civil Engineering

Supervisor: Justine Baillie

Enrolment: ENG4111 – EXT S1, 2017
ENG4112 – EXT S2, 2017

Project Aim: To investigate the supply influence effluent water re-use could have on the Townsville region water restrictions.

Programme: Draft, 15^{th} March 2016

1. Research the background information
    a. Townsville water demand.
    b. Townsville water supply.
        i. Ross Dam
        ii. Burdekin Dam
        iii. Paluma
    c. Townsville water treatment facilities.
        i. Cleveland Bay water purification plant
        ii. Condon water purification plant
        iii. Toomulla water purification plant
        iv. Mount St Johns water treatment
    d. Townsville water restrictions

    i. Frequency/ Probability
    ii. Occurrence Levels
e. Broader review of the issues associated with the re-use of effluent water
f. Existing information and opportunities for effluent water re-use in Townsville (Studies and existing usage).
g. Data collation.

2. Water Balance Modelling (Excel Graphing)
    a. Calculate the supply capabilities of each of the treatment plants under Combinations of:
        i. All water restriction level.
        ii. Peak wet weather flow (PWWF) – Recorded data
        iii. Average dry weather flow (ADWF) – Recorded data
    b. Develop a whole system water balance model for Ross River Dam incorporating river inflows, losses (evaporation, seepage etc), releases to TCC, inflows from Burdekin and wastewater re-use.
    c. Use the water balance model to run a number of scenarios including pumping effluent re-use and water from the Burdekin.
    d. Undertake a sensitivity analysis investigating the impact of trigger levels for pumping and determine the impact on water restriction frequency/ probability.
    e. Determine the percentage reduction in pumping from the Burdekin.

If time permits

3. Calculate the cost implications of pumping from different water sources and the impact of different pumping trigger levels. Determine the cost of reducing water restriction frequency and severity.

Investigate the viability of each of the effluent sources and identify a potential introduction phasing. (Which treatments plants are the best and why)

APPENDIX B

Data Adjustment								
Date Range	Actual Date	Rain event (mm)	recent rain history prior to date range	Similar rain events				
				Date	Rain Recorded (mm)	Dam volume change (ML)	Dry Average (ML)	Wet Average (ML)
4/2/2011 - 13/2/2011	4/02/2011	170	dry	14/02/2002		15655.00		
				28/02/1978		11518.00	13586.50	
27/01/1987 - 31/12/1987	3/01/1987	113	dry	10/01/1984		2366.00	2366.00	
	18/01/1987	63	wet	30/01/1978	56.00	32040.00		
				17/01/1981	56.80	16181.00		
				23/01/2005	67.80	23610.00		
				23/01/2013	70.20	21408.00		23309.75
	15/02/1987	48	dry	24/02/1982	43.60	2599.00		
				28/02/1988	42.80	4638.35		
				17/02/2002	43.60	5205.00		
				4/02/2004	43.80	1927.00		
				13/02/2009	52.60	6075.00		
				17/02/2009	43.20	18227.00	2263.00	
	4/03/1987	26	wet	4/03/1976	26.80	2922.00		

				7/03/1976	26.00	3236.00		
				30/03/1990	24.00	6076.00		
				1/03/1997	27.40	2518.00		
				6/03/1997	25.60	9481.00		
				9/03/2016	25.00	2077.00		7778.50
	26/12/1987	30	dry	3/12/2010	26.40	6076.00	6076.00	
	29/12/1987	68	wet	22/12/1975	73.00	2229.00		
				28/12/1988	70.40	9975.00		
				29/12/1988	73.80	10473.00		
				27/12/1999	75.80	4611.00		10224.00
	30/12/1987	93	wet	27/12/1975	85.60	4958.00		
				20/12/1976	79.80	20213.00		
				27/12/1991	99.00	21012.00		
				22/12/1997	97.40	4361.00		20612.50
	31/12/1987	54	wet	22/12/1976	59.40	7016.00		
				26/12/1999	57.20	8970.00		
				17/12/2000	49.40	16203.00		
				18/12/2000	58.60	5909.00		9524.50
29/7/1994 - 2/2/1996	27/12/1994	51.8	dry	28/12/1975	42.20	8023.00		
				26/12/1990	44.00	19372.00		
				26/12/1999	57.20	8970.00		
				17/12/2000	49.40	16203.00	8496.50	

	10/02/1995	103.8	dry	5/02/1979	109.40	17276.00		
				17/02/1991	93.00	44792.00		
				19/02/2000	108.40	12152.00		
				16/02/2002	106.60	14990.00		
				13/02/2004	107.00	4958.00		
				19/02/2010	92.60	6075.00	5516.50	
	7/08/1995	40.4	dry	23/10/1975	34.7	2077		
				24/10/1975	56.8	2077		
				23/10/1985	58.6	5398		
				19/06/2007	26	2229	2127.67	
	26/10/1995	65.4	dry	24/10/1975	56.8	2077		
				23/10/1985	58.6	5398	2077.00	
	21/11/1995	50.2	dry	24/10/1975	56.8	2077		
				26/12/1990	44	19372		
				17/12/2000	49.4	16203		
				4/11/2010	46	5103	3590.00	
	5/12/1995	46.4	wet	11/12/1975	40.6	2077		
				28/12/1975	42.2	8023		
				26/12/1990	44	19372		
				30/12/1998	40.6	5402		
				26/12/1999	57.2	8970		
				17/12/2000	49.4	16203		
				18/12/2000	58.6	5909		13142.00

	6/01/1996	106	wet	10/01/1984	110	2366		
				23/01/1986	86.4	1374		1870.00
	7/01/1996	111.8	wet	10/01/1984	110	2366		
				23/01/1986	86.4	1374		1870.00
	8/01/1996	31.2	wet	13/01/1975	33.8	4154		
				30/01/1976	31.4	2752		
				9/01/1981	25.4	2229		
				14/01/1981	34.6	4806		
				1/01/1991	26.6	6076		
				3/01/1991	25.4	37983		
				26/01/2006	33	5006		
				25/01/2009	34.2	44792		
				6/01/2017	34.8	189.15625		41387.50
	27/01/1996	31.6	wet	13/01/1975	33.8	4154		
				30/01/1976	31.4	2752		
				9/01/1981	25.4	2229		
				14/01/1981	34.6	4806		
				1/01/1991	26.6	6076		
				3/01/1991	25.4	37983		
				26/01/2006	33	5006		
				25/01/2009	34.2	44792		
				6/01/2017	34.8	189.15625		41387.50

13/9/1996 - 4/2/1997	9/10/1996	40.6	dry	30/12/1998	40.6	5402		
				4/11/2010	46	5103	5252.50	
	30/01/1997	42.6	dry	10/01/1998	46.4	65373		
				16/01/2004	41.8	7624		
				25/01/2009	34.2	44792		
				26/01/2009	42.4	14930		
				10/01/2011	40	6075		
				6/01/2017	34.8	189.15625		
				7/01/2017	36.2	16.640625	3476.20	
	4/02/1997	62.2	wet	15/02/1999	63.4	5499		
				28/02/1999	68.6	12152		
				6/02/2000	62.6	4526		
				26/02/2001	63.6	6076		
				14/02/2004	58	2599		
				13/02/2009	52.6	6075		
				26/02/2009	65.2	6075		6143.14
	5/02/1997	164.8	wet	18/02/2000	171	27317		
				14/02/2002	174.4	15655		
				15/02/2002	144	40013		
				18/02/2014	164.6	23066		26512.75