JOINT ABBOTSFORD-MISSION WATER MASTER PLAN

Master Plan Summary | May 2018

Prepared for the Joint Abbotsford-Mission Water and Sewer Commission by Urban Systems Ltd.

Abbotsford
Mission
Water & Sewer Services

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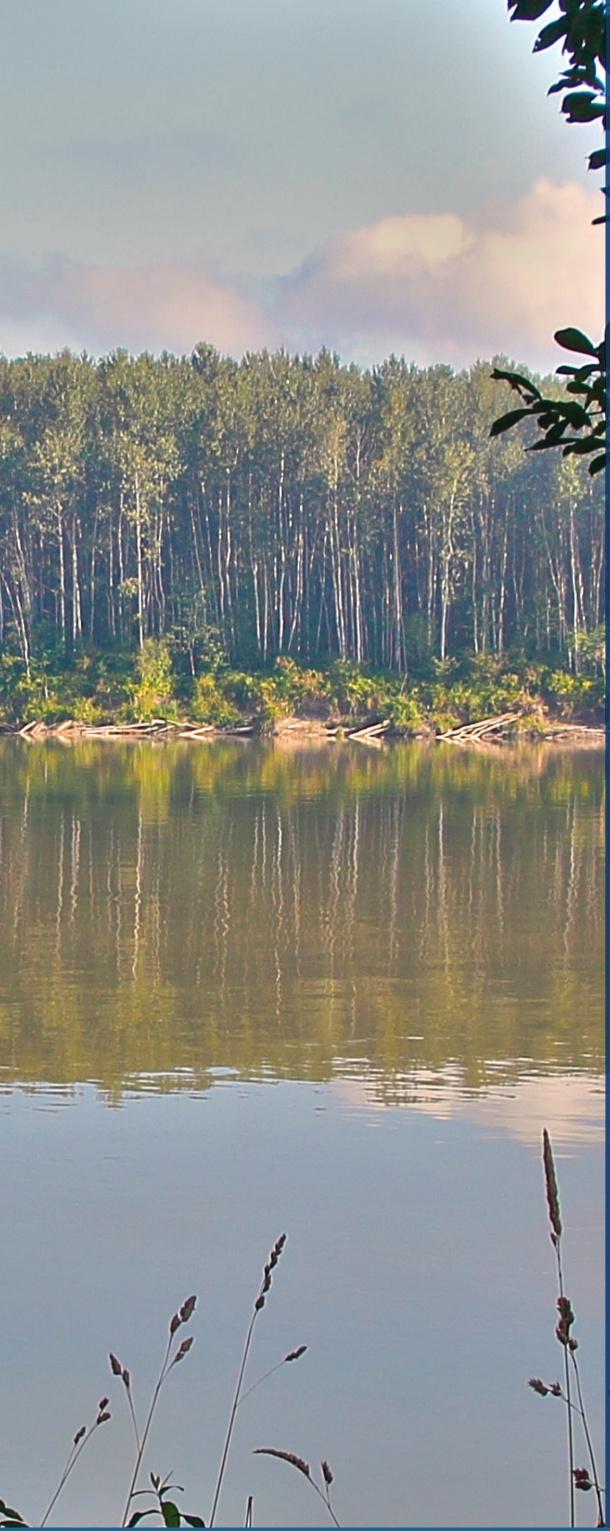


1.0 WATER SUSTAINS OUR COMMUNITIES

Through the Joint Abbotsford-Mission Water and Sewer Commission (AMWSC), both communities come together for regional water supply so that our people, our natural surroundings, our institutions and our economies can thrive. A water supply master plan outlines programs and capital projects to manage water in our region. This document is important for governance and making decisions toward water priorities as it signals to each municipality and its stakeholders how and why chosen projects will be implemented.

A water supply master plan encompasses a range of complicated issues, engineering analyses and technical reporting. This executive summary combines the results of multiple sub-phases of work conducted throughout 2017 and 2018. A list of all technical memos related to this Plan is provided at the end of the document.

1.1 WATER MASTER PLAN

A PROCESS TO EXPLORE AND DECIDE

The Abbotsford-Mission region is a desirable place to live and has become a growing hub of commerce and transport. A safe, resilient water system is critical to the ongoing prosperity of both communities; each municipality appoints elected officials and senior staff to develop plans for water services. A collaborative process for the Commission centers on five core principles to make water decisions for long-term investments:

- Apply the vision of each municipality to guide water priorities
- Lead with policy so that projects can be linked to defined goals
- Select investments that are affordable, adaptable and sustainable
- Balance customer goals with levels of service
- Make incrementable improvements for long-term benefits

When these principles are combined with best practise standards in the water supply industry, we are able to guide the technical analysis toward local goals and streamlines decision making. A four-stage process to develop the joint water supply master plan allows both communities through the Commission to set new priorities, review water assessment results and create direction for the regional system, setting priorities, reviewing water planning results and setting direction for the regional system.

Four Stage Process to develop a plan...

EXPLORE WATER HISTORY

SET GOALS AND DEFINE PRIORITIES

CONDUCT ANALYSIS AND REVIEW RESULTS

SELECT PROJECTS AND SCHEDULE INVESTMENTS

The results of this four stage decision-making process are integrated into this water supply master plan.

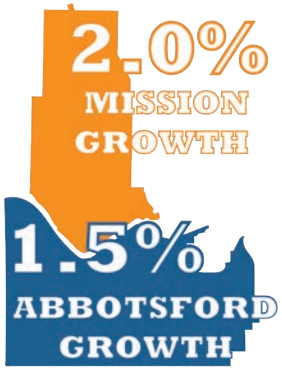
2 reservoirs	**1** soda ash facility	**19** wells (+ 2 mitigation wells)	**1** Cannell Lake UV system	**1** water treatment plant	**95 km** of water main	**5** bulk water meters

1.2 WATER MASTER PLAN

COMMUNITY PLANS & THE WATER SYSTEM

A water supply master plan describes the long-term direction for water supply and transmission and includes a schedule of investments to meet regional levels of service for customers in both Mission and Abbotsford. The location and change in population and land use, as well as local social-economic goals, greatly impacts water system needs. Each community's Official Community Plan (OCP) sets out a vision for land use, development and socio-economic goals which includes special themes for water and environmental management. Each OCP of Mission and Abbotsford helps to focus the priorities of the joint water supply master plan. Ultimately, the direct ties between policy and growth based on each municipality's OCP strengthens the confidence in work to date as it demonstrates that the project is being done to support the goals of the community, and not as a stand-alone water planning exercise. Excerpts from each OCP are consistent with respect to sustainability principles for water and infrastructure which demonstrates the alignment of the two municipalities in creating this joint master plan, such as:

- Commitment to water conservation
- Support for water meters
- Emphasis on green infrastructure
- Healthy watersheds and high-quality groundwater
- Push for smart growth, low-impact development
- Adaptable through variable climates
- Desire for reliable and affordable services



When Official Community Plans guide water master plans there can be local, relatable conversations with all stakeholders which creates stronger overall input as to how water interconnects with environment, infrastructure and daily life. Preparing for future growth, sizing capital projects, and designing water conservation are standard examples of how land use, population and OCPs influence water plans. The combination of water engineering and local community plans is a key ingredient for how water integrates with our daily lives.

> *The Joint Water System currently provides Potable water to approximately 164,000 residents in both the City of Abbotsford and District of Mission*

CASE STUDY PROFILE:

Almost 10 years ago, the AMWSC was presented with a pending water shortage and a reported need to significantly expand source supply. The capital cost estimates were very substantial. Discussions with community members, stakeholders, residents and business leaders emphasised the need to manage costs and take moderate, incremental steps to improve water. These conversations and the analysis by staff uncovered an alternative pathway: employ water conservation to buy a little time, then revisit water planning once each Community's OCP and growth plans were established.

Since that time, water conservation programs have lowered consumption rates such that many residents in the region, and in particular those with water meters, demonstrate per capita water use that rivals the lowest rates in the Province. Furthermore, while water conservation afforded extra time for planning, the Commission reviewed almost 15 new sources and also considered whether large scale pipes were ultimately needed given up-to-date population forecasts. The result of additional studies coupled with conservation has benefited this joint water master plan: the recommended actions and projects in 2018 are significantly more modest than that of 2010. Staff and elected officials take some pride in the history of water sustainability for the region and want to continue with commitments to realizing significant cost savings through modern water management.

1.3 WATER MASTER PLAN

INTEGRATED WATER THEMES

Water is all around us and yet we must take careful steps to manage it. How much water we need, when we need it, and how we safely get it to where it's needed become critical questions in a master plan. When we apply these questions now and 10 years from now and 20 years from now and so on, we can acutely understand where the system could become vulnerable and how we can best respond to keep our communities safe. And, perhaps more than most other public services, water management regularly shows us that when one part is changed, it similarly impacts all other parts too. Given how interrelated water is with so many other services, we often use guiding questions to make sure we've thoroughly looked at the range of issues and ideas.

When we apply these questions…

Are our supplies adequate for the long-term

How much can we gain from water conservation

What projects do we need, how much do they cost and when are they needed

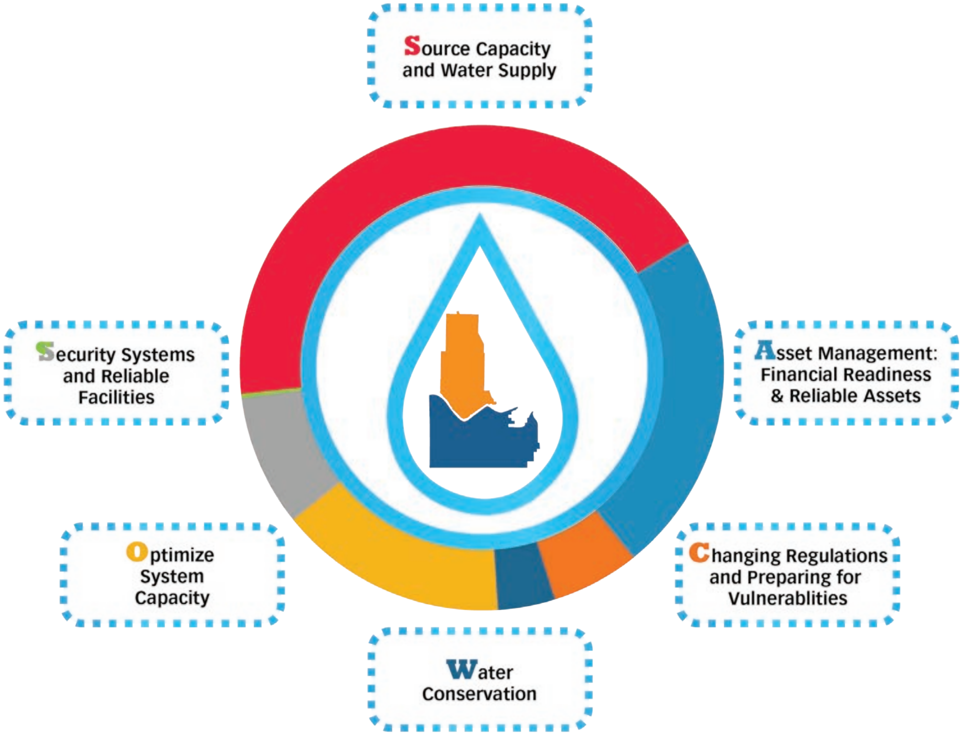
Do water supply and water demand affect projects in the same way

Are there other vulnerabilities to our water system we need to safeguard against

…we can acutely understand where a system could become vulnerable

Master plans get to the core of these questions and itemize projects to improve the system over the long-term. And after the in-depth discussion and technical analysis, the plan process begins to prioritize investment areas which demonstrate the resources needed to achieve the commision's goals for water management.

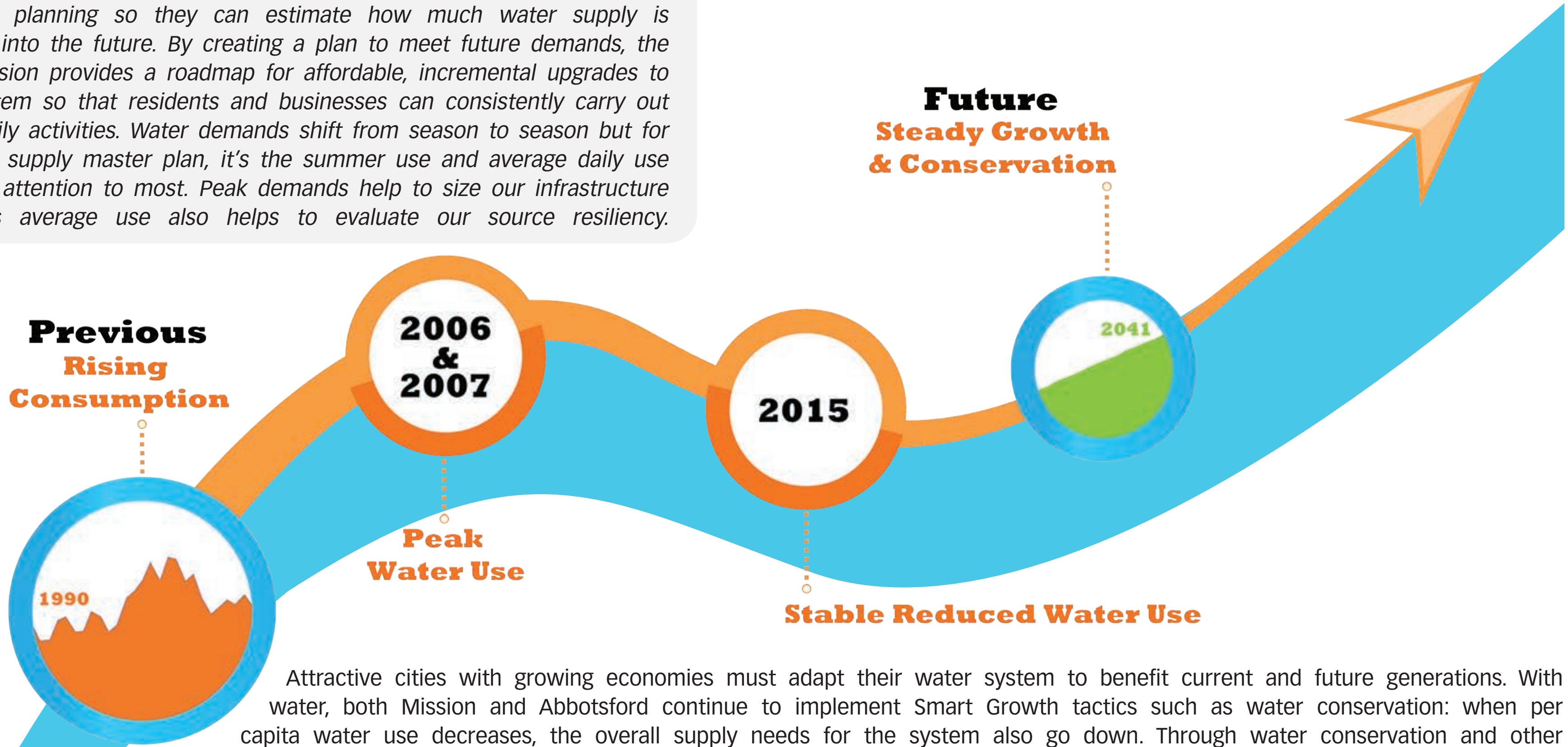
An effective Water Master Plan includes core investments and renewed policies for water source capacity, new security systems, enhanced strategic operations, system optimization, water conservation and improved asset management.



“Role Of Demand Planning”

Water demands tend to change and growing communities embrace demand planning so they can estimate how much water supply is needed into the future. By creating a plan to meet future demands, the Commission provides a roadmap for affordable, incremental upgrades to the system so that residents and businesses can consistently carry out their daily activities. Water demands shift from season to season but for a water supply master plan, it’s the summer use and average daily use we pay attention to most. Peak demands help to size our infrastructure whereas average use also helps to evaluate our source resiliency.

ACTUAL & PROJECTED WATER NEEDS



Attractive cities with growing economies must adapt their water system to benefit current and future generations. With water, both Mission and Abbotsford continue to implement Smart Growth tactics such as water conservation: when per capita water use decreases, the overall supply needs for the system also go down. Through water conservation and other policies to reduce water use, the Commission has delayed big, costly projects and as a result has both lowered the cost of new projects and the costs of operating the system. An important outcome of this joint water master plan is that water conservation and practical Smart Growth standards will further eliminate the need for major expansions, and prolong the life of existing facilities such as reservoirs, pipes and pump stations. When there is significant change in one area of water management, there is a corresponding effect on other categories too. Water master plans should address each major theme through capital projects and special policies so that the total of the actions leads to more sustainable water services. The order and scale of the projects and policies culminate into the overall master plan.

Water consumption is projected to increase over the next 20 years as we support our communities to grow: however, water conservation allows current and future customers to use only what they need to which helps to manage costs of services and delays the need for bigger infrastructure before it’s actually required. This joint water master plan includes expanding source capacity, increased water use resiliency and improving the transmission infrastructure so that adequate supplies can reach both municipalities for decades to come.

1.4 WATER MASTER PLAN

WATER SYSTEM CHALLENGES AND PRIORITIES

A successful water supply system can provide adequate and reliable supply to its customers now and into the future. Adapting to changes in population and climate, for example, creates the need for new projects and policies to maintain water services. The history of AMWSC to adapt to system challenges is evident by its current abilities to meet basic levels of service which stem in part from a steady, targeted water conservation program and a water supply source portfolio which is bolstered by two surface sources, Cannell and Norrish, as well as 19+ groundwater wells. But, pressures on the system to meet future levels of service creates a concise list of *challenges* which provides both the foundation and the focus for the analysis and reporting.

Regional Water Supply *Challenges*

- Need to increase water supply capacity before 2025 by 25MLD for current and future customers, then, add a second phase by 2041
- Need to update water conservation policy to achieve a 0.35% year over year reduction for all customer types to achieve a total savings of 13 MLD (10% overall) by 2041
- Need to update the list of optimization projects and meet levels of service for a 2041 MDD projection of 135MLD including more storage in Zone 4 and Dickson Lake
- Need to create an agreed-upon master plan including capital and operational activities for implementation by the Commission

Each *challenge* is made of other sub-factors and issues that affect schedules, outcomes and drivers to implement a range of solutions. Not all needs are the same and must be weighed separately so it becomes the responsibility of elected officials and utility staff to listen to customer input, conduct analysis and then evaluate the complete list of projects against a set of priorities. These priorities help determine the system gaps today, the potential gaps into the future, the factors that help when comparing alternatives, and the check-lists that help to ensure the outcomes are complete.

How to Integrate and Plan

a. Link OCP goals to water supply projects

b. Establish the rationale and benifits for each solution

c. Be mindful of financial capacities and implement reasonable cost programs

d. Listen to residents and make improvements to meet service expectations

How to Improve

a. Meet maximum daily demands when all sources are available

b. Meet average daily demands when one major source is unavailable

c. Meet permit requirements for water quality

d. Schedule capital works to keep water rates predicatable year-over-year

e. Keep system customers informed of water supply services & initiatives

f. Meet modern standards for efficiency, security, and compliance

Where to Invest

a. Resiliency upgrades: Projects that bring acceptable supply services across a range of risks and limit vulnerabilities

b. Adequacy upgrades: New works that help to meet the needs of growing communities

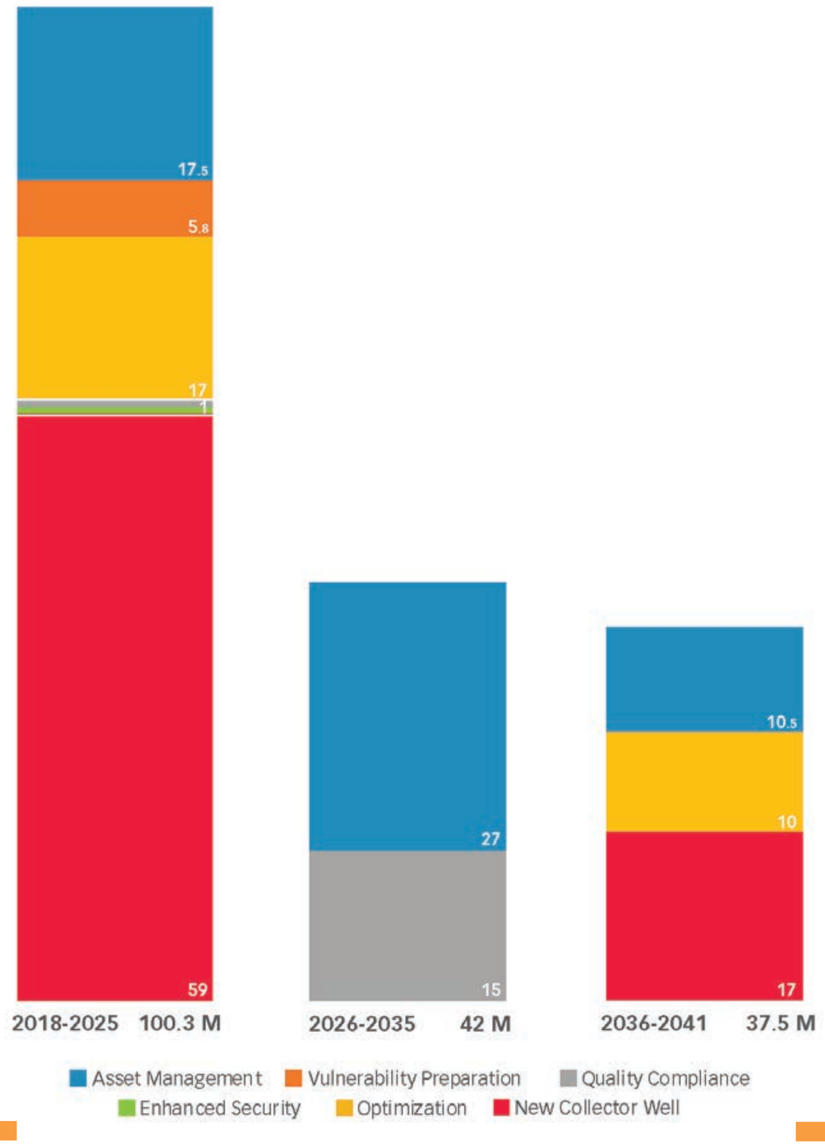
c. Reliability: Upgraded assets that last the tests of time and also provide redundancies

d. Optimization: To conserve and use only what we need and to optimize transmission.

Like the check-list above, every water system must have defined priorities to guide decision-makers to choose projects and to reflect on whether the water master plan is fully complete. Similarly, these priorities also kick-start regular points for ongoing monitoring for ways to enhance services throughout the year. While not every project or investment must address all priorities at once, Staff and the Commission apply these considerations throughout the master plan toward the whole capital plan to create a complete, justified and well-organized list of projects and investments. Just as new projects and system upgrades are important for both communities to grow in size along with reliable water services, this joint plan provides an opportunity to affirm the strengths of the existing supply regime and offer new insights into areas of sustainability and improvement.

To date, the water system has undergone incremental improvement: when one takes a step back and views all upgrades as part of the broader system, it is clear that regular, affordable upgrades keep the system safe and adequate for regional needs. Going forward, the Commission wants to mimic the past by making careful, gradual improvements so that in 25 years, both communities can reflect on an even stronger and more reliable water system. This joint master plan outlines a concise list of justified investments into the interconnected themes of water to carry on the tradition of regular system upgrades. Beyond the tangible infrastructure projects, there are other investments that allow the utility to comply with provincial requirements and remain a reliable water system. In total, the investments for the joint master plan include

2019 - 2045 INVESTMENT



2.0 INVESTMENT SUMMARY

Expand Source Capacity

Construction of a large horizontal groundwater source adjacent the Fraser River in order to meet current and future supply needs when one or more other sources are out of service.

- Top choice among 13 options for source expansion
- Phase 1 incl. 25ML/day by 2025 and 25ML/day more by 2040

Project Outcomes

$76M

- Source Redundancy/Flexibility
- Phased Expansion
- Low footprint/Lowest Cost – High Output
- Innovative and Practical

Strategic Operations and Compliance

Update strategic operations plan and licenses, in order to comply with regulations and best practices for water systems in BC.

- Update watershed protection plan to preserve filtration avoidance at Cannell Lake
- Attain groundwater licenses at all long-term wells
- Update water quality monitoring plan including monitor for corrosion, manganese and PH

Project Outcomes

$16M

- Increase system resiliency
- Exceed water quality requirements
- Comply with regulations and permits (now and future)
- Increase preparedness to avoid losses

Update Asset Management

Develop new methods to assess and respond to asset deterioration in order to maximize the life of assets by prioritizing upgrades and applying new techniques to rate performance.

- Complete groundwater well rehabilitation plan to 2021
- Renew assets including replace, repair, maintain and new policy manuals

Project Outcomes

$2.5M/YR

- Maximize the lifespan of our system
- Remain eligible for Grants
- Align with financial policies
- Fix priority issues and consistently deliver safe water

Optimize Regional Infrastructure

Expand Dickson Lake and construct a new zone 4 Reservoir to increase resiliency of the system through droughts or other significant watershed issues

- Install 4ML reservoir along Cannell supply line incl. Best Avenue Pump Station upgrades
- Expand Dickson Lake by up to 30% to manage climate variability

Project Outcomes

$27M

- Add redundancy to transmission system
- Improve adaptation to droughts
- Phased optimization
- Improve reliability of source portfolio

Protect Against System Vulnerabilities

Update response plans, agreements and hardware-systems, in order to safeguard source quality, supply consistency and to prevent unplanned shutdowns.

- Update plans to regulate land uses near wells and in the watersheds
- New emergency response plans
- Increase security at primary facilities to prevent unauthorized access
- Upgrade assets to withstand external threats e.g. seismic, power outage

Project Outcomes

$5.8M

- Safeguard water quality for generations
- Meets public goals to protect water values
- Apply management techniques at lower cost than built solutions
- Reliable sources through climate variability

Update Water Conservation

Purpose: Renew water conservation plan for all customers and reduce losses to achieve a highly efficient system

- Create new standards for development
- Expand metering and review economic incentives
- Reduce losses and non-revenue water

Project Outcomes

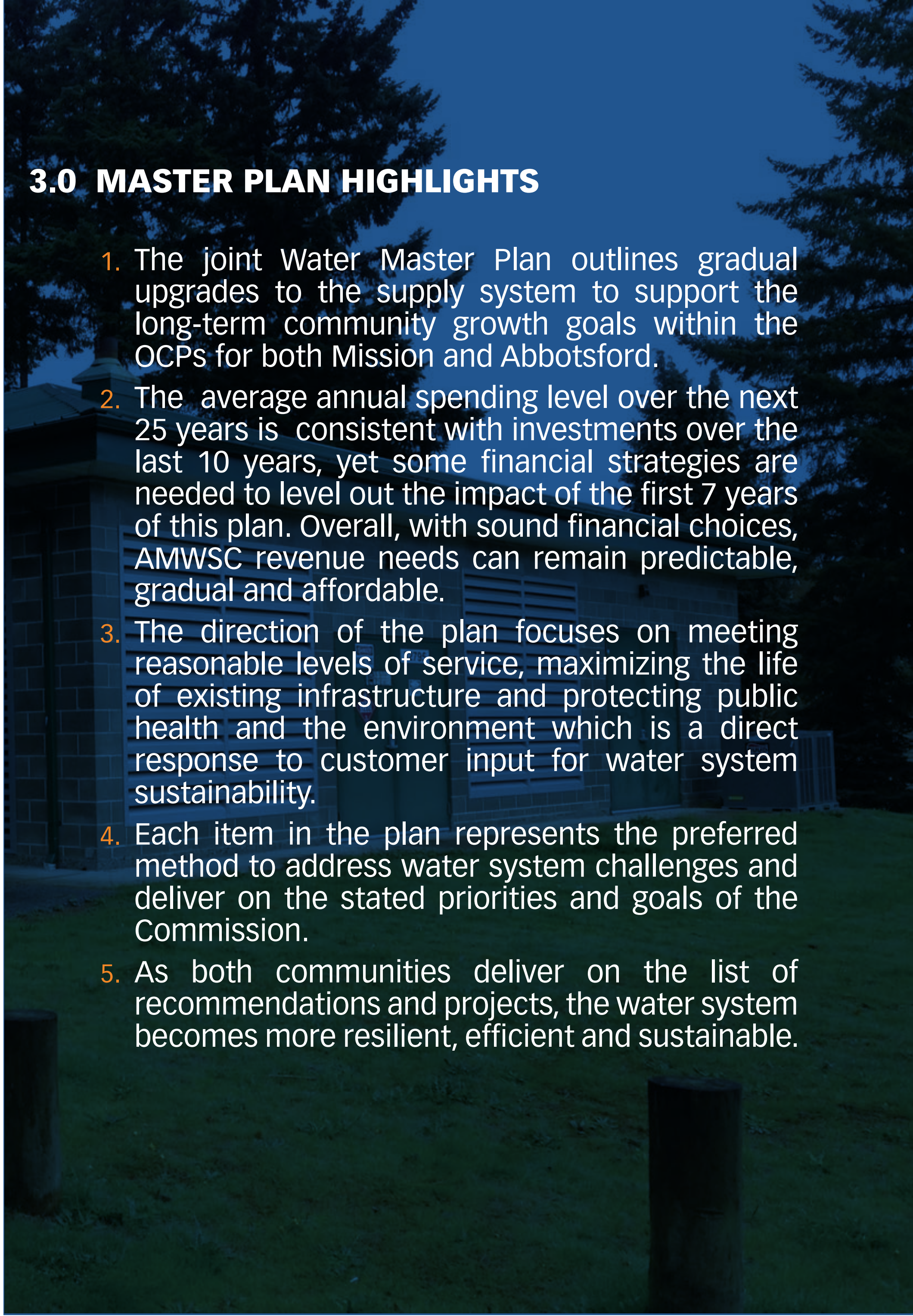
Not for Capital; Operational Budget Item

- Maximize existing supply-assets
- Meets public goals to respect water
- Controls costs of service and keeps water rates predictable
- Builds on strengths of existing program and recent success

🟦 Asset Management 🟧 Vulnerability Preparation ⬜ Quality Compliance 🟩 Enhanced Security 🟦 Conservation 🟨 Optimization 🟥 New Collector Well

In combination, the list of projects, investments and updates to strategic operations reflects the Commission's joint water master plan. Two key related operational strategies for future consideration by the Commission relate to defining ownership responsibilities for supply assets followed by establishing a long-term investment policy to guide how and when planned investments are best configured for financial sustainability. By combining governance strategies with a comprehensive list of capital investments, the Commission can look back favorably on its four-stage master plan process. To date, the core priorities of each Community's OCP were matched with industry-leading best practices for water systems to create a local, custom, comprehensive program to deliver water, sustainably for decades to come. Overall, with annual average investments nearing $7M over 20 years, there is strong rationale to approach senior government for grant support for the new collector well, and to resolve any long-term funding challenges through moderate rate adjustments between 5-10 years from now. There should be some pride and confidence in the community that the core outcomes of the joint master plan link directly with the original goals of the Commission and ultimately lead to reliable water services for decades to come.

REGIONAL WATER SUSTAINABILITY



3.0 MASTER PLAN HIGHLIGHTS

1. The joint Water Master Plan outlines gradual upgrades to the supply system to support the long-term community growth goals within the OCPs for both Mission and Abbotsford.
2. The average annual spending level over the next 25 years is consistent with investments over the last 10 years, yet some financial strategies are needed to level out the impact of the first 7 years of this plan. Overall, with sound financial choices, AMWSC revenue needs can remain predictable, gradual and affordable.
3. The direction of the plan focuses on meeting reasonable levels of service, maximizing the life of existing infrastructure and protecting public health and the environment which is a direct response to customer input for water system sustainability.
4. Each item in the plan represents the preferred method to address water system challenges and deliver on the stated priorities and goals of the Commission.
5. As both communities deliver on the list of recommendations and projects, the water system becomes more resilient, efficient and sustainable.

4.0 ENGAGEMENT

The development of the Joint Water Master Plan was presented in four stages. The table below summarizes the meetings and public engagement at each stage, leading up to the proposed final plan in Stage 4. In addition to the information in the table, a council workshop was undertaken for Abbotsford Council on May 25, 2017, and Mission Council in July 10, 2017. The City of Abbotsford has initiated the Plan 200K website for all of the City's projects that they are undertaking, including the Joint Water Master Plan discussed in this report. The information has been provided to Mission for updates on their website.

Council

- UMC (April 26)
- JSSC (May 18)
- Council Workshop:
  - Abbotsford (May 25)
  - Mission (July 10)
- Stage 1:
  - UMC (October 26) / JSSC (November 9)
- Stage 2 / 3:
  - UMC (Feb 21) / JSSC (March 22)
- Stage 4:
  - UMC (April 25) / JSSC (May 17)

Public Events & Online Engagement

- Farmers Market (Stage 1)
- Canada Day (Stage 1)
- Abbotsford Seven Oaks Mall (Stage 2)
- Abbotsford Clearbrook Library (Stage 3)
- Mission Leisure Centre (Stage 2 & 3)
- Website presence and updates (Stage 1)
- Social Media updates via Twitter, Faceboook and Instagram

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REFERENCE TECHNICAL MEMOS:

System Description
Water Demand Projections and Conservation Review
Supply System Capacity Needs-Projections
Supply System Hydraulic Criteria
Supply System Model Calibration
Supply System Optimization
Solution Set Development: Supply, Conservation, Optimization
Security System Assessment Report
Aquifer Assessment for Expanded Supply
Assessment of Matsqui Bend for Groundwater Supply
Phase 2 Reconnaissance Drilling
Asset Management Program Review
Water Quality – Transmission Assessment
Source Water Management
WMP Financial Review
Water Loss Management

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JOINT ABBOTSFORD-MISSION

WATER MASTER PLAN

Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#1

SYSTEM DESCRIPTION

URBAN systems

TECHNICAL MEMORANDUM

Date: November 14, 2017
To: Tyler Bowie, P. Eng
cc: Steve Brubacher
From: Suzan Lapp, Peter Coxon, Ehren Lee
File: 1790.0022.01
Subject: Water System Descriptions – Technical Memo 1

1. Introduction

The Abbotsford-Mission Water and Sewer Commission (the Commission) owns and governs the joint water supply system for both of its municipalities. In early 2017, the Commission initiated the *Water Source Supply Study* to examine reports and information sources with regards to water supply adequacy and demand projections, and ultimately, to arrive at a *solution set* for source expansion to accommodate growth and ensure reliable water supply services.

This memo summarizes the key infrastructures and sources that comprise the capacities of the system. The objective of the memo is to characterize the water system and define service challenges (now and in the future) to ensure that upcoming problem statements, analysis and reporting are based on a common baseline of facts and issues with regards to water supply. Findings from this memo will be combined later with the results of *Technical Memo 2: Demand Management Planning* to define the projected gap in water supply versus water demands in the design horizon. The interplay among the sources, the configuration of the pipe network, and the links between the municipal systems all factor into supply planning, as outlined herein.

1.1 System Overview

The Commission's water supply system consists of two surface water sources, Norrish Creek (fed by Dickson Lake) and Cannell Lake, along with 19 groundwater wells that augment the two surface water systems to meet peak demands. The transmission system, which conveys the treated water from these three sources, comprises approximately 86 km of large diameter piping and two crossings of the Fraser River. The transmission system is connected to two storage reservoirs, Maclure and Mt. Mary Ann, as well as 23 pressure reducing stations. Each member municipality, Abbotsford and Mission, are then responsible for the delivery of the treated water to their customers from these facilities. The customer base comprises of almost 165,000 residents and the equivalent of 100,000 people in terms of industrial, commercial, institutional, and agricultural demands. The attributes of each element of the supply system, including the existing performance of the portfolio of sources, is reviewed throughout this memo.

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1.2 Memo Summary

A core objective of the Water Supply Source Study is to develop cost-effective and implementable solution sets that comprise of water conservation, system optimization, and source expansion initiatives; this memo explores the existing and potential conditions for the latter two.

The Commission owns and operates a portfolio of sources which provides the ability to increase or decrease production at multiple locations to suit the conditions of the utility, including varying demands or environmental pressures. A review of the strengths and challenges of the portfolio can help to define emerging gaps in meeting the major service terms.

Core observations in regards to source capacity include:

- Cannell Lake provides consistent water quality, however, it's reliable capacity reflects only 15% of average day demand (ADD) supplies. Cannell Lake can be relied upon for greater capacities, up to 60 MLD, to help address maximum day demand (MDD); however, that support is short-term only, perhaps for up to a couple of weeks. Cannell Lake is the primary source for Pressure Zone 4 which prevents the need for Norrish Creek or groundwater supplies to be pumped to that particular high-elevation area.
- Groundwater wells can fluctuate in overall production and use; however, they typically demonstrate a higher operational footprint including energy, permitting, and renewal. Groundwater quality is trending poorly at some wells which will offset the long-term expansion potential. Groundwater can currently provide up to 55 MLD which represents 50% of MDD and 66% of ADD and, therefore, the overall capacity (e.g. more wells) could be increased incrementally, however, not without extensive regulatory processes.
- Norrish Creek can supply 89 MLD and can independently meet 100% of ADD during periods of regular source water quality. Norrish Creek is unable to meet MDD demands on its own due to pipe size limitations of the main Norrish transmission line. Upgrades to the Norrish supply main could enable this source to provide up to 135 MLD or 100% of the supply needs of the system for about 20 years (to 2035), assuming that moderate demand management programs occur which keep per capita consumption similar, but not greater, than existing demands.

Overall, the evaluation of future sources should consider the performance of the existing portfolio (the collective capacity of the sources) as well as other criteria based on political, technical, and public themes. Subsequent memos will evaluate new sources as part of solution sets for consideration by the Commission in developing its long-term water supply plan.

Similarly, the ability to adequately convey potable water (from a reliable portfolio of sources) throughout the system is based on the capacity of the existing infrastructure, which can be exclusive of the capacity of the source. A major element to understanding capacity is to appreciate levels of service. While not explicit in documentation leading up to this study, our review of existing services and system operation and industry best practices point to a proposed, concise list of service terms including:

- Major Service Target: *All maximum day demands (MDD) should be provided by the three supply sources and their transmission systems, independent of Abbotsford and Mission reservoirs and without deficiencies at any of the 23 regional-local system interconnection points.*
- *Major Service Target: There is adequate supply and transmission redundancy to provide average day demands in the event that one of the main sources is unavailable due to environmental (e.g. turbidity, drought) or mechanical issues.*
    - *Note: It is considered an unusual level of service for a source portfolio to meet MDD with the entirety of one of the larger sources temporarily out of service.*
- Major Service Term: *Potable water quality standards, based on service authority permits, can be consistently met under foreseeable, and reasonable conditions.*
- Major Service Term: *The cost of water supply ensures the long-term integrity of meeting service terms 1-3 at a predictable rate.*
- Hydraulic Service Terms are summarized separately as part of the supply and transmission master plan.

Generally, in terms of performance, the system of sources and conveyance infrastructure is able to meet the proposed service terms most of the time. However, drought, climate change, hydraulic deficiencies, and demand growth from community development will create challenges for the existing system to meet service terms. Future reports and findings as part of this study should address a short list of questions as part of the desired outcomes of a prioritized list of solution sets to be implemented by the Commission.

1. Are the major and hydraulic service terms listed herein adequate in their depth and breadth?
2. Are significant upgrades needed (i.e. beyond regular renewal) to achieve the 55 MLD groundwater potential withdrawal rate? Are there any additional factors that limit or reduce the capacity (existing or ultimate capacity) of the groundwater well system?
3. Are there any foreseeable and reasonable conditions or hazards in the Norrish Creek/Dickson Lake watershed that would limit capacity at the Norrish Creek Plant to less than 45 MLD for an extended period of time (e.g. 1 week)? What is the potential for Norrish Creek source to be completely offline for an extended period of time (e.g. more than 1 week)?

4. What is the relationship between transmission system upgrades to meet *service terms* (e.g. optimization projects) and the location and size of existing or new sources?
    - Example: Would relying upon groundwater to a greater extent reduce the need, scale, or timing of any optimization projects?
    - Example: Would a new source such as a collector well or a surface source reduce the scale or timing of optimization projects?
5. Will growth in Pressure zone 4 ultimately exceed the supply potential of Cannell Lake?

A measure of effectiveness for Technical Memo #1 is whether or not the system has been reasonably characterized in terms of existing assets and capacities and the completeness of a list of emerging gaps in delivering services going forward. The information and discussion provided herein expands the characterization of the system and includes key issues for further review in subsequent stages of the study.

2. Norrish Creek Supply Review

Norrish Creek represents the largest supply source for the Commission and includes water filtration to enhance water quality to meet public health requirements as dictated by the system permit. Any long-term source planning includes the considerations of Norrish Creek for current and future water needs.

2.1 Catchment Hydrology and Hydrometrics

The hydrology of Norrish Creek includes multiple attributes and hazards that factor into long-term supply adequacy and reliability, such as the following list of observations.

- The entire Norrish Creek watershed is located on the north side of the Fraser River and has a total land area of 118 km2; approximately 78 km^2 is dedicated as Norrish Creek Community watershed which is the supply area for the source. Key hydrological catchments that comprise the Community watershed include West Norrish Creek (~17 km2), East Norrish Creek (~19 km2), and Dickson Creek to Dickson Lake (~11 km2).
    - The water intake is located approximately 10 km downstream of Dickson Lake on Norrish Creek (KWL, 2009a).
    - Ultimately, Norrish Creek flows into Nicomen Slough which discharges to the Fraser River near Dewdney.
- Dickson Lake provides storage for the Norrish Creek system that is released during the summer and early fall to meet the peak flows demands.
    - Forest harvesting has been active in the watershed since the 1940’s with Teal Cedar Products Ltd. and Tamihi Logging Ltd. as the permit holders.

  - Erosion and sedimentation concerns stem from logging, forest fires, and recreation activities (e.g. ATV, hikers) which affects the reliability of consistent water quality. Watersheds subject to similar risks often establish vigilant source protection frameworks.

- Elevations in the watershed range from 250 m at the intake to 1,420 m at Mt. Deroche along the eastern headwaters (Chapman, September 2000, Assessment of the Norrish Creek Watershed). Precipitation in the watershed occurs as both rain and snow. There is no precipitation data available for the upper portions of the watershed with Mission West Abbey (Environment Canada station 1105192) being the closest station (see Section 3.3 for additional details). The 300-800 m elevation zone is referred to as the transitional snow zone or the rain-on-snow zone where both rainfall and snowfall occur during the winter.

- The lower reach of Norrish Creek, immediately upstream of the intake, is confined by steep banks and is generally non-alluvial. Course sediment is deposited into the main stem of Norrish Creek from the upstream tributaries (i.e. Hanson Creek and Cyr Creek) which experience a significant level of landslides associated with past forestry activity (Chapman, 2000). Dickson Creek has a moderate gradient of 8% and actively transports bedload into Norrish Creek.

- The hydrometric program includes the following sites (KWL, 2016):

  - Dickson Lake;
  - Dickson Creek immediately downstream of Dickson Lake dam (to measure the controlled release);
  - Dickson Creek ~130 m downstream of the Dickson Lake dam (to capture the controlled release plus seepage underflow);
  - Norrish Creek ~230 m upstream of the water intake; and,
  - Norrish Creek at the concrete weir, immediately downstream of the water intake.
    - A manual snow course in the Dickson Lake watershed (ID #1D16) was established in 1991 and is part of the BC snow survey network.

- Two hydrometric stations were discontinued on Norrish Creek: Station # 08MH058 (Norrish Creek Near Dewdney) from 1960-2007 (117 km2); and Station #08MH150 (Norrish Creek above Rose Creek) ~300 upstream of City's water intake from 1984-2006 (78.2 km2). Enclosure A includes the hydrometric results from the historic stations as well as a figure illustrating snow courses and snow water equivalents.

- Peak flows in Norrish Creek are rain and snow generated and therefore occur in the fall and again during spring freshet. Flows decrease in the winter (December to March) and reach minimum levels during the summer season (June to October).

  - The average annual 7-day low flow was 146 MLD prior to the construction of the Norrish Creek water system in the 1980s. In 1973 the creek flows slowed to 67 MLD and an extreme low flow of 42 MLD was recorded in 1985 after the construction of Dickson Lake dam (KWL, 2016).

2.2 Norrish Source: Raw Water Storage Capacity – Current and Future

Dickson Lake levels are controlled by the Dickson Dam, which was built on a rocky landslide deposit. The amount of storage capacity including allocations for other users/uses dictates the reliability and adequacy of storage. Key attributes and considerations for storage capacity are outlined below.

- The geotechnical composition of the dam results in some seepage (KWL, 2016) which occurs 100 m downstream of the dam, and the determined rate of loss is dependent on lake level (KWL, 2009a).
  - The seepage rate can either be considered as a “seepage-as-loss” or “seepage-as-release” (i.e. be considered towards the City’s minimum fish flow). If the seepage rate was classified as “seepage-as-release” then any future license expansions would be reduced accordingly.
- Dickson Lake is licensed to store 15,900 megalitres (ML) and, of that 4,600 ML is gravity released through the outlet and 11,300 ML is pumped out (AE, 2008). This equates to ~20 m of licensed drawdown available on the lake, of which the upper 6 m is gravity controlled.
- A summary of the Commission’s water licences for Norrish Creek / Dickson Lake is shown in Table 1.

Table 1. Summary of Norrish Creek / Dickson Lake Water Licences (AMWSC). ML = megalitres; MLY = megalitres per year; MLD = megalitres per day.

NORRISH CR and DICKSON LK	WATERWORKS	STORAGE		PRIORITY DATE	NOTES
Licence	Max Annual	Max Daily	Volume		
	MLY	MLD	ML		
C064449 Norrish Creek	N/A	11.4	N/A	19600609	Substitution of C028975. Section 15 Amendment*
C063061 Dickson Lake	N/A	N/A	5,674	19700105	Supports C126189 (previously C063060)
C126131 Norrish Creek	19,911.9	90.92	N/A	19910528	Substitution of C102980. Condition clause f **
C126131 Dickson Lake	N/A	N/A	10,225.5	19910528	
C126189 Norrish Creek	9,547.00	39.2	N/A	19700105	Substitution of C63060. Condition clause f***

*Section 18 Amendment: Maximum yearly diversion omitted December 15, 1992.

** C126131 Clause f) - water may be placed in storage throughout the whole year and water may be used for waterworks purpose throughout the whole year providing that the licensee releases water from Dickson Lake storage at a rate equal to the amount taken at the intake plus 0.08495 m^3/s when natural flows are less than 1.416 m^3/s as measured flowing over the control structure (weir) located at the intake structure.

*** C126189 Clause f) requires instream flows "as may from time to time be ordered by an Engineer under the Water Act for the preservation of fish life".

- Norrish Creek water licences provide a maximum storage of ~15,900 ML per year in Dickson Lake and a maximum withdrawal of 141.5 ML per day.
    - The Conditional Licence C126131 and C126189 both include a clause f), as stated in Table 1 that require minimum flow releases.
    - There are no other licensee's on either Norrish Creek or Dickson Lake.
    - The maximum daily capacity that Norrish Creek can supply is 89 MLD (AECOM, 2010).
- Recommended minimum fish flows were developed in 1975 by DFO (Cleugh et al. 1979) with the goal of maintaining salmon habitat and constant flow in Norrish Creek. These flows on lower Norrish Creek comprise of flow over the intake weir plus natural flow downstream of the intake.
    - June to October: 121 to 183 MLD
    - November to May: 242 to 363 MLD
    - It should be noted that the minimum recommended flow in June to October of 121 MLD is below the license requirement of 122.3 MLD (refer to C126131 Clause f)).
- Norrish Creek and its tributaries are fully recorded as of 1995:
    - (http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/water-rights/water_allocation_restrictions_may2016.pdf).
    - Therefore, in order to apply for additional water licences on Norrish Creek, additional storage is required.
- Future storage capacity and options for increasing storage were considered in a report conducted by KWL (2009b) which concluded that any expansion plans must address the seepage-loss classification issue as either a release or loss (important for fisheries and minimum instream flows).
    - If the average daily diversion is increased to 141 MLD from 119 MLD then expansion of the reservoir would be required (includes both Commission demands and instream flow requirements).
    - The risk of the Dickson Reservoir not refilling completely with an increase in either 18% or 21% storage capacity is in the order of 1 in 25 years (KWL, 2009b).
    - Any additional source capacity for Norrish Creek will require storage expansion if deemed possible based on instream flow requirements, fish flow requirements, pumping needs, and

projections of reliable watershed yield. Further consideration to the cost and energy requirements of pumping water from Dickson Lake should be considered if Norrish is ever expanded.

2.3 Treatment and Conveyance Capacity

Demands drawn from Norrish Creek are treated at the Norrish Creek WTP where thereafter potable water is conveyed via the primary Norrish supply pipe. Further considerations for treatment and conveyance capacity are summarized below.

- Current capacity of the water treatment plant is 135 MLD. The water treatment plant comprises two treatment systems:
  - 90 MLD of slow sand filtration and,
  - 54 MLD of membrane filtration; however, we understand that internal channel capacity limits overall reliable capacity to 45 MLD.
  - All the treated water is chlorinated before it leaves the WTP. Final treatment involves ammonia addition to form chloramines and soda ash addition to raise the pH at Bell Road before any consumption occurs (the soda ash facility is infrequently used).
- Norrish Creek's raw water quality can be described as generally good, low in turbidity, colour, and natural organic material, making slow sand filtration a suitable treatment technology. However, the creek experiences high turbidity and organic events during periods of heavy rain and runoff.
  - During high-turbidity events, the slow sand filters are taken out of service to protect them from blinding off; then, only the membrane treatment system is relied upon to produce treated water. As a result, high turbidity events compromise the adequacy and redundancy of water supply for the Commission.
  - Given that the licensed capacity of Norrish Creek system is greater than the WTP treatment capacity, the WTP plus supply main hydraulics are the limiting factors for water supply.
- The Norrish Creek transmission main system (900 Hyprescon and 750/ 600 welded steel mm dia.) conveys the treated water from the water treatment plant (elevation 244 mASL) by gravity to the service area.
  - Interconnection pipes spread throughout the service area in select locations to further convey treated water to municipals systems in District of Mission (Pressure Zone 3 and lower) and for most of the City of Abbotsford.
  - There are two crossings from the north side of the Fraser to the south, referred to as the First River crossing (westerly) and the Second River Crossing (easterly). The First River Crossing comprises a 600 mm dia. steel line and the Second River Crossing comprises a 1050, 900 and 600 mm dia. welded steel line.

- Based upon modelling undertaken by Geoadvice (2012), the maximum sustainable flow of the Norrish Creek transmission system is 89 MLD. Given that the treatment capacity is greater than the conveyance capacity, the conveyance capacity is the limiting factor on the supply side.

2.4 Norrish Creek Supply – Summary Source Framing

The Norrish Creek Source is the largest source of the Commission and it's equipped with advanced water treatment. The adequacy of the source to meet planned and unplanned demand events, such as growth and high-turbidity or drought events, ultimately limits its expansion potential. In summary, the ability to optimize use of the Norrish Creek Source relates to these critical factors:

- The current capacity of the source is 119 MLD, however, license capacity allows for 141 MLD; to meet that capacity would require additional storage and greater flow management to maintain instream flows for fish, especially during low flow periods which coincide with highest potable water demand periods. There is some question as to whether greater withdrawal to meet license capacity and maintaining instream fish flows is possible during the summer months and, in particular, if drought conditions worsen (e.g. become more frequent or last for longer periods of time).
- Any expanded use of the Norrish Creek source requires further consideration to the causes, frequency, and timing of turbidity events which will ultimately dictate whether or not to expand the capacity of the membrane treatment processes.
- Any expanded use of the Norrish Creek source requires expansion to the main supply pipe; this is first priority because treatment and storage expansions are ultimately limited by the 89 MLD capacity of the pipe.

Storage, treatment capacity, and conveyance capacity limit further expansion of the Norrish Creek source. In addition, turbidity spikes, droughts, and operational costs combine with capacity limitations to warrant the review of other sources to compare against further investments at Norrish. In particular, latter stages of the Water Supply Source Study will compare the cost-benefit of expanding storage, conveyance, or treatment at Norrish against other sources such as groundwater or new sources. Upgrades are likely required to maintain reliable supply assuming Norrish remains a key source in the Commission's supply portfolio.

3. Cannell Lake Supply Review

Cannell Lake is a complementary source to Norrish Creek and groundwater wells. It is located approximately 13 km north of Mission's town centre and provides 10-15% of the AMWSC's annual water supply. During times when Norrish Creek is off-line, it provides a greater percentage of the instantaneous supply. The source water quality is consistently high year-round. Treatment includes UV-disinfection and chloramination. Any long-term source planning includes Cannell Lake for current and future water needs.

3.1 Cannell Catchment Hydrology and Hydrometrics

Key observations regarding the hydrologic conditions of the Cannell Lake watershed are outlined below.

- The contributing area to the lake is 2.1 km2, with no significant perennial tributary streams.
- The surface area of Cannell Lake is 35 ha and is contained within Crown Land.
  - The watershed is classified as a Provincial "watershed reserve" (AMWSS, 2014).
  - The elevations throughout the watershed range from the lake level of 278 m up to a maximum of ~650 m, with moderately steep slopes.
- The catchment aspect is generally North to South with the Cannell Lake in the same orientation. The lake discharges to Stake Lake via Cannell Creek and Cardinalis Creek (KWL, 2008).
  - The watershed is part of the Coastal Western Hemlock biogeoclimatic zone and the vegetation consists of second-growth forests that have been affected by forest fires and logging in the 1940s. Snow can occur in the watershed, but the development of a significant snowpack is rare.
- There are no Environment Canada precipitation stations for Cannell Lake watershed, however, the Commission has used a hydrometric station which has been in operation since 2012. The nearest current precipitation stations are the Environment Canada gauges at Stave Lake and Mission West Falls. Previous studies attempted to develop partial water balances based on water levels and withdrawals. Both water balances demonstrated that there is little excess in the water balance for potential increase in withdrawals. Data for the precipitation levels and water balances are outlined in Enclosure A.

3.2 Cannell Lake Source: Raw Water Storage Capacity – Current and Future

Cannell Lake is an interesting example of a source with a license capacity that greatly exceeds its reliable watershed yield. This cements its role as a complementary source, which provides a relatively low baseline of water supply and occasional peak withdrawals, but cannot be relied upon for any expansion. Key observations regarding the storage and license capacity of Cannell Lake are summarized below.

- Cannell Lake water licences provide ~1,850 ML of storage, and a daily maximum withdrawal of ~69 MLD (for a limited period of time; this value varies with time of year and lake level) and daily average allocation of 11.83 MLD. A summary of the AMWSC water licences is provided in Table 2.
- The elevation of the lake spillway is 278.8 mASL (i.e. full pool) and the dam outlet pipe is at 274 mASL (AMWSS, 2014).
- Of Cannell's licensed storage capacity (~1,850 ML), ~1,600 ML can be accessed through gravity. The remaining storage is accessed by a floating pump station.

Table 2. Summary of AMWSC Cannell Lake water licence. ML = megalitres; MLY = megalitres per year; MLD = megalitres per day.

CANNELL LAKE	WATERWORKS		STORAGE	PRIORITY DATE	NOTES
Licence	Max Annual MLY	Max Daily MLD	Volume ML		
C065225	N/A	6.9	N/A	19680416	Substitution for C34998. Section 15 amendment*
C065226	N/A	N/A	1048.5	19680416	Substitution for C34999.
C065227	N/A	2.3	N/A	19400529	Substitution for C16978. Section 15 amendment**
C065228	N/A	N/A	801.8	19400529	Substitution for C16979
C127478	1000	60		20090303	Conditions clause j - l

* Section 15 amendment: max yearly diversion omitted June 30, 1992.

** Section 15 Amendment: max yearly diversion omitted April 14, 1989.

***Clause j) states the minimum lake levels required on specific dates; clause k) "that this license does not authorize the diversion and use of water at any time and to any extent when the water level of Cannell Lake falls below 273.25 mASL"; and, clause l) states "the diversion of water…may be regulated at any time by an order of an Engineer under the Water Act, in order to maintain storage in the lake for preservation of aquatic life".

- The Cannel Lake maximum daily withdrawal cannot be sustained to meet peak flow demands during the summer and early fall months and should only be used to meet demands when Norrish is taken offline (District of Mission, 2012). A reliable annual yield during a 25-year drought is 3,420 ML, while a reliable yield during a normal year is 4,800 ML (AECOM, 2010; KWL, 2008). Cannell Lake water licences have the following provisions included for the protection of fish and aquatic life within the lake (Table 3).

Table 3. Cannell Lake Water Licence C12748 Lake Level Provisions.

Lake Level Requirements	
Clause j) Minimum lake levels must be maintained	
Oct-01	274.4 mASL
Nov-01	275.2 mASL
Dec-01	276.2 mASL

Lake Level Requirements	
Jan-01	277.0 mASL
Feb-01	277.7 mASL
Mar-01	278.3 mASL
Apr-01	278.7 mASL
Apr-15	278.8 mASL
May-15	278.8 mASL
May 16- Sept 30	273.25 mASL

- Additional water licences are also held on Cannell Creek downstream of Cannell Lake by other licensee's (Table 4); they total ~509.7 MLY on Cannell Creek. The licence F046108 has priority over two AMWSC licences (C065225 and C065226) and all of these licences have priority over the AMWSC C127478 licence. There are additional water licences on Cardinalis Creek, however, their points of diversion are located upstream of the confluence with Cannell Creek and do not impact the AMWSC water licences.

Table 4. Additional surface water licences held on Cannell Creek downstream of Cannell Lake

Licence	Daily Diversion (m^3/day)	Priority Date	Notes
C119433 Cannell Creek	0.909	19880127	Livestock
	1363.827	19880127	Pond & Aquaculture
F046108 Cannell Creek	31.823	19620915	General Land Improvements

- Recent studies evaluated the productivity and hydrologic considerations for the Cannell Lake watershed to determine a reliable capacity of the watershed in a normal year. The factors related to watershed size, climate, licences, and lake level requirements create a complex relationship with supply forecasting and generally encourage prudent estimates. Overall, the findings suggest an ongoing withdrawal of 11.8 MLD from Cannell Lake can be supported in a normal year.

3.3 Treatment and Conveyance Capacity

The water from Cannell Lake can be described as generally good in terms of water quality, exhibiting low turbidity and colour. Unlike the Norrish Creek supply, it is less susceptible to seasonal water quality spikes. Other factors affecting treatment and ultimately hydraulic capacity of the Cannell Lake source are outlined below.

- Water treatment processes include UV and chloramination:
    - Water is UV disinfected and chlorinated 1km downstream of Cannell Lake and then ammonia is added at the Cannon Pit PRV station, 7 km further downstream.
    - The treatment capacity is estimated at 70 MLD which roughly equates to the daily maximum withdrawal license capacity of 69 MLD. However, this flow rate is not sustainable due to the limited watershed and downstream hydraulic limitations.
- The limited precipitation data coupled with previous partial water balances suggests that a daily safe withdrawal rate could be as low as about 11.8 MLD, only 15% of the licensed capacity.
- Downstream licences take priority which further limits withdrawal abilities under certain conditions.
- The Cannell Lake transmission pipe (twinned) conveys treated water from Cannell Lake (Elevation 274 m) by gravity to the service area. Interconnection piping further conveys Cannell Lake treated water to municipal systems in each municipality: Mission (Pressure Zone 5 and lower) and all service areas within Abbotsford.
    - Cannell is the only supply for Pressure Zone 4 in Mission.
    - Cannell Lake supply water crosses the Fraser River in the same pipes as water supplied by the Norrish Creek system; at this point, the two supplies are fully blended.
- Previous master plans and hydraulic modelling studies estimate the current maximum sustainable capacity of the Cannell Lake transmission system at 48.7 MLD. However, these demands have not been experienced – so this is a theoretical carrying capacity.

3.4 Cannell Lake Supply – Summary Source Framing

The Cannell Lake source is a complementary supply that provides consistent water quality year-round with a reliable yield of 11.8 MLD. While Cannell Lake has the license capacity to provide daily demands up to 69MLD, this is an unsustainable draw because it exceeds the average inflows to the lake. Licensed lake level requirements further limit withdrawal rates. Overall, the limitations to Cannell Lake prevent it from being relied upon to meet major gaps in existing and future demands. Cannell Lake is currently the primary supply source for Mission Pressure Zone 4 and must be reserved to meet the zone's maximum day demands and also 225 L/s in fire flow demands for 3 hours.

Cannell Lake is poised to remain a complementary source, but does not yet present a case for major investments (e.g. expansions) to meet growing demands or to provide additional supplies during unplanned events.

4. Summary of Abbotsford Sumas Aquifer and 19 wells

The AMWSC currently owns and operates 19 wells that are generally located in the southern portion of the Abbotsford area. The first of these wells were developed as the primary water supply for the former Village of Abbotsford and District of Matsqui, prior to the development of Norrish. Since then, the four Bevan wells were added in 2008. The wells play a critical role in bolstering the integrity of the AMWSC water supply in two primary areas:

- They augment the two surface water systems during periods of peak demand and,
- They are critical to maintaining supply, should the Norrish system, either of the two river crossings or either of the trunk mains conveying water from the surface water systems, be compromised. This criticality was demonstrated in 2013 when the Norrish Creek Water trunk main was out of service for seven weeks after being damaged by a rock slide (AE, 2014).

There are several concerns with the wells with respect to water quality, general engineering/design standards, and regulatory compliance. Primary water quality concerns are elevated manganese and nitrates. Some wells also exhibit arsenic levels just below GCDWQ levels. While most of the wells are chloraminated or chlorinated, there have been issues with maintaining system residuals during extended periods of exclusive groundwater supply.

Several of the earlier developed wells (particularly the 15 that were developed prior to 1995) show signs of aging and require upgrades to maintain serviceability and, in some cases, to achieve compliance with the BC Groundwater Protection Regulation (BC GWPR). In addition, the wells have not been reviewed to ensure compliance with the Guidance Document for Determining Ground Water at Risk of Containing Pathogens (GARP) (AE, 2014). Depending upon how the BC Environmental Assessment Act is interpreted, certain new works to maintain/rehabilitate the existing wells may be considered to be a “reviewable project” under the Act.

4.1 Groundwater Capacity and Water Quality

The 19 wells are generally recognized to currently have a combined capacity of 55 MLD. However, a recent report prepared by Piteau (April 2017) indicates that the yield could be as high as 69.9 MLD (see Table 5 below). This is, however, based upon pump tests and pump performance curves and has not been demonstrated under a real demand scenario. Unlike surface waters supplies, well capacities do reduce with time and wells have to be redeveloped every 5 – 10 years to maintain their yield. Also, depending upon aquifer recharge and seasonal variations, both of which are related to precipitation, geotechnical conditions, and runoff, interference from adjacent wells can significantly impact and reduce sustainable well yields.

Table 5 below provides a summary of the rates of extraction from the wells over the past 14 years. Based upon this data, 2013 saw the wells pumped at their highest rate of 48.1 MLD.

Table 5 Groundwater Well Flow Statistics

Year	Annual Flow (MLY)	Instantaneous Average Flow (MLD)	Maximum Flow (MLD)
2003	1,848	6.1	29.7
2004	1,758	7.0	38.7
2005	1,329	6.6	25.7
2006	1,509	7.9	36.8
2007	1,978	7.5	37.3
2008	1,315	5.2	33.5
2009	1,834	6.0	33.1
2010	963	4.2	20.2
2011	865	3.5	15.3
2012	1,166	4.6	23.2
2013	2,975	13.0	48.1
2014	1,423	5.6	19.2
2015	4,582	15.7	44.4
2016	2,610	8.0	26.9

Unlike the two surface water supplies that rely upon major trunk mains, reservoirs and PRVs (x23) to convey the water to the points of demand, the water from the wells is generally distributed through smaller distribution lines directly to the rest of the system.

Table 6 below provides a summary of the wells and the instantaneous pumping rate for each well. There are 6 wells that have concerns or potential concerns with regards to water quality. Removing the wells with water quality concerns from the overall well supply, would reduce the available capacity to 55.9 MLD.

Table 6 Summary of Production Well Information

Well ID	Instantaneous Pumping Rate (MLD)	Wells with Water Quality Concerns Removed (MLD)
AMWSC Wells		
Farmer #1	5.7	5.7
Farmer #2 1	3.8	-
Farmer #3 [2]	2.2	-
Industrial A [2]	0.8	-
Industrial B [2]	3.3	-
Industrial C	5.1	5.1
Riverside #1	2.5	2.5
Riverside #2	1.5	1.5
McConnell	1.9	1.9
Pine Well [3]	not in service	not in service
Marshall #1	not in service	not in service
Marshall #2	2.8	2.8
Marshall #3	7.8	7.8
Townline #1 [1]	3.9	-
Townline #2	2.7	2.7
Bevan #1	8.3	8.3
Bevan #2	8.9	8.9
Bevan #3	0.3	0.3
Bevan #4	8.4	8.4
Total (MLD)	**69.9**	**55.9**

[1] Elevated nitrates/Mn

[2] Arsenic concerns

[3]. Elevated hydrocarbons/nitrates/Mn/Fe

If the wells are to be relied upon in the future to provide more supply to the overall system, there is the possibility that the water quality could deteriorate further at certain wells as more flow is induced from the recharge areas and the aquifer to satisfy these demands. This would apply to the wells with elevated nitrates, as the agricultural practices contributing to the nitrate source are not likely to change in the near future. Conversely, the mineral water quality concerns could improve, as more water is withdrawn from the aquifer and direct surface water recharge is increased. Ongoing water quality monitoring will provide real, local results on the impacts to water quality at various withdrawal rates. Further, there may be some value in exercising some wells at greater rates for the primary reason of assessing aquifer yield.

Alternatively, groundwater treatment such as activated carbon or other processes effective at minimizing aesthetic and health concerns can be successful in meeting some of the water quality standards and could revive the capacity potential from all wells. However, the increased costs and operational requirements to treat groundwater greatly diminishes the value of the well. Put another way, investments into groundwater treatment at the existing wells of concern may not outperform the business case potential of other sources, such as upper watershed source, or centralized sources that capture greater economies of scale and require less treatment footprints.

Due to water quality concerns and the lack of certainty for groundwater quality trending, the ultimate, theoretical combined well yield is assumed to be 55 MLD. There is room to expand groundwater capacity by adding additional wells, however, the amount of expansion potential is not accurately known but theoretically estimated at 43 MLD (additional) based on broad estimates of other existing groundwater withdrawal rates and recharge estimates. The interplay between groundwater and surface water, and the policy directions of the Province to meet minimum instream flows for ecological purposes, may reduce withdrawal rates into the future. Overall, groundwater has the potential to improve source supply and system reliability and all future initiatives to add well capacity will require detailed study and regulatory approvals.

5. System Capacity and Service Level Considerations

Being able to satisfy demands under most, if not all, demand scenarios is a primary goal of water utilities. These defined demand scenarios help utility leaders to create reasonable and achievable levels of service.

Levels of service are not typically represented by a single number, for example 150MLD. Instead, levels of service define the capacity needs which ultimately become the target for staff to develop capital improvements and management programs that actually achieve the targets. This section works through system capacity challenges to arrive at a proposed level of service for supply in qualitative terms.

Considerations for system capacity and levels of service include:

- Major Service Target: *All maximum day demands (MDD) should be provided by the AMWSC three supply sources and their transmission systems, independent of Abbotsford and Mission reservoirs and without deficiencies at any of the 23 regional-local system interconnection points.*
- Major Service Target: *There is adequate supply and transmission redundancy to provide average day demands in the event that one of the main sources is unavailable due to environmental (e.g. turbidity, drought) or mechanical issues. Note: It is considered an unusual level of service to meet MDD with the entirety of one of the larger sources out of service.*
- Major Service Term: *Potable water quality standards based on service authority permits can be consistently met under foreseeable, reasonable conditions.*
- Major Service Term: *The cost of water supply ensures the long-term integrity of meeting Service Terms 1-3 at a predictable rate.*
- Hydraulic Service Terms to be summarized separately as part of the supply and transmission master plan.

It is important to assess the existing system against the proposed service levels to appreciate any current or emerging gaps in supply capacity and transmission efficiency.

5.1 Infrastructure Limitations

A review of previous reports (e.g Maximum Capacity Analysis by GeoAdvice, 2012; others) suggest that while the portfolio of sources can supply about 1.8x the four-year average for MDD, there are transmission system capacity limitations, such as:

- The Norrish supply line is limited to a maximum day capacity of 89MLD (albeit the full treatment and license capacity equate to approximately 140 MLD);
- The Cannell Lake source is limited by transmission main hydraulic capacity of 60 MLD (albeit the full treatment and license capacity equate to approximately 70 MLD). This withdrawal can only be sustained for short periods (< 3 weeks); a reliable consistent yield is assumed to be approximately 12 MLD. Note: 225 L/s (19.4MLD equivalent for about 3 hours) is required for fire fighting in Zone 4;
- The groundwater wells are capable of providing 55MLD on a reliable basis; however, such withdrawals have never reached this rate; and,
- The transmission system is unable to achieve target hydraulic service standards such as to meet MDD demands which causes an unnecessary drawdown on municipal reservoirs. Hydraulic Service Terms to be summarized separately as part of the supply and transmission master plan.

Previous studies assessed the hydraulic service deficiencies at a conceptual level so as to define potential transmission upgrades to relieve the bottlenecks. Table 7 identifies a short-list of upgrades, including their name and scale of upgrade (e.g. high, medium, low).

Table 7 Sample List of Historic Optimization Projects

Optimization Project Name	Scale	Timing/Need
Norrish Creek Pipe Upgrade	High ($30M)	<10 yrs; Undersized pipe
Townshipline Road Pipe Upgrade	Medium ($10M)	10 to 20 yrs; Undersized pipe
Maclure Road	Medium ($9M)	<10 yrs; Undersized pipe
East Fraser Crossing Twin	Medium ($15M)	<10 yrs; Twin
West Fraser Crossing Twin	Medium ($15M)	10 to 20 yrs; Twin
Various Short Section Twin Projects	Low ($0.5M to $5M)	0 to 20 yrs; Twin

There is a strong likelihood, based on scaled-down demand projections, that the scale, timing, and need of these projects may not be required or they could be deferred; the hydraulic assessments will be completed under separate cover once the Commission has confirmed its own demand projections and conservation programs. The relationship between water consumption, location of future growth, service levels, and potential for conservation reductions directly relate to the need for optimization projects.

Table 8 below summaries the yields, licencing, treatment, conveyance, and reliable capacities for each of the three main water sources, separately and in aggregate.

Table 8 Systems Capacity Review

Capacities (MLD)	Norrish Creek	Cannell Lake	Groundwater	Totals
Licence	141.5	69.1	25	**235.5**
Treatment	117	60	55	**232**
Conveyance	87	60	55	**202**
Sustained Yield[1]	89	11.8	55	**153.3**
Resiliency Yield [2]	0	11.8	55	**67**

Notes:

[1] Sustained Yield – incorporates source productivity as well as treatment and supply line capacity; does not include fire flows

[2] Resiliency Yield during unplanned event with capacity loss of Norrish due to catastrophic failure of source or transmission line; does not include fire flow

These capacities are not a statement of performance of the system against the target service levels. Technical Memorandum #3 will assess the ability of the system to meet demand projections based on desired service levels.

5.2 Climate Change: Considerations for Source Capacity (surface and groundwater systems)

A summary of the climate change impacts for the Abbotsford and Mission region are available from the Pacific Climate Impacts Consortium (PCIC, 2017) as part of the Plan2Adapt Tool. The following provides a summary of the potential impacts to current water systems for the AMWSC service area for the 2050's (2040-2069):

- Snowpacks are projected to decrease annually 25% - 50%
    - Decreased snowpack will result in less water available for surface water storage in both Dickson Lake and Cannell Lake and may also impact the volume of water available for groundwater recharge (albeit it may also increase the total recharge due to greater annual precipitation levels). Based on current modelling of the Dickson Lake watershed, there is enough precipitation to fill the reservoir each year; however, if the reservoir were raised to accommodate future demands it is projected that 1 in every 25 years there may not be sufficient snowpack/runoff to fill the reservoir. This water shortage occurrence will become more frequent with reduced snowpack and warmer temperatures.
    - A decreased snowpack will result in a decreased baseflow in Norrish Creek in the summer months which, in turn, creates further justification for greater storage amounts. Put another way, there may be an increase in supply storage on Dickson Lake to adapt to climate change and to accommodate fish flows, even if the Norrish Creek system isn't prioritized for potable water expansion.
- Mean annual temperature is projected to increase by ~2oC.
    - An increase in temperature will result in increased evaporation from surface water storage (i.e. Dickson Lake and Cannell Lake).
    - An increase in temperature will result in an increased water demand in the summer months when water supplies are most limited, partly for agricultural demands but also for business and residential landscape demands.
    - An increase in temperature will also shift the hydrograph forward, resulting in an earlier spring freshet, particularly for those systems dependent upon snowmelt such as Norrish Creek (i.e. Dickson Lake). This forward shift in the hydrograph also means that Dickson Lake will fill and spill earlier in the year which will result in less snow available to melt later in the year to fill Dickson Lake when the downstream demand starts to increase. This projection doubles the impetus to consider an increase in storage on Dickson Lake even if it is not prioritized for greater potable supply.
- Annual precipitation is projected to increase by ~10%; however, summer precipitation is projected to decrease by ~13% with the fall/winter/summer receiving more precipitation than on average.

- This decrease in summer precipitation will result in high water demands putting additional stress on the surface water storage.
- Less summer precipitation will negatively impact Norrish Creek streamflow, where there are legislative requirements to maintain a minimum flow in the creek for fish. Thus, a greater percentage of the creek's flow would be dedicated to fish and be unavailable to the Commission.
- This shift in precipitation will also result in high intensity rain events occurring more frequently. For Norrish, this would translate into more frequent turbidity events.

- ➢ The combination of these projected changes to annual and season precipitation patterns and increased temperatures may impact water quality due to increased streambank erosion and sediment accumulation. Increased air temperature will also result in warmer surface water which can lead to algal blooms.
- ➢ The rain-on-snow zone in Norrish Creek will increase in elevation and the rain on snow events will become more frequent. Increased annual temperature and decreased summer precipitation can also result in increased wildfire occurrences within the watershed or disease/insect outbreaks within the forest, both of which can impact water quantity and water quality.

5.3 Source Performance Summary

The Commission owns and operates a portfolio of sources which provides the ability to increase or decrease production at multiple locations to suit the conditions of the utility, including varying demands or environmental pressures. A review of the strengths and challenges of the portfolio can help to define emerging gaps in meeting the major service terms. Similarly, any new, potential sources can be viewed through a lens of "which source best complements our existing assets". Table 10 characterizes the key supply attributes of each source.

Table 9 Source Performance Summary

Source	Attribute Summary
Cannell Lake	• *High-elevation source; the only source for Mission Pressure Zone 4 (unless pumping systems added)* • *Provides only a fraction of supply needs due to the relatively small size of the watershed and storage volume (incl. required lake levels)* • *Known for providing stable, high quality surface water for year-round supply to complement Norrish Creek or as a supplementary source to meet MDD (filtration deferral)* • *Drought concerns coupled with lake level requirements creates a risk of source deficiency perhaps once every 5 to 10 years; drought and climate factors reduce the long-term reliability of the source* • *Increased storage is possible; however, the overall annual supply can be increased minimally and maximum day supply is not likely to increase*

Source	Attribute Summary
Groundwater Wells (19)	• *Provides reliable, low-treatment supply year round* • *Wells are distributed throughout Abbotsford in proximity to the majority of customers which provides some transmission efficiency, now and into the future* • *Trending water quality concerns reduce the overall capacity and could trigger treatment if relied upon for long-term supplies* • *Requires regular investments into mechanical assets to maintain reliable production; regulatory approval processes require extensive staff and financial resources* • *Climate change projections suggest greater annual precipitation levels which could increase overall aquifer recharge, but will also cause greater withdrawal rates from other, private wells; some groundwater expansion potential exists, up to 40+MLD*
Norrish Creek	• *Largest source with advanced treatment including slow sand filtration and membrane filtration* • *Turbidity spikes are infrequent but reduce the capacity of the plant to 45 MLD; turbidity spikes are typical to winter periods however more intense summer storms (e.g. potential outcome from climate change) may increase the frequency and hazard potential which puts occasional stress on other sources to meet the productivity of the systems largest source* • *Drought concerns coupled with instream flow requirements for fish creates an irregular source deficiency perhaps once every 5 to 10 years; climate change is poised to exacerbate the drought risk* • *Transmission supply potential limited by pipe size at 89 MLD* • *Existing concerns regarding the ability and cost to expand source storage however there may be a need to expand storage regardless due to the need to store more water due to reduced snowpack and to ensure adequate instream flows through climate change*

Core observations from Table 9 include:

- Cannell Lake provides consistent water quality, however, it's reliable capacity reflects only 15% of ADD supplies. Cannell Lake can be relied upon for greater capacities, up to 60 MLD to help address MDD, however, that support is short-term only, perhaps a couple weeks. Cannell Lake is the primary source Pressure zone 4 which prevents the need for Norrish Creek or groundwater supplies being pumped to higher elevation neighborhoods.
- Groundwater wells can expand in overall production; however, they typically demonstrate a higher operational footprint including energy, permitting, and renewal. Groundwater quality is trending poorly at some wells which will offset the long-term expansion potential. Groundwater can currently provide up to 50% of MDD and about 66% of ADD and the overall capacity can be increased incrementally, however, not without extensive regulatory processes.

- Norrish Creek can meet ADD on its own during regular periods of regular source water quality. Norrish Creek is unable to meet MDD demands on its own due to pipe size limitations of the main Norrish transmission line. Upgrades to the Norrish supply main would enable this source to provide up to 100% of the supply needs of the system for about 20 years assuming that moderate demand management programs occur which keep per capita consumption similar, but not greater, than existing demands.

Overall, the evaluation of future sources should consider the performance of the existing portfolio as well as other criteria based on political, technical, and public themes. Subsequent memos will evaluate new sources as part of solution sets for consideration by the Commission for the long-term water supply plan.

5.4 Strategic Considerations for Supply-Demand Planning

Overall, the performance of the existing sources adequately meets potable supply needs, however, there are limitations in the transmission system when providing MDD conditions today, and there is greater risk of insufficient supply (and transmission) into the future due to growth and climate change. The following service challenges frame the needs for future analysis into supply and transmission resiliency:

1. Are the major and hydraulic service terms listed herein adequate in their depth and breadth?
2. Are significant upgrades needed (i.e. beyond regular renewal) to achieve the 55 MLD groundwater potential withdrawal rate? Are there any additional factors that limit or reduce the existing or ultimately capacity of the groundwater well system?
3. Are there any foreseeable and reasonable conditions or hazards in Norrish Creek/Dickson Lake watershed that would limit capacity at the Norrish Creek Plant to less than 45 MLD for an extended period of time (e.g. 1 week)? What is the potential for Norrish Creek source to be completely offline for an extended period of time (e.g. more than 1 week)?
4. What is the relationship between transmission system upgrades to meet service terms (e.g. optimization projects) and the location and size of existing or new sources?
   - Example: Would relying upon groundwater to a greater extent reduce the need, scale, or timing of any optimization projects?
   - Example: Would a new source such as a collector well or a new surface source reduce the scale or timing of optimization projects?
5. Will growth in Pressure zone 4 ultimately exceed the supply potential of Cannell Lake?

Each of these questions and other elements related to resilient long-term water supply, demand, and conveyance will be explored in subsequent phases of the Water Supply Study.

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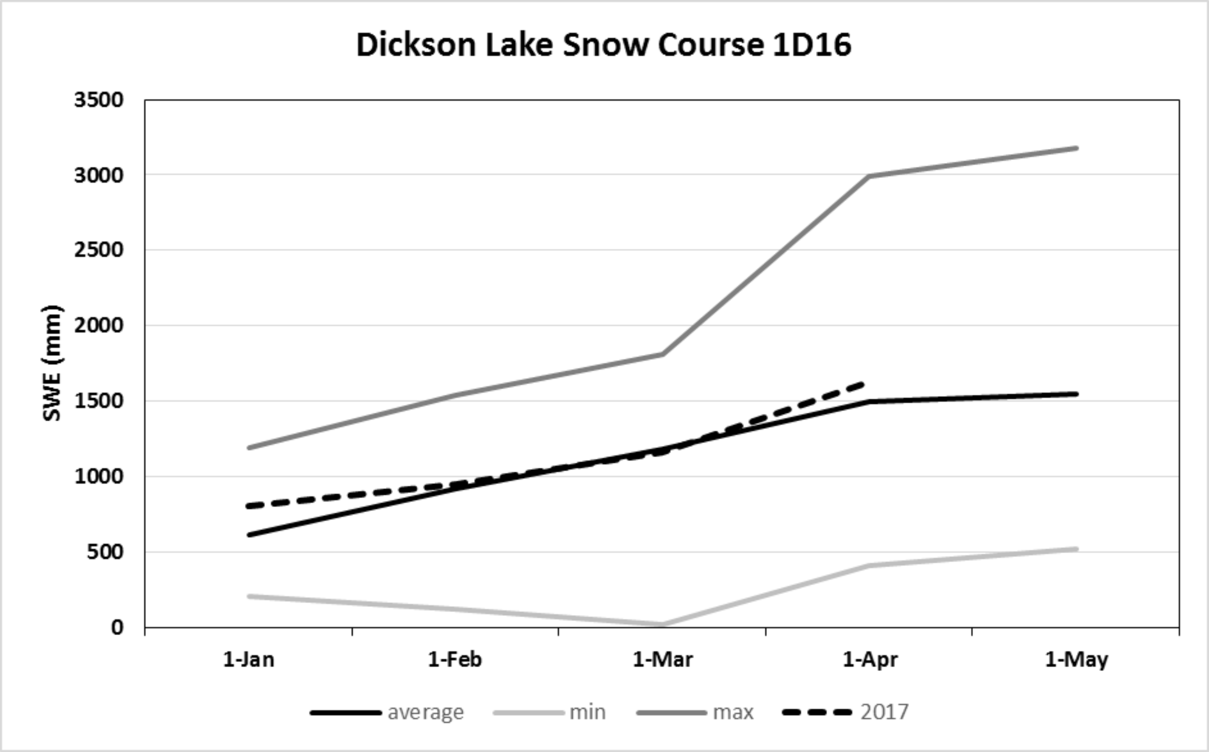


Figure. Dickson Lake snow course (1D16) average, minimum, maximum and 2017 snow water equivalent (mm) from 1991-2017.

Table: Average Monthly Flows (m^3/s) at Station #08MH150.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1984		8.6	11.0	7.5	11.3	7.0	3.2	1.9	5.3	8.6	14.9	6.7	
1985	5.0	5.3	4.4	16.9	13.0	8.5	1.5	1.3	3.5	14.0	9.3	2.7	**7.1**
1986				7.9		3.1	3.9	1.7	2.6			9.1	
1987	9.8	7.3	11.8	10.0	8.7	3.6	2.3	1.5	1.3	0.9	5.4	9.3	**6.0**
1988	5.9	8.9	9.2	12.7	13.7	7.2	3.8	1.8	3.8	7.9	15.1	10.0	**8.3**
1989	11.9	4.1	7.2	13.8	12.8	7.1	2.7	3.7	2.0	7.2	21.0	10.1	**8.6**
1990	9.4				8.7	10.7	2.9	2.3	2.2	10.7			
1991	10.2	20.3	6.0	10.2	9.7	6.7	2.6	5.0	2.5	1.9		11.9	
1992	17.5	11.9	3.9	7.5	4.3	2.0	2.5	1.3	4.6	3.7	9.6	5.4	**6.1**
1993	8.1	5.3	12.7	13.7	9.9	5.4	2.8	2.2	1.4	3.2	6.8	12.2	**7.0**
1994	11.7	9.0	18.3	10.9	5.0	9.1	3.5	1.3	1.9	5.6	8.3	12.6	**8.1**
1995	10.6	15.5	10.0	7.8	6.5	3.0	2.0	1.6	0.9	9.8	16.8	7.2	**7.6**
1996	15.5	8.2	6.2	10.1	6.9	3.0	2.2	2.7	4.0	7.4	9.4	7.2	**6.9**
1997	15.5	8.7	13.0	11.4	15.0	10.0	6.4	1.8	6.1	12.2	11.7	11.6	**10.3**
1998	13.8	8.6	9.6	6.1	7.3	3.6	2.2	1.5	1.4	4.7	18.3	15.3	**7.7**
1999	13.4	8.5	7.7	8.1	13.5	15.8	8.7	3.4	2.7	7.2	15.1	14.8	**9.9**
2000	4.6	5.7	6.7	9.6	13.5	9.9	2.7	1.9	4.3	5.1	5.0	5.1	**6.2**
2001	5.9	3.9	7.7	8.1	10.2	5.7	1.8	3.3	3.0	10.9	12.7	10.0	**7.0**
2002	12.3	9.5	4.8	16.7	13.9	12.1	3.5	2.0	3.1	1.7	9.0	6.6	**7.9**
2003	12.9	5.3	14.2	9.7	5.6	2.4	2.2	1.2	1.4	14.4	9.4	7.9	**7.3**
2004	13.0	6.2	12.2	7.5	7.6	4.1	1.9	3.5	7.4	7.1	11.7	13.7	**8.0**
2005	18.5	8.2	6.6	10.2	4.2	4.2	3.8	2.0	2.9	13.1	11.4	16.1	**8.5**
2006	29.8	11.7	7.0	9.9	12.1	6.4	2.2	1.6	2.0	6.4	27.0	24.6	**11.7**
Average	**12.2**	**8.6**	**9.1**	**10.3**	**9.7**	**6.5**	**3.1**	**2.2**	**3.0**	**7.4**	**12.4**	**10.5**	**7.9**

Table. Environment Canada Precipitation Stations near Cannell Lake.

Gauge Name	Gauge Number	Elevation (m)	Period of Record	Annual Precip (mm)	Distance to Cannell Lake (km)
Stave Falls	1107680	110	1910-2003	2,359.4	4.5
Mission West Abbey	1105192	221	1963-2016	1,883.3	12

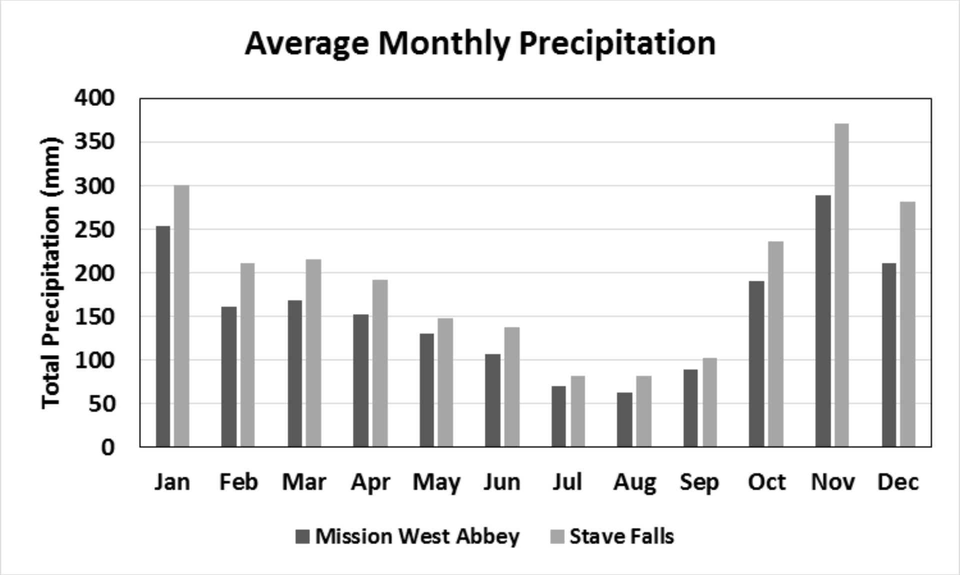


Figure Average Monthly Precipitation at Stave Falls (1107680) and Mission West Abbey (1105192).

Note: Precipitation differences between the two stations are most likely attributed to orographic influences. Based on estimates (KWL, 2008) it is reasonable to expect that the average annual precipitation at Cannell Lake is greater than that recorded at Stave Falls.

- The inflow estimates are associated with drier-than-normal years and do not provide insight into the average water yield for Cannell Lake. It is estimated that 2000-2001 is 75% of normal and 2002-2003 is 84% of normal Cannell Lake water yield.

Table Summary of Partial Water Balances (ML) for the water year (October 1 – September 30)

Component	**WY 2000-2001**	**WY 2002-2003**
Annual Withdrawals (ML)	3,510	4,250
Lake Evaporation (ML)	260	280
Net Change in Storage (ML)	-250	-500
Estimated Inflow (ML)	3,520	4,030

Table: Model Simulation of Municipal Reservoir Drawdown at Demands over 123MLD

Modeling Scenarios	Total Demand (MLD)	Total Supplied from Sources (MLD)	Reservoir Storage Recovery (+) Loss (-) (MLD)
2010 MDD	107.6	109.2	**+1.6**
2010 MDD + 5 %	113.0	114.4	**+1.3**
2010 MDD + 10 %	118.4	119.5	**+1.1**
2010 MDD + 15 %	123.8	123.5	**-0.3**
2010 MDD + 20 %	129.2	127.6	**-1.5**
2010 MDD + 25 %	134.5	132.7	**-1.9**
2010 MDD + 30 %	139.9*	137.3	**-2.6**
2010 MDD + 35 %	145.3	142.8	**-2.5**
2010 MDD + 40 %	150.7	147.7	**-2.9**
2010 MDD + 45 %	156.1	152.0	**-4.0**
2010 MDD + 50 %	161.4	157.5	**-4.0**
2010 MDD + 60 %	172.2	167.0	**-5.2**
2010 MDD + 70 %	183.0	175.9	**-7.1**

***In 2007, the MDD was 139.2 MLD.**

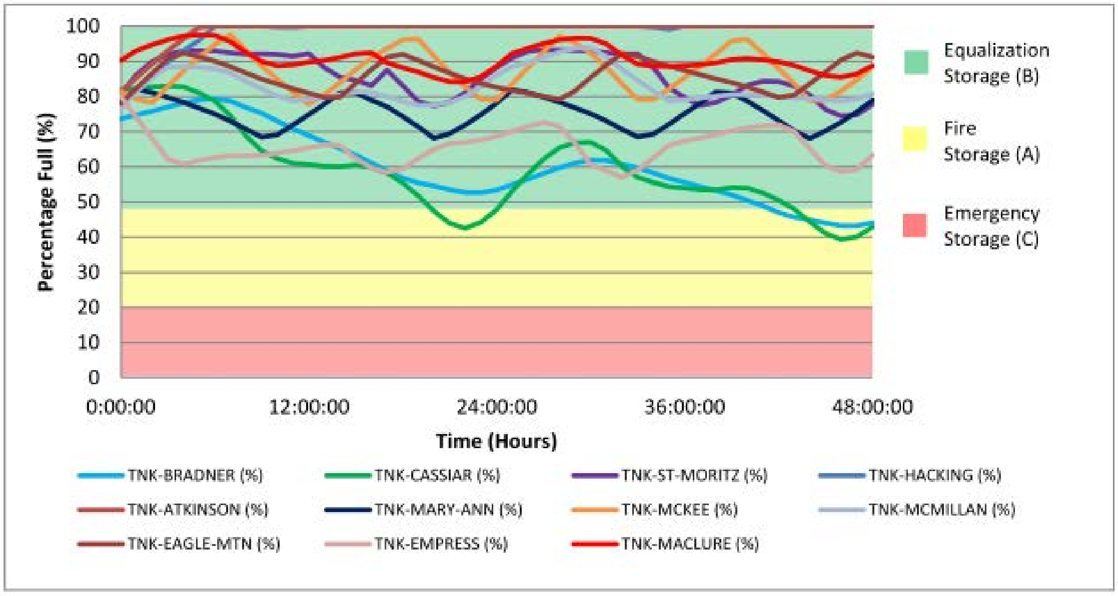


Figure: Model Simulation (Examples) of Insufficient Pressures at Municipal Connections

Table: Model Simulation (Examples) of Municipal Reservoir Drawdown

Municipality	AMWSC Take-Off	Status (MDD)	Status (2010 MDD + 5 %)	Status (2010 MDD + 10 %)	Status (2010 MDD + 15 %)	Status (2010 MDD + 20 %)	Status (2010 MDD + 25 %)	Status (2010 MDD + 30 %)
Abbotsford	Best PRV	OK	OK	OK	OK	OK	OK	OK
Abbotsford	Clayburn PRV	OK	OK	OK	OK	OK	OK	OK
Abbotsford	Clay Village PRV	OK	OK	OK	OK	OK	OK	OK
Abbotsford	Downes PRV	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient
Abbotsford	Empress PRV	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient
Abbotsford	Harris PRV 1 & 2	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient
Abbotsford	Harris PRV 3	OK	OK	OK	OK	OK	OK	OK
Abbotsford	Maclure PRV	OK	OK	OK	OK	Deficient	Deficient	Deficient
Abbotsford	Sandon PRV 1 & 2	OK	OK	OK	OK	OK	OK	OK
Abbotsford	Sandon PRV 3 & 4	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient
Abbotsford	Selkirk PRV	OK	OK	OK	OK	OK	OK	Deficient
Mission	Best PRV	OK	OK	OK	OK	OK	OK	OK
Mission	Cannons PRV	OK	OK	OK	OK	OK	OK	OK
Mission	Cedar Valley PRV 1	OK	OK	OK	OK	OK	OK	OK
Mission	Cedar Valley PRV 2	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient
Mission	Charnley PRV	OK	OK	OK	OK	Deficient	Deficient	Deficient
Mission	Cherry PRV	OK	OK	OK	Deficient	Deficient	Deficient	Deficient
Mission	DTR Hwy 7 PRV	OK	OK	OK	OK	OK	OK	OK
Mission	Mission Way PRV	OK	OK	OK	OK	OK	OK	OK
Mission	Mary & 7th PRV	OK	OK	OK	OK	OK	OK	OK
Mission	Maryann PRV	OK	OK	OK	OK	OK	OK	OK
Mission	Prentis PRV	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient	Deficient
Mission	Shook PRV	OK	OK	OK	OK	OK	OK	OK

JOINT ABBOTSFORD-MISSION

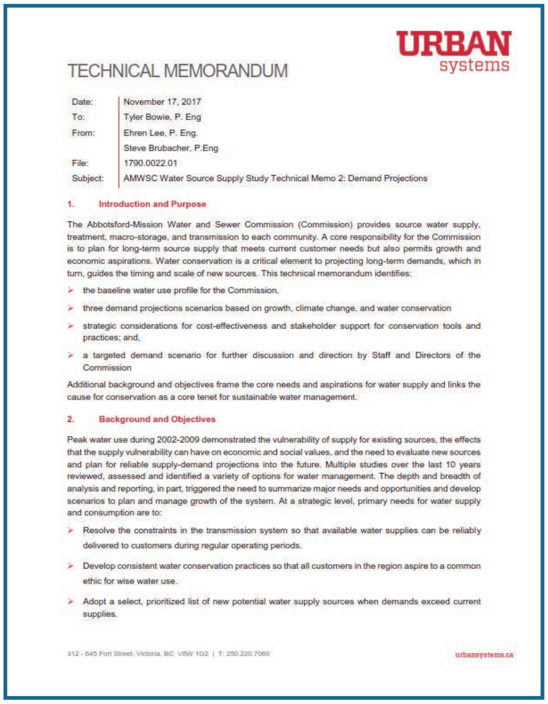
WATER MASTER PLAN

Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#2

WATER DEMAND PROJECTIONS AND CONSERVATION REVIEW



TECHNICAL MEMORANDUM

Date: November 17, 2017
To: Tyler Bowie, P. Eng
From: Ehren Lee, P. Eng.
Steve Brubacher, P.Eng
File: 1790.0022.01
Subject: AMWSC Water Source Supply Study Technical Memo 2: Demand Projections

1. Introduction and Purpose

The Abbotsford-Mission Water and Sewer Commission (Commission) provides source water supply, treatment, macro-storage, and transmission to each community. A core responsibility for the Commission is to plan for long-term source supply that meets current customer needs but also permits growth and economic aspirations. Water conservation is a critical element to projecting long-term demands, which in turn, guides the timing and scale of new sources. This technical memorandum identifies:

- the baseline water use profile for the Commission,
- three demand projections scenarios based on growth, climate change, and water conservation
- strategic considerations for cost-effectiveness and stakeholder support for conservation tools and practices; and,
- a targeted demand scenario for further discussion and direction by Staff and Directors of the Commission

Additional background and objectives frame the core needs and aspirations for water supply and links the cause for conservation as a core tenet for sustainable water management.

2. Background and Objectives

Peak water use during 2002-2009 demonstrated the vulnerability of supply for existing sources, the effects that the supply vulnerability can have on economic and social values, and the need to evaluate new sources and plan for reliable supply-demand projections into the future. Multiple studies over the last 10 years reviewed, assessed and identified a variety of options for water management. The depth and breadth of analysis and reporting, in part, triggered the need to summarize major needs and opportunities and develop scenarios to plan and manage growth of the system. At a strategic level, primary needs for water supply and consumption are to:

- Resolve the constraints in the transmission system so that available water supplies can be reliably delivered to customers during regular operating periods.
- Develop consistent water conservation practices so that all customers in the region aspire to a common ethic for wise water use.
- Adopt a select, prioritized list of new potential water supply sources when demands exceed current supplies.

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- Adopt a select, prioritized list of new potential water supply sources when demands exceed current supplies.

Supply, demand, and transmission are interrelated topics that affect all water utilities with regards to their long-term system planning. The entire Water Source Supply Study investigates each objective-area in some detail under a common framework to uncover synergies and fully consider the choices for conservation and source expansion. Demand planning and water use projections are fundamental focus areas for utility managers because they help to:

- Prepare the Commission and its customers for new initiatives and projects,
- Evaluate choices to support broader community goals,
- Engage test actions for staff to deliver on political and public aspirations,
- Ensure compliance with regulations and alignment with best practices, and
- Define capital projects and levels of service.

Historical demand projections for the Commission signalled the need to expand source capacity as early as 2016. One key objective of the source study is to redevelop demand projections based on best available information. This Technical Memorandum includes sections that cover:

- Water use patterns and utility benchmarking,
- Water conservation practices and recent experiences,
- Community growth summary,
- Water conservation options,
- General impacts on supply and capacity, and
- Opportunities and strategic framing.

Each section builds on previous reports, studies, databases, and practices so that work to date can be acknowledged and effectively summarized to support upcoming investment and policy decisions.

Technical Memo #3 will build on the contents of this memo as well as Technical Memo #1 to arrive at a clear relationship between demand needs and source capacity.

3. Supply and Demand Characteristics

Supply and demand planning is typical of any water purveyor and creates multiple policy pathways for conservation and source expansion.

3.1 Ten Year Water Use Patterns

The last decade of water use shows how impactful excess water use can be, and alternatively, the important role that conservation will play in a long-term supply future for the Commission. Figure 1 illustrates the increasing trend leading into 2010, which also coincides with the water expansion referendum, and the decreasing trend from 2012 to today, a response to enhanced conservation practices put into place and the heightened response by customers to these practices. There seems to be a growing sense of value for water in the region, based on cultural, financial, political, and social indicators; public engagement events over the last five years support the trends as well.

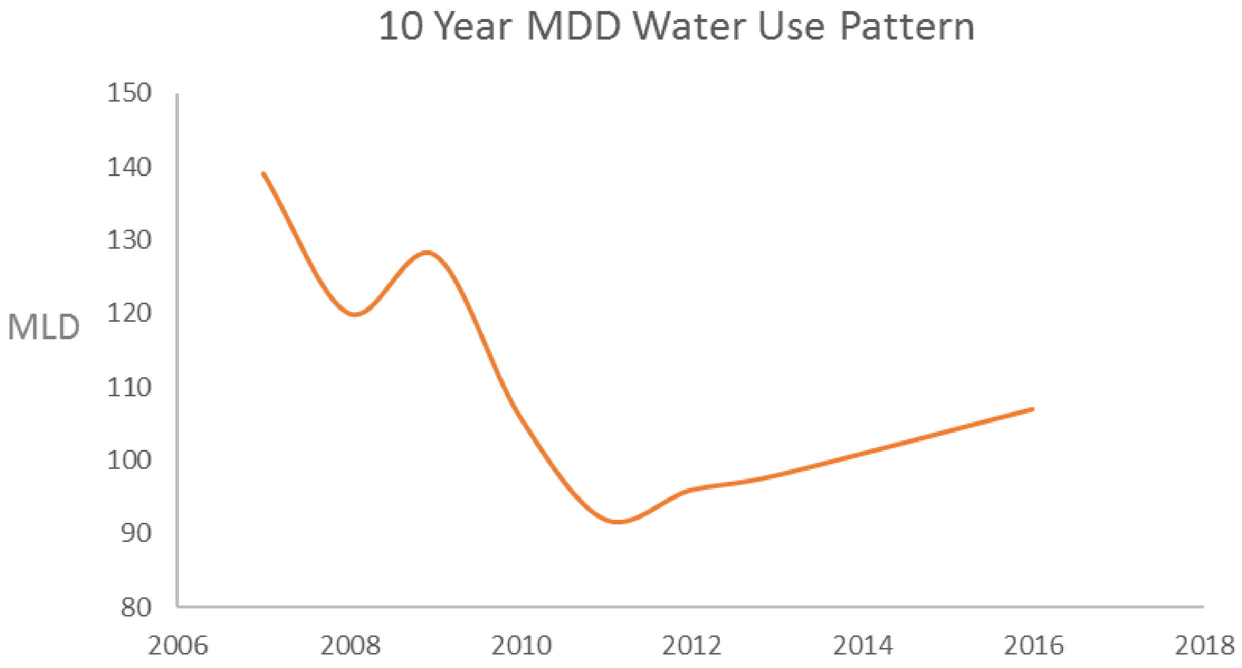

Figure 1: Ten Year Water Use Profile

Water supply and demands are dynamic. Each year, weather patterns, customer habits, and watershed conditions (including aquifers) change which often requires some kind of demand management response from the utility. Whereas excess supply years may trigger flood preparedness activities, drought years often trigger heightened water restrictions and strict enforcement of conservation protocols. The Level 4 drought warnings in 2015 are an important example of the need to plan for foreseeable conditions, but also to adapt to atypical events. Any demand management frameworks should consider the opportunities to use water most effectively during regular and irregular supply conditions.

3.2 Utility Benchmarking

The future goals of the Commission should continue to reflect the vision that has been set and the desired progress towards that vision. Benchmarking against other utilities allows for an occasional check-in with other communities to consider whether there are lessons that can be learned from other communities and applied in helping the Commission achieve its vision. These lessons can help identify new tactics or new energies (e.g. up or down) toward demand management elements. Three BC communities were selected and reviewed for consumption data comparison to help exemplify a comparison for the Commission and its communities in 2016. Nanaimo, Kelowna, and Victoria were selected given that they reflect water utilities with similar demand drivers, such as: varying climate; large-scale growth; joint-water systems; agriculture customers; and a commitment to water conservation. It is worth noting that no two communities are identical both in terms of the customer profile and the climatic conditions so comparisons must be done carefully. As noted earlier, comparisons can help inform further conversations in regards to lessons learned; all of the observations from other communities and from the local experience can be considered by the Commission for their future application, which is perhaps more impactful than unweighted benchmarking. Table 1 provides a basic comparison for water use across each of the four jurisdictions.

Table 1: Utility Water Use Profile Comparison

Topic	Victoria	Kelowna	Nanaimo	AMWSC
Total Serviced Residential Population	101,000	82,000	92,000	168,000
Total Demand for all Customers: MDD (ML/day)	68	88	71	108
ADD (ML/day)	43	44	39	74
Demand Split: Residential of Total	55%	58%	53%	50%
Summer Peaking Factor Comment	*summer demand 1.75x winter use*	*summer demand 2.5x winter use*	*summer demand 2x winter use*	*summer demand 1.75x winter use*
Bulk Consumption Index*	6.7	10.7	7.7	6.4
Conservation Status	*-Universal metered for many decades* *-Conservation initiatives led by the region*	*-Metered for many decades* *-Conservation initiatives led by City, Regional District and*	*-Universal metered for many decades* *-Conservation initiatives led by the region which*	*-Largely metered with select customers still without* *-Conservation has less history*

Topic	Victoria	Kelowna	Nanaimo	AMWSC
	-Water rates encourage conservation *-Emphasis placed on new development for ongoing reductions*	*Okanagan Basin Water Board* *-Water rates encourage conservation* *-Emphasis placed on reducing outdoor water use*	*includes strategies, targets and programs* *-Water rates encourage conservation* *-Emphasis placed on new development for ongoing reductions*	*-Initiatives led by both the - Commission and each municipality*

**total utility consumption on a daily basis divided by population.*

Salient observations from Table 1 include:

- That the AMWSC's current water demand rates are relatively low driven largely by the low consumption profile of urban customers in the City of Abbotsford,
- That coastal communities tend to demonstrate lower peaking factors than interior and arid locales, and
- If the same benchmarking were conducted in 2007 during the peak of the Commission's water use profile to date, the bulk consumption indicator for the AMWSC would exceed Nanaimo by some margin and lean closer towards Kelowna; this signifies the success of conservation programs to date and amplifies the need to continue investments into conservation to prevent a return to old habits.

Beyond the basic statistics in Table 2, it's important to point out that conservation programs in each jurisdiction vary. Each utility adheres to a custom and up-to-date conservation plan with targets and programs including an emphasis on highly efficient new developments and low outdoor use. Perhaps the most important conservation program observation is that Victoria, Nanaimo, and Kelowna are all universally metered and have been for many decades.

Overall, benchmarking does not typically incorporate primary drivers for targets and consumption goals. Typically, the supply capacity, life-cycle costs of the system, the ability to secure grants, and the source context establish the motive(s) to conserve.

4. Demand Management Projections

4.1 Description of Existing Practices and Objectives

Each municipality of the Commission, as well as the Commission itself (the joint governance body), implements specific conservation practices and objectives. Official Community Plans (OCP) complement water-focused reports to provide the fundamental motivations to conserve in both municipalities.

Table 2: OCP Aspirations Per Community

Community Plan Water Topic	Abbotsford	Mission
Commitment to Conservation	• Reduce water use for current and future generations	• Manage water responsibly • Encourage water conservation
Use of Sustainable Infrastructure	• Maximize longevity of existing infrastructure • Upgrade systems to accommodate growth • Continue to meter all customers	• Implement cost-effective infrastructure and green buildings; innovative building standards • Incentives for low-impact development • Explore universal metering
Development-Oriented Initiatives	• Guiding new development for efficient use of water	• Achieve sustainable economic growth

This study intends to apply the broad objectives of each community under a common framework for implementation for the joint-supply system. Table 3 identifies existing conservation practices for each community as well as a broader, Commission-wide description of its status and progress.

Table 3: List of Existing Conservation Practices: Commission and Communities

Commission - Conservation Method	Abbotsford	Mission	Status and Progress
Outdoor Water Restrictions	✓	✓	• Enacted based on water availability and system wide demands • Online dashboard dictates permitted uses; largest reductions in MDD occurred when watering restrictions implemented early into the year and for long-periods
Universal Metering	✓	*partial*	• Considered fundamental to Abbotsford's low trending demands • All new construction in Mission is metered since 2009 on top of 500 customers through a pilot study in 2009
Consumption-Based Billing	✓	*partial*	• Abandoned declining block rate for most customers • Consumption based billing is an important step toward customer-led behavioural change
Fixture Rebates: Toilet and Washers	✓	✓	• Toilet rebates are longstanding for residential and ICI customers; washer rebates are relatively new and limited • Considered modest, gradual conservation technique
Leak Notices	✓		• Available in Abbotsford • Resulted in numerous leak repairs
Leak Kits	✓	✓	• Steady uptake • Considered a long-term resource as leaks arise continuously

Commission - Conservation Method	Abbotsford	Mission	Status and Progress
Subsidized Low-Flow Fixtures	✓	✓	• Considered another basic tool to lower regular demands without behavioural change
Subsidized Rain Barrels	✓	✓	• Steady uptake • Some barriers to installation and how to use the barrels typically limit overall implementation
Irrigation-Landscape Rebates incl. Rain Sensors	✓	✓	• Modest uptake for existing developments • Considered useful tool to guide new developments
Free Irrigation-Landscape Audits	*partial*	*partial*	• Minor uptake but showed significant opportunities for reductions e.g. up to 68% at some residences • Discontinued until staffing resources available
Free Industry/Commercial + Agriculture Audits	*partial*	*partial*	• Steady uptake in 2011-2013; signalled opportunities for significant reductions up to 50% at select facilities • Requires financial incentives such as demand pricing structures or buybacks
Online Education and Information Resources e.g. Tips	✓	✓	• Steady practice that will remain in perpetuity • Considered an incremental method to gradually reduce consumption from new customer awareness and behaviours
Regular Engagement or Social Marketing	✓	✓	• Steady practice that will remain in perpetuity • Considered an incremental method to gradually reduce consumption from new customer awareness and behaviours
Development-Led Conservation	*partial*	*partial*	• Universally required low-flow water fixtures in new buildings (primarily indoor water practices only) • Promotion of low-landscape, efficient outdoor systems

Demand management scenarios and water conservation choices and options can provide further information on the potential effectiveness of additional actions or enhancements to existing practices. How and whether to build on existing practices stems in part to the targets that are ultimately set for water reductions and also based on the cost and effectiveness of existing practices.

Salient observations from Table 3 include:

- The overall type and extent of conservation practices aligns with a mid-level framework based on conservation strategies for communities in BC,
- Abbotsford reductions are significant and appear to outperform the overall conservation practices in place, which may denote cultural water use practices that stem from political messaging and marketing together with universal metering and associated communication around water use with the water bills,
- There is a growing tendency to encourage residents to initiate action, which exposes select barriers and ultimately may limit overall uptake and effectiveness of each method,
- That a greater emphasis toward highest-water users at initial stages e.g. agriculture, industry, institution, parks could have significant early reductions while allowing for the medium-term effects from more gradual practices to occur,
- There could be an increase in emphasis toward to large-lot residential water use practices given the relatively lower consumption behaviours of city-center properties versus suburban customers,
- There could be an increase in emphasis on financial practices to a) encourage greater efficiencies in areas of excess use and b) solidify current and emerging behaviours and prevent default to old, high-water use actions,
- There could be greater attention placed on development oriented practices which allows for new opportunities to live up to community goals and objectives in each OCP, and
- That the importance of metering is partly exemplified by the contrast in consumption patterns per community, including the distinct and effective opportunity to find and fix leaks.

The range of available water conservation practices constantly expands as communities all over BC and Canada look for innovative ways to lower consumption and offset expensive source upgrades. However, the cost-effectiveness of any practice tends to dictate whether it lasts and whether it actually achieves water use reductions. Table 4 provides a relative ranking of their cost-effectiveness of a long list of water conservation practices.

Table 4: Relative Performance for Common Conservation Methods

Conservation Practice	Relative Cost Effectiveness	Relative Implementation Effort
Tiered + Seasonal Rates	High	Low
Bi-monthly Billing		
Utility Efficiency Upgrades		
Residential Water Use Audits		
Outdoor Watering Restrictions	Medium	Medium
Regulations: Reuse and Efficiency		
Universal Meters		
Irrigation and Landscape Regulations		
Education, Engagement and Social Marketing		
Rebates and Fixture Subsidies	Low	High
Commercial Audits		
Leak Surveys		

Given the relative and diverse performance of common conservation practices, it's noteworthy to compare cost-effectiveness and implementation effort of existing AMWSC conservation tactics, such as:

- Maintaining current water conservation effectiveness requires an ongoing commitment to education and outreach even if no new efforts are provided;
- The pursuit of universal metering would signal an advanced leap towards greater reductions at lowest cost; subsequent implementation of tiered rates would elevate the Commission to best practice levels;
- The application of best management practice techniques for conservation in new developments is one of the strongest tools available to two rapidly growing communities in Mission and Abbotsford

- While rebates and subsidies tend to plateau in their implementation, they often remain a helpful program for low-income households and rental units given the specific financial challenges for occasional renovations and upgrades;
- Regulations and restrictions for water conservation typically require effort for enforcement and, therefore, they work best when designing new structures e.g. the innovations come built-in, whereas their application to existing dwellings can be challenging and resource-intensive.

The Commission lacks a formal, adopted conservation direction; the list of current and optional conservation practices and their relative effectiveness can guide choices for demand management.

4.2 Demand Projection Parameters

As part of this study, developing and evaluating five demand scenarios enables the Commission to ultimately select its direction for conservation. Table 5 summarizes basic, but important, demand considerations for the customers of the AMWSC, both current and future, and how they apply to projecting demand needs 25 years into the future.

Table 5: Demand Projection Parameters

Demand Projection Item	Comments and Considerations
Population Growth Rates	• Plan for 200,000 residents by 2040 in Abbotsford (OCP based) • 2% growth year over year in Mission (OCP based) for 25 years • Current water service populations are 32,400 and 135,000 for Mission and Abbotsford, respectively *
Residential Water Consumption	• Water use in multi-family, medium-density (and greater) is less than single family on account of less outdoor demands • New developments will consume less water than existing customers due to requirements of local regulations and the BC Building Code • Reductions due to conservation will occur gradually for existing residents and immediately for new customers • While Abbotsford's residential consumption is relatively quite low, Mission is poised for greater opportunities to reduce consumption rates • Per capita water rates will fluctuate over time due to various factors such as weather; a slight increase to per capita rates, attributable to outdoor water use, is expected at the end of the 25-year horizon and beyond due to the potential of more frequent and severe droughts • Greater reductions in shorter time frames (e.g. 10 year) if universal metering and seasonal rates are implemented
Agriculture Water Consumption	• Mission does not have agriculture water customers (in the service area) and is not projected to develop them • Abbotsford's agriculture customers are projected to increase (no overall reductions) on account of retail and production growth in the sector and due to drought or climate change factors
ICI Customers	• The number of customers and overall consumption will grow in scale to growth • Reductions will occur gradually over the 25-year period recognizing that greater implementation effort is typically required for this customer class over residential

Demand Projection Item	Comments and Considerations
Non-Revenue Water	• Utility drivers to reduce unaccounted for water including leaks and losses include greater efficiencies, lower cost of service and system reliability during maximum demands: as a result, reducing non-revenue water should be a primary target for investigation and repair in all three systems (regional and two local)
Maximum Daily Demand	• Maximum daily demand (MDD) is used for the projections given its role in selecting conservation practices, in determining the size of future infrastructure and in defining the size of future sources

**service populations reflect population of customers which is less than total municipal population*

Five water demand projections enable the comparative review of conservation program directions, including:

- No Conservation: a control model which does not account for any reductions and current demands carry on for 25 years
- High Demand Scenario: a revised conservation pathway which would result in new targets for existing practices, as well as expanded practices in other areas, and result in further reductions near 0.35% per year
- Medium Demand Scenario: a slightly progressive conservation pathway which builds on current practices to continue the trend for a new phase of intensive reductions with existing customers and low-flow requirements for new development to result in reduction of near 0.7% per year
- Medium-Low Demand Scenario: a slightly progressive conservation pathway which builds on many existing strengths of the program, curtails the less effective rebate/subsidy programs and proceeds to grant-supported universal metering and bi-monthly billing as a focused approach to reductions; metering and tiered rates are core components to achieve projected reduction rates near 1.0% per year
- Low Demand scenario: an advanced conservation program that applies most best management practices for water utilities including notable reductions to existing customers and low-flow requirements for new development to result in reductions of about 1.2% per year

Figure 2 illustrates all five demand scenarios, including No Conservation (the control) for comparative commentary. Table 6 includes summaries of each demand scenario, conservation practices, and projected outcomes.

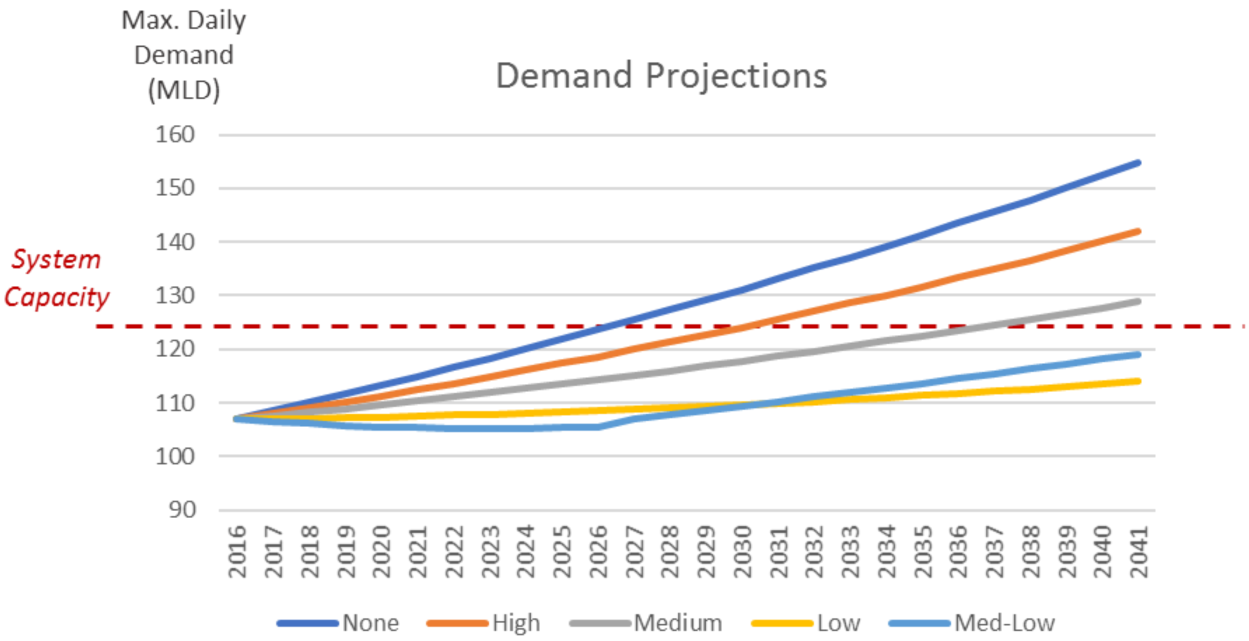

Figure 2: Five Demand Projections and Outcomes of Conservation Scenarios

The key takeaway from Figure 2 is the demand projection at 25 years of 155 MLD. The existing MDD capacity of the system is under review and currently estimated at 123 MLD meaning the capacity of the sources should increase by 25% in the design horizon. Based on this trendline whereby there are no further reductions, the existing capacity of the supply system (there are already bottlenecks in the transmission system) is exceeded in 2028 in terms of maximum daily demand, only 12 years from today[1]. Each of the demand scenarios improve on the timing and size and need to expand, as outlined below. Table A, enclosed, summarizes each conservation input for the demand scenarios.

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[1] There are other supply gaps beyond maximum daily demand conditions, such as during an unplanned loss of a major source and the need to provide up to average daily demands (addressed in solution sets).

Table 6: Four Demand Scenarios

Conservation Topic	High Demand Scenario	Medium Demand Scenario	Low Demand Scenario	Medium-Low Scenario
Theme	Steady program with fine-tuned (similar to current program with enhancements)	Progressive conservation framework that leads to a new phase in intensive reductions	Advanced program that meets best practice and more	Enhanced conservation program with some barriers
Practices	• Continue public awareness and education • Focus on toilet rebates and water kits only for certain customers • Apply proven reduction practices toward new developments • Metering new construction • Expanded social marketing to support wise-water use behaviours	• Include all of 'High Demand' practices • Advanced development regulations to reduce new customer demands • Single-rate pricing structure that promotes wise water use • Broad rebate programs • Water use audit-support • Build-on engagement program	• Include all of 'Medium Demand' practices • Add seasonal or tiered rates coupled with universal meters • Carry through with reuse/recycling regulations • Enforce reductions to highest ICI + Agr users	• Include all of 'High Demand' practices • Advanced development regulations to reduce new customer demands • Add seasonal or tiered rates coupled with universal meters • Scale-back broad rebate programs • Water use audit-support • Build-on engagement program
Annual Reduction	~0.35%	~0.7%	~1.2%	~1.0%
Total Reduction @ 25 years	Up to 10%	Up to 20%	Up to 30%	Up to 25%
New Supply Required for 2042	>20 MLD	Expansion triggered at 25 year horizon	None	Expansion triggered well after design horizon
Blended MDD Residential Rate in 2042	293 lcd	260 lcd	223 lcd	223 lcd

Conservation Topic	High Demand Scenario	Medium Demand Scenario	Low Demand Scenario	Medium-Low Scenario
Offset Potential: *Ability to defer expansion beyond the no conservation scenario*	5-10 extra years	15 extra years	Offset Beyond 2060 at current growth projections	20 extra years
Relative Cost Considerations	• Marginal increase in costs from the existing program • Conservation cost savings trigger early source expansion at multiple times the cost of conservation	• Moderate increase in conservation costs from existing baseline • Additional emphasis on developer-led conservation reduces utility costs and promotes day-one efficiencies • Low-cost programs to existing customers include audits, leak notices and social marketing • Rebate programs for existing customers to remain volunteer resulting in gradual uptake	• Very minor cost increase from medium demand scenario • Best cost-effectiveness for reductions stems from metering and tiered rates • Efficiency and reuse regulations inexpensive to design, more expensive to implement and enforce • If political will exists to proceed to meters and seasonal rates, then propose a new medium demand conservation program that replaces rebates with tiered rates	• Moderate decrease in conservation costs from existing baseline (see below) • Emphasis on metering only if successful with grants then add bi-monthly billing • Greater emphasis on developer-led conservation reduces utility costs and promotes day-one efficiencies • Low-cost programs to existing customers include audits, leak notices and social marketing • Rebate programs significantly scaled back to save costs
Customer Considerations	• Lower barrier implementation	• Low barrier implementation • Greater marketing and engagement required to maximize impacts from rebate program • Requires highest levels of engagement and staffing of all programs	• Presents barriers initially with potential for long-term conservation at low implementation effort • Reuse and efficiency regulations will require in-depth customer-to-government interactions and approvals	• Presents barriers initially for meters and seasonal rates with potential for long-term conservation at low implementation effort • Greater marketing and engagement required to maximize impacts from rebate program • Avoids implementation challenges with advanced regulations and slow-to-apply rebates

All programs are configured to improve cost management of the program yet still result in further reductions. Perhaps the most important takeaway is that conservation programming can begin with the high-demand scenario and then additional practices from the other scenarios can be incrementally added to the program. Further to this point, the medium-low scenario remains an aspirational program for future years but it will not be further considered in comparisons based on the terms of reference for the study and the context of current demands.

5. Demand Management: Strategic Framing

The Commission provides source water, treatment, and transmission to each community, Abbotsford and Mission, and is currently faced with an important decision: to adopt policy direction for water conservation that will ultimately dictate the timing and scale of source expansion.

Recent achievements in water conservation have averted the need to expand which is a significant undertaking previously estimated for 2016. In effect, a noteworthy example of conservation to manage utility costs is actually the story of the Commission itself: water use between 2002-2009 was so high that up to $300M in source expansion costs were being considered for long-term water supply security. Instead, the locally-evolved water conservation program lowered demands significantly and saved a large-scale capital project. Further investments into conservation and the resulting reductions will help to contain utility costs (and customer costs) and allow the Commission to methodically select and evaluate new water sources. In consideration of the three demand scenarios, current water use baseline and costs/barriers for conservation, there are strategic factors that can guide the decision in adopting a conservation policy, such as:

- The existing water conservation program has offset the need to add unnecessary capacity and the deferral of the investment is saving tens of millions of dollars per year for the Commission.
- That greater investments into conservation will require greater resources into implementation and that selecting low cost, high effectiveness, and low enforcement initiatives are preferable.
- That greater emphasis on reductions for new development is a low-barrier approach to reductions; however, unless greater attention is placed toward existing residential customers, conservation effectiveness will be quite gradual and source expansion may be required sooner.
- That Abbotsford's case study for reductions and the direct-relation to low consumption stemming from meters, frequent billing, and demand-oriented water rates is the most applicable evidence for notable results in conservation.
- In particular, with regards to program elements,
    - The pursuit of universal metering and tiered rates, although not required, would signal a leap towards greater reductions at lowest cost
    - The application of best management practice techniques for conservation in new developments is one of the strongest tools available to two rapidly growing communities in Mission and Abbotsford

- While rebates and subsidies tend to plateau in their implementation, they often remain a helpful program for low-income households and rental units given the specific financial challenges for occasional renovations and upgrades.
- Regulations and restrictions for water conservation typically require effort for enforcement and, therefore, they work best when designing new structures e.g. the innovations come built-in, whereas their application to existing dwellings can be challenging and resource-intensive;

➢ Table 1 summarizes the program elements and reduction potential for five conservation scenarios, including a no conservation option.

Table 7: Conservation Choices for Commission Framework

Conservation Choice	Theme	Outcomes	2041 Demand Projection
No Conservation Scenario	*No further reductions targeted*	• Consumption rates remain unchanged from today's conditions*	**146 MLD**
High Demand Scenario	*Steady program with refinements to existing program*	• Cost-effective conservation that achieves some reductions but does not require major spending increases • Includes 0.35% reductions year over year resulting in a 10% total drop in 25 years	**135 MLD**
Medium Demand Scenario	*Additional conservation program that increases expectations to reduce*	• 0.7% per year reductions are significant for fast-growing region; a 20% drop in 25 years would become quite challenging over time • Includes some cost-effective programs Emerging pushback from select customers to achieve targets	**122 MLD**
Low Demand Scenario	*Advanced program that meets best practice and more*	• Largest conservation program with full suite of initiatives • Some potential to offset source expansion (scope) but does not eliminate need for new source • Aggressive targets of >1%/year (total of 30% reductions by 2041) creates notable pressure on customers	**108 MLD**

*Note: abandoning the conservation program is not a guarantee that rates will remain as they are for any length of time and it is likely that rates would increase over time.

➢ At first glance, the tendency can be to select the lowest demand projection out of concern for unnecessary capital costs. However, not all conservation programs are cost-effective and some may cause extraordinary burdens on customers to achieve the targeted consumption rate.

- That overall, in regards to policy and decisions, the high demand scenario is essentially a decision towards tweaking the existing program that will result in more efficient water use, demonstrate improved cost-effectiveness from the existing program and will allow for some factor of safety (i.e. it is a conservative demand projection) for system planning. The high demand scenario is suggested for further analysis in the Water Source Supply Study as it positions the Commission to make decisions around source and transmission upgrades without holding extraordinary risk if advanced targets are not met.
- Moving forward, the Commission should continue to explore various opportunities e.g. apply for senior government grants for water meters for existing customers in Mission and to consider frequent, demand-based billing, that reduce water consumption even further.

Overall, four choices for water conservation provide the broad spectrum of program scale and depth. Of the four choices, however, **the high demand scenario offers a solid return on investment for program cost and projected reductions and further, allows for conservative planning by leaning on the higher end of projections** (recognizing that actual, sustained reductions that exceed the 0.35%/year target serve to lower costs and defer projects even further). A decision to employ universal meters along with tiered rates should be linked with grant eligibility and the high prospects for conservation that emerge from metered consumption and tiered water rates.

Employing the high-demand scenario will be foundational to subsequent hydraulic analyses and supply planning.

URBAN SYSTEMS LTD.

Steve Brubacher, P.Eng.

Principal, Water Practice Leader

Ehren Lee, P.Eng.

Principal, Policy and Strategy

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Supporting Table: Conservation Parameters included in each Program/Scenario

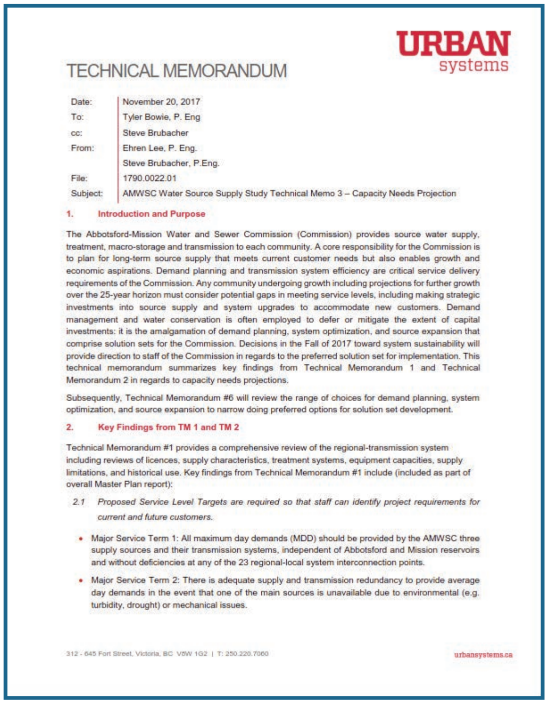
Model Parameter	High Demand Scenario	Medium Demand Scenario	Low Demand Scenario	Medium-Low Scenario
2042 Population	Abbotsford: 193,440 (reflects water service population; actual community exceeds 200K) Mission: 54,220 (reflects water service population; actual community exceeds 60K)			
Residential Reductions	• Res. Existing (Abbotsford): 10%/25 years • Res. Future (Abbotsford): 10%/25 years • Res. Existing (Mission): 10%/25 years • Res. Future (Mission):425 lcd starting year 1	• Res. Existing (Abbotsford): 15%/25 years • Res. Future (Abbotsford): 18%/25 years • Res. Existing (Mission): 25%/25 years • Res. Future (Mission): 350 lcd	• Res. Existing (Abbotsford): 25%/25 years • Res. Future (Abbotsford): 25%/25 years • Res. Existing (Mission): 40%/25 years • Res. Future (Mission): 267 lcd	• Res. Existing (Abbotsford): 20%/25 years • Res. Future (Abbotsford): 20%/25 years • Res. Existing (Mission): 40%/10 years • Res. Future (MIssion): 300 lcd
ICI Reductions	• Down 5% over 25 years (both communities)	• Down 10% over 25 years (both communities)	• Down 15% over 25 years (both communities)	• Down 10% over 25 years (both communities)
Agriculture Reductions	• Up 75% over 25 years (Abbotsford only; Mission n/a)	• Up 55% over 25 years (Abbotsford only; Mission n/a)	• Up 25% over 25 years (Abbotsford only; Mission n/a)	• Up 55% over 25 years (Abbotsford only; Mission n/a)
NRW Reductions	• Down 15% over 25 years (both communities)	• Down 20% over 25 years (both communities)	• Down 25% over 25 years (both communities)	• Down 25% over 25 years (both communities)
Blended Residential Rate in 2042	• 293 lcd	• 260 lcd	• 223 lcd	• 223 lcd

JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN
Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#3

SUPPLY SYSTEM CAPACITY NEEDS PROJECTIONS



URBAN systems

TECHNICAL MEMORANDUM

Date: November 20, 2017
To: Tyler Bowie, P. Eng
cc: Steve Brubacher
From: Ehren Lee, P. Eng.
Steve Brubacher, P.Eng.
File: 1790.0022.01
Subject: AMWSC Water Source Supply Study Technical Memo 3 – Capacity Needs Projection

1. Introduction and Purpose

The Abbotsford-Mission Water and Sewer Commission (Commission) provides source water supply, treatment, macro-storage and transmission to each community. A core responsibility for the Commission is to plan for long-term source supply that meets current customer needs but also enables growth and economic aspirations. Demand planning and transmission system efficiency are critical service delivery requirements of the Commission. Any community undergoing growth including projections for further growth over the 25-year horizon must consider potential gaps in meeting service levels, including making strategic investments into source supply and system upgrades to accommodate new customers. Demand management and water conservation is often employed to defer or mitigate the extent of capital investments: it is the amalgamation of demand planning, system optimization, and source expansion that comprise solution sets for the Commission. Decisions in the Fall of 2017 toward system sustainability will provide direction to staff of the Commission in regards to the preferred solution set for implementation. This technical memorandum summarizes key findings from Technical Memorandum 1 and Technical Memorandum 2 in regards to capacity needs projections.

Subsequently, Technical Memorandum #6 will review the range of choices for demand planning, system optimization, and source expansion to narrow doing preferred options for solution set development.

2. Key Findings from TM 1 and TM 2

Technical Memorandum #1 provides a comprehensive review of the regional-transmission system including reviews of licences, supply characteristics, treatment systems, equipment capacities, supply limitations, and historical use. Key findings from Technical Memorandum #1 include (included as part of overall Master Plan report):

2.1 Proposed Service Level Targets are required so that staff can identify project requirements for current and future customers.

- Major Service Term 1: All maximum day demands (MDD) should be provided by the AMWSC three supply sources and their transmission systems, independent of Abbotsford and Mission reservoirs and without deficiencies at any of the 23 regional-local system interconnection points.
- Major Service Term 2: There is adequate supply and transmission redundancy to provide average day demands in the event that one of the main sources is unavailable due to environmental (e.g. turbidity, drought) or mechanical issues.

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- Major Service Term 2: There is adequate supply and transmission redundancy to provide average day demands in the event that one of the main sources is unavailable due to environmental (e.g. turbidity, drought) or mechanical issues.

  - Note: It is considered an unusual level of service to meet MDD with the entirety of one of the larger sources out of service.
- Major Service Term 3: Potable water quality standards based on service authority permits can be consistently met under foreseeable, reasonable conditions.
- Major Service Term 4: The cost of water supply ensures the long-term integrity of meeting Service Terms 1-3 at a predictable rate.

2.2 *Transmission infrastructure limitations already exist in that service terms are not met in all demand scenarios and because the system cannot convey the supply potential of all sources.*

- The Norrish supply line is limited to a maximum day capacity of 89 MLD (albeit the full treatment and license capacity equate to approximately 140 MLD);
- The Cannell Lake source is limited to license and hydraulic capacity of 60 MLD with 225 L/s (19.4 MLD equivalent for about 3 hours) required for fire fighting in Zone 4;
- The 19 groundwater wells are capable of providing approximately 55 MLD on a reliable basis (after wells with supply or quality concerns are omitted), however, withdrawals have never reached this rate; and,
- The transmission system is unable to achieve target hydraulic service standards such as to meet MDD demands which causes an unnecessary drawdown on municipal reservoirs. Hydraulic Service Terms to be summarized separately as part of the supply and transmission master plan.

2.3 *Source capacity observations give rise to the need to expand source capacity for reliability and resiliency in the pursuit of water sustainability.*

- Cannell Lake provides consistent water quality, however, it's reliable capacity reflects only 15% of average day demand (ADD) supplies (about 11.8 MLD). Cannell Lake can be relied upon for greater capacities, up to 60 MLD to help address maximum day demand (MDD), however, that support is short-term only, perhaps up to two weeks. Cannell Lake is the primary source Pressure Zone 4 which prevents the need for Norrish Creek or groundwater supplies to be pumped to higher elevation neighborhoods. Cannell Lake does not offer significant capacity expansion for future growth.
- Groundwater wells can expand in overall production; however, they typically demonstrate a higher operational footprint including energy, permitting, and renewal than gravity sources (when extensive treatment is not required). Groundwater quality is trending poorly at some wells which will offset the long-term expansion potential. Groundwater can currently provide up to 55 MLD which represents 50% of MDD and 66% of ADD and the overall capacity can be increased incrementally, perhaps up to 45 MLD, however, not without extensive regulatory processes and potential water quality risks.
- Norrish Creek can supply 89 MLD and meet 100% of ADD on its own during periods of regular source water quality. Norrish Creek is unable to meet MDD demands on its own due to pipe size limitations of the principal Norrish transmission line. Upgrades to the Norrish supply main could enable this source to provide up to 135 MLD or 100% of the supply needs of the system for about 20 years

assuming that moderate demand management programs occur which keep per capita consumption similar, but not greater, than existing demands. However, Norrish Creek and Dickson Lake require investments over the long-term to optimize storage and meet license requirements (including instream fish flow requirements) and is prone to drought, landslide and turbidity risks.

- As a portfolio, the three sources provide fairly reliable water supply and can meet MDD demands for some time. However, given the proposed service levels which is to provide up to ADD demands with the main source not in use (i.e. Norrish, due to any of the identified source supply hazards) additional source capacity will be needed in the short-term.

  The establishment of these proposed service terms identify capacity requirements of:

  - ✓ Need to identify additional source capacity to meet ADD with Norrish out of service (7-10 years)
  - ✓ Need to identify and prioritize optimization projects to allow the Commission to meet hydraulic service terms on an ongoing basis.
- Technical Memorandum #6 will review in detail the optimization projects their priority sequencing, whereas this memo centers on a defined source capacity upgrade to meet long-term source needs.
- Technical Memorandum #2 (attachment B) provides a comprehensive review of existing water conservation initiatives, areas of success and concern, and identifies up to four potential demand management scenarios for use in water use projections with growth. Key findings from Technical Memorandum #2 include:

2.4 Conservation efforts since 2010 have helped to defer major source and system expansion; refinements to the existing conservation program will guide demand projections and capital planning.

- The existing water conservation program has offset the need to add unnecessary capacity and the deferral of the investment is saving tens of millions of dollars per year for the Commission.
- That greater investments into conservation will require greater resources into implementation and that selecting low cost, high effectiveness, and low enforcement initiatives are preferable.
- That greater emphasis on reductions for new development is a low-barrier approach to reductions; however, unless greater attention is placed toward existing residential customers, conservation effectiveness will be quite gradual and source expansion may be required sooner.
- That Abbotsford's case study for reductions and the direct-relation to low consumption stemming from meters, frequent billing, and demand-oriented water rates is the most applicable evidence for notable results in conservation.
- In particular, with regards to program elements,
  - ✓ The pursuit of universal metering and tiered rates, although not required, would signal a leap towards greater reductions at the lowest cost

- ✓ The application of best management practice techniques for conservation in new developments is one of the strongest tools available to two rapidly growing communities in Mission and Abbotsford
- ✓ While rebates and subsidies tend to plateau in their implementation, they often remain a helpful program for low-income households and rental units given the specific financial challenges for occasional renovations and upgrades
- ✓ Regulations and restrictions for water conservation typically require effort for enforcement and, therefore, they work best when designing new structures e.g. the innovations come built-in, whereas their application to existing dwellings can be challenging and resource-intensive;

- Table 1 summarizes the program elements and reduction potential for five conservation scenarios, including a no conservation option.

Table 1: Conservation Choices for Commission Framework

Conservation Choice	Theme	Outcomes	2041 Demand Projection
No Conservation Scenario	*No further reductions targeted*	• Consumption rates remain unchanged from today's conditions*	**146 MLD**
High Demand Scenario	*Steady program with refinements to existing program*	• Cost-effective conservation that achieves some reductions but does not require major spending increases • Includes 0.35% reductions year over year resulting in a 10% total drop in 25 years	**135 MLD**
Medium Demand Scenario	*Additional conservation program that increases expectations to reduce*	• 0.7% per year reductions are significant for fast-growing region; a 20% drop in 25 years would become quite challenging over time • Includes some cost-effective programs • Emerging pushback from select customers to achieve targets	**122 MLD**
Low Demand Scenario	*Advanced program that meets best practice and more*	• Largest conservation program with full suite of initiatives • Some potential to offset source expansion (scope) but does not eliminate need for new source • Aggressive targets of >1%/year (total of 30% reductions by 2041) creates notable pressure on customers	**108 MLD**

*Note: abandoning the conservation program is not a guarantee that rates will remain as they are for any length of time and it is likely that rates would increase over time.

- At first glance, the tendency can be to select the lowest demand projection out of concern for unnecessary capital costs. However, not all conservation programs are cost-effective and some may cause extraordinary burdens on customers to achieve the targeted consumption rate.
- That overall, in regards to policy and decisions, the high demand scenario is essentially a decision towards tweaking the existing program that will result in more efficient water use, demonstrate improved cost-effectiveness from the existing program and will allow for some factor of safety (i.e. it is a conservative demand projection) for system planning. The high demand scenario is suggested for further analysis in the Water Source Supply Study as it positions the Commission to make decisions around source and transmission upgrades without holding extraordinary risk if advanced targets are not met.
- Moving forward, the Commission should continue to explore various opportunities e.g. apply for senior government grants for water meters for existing customers in Mission and to consider frequent, demand-based billing, that reduce water consumption even further.
- Supply, demand and transmission are interrelated topics that affect all water utilities with regards to their long-term system planning. For the Commission, important capital investments, such as source expansion and system optimization, are scoped based on demand projections. Section 3 summarizes the needs for analysis to address capacity gaps.

3. Capacity Gaps and Solution Sets: Needs for Technical Analysis

Supply and demand planning is typical of any water purveyor and creates multiple policy pathways for conservation and source expansion. The gaps that emerge from applying the high demand scenario must be defined for upcoming technical analysis to ensure that solution sets are effective and custom to the Commission. Solution sets are comprised of three parts: water conservation program elements; optimization projects that allow for the transmission system to deliver target service levels; and, source supply expansion to meet service levels for water availability. Each element is elaborated on below.

3.1 Demand Management Planning

Program details should cover:

1. Low-Impact development including hardware requirements, landscape considerations, and incentives for advanced water use such as recycling and rain water harvesting.
2. Water restrictions such as maximizing the role of AMI data to reduce peaks and lower MDD such as redefining setpoints for messaging, and or penalties, in both jurisdictions.
3. Social marketing including options to centralize multiple conservation threads in simple and effective messaging with regards to AMI, education, incentives, rebates, customer programs.
4. Frequent Billing including the justification to gradually transition to tiered price-structures and how info-based invoices can also tie to social marketing.
5. Universal Metering with grants as a tool for informing customers of water use, to allow for economic ties to consumption, to provide information for better system planning and to identify leaks and other non-revenue water uses that can be reduced for greater efficiencies.

6. Strategic rebates that apply to customer-specific changes including topics such as low-income/rental units, capacity buy-back programs, leak detectors and the use of rebates or incentives at the time of development.
7. Targets and the metrics for achieving the identified demand projections.

3.2 Optimization Projects

Details of the capital program for optimization projects should cover:

1. The current and future gap in meeting specific hydraulic service terms, such as ensuring that:
    - there are sufficient pressures through MDD at all 23 transmission-to-local interconnections with fire flow also provided in Mission Zone 4,
    - municipal reservoirs are not drawn down unnecessarily during non-emergency scenarios,
    - that Norrish remains a core source with minimal limitations which includes upgrades through optimization of storage of Dickson Lake and potentially upgrading the Norrish Creek supply line in the future, depending on the ability to explore new sources,
    - Pressure Zone 4 customers have adequate supply in the event of an issue with Cannell Lake, and
    - Any new sources and their interconnection upgrades lead to more efficient supply in the long term;
2. That capital projects are prioritized relative to other upgrades based on their performance (e.g. high, medium, low) to achieve service levels for both current and future customers.

3.3 Source Expansion Projects

Program elements should identify the source options that deliver on the following requirements for source expansion:

1. The rationale for source expansion should be explained through the need to meet service levels for source supply for ADD or MDD scenarios as outlined in Table 2.

Table 2: Supply Gap Profile

Service Term	2017 Gap	2041 Projected Need
Supply Maximum Daily Demand	Sufficient*	Sufficient*
Supply Average Daily Demand *while one source (Norrish) is temporarily out of service*	Sufficient (~7-10 years from need)	**Need 25 MLD**

* ability to maximize the potential for any source also depends on the transmission efficiency of the system and the status of optimization projects; some optimization projects are required in the event of supplying either ADD or MDD if a source is not in service.

2. How to prioritize source expansion choices should be based on the ability of the source options to perform against the criteria for source expansions, which are listed in Table 3.

Table 3: Criteria for Evaluating Sources and Supply Projects

Criterium	Factors
1. Resiliency	• Water supply consistency over time e.g. droughts • Amount and severity of hazards/risks
2. Adequacy	• Ability to phase for growing water demands; to meet peak demands • License and regulatory assurances in long term use/supply
3. Serviceability	• Proximity to system and customers • Operational footprint e.g. management, operations
4. Affordability	• Relative cost against other source options • Cash-flow considerations e.g. need for large investments upfront
5. Desirability	• Public perception of water supply • Stakeholder conflicts

Overall, water supply and demands are dynamic. Therefore, solution sets must address the evolving water supply, conservation, and transmission-optimization and consider that management requirements and water issues can fluctuate from year-to-year and season-to-season. By adopting a suite of service levels, the Commission can communicate to staff and its customers that:

- solution sets are comprised of three elements to provide adequate services to meet existing and future needs, and
- capital projects and significant investments are directly related to service needs for existing and future customers.

Technical Memorandum #6, which follows hydraulic analysis (including Technical Memoranda 4/5), will identify and compare options for building solution sets and offer recommendations for preferred programs that meet service levels.

URBAN SYSTEMS LTD.

Steve Brubacher, P.Eng.
Principal, Water Practice Leader

Ehren Lee, P.Eng.
Principal, Policy and Strategy

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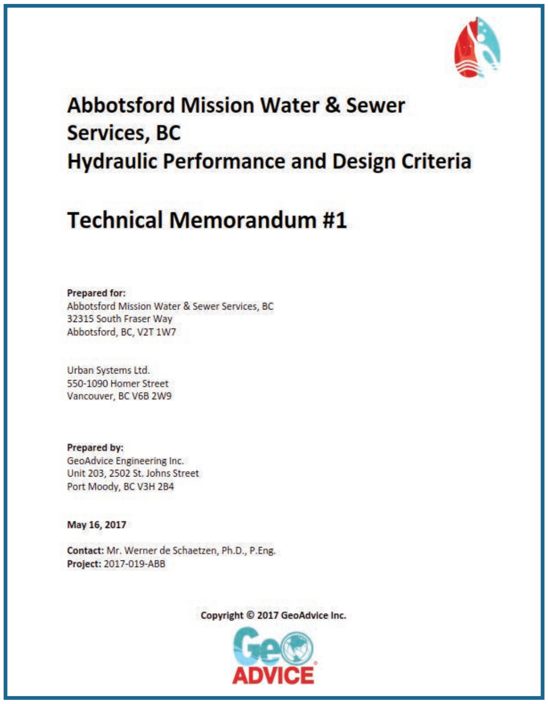
JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN

Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#4

SUPPLY SYSTEM HYDRAULIC CRITERIA



Abbotsford Mission Water & Sewer Services, BC
Hydraulic Performance and Design Criteria

Technical Memorandum #1

Prepared for:
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May 16, 2017

Contact: Mr. Werner de Schaetzen, Ph.D., P.Eng.
Project: 2017-019-ABB

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Project: 2017-019-ABB

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1 INTRODUCTION

Abbotsford Mission Water & Sewer Services, BC (AMWSS) retained Urban Systems Ltd. (USL) to develop the Water Supply Master Plan. GeoAdvice Engineering Inc. (GeoAdvice) partnered with USL as the modeling sub-consultant for this project. This technical memorandum describes the recommended hydraulic performance and design criteria.

2 HYDRAULIC PERFORMANCE AND DESIGN CRITERIA

Based on the City's design specifications and discussions with the City of Abbotsford, the following criteria are recommended for the evaluation of the hydraulic capacity performance of the water supply system.

2.1 HYDRAULIC CRITERIA

The following scenarios will be considered:

- 2041 Maximum Day Demand (MDD). This scenario is used to identify any supply main, PRV station and storage reservoir capacity issues that the current system is susceptible to have under the 2041 MDD condition.
- 2051 Maximum Day Demand (MDD). This scenario is used to size deficient infrastructure identified in the 2041 MDD scenario such that the future system has adequate capacity to convey the 2051 MDD condition.

Table 2.1: Design Scenarios

Sources	Scenario
Norrish Creek	2051 MDD
Cannell Lake Upstream Best PRV/PSV	2051 MDD + Fire Flow (225 L/s)
Cannell Lake Downstream Best PRV/PSV	2051 MDD
Groundwater Wells	2051 MDD

Table 2.2: Design Criteria

Criteria	Parameter Value
Target Velocity: New Supply Pipe	2.0 m/s
Maximum Velocity: New Supply Pipe	4.5 m/s
Target Headloss: New Supply Pipe	3 m/km
Maximum Headloss: New Supply Pipe	5 m/km

2.2 FIRE FLOW CRITERIA

Table 2.3 shows the required fire flow for Industrial land uses.

Table 2.3: Fire Flow Requirements (150 kPa minimum)

Land Use Type	Fire Flow (L/s)*	Storage Reservoir
Industrial	225 L/s	Maclure Storage Reservoir
Industrial	225 L/s	Mt Mary Ann Storage Reservoir

***MMCD**

2.3 WATER QUALITY CRITERIA

Source water quality must meet or exceed the most stringent of either current and anticipated operating permit requirements or the Canadian Guidelines for Drinking Water Quality.

2.4 STORAGE RESERVOIR CAPACITY DESIGN CRITERIA (MMCD)

We will only review the two AMWSS storage reservoirs:

- Maclure Storage Reservoir
- Mt Mary Ann Storage Reservoir

There are three types of storage which need to be considered in the AMWSS water supply system:

- Fire storage (A) – This is the amount of water required to extinguish fires within the service area of a storage reservoir. This storage is based on the worst case fire flow land use scenario.
- Equalization storage (B) – This is the amount of storage required for normal water consumption. MMCD states that this should be 25 % of MDD.
- Emergency storage (C) – The emergency storage requirement is 25 % of A + B.

The required storage reservoir capacity is the sum of the Fire storage (A), Equalization storage (B) and Emergency storage (C).

Table 2.4 shows fire storage (A) requirements used in this analysis.

Table 2.4: Fire Flow (FF) Storage Calculations

Landuse	FF (L/s)	FF (L/min)	FUS* Duration (min)	FF Volume (ML)
Industrial	225	13,500	180	2.43

***Fire Underwriter Survey**

2.5 PRV CAPACITY DESIGN CRITERIA

Each AMWSS PRV station will be reviewed in terms of peak velocity and operational capacity. To limit the amount of "wear and tear", the recommended peak velocity through a PRV should be less than or equal to 6 m/s[1].

2.6 MINIMUM PRESSURES AT KEY LOCATIONS

All the AMWSS PRVs from the supply system to the City/District must be active, i.e. upstream HGL must be higher than the PRV setting. In addition, no new PRV connection to the

---

[1] Maximum velocity criteria of 6 m/s is derived from manufacture rated maximum sustained flow from two common water distribution PRV manufacturers (Singer Valve Model 106-PR and Cal-Val Model 90-01).

City/Mission will be considered, i.e. current configuration of the export nodes (Take-offs) will remain unchanged. No new connections to the City/District will be considered.

2.7 MODELING ASSUMPTIONS APPLIED TO THE SUPPLY SYSTEM

- Best PRV/PSV maintains its current pressure settings for the base scenario. Settings may be adjusted during system optimization to improve hydraulic performance.
- Maclure PRV/PSV maintains its current pressure settings. Settings may be adjusted during system optimization to improve hydraulic performance.
- No District of Mission pressure zones changes. The pressure zones will remain unchanged.
- Initial tank levels are at 80 % of their maximum level.

The following City of Abbotsford infrastructure will be included "by default" in the future modeling scenarios:

- 123/103 Pressure Zone change
- 137/138 Pressure Zone change when Cassiar reservoir is decommissioned
- Vicarro Pump Station (from 231 m to 181 m)
- Mt Village Pump Station will be replaced into a PRV station when Vicarro Pump Station is commissioned

Submission

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Approved by:

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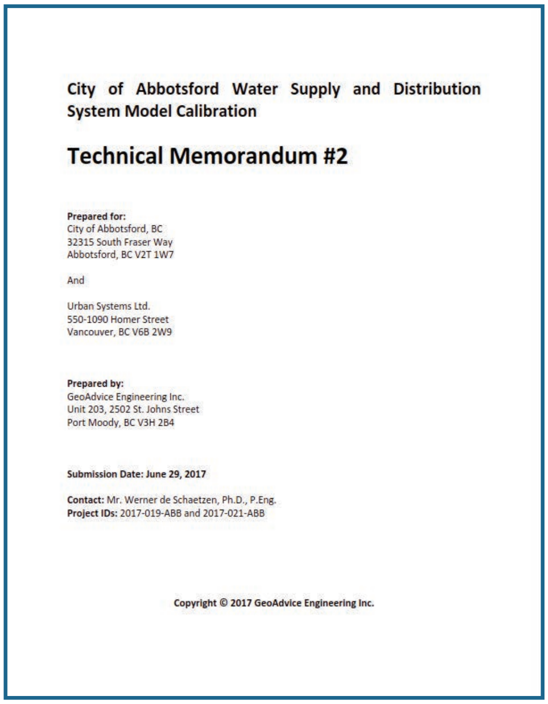
JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN

Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#5

SUPPLY SYSTEM
MODEL CALIBRATION



City of Abbotsford Water Supply and Distribution System Model Calibration

Technical Memorandum #2

Prepared for:
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Project IDs: 2017-019-ABB and 2017-021-ABB

City of Abbotsford Water Supply and Distribution System Model Calibration

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1.0 Introduction

GeoAdvice Engineering Inc. (GeoAdvice) and Urban System Ltd. (USL) were retained by the City of Abbotsford, BC ("City") to prepare the master plans for the Abbotsford Mission Water and Sanitary Services ("AMWSS") water supply system and the City's water distribution system. As part of each of the master plans, GeoAdvice completed the calibration of the AMWSS water supply system and City's water distribution system hydraulic model.

The City's water supply and distribution systems are encompassed within one single hydraulic model. The model includes the entire AMWSS supply system, the City's distribution system, and the District of Mission ("District") distribution system. The following GeoAdvice reports summarize the latest updates of the supply and distribution systems as well as the integration of the District and City models:

- *District of Mission Water Distribution System Modeling and Capacity Analysis (April 2017)*
- *City of Abbotsford Water Model Update (March 2017)*

For the purpose of having fully integrated and consistent results across the water supply and distribution system master plans, both systems were calibrated simultaneously and congruently. The results of the model update and calibration for both projects are included in this technical memorandum.

The water model was calibrated using the InfoWater software program (Innovyze). InfoWater is a water system modeling and management software application. Furthermore, the City's *Water Modeling Standards, Conventions & Guidelines (2010)* were followed in the course of the model update.

This technical memorandum summarizes:

- The steps to update the model; and
- The model calibration methodology and results.

The attached spreadsheet ***2017-019-ABB_2017-021-ABB_TM2_Supply&DistributionSystemModelCalibration_Appendices_r1_2017-06-29.xlsx*** contains the following report appendices:

Appendix A – SCADA Data Excluded From Model Calibration
Appendix B – Updated Pump Curves
Appendix C – Operational Controls
Appendix D – Pattern Controls
Appendix E – Tabular Model Calibration Results
Appendix F – Graphical Model Calibration Results

2.0 Model Update

The first step was to review the existing InfoWater model (File Name: *ABBY_JAN_2017.IWDB*) and GIS data provided by the City on May 17, 2017. The model and the City's GIS were reviewed before beginning the model calibration process.

2.1 Supply/Distribution Model Update

The City's hydraulic model required minor updates and corrections to bring it in-line with the City's actual water supply and distribution systems. **Table 2.1** below summarizes the updates and assumptions that were made in the model.

Table 2.1: List of Model Updates

Update #	Description of Issue	Resolution
1	Discrepancies present between model pipe data (diameter, material, install year, etc.) and GIS data	Joined all model pipes to their counterpart GIS pipe. Imported available GIS data into model. Updated diameters, materials and installation years as needed.
2	Missing new pipes in model from GIS	Added new pipes based on GIS changes identified by the City.
3	Model controls inconsistent with physical system operation	Updated pump station, altitude valve and PRV controls based on SCADA records.

2.2 Existing Demand Update

The existing demands were scaled to match the demands on the calibration day (August 20, 2016) which represents maximum day demand (MDD). **Table 2.2** summarizes the existing 2016 MDD for the City and the District.

Table 2.2: 2016 Maximum Day Demand

City/District	Demand (L/s)	Demand (MLD)
Abbotsford	920.7	79.6
Mission	282.3	24.4
Total	**1,203.0**	**104.0**

3.0 SCADA Data Review

The next step was to review and analyze the SCADA data provided by the City. SCADA data collected included the following:

- Pump on/off status and flows
- Pump inlet and outlet pressures
- Pump control operating procedures
- Reservoir levels and flows
- PRV flows and pressures
- Control valve settings and operating procedures
- Pressure and flow readings at locations within the AMWSS and City systems

The SCADA data was reviewed for the following:

- Data gaps and inconsistencies
- System maintenance periods
- Unusual circumstances
- Field data anomalies

The model was calibrated using 24-hour SCADA data collected by the City. The calibration day was selected to be August 20, 2016 as it represents the Maximum Day Demand (MDD) in 2016. **Table 3.1** summarizes the City SCADA data that were provided and used to compare against the modeling results. In total, 147 SCADA data files were used to calibrate the water supply and distribution system model as explained in **Table 3.1**.

Table 3.1: Summary of the SCADA Data Used to Calibrate Model

Measurement Type	Number of Calibration Points	Model Calibration Use
Pump Station		
Flow	27	• To compare with pump modeling flow predictions
Pressure	15	• To compare with pump modeling suction and discharge pressure predictions
Reservoir		
Level	14	• To compare with reservoir modeling level predictions
PRV		
Flow	28	• To compare with flow modeling predictions
Pressure	46	• To compare with pressure modeling predictions
Pipe Flow	13	• To compare pipe modeling predictions
Junction Pressure	4	• To compare junction modeling predictions

An additional 45 field data measurements were provided and analyzed but were ultimately disregarded due to the following reasons:

- Field data seem invalid and inconsistent with other measurements provided;
- Duplicate SCADA data; or
- There are still pending and unresolved questions about the field data measurements.

The City confirmed to disregard or ignore the field data. A list of all the disregarded field data measurements is presented in **Appendix A**.

Pump Measurements

In total, 42 pump measurements were used for the model calibration. 27 pump flow measurements were used in the calibration to compare against predicted flow modeling results. Additionally, 15 pressure measurements were used in the calibration for comparison, which include the suction and discharge pressures at most of the pump stations. The pump flow and pressure measurements were further used to validate the pump curves in the model.

Tank Level Measurements

In total, 14 tank measurements were used for the model calibration. Additionally, the initial level of the tanks was updated in the model to match the recorded initial water level (midnight on August 20, 2016). For example, at 12:00 AM of August 20, 2016, the tank level recorded for the St. Moritz Tank was 8.84 m and was thus updated in the model. This approach guaranteed that the same boundary conditions were used at the start of the 24-hour modeling simulation. **Table 3.2** summarizes the initial tank levels.

Table 3.2: Tank Initial Levels (August 20, 2016 @ 12:00 AM)

Tank	Initial Level
TNK-ATKINSON	4.28 m
TNK-BRADNER	5.44 m
TNK-CASSIAR	5.67 m
TNK-EAGLE-MTN	5.56 m
TNK-EMPRESS	5.52 m
TNK-HACKING	1.90 m
TNK-LEDGEVIEW	14.87 m
TNK-MACLURE-A	4.04 m
TNK-MACLURE-B	3.94 m
TNK-MACLURE-C	3.98 m
TNK-MARY-ANN	5.34 m
TNK-MCKEE	3.96 m
TNK-MCMILLAN	6.53 m
TNK-ST-MORITZ	8.84 m

The 24-hour tank level measurements were used in the calibration to compare against predicted tank level modeling results for all tanks.

PRV Measurements

In total, 74 PRV measurements were used for the model calibration. 28 PRV flow measurements and 46 PRV pressure measurements were used in the calibration to compare against predicted modeling results.

Pipe Flow Measurements

In total, 13 flow measurements were used in the calibration to compare against predicted flow modeling results.

Junction Pressure Measurements

In total, 4 junction pressure measurements were used in the calibration to compare against predicted pressure modeling results.

4.0 Model Calibration

When calibrating the model, the goal was to compare the measured values from the SCADA data against the predicted results from the model, to show that the model results are in agreement with the observed field data.

The model was calibrated using the criteria specified in **Table 4.1**.

Table 4.1: Recommended Calibration Accuracy

Parameter	Recommended Accuracy
Flow	± 10 - 20 %
Peak Flow	± 10 %
Peak Timing	± 1 hour
Reservoir Level	± 10 - 20 %
Pressure	± 10 %
Shape	Representative of observed pattern

The ‘first cut’ at calibration focused on system boundary facilities such as pumping stations, storage facilities, and control valves. Key facility attributes that were reviewed and adjusted as necessary included pump curves, storage geometry, controls and zone configurations.

Pipe Roughness Update

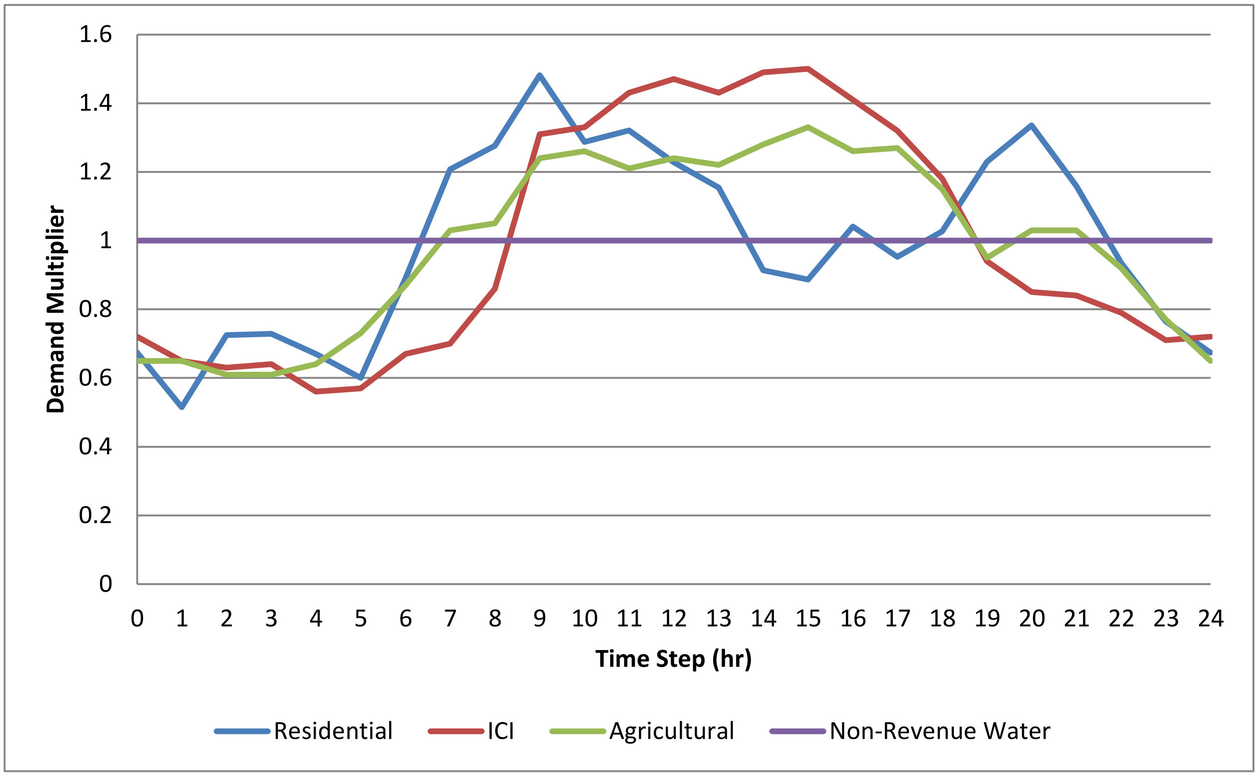
The hydraulic model was set-up to use the Hazen-Williams headloss formula to estimate friction loss through water mains. The pipes were grouped together based on their known physical characteristics, i.e. material, age and diameter. It was assumed that all pipes within a group have the same roughness coefficient. The Hazen-Williams coefficients for each pipe group were updated as part of the 2016 steady state model calibration and, as such, were not further changed as part of this study. Refer to the report *City of Abbotsford Water Model Update (March 2017)* for the calibrated pipe roughness coefficients.

Demand Patterns Update

A demand pattern is a set of multipliers that scale the base demand. The base demand is defined as the average demand at the junction, and the demand pattern is used to characterize the water demand over time. A typical pattern covers a 24-hour cycle to analyze changes during one day.

The model has four (4) key demand patterns. The demand patterns for Commercial, Industrial and Institutional (ICI) demand types are the same. Similarly, both Single-family and Multi-family Residential demand types used the same pattern. All patterns were reviewed and calibrated as necessary based on the observed SCADA flows. Refer to **Figure 4.1** for a graphical representation of each demand pattern used in the model.

Figure 4.1: 2016 MDD Demand Patterns



Furthermore, these patterns were used both for the Abbotsford demands and the District of Mission demands.

Pump Curves Update

All pump curves were reviewed against the available pump flow and pressure SCADA points. Updates were made to curves where the field data showed evidence of impeller deterioration or where it was suspected that the original pump curve was incorrect. The curves for the following pumps were adjusted to calibrate the model:

- Bevan 1, 2, & 4
- Bradner 1
- Industrial C
- McConnell
- Old Yale 5 & 6
- Townline 1 & 2
- Upper Maclure 1
- Westminster 1

The updated pump curves can be found in **Appendix B**.

Operational Controls Update

Operational control schemes were modeled to accurately simulate the hydraulic behavior of the water supply and distribution systems. During an extended period simulation (EPS), controls specify the status of selected pipes, pumps, and valves as a function of time, flow rate, tank water level, or junction pressure.

The calibrated operational controls used in the City model are detailed in **Appendix C**.

Additionally, to calibrate the model, three (3) patterns were created to control the following PRVs:

- PRV-EMPRESS-1
- PRV-SANDON-2
- PRV-SANDON-4

These patterns were created to ensure that observed pressures controlled by these PRVs were mimicked in the model during the calibration scenario. The patterns can be found in **Appendix D**.

4.1 Model Calibration Results

Calibration was completed by comparing field SCADA data and modeling results. A significant amount of effort during calibration was devoted to correcting modeling errors, missing values and SCADA data.

The overall quality of the model accuracy was estimated by comparing the field data measurements against the model predictions. The model calibration results were classified according to categories presented in **Table 4.2**.

Table 4.2: Calibration Agreement Categories

Agreement Status	% Difference
Excellent	± 5%
Good	± 10%
Satisfactory	± 20%
Poor	> 20%

Table 4.3 summarizes the flow calibration results.

Table 4.3: Summary of Flow Calibration Results

Agreement Status	Supply Flow		Distribution Flow	
	Quantity	%	Quantity	%
Excellent	14	52%	29	71%
Good	8	30%	8	20%
Satisfactory	1	4%	3	7%
Poor	4	15%	1	2%
Total	**27**	**100%**	**41**	**100%**

Table 4.4 summarizes the pressure calibration results.

Table 4.4: Summary of Pressure Calibration Results

Agreement Status	Supply Pressure		Distribution Pressure	
	Quantity	%	Quantity	%
Excellent	29	88%	29	91%
Good	3	9%	2	6%
Satisfactory	1	3%	1	3%
Poor	0	0%	0	0%
Total	**33**	**100%**	**32**	**100%**

Table 4.5 summarizes the tank level calibration results.

Table 4.5: Summary of Level Calibration Results

Agreement Status	Supply Level		Distribution Level	
	Quantity	%	Quantity	%
Excellent	2	50%	8	80%
Good	2	50%	1	10%
Satisfactory	0	0%	1	10%
Poor	0	0%	0	0%
Total	**4**	**100%**	**10**	**100%**

Table 4.6 summarizes all of the calibration results.

Table 4.6: Total Summary of Calibration Results

Agreement Status	Supply Total		Distribution Total	
	Quantity	%	Quantity	%
Excellent	45	70%	66	80%
Good	13	20%	11	13%
Satisfactory	2	3%	5	6%
Poor	4	6%	1	1%
Total	**64**	**100%**	**83**	**100%**

The complete tabular calibration results can be found in **Appendix E**, and the complete collection of calibration graphs can be found in **Appendix F**.

As shown in the tables above, there are 5 calibration points with "poor" agreements, all of which are flow calibration points. **Table 4.7** summarizes the "poor" calibration agreements.

Table 4.7: "Poor" Calibration Agreements

SCADA Tag	SCADA Description	Comment
WS.fl_tr7	Maclure Flow	Mass balance calculations performed for the Abbotsford system reveal large discrepancies in the measured flows at these 4 locations. As such, the measured flow data at these locations are suspect and should not be used for model calibration.
WS.flow_400_valve_7	Maclure PSV Flow (400 mm)	
WS.flow_res_out_400_7	Maclure Reservoir Outlet Flow OUT (400 mm)	
WS.flow_res_out_750_7	Maclure Reservoir Outlet Flow OUT (750 mm)	
WW.prv_flow_13	Selkirk PRV Flow	Model over-predicts flow through the Selkirk PRV station. If flow is further restricted, there is insufficient flow to fill the Cassiar storage reservoir. It is suspected that there may be discrepancy in the units provided in the field data.

Mass balance calculations based on the Abbotsford take-off measured flow data revealed large discrepancies in the data at the Maclure control valve station and reservoirs. As such, the field data is suspect and does not provide an accurate representation of the flows at Maclure for model calibration.

Overall, good agreements were achieved between the model results and measured SCADA data. As such, the model can be used as a reliable planning tool for both the AMWSS water supply system and City water distribution system master plans.

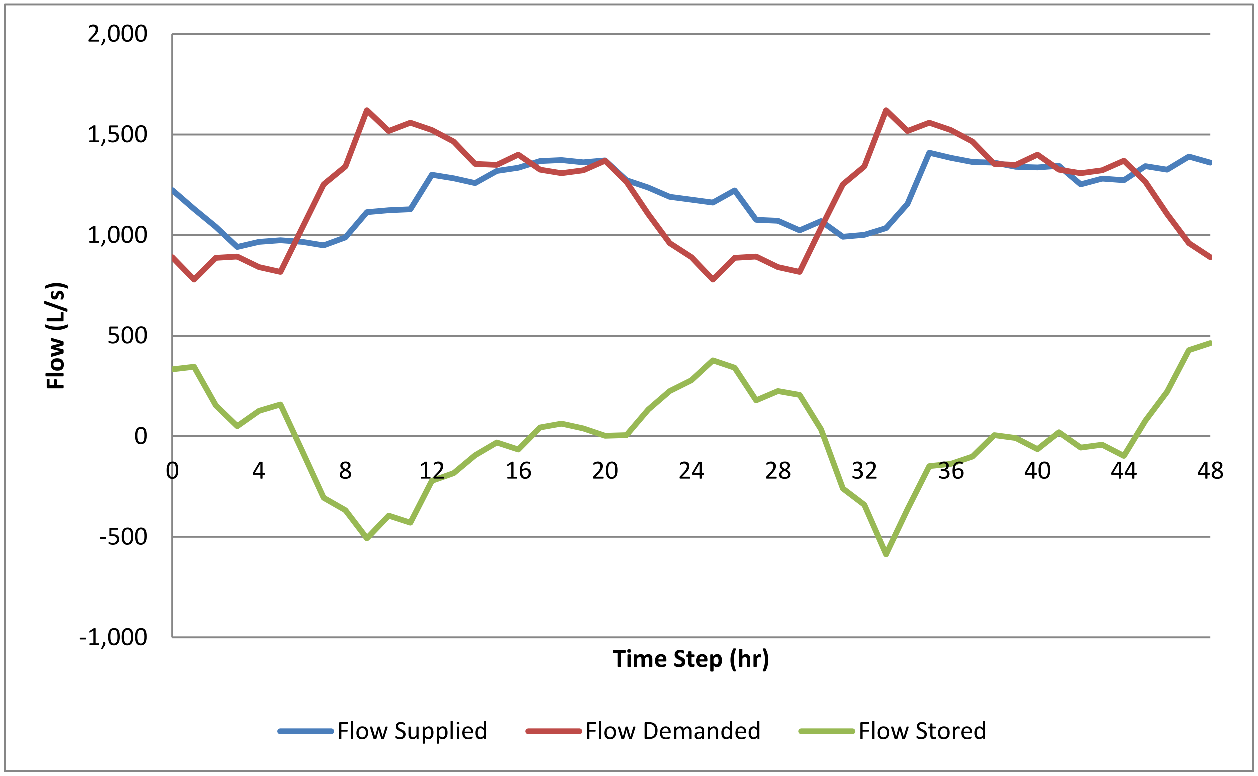
Based upon the findings from the model calibration, it is recommended that the City verify the excluded SCADA points listed in **Appendix A** and review the SCADA points with poor calibration agreements listed in **Table 4.7**.

5.0 EPS Model Validation

With the EPS model calibration complete, the next step was to review the robustness of the model. Key EPS model results, such as total system flows as well as tank cycling, were reviewed over a 2-day period to ensure that the MDD model results were able to converge over a sustained period of the time.

Figure 5.1 shows the total flow supplied by the system, the total flow demanded, and the total flow stored during the 48 hour MDD EPS run.

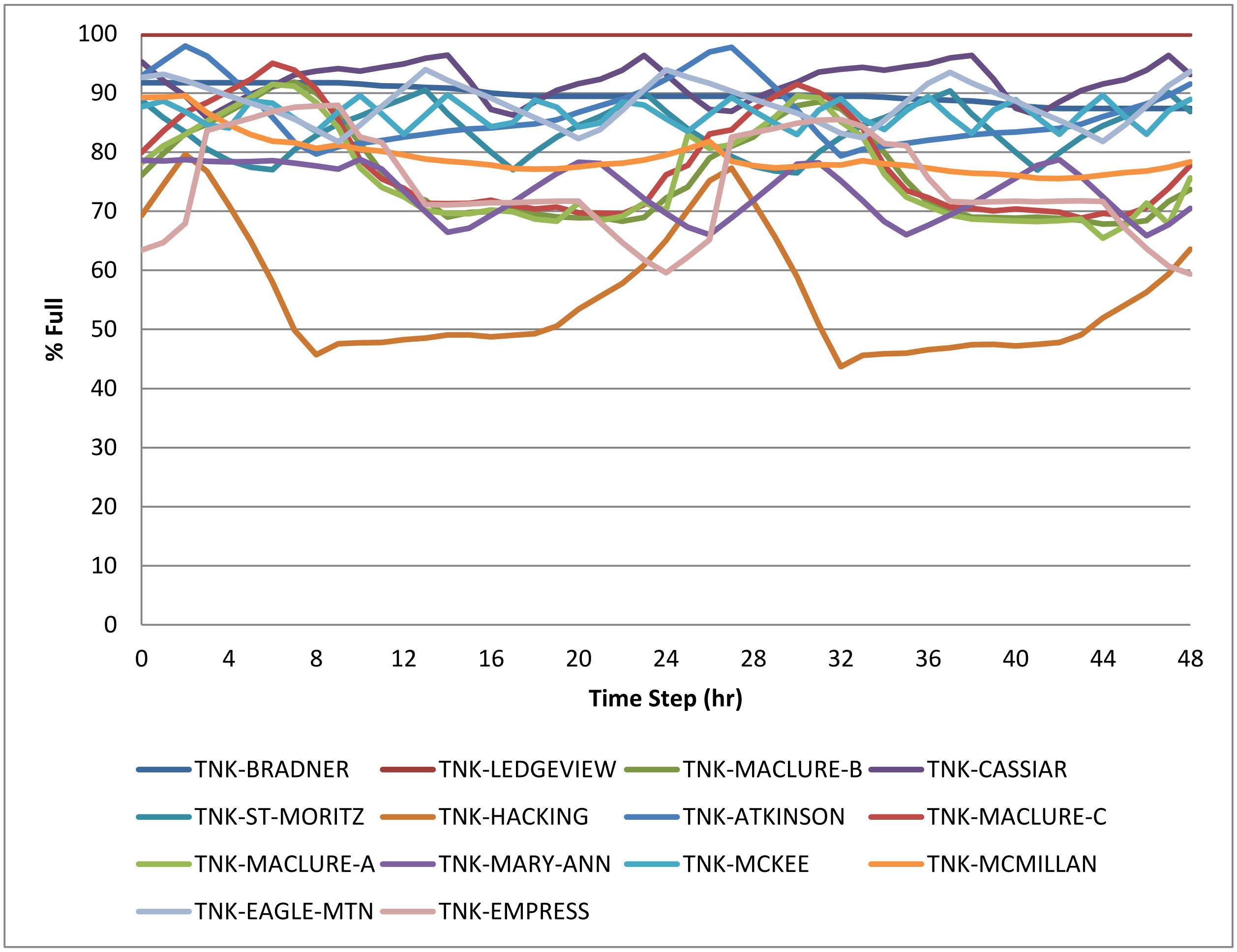
Figure 5.1: System Flow Analysis (2016 MDD EPS)



As shown in **Figure 5.1**, the flow supplied represents the total flow provided by the water sources (i.e. Cannell Lake, Norrish Creek, and the groundwater wells) throughout the 48-hour 2016 MDD EPS run. The flow demanded shows the total flow demanded by all water users throughout the simulation duration. Finally, the flow stored represents the total flow into and out of all storage nodes throughout the 2016 MDD EPS run.

Tank levels were also reviewed to ensure typical level cycling, ensuring that each tank refills over the course of the simulation. **Figure 5.2** shows the levels (% full) of each tank and how each tank cycles over the duration of the 2016 MDD EPS run.

Figure 5.2: Tank Levels (2016 MDD EPS)



As shown in **Figure 5.2**, the tanks are able to cycle over the course of the 48-hour simulation. The Ledgeview tank remains 100% full at all times, which is consistent with the field data. Furthermore, the model predicts that the Hacking tank falls below 50% through the middle of the day, which differs slightly from the field data; however, the model results have an excellent correlation with the Atkinson tank, which is in the same pressure zone as the Hacking tank. It should be noted that the Atkinson tank has a bottom elevation (63.3 m) 2 meters lower than the Hacking tank (65.3 m). Also, the Atkinson tank has a maximum level of 4.60 m; whereas, the Hacking tank has a maximum level of 2.75 m.

Furthermore, the statuses of all control PRV valves feeding from the supply system to the distribution systems were reviewed to ensure adequate pressure was provided by the supply system throughout the simulation duration. Additionally, general system pressures were reviewed and a summary is provided in **Table 5.1** below.

Table 5.1: Summary of System Pressures

System	Average Minimum Pressure	Average Maximum Pressure	Average Pressure
AMWSS Supply	100.3 m	107.7 m	103.0 m
Abbotsford Distribution	65.3 m	68.5 m	67.0 m
Mission Distribution	65.4 m	67.0 m	66.2 m

As shown in the table above, the average minimum, maximum, and average pressures are within the expected ranges for the supply and distribution systems.

Submission

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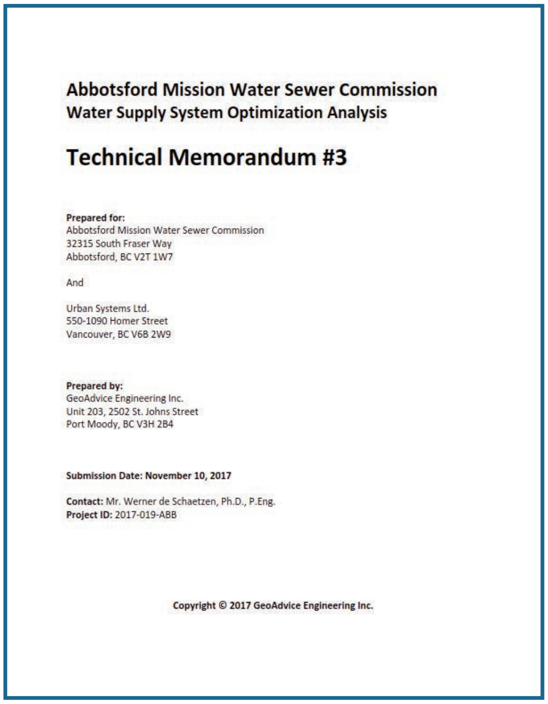
JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN

Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#6

SUPPLY SYSTEM OPTIMIZATION



Abbotsford Mission Water Sewer Commission
Water Supply System Optimization Analysis

Technical Memorandum #3

Prepared for:
Abbotsford Mission Water Sewer Commission
32315 South Fraser Way
Abbotsford, BC V2T 1W7

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Submission Date: November 10, 2017

Contact: Mr. Werner de Schaetzen, Ph.D., P.Eng.
Project ID: 2017-019-ABB

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Abbotsford Mission Water Sewer Commission
Water Supply System Optimization Analysis

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1.0 Introduction

GeoAdvice Engineering Inc. ("GeoAdvice") and Urban System Ltd. ("USL") were retained by the Abbotsford Mission Water and Sewer Commission ("AMWSC") to complete the water supply system master plan. As part of the master plan, GeoAdvice completed a supply system optimization analysis of the AMWSC water supply system using the AMWSC water system hydraulic model.

The water system hydraulic model encompasses the City of Abbotsford ("City") and District of Mission ("District") water distribution systems as well as the AMWSC supply system. The following GeoAdvice reports and technical memoranda summarize the latest updates of the supply and distribution systems as well as the integration and calibration of the District and City models:

- *District of Mission Water Distribution System Modeling and Capacity Analysis (April 2017)*
- *City of Abbotsford Water Model Update (March 2017)*
- *City of Abbotsford Water Supply and Distribution System Model Calibration (June 2017)*

This technical memorandum summarizes:

- The future demand and scenario development;
- The supply system optimization methodology and model results; and
- The supply source security analysis methodology and model results.

2.0 AMWSC Supply System

The City of Abbotsford and District of Mission water distribution systems are currently supplied by the AMWSC supply system from three (3) primary sources, which are summarized in **Table 2.1**.

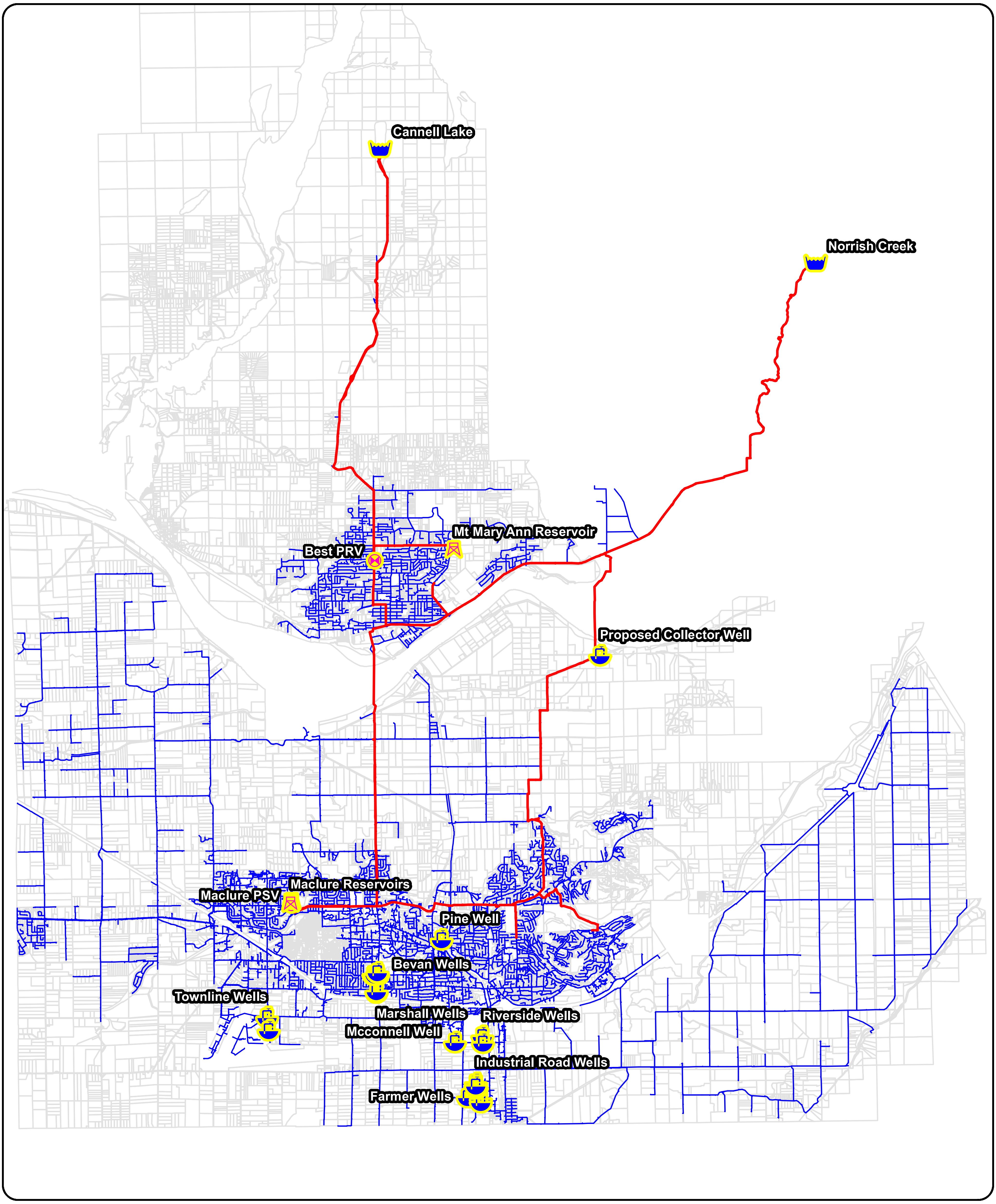
Table 2.1: AMWSC Supply Sources

Source	Source Capacity
Norrish Creek	135 MLD
Cannell Lake	12 MLD
Groundwater Wells	55 MLD

Although the source capacity of Norrish Creek is 135 MLD, the AMWSC has observed that at most 90 MLD is available due to the limited hydraulic capacity of the Norrish Creek transmission main.

For supply security in the future, the AMWSC is considering, as an option, a new collector well assumed to be located on the south side of the Fraser River at the Hyde-Buker crossing.

The supply system and its sources are illustrated in **Figure 2.1**.



GeoAdvice Engineering Inc.

Legend

- Supply Source
- Well
- Storage Reservoir
- Control Valve Station
- Supply System Water Main
- Distribution System Water Main

Project: AMWSC Water Supply Master Plan
Client: Abbotsford Mission Water Sewer Commission, BC
Date: November 2017
Created by: AM
Reviewed by: WdS

AMWSC Supply System

Figure 2.1

3.0 Future Demands and Scenario Setup

In order to conduct the supply optimization analysis, it was important to first load the model with the future demand conditions.

The model was loaded with all future demands from 2016 to 2051 as part of the City of Abbotsford water distribution system master plan. Details on the future demand calculation and allocation prepared by GeoAdvice are provided in **Appendix A**. Background on these numbers is contained in the *Demand Projections* Technical Memo prepared by Urban Systems (April 2017).

Summaries of the future average day demands (ADD) and maximum day demands (MDD) are provided in **Table 3.1**.

Table 3.1: AMWSC Demand Data

Demand Type	ADD (MLD)	MDD (MLD)
Existing Single Family	22.3	32.9
Existing Multi Family	10.2	14.9
Existing Commercial	4.4	6.4
Existing Industrial	8.5	12.1
Existing Institutional	2.9	4.2
Existing Agriculture	7.7	11.0
Subtotal	**55.8**	**81.5**
Existing Non-Revenue Water	10.4	16.9
Existing Total	**66.2**	**98.4**
Residential Growth to 2041	13.1	19.3
Employment Growth to 2041	13.8	19.7
2041 Non-Revenue Water	8.8	14.4
2041 Total	**91.5**	**134.9**
Residential Growth to 2051	19.5	28.8
Employment Growth to 2051	19.1	27.5
2051 Non-Revenue Water	8.8	14.4
2051 Total	**103.3**	**152.2**

The demands provided in **Table 3.1** represent the total demands in the City of Abbotsford and the District of Mission water distribution systems.

4.0 Supply System Optimization Analysis

4.1 Supply Optimization Projects

Prior to this study, the AMWSC identified a number of potential supply system optimization projects, which are outlined in the *Water System Optimization Assessment (August 2013)* report completed by the AMWSC. In consultation with the AMWSC, a select number of these supply optimization projects were investigated under 2041 MDD conditions to determine an optimized solution for servicing the future system.

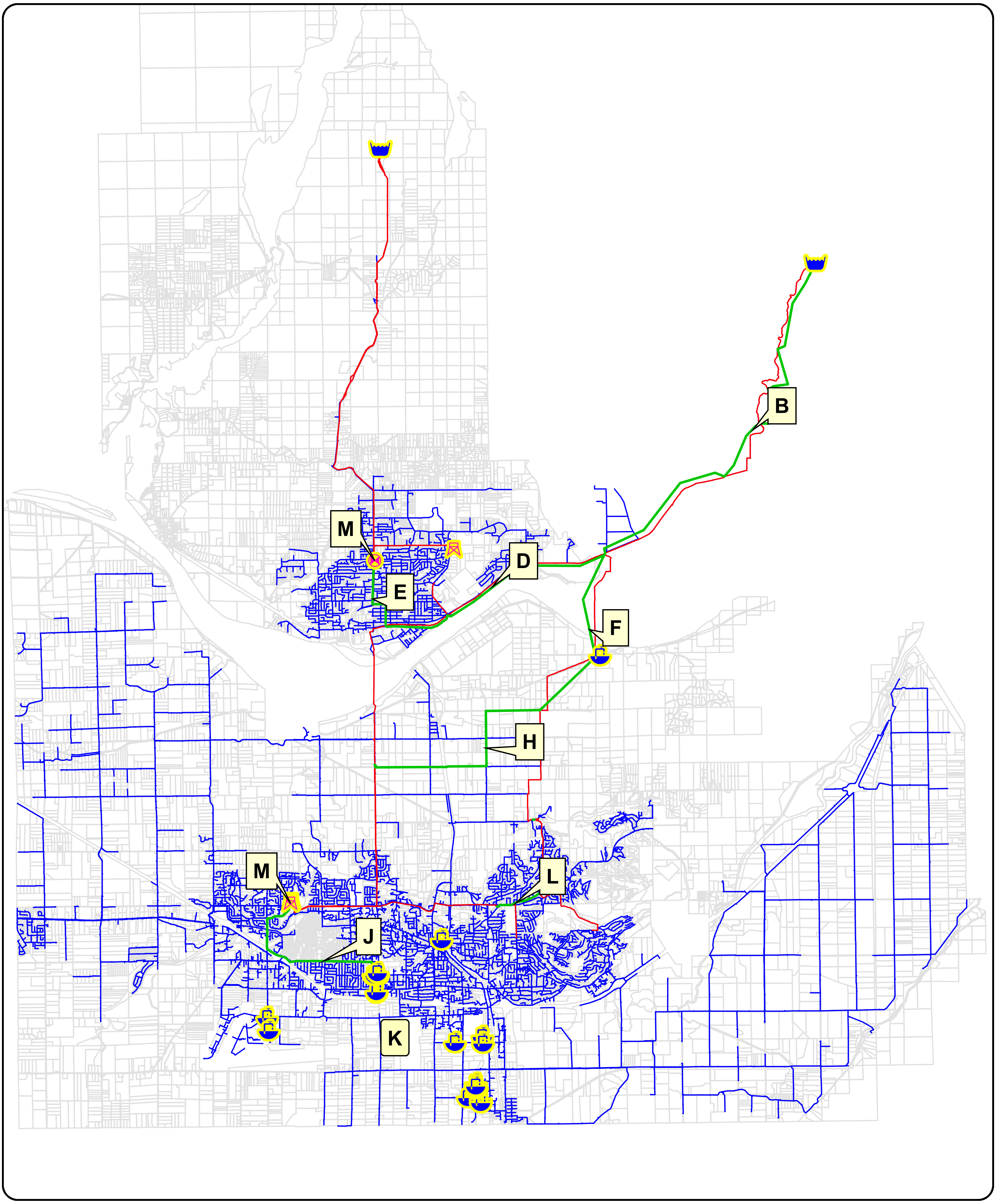
Table 4.1 summarizes the optimization projects that were investigated as part of this analysis.

Table 4.1: Supply Optimization Projects

Project ID*	Description
B	Twinning of Norrish Creek transmission main to Hyde-Buker Road (About 13 km)
D	Twinning of transmission main along Hwy 7 between river crossings
E	Cedar Street transmission main from Best Avenue to Hwy 7
F	Third river crossing
H	East-west transmission main connector south of the Fraser River
K	Modification of well pump operation settings
J	Transmission main from Bevan Wells to Maclure Reservoir
L	Resolution of various transmission main constrictions
M	Installation of flow control and pressure sustaining valves at Best and/or Maclure

*Project IDs are consistent with the AMWSC *Water System Optimization Assessment (August 2013)* report.

Figure 4.1 shows the location of each optimization project listed above.



GeoAdvice Engineering Inc.

Legend

- Supply Source
- Well
- Storage Reservoir
- Pressure Reducing Valve Station
- Supply Optimization Project
- Supply System Water Main
- Distribution System Water Main

Project: AMWSC Water Supply Master Plan
Client: Abbotsford Mission Water Sewer Commission, BC
Date: November 2017
Created by: AM
Reviewed by: WdS

Supply Optimization Projects

Figure 4.1

In order to find an optimized supply solution for servicing the future system, each optimization project was modeled individually under 2041 MDD conditions to determine its ability to meet the future servicing requirements. As agreed with the AMWSC, projects D and E were analyzed together as a single project.

Hydraulic model simulations were conducted for each optimization project, and it was found that, individually, none of the optimization projects could meet the future scenario service requirements. Each hydraulic simulation failed due to system imbalances caused by low pressures and storage reservoirs becoming empty. Under 2041 MDD, none of the optimization projects alone can overcome the high headlosses through the existing supply system.

Optimization projects B and K had the highest impact on the system under future conditions. Project B in particular is critical in maximizing the draw capacity from Norrish Creek. Without the twinning of the Norrish Creek transmission main there is too much headloss through the existing transmission main. In addition, Project K allows full access to the maximum groundwater supply potential.

The next step was to strategically combine optimization projects to find a solution that could meet the future scenario service requirements. Since project K has the lowest estimated cost, it was used as a base for analyzing optimization project combinations. Project L was not further investigated, since the transmission main constrictions identified for this project were not critical. The following combinations of optimization projects were further investigated:

- K + B
- K + D + E
- K + F
- K + J

In analyzing the above optimization project combinations, only the combination of projects K and B was able to meet the future scenario service requirements. The combination of projects K and J had the least positive impact and was, therefore, not pursued further. The following combinations were further investigated to identify a second supply solution; however, none of these combinations were able to meet the future scenario service requirements:

- K + F + H
- K + D + E + F
- K + D + E + F + H

From the conclusions drawn above, the combination of projects B and K was identified as a supply solution. Furthermore, an additional source could be added instead of Project B to overcome the headlosses through the Norrish Creek transmission main.

4.2 Supply Solution Optimization

Three (3) supply solutions were investigated and optimized:

- Supply Solution 1:
    - Groundwater wells operating at maximum capacity (Project K)
    - Norrish Creek transmission main twin (Project B)
    - No collector well
- Supply Solution 2:
    - Groundwater wells operating at maximum capacity (Project K)
    - No Norrish Creek transmission main twin (Project B)
    - Collector well
- Supply Solution 3:
    - Groundwater wells operating at minimum capacity to meet system demands
    - No Norrish Creek transmission main twin (Project B)
    - Collector well

To optimize Supply Solution 1, the minimum length and diameter of the Norrish Creek transmission main twin were determined. The original length of Project B is approximately 13 km. However, to meet the future service requirements under 2041 MDD conditions, the twin main will need to extend from the Norrish Creek intake and run parallel to the existing transmission main for a minimum length of 6,250 m. The minimum required diameter of the twin main is 1,050 mm. To meet the future service requirements under 2051 MDD conditions, the twin main will need to be extended further (> 6,250 m). However, determining the required length of the Norrish twin main under 2051 MDD conditions is beyond the scope of work for this study.

Without the Norrish Creek transmission main twin (Project B), an additional source is needed to provide additional capacity to the supply system. A new collector well, assumed to be located on the south side of the Fraser River at the Hyde-Buker crossing, was modeled as an additional source for Supply Solutions 2 and 3.

Supply Solution 2 maximizes the capacity of the existing groundwater wells. Whereas, Supply Solution 3 seeks to maximize the existing Norrish Creek capacity while minimizing the draw from the groundwater wells.

To assess the AMWSC system capacity of each supply solution, the following hydraulic modeling results were reviewed:

- Reservoirs storage levels
- Municipal connection pressures
- Supply source inflows

Reservoir Storage Levels

Reservoir storage levels were reviewed to determine if the reservoirs are cycling properly over the two-day simulation period. Over the course of a day, demands in the AMWSC system vary significantly. Storage allows pipeline and treatment infrastructure to be sized to meet maximum day flows instead of being sized to meet the peak hour flows. Thus, during normal operation, water levels in the reservoirs are expected to fluctuate. However, when the reservoir level fluctuations exceed the available storage capacity, it may be an indication of a supply and/or a storage shortfall.

Reservoir storage levels at the two (2) AMWSC storage reservoirs were reviewed:

- Maclure A, B, and C
- Mt. Mary Anne

Municipal Connection Pressures

Municipal connection pressures were reviewed to determine if there is sufficient pressure upstream of each municipal PRV connection.

The AMWSC's ability to deliver increased flows to the municipal distribution systems is limited by the capacity of AMWSC transmission mains and by the capacity restrictions imposed at the municipal connections to the AMWSC transmission mains. Therefore, it was critical to identify if any of these AMWSC take-offs were hydraulically "deficient", restricting the system's ability to satisfy the desired demands.

Due to the high pressures in the AMWSC transmission mains, the City's and District's connections to the AMWSC system are controlled through pressure reducing valve (PRV) stations. A PRV station is considered "deficient" when the upstream pressure head (AMWSC system) is lower than the PRV setting (PRV valve is 100% open). A "deficient" PRV station may be the result of sub-optimal control settings, insufficient hydraulic capacity in the City or District water distribution system, or may be an indication that the AMWSC system is unable to supply the desired flow and pressure.

Supply Source Inflows

Supply source inflows were reviewed to determine if there is sufficient supply capacity.

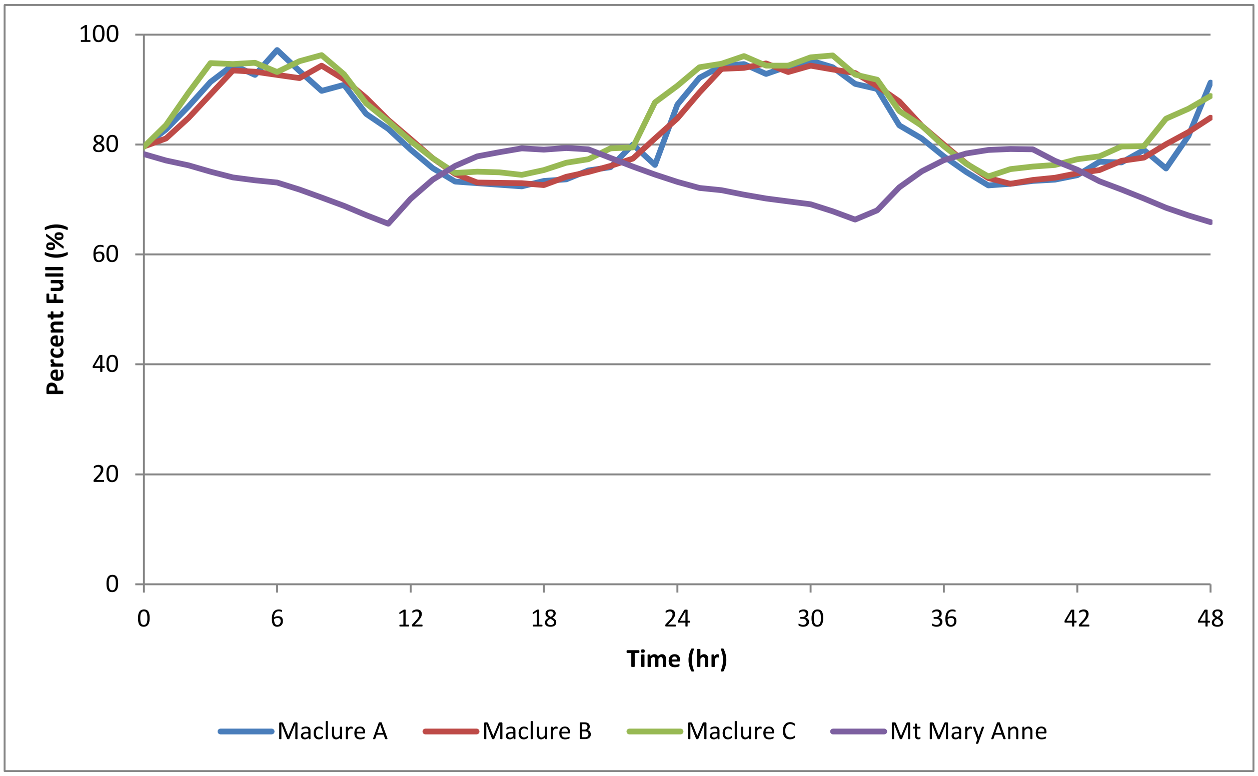
Flows from the groundwater wells, Cannell Lake, Norrish Creek, and the collector well were reviewed for each supply solution.

4.2.1. Supply Solution 1

Figure 4.2 illustrates the two-day reservoir cycles under 2041 MDD conditions, with the Norrish twin main (6,250 m) and the groundwater wells operating at maximum capacity (55 MLD).

Figure 4.2: 2041 MDD Storage Reservoir Levels – Supply Solution 1

Groundwater Wells at Maximum Capacity – With Norrish Twin Main – No Collector Well



As shown in the figure above, the storage reservoirs are able to cycle, with water levels replenishing over the course of the two-day simulation.

Table 4.2 summarizes the PRV setting and minimum upstream pressure modeling results for each municipal PRV connection under 2041 MDD conditions, with the Norrish twin main (6,250 m) and the wells operating at maximum capacity (55 MLD). The minimum upstream pressure is the lowest pressure predicted by the model over the course of the two-day model simulation, upstream of each municipal PRV connection.

Table 4.2: 2041 MDD Supply System Pressure – Supply Solution 1
Groundwater Wells at Maximum Capacity – With Norrish Twin Main – No Collector Well

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-406	52.0	130.1
PRV-BEST-409	49.6	130.4
PRV-BEST-423	49.6	130.4
PRV-BEST-PZ192-1	46.0	49.5
PRV-BEST-PZ192-2	40.1	49.5
PRV-BEST-PZ192-3	39.4	129.4
PRV-BEST-PZ192-4	44.0	129.4
PRV-CANNONS-1	18.0	65.0
PRV-CANNONS-2	16.7	65.1
PRV-CEDAR-VALLEY-1	30.6	119.1
PRV-CEDAR-VALLEY-2	79.3	118.1
PRV-CHARNLEY-1	46.1	83.8
PRV-CHERRY-1	71.8	118.1
PRV-CLAYBURN-1	85.4	181.5
PRV-CLAYBURN-2	82.5	182.1
PRV-CLAY-VILLAGE-1	68.0	181.7
PRV-DOWNS-1	81.7	147.9
PRV-DOWNS-2	79.8	147.1
PRV-DTR-HWY7-1	85.5	175.0
PRV-EMPRESS-1	7.8	13.9
PRV-F-STAVECEDAR-1	87.9	202.7
PRV-F-STAVECEDAR-2	84.4	202.7
PRV-HARRIS-1	154.1	182.5
PRV-HARRIS-2	173.5	183.0
PRV-HARRIS-3	63.0	181.6
PRV-MARY-7TH-1	30.7	120.0
PRV-MARYANN-1	21.4	83.5
PRV-MISSION-WAY-1	92.8	184.0
PRV-PRENTIS-1	80.8	118.6

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-P-SADDLE-1	45.0	116.0
PRV-P-SADDLE-2	62.0	116.0
PRV-SANDON-1	55.0	136.5
PRV-SANDON-2	48.8	136.4
PRV-SANDON-3	69.8	134.0
PRV-SANDON-4	84.0	132.2
PRV-SELKIRK-1	42.4	96.9
PRV-SELKIRK-2	41.9	95.2
PRV-SHOOK-1	70.3	191.2
PRV-STRAITON-100	140.0	176.8
PRV-STRAITON-200	135.0	176.8

As shown in the table above, the upstream pressure at each municipal connection is higher than the setting at each respective PRV. As such, there is sufficient pressure provided by the supply system to allow each PRV connection to operate properly with the groundwater wells at maximum capacity and the proposed Norrish Creek transmission main twin.

Table 4.3 summarizes the average MDD system inflows from each of the three (3) sources under 2041 MDD conditions, with the Norrish twin main (6,250 m) and the groundwater wells operating at maximum capacity.

Table 4.3: 2041 MDD Source Inflows – Supply Solution 1

Groundwater Wells at Maximum Capacity – With Norrish Twin Main – No Collector Well

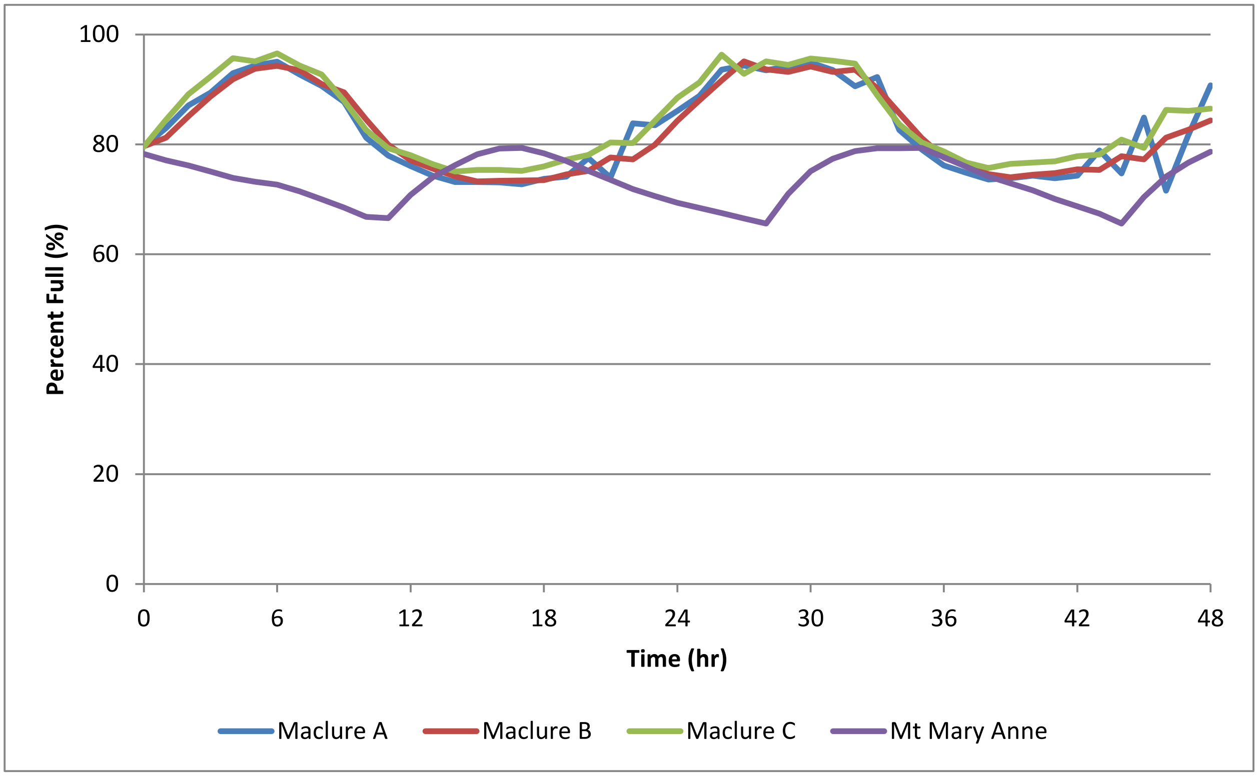
Source	Average Model Flow (MLD)
Norrish Creek	70.9
Cannell Lake	11.7
Groundwater Wells	54.0
Collector Well	-
Total	**136.6**

As shown in the table above, all of the sources operate within their maximum daily capacity under 2041 MDD conditions (refer to **Table 2.1**). Furthermore, the total flow supplied by the sources (136.6 MLD) is higher than the 2041 MDD (134.9 MLD), which indicates that there is sufficient flow supplied by the sources and water is stored over the course of the two-day simulation.

4.2.2. Supply Solution 2

Figure 4.3 illustrates the two-day reservoir cycles under 2041 MDD conditions, with the collector well, without the Norrish twin main, and with the groundwater wells operating at maximum capacity (55 MLD).

Figure 4.3: 2041 MDD Storage Reservoir Levels – Supply Solution 2
Groundwater Wells at Maximum Capacity – No Norrish Twin Main – With Collector Well



As shown in the figure above, the storage reservoirs are able to cycle, with water levels replenishing over the course of the two-day simulation.

Table 4.4 summarizes the PRV setting and minimum upstream pressure modeling results for each municipal PRV connection under 2041 MDD conditions, with the collector well, without the Norrish twin main, and with the wells operating at maximum capacity (55 MLD). The minimum upstream pressure is the lowest pressure predicted by the model over the course of the two-day model simulation, upstream of each municipal PRV connection.

Table 4.4: 2041 MDD Supply System Pressure – Supply Solution 2
Groundwater Wells at Maximum Capacity – No Norrish Twin Main – With Collector Well

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-406	52.0	131.0
PRV-BEST-409	49.6	131.1
PRV-BEST-423	49.6	131.1
PRV-BEST-PZ192-1	46.0	49.0
PRV-BEST-PZ192-2	40.1	49.0
PRV-BEST-PZ192-3	39.4	130.1
PRV-BEST-PZ192-4	44.0	130.1
PRV-CANNONS-1	18.0	66.0
PRV-CANNONS-2	16.7	66.0
PRV-CEDAR-VALLEY-1	30.6	118.8
PRV-CEDAR-VALLEY-2	79.3	117.8
PRV-CHARNLEY-1	46.1	83.5
PRV-CHERRY-1	71.8	118.8
PRV-CLAYBURN-1	85.4	181.6
PRV-CLAYBURN-2	82.5	182.2
PRV-CLAY-VILLAGE-1	68.0	185.7
PRV-DOWNS-1	81.7	148.0
PRV-DOWNS-2	79.8	147.2
PRV-DTR-HWY7-1	85.5	177.1
PRV-EMPRESS-1	7.8	15.9
PRV-F-STAVECEDAR-1	87.9	200.1
PRV-F-STAVECEDAR-2	84.4	200.1
PRV-HARRIS-1	154.1	182.6
PRV-HARRIS-2	173.5	183.1
PRV-HARRIS-3	63.0	181.7
PRV-MARY-7TH-1	30.7	120.7
PRV-MARYANN-1	21.4	84.2
PRV-MISSION-WAY-1	92.8	184.3
PRV-PRENTIS-1	80.8	119.3
PRV-P-SADDLE-1	45.0	118.4
PRV-P-SADDLE-2	62.0	118.4
PRV-SANDON-1	55.0	139.2
PRV-SANDON-2	48.8	139.2
PRV-SANDON-3	69.8	136.7

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-SANDON-4	84.0	134.9
PRV-SELKIRK-1	42.4	100.4
PRV-SELKIRK-2	41.9	98.8
PRV-SHOOK-1	70.3	193.9
PRV-STRAITON-100	140.0	180.7
PRV-STRAITON-200	135.0	180.7

As shown in the table above, the upstream pressure at each municipal connection is higher than the setting at each respective PRV. As such, there is sufficient pressure provided by the supply system to allow each PRV connection to operate properly with the collector well, without the Norrish twin main, and with the groundwater wells operating at maximum capacity.

Table 4.5 summarizes the average MDD system inflows from each of the four (4) sources under 2041 MDD conditions, without the Norrish twin main and the groundwater wells operating at maximum capacity.

Table 4.5: 2041 MDD Source Inflows – Supply Solution 2
Groundwater Wells at Maximum Capacity – No Norrish Twin Main – With Collector Well

Source	Average Model Flow (MLD)
Norrish Creek	58.5
Cannell Lake	11.7
Groundwater Wells	54.0
Collector Well*	12.0
Total	**136.2**

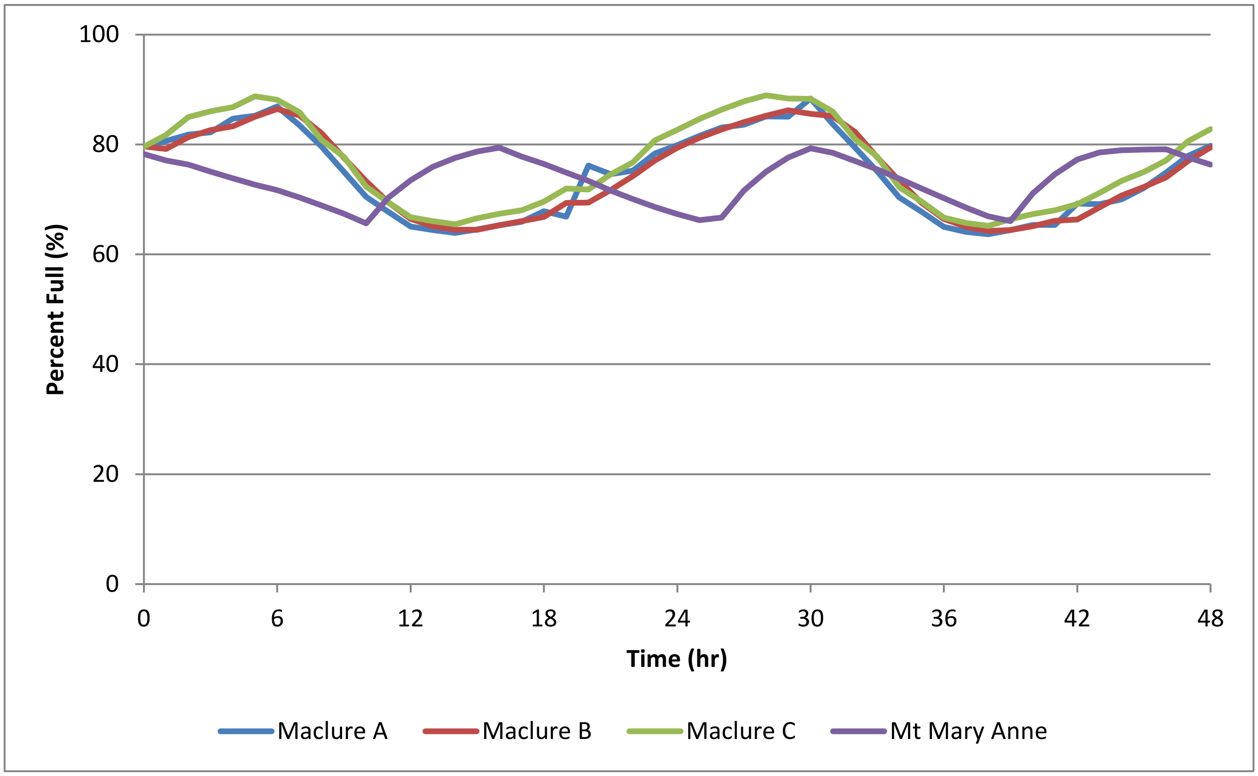
*The collector well is assumed to output a hydraulic grade line of 201 m.

As shown in the table above, all of the sources operate within their maximum daily capacity under 2041 MDD conditions (refer to **Table 2.1**). Furthermore, the total flow supplied by the sources (136.2 MLD) is higher than the 2041 MDD (134.9 MLD), which indicates that there is sufficient flow supplied by the sources and water is stored over the course of the two-day simulation. Finally, without the Norrish twin main, an additional source needs to be added for about 12.0 MLD.

4.2.3. Supply Solution 3

Figure 4.4 illustrates the two-day reservoir cycles under 2041 MDD conditions, with the collector well, without the Norrish twin main, and with the groundwater wells operating at the minimum necessary capacity to meet demands in the system.

Figure 4.4: 2041 MDD Storage Reservoir Levels – Supply Solution 3
Groundwater Wells at Minimum – No Norrish Twin Main – With Collector Well



As shown in the figure above, the storage reservoirs are able to cycle, with water levels replenishing over the course of the two-day simulation.

Table 4.6 summarizes the PRV setting and minimum upstream pressure modeling results for each municipal PRV connection under 2041 MDD conditions, with the collector well, without the Norrish twin main, and with the groundwater wells operating at the minimum necessary capacity to meet system demands. The minimum upstream pressure is the lowest pressure predicted by the model over the course of the two-day model simulation, upstream of each municipal PRV connection.

Table 4.6: 2041 MDD Supply System Pressure – Supply Solution 3 Groundwater Wells at Minimum – No Norrish Twin Main – With Collector Well

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-406	52.0	130.8
PRV-BEST-409	49.6	130.9
PRV-BEST-423	49.6	130.9
PRV-BEST-PZ192-1	46.0	48.4
PRV-BEST-PZ192-2	40.1	48.4
PRV-BEST-PZ192-3	39.4	129.9
PRV-BEST-PZ192-4	44.0	129.9
PRV-CANNONS-1	18.0	65.3
PRV-CANNONS-2	16.7	65.3
PRV-CEDAR-VALLEY-1	30.6	118.2
PRV-CEDAR-VALLEY-2	79.3	117.2
PRV-CHARNLEY-1	46.1	82.9
PRV-CHERRY-1	71.8	118.5
PRV-CLAYBURN-1	85.4	181.4
PRV-CLAYBURN-2	82.5	182.0
PRV-CLAY-VILLAGE-1	68.0	186.7
PRV-DOWNS-1	81.7	147.8
PRV-DOWNS-2	79.8	147.0
PRV-DTR-HWY7-1	85.5	177.7
PRV-EMPRESS-1	7.8	16.8
PRV-F-STAVECEDAR-1	87.9	201.2
PRV-F-STAVECEDAR-2	84.4	201.2
PRV-HARRIS-1	154.1	182.5
PRV-HARRIS-2	173.5	183.1
PRV-HARRIS-3	63.0	181.6
PRV-MARY-7TH-1	30.7	120.5
PRV-MARYANN-1	21.4	83.9
PRV-MISSION-WAY-1	92.8	184.1
PRV-PRENTIS-1	80.8	119.0
PRV-P-SADDLE-1	45.0	118.4
PRV-P-SADDLE-2	62.0	118.4
PRV-SANDON-1	55.0	138.8
PRV-SANDON-2	48.8	138.8
PRV-SANDON-3	69.8	136.3

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-SANDON-4	84.0	134.5
PRV-SELKIRK-1	42.4	100.9
PRV-SELKIRK-2	41.9	99.2
PRV-SHOOK-1	70.3	194.9
PRV-STRAITON-100	140.0	181.6
PRV-STRAITON-200	135.0	181.6

As shown in the table above, the upstream pressure at each municipal connection is higher than the setting at each respective PRV. As such, there is sufficient pressure provided by the supply system to allow each PRV connection to operate properly with the collector well, without the Norrish twin main, and with the groundwater wells operating at the minimum necessary capacity to meet system demands.

Table 4.7 summarizes the average MDD system inflows from each of the four (4) sources under 2041 MDD conditions, with the collector well, without the Norrish twin main, and with the groundwater wells operating at the minimum necessary capacity to meet system demands.

Table 4.7: 2041 MDD Source Inflows – Supply Solution 3
Groundwater Wells at Minimum – No Norrish Twin Main – With Collector Well

Source	Average Model Flow (MLD)
Norrish Creek	62.0
Cannell Lake	12.0
Groundwater Wells	35.9
Collector Well*	25.0
Total	**134.9**

*The collector well is assumed to output a hydraulic grade line of 201 m.

As shown in the table above, all of the sources operate within their maximum daily capacity under 2041 MDD conditions (refer to **Table 2.1**). The total flow supplied by the sources (134.9 MLD) is equal to the 2041 MDD (134.9 MLD), which indicates that there is sufficient flow supplied by the sources over the course of the two-day simulation.

The average flow supplied by Norrish Creek reported in **Table 4.7** is the maximum average flow that can be drawn under the conditions of supply solution 3 without compromising downstream network performance. While the flow from Norrish Creek can be increased if the head at the collector well is decreased, increasing the flow through the Norrish Creek transmission main increases the headlosses through the transmission main, resulting in significant pressure drops in the downstream network.

Upon further investigation, it was found, with the addition of optimization projects D, E, and F, that the head at the collector well could be decreased and the flow from Norrish Creek could be increased. This solution, however, is not as robust as the previous supply solution 3.

Table 4.8 summarizes the average MDD system inflows from each of the four (4) sources under conditions of supply solution 3 with the addition of optimization projects D, E, and F.

Table 4.8: 2041 MDD Source Inflows – Supply Solution 3a

Groundwater Wells at Minimum – No Norrish Twin Main – With Collector Well – With Optimization Projects D, E, and F

Source	Average Model Flow (MLD)
Norrish Creek	73.2
Cannell Lake	11.8
Groundwater Wells	36.0
Collector Well*	14.4
Total	**135.3**

*The collector well is assumed to output a hydraulic grade line of 189 m.

As shown in the table above, all of the sources operate within their maximum daily capacity under 2041 MDD conditions (refer to **Table 2.1**). The total flow supplied by the sources (135.3 MLD) is higher than the 2041 MDD (134.9 MLD), which indicates that there should be sufficient flow supplied by the sources over the course of the two-day simulation. However, with reduced downstream pressure caused by the high headlosses through the Norrish Creek transmission main, reservoir levels do not cycle as well and some PRV inlet pressures drop too much during the peak demand periods of the simulation.

Ultimately, more flow can be drawn from Norrish Creek at the expense of downstream network conditions (i.e. compromised reservoir cycling and PRV inlet pressures).

Please note that supply solution 3a is summarized here for the convenience of the AMWSC but was not included in the supply source security analysis.

5.0 Supply Source Security Analysis

The supply system was further analyzed to ensure there will be sufficient supply security in the future. Model simulations were completed with each source out of service under 2041 ADD conditions.

Note that for all of the following simulation scenarios, the Norrish twin main is simulated using the 2041 MDD optimized length (6,250 m).

5.1 Groundwater Wells Out of Service

The supply system was first analyzed with all the groundwater wells out of service under 2041 ADD conditions. For this analysis, three (3) supply conditions were assessed:

Scenario 1.	Norrish Creek and Cannell Lake supply the entire system with the Norrish twin main in service and the collector well not in service.
Scenario 2.	Norrish Creek, Cannell Lake, and the collector well supply the entire system with the Norrish twin main not in service.
Scenario 3.	Norrish Creek and Cannell Lake supply the entire system with the Norrish twin main and the collector well not in service.

5.1.1. Groundwater Wells Out of Service – Scenario 1

Figure 5.1 illustrates the two-day reservoir cycles for Scenario 1 with the groundwater wells out of service.

Figure 5.1: 2041 ADD Storage Reservoir Levels – Scenario 1
Groundwater Wells Out of Service – With Norrish Twin Main – No Collector Well

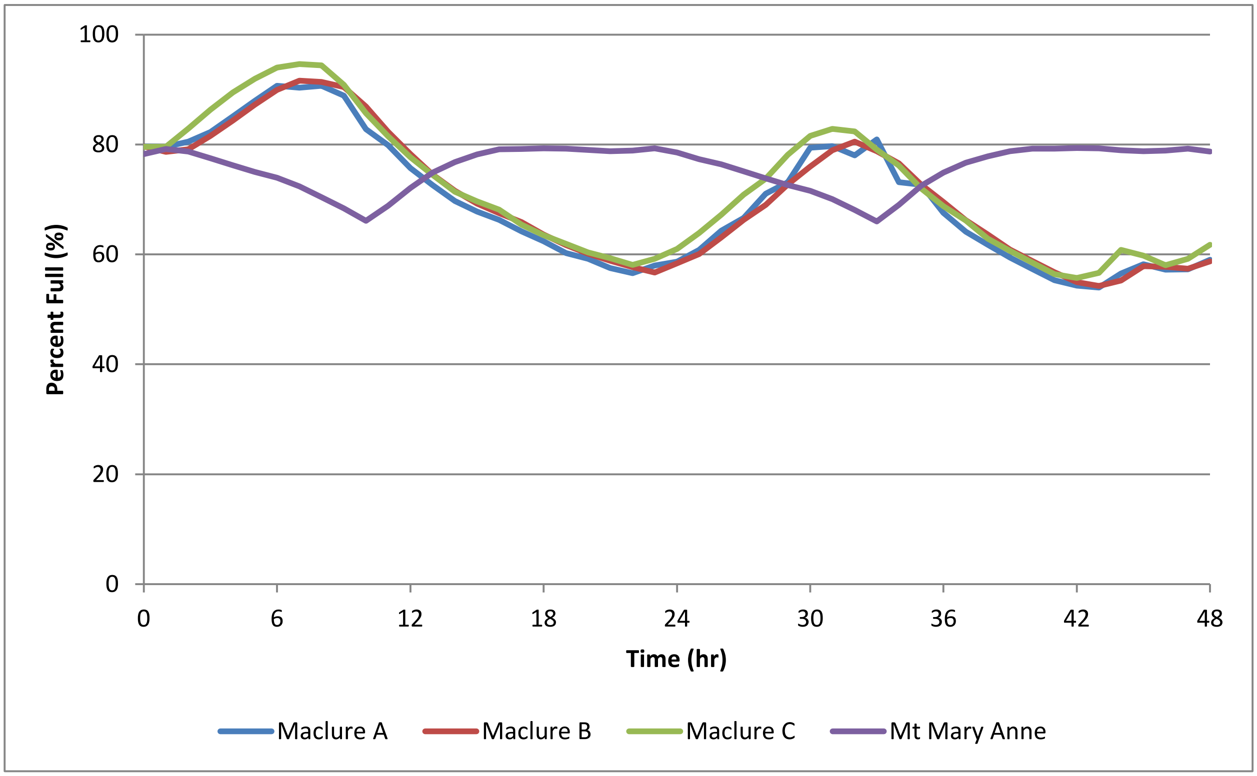


Figure 5.1 shows the Maclure reservoir levels do drop and do not fill completely. Since it is unlikely for all of the groundwater wells to be out of service at once for an extended period of time, the lower level cycling predicted at the Maclure reservoirs may not be critical. The Mt Mary Anne storage reservoir is able to cycle, with the water level replenishing over the course of the two-day simulation.

Table 5.1 summarizes the setting and minimum upstream pressure modeling results for each municipal PRV connection for Scenario 1 with the groundwater wells out of service. The minimum upstream pressure is the lowest pressure predicted by the model over the course of the two-day model simulation, upstream of each municipal PRV connection.

Table 5.1: 2041 ADD Supply System Pressures – Scenario 1
Groundwater Wells Out of Service – With Norrish Twin Main – No Collector Well

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-406	52.0	121.4
PRV-BEST-409	49.6	121.8
PRV-BEST-423	49.6	121.8
PRV-BEST-PZ192-1	46.0	48.6
PRV-BEST-PZ192-2	40.1	48.6
PRV-BEST-PZ192-3	39.4	120.8
PRV-BEST-PZ192-4	44.0	120.9
PRV-CANNONS-1	18.0	68.5
PRV-CANNONS-2	16.7	68.5
PRV-CEDAR-VALLEY-1	30.6	112.4
PRV-CEDAR-VALLEY-2	79.3	111.4
PRV-CHARNLEY-1	46.1	80.4
PRV-CHERRY-1	71.8	110.0
PRV-CLAYBURN-1	85.4	160.0
PRV-CLAYBURN-2	82.5	160.6
PRV-CLAY-VILLAGE-1	68.0	171.9
PRV-DOWNS-1	81.7	126.4
PRV-DOWNS-2	79.8	125.5
PRV-DTR-HWY7-1	85.5	166.5
PRV-EMPRESS-1	7.8	8.4
PRV-F-STAVECEDAR-1	87.9	197.1
PRV-F-STAVECEDAR-2	84.4	197.1
PRV-HARRIS-1	154.1	162.7
PRV-HARRIS-2	173.5	163.3
PRV-HARRIS-3	63.0	161.8
PRV-MARY-7TH-1	30.7	111.5
PRV-MARYANN-1	21.4	75.5
PRV-MISSION-WAY-1	92.8	172.1
PRV-PRENTIS-1	80.8	110.3
PRV-P-SADDLE-1	45.0	102.2
PRV-P-SADDLE-2	62.0	102.2
PRV-SANDON-1	55.0	123.8
PRV-SANDON-2	48.8	123.8
PRV-SANDON-3	69.8	121.4

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-SANDON-4	84.0	121.4
PRV-SELKIRK-1	42.4	86.9
PRV-SELKIRK-2	41.9	85.3
PRV-SHOOK-1	70.3	182.6
PRV-STRAITON-100	140.0	166.9
PRV-STRAITON-200	135.0	166.9

As shown in the table above, there is one (1) instance where the supply system is unable to provide enough pressure at the Harris PRV station under 2041 ADD conditions. The upstream pressure is lower than municipal connection pressure setting for one (1) hour in the model simulation and is within 10%. As such, the low pressure is not critical.

Table 5.2 summarizes the average ADD system inflows from each of the supply sources for Scenario 1 with the groundwater wells out of service.

Table 5.2: 2041 ADD Source Inflows – Scenario 1

Groundwater Wells Out of Service – With Norrish Twin Main – No Collector Well

Source	Average Model Flow (MLD)
Norrish Creek	80.7
Cannell Lake	8.6
Groundwater Wells	**0.0**
Collector Well	**0.0**
Total	**89.3**

As shown in the above table, the system is able to supply 89.3 MLD, which is lower than the 2041 ADD (91.5 MLD). As such, stored flow is used to supplement flow from the supply system. If the groundwater wells are out of service for an extended period of time, the storage reservoirs will eventually drain; however, it is unlikely for all of the groundwater wells to be out of service at once for an extended period of time.

5.1.2. Groundwater Wells Out of Service – Scenario 2

Figure 5.2 illustrates the two-day reservoir cycles for Scenario 2 with the groundwater wells out of service.

Figure 5.2: 2041 ADD Storage Reservoir Levels – Scenario 2
Groundwater Well Out of Service – No Norrish Twin Main – With Collector Well

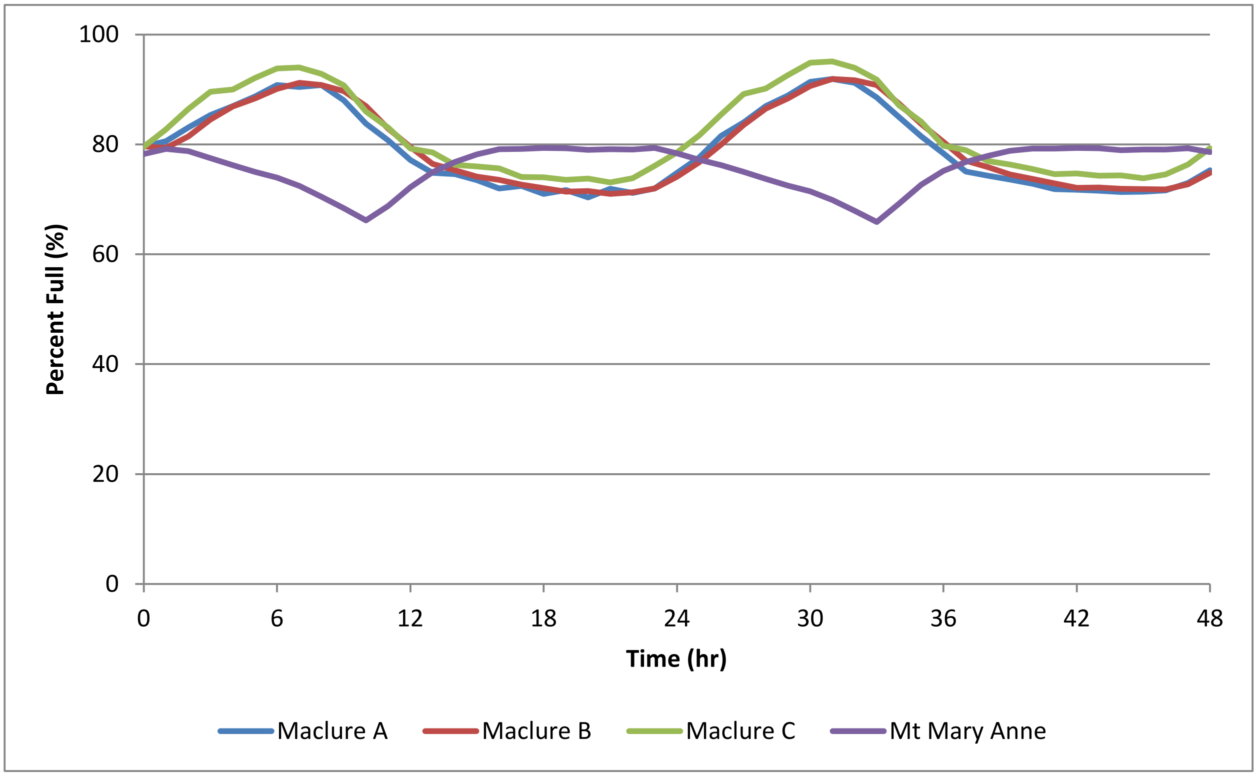


Figure 5.2 shows the storage reservoirs are able to cycle, with the water level replenishing over the course of the two-day simulation.

Table 5.3 summarizes the setting and minimum upstream pressure modeling results for each municipal PRV connection for Scenario 2 with the groundwater wells out of service. The minimum upstream pressure is the lowest pressure predicted by the model over the course of the two-day model simulation, upstream of each municipal PRV connection.

Table 5.3: 2041 ADD Supply System Pressures – Scenario 2
Groundwater Well Out of Service – No Norrish Twin Main – With Collector Well

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-406	52.0	138.2
PRV-BEST-409	49.6	138.2
PRV-BEST-423	49.6	138.2
PRV-BEST-PZ192-1	46.0	51.3
PRV-BEST-PZ192-2	40.1	51.3
PRV-BEST-PZ192-3	39.4	137.2
PRV-BEST-PZ192-4	44.0	137.3
PRV-CANNONS-1	18.0	70.0
PRV-CANNONS-2	16.7	70.0
PRV-CEDAR-VALLEY-1	30.6	121.2
PRV-CEDAR-VALLEY-2	79.3	120.3
PRV-CHARNLEY-1	46.1	85.9
PRV-CHERRY-1	71.8	126.1
PRV-CLAYBURN-1	85.4	181.7
PRV-CLAYBURN-2	82.5	182.3
PRV-CLAY-VILLAGE-1	68.0	190.0
PRV-DOWNS-1	81.7	148.1
PRV-DOWNS-2	79.8	147.3
PRV-DTR-HWY7-1	85.5	181.1
PRV-EMPRESS-1	7.8	25.0
PRV-F-STAVECEDAR-1	87.9	203.3
PRV-F-STAVECEDAR-2	84.4	203.3
PRV-HARRIS-1	154.1	183.0
PRV-HARRIS-2	173.5	183.6
PRV-HARRIS-3	63.0	182.1
PRV-MARY-7TH-1	30.7	124.6
PRV-MARYANN-1	21.4	91.2
PRV-MISSION-WAY-1	92.8	186.1
PRV-PRENTIS-1	80.8	123.4
PRV-P-SADDLE-1	45.0	121.0
PRV-P-SADDLE-2	62.0	121.0
PRV-SANDON-1	55.0	142.1
PRV-SANDON-2	48.8	142.1
PRV-SANDON-3	69.8	139.7

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-SANDON-4	84.0	138.9
PRV-SELKIRK-1	42.4	105.0
PRV-SELKIRK-2	41.9	103.4
PRV-SHOOK-1	70.3	197.8
PRV-STRAITON-100	140.0	185.0
PRV-STRAITON-200	135.0	185.0

As shown in the table above, the supply system is able to provide enough pressure at all PRV stations under 2041 ADD conditions.

Table 5.4 summarizes the average ADD system inflows from each of the supply sources for Scenario 2 with the groundwater wells out of service.

Table 5.4: 2041 ADD Source Inflows – Scenario 2

Groundwater Wells Out of Service – No Norrish Twin Main – With Collector Well

Source	Average Model Flow (MLD)
Norrish Creek	59.5
Cannell Lake	7.4
Groundwater Wells	**0.0**
Collector Well*	24.7
Total	**91.6**

*The collector well is assumed to output a hydraulic grade line of 205 m.

As shown in the table above, the total flow supplied is higher than the 2041 ADD. As such, water is stored over the course of the two-day simulation, and reservoirs will not drain.

5.1.3. Groundwater Wells Out of Service – Scenario 3

Without the Norrish twin main or the collector well, the hydraulic simulation fails due to system imbalances caused by low pressures and storage reservoirs becoming empty. As such, no model results are available for this scenario. In order for the system to operate under 2041 ADD conditions with the groundwater wells out of service, either the Norrish twin main or the collector well must be operational.

5.2 Cannell Lake Out of Service

The supply system was then analyzed with the Cannell Lake source out of service under 2041 ADD conditions. For this analysis, three (3) supply conditions were assessed:

Scenario 4.	Norrish Creek and the groundwater wells supply the entire system with the Norrish twin main in service and the collector well not in service.
Scenario 5.	Norrish Creek, the groundwater wells, and collector well supply the entire system with the Norrish twin main not in service.
Scenario 6.	Norrish Creek and the groundwater wells supply the entire system with the Norrish twin main and the collector well not in service.

For the above scenarios, a number of adjustments were made to the model. In order to service pressure zone 4 in the District of Mission and the Mt Mary Anne storage reservoir, water must be pumped from the Norrish transmission system into the Cannell transmission system.

The pump station at Best was configured in the model to pump to pressure zone 4, maintaining the hydraulic head in the zone at 215 m (consistent with existing zone head). The modeled design head and flow of the pump station are about 60 m and 45 L/s, respectively.

Furthermore, the Cannons PRV station was assumed to be out of service, and the Cherry PRV station was set to “open” to allow the pump station at Best to control the level in the dummy storage reservoir in pressure zone 4.

5.2.1. Cannell Lake Out of Service – Scenario 4

Figure 5.3 illustrates the two-day reservoir cycles for Scenario 4 with the Cannell Lake source out of service.

Figure 5.3: 2041 ADD Storage Reservoir Levels – Scenario 4
Cannell Lake Out of Service – With Norrish Twin Main – No Collector Well

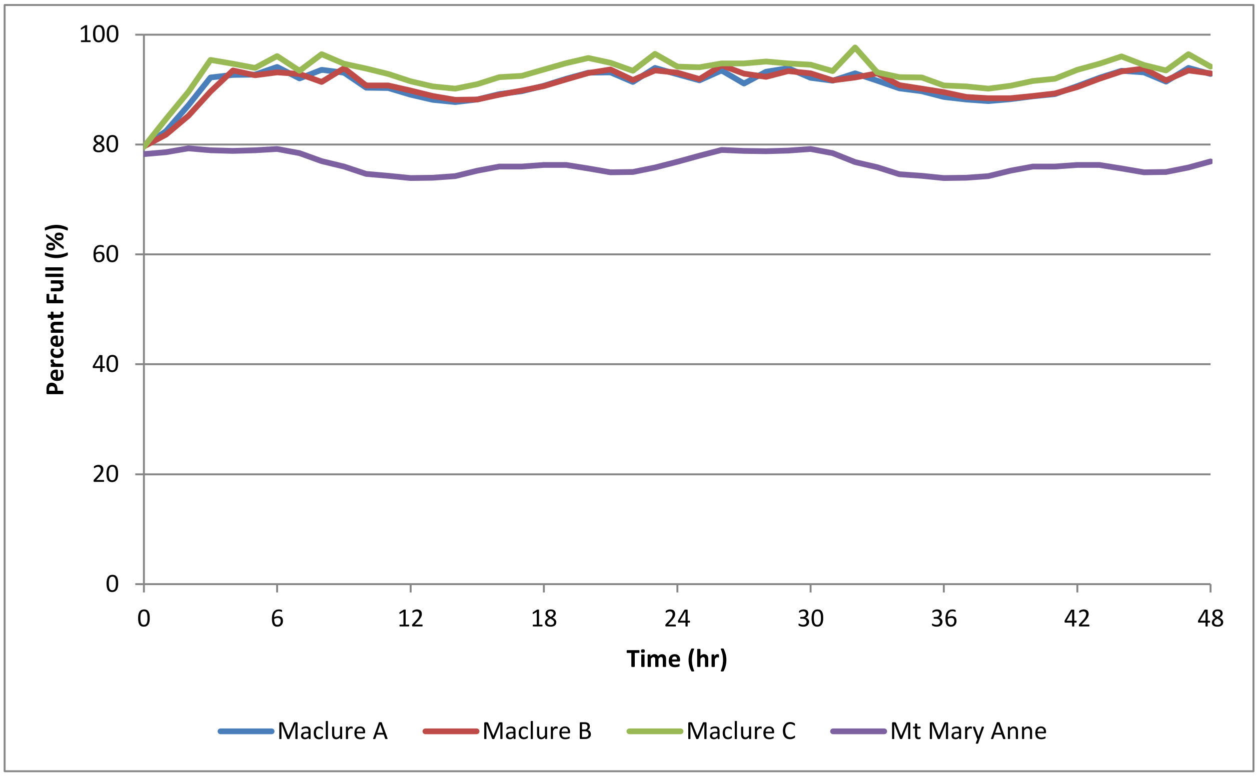


Figure 5.3 shows that the reservoirs are able to cycle over the course of the two-day simulation.

Table 5.5 summarizes the setting and minimum upstream pressure modeling results for each municipal PRV connection for Scenario 4 with the Cannell Lake source out of service. The minimum upstream pressure is the lowest pressure predicted by the model over the course of the two-day model simulation, upstream of each municipal PRV connection.

Table 5.5: 2041 ADD Supply System Pressures – Scenario 4
Cannell Lake Out of Service – With Norrish Twin Main – No Collector Well

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-406	52.0	77.7
PRV-BEST-409	49.6	77.7
PRV-BEST-423	49.6	77.7
PRV-BEST-PZ192-1	46.0	48.7
PRV-BEST-PZ192-2	40.1	48.7
PRV-BEST-PZ192-3	39.4	76.7

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-PZ192-4	44.0	76.7
PRV-CEDAR-VALLEY-1	30.6	119.7
PRV-CEDAR-VALLEY-2	79.3	118.7
PRV-CHARNLEY-1	46.1	83.6
PRV-CLAYBURN-1	85.4	181.7
PRV-CLAYBURN-2	82.5	182.3
PRV-CLAY-VILLAGE-1	68.0	185.5
PRV-DOWNS-1	81.7	148.1
PRV-DOWNS-2	79.8	147.2
PRV-DTR-HWY7-1	85.5	178.7
PRV-EMPRESS-1	7.8	22.9
PRV-F-STAVECEDAR-1	87.9	204.9
PRV-F-STAVECEDAR-2	84.4	204.9
PRV-HARRIS-1	154.1	182.9
PRV-HARRIS-2	173.5	183.5
PRV-HARRIS-3	63.0	182.0
PRV-MARY-7TH-1	30.7	123.9
PRV-MARYANN-1	21.4	30.7
PRV-MISSION-WAY-1	92.8	185.2
PRV-PRENTIS-1	80.8	122.8
PRV-P-SADDLE-1	45.0	118.7
PRV-P-SADDLE-2	62.0	118.7
PRV-SANDON-1	55.0	139.8
PRV-SANDON-2	48.8	139.8
PRV-SANDON-3	69.8	137.3
PRV-SANDON-4	84.0	136.9
PRV-SELKIRK-1	42.4	101.4
PRV-SELKIRK-2	41.9	99.8
PRV-SHOOK-1	70.3	194.5
PRV-STRAITON-100	140.0	180.7
PRV-STRAITON-200	135.0	180.7

As shown in the table above, the supply system is able to provide enough pressure at all PRV stations under 2041 ADD conditions. Pressures at the Cannons and Cherry PRV stations were not reviewed with the Cannell Lake source out of service.

Table 5.6 summarizes the average ADD system inflows from each of the supply sources for Scenario 4 with the Cannell Lake source out of service.

Table 5.6: 2041 ADD Source Inflows – Scenario 4

Cannell Lake Out of Service – With Norrish Twin Main – No Collector Well

Source	Average Model Flow (MLD)
Norrish Creek	58.1
Cannell Lake	**0.0**
Groundwater Wells	37.6
Collector Well	**0.0**
Total	**95.7**

With the Cannell Lake source out of service, for Scenario 4, the sources operate below their maximum daily capacity under 2041 ADD conditions, and the total flow supplied is higher than the 2041 ADD. As such, water is stored over the course of the two-day simulation, and reservoirs will not drain.

5.2.2. Cannell Lake Out of Service – Scenario 5

Figure 5.4 illustrates the two-day reservoir cycles for Scenario 5 with the Cannell Lake source out of service.

Figure 5.4: 2041 ADD Storage Reservoir Levels – Sceanrio 5

Cannell Lake Out of Service – No Norrish Twin Main – With Collector Well

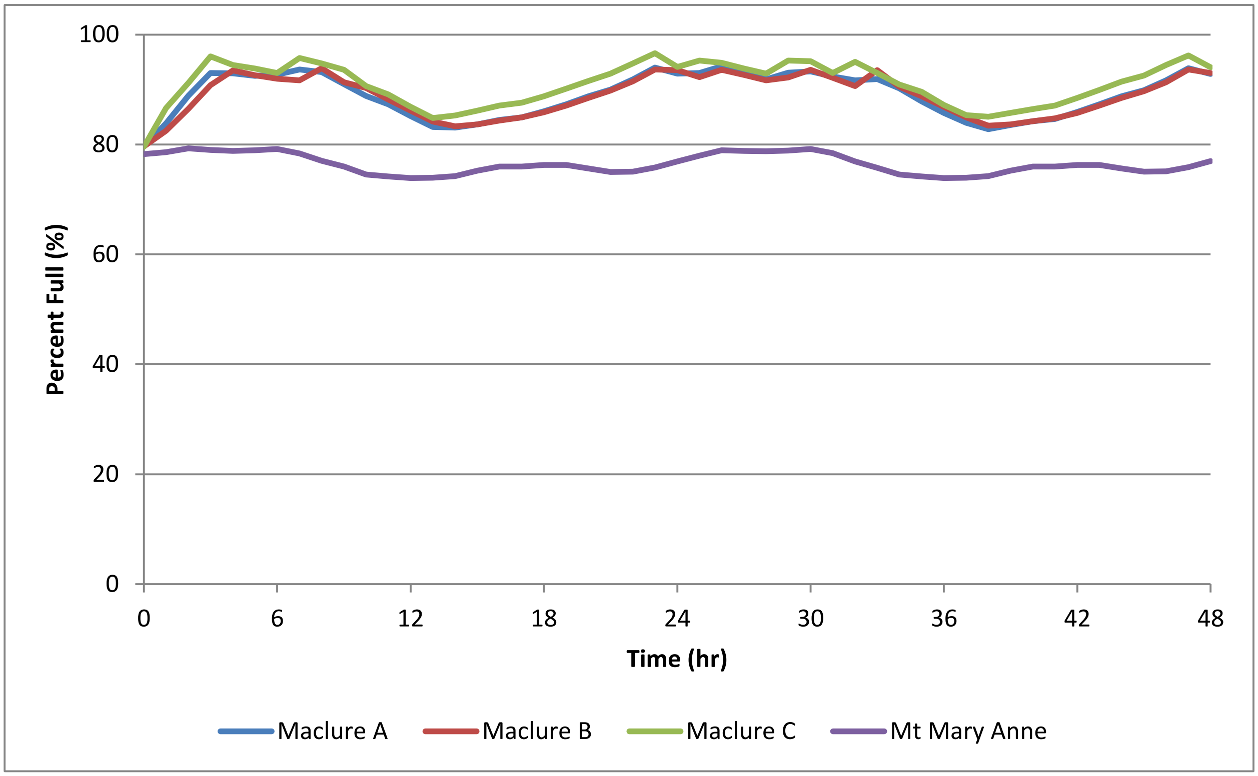


Figure 5.4 shows that the reservoirs are able to cycle over the course of the two-day simulation.

Table 5.7 summarizes the setting and minimum upstream pressure modeling results for each municipal PRV connection for Scenario 5 with the Cannell Lake source out of service. The minimum upstream pressure is the lowest pressure predicted by the model over the course of the two-day model simulation, upstream of each municipal PRV connection.

Table 5.7: 2041 ADD Supply System Pressures – Scenario 5

Cannell Lake Out of Service – No Norrish Twin Main – With Collector Well

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-406	52.0	77.9
PRV-BEST-409	49.6	77.9
PRV-BEST-423	49.6	77.9
PRV-BEST-PZ192-1	46.0	45.9
PRV-BEST-PZ192-2	40.1	45.9
PRV-BEST-PZ192-3	39.4	76.9

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-PZ192-4	44.0	76.9
PRV-CEDAR-VALLEY-1	30.6	119.5
PRV-CEDAR-VALLEY-2	79.3	118.5
PRV-CHARNLEY-1	46.1	81.5
PRV-CLAYBURN-1	85.4	181.8
PRV-CLAYBURN-2	82.5	182.4
PRV-CLAY-VILLAGE-1	68.0	190.6
PRV-DOWNS-1	81.7	148.2
PRV-DOWNS-2	79.8	147.4
PRV-DTR-HWY7-1	85.5	181.8
PRV-EMPRESS-1	7.8	28.7
PRV-F-STAVECEDAR-1	87.9	203.4
PRV-F-STAVECEDAR-2	84.4	203.4
PRV-HARRIS-1	154.1	183.2
PRV-HARRIS-2	173.5	183.8
PRV-HARRIS-3	63.0	182.3
PRV-MARY-7TH-1	30.7	125.9
PRV-MARYANN-1	21.4	31.0
PRV-MISSION-WAY-1	92.8	186.3
PRV-PRENTIS-1	80.8	124.8
PRV-P-SADDLE-1	45.0	121.8
PRV-P-SADDLE-2	62.0	121.8
PRV-SANDON-1	55.0	143.2
PRV-SANDON-2	48.8	143.2
PRV-SANDON-3	69.8	140.7
PRV-SANDON-4	84.0	139.9
PRV-SELKIRK-1	42.4	106.3
PRV-SELKIRK-2	41.9	104.7
PRV-SHOOK-1	70.3	198.2
PRV-STRAITON-100	140.0	185.7
PRV-STRAITON-200	135.0	185.7

As shown in the above table, the Best pump station causes pressures to drop briefly below the setting of one of the Best PRVs servicing pressure zone 3 in the District of Mission. The pressure, however, is within 1% of the PRV setting and is, therefore, not critical.

Pressures at the Cannons and Cherry PRV stations were not reviewed with the Cannell Lake source out of service.

Table 5.8 summarizes the average ADD system inflows from each of the supply sources for Scenario 5 with the Cannell Lake source out of service.

Table 5.8: 2041 ADD Source Inflows - Scenario 5
Cannell Lake Out of Service – No Norrish Twin Main – With Collector Well

Source	Average Model Flow (MLD)
Norrish Creek	52.1
Cannell Lake	**0.0**
Groundwater Wells	37.6
Collector Well*	6.7
Total	**97.1**

*The collector well is assumed to output a hydraulic grade line of 205 m.

With the Cannell Lake source out of service, for Scenario 5, the sources operate below their maximum daily capacity under 2041 ADD conditions, and the total flow supplied is higher than the 2041 ADD. As such, water is stored over the course of the two-day simulation, and reservoirs will not drain.

5.2.3. Cannell Lake Out of Service – Scenario 6

Figure 5.5 illustrates the two-day reservoir cycles for Scenario 6 with the Cannell Lake source out of service.

Figure 5.5: 2041 ADD Storage Reservoir Levels – Scenario 6

Cannell Lake Out of Service – No Norrish Twin Main – No Collector Wells

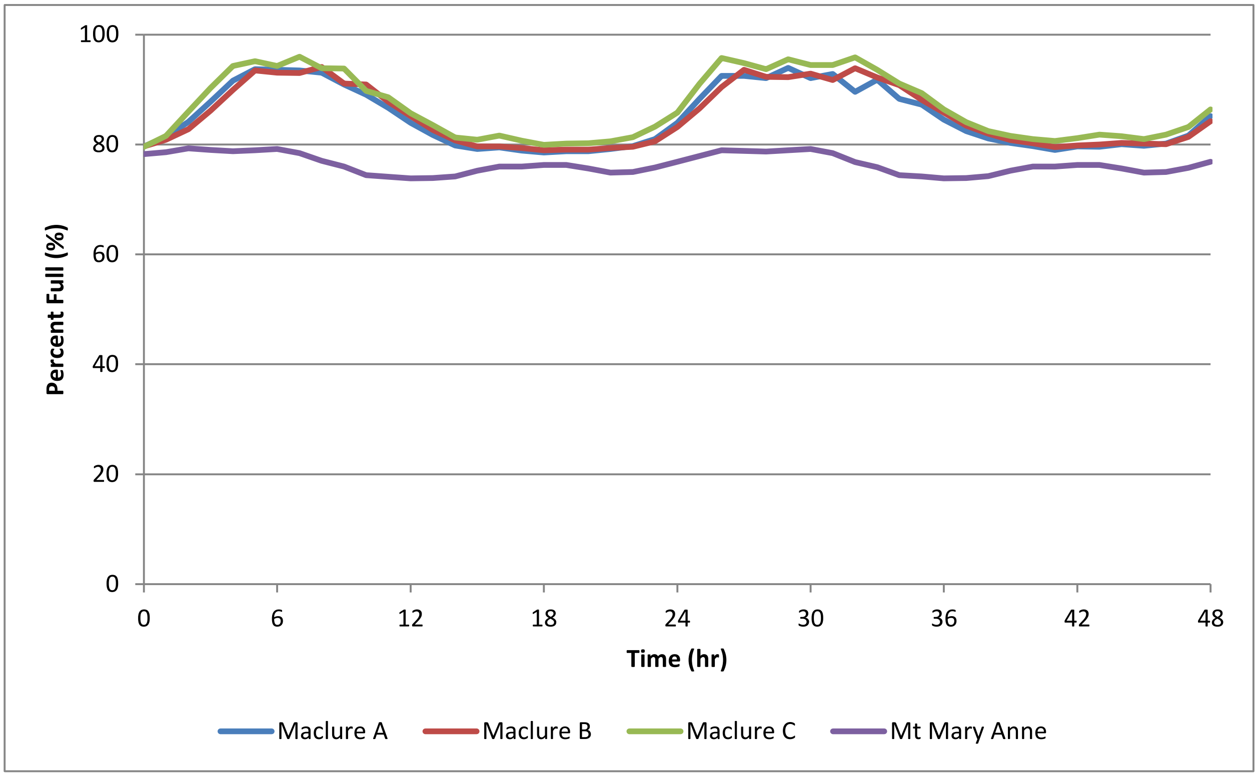


Figure 5.5 shows that the reservoirs are able to cycle over the course of the two-day simulation.

Table 5.9 summarizes the setting and minimum upstream pressure modeling results for each municipal PRV connection for Scenario 6 with the Cannell Lake source out of service. The minimum upstream pressure is the lowest pressure predicted by the model over the course of the two-day model simulation, upstream of each municipal PRV connection.

Table 5.9: 2041 ADD Supply System Pressures – Scenario 6

Cannell Lake Out of Service – No Norrish Twin Main – No Collector Wells

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-406	52.0	77.3
PRV-BEST-409	49.6	77.3
PRV-BEST-423	49.6	77.3
PRV-BEST-PZ192-1	46.0	45.6
PRV-BEST-PZ192-2	40.1	45.6
PRV-BEST-PZ192-3	39.4	76.3

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-PZ192-4	44.0	76.3
PRV-CEDAR-VALLEY-1	30.6	118.3
PRV-CEDAR-VALLEY-2	79.3	117.3
PRV-CHARNLEY-1	46.1	81.2
PRV-CLAYBURN-1	85.4	181.6
PRV-CLAYBURN-2	82.5	182.2
PRV-CLAY-VILLAGE-1	68.0	182.0
PRV-DOWNS-1	81.7	148.0
PRV-DOWNS-2	79.8	147.2
PRV-DTR-HWY7-1	85.5	175.3
PRV-EMPRESS-1	7.8	12.1
PRV-F-STAVECEDAR-1	87.9	196.3
PRV-F-STAVECEDAR-2	84.4	196.3
PRV-HARRIS-1	154.1	182.7
PRV-HARRIS-2	173.5	183.3
PRV-HARRIS-3	63.0	181.8
PRV-MARY-7TH-1	30.7	121.8
PRV-MARYANN-1	21.4	30.3
PRV-MISSION-WAY-1	92.8	184.2
PRV-PRENTIS-1	80.8	120.7
PRV-P-SADDLE-1	45.0	116.4
PRV-P-SADDLE-2	62.0	116.4
PRV-SANDON-1	55.0	137.1
PRV-SANDON-2	48.8	137.1
PRV-SANDON-3	69.8	134.6
PRV-SANDON-4	84.0	133.8
PRV-SELKIRK-1	42.4	98.5
PRV-SELKIRK-2	41.9	96.9
PRV-SHOOK-1	70.3	190.5
PRV-STRAITON-100	140.0	177.2
PRV-STRAITON-200	135.0	177.2

As shown in the above table, the Best pump station causes pressures to drop briefly below the setting of one of the Best PRVs servicing pressure zone 3 in the District of Mission. The pressure, however, is within 1% of the PRV setting and is, therefore, not critical.

Pressures at the Cannons and Cherry PRV stations were not reviewed with the Cannell Lake source out of service.

Table 5.10 summarizes the average ADD system inflows from each of the supply sources for Scenario 6 with the Cannell Lake source out of service.

Table 5.10: 2041 ADD Source Inflows – Scenario 6
Cannell Lake Out of Service – No Norrish Twin Main – No Collector Wells

Source	Average Model Flow (MLD)
Norrish Creek	56.7
Cannell Lake	**0.0**
Groundwater Wells	37.8
Collector Well	**0.0**
Total	**94.5**

With the Cannell Lake source out of service, for Scenario 6, the sources operate below their maximum daily capacity under 2041 ADD conditions, and the total flow supplied is higher than the 2041 ADD. As such, water is stored over the course of the two-day simulation, and reservoirs will not drain.

5.3 Norrish Creek Out of Service

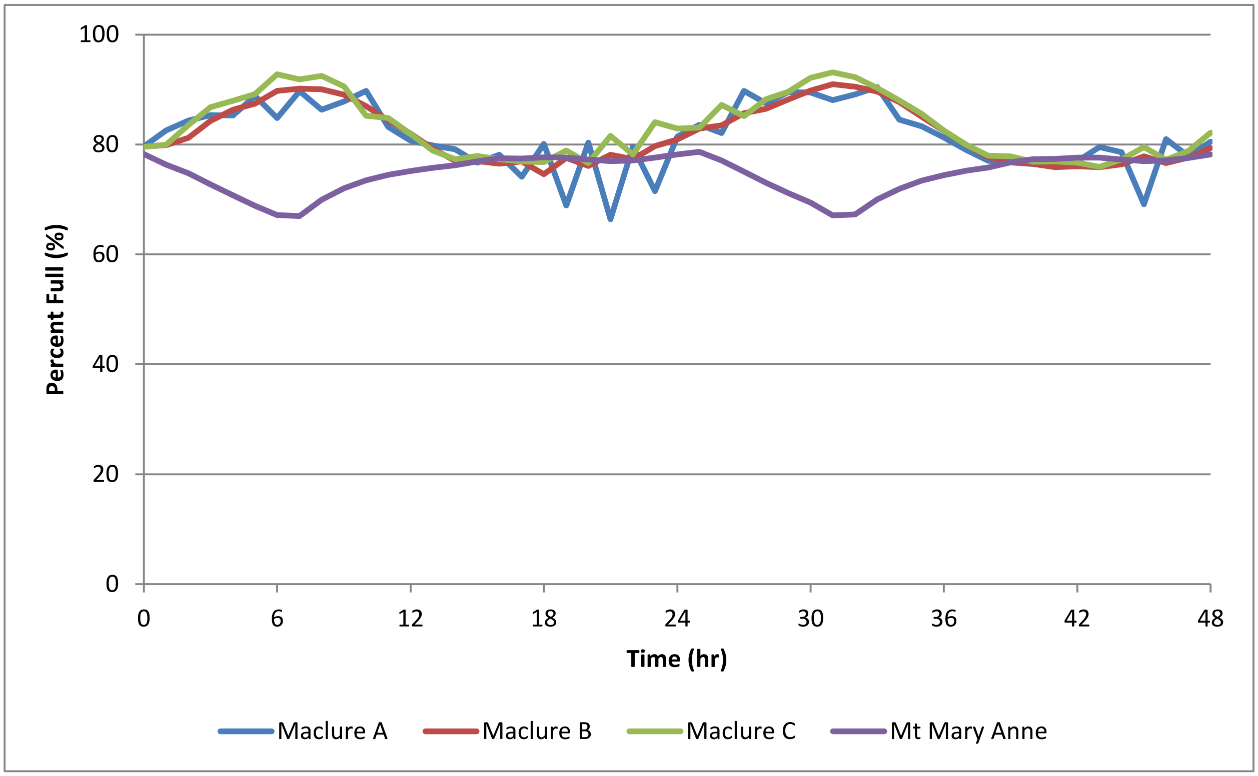
Finally, the supply system was analyzed with the Norrish Creek source out of service under 2041 ADD conditions. For this analysis, two (2) supply conditions were assessed:

Scenario 7. Cannell Lake and the groundwater wells supply the entire system with the collector well in service.
Scenario 8. Cannell Lake and the groundwater wells supply the entire system with the collector well out of service.

5.3.1. Norrish Creek Out of Service – Scenario 7

Figure 5.6 illustrates the two-day reservoir cycles for Scenario 7 with the Norrish Creek source out of service.

Figure 5.6: 2041 ADD Storage Reservoir Levels – Scenario 7
Norrish Creek Out of Service – With Collector Well



As shown in the figure above, the storage reservoirs are able to cycle, with water levels replenishing over the course of the two-day simulation.

Table 5.11 summarizes the setting and minimum upstream pressure modeling results for each municipal PRV connection for Scenario 7 with the Norrish Creek source out of service. The minimum upstream pressure is the lowest pressure predicted by the model over the course of the two-day model simulation, upstream of each municipal PRV connection.

Table 5.11: 2041 ADD Supply System Pressures – Scenario 7
Norrish Creek Out of Service – With Collector Well

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-406	52.0	134.9
PRV-BEST-409	49.6	134.9
PRV-BEST-423	49.6	134.9
PRV-BEST-PZ192-1	46.0	48.9
PRV-BEST-PZ192-2	40.1	48.9

PRV Model ID	Setting (m)	Minimum Upstream Pressure (m)
PRV-BEST-PZ192-3	39.4	133.9
PRV-BEST-PZ192-4	44.0	133.9
PRV-CANNONS-1	18.0	69.2
PRV-CANNONS-2	16.7	69.2
PRV-CEDAR-VALLEY-1	30.6	118.5
PRV-CEDAR-VALLEY-2	79.3	117.5
PRV-CHARNLEY-1	46.1	83.3
PRV-CHERRY-1	71.8	122.7
PRV-CLAYBURN-1	85.4	181.4
PRV-CLAYBURN-2	82.5	182.0
PRV-CLAY-VILLAGE-1	68.0	175.5
PRV-DOWNS-1	81.7	147.9
PRV-DOWNS-2	79.8	147.0
PRV-DTR-HWY7-1	85.5	169.0
PRV-EMPRESS-1	7.8	9.5
PRV-F-STAVECEDAR-1	87.9	178.7
PRV-F-STAVECEDAR-2	84.4	178.7
PRV-HARRIS-1	154.1	182.3
PRV-HARRIS-2	173.5	182.9
PRV-HARRIS-3	63.0	181.4
PRV-MARY-7TH-1	30.7	118.5
PRV-MARYANN-1	21.4	87.9
PRV-MISSION-WAY-1	92.8	183.1
PRV-PRENTIS-1	80.8	117.5
PRV-P-SADDLE-1	45.0	113.0
PRV-P-SADDLE-2	62.0	113.0
PRV-SANDON-1	55.0	133.2
PRV-SANDON-2	48.8	133.2
PRV-SANDON-3	69.8	130.7
PRV-SANDON-4	84.0	129.9
PRV-SELKIRK-1	42.4	92.2
PRV-SELKIRK-2	41.9	90.5
PRV-SHOOK-1	70.3	182.9
PRV-STRAITON-100	140.0	170.9
PRV-STRAITON-200	135.0	170.9

As shown in the table above, the supply system is able to provide enough pressure at all PRV stations under 2041 ADD conditions.

Table 5.12 summarizes the average ADD system inflows from each of the sources for Scenario 7 with the Norrish Creek source out of service.

Table 5.12: 2041 ADD Source Inflows – Scenario 7
Norrish Creek Out of Service – With Collector Well

Source	Average Model Flow (MLD)
Norrish Creek	**0.0**
Cannell Lake	11.6
Groundwater Wells	54.4
Collector Well*	27.3
Total	**93.3**

*The collector well is assumed to output a hydraulic grade line of 205 m.

With the Norrish Creek source out of service, for Scenario 7, the sources operate within their maximum daily capacity under 2041 ADD conditions, and the total flow supplied is higher than the 2041 ADD. As such, water is stored over the course of the two-day simulation, and reservoirs will not drain.

5.3.2. Norrish Creek Out of Service – Scenario 8

Without the collector well, the hydraulic simulation fails due to system imbalances caused by low pressures and storage reservoirs becoming empty. As such, no model results are available for this scenario. In order for the system to operate under 2041 ADD conditions with the Norrish Creek source out of service, the collector well is required to supplement flows to the supply system.

6.0 Conclusion

GeoAdvice and USL were retained by the AMWSC to complete the water supply master plan. As part of the master plan, GeoAdvice completed a supply system optimization of the AMWSC system using the AMWSC water system hydraulic model.

Three (3) supply solutions were reviewed. All supply solutions were able to meet the future servicing requirements of the 2041 MDD conditions.

Ultimately, either a partial twin (6,250 m) of the Norrish Creek transmission main is required or an additional source needs to be added to provide a capacity of approximately 12 MLD (**Table 4.5**).

If the additional source capacity is increased to 25 MLD, then the draw from the groundwater wells can be decreased from 54 MLD to 36 MLD. If the draw from the groundwater wells is further decreased, forcing an increase in the flow from Norrish Creek, the model predicts that the sources cannot maintain the 2041 MDD system flows and pressures over an extended period.

Finally, in order to meet the future servicing requirements of 2041 ADD conditions with one source out of service, the new source needs to provide a capacity of approximately 27 MLD (**Table 5.12**).

Submission

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Appendix A Future Demand Calculation Assumptions

Land Use	ADD (L/s)	MDD (L/s)	ADD (MLD)	MDD (MLD)
Single Family	257.5	381.4	22.3	32.9
Multi Family	117.7	172.0	10.2	14.9
Commercial	50.8	74.0	4.4	6.4
Industrial	97.9	140.3	8.5	12.1
Institutional	33.2	48.4	2.9	4.2
Agricultural	89.2	126.8	7.7	11.0
Subtotal	**646.3**	**942.9**	**55.8**	**81.5**
Existing Non-Revenue Water	119.9	196.0	10.4	16.9
Exiting Total	**766.2**	**1138.8**	**66.2**	**98.4**
Residential Growth to 2021	23.5	34.5	2.0	3.0
ICI Growth to 2021	17.8	25.6	1.5	2.2
Agricultural Growth to 2021	12.5	17.8	1.1	1.5
2021 Non-Revenue Water	116.2	190.0	10.0	16.4
2021 Total	**816.4**	**1210.7**	**70.5**	**104.6**
Residential Growth to 2026	49.6	73.1	4.3	6.3
ICI Growth to 2026	36.2	52.2	3.1	4.5
Agricultural Growth to 2026	25.0	35.5	2.2	3.1
2026 Non-Revenue Water	112.5	183.9	9.7	15.9
2026 Total	**869.7**	**1287.6**	**75.1**	**111.2**
Residential Growth to 2031	77.0	113.6	6.6	9.8
ICI Growth to 2031	54.9	79.2	4.7	6.8
Agricultural Growth to 2031	37.5	53.3	3.2	4.6
2031 Non-Revenue Water	108.9	178.1	9.4	15.4
2031 Total	**924.6**	**1367.0**	**79.9**	**118.1**
Residential Growth to 2036	105.6	156.3	9.1	13.5
ICI Growth to 2036	73.8	106.6	6.4	9.2
Agricultural Growth to 2036	50.0	71.1	4.3	6.1
2036 Non-Revenue Water	105.4	172.4	9.1	14.9
2036 Total	**981.2**	**1449.1**	**84.8**	**125.2**
Residential Growth to 2041	135.8	201.3	11.7	17.4
ICI Growth to 2041	93.0	134.4	8.0	11.6
Agricultural Growth to 2041	62.5	88.8	5.4	7.7
2041 Non-Revenue Water	102.1	166.9	8.8	14.4
2041 Total	**1039.7**	**1534.3**	**89.8**	**132.6**
Residential Growth to 2051	212.9	316.1	18.4	27.3
ICI Growth to 2051	150.2	217.1	13.0	18.8
Agricultural Growth to 2051	62.5	88.8	5.4	7.7
2051 Non-Revenue Water	102.1	166.9	8.8	14.4
2051 Total	**1174.0**	**1731.7**	**101.4**	**149.6**

Key Assumptions and Parameters

Abbotsford

MDD/ADD Peaking Factor:	1.42	
Agricultural Annual Growth Rate:	2.26%	
Existing Serviced Residential Population:	122,461	
Existing Serviced ICI Equivalent Population:	68,935	
Existing Serviced Agricultural Population:	39,584	(actual and equivalent)
2041 Serviced Residential Population:	193,154	
2041 Serviced ICI Equivalent Population:	114,620	
2041 Serviced Agricultural Equivalent Population:	81,397	(actual and equivalent)
2051 Serviced Residential Population:	217,382	
2051 Serviced ICI Equivalent Population:	133,250	
2051 Serviced Agricultural Equivalent Population:	81,397	(actual and equivalent)
Residential MDD Per Capita Demand Rate (Existing):	279 L/cap/day	
ICI MDD Per Capita Demand Rate (Existing):	279 L/cap/day	
Agricultural MDD Per Capita Demand Rate (Existing):	277 L/cap/day	
Residential MDD Per Capita Demand Rate (2041):	229 L/cap/day	
ICI MDD Per Capita Demand Rate (2041):	253 L/cap/day	
Agricultural MDD Per Capita Demand Rate (2041):	229 L/cap/day	
Future Residential MDD Per Capita Demand Rate (2051):	230 L/cap/day	
ICI MDD Per Capita Demand Rate (2051):	263 L/cap/day	
Agricultural MDD Per Capita Demand Rate (2051):	229 L/cap/day	

Mission

MDD/ADD Peaking Factor:	1.59
Annual Growth Rate:	2%
Existing Residential Annual Reduction Rate	-0.42%
ICI Annual Reduction Rate:	-0.20%
NRW Annual Growth Rate:	-0.65%
Existing Serviced Residential Population:	32,400
Existing Serviced Employment Population:	19,839
2041 Serviced Residential Population:	54,861
2041 Serviced Employment Population:	31,910
2051 Serviced Residential Population:	66,875
2051 Serviced Employment Population:	38,898
Residential MDD Per Capita Demand Rate (Existing):	508 L/cap/day
ICI MDD Per Capita Demand Rate (Existing):	175 L/cap/day
Residential MDD Per Capita Demand Rate (2041):	424 L/cap/day
ICI MDD Per Capita Demand Rate (2041):	166 L/cap/day
Residential MDD Per Capita Demand Rate (2051):	411 L/cap/day
ICI MDD Per Capita Demand Rate (2051):	166 L/cap/day

JOINT ABBOTSFORD-MISSION

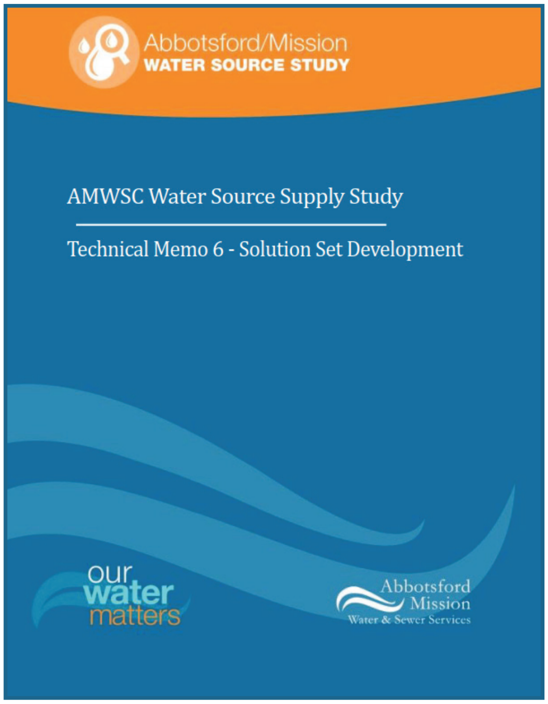
WATER MASTER PLAN

Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#7

SOLUTION SET DEVELOPMENT SUPPLY CONSERVATION OPTIMIZATION



Abbotsford/Mission
WATER SOURCE STUDY

AMWSC Water Source Supply Study

Technical Memo 6 - Solution Set Development

our water matters

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WATER SOURCE STUDY

AMWSC Water Source Supply Study

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1 INTRODUCTION AND PURPOSE

The Abbotsford Mission Water and Sewer Commission (the Commission) provides source water supply, treatment, and transmission to each participating community. **A core responsibility for the Commission is to plan for long-term source and transmission supply so that customer needs are met for current and future planning horizons in a responsible manner that enables growth and economic aspirations.** The *Water Source Supply Study* comprises of multiple phases where each milestone provides important information to support decision-making towards an implementation plan for long-term reliable water services.

Now at this stage, the technical analysis begins to converge toward an implementation plan for meeting levels of service for current and future water system customers. That long-term plan consists of solution sets which include three distinct investment areas: water conservation programs, transmission system upgrades, and source expansion(s). Each investment area interplays with the others creating a nested approach to cost-effectively meeting service levels.

Working sessions with the AMWSC Commission in May, July, and September 2017 afforded staff and the consulting team to hear firsthand perspectives, ideas, and opportunities in regards to each area of solution set development. To date, the Commission has affirmed its goal to identify a long-term plan that meets the needs of current and future customers in a *phaseable,* incrementable, and affordable manner. All analysis to date has applied these themes so as to meet the needs of the Commission and to ensure that recommendations align with social, technical, and political aspirations. Further, the direct ties between policy framing and growth projections from each municipality's OCP strengthens the confidence in work to date as it demonstrates that the project is being done to support the goals of the community, and not as a stand-alone water planning exercise. In effect, this memo signals that input to date from the Commission, from staff at each municipality, and from the project-process is converging toward a long-term plan for resilient water supply. Technical Memorandum #6 works through the range of options to arrive at a short-list of solution sets for consideration and direction by the Commission.

The format for this memo includes:

- A brief overview of demand planning choices and the preferred water conservation program for program-building and implementation,
- A summary review of hydraulic modeling analysis which uncovers select optimization projects to meet service levels throughout the system for the regional service area to improve transmission,
- A long-list of available sources including a pre-feasibility scan to narrow the range of options to two preferred choices as a complement to the existing portfolio of sources,
- Some preliminary costing for each of the solution set components including annual program costs for water conservation, capital costs for system optimization, as well as capital and life-cycle operating (including net present value analysis) for the two preferred source expansion projects, and
- Recommendations for long-term planning including milestones, outcomes, and investment levels

Information provided in this report can support Commission discussions during the next working session in September 2017 and ultimately become the backdrop to directions and decisions at the November 2017 working session, and later as part of the Joint Water Master Plan. Building the solution sets is the core objective of the Water Supply Source Study and each investment area for solution sets is explored independently below.

2 WATER CONSERVATION PROGRAMMING

2.1 Demand Projections to Guide Conservation Programs

Conservation efforts since 2010 have helped to defer major source and system expansion. Going forward, water conservation remains a critical component to solution sets as the reductions in per capita usage will defer or eliminate pipe-expansion projects for the long-run. The desired outcomes for the water conservation program for solution sets are to:

a) Identify the demand targets for system planning, and
b) Define the focus areas of the conservation program, including their annual costs, so that a detailed blueprint can be made in 2018.

Technical Memoranda 2 and 3 provide additional details on the existing program and the suitability of various programs given the status and needs of the Commission. For reference, the context for water conservation surrounds these major topics:

- The existing water conservation program has offset the need to add unnecessary capacity and the deferral of the investment is saving tens of millions of dollars per year for the Commission;
- That select areas of the existing conservation program will be expanded and enhanced, while other areas may be scaled-back or eliminated in order to meet proposed targets at best cost;
- That greater emphasis on reductions for new development is a lower-barrier approach to reductions; however, unless greater attention is also placed toward existing residential customers, conservation effectiveness will be quite gradual and source expansion may be required sooner;
- That real-time information and knowledge sharing in regard to community water demands and conservation choices at the individual and community level must continue and become ever more tailored to the specific customer behaviours in the service area; and
- That Abbotsford's case study for reductions and the direct-relation to low consumption stemming from meters, frequent billing and demand-oriented water rates is the most applicable evidence for notable results in conservation for the region.

Background information and previous analysis culminate into a short-list of program choices to demand projections and conservation planning as outlined in Table 1.

Table 1: Conservation Choices for Commission Framework

Conservation Choice	Theme	Outcomes	2041 Demand Projection
No Conservation Scenario	*No further reductions targeted*	• Consumption rates remain unchanged from today's conditions*	**146 MLD**
High Demand Scenario	*Steady program with refinements to existing program*	• Cost-effective conservation that achieves some reductions but does not require major spending increases • Includes 0.35% reductions year over year resulting in a 10% total drop in 25 years	**135 MLD**
Medium Demand Scenario	*Additional conservation program that increases expectations to reduce*	• 0.7% per year reductions are significant for fast-growing region; a 20% drop in 25 years would become quite challenging over time • Includes some cost-effective programs • Emerging pushback from select customers to achieve targets	**122 MLD**
Low Demand Scenario	*Advanced program that meets best practice and more*	• Largest conservation program with full suite of initiatives • Some potential to offset source expansion (scope) but does not eliminate need for new source • Aggressive targets of >1%/year (total of 30% reductions by 2041) creates notable pressure on customers	**108 MLD**

**Note: abandoning the conservation program is not a guarantee that water use rates would remain as they are for any length of time and it is likely that water use rates would increase over time.*

While various permutations of the above scenarios are available, presenting four demand scenarios provides a broad spectrum of choices to position the Commission for direction in regard to the significance of any conservation program and the major initiatives to pursue. Overall, dialogue with staff and elected officials, technical analysis, as well as industry research and case study review converge the analysis towards an agreed-upon and sensible approach to demand projections and conservation planning:

- To apply the high-demand scenario of 0.35%/year (10% total by 2041) for system planning so as to further enhance the existing program and to add select initiatives based on performance and cost effectiveness,
- To develop a conservation Blueprint in 2018 which enacts the high-demand scenario and provides detailed tactics for implementation,
- To incorporate other, more advanced conservation programs such as universal metering (i.e. for Mission) if grants are received or to institute frequent billing and demand-based (e.g. tiered) rates as the justification to do so, grows, and
- To continue to remain open to new programs as local results and industry-wide case studies continue to come forward over time.

In summary, the high demand scenario is essentially a decision towards fine-tuning the existing program that will result in more efficient water use, demonstrate improved cost-effectiveness from the existing programs and will allow for some factor of safety (i.e. it is a conservative demand projection) for system planning. The high demand scenario is recommended for further analysis in the *Water Source Supply Study* as it positions the Commission to make decisions around source and transmission upgrades without holding extraordinary risk if advanced targets are not met.

2.2 Conservation Program: Framework Description for Future Blueprint

Based on achieving, at minimum, the reduction targets of the high-demand scenario, the Commission should advance conservation programs in the following areas, as outlined in Table 2.

Table 2: Water Conservation Program Summary for High Demand Projections

Program Focus Area	Description, Effort, and Outcomes
Low-Impact Development	+$25,000/yr -3MLD reduction
- *High efficiency hardware in new buildings*	• Require all major water using appliances to meet low-efficiency targets; look to municipalities for pressure management on a zone-by-zone basis as well as individual properties as needed
- *Low landscape requirements*	• Drip irrigation requirements; native and drought-tolerant species; incentives for rain water harvesting
Maintain Restrictions Policy	+$25,000/yr -1MLD reduction
- *Use AMI data in Abbotsford to reduce peaks and lower MDD*	• See other actions herein
- *Review demand thresholds to suit targets/messaging*	• Update thresholds and AMI response plans to suit reductions for chosen scenario
Social Marketing	+$75,000/yr -1MLD reduction
- *Update/expand social marketing*	• Consistent messaging based on actual, in-field water usage to counteract increasing water usage
- *Create customer message/education platforms*	• In-depth analysis/focus groups to appreciate customer behaviours and ideas
Economic Strategies	+$50,000/yr -3 MLD reduction
- *Gradually transition to tiered rates for different customer classes (metered customers only)*	• Consider a high threshold first (obvious excessive use) to initiate tiered-rates • Use AMI thresholds to line up with future tiered-rate thresholds
- *Refine rebate program for residential*	• Showers, dishwashers, laundry rebates for low-income and rental units
- *Capacity buy-back feasibility*	• Review options and implement for select customers: agriculture, commercial and industrial

Complete Metering Program	+$25,000/yr (varies if universal metering pursued) -2MLD reduction
- *Procure meters for remaining customers in Mission*	• Apply for senior government grants • Transition rate structure to incentivize metering
- *Expand leak-detectors*	• All customer connections at time of development/renovation • All civic connections within 5 years
Loss Management: NRW	$100,000/yr -2MLD reduction

Total program costing on an annual basis is estimated at $550,000 to achieve 0.35% year over year reductions until 2041 (these costs are categorized as 'operation' meaning that they will not constitute part of the long-term capital plan). Given the program highlights above, investments into water conservation should increase by approximately $250,000 not indexed to account for program escalation. Even though reductions for the *high demand scenario* are projected to be moderate and only slightly greater than recent conservation efforts, it should be noted that *each additional percentage reduction from here forward becomes more challenging and requires greater resources* than the initial conservation results from 7-8 years ago. Additional details are required to implement this program by way of the conservation Blueprint for 2018, however the targeted reductions for the Commission as part of the solution set should result in a total reduction of 12MLD by 2041. The role of conservation in the recommended solution set(s) are outlined in this memo.

3 TRANSMISSION SYSTEM OPTIMIZATION

Technical Memorandum #1 provides a comprehensive review of the regional-transmission system including reviews of licences, supply characteristics, treatment systems, equipment capacities, supply limitations, and historical use. While previous assessments have looked at supply deficiencies due to growth, there remained a gap in understanding service levels with which to define gaps; an important takeaway from this study is the establishment of transmission service targets. As a result, gap analysis from this study and pending capital plans to optimize the system can be based on clear service levels. This approach aligns with industry best practices, creates transparency within capital planning and leads to better decision-making processes. Optimization projects comprise the second of three elements that make up solution sets.

3.1 Description of Optimization Projects

Optimization projects enable water utilities to meet service levels by reducing or eliminating transmission bottlenecks or by adding new infrastructure or sources to more effectively deliver potable water. Optimization projects in particular typically include any one or more of the following upgrades:

- Upsize pumps, valves, or pipes to better meet demands during max days and average days without reliance on municipal distribution systems to meet gaps
- Add looping to systems and redesigning hydraulic facilities to provide equitable access everywhere e.g. pressure maintenance

- Add in special equipment e.g. generators, twinning pipes, expanding storage, to provide redundancy during extraordinary events e.g. pipe break
- Expand treatment capacity in the event of poor source water quality

Previous analysis identified multiple optimization projects to meet the historic demand projections. As a result of recent water conservation efforts and more accurate demand projections that align with each municipality's OCP, the need for optimization projects has decreased. The updated list of optimization projects is presented in Section 3.4 following the definition of service levels (for which projects are designed to achieve) and a review of the technical review methodology.

3.2 Service Levels for Gap Analysis and to Guide Optimization

Major service terms for system performance include these four topics:

- Major Service Term 1: All maximum day demands (MDD) should be provided by the AMWSC three supply sources and their transmission systems, independent of Abbotsford and Mission reservoirs and without deficiencies at any of the 23 regional-local system interconnection points.
- Major Service Term 2: There is adequate supply and transmission redundancy to provide average day demands in the event that one of the main sources is unavailable due to environmental (e.g. turbidity, drought) or system failure issues.

Note: It is considered an unusual level of service to meet MDD with the entirety of one of the larger sources out of service.

- Major Service Term 3: Potable water quality standards based on service authority permits can be consistently met under foreseeable, reasonable conditions.
- Major Service Term 4: The cost of water supply ensures the long-term integrity of meeting Service Terms 1-3 at a predictable rate.

Current service levels are generally met in most areas, however, there are limitations, such as;

- The Norrish supply line is limited to a maximum day capacity of 89 MLD (albeit the full treatment and license capacity equate to approximately 140 MLD);
- The Cannell Lake source is limited to license and hydraulic capacity of 60 MLD with 225 L/s (19.4MLD equivalent for about 3 hours) required for firefighting in Zone 4;
- The transmission system is unable to achieve target hydraulic service standards such as to meet MDD demands without either increasing capacity of the Norrish Supply Line or by adding additional source(s) capacity elsewhere.
- Staff estimate that of the existing sources, only 90% of the available supply can be distributed to both municipalities and that optimization projects should address any future gaps that emerge from population and demand growth.

Hydraulic analysis provides for investigations that test the performance of the system to uncover gaps in meeting service targets. Each of the seven tested scenarios allowed for performance evaluation through both MDD and ADD conditions. For MDD, any or all of the available sources were applied to meet high-seasonal demands up to 2051. Some scenarios allowed for expansion of the supply pipes from existing source (i.e. twinning of the Norrish Creek Supply Line) while other scenarios relied instead on source expansion either by more groundwater supply or from a new collector well adjacent the Fraser River (discussed in detail in the source evaluation sections of this memo and previous reports as part of this study). The primary objective of assessing MDD results is to determine whether source expansion or system upgrading is required to meet high-seasonal demands with population growth to 2041. Results of the analysis to the 2041 scenario (as required as an outcome to this study) are summarized later in this section.

Similarly, for ADD conditions, the primary intent was to test performance of the transmission system during 2017 and 2041 demand scenarios, however, in these instances, any one of the sources was turned off assuming longer term interruption of supply. This approach allows utility managers and Commission members to assess the resiliency of supply and transmission under an extraordinary event; this is a recommended approach for a utility that utilizes a portfolio of water supplies. As with the AMWSC, source interruptions are inevitable and determining the most suitable backup supply conditions is appropriate for a fast-growing economic and social hub of a large region.

Overall, optimization analysis reveals the ability of the system to supply and transmit potable water during high water use periods and when a source (such as Norrish, the largest source) is out of service. A summary of the results of the analysis includes (refer to Technical Memorandum #5 for complete details on optimization analysis and the range of service scenarios):

- That each of the demand scenarios to 2041 incorporate the high demand conservation program and is based on the projected growth rates in each municipality
- That many of the previously developed (2013) optimization projects are no longer required as the growth and demand projections are now more accurate and lower, which places less strain on supply and transmission infrastructure
- That twinning of the Norrish Creek supply main is only required if no other sources are developed; even if the Norrish Creek supply main is twinned, additional sources are required under the ADD service level targets meaning the twinning project is an expensive supply option that does not significantly increase resiliency
- That 2041 MDD demands can be met without impacts to level of service targets when all sources are utilized
- That 2041 ADD demands with one source out of service cannot be met: source expansion is required to meet the 2041 ADD service targets; for analysis, only the collector well was analysed given that all other sources demonstrated low feasibility and because the only other comparable (in terms of feasibility) source, which is groundwater expansion, has less of an impact on the transmission system due to its location within the City of Abbotsford distribution system

- That back up reservoir storage is required for Pressure Zone 4 (Mission) in the event that Cannell Lake source suffers an interruption or a local fire occurs
- That a new pumping station is required to distribute groundwater from the Maclure reservoir to Mission in the event that Norrish is offline unless the collector wells are constructed
- That expansion to the Dickson Lake reservoir is required (from Tech Memorandum #1) to optimize source storage through resiliency challenges from climate change, watershed activities, and to support instream fish flow requirements

Overall, the AMWSC water supply system demonstrates adequate performance at this time and that a concise, but important, list of optimization projects in addition to source expansion will set up the system for long-term service delivery.

3.3 Description of Optimization Projects

Table 3 summarizes the optimization projects proposed as an additional investment area within the short-list of solution sets.

Table 3: Preliminary Summary of Optimization Projects

Project Name	Scope/Cost	Purpose
Mission Zone 4 Reservoir	$17M	• Resiliency upgrade during Cannell interruptions and or fire protection
Maclure Booster Station	$5M	• System redundancy for supply provision to Mission from wells on south side of the river (not required if a collector well is constructed)
Dickson Lake Storage Upgrades	*$10M*	• Reliability upgrades to adapt to climate change and better manage instream flows for fish
Norrish Creek Twinning (1)	*$35M*	• Only required if no other sources developed
Norrish Creek Twinning (2)	*$50M*	• Only required if no other sources developed

**includes $2M for Best Avenue PS upgrade to allow for inter-zone transmission.*

All solution sets will incorporate the Mission Zone 4 reservoir and the Dickson Lake Storage Upgrades. The Maclure Booster Station will only be included if groundwater is selected as the preferred approach to source resiliency.

4 SOURCE EXPANSION REVIEW

The AMWSC operates a portfolio of sources which includes 19 groundwater wells, the high-capacity Norrish Creek supply system, and Cannell Lake. Overall, the portfolio provides for generally acceptable source performance to meet current demands; however, the establishment of service levels of reliable supply for ADD when one source is out of service creates a need to increase resiliency in an incremental manner through source expansion.

Previous technical analysis reviewed the capacities of each source in detail. For convenience, the summary of source attributes includes:

- Cannell Lake provides consistent water quality, however, it’s reliable capacity reflects only 15% of average day demand (ADD) supplies. Cannell Lake can be relied upon for greater capacities, up to 60 MLD to help address maximum day demand (MDD), however, that support is short-term only, perhaps up to a few weeks. Cannell Lake is the primary source to Pressure Zone 4 which prevents the need for Norrish Creek or groundwater supplies to be pumped to higher elevation neighborhoods. Cannell Lake does not offer significant capacity expansion for future growth.

- Groundwater wells can expand in overall production; however, they typically demonstrate a higher operational footprint including energy, permitting, and renewal than gravity sources (when extensive treatment is not required). Groundwater quality is trending poorly at some wells which will offset the long-term expansion potential. Groundwater can currently provide up to 55 MLD which represents 50% of MDD and 66% of ADD and the overall capacity can be increased incrementally, perhaps up to 25 MLD (which is not adequate to meet service targets beyond 2041), however not without extensive regulatory processes and further management systems to account for potential water quantity impacts and quality risks.

- Norrish Creek can supply 89 MLD and theoretically meet 100% of ADD on its own during periods of regular source water quality. Norrish Creek is unable to meet MDD demands on its own due to pipe size limitations of the principal Norrish transmission line. Upgrades to the Norrish supply main could enable this source to provide up to 135 MLD; however, Norrish Creek and Dickson Lake require investments over the long-term to optimize storage and meet license requirements (including instream fish flow requirements), it is also prone to drought, landslide and turbidity risks and when it is out of service, the AMWSC is unable to meet its service level targets for reliable ADD supplies.

- With consideration to the source attributes and capacities as well as service level standard, there is a need to identify additional source capacity to meet ADD with Norrish out of service as summarized in Table 4.

Table 4: Emerging Gap for ADD Supply Target

Year	ADD Capacity (2017) with Norrish Source Out of Service	Projected ADD incl. Growth and Conservation	ADD Supply Gap
2017	67 MLD	67 MLD	0
2031	67 MLD	~80 MLD	13 MLD
2041	67 MLD	~90 MLD	23 MLD
2051	67 MLD	~100 MLD	33 MLD

For planning purposes, the targeted source expansion is projected at 25 MLD. A long-term resiliency plan for beyond 2060 will require a targeted source expansion of approximately 50 MLD. At this time, the Commission should evaluate sources with the goal to supply 25 MLD initially and expansion to 50 MLD in about 25 years and to further assess the source with respect to its performance against the evaluation criteria as outlined in Technical Memorandum 1.

4.1 Review of Source Expansion Evaluation Criteria

Evaluation criteria allow for comparative performance analysis across a range of choices against a common list of topics. Table 5 lists and describes the criteria for source expansion.

Table 5: Evaluation Criteria for Source Expansion

Criterium	Factors
1. Resiliency	• Water supply consistency over time e.g. droughts • Amount and severity of hazards/risks
2. Adequacy	• Ability to phase for growing water demands; to meet peak demands • License and regulatory assurances in long term use/supply
3. Serviceability	• Proximity to system and customers • Operational footprint e.g. management, operations
4. Affordability	• Relative cost against other source options • Cash-flow considerations e.g. need for large investments upfront
5. Desirability	• Public perception of water supply • Stakeholder conflicts

While helpful to narrow down the range of choices from a shortened list, employing five criteria plus sub-topics can be cumbersome when applied to more than 10 source options such as the number of sources considered in 2011.

As part of the comparative performance review, the long-list of source options was reviewed through a pre-feasibility scan to create a shortened list for more substantive assessment.

4.2 Long List of Source Expansions Options: Prefeasibility Scan

Table 6 summarizes the long list of source expansion options that have been developed and evaluated over the last 10 years stemming back to the last supply master plan.

Table 6: Long List of Source Options - Overview

Source Expansion Project Name	Brief Project Description
Cannell Lake Expansion	*Increase storage and consider inter-watershed transfers to maximize gravity supply*
Miracle Valley Groundwater Development	*Develop a well-field for increased groundwater supply and convey water tens of kilometers to regional pipes*
Hayward Lake Extension	*Construct intake and treatment for increased supply*
Harrison Lake Extension	*Extend pipes to Harrison lake then treat for increased supply*
Chilliwack Lake Extension	*Extend pipes to Chilliwack Lake then possibly treat for increased supply*
Norrish Creek Expansion	*Increase storage capacity, treatment capacity, and twin the main supply line*
Stave Lake Development	*Construct intake and treatment plant to replace all other supplies*
Fraser River Intake	*Construct river intake, settling ponds, and treatment plant to replace all other supplies*
Expand Local Aquifers	*Multiple groundwater locations near existing wells (19) with small extensions to the existing transmission system*
Extension to Metro Vancouver	*Extension and expansion of the GVRD potable water system and its service area to supply AMWSC*
Connect to Clearbrook Waterworks District	*Small-scale expansion to integrate the two adjacent systems*
Wastewater Reuse	*Increase treatment levels at the J.A.M.E.S Plant to provide treated effluent suitable for potable substitution e.g. irrigation*
Temporary Storage	*Constructing large urban storage tanks to provide short-term (e.g hours) of storage when water use is at it's highest*

At first glance, the long-list of projects provides some comfort that there are multiple choices to address the emerging supply gap; however, the diversity of expansion options justifies the need to scan for pre-feasibility so that technical assessments are limited to a shortened-list that are worthy of comparative study. Fortunately, the AMWSC has extensive information resources in regards to the merits and drawbacks for each source; efforts over the last 10 years to develop a long-term water plan included broad and in-depth exploration of many source options. Through interviews with staff and ongoing research into available reports, the long-list of sources above was reviewed under the following pre-feasibility questions:

- Which sources are located in highly-active watersheds that offer notable risks of poor water quality or water quantity?
- Which sources are located at such a distance that the cost to extend far outweighs the cost to add about 20% more capacity (i.e. 25 MLD)?
- Which sources present significant drawbacks in terms of public perceptions and or major regulatory hurdles such that making decisions would become imprudent?
- Which sources cannot offer reasonable terms for development due to low engineering feasibility?
- Which sources are worthy of additional review because they can move through the list of pre-scan questions listed above?

Table 7 summarizes the results of the review of the long-list of sources based on best available information.

Table 7: Pre-Feasibility Scan of Long List of Sources

Pre-Feasibility Scan Results: Category Name	Applicable Sources
Highly-Active Watersheds with Large Upfront Costs for Extension	• Chilliwack Lake Extension • Harrison Lake Extension
Lowest Engineering/Economical Feasibility	• Temporary Storage (unreliable to address multiple days of supply shortage) • Hayward Lake Extension (leachate concerns from local landfill) • Fraser River Intake (high turbidity, big scale and high treatment costs)
Lowest Public and Political Interest	• Wastewater reuse • Extension to Metro Vancouver • Connect to Clearbrook Waterworks District
Sources for Further Comparative Review	• Norrish Creek Expansion • Miracle Valley Groundwater Development • Expand Local Aquifers (1) – Additional Vertical Wells • Expand Local Aquifers (2) – Fraser River Collector Well • Stave Lake Development

Each of the five (5) sources that pass the pre-feasibility scan offer diverse strengths and some challenges when considering their potential to complement the existing source portfolio including their ability to meet the emerging supply gap. Any of the sources deemed unsuitable for further review can be considered again well into the future if any other supply issues emerge. At this time, however, it becomes imperative to prioritize the remaining, feasible sources by applying the evaluation criteria and assessing their performance relative to each other.

4.3 Evaluation Criteria and Source Performance

The five sources that emerge from the shortened list of expansion options provide for varying degrees of performance when considering the service needs of the AMWSC. Table 8 provides a comprehensive review of each source in light of the evaluation criteria and includes order of magnitude costing (capital only at this time) and key considerations that overall provide a summary framing for considering next steps.

Table 8: Shortened List of Expansion Options: Sources

Source Name	Evaluation Criteria					Capacity and Development Considerations	Order of Magnitude Capital Cost	Summary Comments and Risk Considerations
	Resiliency	*Adequacy*	*Serviceability*	*Affordability*	*Desirability*			
Collector Wells at Fraser River	● **GOOD** *Large flow; multiple barrier protection*	● **GOOD** *Phaseable; proven permitting process*	● **GOOD** *Proximal source; average operational needs*	● **GOOD** *Good cost performance (unless iron/manganese removal req.)*	◓ **FAIR** *No known conflicts; queries toward water quality*	• 25 MLD to 50 MLD and beyond • Small-scale pipe extension • Centralizes groundwater sources for efficiencies • Requires field verification and potentially treatment to remove iron and manganese	• Up to $50M depending on the level of treatment required for 25 MLD	***Potential for high-capacity, long-term phaseable source to be located adjacent existing system with further analysis need to verify yield and treatment needs.***
Additional Groundwater	◓ **FAIR** *Hazards on the rise; reaching maximum aquifer withdrawl*	◓ **FAIR** *Phaseable; permitting is complex and costly*	● **GOOD** *Proximal source; average operational needs*	● **GOOD** *Average cost performance among the 5*	◓ **FAIR** *Public support okay; increasing conflicts with other well owners*	• Up to 25 MLD only • Small-scale pipe extension plus new booster pumps • Permits for well expansion becoming more complex and expensive	• Up to $20M for 25 MLD	***Potential for modest, proximal, phaseable capacity increases, however, traditional groundwater sources are becoming more difficult to expand and manage and cannot meet 2041 service goals.***
Expand Norrish Creek	○ **POOR** *Presence of droughts, erosion, and turbidity; no added redundancy*	◓ **FAIR** *Licensing and expansion becoming ever more complex*	◓ **FAIR** *Proximal to existing pipes; operational needs increasing with treatment/watershed activities*	○ **POOR** *Below-average cost performance*	◓ **FAIR** *Public support okay; increasing complexity with instream fish flows*	• Intent to reach full license capacity of 141 MLD • Requires reservoir, treatment, and supply pipe expansion • Does not offer additional redundancy	• Up to $120M for project completion for 40 MLD	***Potential for long-term source expansion, however, it requires extensive new works and does not address resiliency-service goals.***
Miracle Valley Groundwater Development	◓ **FAIR** *Potential for consistent supply; typical hazards for unconfined aquifers*	◓ **FAIR** *Cannot meet 2041 service goals; permitting likely average*	◓ **FAIR** *Average operational footprint; require large extension relative to supply*	◓ **FAIR** *Average cost performance*	● **GOOD** *Public support okay; No known conflicts*	• Up to 20 MLD only • Medium-scale pipe extension • Requires aquifer studies and investigation and field verification	• Up to $60M depending on the level of treatment and number of wells to be drilled; for 20 MLD	***Potential for low-scale source expansion that does not meet 2041 service goals and requires relatively expensive extension costs.***
Stave Lake Development	● **GOOD** *Well managed supply; hazards managed*	◓ **FAIR** *Not able to phase-in capacity; average permitting process*	○ **POOR** *Major expansion; overall operational increase i.e. every drop filtered*	○ **POOR** *Highest cost*	◓ **FAIR** *Public support is low post-referendum*	• Up to 300 MLD and beyond • Includes decommissioning of other sources to centralize at Stave Lake • Requires filtration and large-scale pipe extensions	• Up to $300M for 200 MLD	***Represents the most-expensive, non-incrementable source option that includes a write-down of existing source-assets.***

Overall, given the performance of each source against the criteria and needs of the AMWSC, two sources warrant further costing analysis, including life-cycle and net-present value comparisons, so as to appreciate the financial impacts of either direction. The Collector Wells at Fraser River and Additional Groundwater Development emerge as highest performing options against the criteria, given that:

- The Stave Lake Development option is the most expensive and has low public and political support
- The Miracle Valley Groundwater Development option cannot meet the 2041 service goals (or beyond) and requires relatively large pipe extensions (given the size of the supply), and
- The Norrish Creek Expansion requires extensive new works at a high cost yet does not offer source redundancy nor meet the ADD service terms for 2041

Two sources offer multiple choices for expanding capacity as part of comprehensive solution sets. However, there are still distinct differences between the two high-potential sources. In particular, when financial considerations are combined with qualitative strategic considerations, in terms of management and operations, then there can be confidence with the information to provide recommendations to the Commission for long-term source expansion. Both financial and ownership factors are discussed in Section 4.4.

Piteau Associates has completed desktop reviews for both the groundwater expansion and collector well construction and their reports are contained in separate memoranda (all combined as part of the Joint Water Master Plan). Both source options appear to have enough potential to be considered further. Groundwater expansion, as proposed, is not expected to result in aquifer depletion, however, influence on flows in creeks and other operating wells could constrain the maximum pumping rates. The largest risk for groundwater expansion is water quality degradation resulting in the need to discontinue use or add treatment. The regulatory challenges associated with adding additional groundwater are significant and approximately 4-6 years of investigative work is expected before additional groundwater expansion potential can be confirmed.

For the collector well option, Piteau confirms that the study area appears prospective for adding the 50 MLD of capacity. They note that in addition to the collector well approach that a more conventional vertical well field adjacent to the Fraser River may also be viable. While additional field investigation activities are required for this option as well, the regulatory challenges are expected to be significantly less and require a much shorter time frame.

4.4 Life-Cycle Cost Comparisons for Two Preferred Sources

Life-cycle costing allows for comparisons between the capital and operating costs of multiple options. At times, the ongoing costs of one option may, in the long-run, offset any initial capital savings. Life-cycle costing informs owners as to which option is most cost-effective over the duration of the planning horizon. Typically, life-cycle costing is calculated in today’s dollars then forecast over a time period which includes the time-value of money by way of a discount rate. The outcome of this common financial analysis is often the net-present value, which signifies the investment-impact of making either choice as a decision today, net of the life-cycle cost to own and operate the investment.

Cost estimates at this stage incorporate multiple assumptions which are required to conduct financial forecasts. Assumptions for this analysis include:

- consumables such as power, chemicals, and equipment
- operations resources such as administration
- interim financing through construction as well as project oversight and management
- contractor profits and overhead
- planning horizon and duration of analysis (i.e. 25 years)
- various engineering requirements such as treatment technologies, unit sizes, and operating efficiencies
- inflation and time-value of money represented by a discount factor (i.e. 3.5%)

These types of assumptions are common and required when forecasting costs and preparing net-present value analysis. Ultimately, the assumptions are preliminary at this time but suitable for comparative purposes because all options incorporate the same factors.

Table 9 summarizes the source expansion choices for both traditional groundwater and for collector wells. Two versions of the collector wells are presented given that it has not been confirmed whether iron and manganese removal will be required. In the case of the groundwater option, since adequate capacity isn't expected to exist beyond 2041, the collector well is brought online in 2041 for this option as well. With the treatment variability this results in four potential source options for comparison. Detailed cost estimates are contained in Appendix A.

Table 9: Net-Present Value Cost Summary for Source Expansion

Cost Element	**Collector Wells** at Fraser River w/o Iron-Manganese	**Traditional Groundwater** w/ collector well expansion in Yr 25 w/o Iron/Manganese Treatment	**Collector Wells** at Fraser River with Iron/Manganese Treatment	**Traditional Groundwater** w/ collector well expansion in Yr 25 with Iron/Manganese Treatment
NPV Capital Yr 1-42	$44.5M	$49.3M	$69.1M*	$57.3M
NPV Operating Yr 1-42	$9.9M	$16.5M	$12.3M	$17.1M
NPV Total	**$54.4M**	**$65.8M**	**$81.4M**	**$74.4M**

**Non-discounted capital cost for the collector well is $76M which is carried forward in reporting and outlined in detail in Appendix A.*

Key insights from Table 9 include that the operational costs of traditional groundwater exceed standard collector wells both with and without iron and manganese removal by some margin, and that the NPV of the collector wells is lower than traditional groundwater wells when there is no need for iron or manganese removal. The need for iron and manganese removed increases the capital costs for both options but have a greater impact on the collector well NPV due to the timing for the capital expenditures.

Also note that if the collector well option is pursued that staff will bring forward additional costing analysis on the most cost-effective options for installing capacity in phases and their cost-efficiencies (for example, one large building to house all components for the life of the building rather than building sequential add-ons as needed) during the source development phase.

4.5 Source Expansion Summary

Service level targets for the AMWSC signal the need to meet 2041 ADD projections with one of the sources within the supply portfolio out of service. This approach to supply security is consistent with a growing region, home to emerging commerce and business plans by ensuring ample supply through a range of water servicing challenges. Demand projections as part of this study point to a source expansion of 25 MLD in about 10 years followed by a second phase of expansion (another 25MLD) by 2041; these demands can be best met through new traditional groundwater wells or by way of a collector well system adjacent the Fraser River.

Life-cycle and net present value analysis reveal near-identical cost performance between the collector wells and the traditional groundwater wells if iron and manganese treatment aren’t required. There is a potential differentiator which stems from the uncertain requirement to remove iron and manganese: a function of water quality at the collector well. Ongoing studies into the collector well feasibility will gradually uncover the likelihood and scale of iron and manganese removal. Further investigations are required for both types of sources to verify adequate source yield as well as local water quality conditions.

In terms of the evaluation criteria, the collector wells demonstrate slightly better performance in particular because of the ability to secure supply for demands beyond 2041, since permitting is less complex and the operational footprint of one larger, centralized source provides longer-term efficiencies over traditional wells scattered throughout the landscape followed by ultimately a collector well.

Based on information to date, the stated objectives of the AMWSC, the analysis of the study so far including commentary from staff, and previous public input, the recommended path forward for source expansion is to:

- Direct staff to complete field verification of the feasibility and treatment-levels for collector wells at Fraser River to determine the reliable yield and the need for iron and manganese removal;
- Proceed with the collector well development and simultaneously look to optimize traditional groundwater well expansion;

- Complete groundwater licensing for the existing wells to the maximum extraction rate possible; and
- Proceed with senior government grant support for collector well development adjacent the Fraser River and advance the project as public funds emerge.

5 SOLUTION SETS AND IMPLEMENTATION PLANNING

Solution sets comprise three primary investment areas: conservation programming, system optimization projects, and source expansion. The cumulative effect of effective solution sets is to prepare the AMWSC for cost-effective and adequate supply and transmission functions for the long-term. High performing service delivery is the foundation of any utility and the solution sets proposed herein enable the Commission to direct the works and services for water supply to the region for decades to come. This memorandum provides for the background rationale, analysis, results, and executive framing to recommend the most appropriate solution sets moving forward.

5.1 Developing Solution Sets

Work to date has been guided by evaluation criteria, system objectives, and overall planning aspirations as follows:

- To estimate water demands for current and future customers up to 2041 with consideration to growth, conservation, and droughts
- To review transmission effectiveness through the lens of service delivery targets such as source capacity, pressure requirements, storage balancing, and peak-demand management
- To integrate the inputs and objectives of this study with complementary plans of each municipality such as Official Community Plans, land use strategies, economic, and business growth plans as well as environmental and climate preparedness
- To respect the interplay among demand planning, transmission modelling, and source evaluations and to corral best available information when designing various permutations for long-term programming
- To compare and evaluate choices in terms of industry best practice, sensible service levels, and strategic criteria that allow for relative performance of various choices so as to narrow the broad-range of options to a recommended solution set for implementation

Technical Memorandum 6 presents the summary outputs from each of the five previous phases in light of the project objectives. With consideration to Commission feedback, staff input and ongoing analysis and research, the highest performing solution sets are comprised of the elements outlined in Table 10.

Table 10: Solution Set Summary Including Implementation

Solution Set Investment Area	Program Description and Outcomes	Forecasted Resources
Water Conservation	• Adopt the 0.35% per year reduction target; 10% total over 20 yrs • Commit to design and implement the detailed conservation *Blueprint* based on the strategic areas of focus outlined herein including low-impact development • Remain open to emerging opportunities for greater reductions such as senior-government supported meter installations in Mission	$550,000/yr (approx. $250,000/yr more than current)
System Optimization	• Initiate predesign activities for a storage tank in Mission Zone 4 including Best Avenue PS ($17M) • Prepare for optimization of storage and instream flow management through Dickson Lake and Norrish Creek including expansion of the reservoir by 2041 (budget $10M) • Only consider a new Maclure pumpstation if collector wells cannot be developed and traditional groundwater expansion is required • Implement best practice asset management to ensure existing and future assets are properly funded for maintenance or renewal	$27M
Source Expansion	• Proceed with field studies to verify the development potential for collector wells adjacent the Fraser River incl. the potential to maximize groundwater sources on an interim basis • Develop financial plans to prepare for the new source including capital and operating costs	$76M* (Phase 1: $59M Phase 2: $17M)

**Non-discounted capital costs presented here, whereas costs in Table 9 were discounted for NPV calculations. .*

With this solution set, the AMWSC has achieved a significant milestone in identifying a recommended path forward that addresses water conservation, system optimization, and source expansion. Pending investigations into field verifying source yields and any treatment needs will further refine the source expansion cost estimates.

Next steps in the study process explore the needs and opportunities for a Joint Water Master Plan and linking the solution sets (above) with other investment areas such as compliance, asset management, vulnerabilities and strategic operations.

We look forward to presenting the recommended solution set with the Commission for consideration and direction.

URBAN SYSTEMS LTD.

Steve Brubacher, P.Eng.

Principal, Water Practice Leader

Ehren Lee, P.Eng.

Principal, Policy and Strategy

APPENDIX A

Detailed Cost Estimates

our water matters

Abbotsford Mission
Water & Sewer Services

Summary - Collector Well Option By: Urban Systems

One-Time and Ongoing Costs

Treatment	Capital Costs	Annual O&M Costs (25 MLD)	Annual O&M Costs (50 MLD)
UV, Fe/Mn Removal and Chloramination	$ 76,400,000	$ 330,000	$ 540,000
UV and Chloramination	$ 49,100,000	$ 276,000	$ 416,000

Net Present Value

Assumptions	
Discount Rate	1.4%
Time period	2017 to 2059

Costs (from 2020 to 2059)	**UV, Fe/Mn Removal and Chloramination**		**UV and Chloramination**	
	Total Costs (no discounting)	**Present Value**	**Total Costs (no discounting)**	**Present Value**
Capital Costs	$ 76,400,000	$ 69,100,000	$ 49,100,000	$ 44,500,000
O&M	$ 17,100,000	$ 12,300,000	$ 13,700,000	$ 9,900,000
Total	**$ 93,500,000**	**$ 81,400,000**	**$ 62,800,000**	**$ 54,400,000**

Net Present Value (2017 to 2059)	**$ 81,400,000**	**$ 54,400,000**

Notes

(1) All costs in constant 2017 dollars.

(2) Collector Well, treatment building, and piping sized for 50 MLD with pumping and treatment equipment sized for 25 MLD. Upgrade to 50 MLD facility includes a 30% cost allowance for phasing requirements. Assume upgrade to 50 MLD completed in 2041.

(3) Collector Well operating costs based on running at 50% capacity 4 hours/day = 2.1 MLD. When upgraded to 50 MLD operating capacity = 4.2 MLD

Summary - Collector Well Option By: Urban Systems

One-Time and Ongoing Costs

Treatment	Capital Costs	Annual O&M Costs (25 MLD)	Annual O&M Costs (50 MLD)
UV, Fe/Mn Removal and Chloramination	$ 76,400,000	$ 330,000	$ 540,000
UV and Chloramination	$ 49,100,000	$ 276,000	$ 416,000

Net Present Value

Assumptions	
Discount Rate	1.4%
Time period	2017 to 2059

Costs (from 2020 to 2059)	**UV, Fe/Mn Removal and Chloramination**		**UV and Chloramination**	
	Total Costs (no discounting)	**Present Value**	**Total Costs (no discounting)**	**Present Value**
Capital Costs	$ 76,400,000	$ 69,100,000	$ 49,100,000	$ 44,500,000
O&M	$ 17,100,000	$ 12,300,000	$ 13,700,000	$ 9,900,000
Total	**$ 93,500,000**	**$ 81,400,000**	**$ 62,800,000**	**$ 54,400,000**

Net Present Value (2017 to 2059)	**$ 81,400,000**	**$ 54,400,000**

Notes

(1) All costs in constant 2017 dollars.

(2) Collector Well, treatment building, and piping sized for 50 MLD with pumping and treatment equipment sized for 25 MLD. Upgrade to 50 MLD facility includes a 30% cost allowance for phasing requirements. Assume upgrade to 50 MLD completed in 2041.

(3) Collector Well operating costs based on running at 50% capacity 4 hours/day = 2.1 MLD. When upgraded to 50 MLD operating capacity = 4.2 MLD

AMWSC - Water Supply Study - Life Cycle Cost Evaluation Prepared: 16-Aug-17

Collector Well with Iron/Manganese Treatment

Collector Well Operating Costs (25 MLD)

Item	Unit	Unit Cost	Amount	Cost
Power				
Low Lift Pumps (Through UV and Filters)	kWh	$ 0.10	80,000	$ 8,000
UV System	kWh	$ 0.10	20,000	$ 2,000
High Lift Pump Station	kWh	$ 0.10	740,000	$ 74,000
Process				
Chlorine (On-site Generation)	m^3	$ 0.004	760,000	$ 3,000
Ammonia (Chloramination)	m^3	$ 0.001	760,000	$ 1,000
Lab Supplies and Analysis	LS	$ 4,000	1	$ 4,000
Labour				
Operator Time	LS	$ 50,000	1	$ 50,000
Vehicle Allowance	LS	$ 10,000	1	$ 10,000
Equipment Repair/Replacement and Maintenance				
Maintenance and Repairs	LS	$ 135,000	1	$ 135,000
Subtotal				**$ 287,000**
Contingency (15%)				**$ 43,100**
Total				**$ 330,100**

Collector Well Operating Costs (50 MLD)

Item	Unit	Unit Cost	Amount	Cost
Power				
Low Lift Pumps (Through UV and Filters)	kWh	$ 0.10	160,000	$ 16,000
UV System	kWh	$ 0.10	40,000	$ 4,000
High Lift Pump Station	kWh	$ 0.10	1,480,000	$ 148,000
Process				
Chlorine (On-site Generation)	m^3	$ 0.004	1,520,000	$ 6,000
Ammonia (Chloramination)	m^3	$ 0.001	1,520,000	$ 1,000
Lab Supplies and Analysis	LS	$ 6,000	1	$ 6,000
Labour				
Operator Time	LS	$ 50,000	1	$ 50,000
Vehicle Allowance	LS	$ 10,000	1	$ 10,000
Equipment Repair/Replacement and Maintenance				
Maintenance and Repairs	LS	$ 225,000	1	$ 225,000
Subtotal				**$ 466,000**
Contingency (15%)				**$ 69,900**
Total				**$ 535,900**

Cost per additional m^3 of treated water	**$ 0.12**

Collector Well without Iron/Manganese Treatment

Collector Well Operating Costs (25 MLD)

Item	Unit	Unit Cost	Amount	Cost
Power				
Low Lift Pumps (Through UV)	kWh	$ 0.10	64,000	$ 6,000
UV System	kWh	$ 0.10	20,000	$ 2,000
High Lift Pump Station	kWh	$ 0.10	740,000	$ 74,000
Process				
Chlorine (On-site Generation)	m^3	$ 0.003	760,000	$ 3,000
Ammonia (Chloramination)	m^3	$ 0.001	760,000	$ 1,000
Lab Supplies and Analysis	LS	$ 4,000	1	$ 4,000
Labour				
Operator Time	LS	$ 50,000	1	$ 50,000
Vehicle Allowance	LS	$ 10,000	1	$ 10,000
Equipment Repair/Replacement and Maintenance				
Maintenance and Repairs	LS	$ 90,000	1	$ 90,000
Subtotal				**$ 240,000**
Contingency (15%)				**$ 36,000**
Total				**$ 276,000**

Collector Well Operating Costs (50 MLD)

Item	Unit	Unit Cost	Amount	Cost
Power				
Low Lift Pumps (Through UV)	kWh	$ 0.10	128,000	$ 13,000
UV System	kWh	$ 0.10	40,000	$ 4,000
High Lift Pump Station	kWh	$ 0.10	1,480,000	$ 148,000
Process				
Chlorine (On-site Generation)	m^3	$ 0.003	1,520,000	$ 5,000
Ammonia (Chloramination)	m^3	$ 0.001	1,520,000	$ 1,000
Lab Supplies and Analysis	LS	$ 6,000	1	$ 6,000
Labour				
Operator Time	LS	$ 50,000	1	$ 50,000
Vehicle Allowance	LS	$ 10,000	1	$ 10,000
Equipment Repair/Replacement and Maintenance				
Maintenance and Repairs	LS	$ 125,000	1	$ 125,000
Subtotal				**$ 362,000**
Contingency (15%)				**$ 54,300**
Total				**$ 416,300**

Cost per additional m^3 of treated water	**$ 0.12**

2.0% Inflation
3.4% Interest Rate
1.4% Discount Rate - Note real discount rate is defined as (1 + interest rate) / (1 + inflation rate) - 1

Collector Well with Iron/Manganese Treatment: Lifecycle Costs

Year	Year	Annual Cost (2017 $)	Annual Cost (Future $)	Present Cost (2017 $)
0	2017	$0	$0	$0
1	2018	$0	$0	$0
2	2019	$0	$0	$0
3	2020	$330,100	$350,305	$316,615
4	2021	$330,100	$357,311	$312,244
5	2022	$330,100	$364,457	$307,933
6	2023	$330,100	$371,746	$303,681
7	2024	$330,100	$379,181	$299,488
8	2025	$330,100	$386,765	$295,353
9	2026	$330,100	$394,500	$291,275
10	2027	$330,100	$402,390	$287,254
11	2028	$330,100	$410,438	$283,288
12	2029	$330,100	$418,647	$279,377
13	2030	$330,100	$427,020	$275,519
14	2031	$330,100	$435,560	$271,715
15	2032	$330,100	$444,271	$267,964
16	2033	$330,100	$453,157	$264,264
17	2034	$330,100	$462,220	$260,616
18	2035	$330,100	$471,464	$257,017
19	2036	$330,100	$480,893	$253,469
20	2037	$330,100	$490,511	$249,969
21	2038	$330,100	$500,321	$246,518
22	2039	$330,100	$510,328	$243,114
23	2040	$330,100	$520,534	$239,758
24	2041	$535,900	$861,962	$383,860
25	2042	$535,900	$879,201	$378,560
26	2043	$535,900	$896,785	$373,333
27	2044	$535,900	$914,720	$368,179
28	2045	$535,900	$933,015	$363,096
29	2046	$535,900	$951,675	$358,082
30	2047	$535,900	$970,709	$353,139
31	2048	$535,900	$990,123	$348,263
32	2049	$535,900	$1,009,925	$343,454
33	2050	$535,900	$1,030,124	$338,713
34	2051	$535,900	$1,050,726	$334,036
35	2052	$535,900	$1,071,741	$329,424
36	2053	$535,900	$1,093,176	$324,876
37	2054	$535,900	$1,115,039	$320,390
38	2055	$535,900	$1,137,340	$315,967
39	2056	$535,900	$1,160,087	$311,604
40	2057	$535,900	$1,183,288	$307,302
41	2058	$535,900	$1,206,954	$303,059
42	2059	$535,900	$1,231,093	$298,875
Total Project NPV (rounded)				**$12,260,644**

$12,260,644.35

Collector Well with Iron/Manganese Treatment: Lifecycle Costs

Year	Year	Annual Cost (2017 $)	Annual Cost (Future $)	Present Cost (2017 $)
0	2017	$0	$0	$0
1	2018	$0	$0	$0
2	2019	$0	$0	$0
3	2020	$276,000	$292,893	$264,725
4	2021	$276,000	$298,751	$261,070
5	2022	$276,000	$304,726	$257,466
6	2023	$276,000	$310,821	$253,911
7	2024	$276,000	$317,037	$250,405
8	2025	$276,000	$323,378	$246,948
9	2026	$276,000	$329,846	$243,538
10	2027	$276,000	$336,442	$240,176
11	2028	$276,000	$343,171	$236,860
12	2029	$276,000	$350,035	$233,590
13	2030	$276,000	$357,035	$230,365
14	2031	$276,000	$364,176	$227,184
15	2032	$276,000	$371,460	$224,047
16	2033	$276,000	$378,889	$220,954
17	2034	$276,000	$386,467	$217,903
18	2035	$276,000	$394,196	$214,895
19	2036	$276,000	$402,080	$211,928
20	2037	$276,000	$410,121	$209,002
21	2038	$276,000	$418,324	$206,116
22	2039	$276,000	$426,690	$203,270
23	2040	$276,000	$435,224	$200,464
24	2041	$416,300	$669,592	$298,192
25	2042	$416,300	$682,984	$294,075
26	2043	$416,300	$696,644	$290,014
27	2044	$416,300	$710,577	$286,010
28	2045	$416,300	$724,788	$282,061
29	2046	$416,300	$739,284	$278,167
30	2047	$416,300	$754,070	$274,326
31	2048	$416,300	$769,151	$270,539
32	2049	$416,300	$784,534	$266,804
33	2050	$416,300	$800,225	$263,120
34	2051	$416,300	$816,229	$259,487
35	2052	$416,300	$832,554	$255,905
36	2053	$416,300	$849,205	$252,371
37	2054	$416,300	$866,189	$248,887
38	2055	$416,300	$883,513	$245,451
39	2056	$416,300	$901,183	$242,062
40	2057	$416,300	$919,207	$238,720
41	2058	$416,300	$937,591	$235,424
42	2059	$416,300	$956,343	$232,173
Total Project NPV (rounded)				**$9,868,605**

$9,868,604.67

NPV based on 3.5% combined interest/inflation discount rate.

Assume average power cost of $0.10 per kWh
Assume an operating head low lift pump head of 25 m including lift from collector wet well, UV as well as iron and manganese filters. Assume head of 20 m without iron and manganese filters.
Water treatment plant running at 50% capacity for four hours per day. Average 2.1 MLD per day flow for 25 MLD facility. Average 4.1 MLD per day flow at 50 MLD facility.
High lift pump station operating at flow of WTP and TDH of 250 m.
Chlorine dose of 2.5 mg/L assumed for iron/manganese filtration and chloramination. Chlorine dose of 2.0 mg/L assumed for just chloramination (without iron and manganese filtration). Chlorine cost based on on-site generation costs provided by manufacturer.
Ammonia dose of 0.66 mg/L assumed for chloramination. 2.0 mg/L monochloramine concentration. Ammonia costs based on AMWSC budget numbers.
Lab supplies and analysis cost based on percentage of AMWSC operations budget proportional to WTP flows.
Operator time based on AMWSC operations budgets for similar water treatment system with allowance for HLPS operation time.
Maintenance and repair cost estimated at 2% of process mechanical equipment per year with 10% allowance for admin.
Assume residuals treatment costs are minimal due to low operating rates.
Treatment cost per cubic meter of water is in addition to total annual costs for flows exceeding annual allowance of 760-1,520 ML

AMWSC - Water Supply Study - Life Cycle Cost Evaluation Prepared: 03-Jan-18

25 MLD Collector Well <u>with</u> Iron/Manganese Treatment

Item	Description	Unit	Amount	Cost/Unit	Total
1.0 Collector Well - 25 MLD Capacity for Pumping and Treatment					
1.1	Collector Well (50 MLD)	LS	1	$ 4,300,000	$ 4,300,000
1.2	Low Lift Pump Station (Through UV and Fe/Mn Filters)	LS	1	$ 1,000,000	$ 1,000,000
1.3	Water Treatment Plant (UV, Cl2, Fe/Mn Treatment and Chloramination)	LS	1	$ 14,400,000	$ 14,400,000
1.4	High Lift Pump Station	LS	1	$ 3,700,000	$ 3,700,000
1.5	3 Phase Power Extension	LS	1	$ 480,000	$ 480,000
1.6	Watermain (4.2 km of 900 mm diameter)	LS	1	$ 3,780,000	$ 3,780,000
1.7	Tie-in (High pressure hot tap)	LS	1	$ 150,000	$ 150,000
Subtotal					**$ 27,810,000**
General Requirements (Bonding, Mobilization/Demobilization, etc.) - 10%					**$ 2,800,000**
Contractor Profit/Overhead - 10%					**$ 2,800,000**
Construction Contingency - 35%					**$ 11,700,000**
Total Direct Costs					**$ 45,110,000**
Engineering - 15%					**$ 6,800,000**
Administration - 10%					**$ 4,500,000**
EA and Mitigation - Allowance					**$ 1,000,000**
Interim Financing - 4%					**$ 1,800,000**
TOTAL					**$ 59,210,000**

50 MLD Collector Well <u>with</u> Iron/Manganese Treatment

Item	Description	Unit	Amount	Cost/Unit	Total
1.0 Collector Well - 25 MLD Capacity for Pumping and Treatment					
1.1	Collector Well (50 MLD)	LS	1	$ 4,300,000	$ 4,300,000
1.2	Low Lift Pump Station (Through UV and Fe/Mn Filters)	LS	1	$ 1,300,000	$ 1,300,000
1.3	Water Treatment Plant (UV, Cl2, Fe/Mn Treatment and Chloramination)	LS	1	$ 18,600,000	$ 18,600,000
1.4	High Lift Pump Station	LS	1	$ 5,600,000	$ 5,600,000
1.5	3 Phase Power Extension	LS	1	$ 480,000	$ 480,000
1.6	Watermain (4.2 km of 900 mm diameter)	LS	1	$ 3,780,000	$ 3,780,000
1.7	Tie-in (High pressure hot tap)	LS	1	$ 150,000	$ 150,000
Subtotal					**$ 34,210,000**
General Requirements (Bonding, Mobilization/Demobilization, etc.) - 10%					**$ 3,400,000**
Contractor Profit/Overhead - 10%					**$ 3,400,000**
Construction Contingency - 35%					**$ 14,400,000**
Total Direct Costs					**$ 55,410,000**
Engineering - 15%					**$ 8,300,000**
Administration - 10%					**$ 5,500,000**
EA and Mitigation - Allowance					**$ 1,000,000**
Interim Financing - 4%					**$ 2,200,000**
TOTAL					**$ 72,410,000**

25 MLD Collector Well <u>without</u> Iron/Manganese Treatment

Item	Description	Unit	Amount	Cost/Unit	Total
1.0 Collector Well - 25 MLD Capacity for Pumping and Treatment (No Fe/Mn Treatment)					
1.1	Collector Well (50 MLD)	LS	1	$ 4,300,000	$ 4,300,000
1.2	Low Lift Pump Station (Through UV)	LS	1	$ 1,000,000	$ 1,000,000
1.3	Water Treatment Plant (UV, Cl2 and Chloramination)	LS	1	$ 4,300,000	$ 4,300,000
1.4	High Lift Pump Station	LS	1	$ 3,700,000	$ 3,700,000
1.5	3 Phase Power Extension	LS	1	$ 480,000	$ 480,000
1.6	Watermain (4.2 km of 900 mm diameter)	LS	1	$ 3,780,000	$ 3,780,000
1.7	Tie-in (High pressure hot tap)	LS	1	$ 150,000	$ 150,000
Subtotal					**$ 17,710,000**
General Requirements (Bonding, Mobilization/Demobilization, etc.) - 10%					**$ 1,800,000**
Contractor Profit/Overhead - 10%					**$ 1,800,000**
Construction Contingency - 35%					**$ 7,500,000**
Total Direct Costs					**$ 28,810,000**
Engineering - 15%					**$ 4,300,000**
Administration - 10%					**$ 2,900,000**
EA and Mitigation - Allowance					**$ 1,000,000**
Interim Financing - 4%					**$ 1,153,000**
TOTAL					**$ 38,163,000**

50 MLD Collector Well <u>without</u> Iron/Manganese Treatment

Item	Description	Unit	Amount	Cost/Unit	Total
1.0 Collector Well - No Iron and Manganese Treatment					
1.1	Collector Well (50 MLD)	LS	1	$ 4,300,000	$ 4,300,000
1.2	Low Lift Pump Station	LS	1	$ 1,300,000	$ 1,300,000
1.3	Water Treatment Plant (UV, Cl2 and Chloramination)	LS	1	$ 6,200,000	$ 6,200,000
1.4	High Lift Pump Station	LS	1	$ 5,600,000	$ 5,600,000
1.5	3 Phase Power Extension	LS	1	$ 480,000	$ 480,000
1.6	Watermain (4.2 km of 900 mm diameter)	LS	1	$ 3,780,000	$ 3,780,000
1.7	Tie-in (High pressure hot tap)	LS	1	$ 150,000	$ 150,000
Subtotal					**$ 21,810,000**
General Requirements (Bonding, Mobilization/Demobilization, etc.) - 10%					**$ 2,200,000**
Contractor Profit/Overhead - 10%					**$ 2,200,000**
Construction Contingency - 35%					**$ 9,200,000**
Total Direct Costs					**$ 35,410,000**
Engineering - 15%					**$ 5,300,000**
Administration - 10%					**$ 3,500,000**
EA and Mitigation - Allowance					**$ 1,000,000**
Interim Financing - 4%					**$ 1,400,000**
TOTAL					**$ 46,610,000**

2.0% Inflation
3.4% Interest Rate
1.40% Discount Rate - Note real discount rate is defined as (1 + interest rate) / (1 + inflation rate) - 1

Collector Well <u>with</u> Iron/Manganese Treatment: Lifecycle Costs

Year	Year	Annual Cost (2017 $)	Annual Cost (Future $)	Present Cost (2017 $)
0	2017	$0	$0	$0
1	2018	$500,000	$510,000	$493,097
2	2019	$0	$0	$0
3	2020	$58,710,000	$62,303,522	$56,311,645
4	2021	$0	$0	$0
5	2022	$0	$0	$0
6	2023	$0	$0	$0
7	2024	$0	$0	$0
8	2025	$0	$0	$0
9	2026	$0	$0	$0
10	2027	$0	$0	$0
11	2028	$0	$0	$0
12	2029	$0	$0	$0
13	2030	$0	$0	$0
14	2031	$0	$0	$0
15	2032	$0	$0	$0
16	2033	$0	$0	$0
17	2034	$0	$0	$0
18	2035	$0	$0	$0
19	2036	$0	$0	$0
20	2037	$0	$0	$0
21	2038	$0	$0	$0
22	2039	$0	$0	$0
23	2040	$0	$0	$0
24	2041	$17,160,000	$27,600,783	$12,291,542
25	2042	$0	$0	$0
26	2043	$0	$0	$0
27	2044	$0	$0	$0
28	2045	$0	$0	$0
29	2046	$0	$0	$0
30	2047	$0	$0	$0
31	2048	$0	$0	$0
32	2049	$0	$0	$0
33	2050	$0	$0	$0
34	2051	$0	$0	$0
35	2052	$0	$0	$0
36	2053	$0	$0	$0
37	2054	$0	$0	$0
38	2055	$0	$0	$0
39	2056	$0	$0	$0
40	2057	$0	$0	$0
41	2058	$0	$0	$0
42	2059	$0	$0	$0
	Total Project NPV (rounded)			**$69,096,284**

$69,096,284

Collector Well <u>without</u> Iron/Manganese Treatment: Lifecycle Costs

Year	Year	Annual Cost (2017 $)	Annual Cost (Future $)	Present Cost (2017 $)
0	2017	$0	$0	$0
1	2018	$500,000	$510,000	$493,097
2	2019	$0	$0	$0
3	2020	$37,663,000	$39,968,277	$36,124,434
4	2021	$0	$0	$0
5	2022	$0	$0	$0
6	2023	$0	$0	$0
7	2024	$0	$0	$0
8	2025	$0	$0	$0
9	2026	$0	$0	$0
10	2027	$0	$0	$0
11	2028	$0	$0	$0
12	2029	$0	$0	$0
13	2030	$0	$0	$0
14	2031	$0	$0	$0
15	2032	$0	$0	$0
16	2033	$0	$0	$0
17	2034	$0	$0	$0
18	2035	$0	$0	$0
19	2036	$0	$0	$0
20	2037	$0	$0	$0
21	2038	$0	$0	$0
22	2039	$0	$0	$0
23	2040	$0	$0	$0
24	2041	$10,981,100	$17,662,410	$7,865,656
25	2042	$0	$0	$0
26	2043	$0	$0	$0
27	2044	$0	$0	$0
28	2045	$0	$0	$0
29	2046	$0	$0	$0
30	2047	$0	$0	$0
31	2048	$0	$0	$0
32	2049	$0	$0	$0
33	2050	$0	$0	$0
34	2051	$0	$0	$0
35	2052	$0	$0	$0
36	2053	$0	$0	$0
37	2054	$0	$0	$0
38	2055	$0	$0	$0
39	2056	$0	$0	$0
40	2057	$0	$0	$0
41	2058	$0	$0	$0
42	2059	$0	$0	$0
	Total Project NPV (rounded)			**$44,483,186**

$44,483,186

Costs are in 2017 Canadian dollars and allowances have not been included for future fluctuations in Canadian Dollar exchange rates.

Collector well, buildings, wet wells and tie-in piping sized for 50 MLD
Treatment equipment and pumps sized for 25 MLD
Collector well costs provided by Piteau.
Treatment process assumes low lift, UV, chlorination, iron/manganese filtration, primary disinfection clearwell and chloramination (in HLPS). Second table labelled no Fe/Mn treatmetn does not include iron/manganese treatment equipment or required building space.
Low Lift Pump Station and Treatment Costs based on 2005 estimate for MacArthur Island Collector Well Project scaled to 2017. Approximately 200 HP station at 25 MLD capacity.
2005 Water and Wastewater Asset Cost Study by Ontario Ministry of Public Infrastructure Renewal used for UV and Chloramination costs
ENR construction cost index used to scale construction costs (3.3% per year on average)
Six tenths rule used for scaling treatment equipment costs.
20% addition to facility costs assumed for site work
20% addition to facility costs assumed for SCADA and standby power.
High lift pump station assumes ANSI Class 300# flanges required. Maximum pump size of 500 HP for low voltage. Assume in-building hydropneumatic tank required for surge protection. HGL based on modelling information provided by Geoadvice. Approximately 1,000 HP at 25 MLD flow.
Watermain sized for 1-1.5 m/s at 50 MLD
Assume STD weight FBE coated steel for HLPS watermain tie-in.
Tie-in costs based on similar, high pressure hot tap in Kamloops area.
Assumes no land acquisition costs.
Allow for 30% additional phasing costs when upgrading from 25 to 50 MLD facility.
Assumes treated backwash water would be returned to the collector well.

Summary - Vertical Wells with Collector Well Option By: Urban Systems

One-Time and Ongoing Costs

Collector Well Treatment	Capital Costs	Annual O&M Costs (Vertical Wells)	Annual O&M Costs (Collector Well)
UV, Fe/Mn Removal and Chloramination	$ 72,200,000	$ 444,000	$ 330,000
UV and Chloramination	$ 61,000,000	$ 444,000	$ 276,000

Net Present Value

Assumptions	
Discount Rate	1.4%
Time period	2017 to 2059

Costs (from 2020 to 2059)	UV, Fe/Mn Removal and Chloramination		UV and Chloramination	
	Total Costs (no discounting)	Present Value	Total Costs (no discounting)	Present Value
Capital Costs	$ 72,200,000	$ 57,300,000	$ 61,000,000	$ 49,300,000
O&M	$ 24,000,000	$ 17,100,000	$ 23,000,000	$ 16,500,000
Total	**$ 96,200,000**	**$ 74,400,000**	**$ 84,000,000**	**$ 65,800,000**

Net Present Value (2017 to 2059)	**$ 74,400,000**		**$ 65,800,000**

Notes

(1) All costs in constant 2017 dollars.

(2) Groundwater Well operating costs based on running at 50% capacity 4 hours/day = 2.1 MLD. Collector Well operating costs based on running at 50% capacity 4 hours/day = 2.1 MLD.

(3) Capital costs include: 35% contingency, 15% engineering, 10% administration and 4% interim financing.

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4 x Vertical Wells

Vertical Wells Operating Costs (25 MLD)

Item	Unit	Unit Cost	Amount	Cost
Power				
Well Pumps	kWh	$ 0.10	300,000	$ 30,000
Booster Station (emergency only)	kWh	$ 0.10	80,000	$ 8,000
Process				
Chlorine (On-site Generation)	m^3	$ 0.003	760,000	$ 3,000
Ammonia (Chloramination)	m^3	$ 0.001	760,000	$ 1,000
Lab Supplies and Analysis	LS	$ 4,000	1	$ 4,000
Labour				
Operator Time	LS	$ 10,000	1	$ 10,000
Vehicle Allowance	LS	$ 10,000	1	$ 10,000
Equipment Repair/Replacement and Maintenance				
Maintenance and Repairs	LS	$ 70,000	1	$ 70,000
Environmental Monitoring				
Environmental Monitoring/Permits	LS	$ 250,000	1	$ 250,000
Subtotal				**$ 386,000**
Contingency (15%)				**$ 57,900**
Total				**$ 443,900**

Cost per additional m^3 of treated water	**$ 0.04**
Cost per additional m^3 of treated water Boosted to Mission	**$ 0.10**

Collector Well with Iron/Manganese Treatment

Collector Well Operating Costs (25 MLD)

Item	Unit	Unit Cost	Amount	Cost
Power				
Low Lift Pumps (Through UV and Filters)	kWh	$ 0.10	80,000	$ 8,000
UV System	kWh	$ 0.10	20,000	$ 2,000
High Lift Pump Station	kWh	$ 0.10	740,000	$ 74,000
Process				
Chlorine (On-site Generation)	m^3	$ 0.004	760,000	$ 3,000
Ammonia (Chloramination)	m^3	$ 0.001	760,000	$ 1,000
Lab Supplies and Analysis	LS	$ 4,000	1	$ 4,000
Labour				
Operator Time	LS	$ 50,000	1	$ 50,000
Vehicle Allowance	LS	$ 10,000	1	$ 10,000
Equipment Repair/Replacement and Maintenance				
Maintenance and Repairs	LS	$ 135,000	1	$ 135,000
Subtotal				**$ 287,000**
Contingency (15%)				**$ 43,100**
Total				**$ 330,100**

Cost per additional m^3 of treated water	**$ 0.121**

Collector Well without Iron/Manganese Treatment

Collector Well Operating Costs (25 MLD)

Item	Unit	Unit Cost	Amount	Cost
Power				
Low Lift Pumps (Through UV)	kWh	$ 0.10	64,000	$ 6,000
UV System	kWh	$ 0.10	20,000	$ 2,000
High Lift Pump Station	kWh	$ 0.10	740,000	$ 74,000
Process				
Chlorine (On-site Generation)	m^3	$ 0.003	760,000	$ 3,000
Ammonia (Chloramination)	m^3	$ 0.001	760,000	$ 1,000
Lab Supplies and Analysis	LS	$ 4,000	1	$ 4,000
Labour				
Operator Time	LS	$ 50,000	1	$ 50,000
Vehicle Allowance	LS	$ 10,000	1	$ 10,000
Equipment Repair/Replacement and Maintenance				
Maintenance and Repairs	LS	$ 90,000	1	$ 90,000
Subtotal				**$ 240,000**
Contingency (15%)				**$ 36,000**
Total				**$ 276,000**

Cost per additional m^3 of treated water	**$ 0.118**

2.0% Inflation
3.4% Interest Rate
1.4% Discount Rate - Note real discount rate is defined as (1 + interest rate) / (1 + inflation rate) - 1

Vertical Wells and Collector Well, with Iron/Manganese Treatment): Lifecycle Costs

Year	Year	Annual Cost (Future $)	Annual Cost (Future $)	Present Cost (2017 $)
0	2017	$0	$0	$0
1	2018	$0	$0	$0
2	2019	$0	$0	$0
3	2020	$443,900	$471,070	$425,766
4	2021	$443,900	$480,492	$419,888
5	2022	$443,900	$490,101	$414,091
6	2023	$443,900	$499,903	$408,373
7	2024	$443,900	$509,902	$402,735
8	2025	$443,900	$520,100	$397,175
9	2026	$443,900	$530,502	$391,691
10	2027	$443,900	$541,112	$386,283
11	2028	$443,900	$551,934	$380,950
12	2029	$443,900	$562,973	$375,690
13	2030	$443,900	$574,232	$370,503
14	2031	$443,900	$585,717	$365,388
15	2032	$443,900	$597,431	$360,343
16	2033	$443,900	$609,380	$355,368
17	2034	$443,900	$621,567	$350,461
18	2035	$443,900	$633,999	$345,622
19	2036	$443,900	$646,678	$340,851
20	2037	$443,900	$659,612	$336,145
21	2038	$443,900	$672,804	$331,503
22	2039	$443,900	$686,260	$326,927
23	2040	$443,900	$699,986	$322,413
24	2041	$774,000	$1,244,930	$554,409
25	2042	$774,000	$1,269,829	$546,754
26	2043	$774,000	$1,295,226	$539,205
27	2044	$774,000	$1,321,130	$531,761
28	2045	$774,000	$1,347,553	$524,419
29	2046	$774,000	$1,374,504	$517,178
30	2047	$774,000	$1,401,994	$510,038
31	2048	$774,000	$1,430,034	$502,996
32	2049	$774,000	$1,458,634	$496,051
33	2050	$774,000	$1,487,807	$489,202
34	2051	$774,000	$1,517,563	$482,448
35	2052	$774,000	$1,547,915	$475,787
36	2053	$774,000	$1,578,873	$469,218
37	2054	$774,000	$1,610,450	$462,740
38	2055	$774,000	$1,642,659	$456,351
39	2056	$774,000	$1,675,512	$450,050
40	2057	$774,000	$1,709,023	$443,836
41	2058	$774,000	$1,743,203	$437,708
42	2059	$774,000	$1,778,067	$431,665
	Total Project NPV (rounded)			**$17,129,979**

$17,129,979

Vertical Wells and Collector Well, without Iron/Manganese Treatment): Lifecycle Costs

Year	Year	Annual Cost (Future $)	Annual Cost (Future $)	Present Cost (2017 $)
0	2017	$0	$0	$0
1	2018	$0	$0	$0
2	2019	$0	$0	$0
3	2020	$443,900	$471,070	$425,766
4	2021	$443,900	$480,492	$419,888
5	2022	$443,900	$490,101	$414,091
6	2023	$443,900	$499,903	$408,373
7	2024	$443,900	$509,902	$402,735
8	2025	$443,900	$520,100	$397,175
9	2026	$443,900	$530,502	$391,691
10	2027	$443,900	$541,112	$386,283
11	2028	$443,900	$551,934	$380,950
12	2029	$443,900	$562,973	$375,690
13	2030	$443,900	$574,232	$370,503
14	2031	$443,900	$585,717	$365,388
15	2032	$443,900	$597,431	$360,343
16	2033	$443,900	$609,380	$355,368
17	2034	$443,900	$621,567	$350,461
18	2035	$443,900	$633,999	$345,622
19	2036	$443,900	$646,678	$340,851
20	2037	$443,900	$659,612	$336,145
21	2038	$443,900	$672,804	$331,503
22	2039	$443,900	$686,260	$326,927
23	2040	$443,900	$699,986	$322,413
24	2041	$719,900	$1,157,914	$515,657
25	2042	$719,900	$1,181,072	$508,538
26	2043	$719,900	$1,204,694	$501,517
27	2044	$719,900	$1,228,788	$494,592
28	2045	$719,900	$1,253,363	$487,764
29	2046	$719,900	$1,278,431	$481,029
30	2047	$719,900	$1,303,999	$474,388
31	2048	$719,900	$1,330,079	$467,838
32	2049	$719,900	$1,356,681	$461,379
33	2050	$719,900	$1,383,814	$455,009
34	2051	$719,900	$1,411,491	$448,726
35	2052	$719,900	$1,439,720	$442,531
36	2053	$719,900	$1,468,515	$436,421
37	2054	$719,900	$1,497,885	$430,396
38	2055	$719,900	$1,527,843	$424,453
39	2056	$719,900	$1,558,400	$418,593
40	2057	$719,900	$1,589,568	$412,814
41	2058	$719,900	$1,621,359	$407,114
42	2059	$719,900	$1,653,786	$401,493
	Total Project NPV (rounded)			**$16,478,416**

$16,478,416

Assume average power cost of $0.10 per kWh.
Assume wells pumping directly into distribution system in vicinity of Bevan Wells with minimal transmission losses to reservoir.
Operate each well at 50% flow capacity for 4 hours each day.
Booster station would only be utilized to supply water from Maclure to Mission during emergencies. Would run 4 hours per week to confirm operation.
Chlorine dose of 2.0 mg/L assumed for chloramination. Chlorine cost based on on-site generation costs provided by manufacturer.
Ammonia dose of 0.66 mg/L assumed for chloramination. 2.0 mg/L monochloramine concentration. Ammonia costs based on AMWSC budget numbers.
Lab supplies and analysis cost based on percentage of AMWSC operations budget proportional to WTP flows.
Operator time based on AMWSC operations budgets for Bevan Wells with allowance for booster station inspections.
Maintenance and repair cost estimated at 2% of process mechanical equipment per year with 10% allowance for admin.
Cost per additional cubic meter of water booster to mission includes well and booster station costs.
Environmental monitoring costs based on current estimates for Bevan Wells.
Assume an operating head low lift pump head of 25 m including lift from collector wet well, UV as well as iron and manganese filters. Assume head of 20 m without iron and manganese filters.
Water treatment plant running at 50% capacity for four hours per day. Average 2.1 MLD per day flow for 25 MLD facility.
High lift pump station operating at flow of WTP and TDH of 250 m.
Chlorine dose of 2.5 mg/L assumed for iron/manganese filtration and chloramination. Chlorine dose of 2.0 mg/L assumed for just chloramination (without iron and manganese filtration). Chlorine cost based on on-site generation costs provided by manufacturer.
Operator time based on AMWSC operations budgets for similar water treatment system with allowance for HLPS operation time.
Lab supplies and analysis cost based on percentage of AMWSC operations budget proportional to WTP flows.
Assume residuals treatment costs are minimal due to low operating rates.
Treatment cost per cubic meter of water is in addition to total annual costs for flows exceeding annual allowance of 760-1,520 ML

AMWSC - Water Supply Study - Life Cycle Cost Evaluation Prepared: 16-Aug-17

25 MLD Vertical Wells

Item	Description	Unit	Amount	Cost/Unit	Total
1.0 Vertical Groundwater Wells (x4)					
1.1	Groundwater Wells (4 x 6.25 MLD)	LS	1	$ 500,000	$ 500,000
1.2	Well Building and Pumps	LS	1	$ 2,200,000	$ 2,200,000
1.3	Chloramination	LS	1	$ 2,300,000	$ 2,300,000
1.4	Watermain and Tie-in (2000 m of 500 mm diameter)	LS	1	$ 2,000,000	$ 2,000,000
1.5	HLPS, Watermain and Tie-in (Maclure-Norrish)	LS	1	$ 2,400,000	$ 2,400,000
Subtotal					**$ 9,400,000**
General Requirements (Bonding, Mobilization/Demobilization, etc.) - 10%					**$ 940,000**
Contractor Profit/Overhead - 10%					**$ 940,000**
Construction Contingency - 35%					**$ 3,900,000**
Total Direct Costs					**$ 15,180,000**
Engineering - 15%					**$ 2,300,000**
Administration - 10%					**$ 1,500,000**
EA and Mitigation					**$ 3,200,000**
Interim Financing - 4%					**$ 610,000**
TOTAL					**$ 22,790,000**

25 MLD Collector Well <u>with</u> Iron/Manganese Treatment

Item	Description	Unit	Amount	Cost/Unit	Total
1.0 Collector Well - 25 MLD Capacity					
1.1	Collector Well (25 MLD)	LS	1	$ 3,300,000	$ 3,300,000
1.2	Low Lift Pump Station (Through UV and Fe/Mn Filters)	LS	1	$ 1,000,000	$ 1,000,000
1.3	Water Treatment Plant (UV, Cl2, Fe/Mn Treatment and Chloramination)	LS	1	$ 10,800,000	$ 10,800,000
1.4	High Lift Pump Station	LS	1	$ 3,700,000	$ 3,700,000
1.5	3 Phase Power Extension	LS	1	$ 480,000	$ 480,000
1.6	Watermain (4.2 km of 900 mm diameter)	LS	1	$ 3,780,000	$ 3,780,000
1.7	Tie-in (High pressure hot tap)	LS	1	$ 150,000	$ 150,000
Subtotal					**$ 23,210,000**
General Requirements (Bonding, Mobilization/Demobilization, etc.) - 10%					**$ 2,300,000**
Contractor Profit/Overhead - 10%					**$ 2,300,000**
Construction Contingency - 35%					**$ 9,700,000**
Total Direct Costs					**$ 37,510,000**
Engineering - 15%					**$ 5,600,000**
Administration - 10%					**$ 3,800,000**
EA and Mitigation - Allowance					**$ 1,000,000**
Interim Financing - 4%					**$ 1,500,000**
TOTAL					**$ 49,410,000**

25 MLD Collector Well <u>without</u> Iron/Manganese Treatment

Item	Description	Unit	Amount	Cost/Unit	Total
1.0 Collector Well - 25 MLD Capacity (No Fe/Mn Treatment)					
1.1	Collector Well (50 MLD)	LS	1	$ 4,300,000	$ 4,300,000
1.2	Low Lift Pump Station (Through UV)	LS	1	$ 1,000,000	$ 1,000,000
1.3	Water Treatment Plant (UV, Cl2 and Chloramination)	LS	1	$ 4,300,000	$ 4,300,000
1.4	High Lift Pump Station	LS	1	$ 3,700,000	$ 3,700,000
1.5	3 Phase Power Extension	LS	1	$ 480,000	$ 480,000
1.6	Watermain (4.2 km of 900 mm diameter)	LS	1	$ 3,780,000	$ 3,780,000
1.7	Tie-in (High pressure hot tap)	LS	1	$ 150,000	$ 150,000
Subtotal					**$ 17,710,000**
General Requirements (Bonding, Mobilization/Demobilization, etc.) - 10%					**$ 1,800,000**
Contractor Profit/Overhead - 10%					**$ 1,800,000**
Construction Contingency - 35%					**$ 7,500,000**
Total Direct Costs					**$ 28,810,000**
Engineering - 15%					**$ 4,300,000**
Administration - 10%					**$ 2,900,000**
EA and Mitigation - Allowance					**$ 1,000,000**
Interim Financing - 4%					**$ 1,200,000**
TOTAL					**$ 38,210,000**

2.0% Inflation
3.4% Interest Rate
1.4% Discount Rate - Note real discount rate is defined as (1 + interest rate) / (1 + inflation rate) - 1

Collector Well <u>with</u> Iron/Manganese Treatment: Lifecycle Costs

Year	Year	Annual Cost (Future $)	Annual Cost (Future $)	Present Cost (2017 $)
0	2017	$0	$0	$0
1	2018	$600,000	$612,000	$591,716
2	2019	$1,100,000	$1,144,440	$1,069,835
3	2020	$21,090,000	$22,380,877	$20,228,455
4	2021	$0	$0	$0
5	2022	$0	$0	$0
6	2023	$0	$0	$0
7	2024	$0	$0	$0
8	2025	$0	$0	$0
9	2026	$0	$0	$0
10	2027	$0	$0	$0
11	2028	$0	$0	$0
12	2029	$0	$0	$0
13	2030	$0	$0	$0
14	2031	$0	$0	$0
15	2032	$0	$0	$0
16	2033	$0	$0	$0
17	2034	$0	$0	$0
18	2035	$0	$0	$0
19	2036	$0	$0	$0
20	2037	$0	$0	$0
21	2038	$0	$0	$0
22	2039	$355,000	$548,823	$261,453
23	2040	$0	$0	$0
24	2041	$49,055,000	$78,901,889	$35,137,621
25	2042	$0	$0	$0
26	2043	$0	$0	$0
27	2044	$0	$0	$0
28	2045	$0	$0	$0
29	2046	$0	$0	$0
30	2047	$0	$0	$0
31	2048	$0	$0	$0
32	2049	$0	$0	$0
33	2050	$0	$0	$0
34	2051	$0	$0	$0
35	2052	$0	$0	$0
36	2053	$0	$0	$0
37	2054	$0	$0	$0
38	2055	$0	$0	$0
39	2056	$0	$0	$0
40	2057	$0	$0	$0
41	2058	$0	$0	$0
42	2059	$0	$0	$0
Total Project NPV (rounded)				**$57,289,080**

$57,289,080

Collector Well <u>without</u> Iron/Manganese Treatment: Lifecycle Costs

Year	Year	Annual Cost (Future $)	Annual Cost (Future $)	Present Cost (2017 $)
0	2017	$0	$0	$0
1	2018	$600,000	$612,000	$591,716
2	2019	$1,100,000	$1,144,440	$1,069,835
3	2020	$21,090,000	$22,380,877	$20,228,455
4	2021	$0	$0	$0
5	2022	$0	$0	$0
6	2023	$0	$0	$0
7	2024	$0	$0	$0
8	2025	$0	$0	$0
9	2026	$0	$0	$0
10	2027	$0	$0	$0
11	2028	$0	$0	$0
12	2029	$0	$0	$0
13	2030	$0	$0	$0
14	2031	$0	$0	$0
15	2032	$0	$0	$0
16	2033	$0	$0	$0
17	2034	$0	$0	$0
18	2035	$0	$0	$0
19	2036	$0	$0	$0
20	2037	$0	$0	$0
21	2038	$0	$0	$0
22	2039	$355,000	$548,823	$261,453
23	2040	$0	$0	$0
24	2041	$37,855,000	$60,887,392	$27,115,170
25	2042	$0	$0	$0
26	2043	$0	$0	$0
27	2044	$0	$0	$0
28	2045	$0	$0	$0
29	2046	$0	$0	$0
30	2047	$0	$0	$0
31	2048	$0	$0	$0
32	2049	$0	$0	$0
33	2050	$0	$0	$0
34	2051	$0	$0	$0
35	2052	$0	$0	$0
36	2053	$0	$0	$0
37	2054	$0	$0	$0
38	2055	$0	$0	$0
39	2056	$0	$0	$0
40	2057	$0	$0	$0
41	2058	$0	$0	$0
42	2059	$0	$0	$0
Total Project NPV (rounded)				**$49,266,629**

$49,266,629

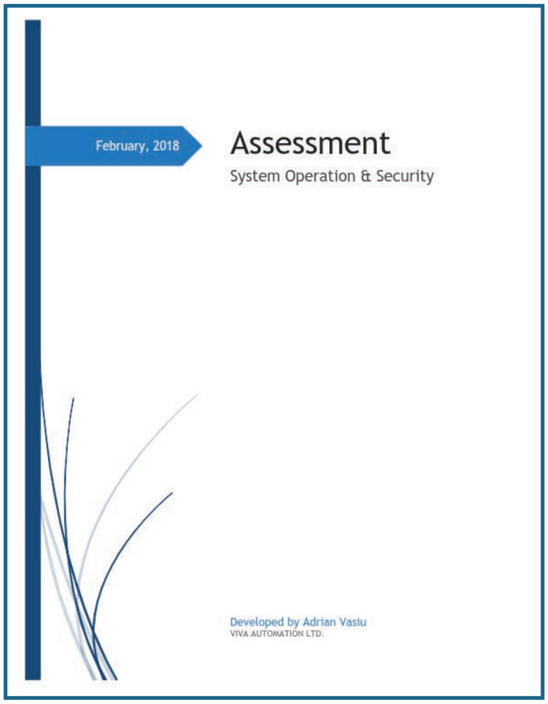
Costs are in 2017 Canadian dollars and allowances have not been included for future fluctuations in Canadian Dollar exchange rates.
Groundwater well costs include drilling and Hydrogeo. Costs provided by Piteau.
Well Building and pumps includes well pumps, building and associated mechanical and electrical equipment.
Chloramination for 25 MLD - includes building space.
2005 Water and Wastewater Asset Cost Study by Ontario Ministry of Public Infrastructure Renewal used for Chloramination costs.
ENR construction cost index used to scale construction costs (3.3% per year on average)
20% addition to facility costs assumed for site work
20% addition to facility costs assumed for SCADA and standby power.
Watermains sized for 1-1.5 m/s at 25 MLD
Assumes no land acquisition costs.
15 MLD pump station at Maclure to feed groundwater into the transmission main to Mission. Approximately 500 HP booster station
Assume 50% cost addition for pump station due to retrofit component at existing reservoir site
Collector well, buildings, wet wells and tie-in piping sized for 25 MLD
Treatment equipment and pumps sized for 25 MLD
Collector well costs provided by Piteau.
Treatment process assumes low lift, UV, chlorination, iron/manganese filtration, primary disinfection clearwell and chloramination (in HLPS). Second table labelled no Fe/Mn treatmetn does not include iron/manganese treatment equipment or required building space.
Low Lift Pump Station and Treatment Costs based on 2005 estimate for MacArthur Island Collector Well Project scaled to 2017. Approximately 200 HP station at 25 MLD capacity.
Six tenths rule used for scaling treatment equipment costs.
High lift pump station assumes ANSI Class 300# flanges required. Maximum pump size of 500 HP for low voltage. Assume in-building hydropneumatic tank required for surge protection. HGL based on modelling information provided by Geoadvice. Approximately 1,000 HP at 25 MLD flow.
Assume STD weight FBE coated steel for HLPS watermain tie-in.
Tie-in costs based on similar, high pressure hot tap in Kamloops area.
Assumes no land acquisition costs.
Assumes treated backwash water would be returned to the collector well.

JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN
Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#8

SECURITY SYSTEM ASSESSMENT REPORT



February, 2018

Assessment

System Operation & Security

Developed by Adrian Vasiu
VIVA AUTOMATION LTD.

February, 2018

Assessment

System Operation & Security

Developed by Adrian Vasiu
VIVA AUTOMATION LTD.

Introduction

Viva Automation Ltd. has been sub-contracted by Urban Systems Ltd. to provide a Security Assessment of all the Water Facilities under the jurisdiction of the Abbotsford / Mission Water & Sewer Services part of the "Water Supply / Source Study and Water Master Plan" project.

The information collected for this assessment has been done through site visits (Physical Security) and questionnaire (Cyber Security). While discussions with Operations personnel were conducted during the Site visits, they were limited in scope because of time restrictions and personnel availability constraints.

So, in order to alleviate some of these constraints, the developed questionnaire was to be filled by following personnel categories:

- Operations Manager responsible with budget / project assignments - the main reason was to raise awareness (if not already familiar) of the scope of work and boundaries that are part of each Security category so they would be able to assign priorities and address every aspect in an educated manner
- Automation Manager - to ensure all automation-related security matters would be seriously taken into consideration and assign budgets and personnel to constantly test / monitor, promote and protect / guard all assets under department's control
- IT Manager - to ensure there is a viable and solid collaboration between Automation and IT departments and security-related tasks have well defined boundaries in order to eliminate grey areas that none of these departments are responsible for

Acknowledgement

The following report has been made possible with the help of following people and we would like to thank them for their participation:

- Mr. Darren J. Scott (special thanks for driving me around and providing detailed site information and displaying great care and pride in working for the City of Abbotsford - an outstanding employee)
- Mr. Daniel Fok
- Mr. Mike Wyness
- Mr. Dwayne Graham
- Mr. John McAuley
- Mr. Tyler Bowie
- Mr. Steve Brubacher

Assessment

1 Governance and Risk Management

This section represents the cornerstone of Security Management in any organization and when not addressed appropriately, will predict serious failures of all implemented security measures for the simple reason that there is no plan.

In other words, "Governance" means adequate planning while "Risk Management" addresses various levels of risk associated with all security-related tasks / activities. In the absence of a plan, there is no way of knowing what to do or how to address a problem when it arises. There would be no clear definition of what type of an incident represents a security violation or a nuisance. Furthermore, there would be no interdepartmental coordination and no clear solution for employees to follow.

Because Security does not necessarily mean a breach that has an illegal purpose, it can also mean a calamity or natural event that can have a catastrophic impact on the health of any organization.

For all above reasons **we strongly recommend the development of a plan that will allow your organization to prepare and react in a well-thought and organized manner when a Security related incident occurs**.

Such plan should include at minimum following procedures used for:

- Searching for viruses / breaches (discovery does not mean the problem started an hour ago)
- Monitoring device logs and network activities
- Ensuring effectiveness of all implemented security policies
- Researching device vulnerabilities and patch application
- Training of regular employees (safe practices)
- Raising awareness of recently discovered vulnerabilities
- Evaluating effectiveness of implemented procedures

2 Physical Security

Upon the inspection of the water sites, the overall impression is that the Abbotsford / Mission Water & Sewer Services group are doing a great job in maintaining their facilities from brush clearance to building cleanliness, signage and perimeter protection.

The fences are of same size and style as the surrounding houses (good for not attracting attention), the internal perimeter around fences is clear (good for visibility and elimination of places to hide) and the majority of the buildings where chemicals are stored are equipped with security cameras and adequate signage.

The outdoor lighting of each facility is adequate and was told that tests are being performed as part of weekly routines to search for burnt lightbulbs.

As some of the wells are used as "fill stations" by Street Sweeper teams, they are equipped with card reading equipment to permit access to the water source when needed.

Site	Perimeter	Fencing / Clearance	Building	Alarming	Water Source	Lighting	Chemicals
Townline Well & Disinfection							
Well 1 (hatch)	Ok	barrier	N/A	intrusion	Ok	Ok	N/A
Well 2		Ok	Roof access from large tree branches	Intrusion, recording cameras	Ok	Ok	Chlorine, Ammonia, Diesel
Farmer Wells							
Well 1 & 2	Ok	Ok	Ok	Intrusion, recording cameras	Ok	Ok	Chlorine, Ammonia, Diesel
Industrial Wells	Latched entry gate, wooded / unprotected back						
Well A (not in service), Well B & C (hatch)	Wooded area	None	N/A	None	Ok	None	N/A
Controls / Genset building	Wooded area	None	Previous break-in, door bar	HMI intrusion	N/A	Ok	Diesel
Disinfection Building	Wooded area	None		None	N/A	Just front door	Chlorine, Ammonia
Riverside	Latched entry gate, wooded / unprotected back						
Well 1 (backroad)		None		None	Ok	Main door	Diesel
Well 2	Wooded Area	None around back	Ok	None	Ok	Front door	N/A
Pine Well	Commercial	Ok	Ok	Timer intrusion	Ok	Street only	N/A
Allen Park (recovery well of Bevan Wells)	Ok	Ok	Two kiosks	HMI intrusion	Ok	Street only	N/A
Garibaldi Park (recovery well of Bevan Wells)	Ok	Ok	Two kiosks	HMI intrusion	Ok	Street only	N/A
Bevan Wells (4)	Ok	None / Ok	Ok	Intrusion, recording cameras	One well head close to sidewalk	Ok	Chlorine, Ammonia, Diesel
Marshall Wells							
Well 1, Well 2 / 3	Ok	Ok	Ok	Intrusion, recording cameras	Not in service	Ok	Chlorine, Ammonia, Diesel
McConnell Well	Ok	Large tree behind	Ok; container ?!	Timer intrusion	Ok	Ok	

Maclure Reservoir	Ok	Ok	Ok	Intrusion, hatch	Ok	Buildings ok, not around reservoir	Diesel, sodium thiosulphate
Cannon's Pit (ammonia station)	Ok	Ok	Ok	Intrusion	N/A	Front door only	Ammonia
Cannell Lake Water Treatment Plant	Ok	Ok	Ok	Intrusion, recording cameras	Ok	Ok	Chlorine, diesel
Cannell Booster	Ok	Ok	Ok	Intrusion	PRV only	Ok	Chlorine
Mt. MaryAnn Reservoir	Ok	Ok	Ok	none	Ok	Front & back	N/A
Bell Road (ammonia station)	Ok	Ok	Ok	Intrusion, motion detectors	N/A	Ok	Ammonia, Soda Ash, Diesel
Hyde Burke (river crossing)	Isolated	None	Kiosk	Intrusion	N/A	None	N/A
Norrish Creek Water Treatment Plant	Ok, gates open	Low fence, vegetation not cleared (in some areas)	Ok	Intrusion, recording cameras, Security Guards off-hours	Ok	Ok	Chlorine, Citric Acid, Sodium Bisulfate, Sodium Hydroxide, Diesel,
Norrish Creek Intake	River / forest	Damaged gate	Kiosk	Intrusion, recording camera	River intake	Ok	N/A
Norrish Creek Chlorine Station (not in service)	forest	None	Ok	intrusion	Valve chamber	Ok	Diesel
Dickson Lake (Intake building)	Isolated	None	Prone to vandalism	None	Lake intake	None	N/A
Dickson Lake (Genset building)	Isolated	None	Previous break-in, door bar	None	N/A	None	Diesel

Table 1 - List of inspected sites

2.1 Perimeter Clearance

From past experience, the external perimeter of the fence where large blackberry bushes are present were left untouched as a deterrent and not for lack of resources or oversight.

The internal perimeter of each facility (where present) is clear and no temporary / man-made obstructions are visible.

2.2 Fencing

The Norrish Creek Water Treatment Plant had gates fully open during daytime allowing anyone to get in. Because most of the times there is only one person working in the plant, the installation of an access control system or as a minimum a gate motion notification system is recommended.

Even though the fence around the Norrish Creek Water Treatment Plant has same height, it has been noted to be very low in some areas where the nearby terrain elevation is higher than the fence. In such areas we recommend **raising the fence to a more adequate height**.

For the Norrish Creek Intake, the gate has been damaged (before site visit) - hopefully by the time this report is submitted, the gate has been fixed / reinforced so it will not happen again. Also, it has been reported that the area is frequented by various people for recreational purposes - because this is a restricted area, **we recommend finding an appropriate solution that will keep them out**.

Even though Dickson Lake (Intake Building) is isolated and not too many people are frequenting that area, we recommend **installing few security cameras (with DVR situated in the Genset Building) so in case the buildings are vandalized there is evidence that can help identifying the perpetrators**.

2.4 Video

At this point, all video recording devices are kept in the same facility as the cameras. Because in the case of a security breach or property damage (such as fire / vandalism) recording equipment can be damaged or stolen, we recommend moving all recording equipment in a fire-resistant / vandal proof enclosure hidden from prying eyes.

2.5 Intrusion detection / alarming

In the unique case of Norrish Creek Water Treatment Plant where an external Security company is employed to provide support during OFF hours, it has been noted that the awarded company employees have limited verbal English skills which act as an impediment to conveying messages, requests and reports to Operations personnel. Because this situation will negatively affect the Security of this facility, it is important to address this issue and find a solution that minimizes this security risk.

In order to evaluate the performance / efficiency / usefulness of such contracted service, it is important for Operations department to develop / maintain a daily/monthly task list that is given to the Service provider so they would be fully aware of their duties and responsibilities and eliminate misinterpretations or confusion.

3 Computer Security

Even though this section is mainly considered part of the “cyber” component, it is important for the client to understand that physical security incidents (such as breach of a facility or theft / loss of an electronic device such as a laptop or a radio) can directly affect this entire area. And this is the main reason physical security and cyber security must be treated as a single entity.

In order for any organization to be able to evaluate the performance of a computer system / network (or as a matter of fact the performance of a department responsible for maintaining these systems), the

development of guidelines is more important than the maintenance work done on a daily basis. When an employee only has time to address technical issues brought to their attention and never have time to perform local / system assessments, then the chance of finding a breach / intrusion is zero.

Even though using built-in Operating System features such as logging, domain controller user authentication and user policies restrictions represent the cornerstone of computer systems, they are totally ineffective when it comes to security breaches from either internal or external sources. **Every modern computer network must contain at least an intrusion detection system as well as a centralized logging system that are being monitored by an employee assigned to deal only with security related tasks**.

Firewalls and anti-virus software alone do not represent a deterrent and they just give the user / organization a false sense of security. Anti-virus software is only capable of detecting and removing well publicized viruses and they were never designed to stop a new virus from creating havoc within an organization.

Operating system and web server exploitations will always exist and because of it, it is very important that **the installation of patches and updates** (for every installed software) **is done on regular basis and preferably through a centralized location**. Any computer that is not part of a well-known domain should be denied access to the network.

Devices that are exposed to different environments (such as laptops and work smartphones - exposed to Home and Work networks) **must be treated differently than devices that have a permanent location. The City should develop a procedure that clearly stipulates what has to be done before connecting them to its internal network**.

3.1 Data Management

Because project data is very important to your organization, it is imperative to develop a set of data management guidelines that every employee is aware of and most importantly follows. Even though data backups are automatically performed on a regular basis, most organizations rarely inspect the integrity of these files only to find out that they are useless when they need to perform a recovery. Furthermore, never store backup data on the same premises as the primary storage location.

Because Automation data is not shared between departments on a continuous basis, the City is utilizing standard practices related to its storage, manipulation and verification.

The main reason for doing so is primarily driven by industry standards and expectations. A certain association makes recommendations and a municipality decides when to implement them based on resources and funding availability. And usually this is not a priority until the need to share data between departments on a continuous basis becomes a necessity.

As a matter of fact, **all industries are moving towards implementing an organization-wide data management model so that any electronic data can be shared between departments / platforms on a continuous basis**. Until recently automation data was being collected just for the simple reason that the software was capable of doing so. Very seldom one would hear a request to use the data for a Water Model or Environmental Assessment project when in fact this data can be used for many other purposes such as Energy Assessments / Optimization, Failure prediction and device replacement schedules, automatic maintenance requests and many more.

When the appropriate time comes for the City to implement such data sharing capabilities we always recommend the **development of a plan / strategy before delving into addressing any particular case**. Knowing that the City already owns and operates an “OSIsoft PI System” it means that the potential of using automation data has been acknowledged and hopefully a strategy of its deployment is in the works if not already completed.

3.2 Data Exchange

We encourage the City to develop a procedure / environment that allow various parties to exchange data in a controlled and safe manner:

- Implementation of a web-based data exchange portal - to be used by employees as well as contractors (no other means should be permitted)
- Allow transfer of “safe / verified” data through means approved by the City - such as network data repository or when not possible, data carriers (designated personnel)
- Inspection of various devices after on-site work is completed and before integration into local network
- Restrict access to phones, USB drives

3.3 Remote Access

Even though internet access is now the norm in every workplace, its use has to be controlled in a manner that creates a safe internal work environment. Such an environment can only be achieved through a **set of guidelines employees have to follow as well as a set of security policies designed to minimize the impact of an external breach / virus**. Most internet use is acceptable for work purposes (with very few exceptions that can be easily corrected) so attention has to be shifted towards emails and remote access - these are the primary sources of network breaches in most organizations.

In current times is important to acknowledge that accessing the work network from home or other location is a convenience that saves the City money (at least travel costs / time), it cannot remain an asset unless proper planning is completed and implemented.

Allowing internal network access from the internet under various circumstances (to employees or contractors) **should be done in a well-thought manner by clearly identifying who is permitted to do so, what conditions must be applied** (to individuals / groups), **how is this process going to be monitored and what are the measures that need to be implemented in order to create a safe environment**.

It has been brought to our attention that because of the remoteness of the Norrish Creek Water Treatment Plant, there are cases when the plant becomes inaccessible through VPN and City personnel would be required to drive to the Plant to assess its operation condition. We strongly recommend the **use of VPN Tunneling appliances to permanently connect remote sites** in which a telephone line is present. And on top of that, **a radio path study should be performed to find out if a Radio back-up path can be established between the plant and Bell Road** (Ammonia Station). If such radio path is not feasible, **the use of a back-up satellite internet connection may be required**.

3.4 Reporting

In the absence of means to track lost or stolen devices or any security-related incidents, there is no way of finding out the reason behind a security breach nor passing down the solution / implications to the next generation of employees.

Whether a physical security incident is being reported or a virus is found on a certain city computer, it is important to **develop a system that maintains records of such cases and even more important, allows employees to write down what was done to resolve the issue.** Such tool will prove very useful for the city and is not difficult to implement.

4 Automation Security

Because Automation Systems use various proprietary technologies that are vendor specific and they have to be designed / programmed in a certain manner, a totally different approach is required for each protocol (totally different approach than a traditional IT computer). In other words, the more vendors / technologies, the more complex the automation system becomes (in terms of maintenance as well as security challenges). Because of these reasons, **it is imperative to limit the use of a device / software to as few as possible in order to reduce the risk of mismanagement**. Nowadays multiple plants can be integrated through a single SCADA vendor in order to reduce their annual software support costs as well as number of maintenance hours.

Until recently many SCADA systems vendors always advised against performing Operating System updates as they will render the system inoperable. Even today, any Operating System updates will by default have to be followed by a SCADA software update. Because such update process is time consuming, most SCADA administrators have deliberately restricted remote access and separated the SCADA network from the rest of the IT infrastructure. Unfortunately, with an increased need of exchanging data between various systems such as SCADA, Asset Management, Water Modeling, GIS and others, **a new approach has to be developed in order to keep up with these technological advances**.

Web technologies (such as web servers and web-enabled databases) are the new standard that **your organization has to prepare to address in the very near future**. And in order to perform these upgrades in a useful and cost-effective manner, an upgrade strategy has to be developed (that will address all database driven software purchases and their ability to interconnect between each other).

Once an automation device (such as PLC, HMI) is exposed to the internet, a new **set of security rules have to be developed in order to keep them safe**. The need to have automation data shared with other departments for the purpose of enhancing the organization's capabilities is unquestionable and the market will dictate the time to do it (whether through regulations or simply technical requirements).

Like any other technological advancement, automation security will become an integral component of any organization whether we want to address it or not.

In today's environment, Automation networks are being mixed with IT managed networks raising a great number of security related concerns and here are some of them:

- Responsibilities of commonly used portions of a network - who is responsible for managing it and reasons for doing so? Never assign responsibilities for a network area administration to multiple departments!
- Because in many cases IT security principles do not apply to automation networks, are there any automation specific security policies developed and employees being aware of?
- When automation data (including software, PDF documents, program files) is being passed between these networks, are there rules in place that have been designed to safeguard the integrity of the system?

5 Telecommunications / Network Security

Any radio system, especially the ones used for the purpose of exchanging data between a remote station and a SCADA computer were traditionally considered inaccessible to most people because of their technological complexity as well as their limited range. And for this reason alone, they were and still are considered safe for use even though the data passed through is unencrypted and therefore easily intercepted by anyone with the know-how.

Any ethernet-based radio must at minimum incorporate an encryption protocol as well as the implementation of a "Remotes List" that will restrict use to known radios. **Any radios that do not offer such basic functionality should be replaced immediately regardless whether they are licensed or unlicensed** (spread spectrum).

6 Business Continuity and Disaster Recovery

In order for an organization to be able to properly respond to a security related event / disaster there has to be a certain level of preparation competed (in advance) that will address personnel responsibilities from top to bottom.

In other words, when one does not know what to do when a security breach has been discovered or a catastrophic event occurs, it means chaos will replace organized activities.

Even though the scope of this assessment is not meant to address disaster recovery, it is important for the client to know that any procedures developed to address Security related matters must be included in the organization's "Business Continuity and Disaster Recovery" document.

From security prospective, **the development of detailed step-by-step procedures / scenarios used to aid employees in the event of any security incident** should at minimum include following responsibilities:

- Network Zone separation / isolation (meant to stop the expansion of a breach / virus)
- Identification and isolation of all compromised devices / areas (discovered or not)
- Implementation of a cleansing procedure
- Verification of compromised data / areas
- Recovery of data / assets
- Assessment of losses and business impact

7 Service Level Agreements

Because almost every external project goes through an RFP / Contract process, it is important for the City to **include a "Security" related section that will stipulate in clear terms what are the general rules to be followed / expectations** when it comes to:

- exchange of any electronic files / documents
- email communication
- city's network or computer access policies / procedures

Besides mentioned general requirements, **a more customized set of rules should be developed to address specific IT or Automation related projects** (when deemed necessary).

Similar agreements should also be developed for City employees in order for them to understand and become aware of all active policies related to Security (Physical or Electronic).

8 Funding

In terms of necessary budget required to address all areas covered by this assessment, the City should secure a minimum of $300,000. Please note that this amount is informative in nature and a more accurate budget can be obtained by preparing a detailed Scope of Work.

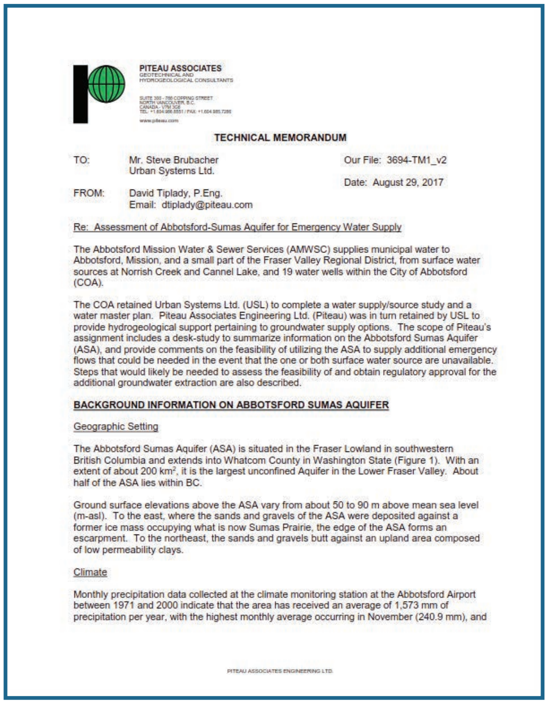
JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN

Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#9

AQUIFER ASSESSMENT FOR EXPANDED SUPPLY



PITEAU ASSOCIATES
GEOTECHNICAL AND
HYDROGEOLOGICAL CONSULTANTS

TECHNICAL MEMORANDUM

TO: Mr. Steve Brubacher
Urban Systems Ltd.

Our File: 3694-TM1_v2

Date: August 29, 2017

FROM: David Tiplady, P.Eng.
Email: dtiplady@piteau.com

Re: Assessment of Abbotsford-Sumas Aquifer for Emergency Water Supply

The Abbotsford Mission Water & Sewer Services (AMWSC) supplies municipal water to Abbotsford, Mission, and a small part of the Fraser Valley Regional District, from surface water sources at Norrish Creek and Cannel Lake, and 19 water wells within the City of Abbotsford (COA).

The COA retained Urban Systems Ltd. (USL) to complete a water supply/source study and a water master plan. Piteau Associates Engineering Ltd. (Piteau) was in turn retained by USL to provide hydrogeological support pertaining to groundwater supply options. The scope of Piteau's assignment includes a desk-study to summarize information on the Abbotsford Sumas Aquifer (ASA), and provide comments on the feasibility of utilizing the ASA to supply additional emergency flows that could be needed in the event that the one or both surface water source are unavailable. Steps that would likely be needed to assess the feasibility of and obtain regulatory approval for the additional groundwater extraction are also described.

BACKGROUND INFORMATION ON ABBOTSFORD SUMAS AQUIFER

Geographic Setting

The Abbotsford Sumas Aquifer (ASA) is situated in the Fraser Lowland in southwestern British Columbia and extends into Whatcom County in Washington State (Figure 1). With an extent of about 200 km^2, it is the largest unconfined Aquifer in the Lower Fraser Valley. About half of the ASA lies within BC.

Ground surface elevations above the ASA vary from about 50 to 90 m above mean sea level (m-asl). To the east, where the sands and gravels of the ASA were deposited against a former ice mass occupying what is now Sumas Prairie, the edge of the ASA forms an escarpment. To the northeast, the sands and gravels butt against an upland area composed of low permeability clays.

Climate

Monthly precipitation data collected at the climate monitoring station at the Abbotsford Airport between 1971 and 2000 indicate that the area has received an average of 1,573 mm of precipitation per year, with the highest monthly average occurring in November (240.9 mm), and

PITEAU ASSOCIATES ENGINEERING LTD.

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Climate

Monthly precipitation data collected at the climate monitoring station at the Abbotsford Airport between 1971 and 2000 indicate that the area has received an average of 1,573 mm of precipitation per year, with the highest monthly average occurring in November (240.9 mm), and the lowest in August (49.3 mm). Between May to September, average monthly precipitation is less than 100 mm.

The average annual temperature is 10°C, with a minimum monthly average of 2.6°C in January, ranging up to a maximum of 17.7°C in August.

Geology

Surficial geology for the Abbotsford region based on mapping by Armstrong et al. (1980) is shown on Figure 2.

The ASA is a unit within a complex sequence of quaternary sediments deposited during the last glacial period. It is composed of a succession of stratified, permeable, glaciofluvial sands and gravels interspersed with minor till and clayey silt lenses, collectively called the Sumas Drift. The Sumas Drift comprises recessional outwash deposits and were laid down during the final stages of glacial retreat, and include various physiographic features such as kettles, outwash plains, pitted outwash, and meltwater channels.

The aquifer is underlain by glaciomarine and marine clays belonging to the Fort Langley formation. These are characterized by low permeability stony silt to loamy clay up to 100 m thick. This unit intercepts ground surface in the Abbotsford Upland area to the northwest, effectively bounding the ASA on this side. The ASA is known to reach 70 m thick locally, and is between 5 and 30 m along the Canada-US border.

Surface Water

Surface watercourses in the Abbotsford area are shown on Figure 2.

The northeastern portion of the ASA is drained by Downes Creek, Horn Creek, Boa Brook, Willband Creek and Clayburn Creek. These drain into the Gifford Slough and Matsqui Slough watersheds, which ultimately report to the Fraser River. Downes Creek also picks up groundwater from the Aldergrove aquifer in its headwaters to the west.

Fishtrap Creek originates as Fishtrap Creek and East Fishtrap Creek in the Abbotsford Uplands to the northeast, and flows to the southwest across the ASA to eventually converge with the Nooksack River in the United States. The lower reach of Pepin Creek, located west of Fishtrap Creek, also drains southward across the border.

Marshall Creek (a.k.a. Lonzo Creek) and Shamrock Creek collect groundwater discharging along the eastern Aquifer escarpment and drain into the Sumas River.

Mill Lake is located approximately 200 m northeast of the Bevan well field. Approximately 15 m of sand and gravel underlain by a 5 m thick layer of silt and clay separates the base of the lake from Aquifer. Hence, the lake is not interpreted to receive water from the ASA.

Laxton Lake is seated in a pocket of peat and silt deposits, and was dredged to a depth of about 6 m in 1988. It is interpreted to receive water from the ASA when the surrounding water table is high, and lose water to the ASA when it is low. During the wetter months, Laxton Lake decants into Judson Lake, which is a shallower (~1m deep) wetland that straddles the international boundary. Unlike Laxton Lake, Judson Lake is above the local water table most of the time, receiving groundwater inputs only during periods of extremely high groundwater levels and low lake levels.

Aquifer Recharge

The ASA is recharged annually by three mechanisms: direct infiltration from rain or snow melt during winter months, runoff from the clay uplands to the north (west half only), and seasonal recharge from Fishtrap Creek. Recharge from direct infiltration is the primary component.

Allen et. al. (2014) estimated that 65% of total precipitation reports recharges the ASA. This is only slightly greater than estimates by Piteau (2016) based on soil-water budgets for rural and urban areas, which indicated recharge equivalent to 62% and 52% of total precipitation, respectively. Based on these values, and accounting for the other components, total recharge to the Canadian portion of the ASA is estimated to average about 65,000 ML/yr, or 177 MLD (Piteau, 2016). Most of this recharge occurs between November and May.

Groundwater Withdrawals

Major groundwater users on the Canadian portion of the ASA include the Fraser Valley Trout Hatchery, the AMWSC/COA, Clearbrook Waterworks District (CWD), food processing and other industries, farm operations (mainly irrigation), and domestic users. Information available on higher capacity production wells operated by these users is summarized in Table I.

On behalf of the AMWSC, the COA maintains and operates 19 production wells that draw from the ASA. These are situated as single wells or in clusters of up to three (Figure 2). The wells range between 200 mm to 450 mm in diameter, and draw groundwater from depths ranging from 11 to 56 m-bgl. The first wells were put into operation in 1958 (Marshall #1), and the most recent (Bevan wellfield) went into service in 2009.

The AMWSC/COA wells are generally active between May and September. Averaged over a year, the wells draw on average about 150 L/s (13 MLD). This is far less than sum of the reported maximum instantaneous pumping rates for each of the wells, which is approximately 780 L/s (69 MLD). Two of the wells (Pine and Marshall No. 1) are not in service.

The Fraser Valley Trout Hatchery has four production wells located along the eastern escarpment of the ASA (Figure 2). Nominal installed yields range from 29 to 158 L/s and well depths range from 29 to 37m (Zubel, 1980). More up-to-date groundwater extraction information is unavailable. Assuming that the wells operate year-round at an average collective extraction rate of 172 L/s (half the sum of their installed yields), it is estimated that they withdraw about 15 MLD. After passing through the hatchery pens, all of this water is discharged into Marshall Creek.

The CWD is the sole water provider to the Clearbrook area in Abbotsford. They operate three production wells located approximately 1.2 km northwest of the Bevan well field. Current average pumping rates are about 35 L/s (3.0 MLD).

Several production wells draw water from the ASA to supply industries such as laundering, food processing, and nursery operations. Many of these are located along Highway 1 and Riverside Road (Figure 2). Based on sewage meter readings monitored by the COA, and responses to a water well user survey distributed by the COA in 2009, these wells are estimated to extract about 19 L/s (1.7 MLD).

The COA water distribution network reaches most residences overlying the ASA, with the exception of those located in south and west of the Abbotsford Airport. In this area, it is assumed that residences rely exclusively on well water to meet their water needs. Based on the number of land parcels in this area, the average number of dwellings per parcel, and an average demand of 650 L/person/day, Piteau estimates groundwater withdrawals in this area amount to about 7 L/s (0.6 MLD). Assuming that domestic well water use elsewhere across the ASA is about half of this amount, the total estimated groundwater withdrawal via domestic wells is about (10 L/s) 0.9 MLD.

Piteau (2010) estimated the amount of groundwater withdrawn each year for irrigation at 7 million cubic meters per growing season. This is equivalent to an annual average flow of 220 L/s (19 MLD).

Based on the foregoing, Piteau estimates the total annual amount of groundwater pumped from the portion of the Canadian portion of the ASA averages about 530 L/s (46 MLD). This is equivalent to approximately 26% of total average annual recharge estimated above (177 MLD).

Performance and Sustainability

Long-term trends in groundwater levels indicate that water levels in the ASA have not varied by more than 3 m over the 50-year-long period of record, and have remained constant, or risen slightly since the 1990’s. The long-term groundwater level trends are noted to correspond to long-term precipitation trends. Based on these observations, it is concluded that total groundwater extraction by domestic, agricultural, municipal, and industrial operations is sustained by aquifer recharge. There is no evidence to indicate that aquifer depletion is occurring, or has occurred in the past.

Groundwater Quality

Groundwater sampling and analysis in the lower Fraser River Valley commenced in 1955 (Hii et al., 1999). The initial studies focused on inorganic constituents and it was found that the predominant natural constituents were calcium and magnesium bicarbonate. The total dissolved solids concentrations ranged between less than 100 mg/L at shallow depths, to over 300 mg/L where water-bearing sands and gravels are confined or partly confined by till and clay lenses.

Although groundwater quality in the ASA is generally regarded as good, water quality problems experienced in AMWSC wells include:

- Nitrate concentrations exceeding the 0.010 mg/L maximum allowable concentration (MAC) recommended in the Guidelines for Canadian Drinking Water Quality (GCDWQ) in the Pine, Townline 1, and Farmer 2 wells. This deterioration of groundwater quality is linked to infiltration from surface applications of manure in portions of the ASA (Liebscher et. al., 1992). The most significantly impacted portion of the ASA is shown on Figure 2.

- Concentrations of manganese in groundwater elevated above the 0.050 mg/L aesthetic objective (AO) in the Pine, Townline 1, and Farmer 2 wells. Based on extensive scaling within distribution piping and consumer complaints, Associated Engineering (2014) recommended that Farmer 2 not be used, and that the water needs to be treated or a new well with satisfactory water quality commissioned.

- Concentrations of iron in groundwater elevated above the recommended AO (0.30 mg/L) in the Pine well.

- Arsenic in groundwater from Industrial A, Industrial B, and Farmer 3 nearing the MAC (0.010 mg/L).

FEASIBILITY OF EXPANDING GROUNDWATER SUPPLY

This section includes comments on feasibility of utilizing groundwater in the ASA to provide short-term emergency flows ranging up to 925 L/s (80 MLD) on an as required basis. It is assumed that this would be sourced from the Bevan Wells (25 MLD), other existing AMWSC/COA wells (30 MLD), and a series of new wells at suitable locations within the ASA (25 MLD).

Groundwater Availability

To remain consistent with previous analyses for the Bevan Wells, and to include a degree of conservatism, it is assumed that emergency use of the AMWSC/COA wells at a combined rate of 925 L/s (80 MLD) need to be capable of operating for a minimum duration of 100 days per year. The equivalent annual extraction is 250 L/s (22 MLD), and would increase the amount of groundwater pumped from the portion of the ASA north of the border from the current 26% of average annual recharge to approximately 37%. Given this result, and the expectation that such flows would occur only occasionally, it is unlikely that the additional groundwater extraction would result in aquifer depletion. However, short-term effects of pumping such as reducing low flows in creeks, and interference with other operating wells, could constrain maximum pumping rates unless mitigated.

Effects of Climate Change

A comprehensive review of expected climate change in BC by the Forest Science Program (Pike et. al., 2010) predicts that by the 2050s, changes in seasonal air temperature for the south coast of BC will range from +1.3°C in spring to +1.7°C in summer, with an average change of +1.5°C. Average annual precipitation is predicted to increase by 6%, with a seasonal breakdown of +9% in autumn, +6% in winter, +7% in spring, and -13% in summer.

The 6% increase in annual recharge is expected to increase groundwater recharge by a similar amount, thus potentially causing a slight increase in safe yield for the ASA. However, reduction in average summer precipitation may have an offsetting effect with respect to surface water flows, and the need to maintain environmental flows may constrain any expansion potential. Therefore, for the purposes of this evaluation, it can be reasonably concluded that the effects of climate change will be small in terms of effects on safe aquifer yield and the amount of groundwater that can be removed by AMWSC wells.

Risks

The primary risk associated with the groundwater supply sourced from the ASA relates to the potential for changes in groundwater quality that could necessitate discontinuing use of affected wells, costs for new infrastructure (e.g., new wells or water treatment systems), and/or changes in operating practices (e.g., mixing) to mitigate the effects.

As indicated earlier, some AMWSC wells have already experienced elevated nitrate concentrations linked to agricultural practices that have created operational challenges. Similarly, concentrations of naturally occurring manganese and iron exceeding recommended limits have resulted in some wells from not being utilized. Concentrations of naturally occurring arsenic in some wells are nearing the MAC. Trends with respect to these water quality concerns may change over time, and possibly in response to long-term increased pumping, both from existing wells and/or from the ASA overall.

Other potential groundwater pollution hazards that could result in unexpected costs for new infrastructure (e.g., new wells or water treatment systems), and/or changes in operating practices, could include:

- contaminated sites where activities such as storage and dispensing of petroleum products, dry cleaning, lumber treatment, coal gasification, landfilling with contaminated material, storage and disposal of wastes, and chemical storage have taken place;
- large-scale releases of petroleum products or hazardous chemicals as a result of a major incident, such as a tanker truck rupture or train derailment, etc.; and
- improperly abandoned wells that may act to convey contaminants between the surface and the aquifer.

In terms of groundwater supply, the risk to the associated with these types of potential hazards depends on many factors. In some cases, the risk is mitigated by natural processes that attenuate the spread of contamination, regulations, and best management practices, and municipal policies.

As with most other possible water sources, the safe yield of the ASA could also be affected by climate factors such as long-term drought.

Regulatory Aspects

In accordance with Water Sustainability Act (WSA) and Water Sustainability Regulation (WSR), increasing the rate of groundwater extraction from existing wells via existing or new wells will require licensing. As part of the licensing process, potential interference with neighbouring wells, and effects on surface water flows, will need to be evaluated.

Any new groundwater extraction project that extracts more than 75 L/s (6.5 MLD), or modification of an existing project that is pumped at 75 L/s or greater, that increases extraction by 35%, or more, over the current rate of extraction, is considered reviewable under the BC Environmental Assessment Act.

The AMWSC and COA have experience with the environmental assessment (EA) process after obtaining EA Certificate W11-01 for the Bevan Wells in May 2011. This certificate allowed for withdrawal of groundwater at up to 290 L/s (25 MLD) for a maximum of 100 days per year for a duration of five years (equivalent to 6.8 MLD on an annual basis). In 2013, the AMWSC applied for an amendment to extend the EA certificate indefinitely (amended certificate issued June, 2017).

Based on the complex and drawn-out process to achieve an EA certificate for Bevan wells, it can be anticipated the process needed in support of even achieving certification for an additional 55 MLD groundwater supply (to supplement 25 MLD from the Bevan wells) will be as or more challenging, and that measures needed to mitigate effects on surface water flows and well users may be more costly. Moreover, given that the additional groundwater would need to be sourced from wells in the southern half of the Canadian portion of the ASA (i.e., between Canada-USA border and Highway 1), it is likely that the zone of influence will be more extensive, and additional investigation and assessment will be needed to determine the effects south of the border.

SUGGESTED WORKPLAN

Elements of the work plan required to assess the feasibility of developing an 80 MLD emergency groundwater source are outlined below.

Preliminary Groundwater Flow Modelling

The groundwater flow model and analysis methodology developed in support of the original (2010) EA for the Bevan Wells, and the amendment to the EA (2017), can be used to provide a preliminary assessment of the extent of the zone of influence (ZOI) associated with extracting 80 MLD. However, as this model only simulates conditions in the portion of the ASA north of the border, the results will not predict effects in the south (USA) portion. This would involve validating the model against most recent pumping rate, surface and groundwater data collected in 2015 and 2016, and simulating the year-over-year effects over a five-year period with reduced precipitation. During each year of the simulation pumping would be assumed to occur during the 120 day[1] interval ending in the late fall. As in the modelling work completed in support of the Bevan Wells, the ZOI could be defined as the area where project-related drawdown in head within the aquifer is greater than 10 cm, and portions of watercourses where the predicted reduction in summer low flows exceeds a designated threshold[2].

Potential locations for new wells to provide a combined 25 MLD can be evaluated during the preliminary modelling step in terms of predicted effects on creeks and operating wells and measures to mitigate impacts could be identified.

It is expected that this step would require approximately three months to complete at a cost of between $75,000 and $100,000.

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[1] Although the actual maximum duration of pumping at 80 MLD would be 100 days, a duration of 120 days was required during the evaluation phase to provide a degree of conservatism.

[2] For the Bevan Wells assessment, the threshold for determining impacts to surface water was based on the ratio of summer low-flow to average annual discharge. Creeks experiencing summer low-flows less than 20% of their average annual discharge had a threshold of 1%, and those with summer low-flows greater than 20% of average annual discharge had a threshold of 10%.

Enhanced Aquifer Evaluation

If the predicted effects and potential mitigation measures for the Canadian portion of the ASA appear manageable, additional evaluation may be needed to predict effects on wells and surface water resources throughout in the portion of the ASA south of the border. This will require additional research to identify information on aquifer properties, aquifer water levels, groundwater utilization, and surface water flow rates. Investigations may be needed to fill data gaps.

When there is sufficient information available, the groundwater flow model developed for the Canadian portion of the ASA will need to be expanded to include all or a part of the portion of the ASA south of the international border. Following calibration and validation, the model would be used to predict effects of extracting 80 MLD of groundwater will have on surface water and wells throughout the Canadian and US portions of the ASA.

Prior to initiating enhanced aquifer evaluation, it would be advisable to engage in discussions with the Environmental Assessment Office (EAO) and possibly US-based agencies, to define appropriate criteria for evaluating the significance of potential effects within Washington, and to identify impact mitigation strategies that may be considered reasonable.

It is expected that this step would require approximately one to two years to complete and the cost may range from $500,000 to $1,000,000.

Test Well Construction and Aquifer Pump Testing at Prospective New Well Sites

The new wells needed to provide 25 MLD could be clustered in a wellfield or distributed throughout the southern portion of the Canadian Portion of the ASA. In either case, test drilling and aquifer pump testing will be required at prospective locations to quantify aquifer conditions and groundwater quality. Necessary investigations will likely include test drilling and construction of test water wells and monitoring wells, conducting aquifer pump testing, and possibly evaluating requirements for groundwater treatment.

Providing that no major impediments are identified during initial discussions with the EAO and other parties, investigations for prospective new well sites could potentially be initiated while the enhanced aquifer evaluations are underway.

It is expected that this step would require approximately six months. The cost may range between about $400,000 and $600,000.

Environmental Assessment and Permitting

Once locations for new well sites have been proven, the EA process can be initiated. In accordance with the British Columbia Environmental Assessment Act. The scope of the assessment will need to be developed in conjunction with an environmental consultant and with input from the EAO.

It is expected that this step would require approximately two to three years to complete. The cost could range between $1 million and $1.5 million.

Construction of Production Wells and Other Mitigation Requirements

When a new EA certificate has been issued, or when there is sufficient confidence that one will be issued, new production wells and other required measures for effects mitigation can be constructed and tested.

It is expected that this step would require approximately six months to one year to complete. Costs for this step have not been estimated due to uncertainty about the number of production wells, and the mitigation measures, that would be needed.

CONCLUSIONS AND RECOMMENDATIONS

This letter-report describes the results a desk-study completed by Piteau to summarize information on the Abbotsford Sumas Aquifer, and provide comments on the feasibility of developing an additional 55 MLD of supply capacity. Key points following from this review are as follows:

1. Aquifer water balance calculations indicate that extraction of an additional 55 MLD of groundwater will not result in aquifer depletion. However, short-term effects of pumping such as reducing low flows in creeks, and interference with other operating wells, could constrain maximum pumping rates unless mitigated.

2. Climate change may result in a modest increase in annual recharge to the ASA, and thus may slightly increase the aquifer's safe yield. However, the need to sustain low flows in creeks during predicted drier summers may have an offsetting effect.

3. The primary risk associated with groundwater supplies drawing from the ASA is the potential for changing groundwater quality that could necessitate discontinuing use of affected wells, or result in unexpected costs for new infrastructure (e.g., new wells or water treatment systems), and/or changes in operating practices (e.g., mixing) to mitigate potential health effects.

4. Tasks needed to assess the feasibility of obtaining an additional 55 MLD of groundwater supply from the ASA, obtain an EA Certificate, construct additional production wells and satisfy mitigation requirements, may need to include:

    - a preliminary assessment;
    - an enhanced aquifer evaluation to assess effects south of the border;
    - investigation of prospective new well sites;
    - environmental assessment, permitting, and construction; and
    - construction of new production wells and mitigation requirements.

5. The estimated time to complete the tasks described above is four to six years. Not including construction of production wells or effects mitigation, the estimated costs may range between about $2 million and $3.2 million. Actual amounts may be more or less.

LIMITATIONS

This investigation has been conducted using a standard of care consistent with that expected of scientific and engineering professionals undertaking similar work under similar conditions in BC. No warranty is expressed or implied.

This report is prepared for the sole use of the Urban Systems Ltd. and the AMWSC. Any use, interpretation, or reliance on this information by any third party, other than the BC Environmental Assessment Office, is at the sole risk of that party, and Piteau accepts no liability for such unauthorized use.

CLOSURE

We trust this letter-report is sufficient for your current needs. Please contact the undersigned if you have any questions or comments.

We appreciate the opportunity to be of service on this project.

Yours truly,

PITEAU ASSOCIATES ENGINEERING LTD.

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
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Apr/27
2018

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DJT/dls

Att.

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TABLE

TABLE I

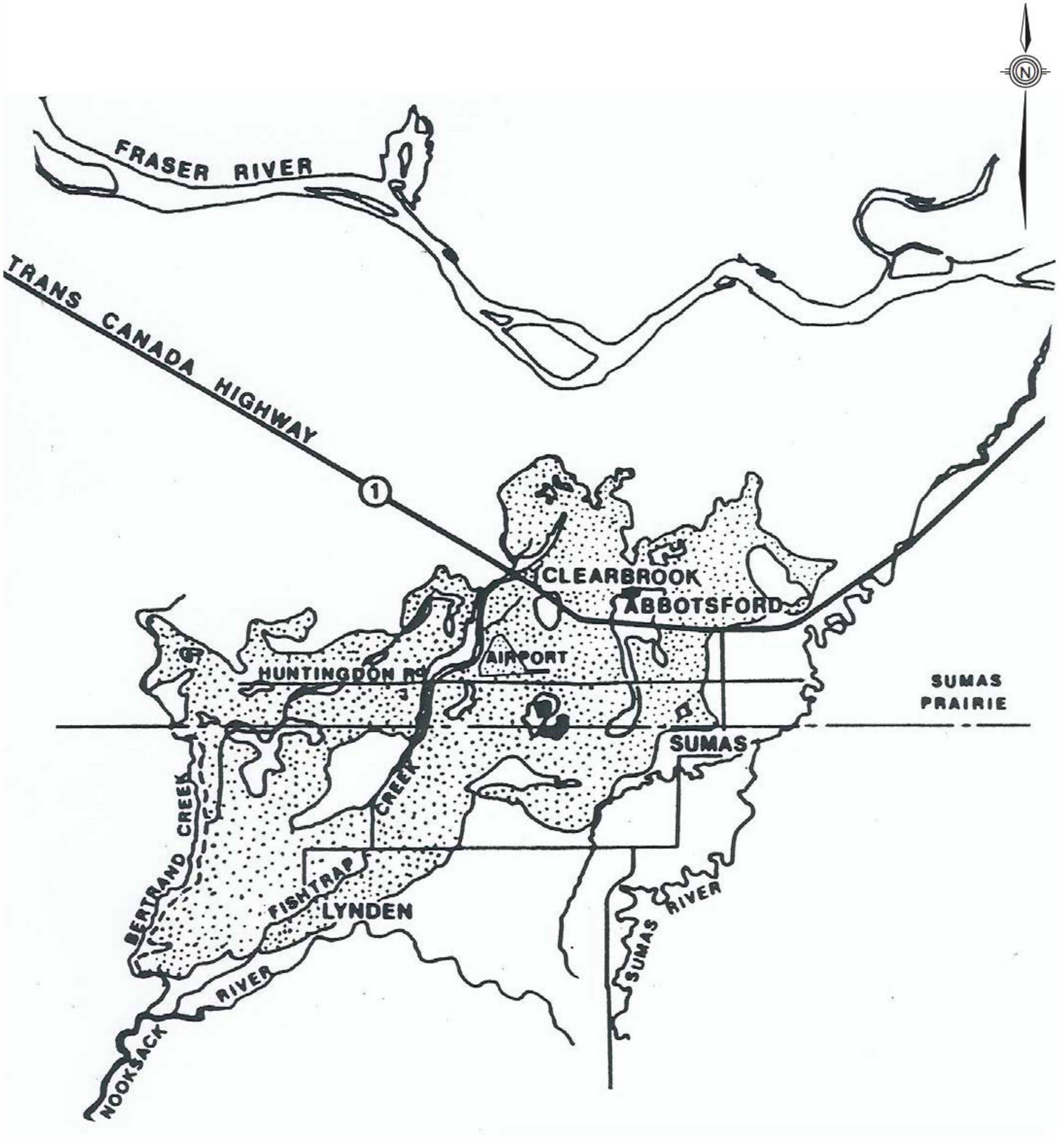
SUMMARY OF PRODUCTION WELL INFORMATION

Well ID	Figure ID[1]	Year Constructed	Nominal Diameter (inches)	Depth		Instantaneous Pumping Rate			Estimated Aggregate Average Pumping Rate			Operating Schedule
				Total (m-bgl)	Screened Interval (m-bgl)	L/s	USgpm	MLD	L/s	USgpm	MLD	
AMWSC Wells												
Farmer #1	FR-1	1973	18	44.0	35-44	66	1,110	5.7				intermittently summer only
Farmer #2	FR-2	1977	18	47.0	35-47	44	697	3.8				
Farmer #3	FR-3	1982	12	40.6	34.6-40.6	25	396	2.2	8	127	2.2	
Industrial A	IN-A	1992	8	50.6	37.5-50.6	9.5	151	0.8				
Industrial B	IN-B	1993	12	61.1	45.4-56.1	38	602	3.3				
Industrial C	IN-C	1994	12	45.7	28.0-45.6	59	935	5.1	33	523	2.2	
Riverside #1	RI-1	1968	12	15.2	12-15.2	29	476	2.5				
Riverside #2	RI-2	1972	12	16.0	11.4-16.0	17	269	1.5	5	79	2.2	
McConnell	MC-1	1992	16	43.0	33.7-38.3	22	349	1.9	6	95	0.5	
Pine Well	PI-1	1960	12	21.5	16.7-21.3	not in service						
Marshall #1	M-1	1958	12	38.1	33.0-37.8	not in service						
Marshall #2	M-2	1967	14	36.9	29.9-36.0	32	507	2.8				
Marshall #3	M-3	1971	18	42.1	33.6-42.1	90	1,427	7.8	15	238	1.3	
Townline #1	TL-1	1975	18	26.8	14.0-26.8	45	729	3.9				
Townline #2	TL-2	1978	10	18.7	15.1-18.7	31	491	2.7	20	317	2.2	
Bevan #1	Bevan Well Field	2007	16	38.7	29.2-38.2	96	1,522	8.3				
Bevan #2		2007	16	41.5	37.5-40.9	103	1,626	8.9				
Bevan #3		2008	16	40.2	35.6-39.3	3.7	59	0.3				
Bevan #4		2008	16	40.2	34.8-39.6	97	1,544	8.4	58	922	2.2	
Fraser Valley Trout Hatchery Wells												
Hatchery #1	PW-1	1969	16	70.4	37.3	125	1,980	11				continuously, year-round
Hatchery #2	PW-2	1969	16	49.1	28.7	29	460	2.5				
Hatchery #3	PW-3	1967	8	42.1	29.0	32	510	2.8				
Hatchery #4	PW-4	1980	20	90.8	36.3	158	2,500	14	172	2726	15	
Clearbrook Water District Wells												
RW 3-93/11	3-93	1993	10	58.8	34.8-40.7	54	856	4.7				continuously, year-round
RW 7-13/13	7-13	2013	16	39.9	32.2-39.9	48	761	4.1				
RW 1-87/14	1-87/14	2014	16	40.5	32.9-40.4	47	745	4.1	35	555	3.0	
Private Industry Wells												
Lucerne Foods	LUCERNE	-	-	18.3	-	24	380	2.1	4.1	65	0.4	continuously, year-round
Eco Tex services	ECOTEX	-	-	18.0	-	11	175	1.0	1.9	30	0.2	
Lilydale Foods	LILYDALE	-	-	43.9	-	19	300	1.6	7.6	120	0.7	
Snowcrest Packers	SNOWCREST	-	-	25.9	-	2.5	40	0.2	0.8	12	0.1	
Versacold	VERSACOLD	-	-	-	-		-	-	4.7	75	0.4	
Saputo Foods	SAPUTO	-	-	-	-	-	-	-	-	-	-	

Notes:
1. See Figure 2 for well locations.
2. Irrigation wells and domestic supply wells not included.

FIGURES

DWG. NUMBER: 3694-001.CDR



0 2000 400 6000 8000 10000m

SCALE 1:200,000

NOTES:
1. MODIFIED FROM LEIBSCHER ET. AL. 1992.

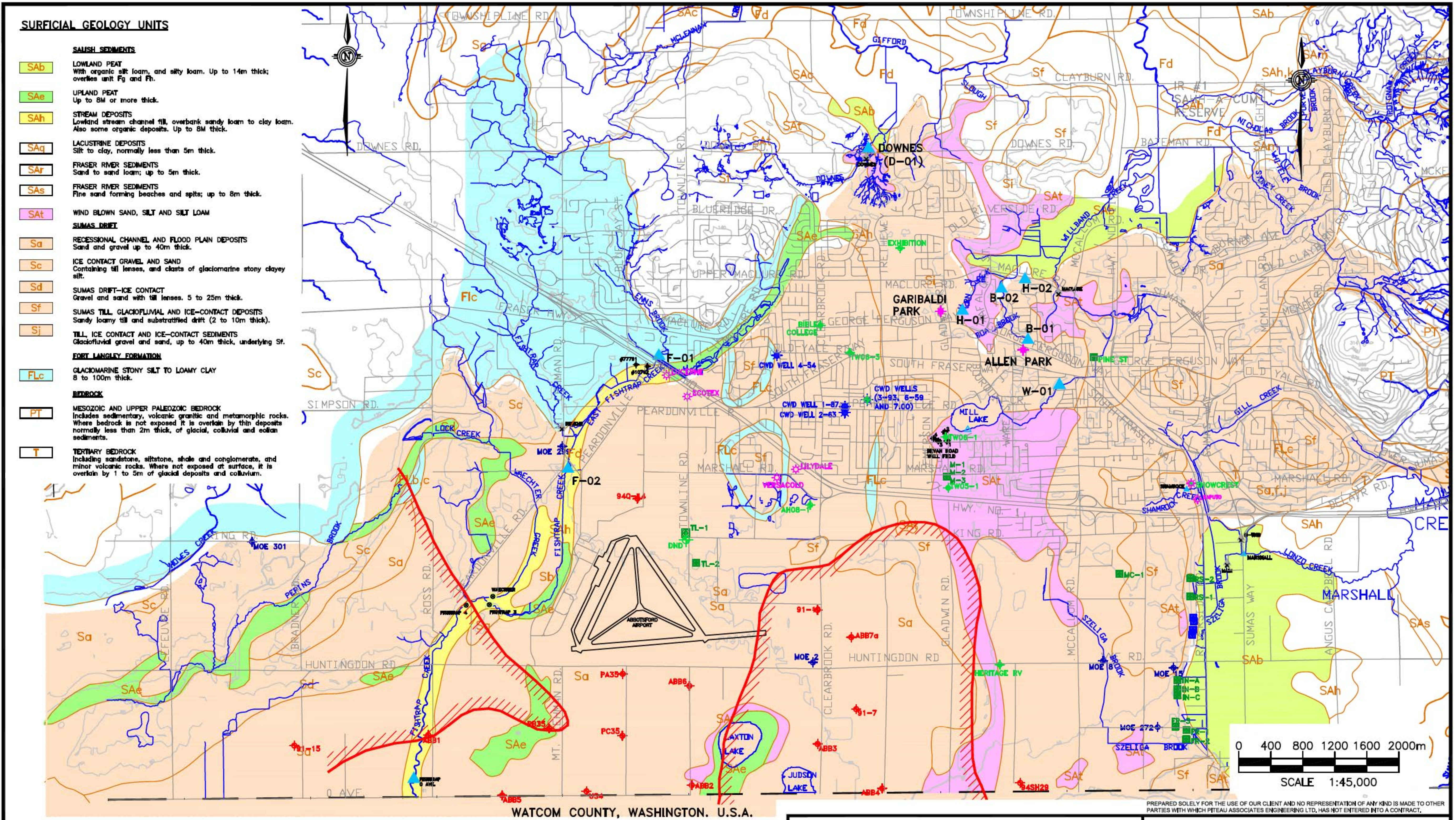
URBAN SYSTEMS LTD.
AMWSC WATER SUPPLY / SOURCE STUDY &
WATER MASTER PLAN

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

MAP OF ABBOTSFORD SUMAS AQUIFER

BY: DJT/lf	DATE: APR 17
APPROVED: DJT	FIG: 1

DWG. NUMBER: K:\3694\Cadd\3694-002.dwg (Fig 2)



SURFICIAL GEOLOGY UNITS

SALISH SEDIMENTS

SAb	LOWLAND PEAT With organic silt loam, and silty loam. Up to 14m thick; overlies unit Fg and Fh.
SAe	UPLAND PEAT Up to 8M or more thick.
SAh	STREAM DEPOSITS Lowland stream channel fill, overbank sandy loam to clay loam. Also some organic deposits. Up to 8M thick.
SAq	LACUSTRINE DEPOSITS Silt to clay, normally less than 5m thick.
SAr	FRASER RIVER SEDIMENTS Sand to sand loam; up to 5m thick.
SAs	FRASER RIVER SEDIMENTS Fine sand forming beaches and spits; up to 8m thick.
SAt	WIND BLOWN SAND, SILT AND SILT LOAM

SUMAS DRIFT

Sa	RECESSIONAL CHANNEL AND FLOOD PLAIN DEPOSITS Sand and gravel up to 40m thick.
Sc	ICE CONTACT GRAVEL AND SAND Containing till lenses, and clasts of glaciomarine stony clayey silt.
Sd	SUMAS DRIFT—ICE CONTACT Gravel and sand with till lenses. 5 to 25m thick.
Sf	SUMAS TILL, GLACIOFLUVIAL AND ICE—CONTACT DEPOSITS Sandy loamy till and substratified drift (2 to 10m thick).
Sj	TILL, ICE CONTACT AND ICE—CONTACT SEDIMENTS Glaciofluvial gravel and sand, up to 40m thick, underlying Sf.

FORT LANGLEY FORMATION

FLc	GLACIOMARINE STONY SILT TO LOAMY CLAY 8 to 100m thick.

BEDROCK

PT	MESOZOIC AND UPPER PALEOZOIC BEDROCK Includes sedimentary, volcanic granitic and metamorphic rocks. Where bedrock is not exposed it is overlain by thin deposits normally less than 2m thick, of glacial, colluvial and eolian sediments.
T	TERTIARY BEDROCK Including sandstone, siltstone, shale and conglomerate, and minor volcanic rocks. Where not exposed at surface, it is overlain by 1 to 5m of glacial deposits and colluvium.

LEGEND

- ✦ B.C. MINISTRY OF ENVIRONMENT OBSERVATION WELL
- ✦ MONITORING WELL MONITORED BY COA
- ✦ ENVIRONMENT CANADA MONITORING WELL
- ✦ PRIVATE WELL IDENTIFIED BY WELL TAG No.
- 🟩 CITY OF ABBOTSFORD PRODUCTION WELL
- 🟦 FRASER VALLEY TROUT HATCHERY WELL
- ✹ CLEARBROOK WATER DISTRICT PRODUCTION WELL
- ☼ PRIVATE INDUSTRY PRODUCTION WELL
- ◆ BEVAN ROAD WELL
- ⌖ MONITORING WELL INSTALLED BY PITEAU
- ✦ MITIGATION WELL
- ⊗ LOCATION OF SPOT—MEASUREMENT OF SURFACE WATER FLOWS (SEP. 2009)
- △ MILL LAKE MONITORING STATION
- ▲ CREEK MONITORING STATION
- × HISTORICAL CREEK MONITORING STATION
- ● ABBOTSFORD SUMAS AQUIFER (CANADIAN PORTION)
- ▨ APPROXIMATE EXTENT OF AREA WITH SHALLOW GROUNDWATER WITH NITRATE CONCENTRATIONS IN EXCESS OF 15mg/L

NOTE:

SURFICIAL GEOLOGY FROM ARMSTRONG ET. AL., 1980

PREPARED SOLELY FOR THE USE OF OUR CLIENT AND NO REPRESENTATION OF ANY KIND IS MADE TO OTHER PARTIES WITH WHICH PITEAU ASSOCIATES ENGINEERING LTD. HAS NOT ENTERED INTO A CONTRACT.

URBAN SYSTEMS LTD.
AMWSC WATER SUPPLY / SOURCE STUDY &
WATER MASTER PLAN

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

ABBOTSFORD SUMAS AQUIFER

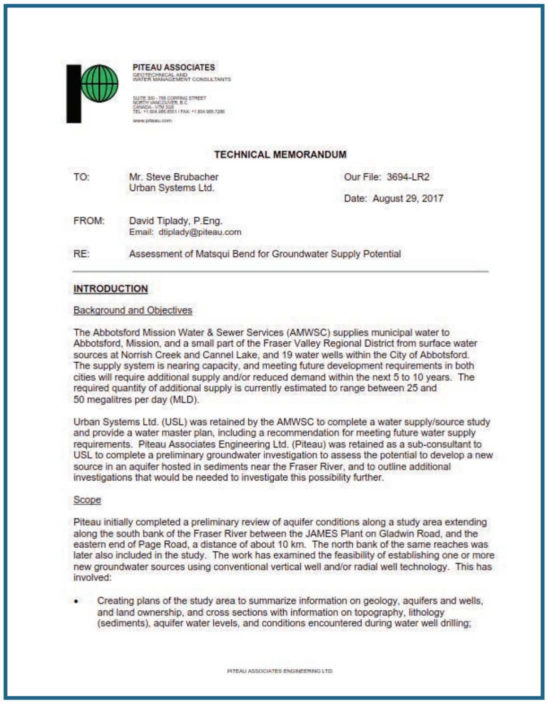
BY: DJT/sl
DATE: APR 17
APPROVED: DJT
FIG: 2

JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN
Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#10

ASSESSMENT OF MATSQUI BEND GROUNDWATER SUPPLY



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TECHNICAL MEMORANDUM

TO: Mr. Steve Brubacher
Urban Systems Ltd.

Our File: 3694-LR2

Date: August 29, 2017

FROM: David Tiplady, P.Eng.
Email: dtiplady@piteau.com

RE: Assessment of Matsqui Bend for Groundwater Supply Potential

---

INTRODUCTION

Background and Objectives

The Abbotsford Mission Water & Sewer Services (AMWSC) supplies municipal water to Abbotsford, Mission, and a small part of the Fraser Valley Regional District from surface water sources at Norrish Creek and Cannel Lake, and 19 water wells within the City of Abbotsford. The supply system is nearing capacity, and meeting future development requirements in both cities will require additional supply and/or reduced demand within the next 5 to 10 years. The required quantity of additional supply is currently estimated to range between 25 and 50 megalitres per day (MLD).

Urban Systems Ltd. (USL) was retained by the AMWSC to complete a water supply/source study and provide a water master plan, including a recommendation for meeting future water supply requirements. Piteau Associates Engineering Ltd. (Piteau) was retained as a sub-consultant to USL to complete a preliminary groundwater investigation to assess the potential to develop a new source in an aquifer hosted in sediments near the Fraser River, and to outline additional investigations that would be needed to investigate this possibility further.

Scope

Piteau initially completed a preliminary review of aquifer conditions along a study area extending along the south bank of the Fraser River between the JAMES Plant on Gladwin Road, and the eastern end of Page Road, a distance of about 10 km. The north bank of the same reaches was later also included in the study. The work has examined the feasibility of establishing one or more new groundwater sources using conventional vertical well and/or radial well technology. This has involved:

- Creating plans of the study area to summarize information on geology, aquifers and wells, and land ownership, and cross sections with information on topography, lithology (sediments), aquifer water levels, and conditions encountered during water well drilling;

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- Creating plans of the study area to summarize information on geology, aquifers and wells, and land ownership, and cross sections with information on topography, lithology (sediments), aquifer water levels, and conditions encountered during water well drilling;

- Evaluating prospective development areas in terms of supply capacity, access (e.g., land ownership), proximity to existing infrastructure, ambient groundwater quality, known or suspected sources of anthropogenic contamination, potential for impacts to the groundwater source in terms of water quality or capacity, expandability, risks, and impacts of climate change;
- Reviewing regulatory issues (e.g., potential licensing issues and/or applicability of the *Environmental Assessment Act*);
- Commenting on likely groundwater quality issues relating to non-anthropogenic sources such as surface water pathogens (e.g., Giardia and Cryptosporidium) and background water quality (e.g., arsenic, iron, manganese, etc.); and
- Reviewing environmental effects associated with development and operation of groundwater sources and potential for flooding and flowing artesian well conditions.

Study Participants

The project team has included David Tiplady, P.Eng., Vice President of Groundwater, and Arnd Burgert, P.Geo., Sr. Hydrogeologist and Project Manager, from Piteau. John Harris, P.Eng. of International Water Supply Ltd. in Barrie, Ontario has also been involved as a technical expert on siting, design, and construction of radial collector wells.

INFORMATION ON STUDY AREA

The Study Area covers the northern portion of Matsqui Prairie and the southern portion of Mission and Hatzic, as outlined on Figure 1. The area lies within 100 m of the Fraser River, extending along both banks for a distance of about 10 km. On the left (south) bank, the included area extends from the JAMES Plant on Gladwin Road to the eastern end of Page Road, while on the right (north) bank, the area extends from the Mandale Slough area south of Mission Bridge (Hwy. 11) to east of Hatzic Slough.

Surficial Geology

Surficial Geology of the Study Area (Armstrong, J.E. and Hicock, S.R., 1980) is shown on Figure 2. Sediments consist of stratified fluvial materials that were deposited by the Fraser River, including layers of unconsolidated silt, sand, and gravel.

The depositional sequence is shown in cross section on Figures 3 and 4. The locations of the sections are shown by black lines on Figure 2. The upper 10 m of sediments typically consists of silty sand (Unit Fh), and below this coarser beds including sand and gravel are present.

Borehole logs for geotechnical test holes drilled as part of the Mission Bridge construction project (Klohn-Crippen, 2000) confirm that a sand unit lying beneath Fraser River at the bridge extends beneath the shore beyond both river banks, as depicted in Figure 3. A geotechnical study (Agra Earth & Environmental, 1995) completed for the design of a Fraser River water main crossing near the east end of the Study Area also confirms the presence of sandy deposits beneath the bed of the Fraser River.

As a result of their deposition in a fluvial environment, the sediment beds are deposited in sub-horizontal layers. However, grain size composition of the sediments can change rapidly, with coarser deposits conforming to the shapes of former river channels. The beds are not discrete layers like a stack of pancakes, but rather a complex sequence of interconnected strata.

As shown on Figure 3, a bedrock knob or ridge is present near the intersection of the two cross sections, with a crest elevation of about 25 m below sea level. Its presence was confirmed by geotechnical test holes drilled in the Mission Bridge right-of-way (Klohn-Crippen, 2000).

Aquifers

Aquifer mapping (Figure 5) by the BC Ministry of Environment (Kreye et al., 1998) indicates that Aquifer 22 (the Matsqui Prairie Aquifer) is present in the Matsqui Prairie area south of the Fraser River. Its mapped extents encompass an area of 40 km^2, and the depth to groundwater is typically about 3 m. Aquifer 22 is rated as having moderate productivity and moderate vulnerability to contamination from surface sources.

North of the Fraser River, the Study Area covers portions of Aquifer 12 (Nicomen Slough Aquifer), Aquifer 17 (Mission Floodplain Aquifer), and Aquifer 18 (Mission Aquifer). Aquifer 18 is a fractured bedrock aquifer that is not prospective for obtaining a high-yielding source. Aquifer 12 is an unconfined aquifer encompassing an area of 50 km^2, and consists of Fraser River sediments (silt, sand and gravel). Depth to water is typically 4 m, productivity is moderate, and aquifer vulnerability is considered high.

Aquifer 17 covers 7 km^2, is unconfined, and consists of Fraser River sediments. The depth to groundwater is typically 3.5m, and the aquifer is rated as high productivity and high vulnerability.

Existing Water Wells

Locations of registered water wells are shown on Figure 5 (MOE, 2016). Well depths range from dug wells less than 4 m to drilled wells over 50 m. Driller's estimated well yields range from 0.6 to 25.2 L/s. The wells are generally completed with screens set in silty sand units shallower than about 15 m below ground level. The higher yielding wells have a deeper sandy gravel source. Their main uses are for irrigation and domestic supply, but three wells on Thompson Avenue in Mission (WTN 34131, 34134, and 34135) were drilled for the District of Mission in 1976 were likely intended for municipal use.

Water Quality

No water quality information is available for Aquifer 22. Iron has been reported as a water quality issue in Aquifer 12. In Aquifer 17, a well drilled to a depth of 165 m reported iron between 17 and 34 m depths, and saline water between 54 and 66 m depths.

There are no known contaminated sites with the potential to affect groundwater quality in the Matsqui Prairie area south of the Fraser River. On the north bank, historical and current industrial land uses within the Study Area have included sawmills and automotive repair or wrecking. These activities are listed in the Contaminated Sites Regulation Schedule 2, which itemizes land uses that pose an elevated risk of impacts to soil or groundwater conditions. Accordingly, siting a groundwater source on the north shore would require assessment of potential risk of pollutants from industrial sources.

In any of the three aquifers, it can be anticipated that dissolved iron and/or manganese may be present at elevated concentrations in groundwater, potentially necessitating treatment. This risk could be further assessed during field investigations, and the production wells/collector could be sited and designed so as to reduce metals concentrations by maximizing dilution by inducing seepage from the Fraser River.

Surface Water

Mapped streams and drainages in the vicinity of the Study Area are shown on Figure 1. On the south shore, drainages in the Study Area are limited to ditches. The BC MOE Fisheries Information Summary System (FISS) database does not indicate fish presence in these ditches, but fish habitat cannot be ruled out on this basis. On the north shore, the Study Area is intersected by D'Herbomez Creek and Lower Hatzic Slough. The FISS database indicates that Lower Hatzic Slough, Windebank Creek, Mandale Slough, and the lower reach of D'Herbomez Creek are all habitat for Coho salmon.

Existing water license locations near the Study Area are shown on Figure 1. In the Matsqui Prairie area, the only surface water license north of the CN Rail line is for irrigation from the Fraser River. Water licenses on the north shore include one license on D'Herbomez Creek, one domestic license on Catchpole Spring, and several on Hatzic Slough.

The Water Survey of Canada (2017) has recorded stage and discharge records for the Fraser River at Mission since 1969. This station is situated at the north abutment of the rail bridge, as marked on Figure 1. The data are summarized on Figure 6, and show that stage and discharge reach a yearly maximum during freshet in June. The yearly variation in stage is typically 3 m. Hourly stage measurements in the lower graph on Figure 6 show about 0.3 to 1.5 m of tidal influence at this station, cycling approximately twice per day.

The morphology of the Fraser River channel has been mapped by Church and Ham (2004). Their study involved drawing channel cross sections along the lines indicated on Figure 7. Selected cross sections looking downstream are presented on Figure 8. These indicate channel depths in 1999 ranged from about 11 to 21 m below the reference water line, and that in places the channel invert has changed by up to about 5 m compared to historical depths.

Research by Ward (1976) indicates that a salt-water wedge can intrude as much as 21 km upstream from Steveston at low water. As Abbotsford is approximately 75 km upstream from Steveston, the Fraser River is not susceptible to elevated salinity from sea water at in the study area.

Land Ownership and Access

Property boundaries are shown on Figure 9, with ownership of riverfront parcels listed in the table on the figure. Most of the riverfront properties on the south shore are owned by government agencies. All of these properties are all situated on the north side of the dyke, and are thus within the Fraser River flood plain. All riverfront properties on the north shore are privately owned.

FEASIBILITY OF DEVELOPING A GROUNDWATER SOURCE IN THE MATSQUI BEND AREA

Requirements for a High-Capacity System

Options for development of a 25 to 50 MLD groundwater source recharged with infiltration from the Fraser River that have been considered include a radial collector system and a series of vertical wells. Either system will require the following conditions:

- Aquifer sediments must be sufficiently permeable to transmit the required groundwater flow rates. Fluvial sand and gravel deposits having a relatively high capacity to transmit groundwater may form suitable target formations, while fine-grained deposits rich in silt and clay (glacial till, marine mud deposits, or fine-grained overbank deposits) do not. A material's ability to convey groundwater is quantified using the term hydraulic conductivity.
- The aquifer must be of sufficient size to accommodate sufficient well screen length so that screen entrance velocities are acceptable.
- Recharge to the aquifer must be sufficient to sustain the required demand without causing unacceptable impacts on existing water wells or impacting surface water flows.

These three criteria are interrelated, and their applicability to the Study Area is further discussed in this section.

Information from construction records for existing wells indicate that fine- to coarse-grained sand layers are present within 15 m of ground level in aquifers 12, 17, and 22. Where indicated, yields for existing wells drawing from the upper portion of this aquifer average about 3.6 L/s and range up to 10.9 L/s. No estimates of hydraulic conductivity are available for these materials.

A large capacity groundwater extraction system will need to induce infiltration of water from the Fraser River. Since the maximum rate of flow from the river to a well will be inversely proportional to its distance from the river bank, proximity to the river will need to be optimized.

Conventional Vertical Water Wells

One option for developing a water supply in the Study Area is to utilize a series of conventional vertical water wells. Assuming a screen slot size of 0.89 mm (0.035"), the length of 300 mm (12") diameter screen required to supply 25 and 50 MLD would be 50 m and 100 m, respectively. Assuming this is achieved with vertical wells each with an average screen length of 10 m, between 5 and 10 wells could be required. The amount of screen and number of wells will also be influenced by the hydraulic properties of the aquifer sediments and the boundary conditions.

Based on the desire to position groundwater extraction points as close as possible to the river, it would be necessary to position wells within the floodplain on the north side of the dyke. Completion designs for the tops of the wells would need to incorporate flood-proofing.

Radial Collector Well

Assuming suitable aquifer conditions, a radial collector well could be considered as an alternative to conventional vertical wells. A radial well is constructed by penetrating an aquifer with a large (~5 to 7 m) diameter concrete caisson, and driving horizontal well screens from openings in the sides of the caisson into the aquifer. Depending on soil and hydraulic conditions, it may be possible to achieve the required length with two or four radial screens oriented parallel to the river, or potentially at an angle towards the river. The radial well has an advantage over conventional water wells since the length of screen is not limited by aquifer thickness, and depending on the positioning of the screen laterals, the wells can achieve a larger amount of drawdown.

Appendix A includes an estimate of potential inflow to a radial collector well with screen laterals oriented parallel to the river. The calculation is based on a simple analytic formula for steady-state flow towards horizontal line sink in an unconfined aquifer. Using an assumed hydraulic conductivity (K) typical for sand (5×10^{-4} m/s), and assumed values for saturated thickness (H), drawdown (H-h), and a 30m offset from the river (L), the calculations indicate a capacity of 25 MLD could be achieved with a lateral length (X) of 52 m. Using the same assumptions, a lateral length of 104 m would be needed to achieve a flow of 50 MLD.

This analysis is based on idealized conditions, such as uniform hydraulic conductivity (K) and a direct hydraulic connection between the aquifer and the Fraser River. It ignores partial penetration effects for the collector, horizontal to vertical anisotropy, and does not account for groundwater flow toward from the landward side or the ends of the collector. As such, the results are a rough estimate. Nevertheless, they do highlight the relevance of the key variables and the sensitivity of the maximum flowrate to changing river levels that would influence saturated thickness (H), available drawdown (H-h), and offset from the river (L).

Flood proofing of a radial well is straightforward, and involves positioning the top of the caisson at a position above the flood level, and ensuring all mechanical and electrical connections are sufficiently protected through burial.

An existing flood protection dyke parallels the Fraser River at Matsqui Prairie. Water wells or a radial collector well must be offset a sufficient distance to avoid destabilizing the dyke.

Groundwater Treatment

Assuming that the objective is to utilize wells drawing from one or more aquifers that have a strong hydraulic connection to the Fraser River, it should be assumed that the water would be considered as groundwater at risk of containing pathogens (GARP), and that treatment to remove Cryptosporidium oocysts and Giardia cysts would be required. Additionally, it may be necessary to treat for other natural constituents such as dissolved iron and manganese.

Regulatory Considerations

Pursuant to the Water Sustainability Act, a municipal groundwater source must be licensed by the Ministry of Forests, Lands, and Natural Resource Operations. Additionally, in accordance with the Reviewable Projects Regulation under the Environmental Assessment Act, a groundwater source with a yield of over 6.5 MLD (75 L/s) is subject to an Environmental Assessment by the Environmental Assessment Office.

As most of the groundwater from wells, or a radial well collector, will be recharged by infiltration from the Fraser River, it can be anticipated that the project would have a relatively small influence on nearby groundwater and surface water resources. The level of effort involved in an environmental assessment would therefore be less than in the case of the AMWSC's Bevan Wells, where the assessment had to address effects on low-flows in several sensitive creeks and municipal wells operated by another agency. At approximately 1,750 m^3/s or 150,000 MLD (Figure 6), the average seasonal low-flow in the Fraser River is more than 3,000 times greater than the maximum anticipated rate of groundwater extraction (50 MLD) for this project, thus indicating that any effects on the Fraser River will be negligible.

RECOMMENDED INVESTIGATIONS

Based on the desktop study summarized in the report, the Study Area appears prospective for development of a groundwater supply with a capacity of 25 to 50 MLD. However, further information is needed to assess local conditions with respect to thickness and hydraulic conductivity of sandy material along the river, and the degree of hydraulic connection with the river. In this regard, the following phased investigations are recommended.

Phase 1 – Reconnaissance Drilling

A series of reconnaissance test holes should be drilled at intervals along the riverfront in areas of interest to assess the thickness and properties (e.g., hydraulic conductivity) of sandy aquifer materials. The resonant sonic drilling method is preferred, as this returns a continuous soil core, and facilitates collection of bulk samples for grain size analysis. Where soils appear to be sufficiently permeable to warrant further consideration, boreholes can be converted to monitoring wells to facilitate collection of water samples for water quality analyses, upset testing to estimate hydraulic conductivity, and water level monitoring.

Allowing for a spacing of 500 m, up to 14 borehole/monitoring wells would be required to investigate conditions throughout the entire study area. However, fewer boreholes will be necessary if the investigation focusses on one or a few preferred locations.

Data gathered during this reconnaissance investigation can be used to refine input parameters for the preliminary flow calculations indicated in Appendix A, and provide rough estimates of the number of wells, and/or length of collector that would be required to achieve the required flow at the locations investigated. Based on these results, prospective locations for further study can be identified.

Phase 2a – Geophysical Investigation

Depending on the results of Phase 1, consideration should be given to conducting geophysical surveys at prospective well or radial collector sites. Electromagnetic sounding, used in conjunction with a borehole program, can be useful in differentiating potential aquifer zones from low-permeability zones, and may be helpful in terms of optimizing the selection of locations for subsequent investigations.

Phase 2b – Test Well Drilling and Aquifer Pump Testing

If results of the reconnaissance drilling program indicate favourable conditions are present, a test well program would be required to estimate aquifer properties and the potential to induce infiltration from the Fraser River. One or more test wells would be drilled, likely with 200 mm diameter casings to accommodate an appropriately sized submersible test pump. Aquifer pumping tests would be completed to stress the aquifer and would provide the basis for refined estimates of aquifer properties and boundary conditions. Samples of groundwater pumped from the test wells would be analyzed to assess potability and treatment requirements.

The results of these investigations should be used as the basis of a three-dimensional groundwater flow model that can be used to evaluate the approximate physical requirements for a 25 to 50 MLD groundwater source.

Phase 3 – Detailed Investigation

Based on the results of the first two phases, site selection would be finalized, and a detailed test well program would be initiated. This would involve drilling a series of test holes/monitoring along the proposed alignment for horizontal collectors or water wells, and conducting additional extended aquifer pump testing at times of high and low Fraser River stages.

Estimated Costs

A detailed breakdown of steps and possible level of effort to complete an investigation is included with Appendix B. A Class D (preliminary) estimate of costs to complete this program of investigation is as follows:

Phase	Task	Fees	Expenses	Contractor	Total
1	Reconnaissance drilling (4 holes)	25,000	7,000	34,000	66,000
2a	Geophysical survey (optional)			14,000	14,000
2b	Test well construction and aquifer pumping Tests at 2 prospective sites	45,000	7,000	58,000	110,000
3	Detailed Investigations at one site	50,000	10,000	175,000	235,000
	Total:	$120,000	$24,000	$281,000	$425,000

Actual costs may vary depending on the level of effort to achieve project objectives. The following items are not included in the amounts indicated above:

- Environmental assessment and licensing;
- Design, procurement, and construction of a radial collector well or vertical wells, and all related infrastructure; and
- Decommissioning of test wells and monitoring wells.

CONCLUSIONS AND RECOMMENDATIONS

This technical memorandum summarizes the results of an assessment of the feasibility of developing a 25 to 50 MLD water supply from a groundwater source in the Study Area adjacent to the Fraser River at Matsqui Bend.

The Study Area appears prospective for developing a high-capacity water supply provided that a well or wells can be sited within about 30 m of the Fraser River.

Options for developing a high-capacity supply include (i) a series conventional vertical water wells, or (ii) one or more radial groundwater collectors. In either case, the system will require the presence of an aquifer with permeable soils in close proximity to the Fraser River, and a strong hydraulic connection between the river and the aquifer. To determine where favourable conditions exist, a phased investigation approach is recommended, with each phase predicated on success of the preceding phases. The program would include:

- drilling reconnaissance test holes and installing monitoring wells;
- a geophysical investigation (optional);
- drilling of test wells and aquifer pump testing at prospective well locations; and
- detailed investigations at promising well sites including additional drilling, well construction, and extended aquifer pump testing.

A preliminary cost estimate to complete the investigation is on the order of $425,000. This is based on an assumed level of effort. Actual costs to achieve the project objective may vary.

LIMITATIONS

This investigation has been conducted using a standard of care consistent with that expected of scientific and engineering professionals undertaking similar work under similar conditions in BC. No warranty is expressed or implied.

This report is prepared for the sole use of Urban Systems Ltd. and the AMWSC. Any use, interpretation, or reliance on this information by any third party, other than the BC Environmental Assessment Office, is at the sole risk of that party, and Piteau accepts no liability for such unauthorized use.

CLOSURE

We trust this technical memorandum is sufficient for your current needs. Please contact the undersigned if you have any questions or comments.

Respectfully submitted,

PITEAU ASSOCIATES ENGINEERING LTD.

Feb. 16, 2018
A. BURGERT
#30284
AB

Arnd Burgert, P.Geo.
Senior Hydrogeologist

D. J. TIPLADY
16053
Feb 15 2018

David Tiplady, P.Eng.
Principal Hydrogeologist

AB/DT/dls
Att.

REFERENCES

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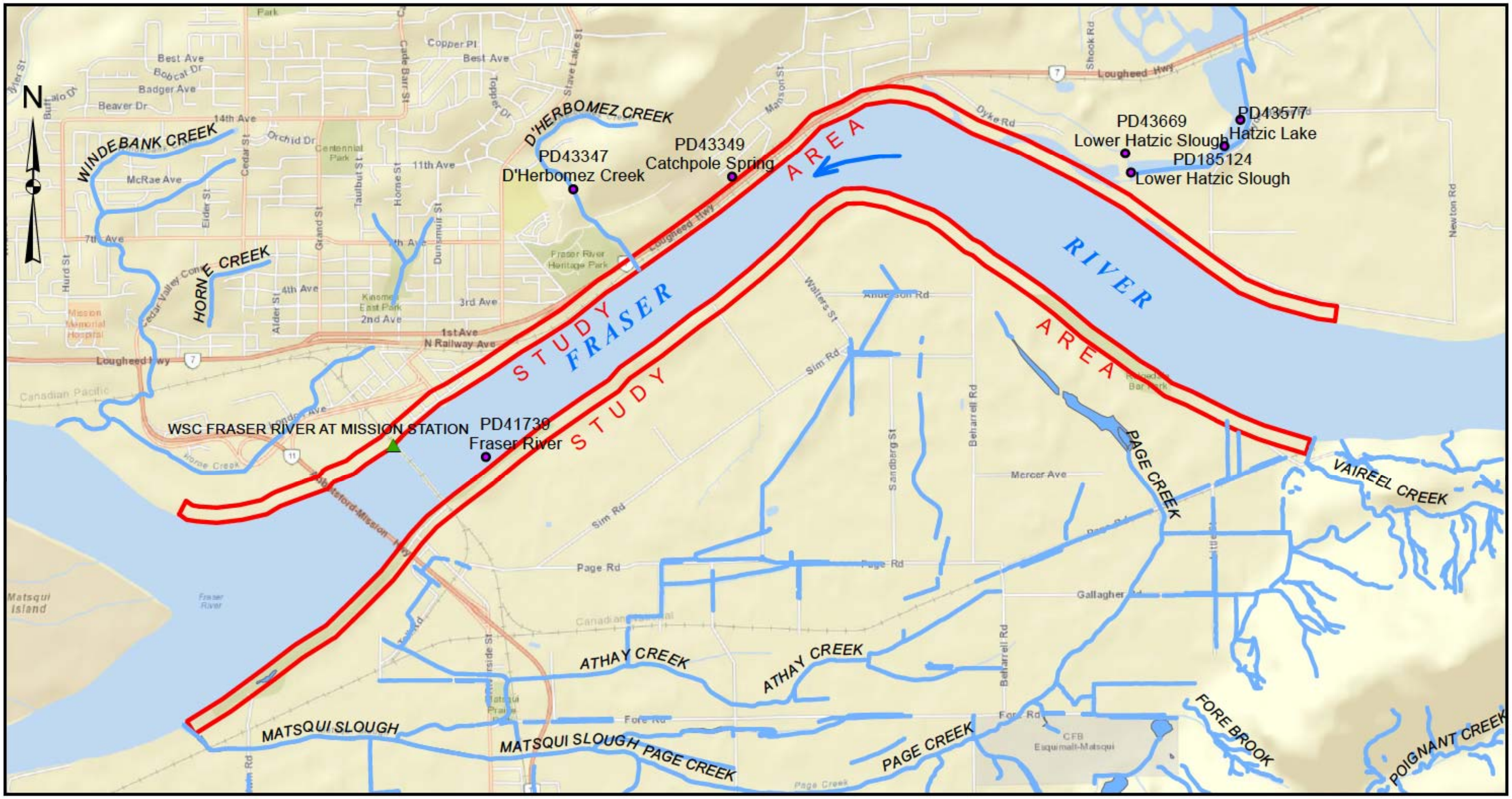
FIGURES

H:\Project\3694\ArcGis\3694_StudyArea.mxd



Legend

- ● Surface Water License
- ▲ WSC Gauging Station

0 500 1,000 1,500 2,000 m

SCALE: 1:40,000

URBAN SYSTEMS LTD.
AMWSC WATER SOURCE INVESTIGATION
ABBOTSFORD, B.C.

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

STUDY AREA AND SURFACE WATER HYDROLOGY

BY: AB	DATE: JUL 17
APPROVED: DJT	FIG: 1

H:\Project\3694\Maps\Surficial 11x17.grf

Legend

A ⌴ A' Location of Cross Section

QUATERNARY

POSTGLACIAL

SALISH SEDIMENTS

SAb-e	*Bog, swamp, and shallow lake deposits:* SAb, *low.and peat, organic silt loam, and silty clay loam 0.3 to 10+m thick overlying Fraser River Sediments* (Fc, d, g, h) *or Salish lacustrine deposits* (SAq, r); SAc, *similar to* SAb *except that the organic sediments are overlain by up to 1 m of silt loam, silt, and sand (Fraser River overbank deposits);* SAd, *lowland organic sandy loam to clay loam 15 to 45 cm thick overlying Fraser River Sediments* (Fd); SAe, *upland peat up to 8+m thick*
SAh-k	*Stream deposits, includes channel fill, floodplain, and overbank sediments:* SAh, *lowland stream channel fill and overbank sandy loam, and clay loam; in places contains disseminated organic material; up to 8 m thick;* SAi, *floodplain gravel and sand deposited by Chilliwack River in Sumas Valley; grades from gravel through sand into silt at the outer edges of a fan-shaped area; in part intermixed with Fraser River Sediments*(Fg,h) *and with Salish lacustrine deposits* (SAq, r), *maximum thickness 15 m;* SAj, *mountain stream channel gravel and minor sand, up to 10 m thick:* SAk, *lowland stream channel fill sand and gravel, minor silt, and clayey silt, up to 5 m thick*
SAm-p	*Slope deposits, colluvial sediments deposited by mass wasting processes:* SAm, *slopewash sand,up to 4m thick,resting on* Fc,d and Sa,j; SAn, *slopewash clayey silt and silty clay up to 2 m thick, overlying* Sa; SAo, *fan and landslide gravel, sand and rubble, up to 15+m thick, overlying Fraser River Sediments* (Fg,h) *and Salish lacustrine deposits* (SAq,r); SAp, *landslide and fan gravel and rubble, up to 10 m thick, overlying Sumas Drift* (Sa,c,f) *and Fort Langley Sediments*
SAt	*Eolian deposits:* SAt, *windblown sand, silt, and silt loam, 1 to 8 m thick* *Eolian deposits have been mapped as a separate unit where they are more than 1 m thick. In addition most pre-Salish Sediments exposed east of 122°25'W are mantled by windblown sand and silt 5 cm to 1 m thick. Included are areas mapped as* T *and* PT *up to at least 1000 m elevation*

FRASER RIVER SEDIMENTS

Fa, Fc-h	*Channel fill and floodplain deposits, overlying and cutting estuarine sediments* (Fe) *and commonly overlain by overbank sediments:* Fa, *channel deposits, sand, and gravel occurring along present day Fraser River channels; normally overlie older channel deposits* (Ff), *and combined thickness may vary from 10 to 60 m;* Fc, *overbank silty to silty clay loam and minor sand up to 2 m thick overlying* Fd; Fd, *channel fill, clayey silt, and silty clay up to 10 m thick overlying* Ff; Fe*, *estuarine fine sand to clayey silt, in places fossiliferous; probably underlies extensive areas in Sumas and Matsqui valleys; thickness may vary from 10 to 150 m;* Ff*, *channel and floodplain sand and gravel, up to 60 m thick, underlying* Fd,g,h; *may be in part Sumas outwash* (Sa,j); Fg, *channelled deposits (expressed at surface by ridges and swales), silty clay loam, silt loam, silty clay, and minor organic sediments, up to 10 m thick, overlie* Ff *and* Fe; Fh, *channelled deposits similar to* Fg *but coarser textured, sandy loam and loamy sand*

PLEISTOCENE

SUMAS DRIFT

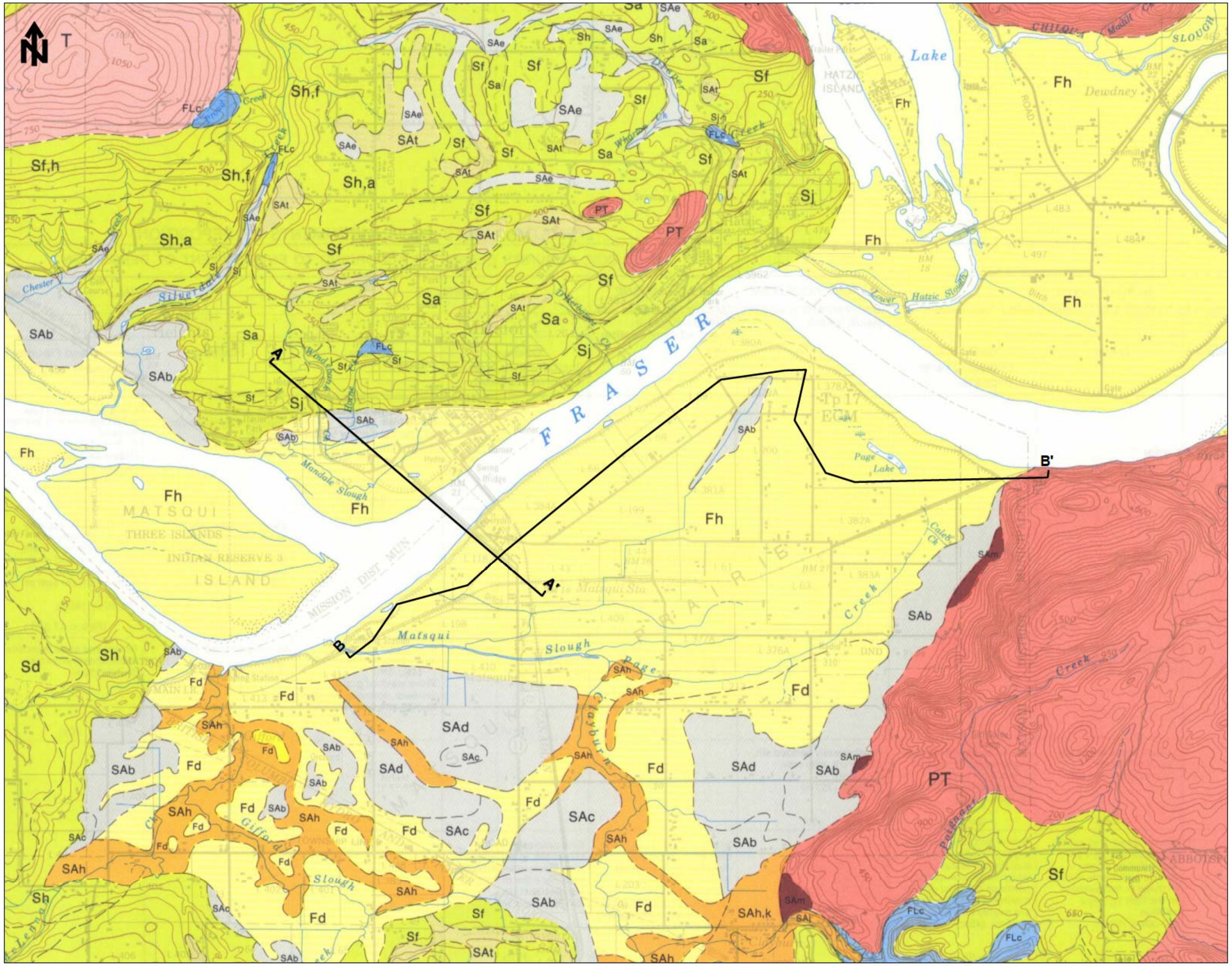
Sa,e,i	*Recessional glaciofluvial deposits:* Sa, *recessional channel and floodplain deposits laid down by proglacial streams; gravel and sand up to 40 m thick, normal range of thickness 5-25 m;* Se, *proglacial deltaic gravel and sand up to 10 m thick;* Si, *similar to* Sa *except that it is pitted outwash*
Sf,g	*Lodgment and minor flow till:* Sf, *sandy till and substratified drift, 2 to 10 m thick;* Sg, *sandy till and substratified drift 0.5 to 2 m thick, in most places overlying Fort Langley glaciomarine sediments* (FLc)
Sj	*Advance glaciofluvial deposits:* Sj, *gravel and sand up to 40 m thick, proglacial channel fill, floodplain, and deltaic sediments probably all included here*

FORT LANGLEY FORMATION

FLa, c,d	*Glaciomarine deposits, marine sediments, and minor till;* FLa, *lodgment till and flow till with sandy loam matrix; may contain clasts of and interbedded with* FLc *and* FLd; FLc, *glaciomarine stony silt to loamy clay, 8 to 100 m thick;* FLd, *silty clay to sandy loam up to 30 m thick, generally intimately intermixed with* FLc *and shown as a separate unit only where it occurs in mappable exposures*
FLb,e	*Glaciofluvial sediments:* FLb, *channel fill, floodplain, and ice-contact gravel and sand, in places containing clasts of till and glaciomarine sediments, 5 to 20 m thick, interbedded with* FLa,c,d; FLe, *proglacial deltaic gravel and sand, up to 60 m thick, in places interbedded with* FLa,c,d

PRE-TERTIARY

PT	*Mesozoic and Upper Paleozoic bedrock; includes sedimentary, volcanic, granitic, and metamorphic rocks, mantled in 90 per cent of the area by deposits, 1 to 5 m thick, of glacial* (S and V), *colluvial* (SAm,p), *and eolian* (SAt) *sediments*



SCALE 1:25,000

0 250 500 750 1000 1250 m

Source: Armstrong, J.E. and Hicock, S.R., 1980. Surficial Geology of Mission map area, British Columbia. Geological Survey of Canada Map Sheet 1485-A (1: 50,000 scale).

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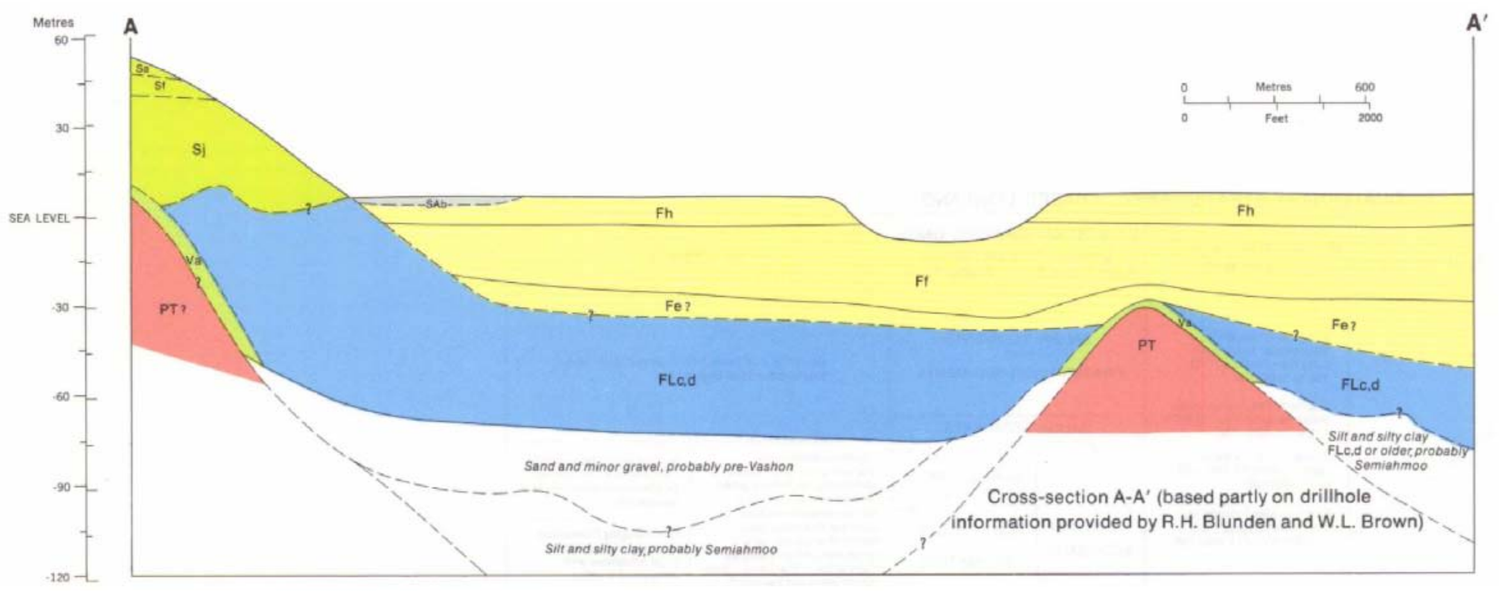
ABBOTSFORD, B.C.

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

SURFICIAL GEOLOGY

BY: AB
DATE: JUL 17
APPROVED: DJT
FIG: 2

H:\Project\3694\EnviroInsite\XSA 11x17.grf



Cross-section A-A′ (based partly on drillhole information provided by R.H. Blunden and W.L. Brown)

Legend

QUATERNARY

POSTGLACIAL

SALISH SEDIMENTS

SAb-e *Bog, swamp, and shallow lake deposits:* SAb, *low and peat, organic silt loam, and silty clay loam 0.3 to 10+m thick overlying Fraser River Sediments* (Fc, d, g, h) *or Salish lacustrine deposits* (SAq, r); SAc, *similar to* SAb *except that the organic sediments are overlain by up to 1 m of silt loam, silt, and sand (Fraser River overbank deposits);* SAd, *lowland organic sandy loam to clay loam 15 to 45 cm thick overlying Fraser River Sediments* (Fd); SAe, *upland peat up to 8+m thick*

FRASER RIVER SEDIMENTS

Fa | Fc-h *Channel fill and floodplain deposits, overlying and cutting estuarine sediments* (Fe) *and commonly overlain by overbank sediments:* Fa, *channel deposits, sand, and gravel occurring along present day Fraser River channels; normally overlie older channel deposits* (Ff), *and combined thickness may vary from 10 to 60 m;* Fc, *overbank silty to silty clay loam and minor sand up to 2 m thick overlying* Fd; Fd, *channel fill, clayey silt, and silty clay up to 10 m thick overlying* Ff; Fe*, *estuarine fine sand to clayey silt, in places fossiliferous; probably underlies extensive areas in Sumas and Matsqui valleys; thickness may vary from 10 to 150 m;* Ff*, *channel and floodplain sand and gravel, up to 60 m thick, underlying* Fd,g,h; *may be in part Sumas outwash* (Sa,j); Fg, *channelled deposits (expressed at surface by ridges and swales), silty clay loam, silt loam, silty clay, and minor organic sediments, up to 10 m thick, overlie* Ff *and* Fe; Fh, *channelled deposits similar to* Fg *but coarser textured, sandy loam and loamy sand*

PLEISTOCENE

SUMAS DRIFT

Sj *Advance glaciofluvial deposits:* Sj, *gravel and sand up to 40 m thick, proglacial channel fill, floodplain, and deltaic sediments probably all included here*

FORT LANGLEY FORMATION

FLa, c,d *Glaciomarine deposits, marine sediments, and minor till;* FLa, *lodgment till and flow till with sandy loam matrix; may contain clasts of and interbedded with* FLc *and* FLd; FLc, *glaciomarine stony silt to loamy clay, 8 to 100 m thick;* FLd, *silty clay to sandy loam up to 30 m thick, generally intimately intermixed with* FLc *and shown as a separate unit only where it occurs in mappable exposures*

VASHON DRIFT

Va,b *Till and glaciofluvial deposits:* Va, *lodgment till with sandy loam matrix, up to 10 m thick, overlain in many places by gravelly ablation till up to 3 m thick. Vashon Till exposed in the northwest part of the map area is drumlinized.* Vb, *glaciofluvial sandy gravel and gravelly sand, mainly proglacial advance deltaic deposits, up to 25 m thick*

PRE-TERTIARY

PT *Mesozoic and Upper Paleozoic bedrock; includes sedimentary, volcanic, granitic, and metamorphic rocks, mantled in 90 per cent of the area by deposits, 1 to 5 m thick, of glacial* (S *and* V), *colluvial* (SAm,p), *and eolian* (SAt) *sediments*

SCALE 1:25,000

0 250 500 750 1000 1250 m

Source: Armstrong, J.E. and Hicock, S.R., 1980. Surficial Geology of Mission map area, British Columbia. Geological Survey of Canada Map Sheet 1485-A (1: 50,000 scale).

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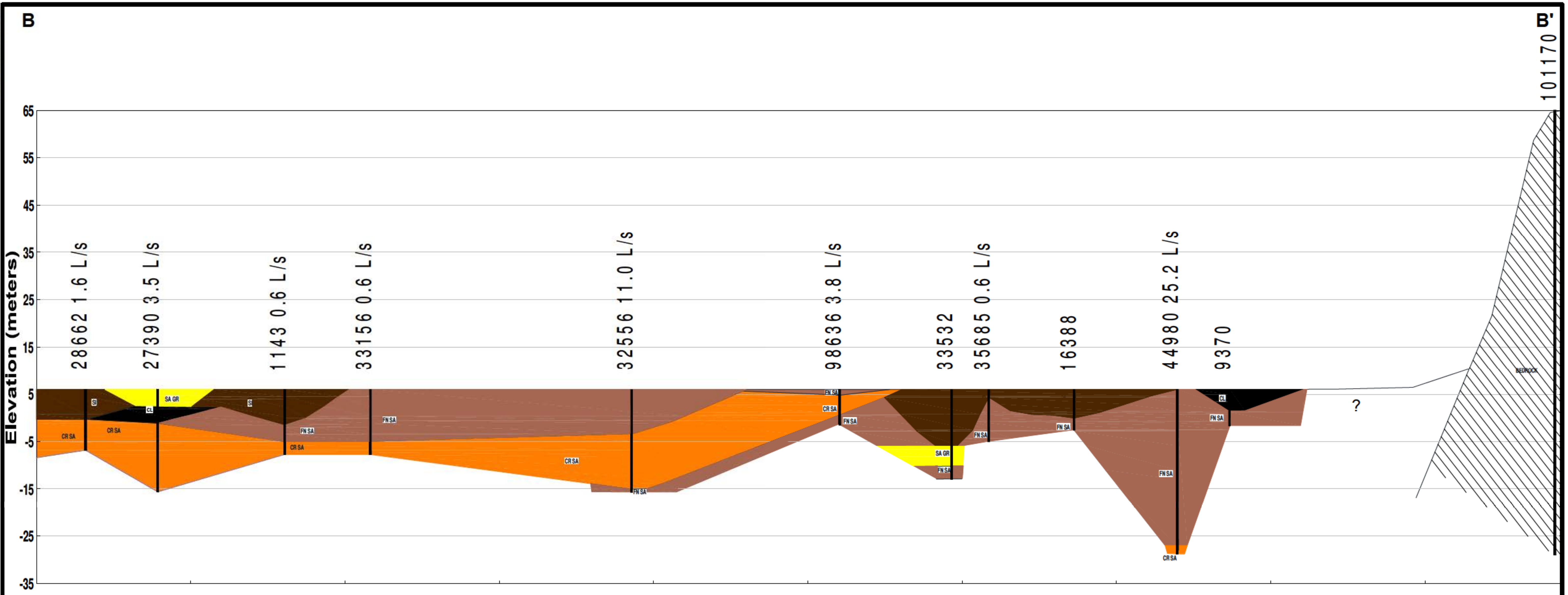
CROSS SECTION A-A'

BY: AB
DATE: JUL 17
APPROVED: DJT
FIG: 3

H:\Project\3694\EnviroInsite\XSB.grf



SI Silt

FN SA Fine Sand

CR SA Coarse Sand

SA GR Sand and Gravel

33156 0.6 L/s

Water well with BC MOE Well Tag No.
and driller's estimated yield

SCALE 1:25,000

0 250 500 750 1000 1250 m

VERTICAL EXAGGERATION 30X

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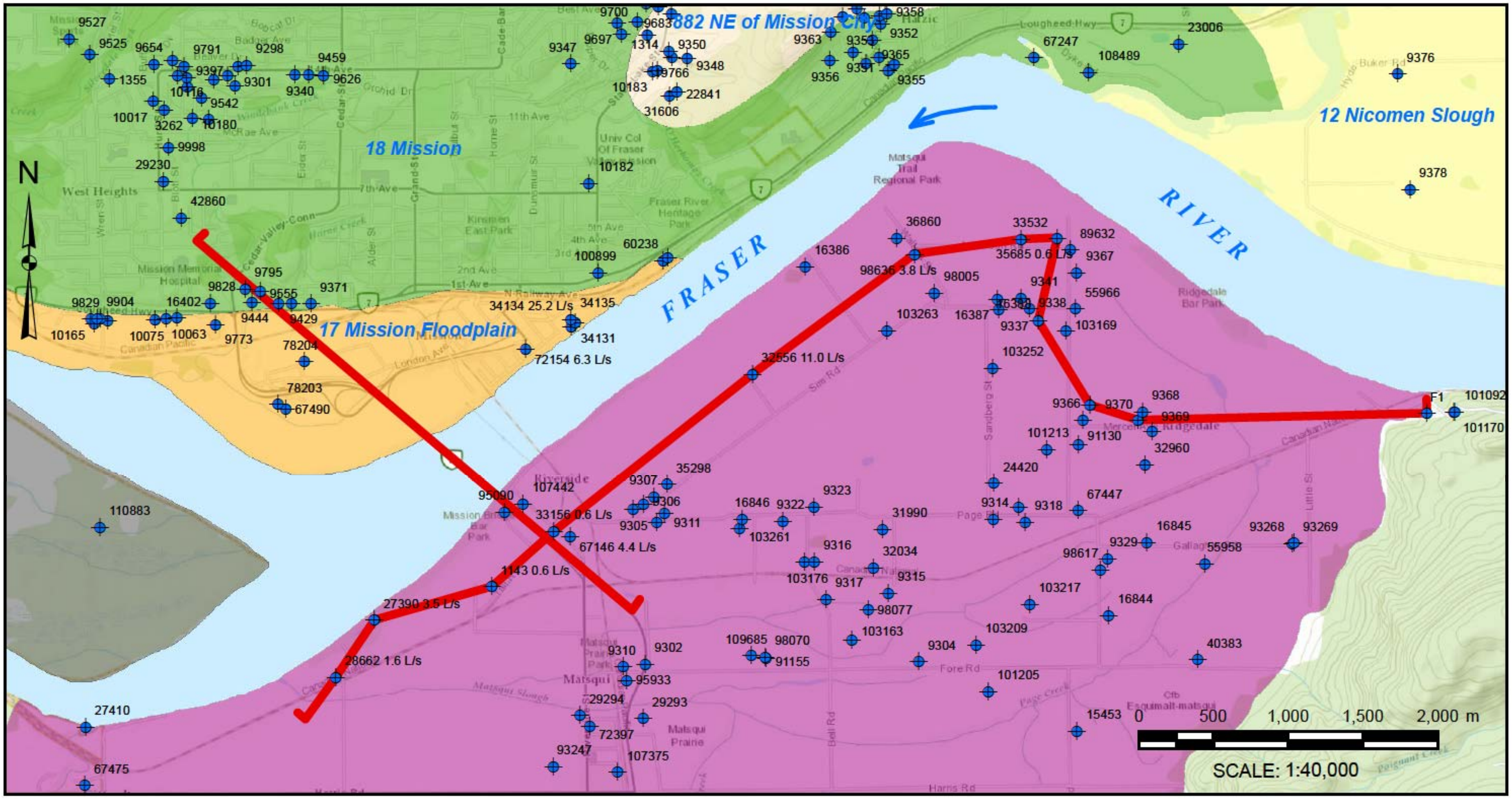
CROSS SECTION B-B'

BY: AB
DATE: JUL 17
APPROVED: DJT
FIG: 4

H:\Project\3694\ArcGis\3694_Aquifer.mxd



Legend

Aquifer Labels

⌖ Registered Water Well with Well Tag No.

🟥 Cross Section

Aquifer Mapping: Kreye et al., 1998. An Aquifer Classification System for Groundwater Management in British Columbia, BC Ministry of Environment, Water Management Division, Victoria.

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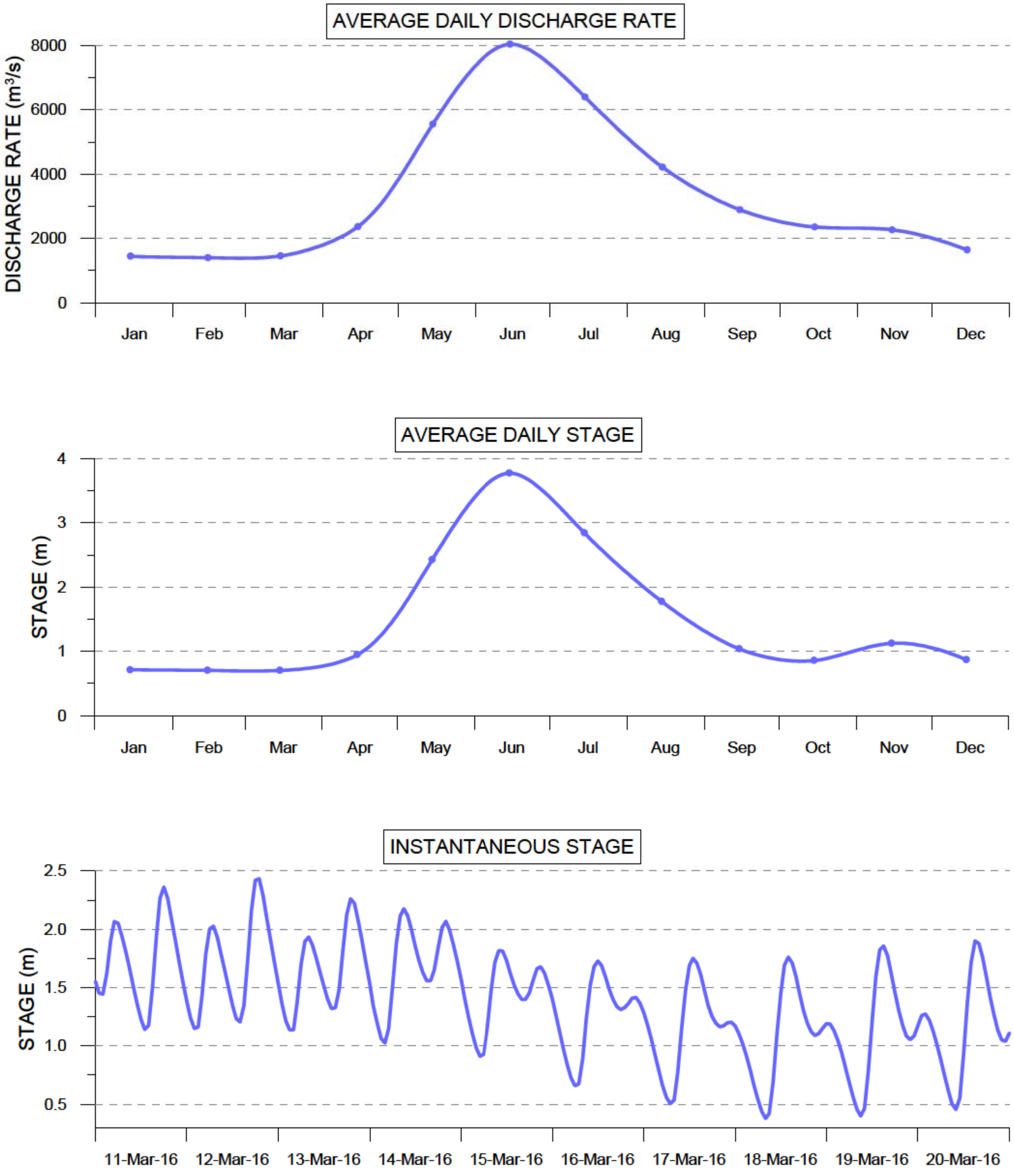
MAPPED AQUIFERS AND LOCATIONS OF REGISTERED WATER WELLS

BY: AB
DATE: AUG 17
APPROVED: DJT
FIG: 5

H:\Project\3694\Fraser Discharge Stage\Fraser.grf



NOTE:
All data from Water Survey of Canada Fraser River at Mission Station (08MH024).
Discharge statistics are for the interval 1965 - 1992.
Stage statistics are for the interval 1969 - 2014.

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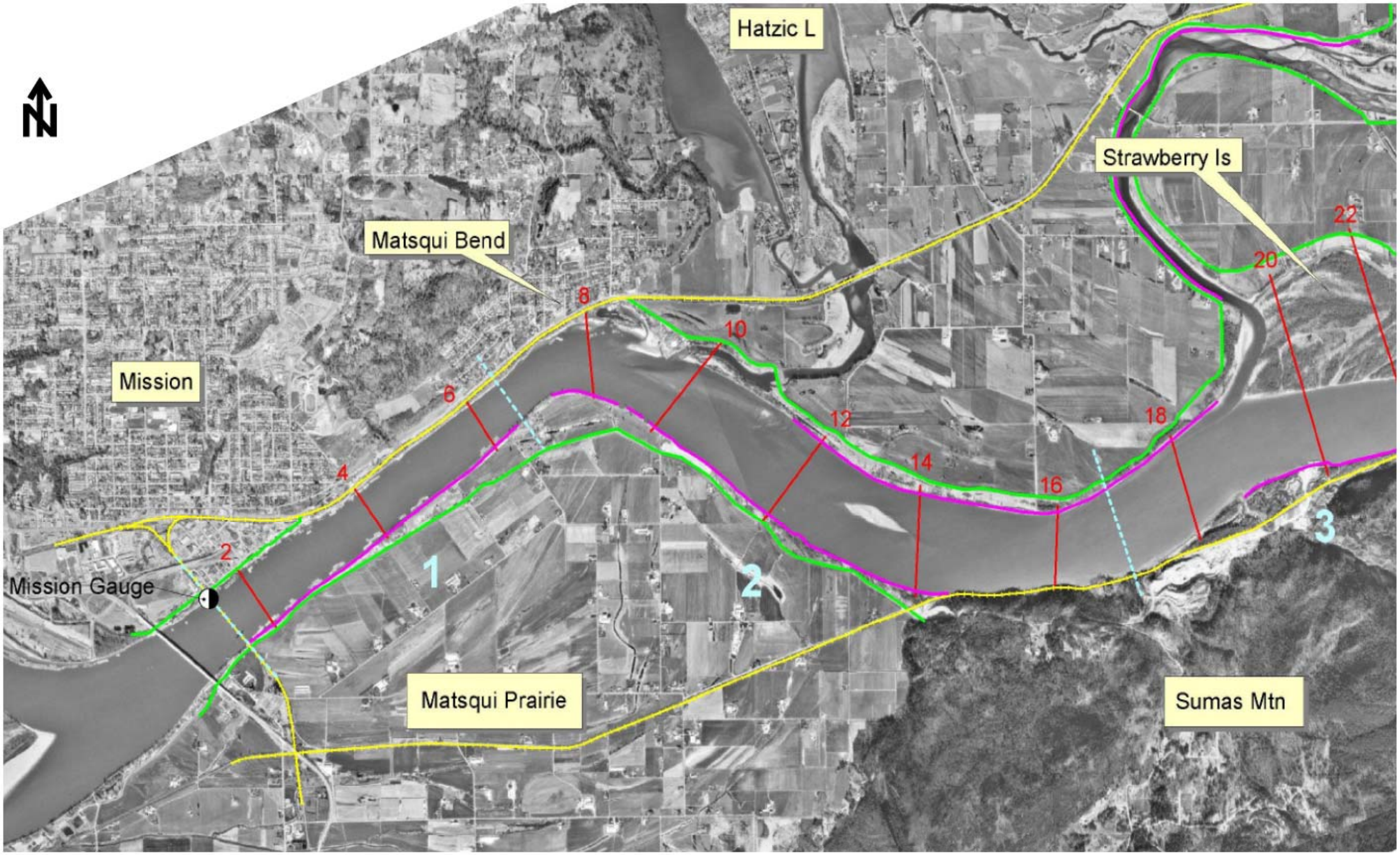
FRASER RIVER DISCHARGE AND STAGE

BY: AB
DATE: JUL 17
APPROVED: DJT
FIG: 6

H:\Project\3694\River Morphology\River Morph Map.grf



SCALE 1:50,000

0.0 0.5 1.0 1.5 2.0 2.5 km

Source: Church and Ham, 2004.

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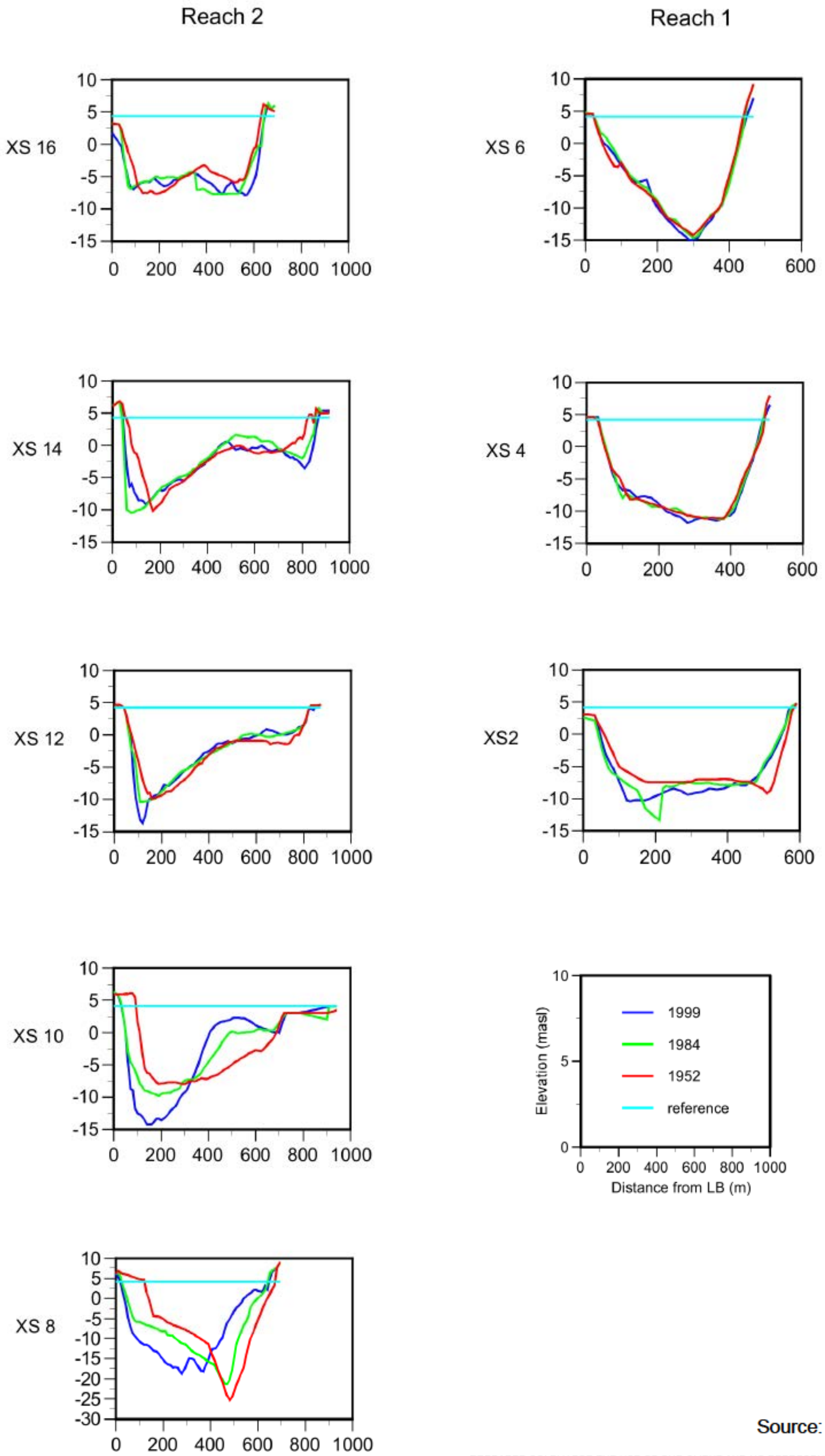
FRASER RIVER MORPHOLOGY - LOCATIONS OF CROSS SECTIONS

BY: AB
DATE: JUN 17
APPROVED: DJT
FIG: 7

H:\Project\3694\River Morphology\River Morph XS.grf



Source: Church and Ham, 2004.

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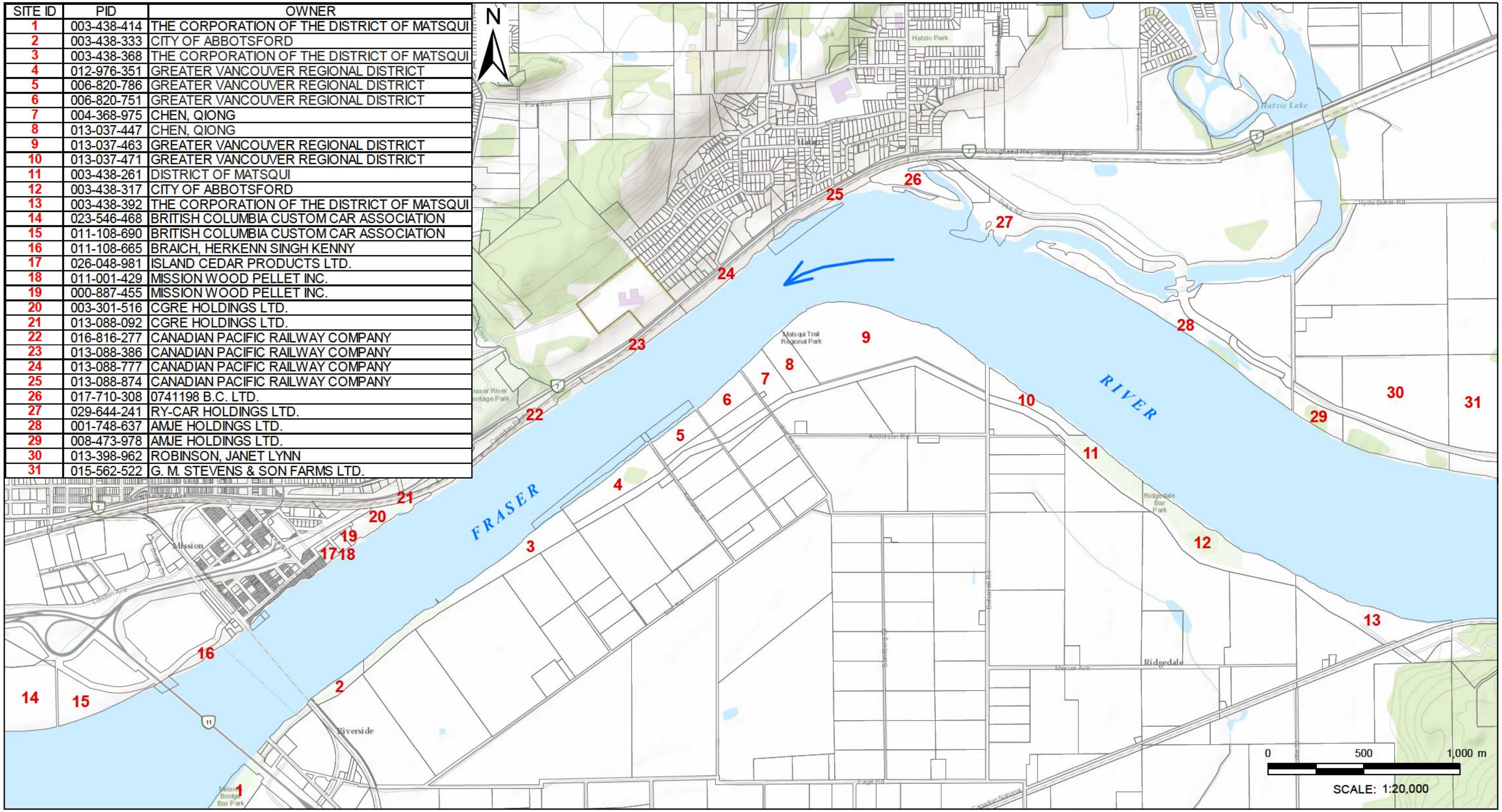
FRASER RIVER MORPHOLOGY - CROSS SECTIONS LOOKING DOWNSTREAM

BY: AB
DATE: JUN 17
APPROVED: DJT
FIG: 8

H:\Project\3694\ArcGis\3694_Cadastry.mxd

SITE ID	PID	OWNER
1	003-438-414	THE CORPORATION OF THE DISTRICT OF MATSQUI
2	003-438-333	CITY OF ABBOTSFORD
3	003-438-368	THE CORPORATION OF THE DISTRICT OF MATSQUI
4	012-976-351	GREATER VANCOUVER REGIONAL DISTRICT
5	006-820-786	GREATER VANCOUVER REGIONAL DISTRICT
6	006-820-751	GREATER VANCOUVER REGIONAL DISTRICT
7	004-368-975	CHEN, QIONG
8	013-037-447	CHEN, QIONG
9	013-037-463	GREATER VANCOUVER REGIONAL DISTRICT
10	013-037-471	GREATER VANCOUVER REGIONAL DISTRICT
11	003-438-261	DISTRICT OF MATSQUI
12	003-438-317	CITY OF ABBOTSFORD
13	003-438-392	THE CORPORATION OF THE DISTRICT OF MATSQUI
14	023-546-468	BRITISH COLUMBIA CUSTOM CAR ASSOCIATION
15	011-108-690	BRITISH COLUMBIA CUSTOM CAR ASSOCIATION
16	011-108-665	BRAICH, HERKENN SINGH KENNY
17	026-048-981	ISLAND CEDAR PRODUCTS LTD.
18	011-001-429	MISSION WOOD PELLET INC.
19	000-887-455	MISSION WOOD PELLET INC.
20	003-301-516	CGRE HOLDINGS LTD.
21	013-088-092	CGRE HOLDINGS LTD.
22	016-816-277	CANADIAN PACIFIC RAILWAY COMPANY
23	013-088-386	CANADIAN PACIFIC RAILWAY COMPANY
24	013-088-777	CANADIAN PACIFIC RAILWAY COMPANY
25	013-088-874	CANADIAN PACIFIC RAILWAY COMPANY
26	017-710-308	0741198 B.C. LTD.
27	029-644-241	RY-CAR HOLDINGS LTD.
28	001-748-637	AMJE HOLDINGS LTD.
29	008-473-978	AMJE HOLDINGS LTD.
30	013-398-962	ROBINSON, JANET LYNN
31	015-562-522	G. M. STEVENS & SON FARMS LTD.



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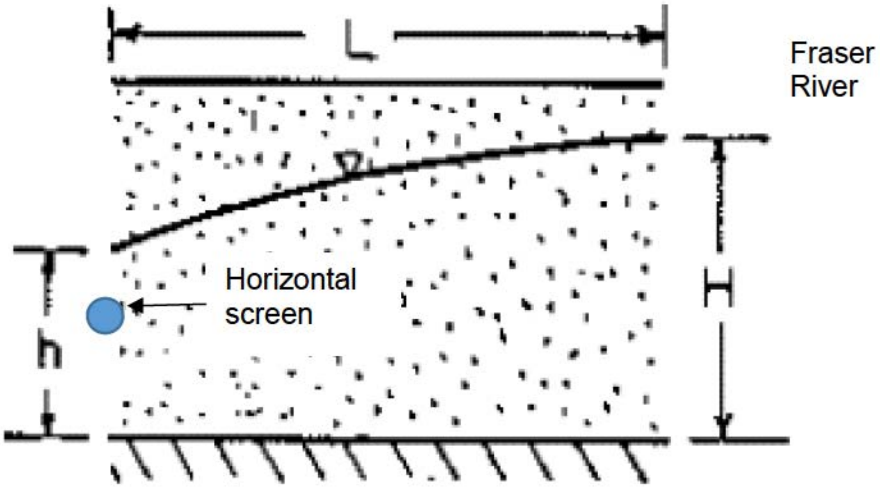
CADASTRY

BY: AB
DATE: JUL 17
APPROVED: DJT
FIG: 9

APPENDIX A

APPENDIX A

PRELIMINARY FLOW CALCULATIONS FOR HORIZONTAL GROUNDWATER COLLECTOR



Equation for steady state flow from line source (river) to a line sink (horizontal screen) in unconfined aquifer:

$$\frac{Q}{X} = \frac{K(H^2 - h^2)}{2L}$$

Symbol	Description	Unit	Assumed Value	Calculated Value
K	Hydraulic conductivity	m/s	5E-04	
H	Saturated thickness at river	m	30	
h	Saturated thickness at collector	m	15	
L	Distance between collector and river	m	30	
Q/X	Groundwater inflow per unit length	m^2/s		0.0056
X	Length of collector parallel to river	m	52	
Q	Groundwater inflow	m^3/s		0.29
		L/s		293
		MLD		25

APPENDIX B

APPENDIX B

ASSUMED LEVEL OF EFFORT FOR INVESTIGATIONS AT MATSQUI BEND

Phase 1 – Reconnaissance Drilling:

- four test boreholes to 30 m depth, drilled with track-mounted Sonic rig and completed as monitoring wells;
- five grain size analyses on soil samples from each borehole;
- hydraulic upset testing with each well;
- water level monitoring for one month in four monitoring wells and in the Fraser River;
- one water quality analysis on a sample collected from each well; and
- analysis, interpretation, and reporting.

Phase 2a – Geophysical Investigation:

- two TEM lines, each 1,000m in length, assuming meadow or deciduous timber with light underbrush (no linecutting); and
- plotting of maps and cross sections to present the results.

Phase 2b – Test Well Drilling:

- construct two test wells to 24 m depth, drilled with DR24 drilling rig;
- one 4-hour variable rate test with each test well;
- one 48-hour constant-rate test with each well;
- field testing for iron throughout the constant rate test;
- two water quality analyses per constant rate test; and
- analysis, interpretation, 3-dimensional groundwater flow modelling, and reporting.

Phase 3 – Detailed Investigation:

- four additional test boreholes (Sonic drill rig), completed as monitoring wells;
- two additional test wells to 24 m depth, drilled with DR24 rig;
- extended duration (10-day) aquifer pumping tests during seasonal low and high water in Fraser River;
- up to eight water quality analyses on samples collected during the tests; and
- up to 30 grain size analyses on sediment samples from test wells and test boreholes.

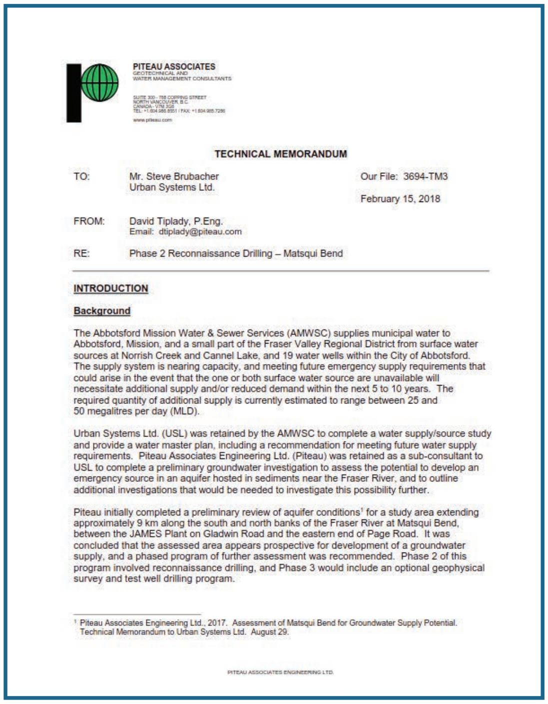
JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN

Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#11

PHASE 2
RECONNAISSANCE DRILLING



PITEAU ASSOCIATES
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NORTH VANCOUVER, B.C.
CANADA - V7M 3G6
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TECHNICAL MEMORANDUM

TO: Mr. Steve Brubacher
Urban Systems Ltd.

Our File: 3694-TM3

February 15, 2018

FROM: David Tiplady, P.Eng.
Email: dtiplady@piteau.com

RE: Phase 2 Reconnaissance Drilling – Matsqui Bend

INTRODUCTION

Background

The Abbotsford Mission Water & Sewer Services (AMWSC) supplies municipal water to Abbotsford, Mission, and a small part of the Fraser Valley Regional District from surface water sources at Norrish Creek and Cannel Lake, and 19 water wells within the City of Abbotsford. The supply system is nearing capacity, and meeting future emergency supply requirements that could arise in the event that the one or both surface water source are unavailable will necessitate additional supply and/or reduced demand within the next 5 to 10 years. The required quantity of additional supply is currently estimated to range between 25 and 50 megalitres per day (MLD).

Urban Systems Ltd. (USL) was retained by the AMWSC to complete a water supply/source study and provide a water master plan, including a recommendation for meeting future water supply requirements. Piteau Associates Engineering Ltd. (Piteau) was retained as a sub-consultant to USL to complete a preliminary groundwater investigation to assess the potential to develop an emergency source in an aquifer hosted in sediments near the Fraser River, and to outline additional investigations that would be needed to investigate this possibility further.

Piteau initially completed a preliminary review of aquifer conditions[1] for a study area extending approximately 9 km along the south and north banks of the Fraser River at Matsqui Bend, between the JAMES Plant on Gladwin Road and the eastern end of Page Road. It was concluded that the assessed area appears prospective for development of a groundwater supply, and a phased program of further assessment was recommended. Phase 2 of this program involved reconnaissance drilling, and Phase 3 would include an optional geophysical survey and test well drilling program.

---

[1] Piteau Associates Engineering Ltd., 2017. Assessment of Matsqui Bend for Groundwater Supply Potential. Technical Memorandum to Urban Systems Ltd. August 29.

PITEAU ASSOCIATES
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---

[1] Piteau Associates Engineering Ltd., 2017. Assessment of Matsqui Bend for Groundwater Supply Potential. Technical Memorandum to Urban Systems Ltd. August 29.

The results of the reconnaissance drilling (Phase 2) program are described in this technical memorandum.

Objective and Scope

The objective of the reconnaissance drilling program was to assess soil and groundwater conditions within the area of interest. The work involved:

- drilling four boreholes to investigate hydrostratigraphy, and facilitate collection of soil samples and installation of monitoring wells;
- completing grain size analyses of soil samples;
- completing hydraulic upset tests with monitoring wells to assess hydraulic conductivity of the soils surrounding the screened zones;
- monitoring levels in the monitoring wells using dataloggers; and
- collecting groundwater samples for chemical analysis.

SUMMARY OF WORK

Drilling and Monitoring Well Construction

Four test holes were drilled adjacent to the Fraser River on land owned by the City of Abbotsford (Figure 1). This was completed between October 24 and 27, 2017 using a track-mounted SonicSamp CRS-XL Max drill rig operated by Downrite Drilling. The drilling equipment returns a continuous core, and facilitates collection of bulk soil samples.

The boreholes were drilled to depths of 30.5 metres below ground. After backfilling the lower portions of the borehole with sand and bentonite, monitoring well standpipes constructed from 2” diameter PVC tubing with screen sections at the base were installed with screen depth intervals targeting coarser sands that were within the optimal depth of interest for a groundwater collector. Silica sand was placed around the screen sections, and bentonite seals were placed above the sand.

Following construction, the monitoring wells were developed to produce sediment-free groundwater. This was achieved by pumping water and sediment from the casing using Waterra™ foot valves pumps.

Logs including information on stratigraphy and monitoring well standpipe information are included with Appendix A.

Grain Size Analyses

Grain size analyses were completed with five sediment samples from each borehole. The analyses are included in Appendix B. Estimates of the hydraulic conductivity of these soils determined using the Hazen[2] method are included in Table I.

---

[2] Hazen, A., 1911. Discussion: Dams on sand foundations. Transactions: American Society of Civil Engineers, v.73, p199.

Hydraulic Upset Testing

Rising-head and falling-head hydraulic upset tests were completed with the monitoring wells. The falling-head tests involved lowering a heavy cylinder (slug) into the standpipe casing to cause a sudden rise in the water level. The subsequent decline in the excess head (relative to pre-test static water level) was then measured and recorded at frequent intervals using a pressure transducer and datalogger. The rising-head tests were similar to the falling-head tests, but involved monitoring the rise of the water level after the slug had been removed from the standpipe.

The falling-head and rising-head test data were analyzed using the Hvorslev[3] method. The analysis results are included in Appendix C, and the estimated values of hydraulic conductivity are summarized in Table I (in italics).

Surveying

Wade & Associates Land Surveying Ltd. were retained to survey location and top of casing elevation for each monitoring well. The surface water elevation in the Fraser River adjacent to each monitoring well site was also determined.

Water Level Monitoring

Transducer-dataloggers were used to record water levels in each of the monitoring wells at 10-minute intervals between October 27 and December 9, 2017.

The level fluctuations were compared to Fraser River stage measurements obtained from the Water Survey of Canada's Mission station. Results are shown on Figure 2.

Collection of Groundwater Samples

Groundwater samples for chemical analysis were collected from the monitoring wells on December 9, 2017 using a peristaltic pump drawing from suction tubes positioned near the centre of the screen. The samples were placed in appropriate bottles provided by the project laboratory (with preservative, if necessary), labelled, and stored in ice-chilled coolers. Additionally, samples to be analyzed for dissolved metals were passed through 0.5 μm filter to remove solid particulates and acidified to fix dissolved metals.

Samples from each of the four monitoring wells were analyzed for dissolved metals, anions, and nutrients. Additionally, samples from MW17-2 were also analyzed for total metals, total and dissolved organic carbon, UV transmittance, silicate, sulfide, and pharmaceuticals.

All analyses were completed by ALS Environmental. A Certificate of Analysis is included in Appendix D and analyses results are summarized in Table II.

---

[3] Hvorslev, M.J., 1951. Time Lag and Soil Permeability in Ground-Water Observations, Bull. No. 36, Waterways Experimental Station, Corps of Engineers, US Army, Vicksburg, Mississippi, pp. 1-50.

ANALYSIS AND INTERPRETATION

Stratigraphy

Materials encountered during drilling included mainly fine to medium sand containing less than 10% silt. No consistent gradational pattern was observed.

Groundwater Conditions

Saturated hydraulic conductivity (K) is a measure of a soil's ability to transmit water when subjected to a hydraulic gradient. Coarser soils generally have higher K values, and are targeted for groundwater supplies due to their ability to transmit larger amounts of water than finer materials.

Estimates of hydraulic conductivity for soils encountered during this investigation (Table I) range from 3×10^{-5} to 2×10^{-3} m/s. Based on the inherent limitations of the Hazen method, values determined from grain size curves are considered less accurate than results from hydraulic upset testing.

Trends depicted on Figure 2 indicate some similarity between groundwater levels in the monitoring wells and the adjacent river. The amplitude of the groundwater fluctuations is attenuated relative to those in the river, and the peaks lag those in the river by about 50 minutes.

The water level elevations in the monitoring wells were higher than adjacent river levels at nearly all times. The difference between the groundwater and river elevations appears smallest at MW17-4. This suggests that of the sites investigated, resistance to flow of water between the sediments and the river is least in the vicinity MW17-4.

Chemical Analysis Results

Results of laboratory water analyses are summarized in Table II. Concentrations of all analyzed parameters were below Maximum Allowable Concentrations (MACs) and Aesthetic Objective (AOs) recommended in the Guidelines for Canadian Drinking Water Quality (GCDWQ[4]) for all analytes except iron and manganese. The dissolved iron concentrations ranged from 4.57 to 37.7 mg/L, and exceeded the AO of 0.3 mg/L. The lowest concentration occurred in the sample from MW17-4.

Dissolved manganese concentrations ranged from 1.0 to 1.9 mg/L, and exceeded the AO of 0.05 mg/L. As with dissolved iron, the lowest concentration occurred in the sample from MW17-4. While there is currently no health-based MAC for manganese, it should be noted that in August 2016 the Federal-Provincial-Territorial Committee on Drinking Water ended consultation on proposed revisions to the GCDWQ that would result in a MAC of 0.1 mg/L and an AO of 0.02 mg/L for manganese. The MAC is being considered because manganese may have the potential to affect neurological development[5].

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[4] Health Canada, 2017. Guidelines for Canadian Drinking Water Quality Summary Table. February.

[5] Health Canada, 2016. Manganese in Drinking Water: Document for Public Consultation. May.

It is noteworthy that the pharmaceuticals tricarban and triclosan were detected in groundwater from MW17-2 at concentrations of 0.0088 and 0.064 µg/L, respectively. Both compounds are antibacterials often found in antibacterial soaps and other personal care products. While there are no maximum limits set by Health Canada or the US Environmental Protection Agency, it is noted that the Minnesota Department of Health has developed guidance values of 100 and 50 ug/L, for tricarban and triclosan, respectively, in drinking water.

Water Supply Potential

The available information suggests that of the four locations investigated, conditions at MW17-4 appear the most favourable for development of a municipal groundwater source based on the following considerations:

- Highest estimated hydraulic conductivities in water-bearing soils;
- More favourable water quality due to lower concentrations of dissolved iron and manganese; and
- Lowest apparent resistance for groundwater flowing towards Fraser River.

Based on the relatively shallow depth to the more permeable soils, and the desire for a shallow depth of installation (to maximize infiltration from the river), a horizontal groundwater collection system appears to be more feasible than vertical wells.

Appendix E includes an estimate of potential inflow to a radial collector well with screen laterals oriented parallel to the river. The calculation is based on a formula for steady-state flow towards horizontal line sink parallel to a river boundary in an unconfined aquifer. Using a value of 6.8×10^{-4} m/s for hydraulic conductivity (as measured by falling-head testing with MW17-4), and assumed values for saturated thickness (H), drawdown (H-h), and a 30 m offset from the river (L), the calculations indicate a capacity of 25 MLD could be achieved with a collector length (X) of 52 m. Using the same assumptions, a lateral length of 104 m would be needed to achieve a flow of 50 MLD.

This analysis is based on idealized conditions, such as uniform material properties and a direct hydraulic connection between the aquifer and the Fraser River. It ignores partial penetration effects for the collector, horizontal to vertical anisotropy, and does not account for groundwater flow toward from the landward side or the ends of the collector. As such, the results are a rough estimate, and are likely to overestimate the flows per unit length parallel to the river. Nevertheless, they do highlight the relevance of the key variables and the sensitivity of the maximum flowrate to changing river levels that would influence saturated thickness (H), available drawdown (H-h), and offset from the river (L).

RECOMMENDED INVESTIGATIONS

The land in the vicinity of MW17-4 appears most prospective for development of a groundwater supply with a capacity of 25 to 50 MLD. If the AMWSC wishes to investigate this site further, Piteau recommends the following investigations to assess the hydrostratigraphy, groundwater conditions, and water quality.

Geophysical Investigation (Optional)

Geophysical surveys using the transient electromagnetic (TEM) sounding, and possibly other methods, could be employed to differentiate potential water-bearing zones from lower-permeability zones, and for optimizing the selection of test wells locations.

Test Well Drilling and Aquifer Pump Testing

A test well program will be needed to further evaluate hydraulic properties of water-bearing sediments, and the potential to induce infiltration from the Fraser River. This would necessitate installation of one or more 300 mm (12") diameter test wells to accommodate a 200 mm (8") diameter screen with an artificial sand pack. Additional monitoring wells, with deep and shallow screens, would also be required. A pumping test with the new test well(s) would provide the basis for refined estimates of aquifer properties, boundary conditions, and long-term groundwater quality trends.

The investigation results should be used as the basis of a three-dimensional groundwater flow model that can be used to evaluate the approximate physical requirements for a 25 to 50 MLD groundwater source.

Detailed Investigation

Subject to favourable results from the geophysical and test well investigations described above, a more detailed investigation would be necessary. This would involve drilling a series of test holes/monitoring wells along the proposed alignment for horizontal collectors or water wells, and conducting additional extended aquifer pump testing at times of high and low Fraser River stages.

CONCLUSIONS AND RECOMMENDATIONS

This technical memorandum summarizes the results of reconnaissance drilling to provide a preliminary assessment of the feasibility of developing a 25 to 50 MLD groundwater adjacent to the Fraser River at Matsqui Bend.

Of the four locations investigated, conditions at MW17-4 appear the most prospective for development of a municipal groundwater source that includes treatment to remove dissolved iron and manganese and surface water pathogens.

Additional investigations needed to further assess feasibility, and provide design information for a groundwater collector system include geophysical investigations (optional), construction of one or more test wells, aquifer pump testing, and numerical modelling. Assuming favourable results, further detailed investigations would be needed to provide design information.

LIMITATIONS

This investigation has been conducted using a standard of care consistent with that expected of scientific and engineering professionals undertaking similar work under similar conditions in BC. No warranty is expressed or implied.

This report is prepared for the sole use of Urban Systems Ltd. and the AMWSC. Any use, interpretation, or reliance on this information by any third party, other than the BC Environmental Assessment Office, is at the sole risk of that party, and Piteau accepts no liability for such unauthorized use.

CLOSURE

We trust this technical memorandum is sufficient for your current needs. Please contact the undersigned if you have any questions or comments.

Respectfully submitted,

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TABLES

TABLE I

GROUNDWATER LEVELS AND ESTIMATED HYDRAULIC CONDUCTIVITIES

	Top of Casing Elevation	UTM Coordinates		Depth to Water			Estimated Hydraulic Conductivity (K)			
MW ID	(m-geod)	E	N	Date	Time	(m-btoc)	Test Type	Analysis	Depth Range (m-bg)	K (m/s)
MW17-1	6.89	556576	5442019	25-Oct-17	8:08	5.82	Grain Size	Hazen	10.7 - 11.3	5.8E-05
							Falling Head	_Hvorslev*_	_14.3 - 17.4_	_6.6E-04_
							Rising Head	_Hvorslev*_	_14.3 - 17.4_	_2.5E-04_
				26-Oct-17	15:10	5.52	Grain Size	Hazen	14.6 - 15.2	1.0E-04
				8-Dec-17	11:03	5.48	"	"	16.8 - 17.4	2.9E-04
							"	"	20.1 - 20.7	2.6E-04
							"	"	28.7 - 29.3	4.0E-04
MW17-2	6.50	555969	5442313	24-Oct-17	14:10	4.53	Grain Size	Hazen	12.5 - 13.1	5.3E-04
							Falling Head	_Hvorslev*_	_16.8 - 19.8_	_4.2E-04_
							Rising Head	_Hvorslev*_	_16.8 - 19.8_	_2.6E-04_
				26-Oct-17	15:42	4.69	Grain Size	Hazen	17.4 - 18.0	5.8E-04
				8-Dec-17	12:10	4.61	"	"	20.4 - 21.0	3.2E-04
							"	"	25.0 - 25.6	4.4E-04
							"	"	29.9 - 30.5	7.1E-05
MW17-3	5.11	555213	5442894	24-Oct-17	14:10	3.67	Grain Size	Hazen	8.5 - 9.1	4.0E-04
				26-Oct-17	13:35	3.86	"	"	13.1 - 13.7	4.2E-04
				8-Dec-17	13:30	3.39	"	"	17.4 - 18.0	3.2E-04
							Falling Head	_Hvorslev*_	_17.7 - 20.7_	_2.5E-04_
							Rising Head	_Hvorslev*_	_17.7 - 20.7_	_2.8E-04_
							Grain Size	Hazen	25.0 - 25.6	3.6E-04
							"	"	29.6 - 30.2	1.7E-04
MW17-4	5.75	552487	5442455	26-Oct-17	14:44	4.34	Grain Size	Hazen	8.5 - 9.1	8.1E-05
							Falling Head	_Hvorslev*_	_12.8 - 15.8_	_6.8E-04_
				26-Oct-17	16:26	4.26	Grain Size	Hazen	14.3 - 14.9	1.7E-03
				8-Dec-17	9:51	4.65	"	"	17.4 - 18.0	3.2E-04
							"	"	23.5 - 24.1	2.9E-04
							"	"	29.0 - 29.6	9.0E-04

H:\Project\3694\Report\LR3 Reconnaissance Drilling\[Tab I K Summary_v2.xlsx]Sheet1

* Hvorslev analyses assume 10:1 horizontal to vertical anisotropy.

TABLE II

WATER QUALITY ANALYSES RESULTS

Analyte	Sample ID	MW17-1	MW17-2	MW17-3	MW17-4	Canadian Drinking Water Quality Guideline[1]	
	Units					MAC	AO/OG
Physical Parameters							
UV Absorbance (254 nm)	Abs/cm	-	0.052	-	-	-	-
Transmittance, UV (254 nm)	%T/cm	-	88.7	-	-	-	-
Hardness (as CaCO3)	mg/L	178	194	156	197	-	-
Anions							
Bromide (Br)	mg/L	0.111	<0.050	<0.050	0.069	-	-
Chloride (Cl)	mg/L	4.54	7.64	10.2	6.07	-	250
Fluoride (F)	mg/L	0.229	0.094	0.1	0.223	1.5	-
Sulfate (SO4)	mg/L	21	1.64	21.7	58.1	-	-
Nutrients							
Ammonia, Total (as N)	mg/L	0.537	0.507	0.114	0.151	-	-
Nitrate (as N)	mg/L	<0.0050	<0.0050	<0.0050	3.59	10	-
Nitrite (as N)	mg/L	<0.0010	<0.0010	<0.0010	0.0148	1	-
Other Parameters							
Silicate (as SiO2)	mg/L	-	24.6	-	-	-	-
Sulphide as S	mg/L	-	<0.018	-	-	-	-
Dissolved Organic Carbon	mg/L	-	2.51	-	-	-	-
Total Organic Carbon	mg/L	-	3.13	-	-	-	-

TABLE II

WATER QUALITY ANALYSES RESULTS

Analyte	Sample ID	MW17-1	MW17-2	MW17-3	MW17-4	Canadian Drinking Water Quality Guideline[1]	
	Units					MAC	AO/OG
Total Metals							
Aluminum	mg/L	-	0.0551	-	-	-	0.1
Antimony	mg/L	-	<0.00010	-	-	0.006	-
Arsenic	mg/L	-	0.00712	-	-	0.01	-
Barium	mg/L	-	0.0842	-	-	1	-
Beryllium	mg/L	-	<0.00010	-	-	-	-
Bismuth	mg/L	-	<0.000050	-	-	-	-
Boron	mg/L	-	0.019	-	-	5	-
Cadmium	mg/L	-	<0.0000050	-	-	0.005	-
Calcium	mg/L	-	45.8	-	-	-	-
Cesium	mg/L	-	0.000011	-	-	-	-
Chromium	mg/L	-	0.00024	-	-	0.05	-
Cobalt	mg/L	-	0.00019	-	-	-	-
Copper	mg/L	-	<0.00050	-	-	-	1.0
Iron	mg/L	-	**33.3**	-	-	-	0.3
Lead	mg/L	-	<0.000050	-	-	0.01	-
Lithium	mg/L	-	0.0028	-	-	-	-
Magnesium	mg/L	-	18.3	-	-	-	-
Manganese	mg/L	-	**1.24**	-	-	-	0.05
Mercury	mg/L	-	<0.0000050	-	-	0.001	-
Molybdenum	mg/L	-	0.00123	-	-	-	-
Nickel	mg/L	-	<0.00050	-	-	-	-
Phosphorus	mg/L	-	0.227	-	-	-	-
Potassium	mg/L	-	1.34	-	-	-	-
Rubidium	mg/L	-	0.00165	-	-	-	-
Selenium	mg/L	-	<0.000050	-	-	0.05	-
Silicon	mg/L	-	15.7	-	-	-	-
Silver	mg/L	-	<0.000010	-	-	-	-
Sodium	mg/L	-	5.43	-	-	-	200
Strontium	mg/L	-	0.184	-	-	-	-
Sulfur	mg/L	-	0.7	-	-	-	-
Tellurium	mg/L	-	<0.00020	-	-	-	-
Thallium	mg/L	-	<0.000010	-	-	-	-
Thorium	mg/L	-	<0.00010	-	-	-	-
Tin	mg/L	-	0.00016	-	-	-	-
Titanium	mg/L	-	0.0018	-	-	-	-
Tungsten	mg/L	-	<0.00010	-	-	-	-
Uranium	mg/L	-	0.00004	-	-	0.02	-
Vanadium	mg/L	-	<0.00050	-	-	-	-
Zinc	mg/L	-	<0.0030	-	-	-	5
Zirconium	mg/L	-	0.000073	-	-	-	-

TABLE II

WATER QUALITY ANALYSES RESULTS

Analyte	Sample ID	MW17-1	MW17-2	MW17-3	MW17-4	Canadian Drinking Water Quality Guideline[1]	
	Units					MAC	AO/OG
Dissolved Metals							
Aluminum	mg/L	0.0239	0.0047	0.0053	0.0037	-	0.1
Antimony	mg/L	<0.00010	<0.00010	<0.00010	0.00011	0.006	-
Arsenic	mg/L	0.00815	0.00707	0.00201	0.00244	0.01	-
Barium	mg/L	0.0905	0.0905	0.0663	0.0546	1	-
Beryllium	mg/L	<0.00010	<0.00010	<0.00010	<0.00010	-	-
Bismuth	mg/L	<0.000050	<0.000050	<0.000050	<0.000050	-	-
Boron	mg/L	0.072	0.022	0.014	0.031	5	-
Cadmium	mg/L	<0.0000050	<0.0000050	<0.0000050	<0.0000050	0.005	-
Calcium	mg/L	47.8	46.8	36.3	45.2	-	-
Cesium	mg/L	0.00001	<0.000010	<0.000010	<0.000010	-	-
Chromium	mg/L	0.00123	0.0001	<0.00010	<0.00010	0.05	-
Cobalt	mg/L	0.00278	0.00018	0.00033	0.00133	-	-
Copper	mg/L	0.00043	0.00095	<0.00020	<0.00020	-	1.0
Iron	mg/L	**37.7**	**36.9**	**10.3**	**4.57**	-	0.3
Lead	mg/L	<0.000050	0.000058	<0.000050	<0.000050	0.01	-
Lithium	mg/L	0.0068	0.0029	0.0025	0.0034	-	-
Magnesium	mg/L	14.3	18.8	16.0	20.5	-	-
Manganese	mg/L	**1.89**	**1.22**	**1.45**	**1.00**	-	0.05
Mercury	mg/L	<0.0000050	<0.0000050	<0.0000050	<0.0000050	0.001	-
Molybdenum	mg/L	0.0048	0.00153	0.000955	0.00965	-	-
Nickel	mg/L	0.00546	<0.00050	<0.00050	0.00155	-	-
Phosphorus	mg/L	0.245	0.213	0.099	<0.050	-	-
Potassium	mg/L	2.32	1.43	1.7	2.52	-	-
Rubidium	mg/L	0.00178	0.00157	0.00103	0.00138	-	-
Selenium	mg/L	0.000253	<0.000050	<0.000050	0.00014	0.05	-
Silicon	mg/L	26.2	16.9	21.8	11.2	-	-
Silver	mg/L	<0.000010	<0.000010	<0.000010	<0.000010	-	-
Sodium	mg/L	37.7	5.45	5.21	30.7	-	200
Strontium	mg/L	0.204	0.194	0.148	0.225	-	-
Sulfur	mg/L	7.34	0.61	7.5	19.8	-	-
Tellurium	mg/L	<0.00020	<0.00020	<0.00020	<0.00020	-	-
Thallium	mg/L	<0.000010	<0.000010	<0.000010	<0.000010	-	-
Thorium	mg/L	<0.00010	<0.00010	<0.00010	<0.00010	-	-
Tin	mg/L	0.00071	<0.00010	<0.00010	<0.00010	-	-
Titanium	mg/L	0.00162	<0.00030	<0.00030	<0.00030	-	-
Tungsten	mg/L	<0.00010	<0.00010	<0.00010	<0.00010	-	-
Uranium	mg/L	0.00107	0.000035	0.00003	0.000172	0.02	-
Vanadium	mg/L	0.00126	<0.00050	<0.00050	<0.00050	-	-
Zinc	mg/L	0.0015	0.0015	<0.0010	<0.0010	-	5
Zirconium	mg/L	0.000548	<0.000060	<0.000060	<0.000060	-	-

TABLE II

WATER QUALITY ANALYSES RESULTS

Analyte	Sample ID	MW17-1	MW17-2	MW17-3	MW17-4	Canadian Drinking Water Quality Guideline[1]	
	Units					MAC	AO/OG
Pharmaceuticals							
Acesulfame K	ug/L	-	<0.010	-	-	-	-
Acetaminophen	ug/L	-	<0.020	-	-	-	-
Albuterol	ug/L	-	<0.0010	-	-	-	-
Amitriptyline	ug/L	-	<0.0050	-	-	-	-
Amlodipine	ug/L	-	<0.0050	-	-	-	-
Amphetamine	ug/L	-	<0.010	-	-	-	-
Ampicillin	ug/L	-	<0.020	-	-	-	-
Atenolol	ug/L	-	<0.0050	-	-	-	-
Atorvastatin	ug/L	-	<0.0050	-	-	-	-
Azithromycin	ug/L	-	<0.10	-	-	-	-
Benzoylecgonine	ug/L	-	<0.0020	-	-	-	-
Bezafibrate	ug/L	-	<0.010	-	-	-	-
Carbadox	ug/L	-	<0.10	-	-	-	-
Carbamazepine	ug/L	-	<0.0020	-	-	-	-
Cimetidine	ug/L	-	<0.0050	-	-	-	-
Clarithromycin	ug/L	-	<0.0010	-	-	-	-
Clinafloxacin	ug/L	-	<0.20	-	-	-	-
Clofibric Acid	ug/L	-	<0.0020	-	-	-	-
Clotrimazole	ug/L	-	<0.050	-	-	-	-
Cloxacillin	ug/L	-	<0.0020	-	-	-	-
Codeine	ug/L	-	<0.010	-	-	-	-
Cotinine	ug/L	-	<0.0050	-	-	-	-
Cyclophosphamide	ug/L	-	<0.0050	-	-	-	-
Dehydronifedipine	ug/L	-	<0.0020	-	-	-	-
Diazepam	ug/L	-	<0.0050	-	-	-	-
Diclofenac	ug/L	-	<0.010	-	-	-	-
Diethylstilbestrol	ug/L	-	<0.0050	-	-	-	-
Digoxigenin	ug/L	-	<0.050	-	-	-	-
Diltiazem	ug/L	-	<0.0020	-	-	-	-
1,7-Dimethylxanthine	ug/L	-	<0.0050	-	-	-	-
Diphenhydramine	ug/L	-	<0.0010	-	-	-	-
Enrofloxacin	ug/L	-	<0.010	-	-	-	-
Erythromycin	ug/L	-	<0.0010	-	-	-	-
Erythromycin Anhydrate	ug/L	-	<0.010	-	-	-	-
Fenoprofen	ug/L	-	<0.050	-	-	-	-
Flumequine	ug/L	-	<0.050	-	-	-	-
Fluoxetine	ug/L	-	<0.0020	-	-	-	-
Furosemide	ug/L	-	<0.010	-	-	-	-
Gemfibrozil	ug/L	-	<0.0020	-	-	-	-
Glipizide	ug/L	-	<0.010	-	-	-	-
Glyburide	ug/L	-	<0.0050	-	-	-	-
Hydrochlorothiazide	ug/L	-	<0.010	-	-	-	-
2-Hydroxy Ibuprofen	ug/L	-	<0.40	-	-	-	-
Ibuprofen	ug/L	-	<0.050	-	-	-	-
Indomethacin	ug/L	-	<0.010	-	-	-	-
Ketoprofen	ug/L	-	<0.020	-	-	-	-
Lidocaine	ug/L	-	<0.00050	-	-	-	-
Lincomycin	ug/L	-	<0.010	-	-	-	-
Lomefloxacin	ug/L	-	<0.020	-	-	-	-

TABLE II

WATER QUALITY ANALYSES RESULTS

Analyte	Sample ID	MW17-1	MW17-2	MW17-3	MW17-4	Canadian Drinking Water Quality Guideline[1]	
	Units					MAC	AO/OG
Pharmaceuticals (cont'd)							
Metoprolol	ug/L	-	<0.010	-	-	-	-
Miconazole	ug/L	-	<0.0050	-	-	-	-
Naproxen	ug/L	-	<0.010	-	-	-	-
Norfloxacin	ug/L	-	<0.50	-	-	-	-
Norgestimate	ug/L	-	<0.050	-	-	-	-
Novobiocin	ug/L	-	<0.0050	-	-	-	-
Ofloxacin	ug/L	-	<0.050	-	-	-	-
Ormetoprim	ug/L	-	<0.0010	-	-	-	-
Oxacillin	ug/L	-	<0.0020	-	-	-	-
Oxolinic Acid	ug/L	-	<0.020	-	-	-	-
Penicillin G	ug/L	-	<0.020	-	-	-	-
Penicillin V	ug/L	-	<0.020	-	-	-	-
Pentoxifylline	ug/L	-	<0.0020	-	-	-	-
Ranitidine	ug/L	-	<0.0010	-	-	-	-
Roxithromycin	ug/L	-	<0.0050	-	-	-	-
Sarafloxacin	ug/L	-	<0.020	-	-	-	-
Sucralose	ug/L	-	<0.050	-	-	-	-
Sulfabenzamide	ug/L	-	<0.0050	-	-	-	-
Sulfacetamide	ug/L	-	<0.020	-	-	-	-
Sulfachloropyridazine	ug/L	-	<0.010	-	-	-	-
Sulfadiazine	ug/L	-	<0.0050	-	-	-	-
Sulfadimethoxine	ug/L	-	<0.0050	-	-	-	-
Sulfaguanidine	ug/L	-	<0.020	-	-	-	-
Sulfamerazine	ug/L	-	<0.0050	-	-	-	-
Sulfameter	ug/L	-	<0.0050	-	-	-	-
Sulfamethazine	ug/L	-	<0.0050	-	-	-	-
Sulfamethizole	ug/L	-	<0.0050	-	-	-	-
Sulfamethoxazole	ug/L	-	<0.0050	-	-	-	-
Sulfamethoxypyridazine	ug/L	-	<0.0050	-	-	-	-
Sulfamoxole	ug/L	-	<0.0050	-	-	-	-
Sulfanilamide	ug/L	-	<0.25	-	-	-	-
Sulfaphenazole	ug/L	-	<0.0050	-	-	-	-
Sulfapyridine	ug/L	-	<0.0050	-	-	-	-
Sulfaquinoxaline	ug/L	-	<0.0050	-	-	-	-
Sulfathiazole	ug/L	-	<0.0050	-	-	-	-
Sulfisoxazole	ug/L	-	<0.0050	-	-	-	-
Thiabendazole	ug/L	-	<0.0050	-	-	-	-
Triclocarban	ug/L	-	0.0088	-	-	-	-
Triclosan	ug/L	-	0.064	-	-	-	-
Trimethoprim	ug/L	-	<0.0020	-	-	-	-
Tylosin	ug/L	-	<0.050	-	-	-	-
Warfarin	ug/L	-	<0.0010	-	-	-	-
10-Hydroxy-Amitriptyline	ug/L	-	<0.0010	-	-	-	-

NOTES:

1) MAC is the Maximum Allowable Concentration based on human health. AO is the Aesthetic Objective.

2) **Bold highlighted** text indicates a CDWQG exceedance.

FIGURES

H:\Project\3694\ArcGis\3694_Field_Map.mxd

0 100 200 300 400 500 m

SCALE: 1:14,244

Legend

⌖ Monitoring Well Location

🟥 Cross Section

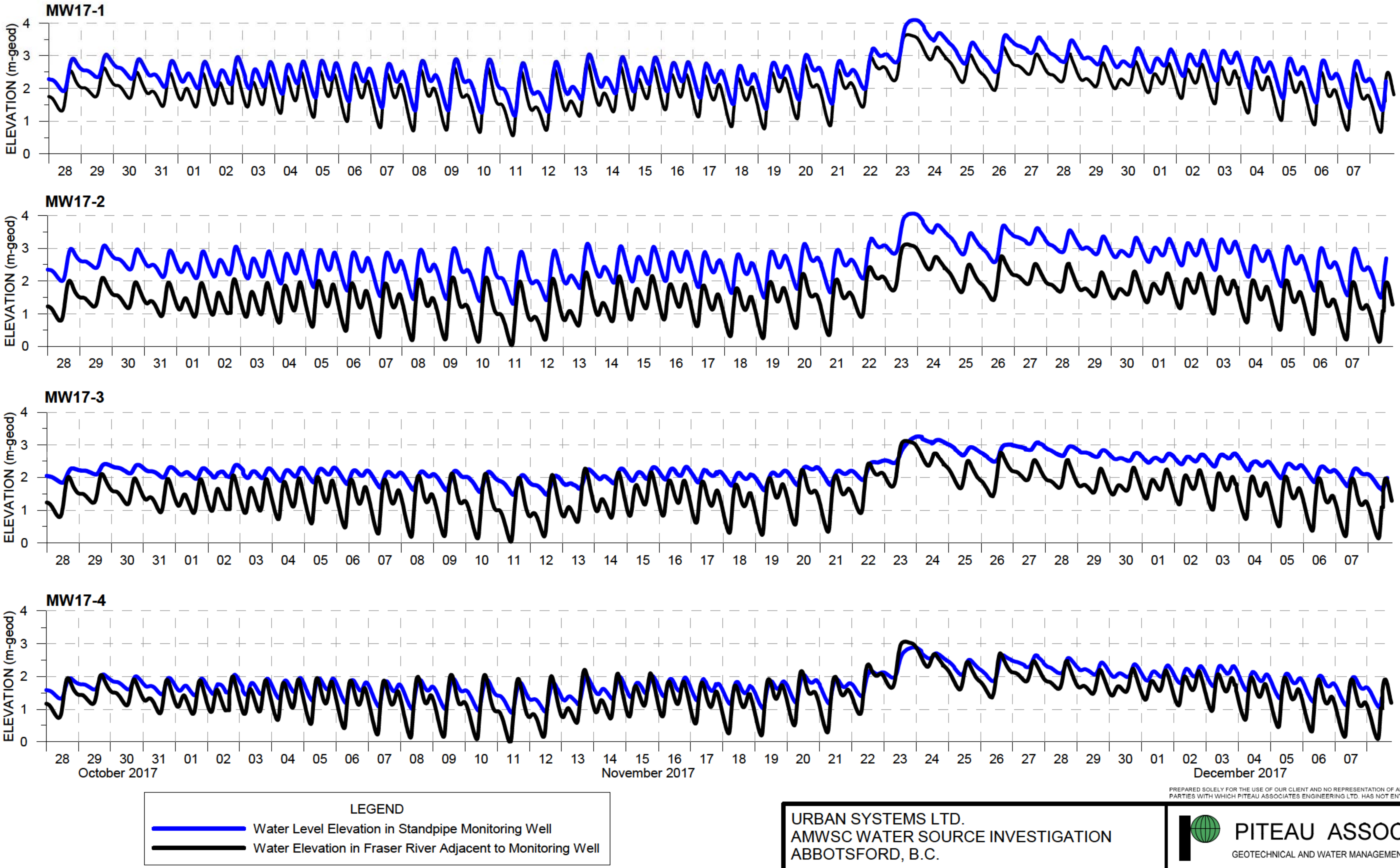
URBAN SYSTEMS LTD.
AMWSC WATER SOURCE INVESTIGATION
ABBOTSFORD, B.C.

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

MONITORING WELL LOCATIONS

BY: AB
DATE: NOV 17
APPROVED: DJT
FIG: 1

H:\Project\3694\Logger data\2 Loggersv3.grf



NOTES:
1) Fraser River Elevation data are for the river adjacent to standpipe monitoring well, using the surveyed elevation as a datum and applying a time shift pro-rated based on the peak time shift between Whonock and Mission stations.

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ABBOTSFORD, B.C.

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GROUNDWATER LEVELS AND
FRASER RIVER WATER LEVELS

BY: AB
DATE: DEC 17
APPROVED: DJT
FIG: 2

APPENDIX A

BOREHOLE LOGS

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

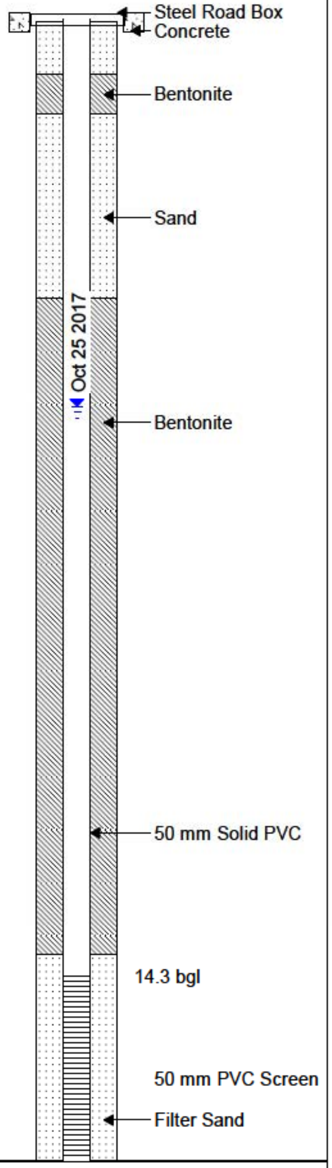
Client: Urban Systems Ltd.

Drillhole Number: MW17-1

Page 1 of 2

Project: AMWSC Water Source Investigation
Location: Matsqui
Project Number: 3694
Logged By: Robert Bulger
Borehole Diameter: 150 mm (6")

Elevation (maSL)	Lithologic Description	Depth (mbg)	Sample ID
6.9	Ground Surface	0.0	
5.4	**Cobbles** Grey moist, some sand silt and gravel (fill)	1.5	
3.8	**Sand and Silt** Grey brown, moist, trace gravel (fill)	3.0	
2.9	**Silt** Grey with some rusty brown mottling, moist (native)	4.0	
2.3	**Peaty Silt** Brown, wet	4.6	
0.9	**Silt** Grey, wet, some clay	5.9	
0.2	**Sand** Grey, wet, fine grained, some silt	6.7	
-0.7	**Sand** Grey, wet	7.6	
-1.3	**Sand** Grey, wet, fine grained some silt	8.2	
-1.9	**Sand** Grey, wet	8.8	27-29
-5.3	**Sand** Grey, wet, fine grained, some silt	12.2	35-37
-6.8	**Sand** Grey, wet fine grained	13.7	
	Sand Grey, wet, fine grained		48-50



Drilling Contractor: Downrite Drilling
Drilling Method: Sonic
Drilling Started: Oct 24 2017
Drilling Ended: Oct 24 2017

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Drillhole Number: MW17-1
Project: AMWSC Water Source Investigation
Location: Matsqui

Elevation	Lithologic Description	Depth (mbg)
-10.8		17.7
-12.0	**Sand** Grey, wet, fine grained some silt	18.9
-14.1	**Sand** Grey, wet	21.0
-14.4	**Sand** Grey, wet, fine grained some silt	21.3
-21.8	**Sand** Grey wet	28.7
-22.4	**Sand** Grey, wet, fine to medium grained, trace gravel	29.3
-23.6	**Sand** Grey, wet, fine grained, some silt	30.5
	End of Hole	

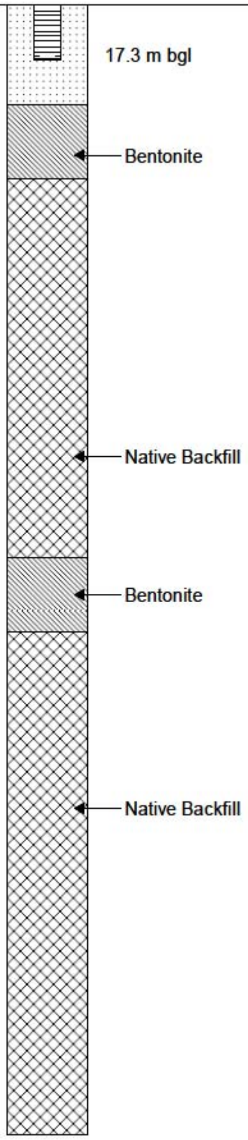
Sample ID
55-57
66-68
76-78
82-84
86-88
94-96

Depth Below Ground Surface (ft): 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110

Depth Below Ground Surface (m): 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33

Remarks

Constructed Well



PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

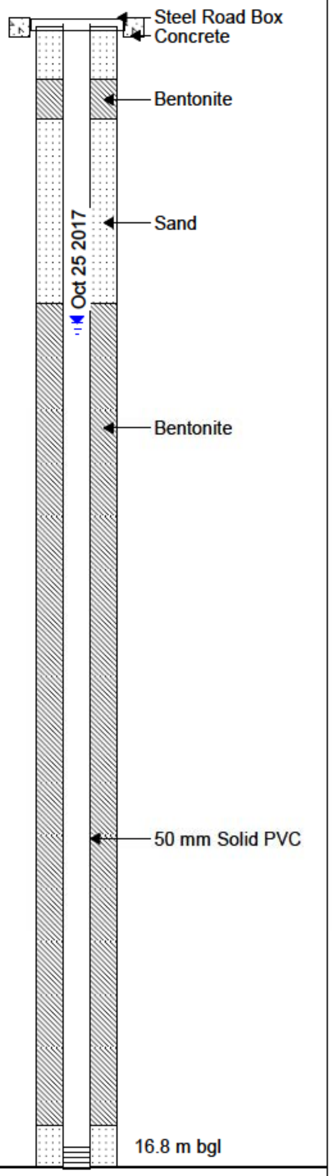
Client: Urban Systems Ltd.

Drillhole Number: MW17-2

Project: AMWSC Water Source Investigation
Location: Matsqui
Project Number: 3694
Logged By: Robert Bulger
Borehole Diameter: 150 mm (6")

Elevation (maSL)	Lithologic Description	Depth (mbg)	Sample ID	Remarks
6.5	Ground Surface	0.0		
5.3	**Cobbles** Grey moist, some sand silt and gravel (fill)	1.2		
2.5	**Silt** Grey, moist (native)	4.0		
0.4	**Sand** Grey brown, moist	6.1		
-2.6	**Sand and Silt** Grey, wet, fine grained	9.1		
-5.1	**Sand** Grey, wet, fine grained some silt	11.6		
-5.7	**Sand** Grey, wet, fine to medium grained, some silt, trace gravel	12.2	38-40	
-8.7	**Sand** Grey, wet, trace gravel	15.2	41-43 47-49	
	Sand Grey, wet, fine to medium grained			

Constructed Well



Drilling Contractor: Downrite Drilling
Drilling Method: Sonic
Drilling Started: Oct 25 2017
Drilling Ended: Oct 25 2017

Drillhole Number: MW17-2 **Page 2 of 2**
Project: AMWSC Water Source Investigation
Location: Matsqui

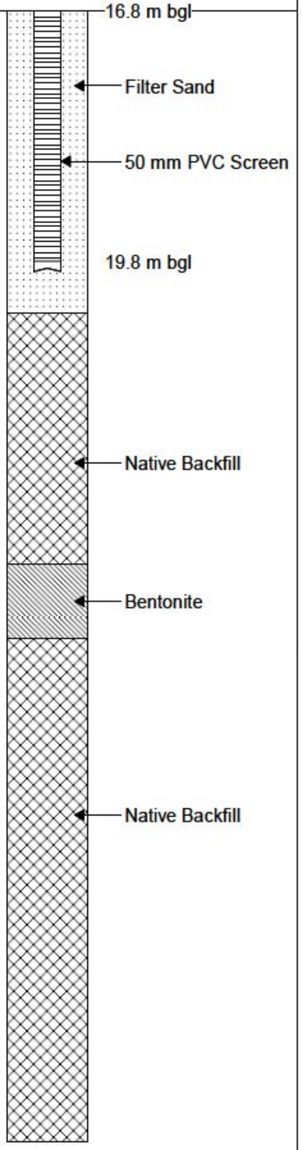
Depth Below Ground Surface
56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110
17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33

Elevation	Lithologic Description	Depth (mbg)
-16.1		22.6
	Sand Grey, wet, trace gravel	
-17.9		24.4
	Sand Grey wet, fine to medium grained	
-20.8		27.3
	Sand Grey, wet, fine grained, some silt	
	Sand Grey, wet	
-22.2		28.7
-22.5		29.0
	Sand Grey, wet, fine grained	
-23.4		29.9
	Sand Grey, wet	
-24.0		30.5
	Sand Grey, wet, fine grained	
	End of Hole	

Sample ID
57-59
62-64
67-69
72-74
72-79
82-84
87-89
98-100

Remarks

Constructed Well



PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Client: Urban Systems Ltd.

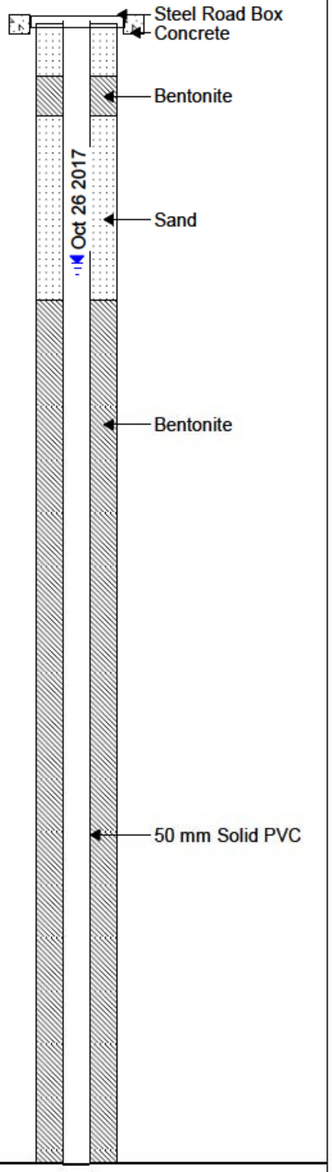
Drillhole Number: MW17-3

Page 1 of 2

Project: AMWSC Water Source Investigation
Location: Matsqui
Project Number: 3694
Logged By: Robert Bulger
Borehole Diameter: 150 mm (6")

Elevation (maSL)	Lithologic Description	Depth (mbg)	Sample ID	Remarks
5.1	Ground Surface	0.0		
	Silt Light grey brown, moist (native)			
2.1		3.0		
	Sand Grey brown, moist becoming wet @ 4.5 m, fine to medium grained		28-30	
-6.5		11.6		
-7.1	**Sand** Grey, wet, some silt,	12.2	38-40	
	Sand Grey, wet, fine to medium grained		43-45	
-9.2		14.3		
-9.8	**Sand** Grey, wet, trace wood pieces	14.9	47-49	
	Sand Grey, wet, fine grained, some sand		51-53	
	Sand Grey wet, fine to medium grained			

Constructed Well



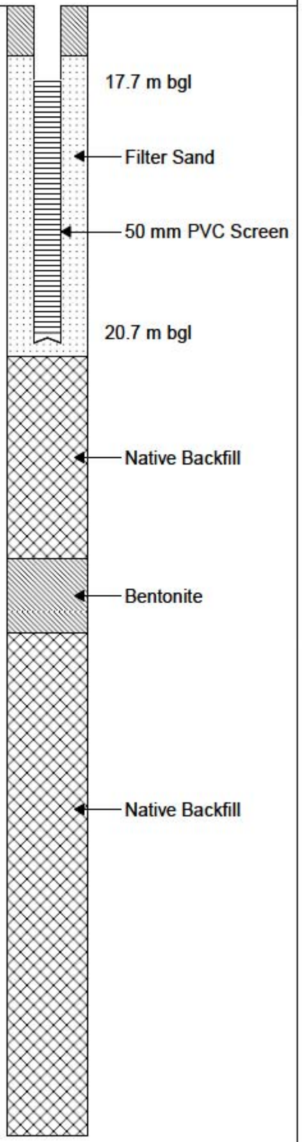
Drilling Contractor: Downrite Drilling
Drilling Method: Sonic
Drilling Started: Oct 26 2017
Drilling Ended: Oct 26 2017

PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

Drillhole Number: MW17-3 **Page 2 of 2**
Project: AMWSC Water Source Investigation
Location: Matsqui

Depth Below Ground Surface	Elevation	Lithologic Description	Depth (mbg)	Lithology	Sample ID	Remarks
56–74 / 17–22	-17.4		22.6		57-59 62-64 67-69 72-74	
74–77 / 23	-18.5	**Silt** Grey, wet	23.6			
77–88 / 24–26	-21.7	**Sand** Grey, wet, fine grained	26.8		77.5-79 82-84	
88–90 / 27	-22.3	**Sand** Grey, wet, fine grained some silt	27.4		88-90	
90–94 / 28	-23.5	**Sand** Grey, wet	28.7			
94–100 / 29–30	-25.4	**Sand** Grey, wet, fine grained	30.5		97-99	
100–110 / 31–33		End of Hole				

Constructed Well



PITEAU ASSOCIATES
GEOTECHNICAL AND WATER MANAGEMENT CONSULTANTS

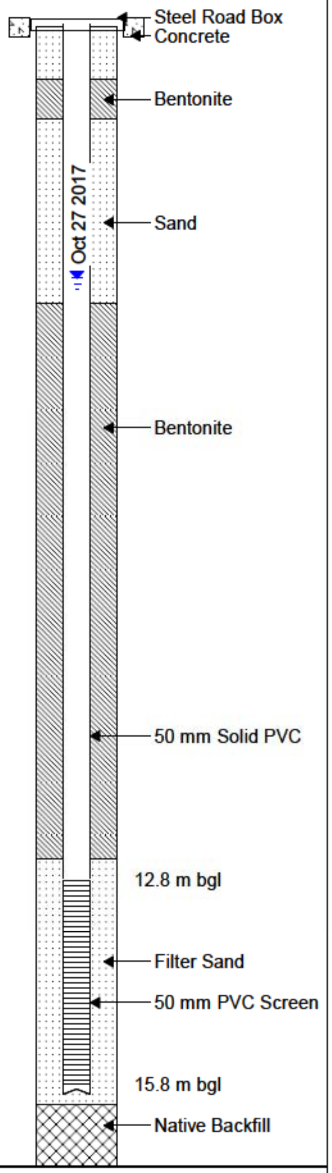
Client: Urban Systems Ltd.

Drillhole Number: MW17-4

Project: AMWSC Water Source Investigation
Location: Matsqui
Project Number: 3694
Logged By: Robert Bulger
Borehole Diameter: 150 mm (6")

Elevation (maSL)	Lithologic Description	Depth (mbg)	Sample ID	Remarks
5.8	Ground Surface	0.0		
	Silt Grey brown, moist (native)			
2.7		3.0		
	Sand Grey brown, moist becoming wet @ 4.5 m, fine grained			
			28-30	
-5.5		11.3		
	Sand Grey, wet, fine grained		38-40	
-6.4		12.2		
	Sand Grey, wet, fine to medium grained		41-43	
			47-49	
			52-54	

Constructed Well

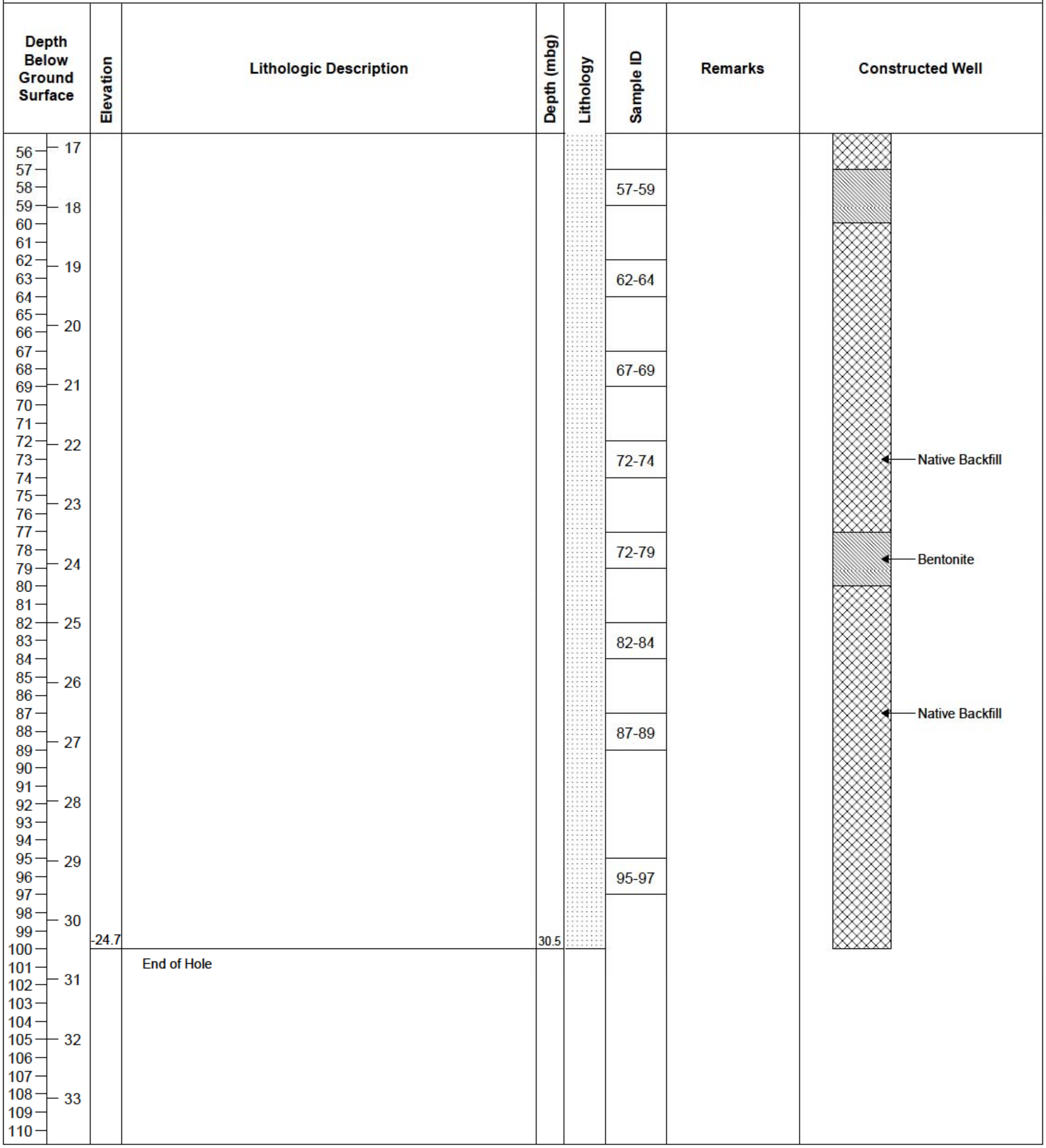


Drilling Contractor: Downrite Drilling
Drilling Method: Sonic
Drilling Started: Oct 27 2017
Drilling Ended: Oct 27 2017

Drillhole Number: MW17-4

Project: AMWSC Water Source Investigation

Location: Matsqui



APPENDIX B

GRAIN SIZE ANALYSES

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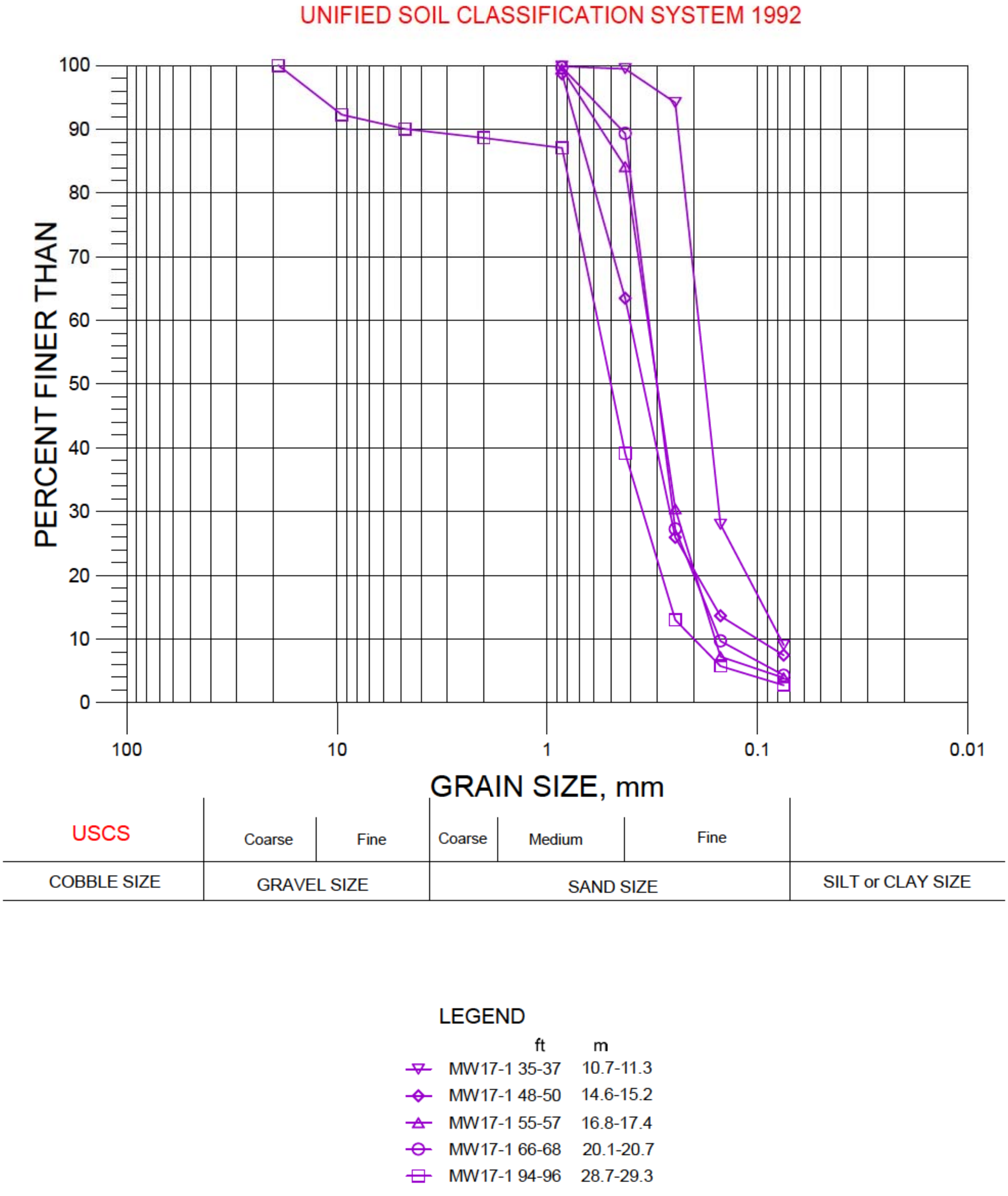


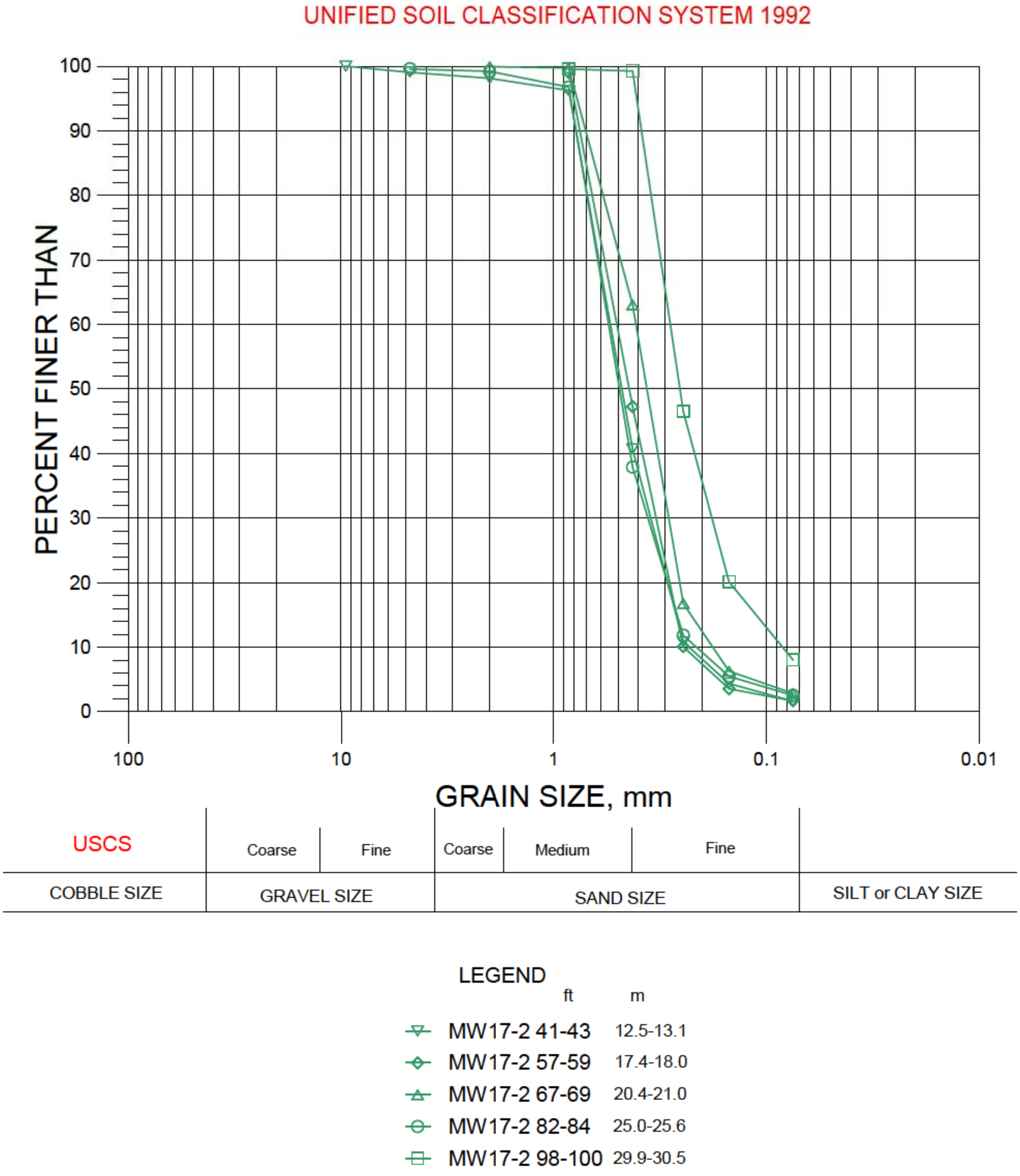
THE CITY OF ABBOTSFORD
GROUNDWATER SUPPLY ASSESSMENT
MATSQUI, B.C.

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

GRAIN SIZE ANALYSES
MW17-1

BY: AB
DATE: OCT 17
APPROVED: DJT
FIG: A-1

H:\Project\3694\Gradations\Gradations MW17-2.grf



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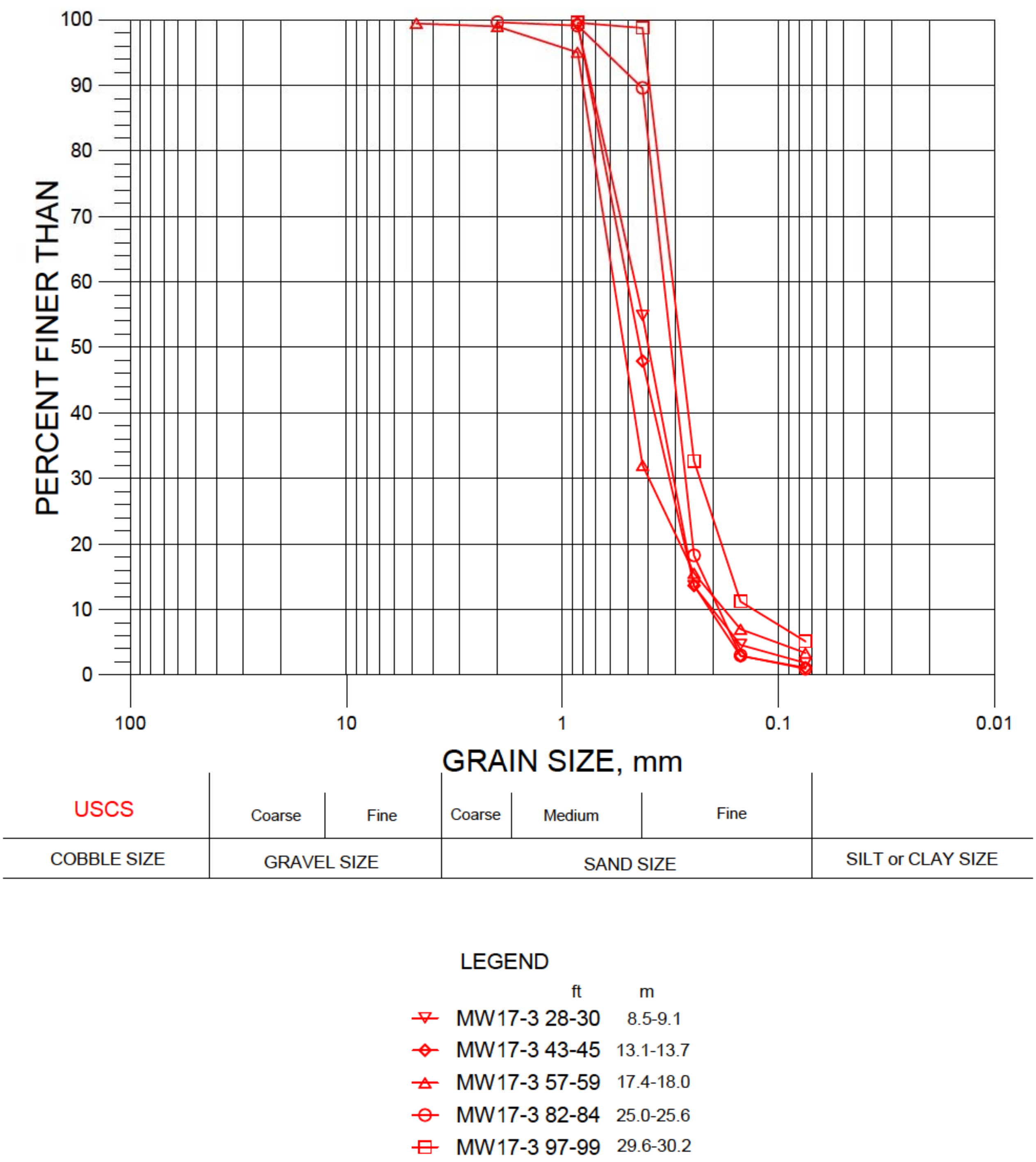
GRAIN SIZE ANALYSES
MW17-2

BY: AB
DATE: OCT 17
APPROVED: DJT
FIG: A-2

H:\Project\3694\Gradations\GradationsMW17-3.grf

UNIFIED SOIL CLASSIFICATION SYSTEM 1992



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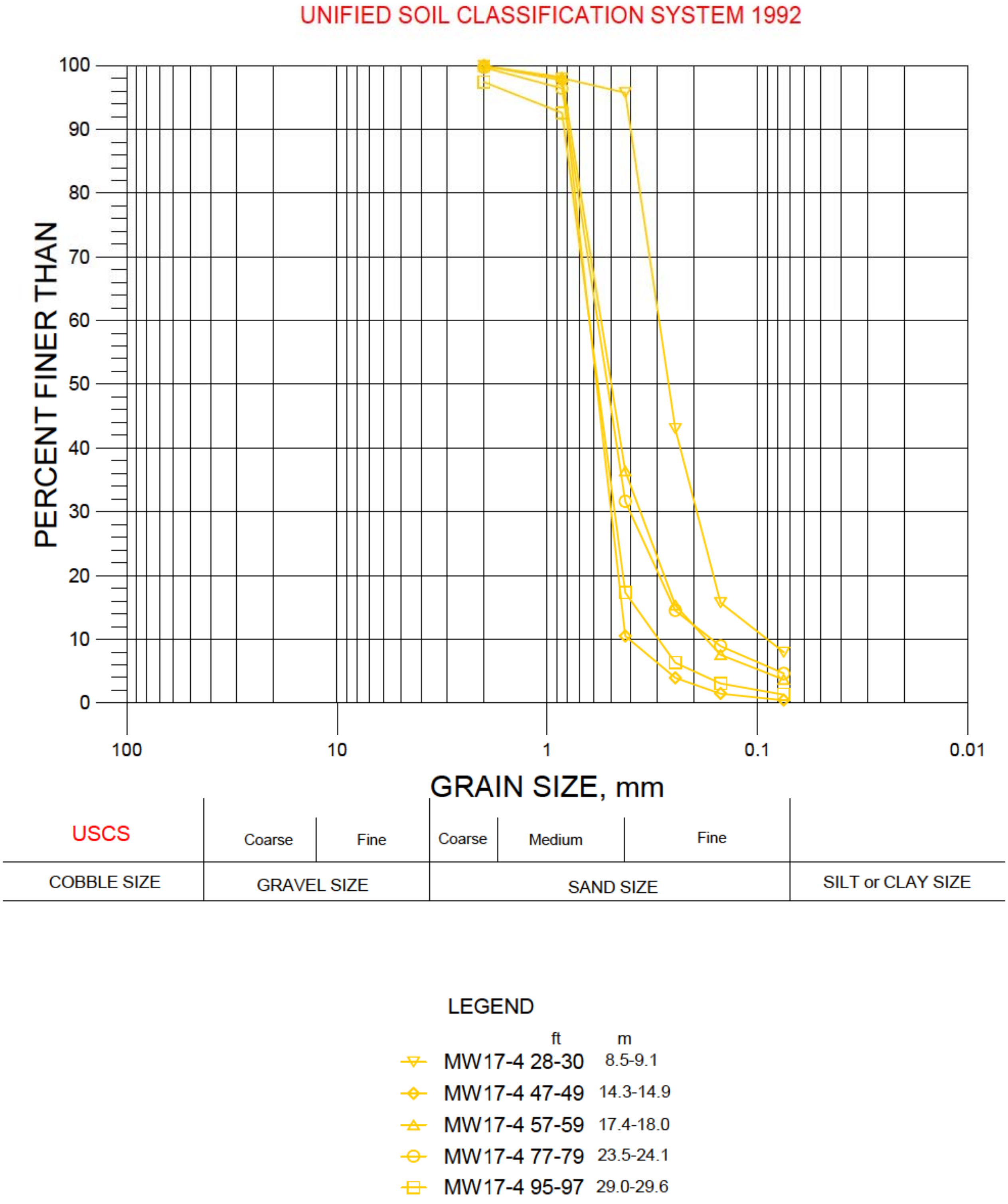
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

GRAIN SIZE ANALYSES
MW17-3

BY: AB
DATE: OCT 17
APPROVED: DJT
FIG: A-3

H:\Project\3694\Gradations\Gradations MW17-4.grf



THE CITY OF ABBOTSFORD
GROUNDWATER SUPPLY ASSESSMENT
MATSQUI, B.C.

PITEAU ASSOCIATES
GEOTECHNICAL AND HYDROGEOLOGICAL CONSULTANTS

GRAIN SIZE ANALYSES
MW17-4

BY: AB
DATE: OCT 17
APPROVED: DJT
FIG: A-4

APPENDIX C

ANALYSES RESULTS FOR HYDRAULIC UPSET TESTING

FALLING HEAD TEST IN MW17-1

Hole:	MW17-1			
Datum Elevation:	6.89 m	Lithology: Medium-grained Sand		
Ground Elevation:	6.89 m-asl			
PVC Stick-up:	0.00 m		Hole Diameter:	152.0 mm
Piezometer Depth:	17.30 m		Piezometer I.D.:	50.0 mm
Length of Pocket:	4.08 m			
Static Water Depth:	5.152 m			
Initial Excess Head (H_o):	0.135 m			
Current excess head (h):	Varies with time (difference between current and static water depths)			

Date	Elasped Time (min)	Reading Depth (m)	Water Depth (m-bGL)	Water Elev. (m-asl)	Residual Head h/H_o (m/m)
10/27/2017	0.000	5.287	5.287		1.000
	0.017	5.250	5.250		0.725
	0.033	5.239	5.239		0.641
	0.050	5.231	5.231		0.583
	0.067	5.217	5.217		0.482
	0.083	5.210	5.210		0.428
	0.100	5.201	5.201		0.366
	0.117	5.188	5.188		0.264
	0.133	5.167	5.167		0.113
	0.150	5.188	5.188		0.268
	0.167	5.171	5.171		0.138
	0.183	5.174	5.174		0.161
	0.200	5.170	5.170		0.134
	0.217	5.165	5.165		0.099
	0.233	5.165	5.165		0.099
	0.250	5.163	5.163		0.084
	0.267	5.162	5.162		0.075
	0.283	5.161	5.161		0.064
	0.300	5.159	5.159		0.054
	0.317	5.158	5.158		0.047

CALCULATION

$K = d^2(\ln(2m^{0.5}L/D))/8LTi$

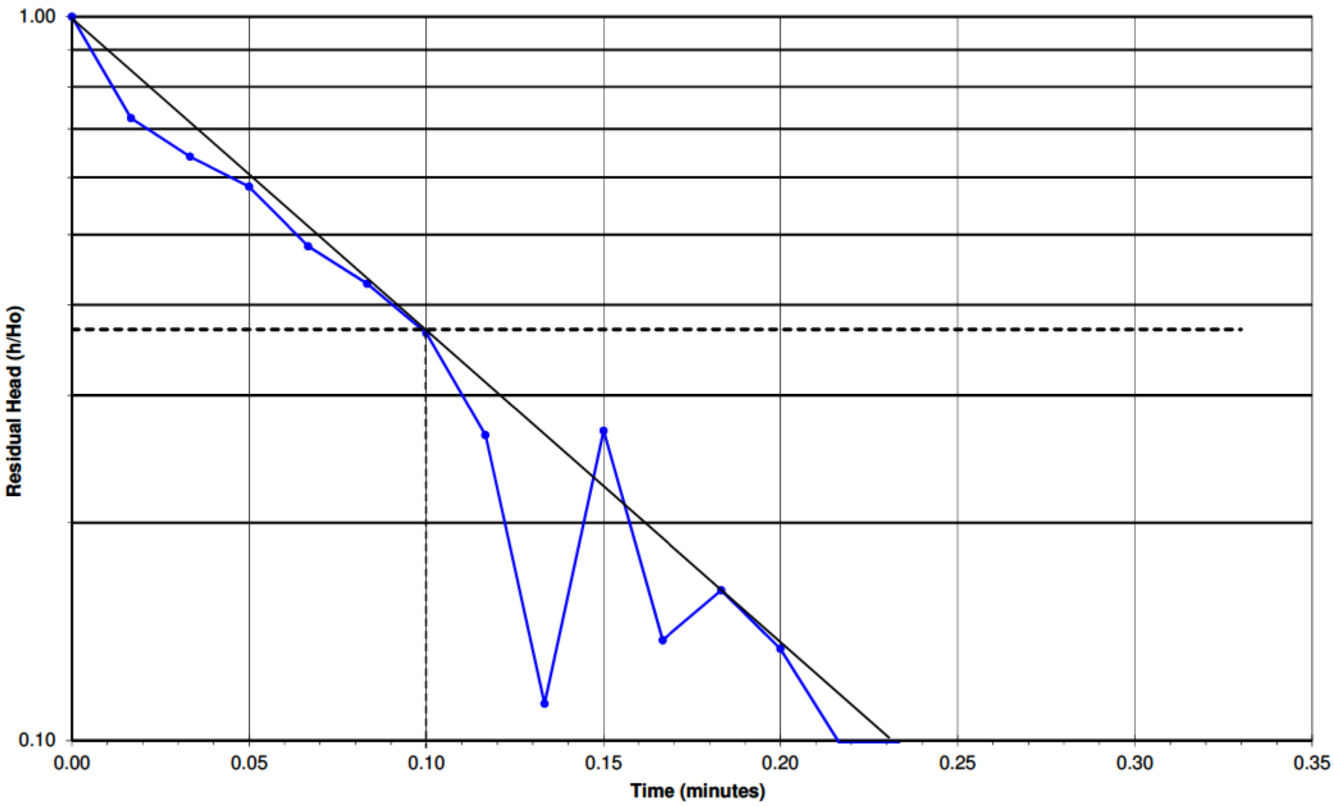
where

K= Hydraulic conductivity
D= Hole Diameter (m)
d= Tube Diameter (m)
m= Anisotropy (K_h/K_v)
L= Test Pocket Length (m)
Ti= Time for 63% drop on residual head plot (i.e. from 1 to 0.37 on y axis)
all above variables in consistent units

D= 0.152 m
d= 0.050 m
m= 10
L= 4.1 m
Ti= 0.01 min

K= 3.9E-02 m/min
K= 6.6E-04 m/s
Calculation from Hvorslev (1951)

RESIDUAL HEAD VS. ELAPSED TIME



RISING HEAD TEST IN MW17-1

Hole:	MW17-1			
Datum Elevation:	6.89 m	Lithology: Fine Sand		
Ground Elevation:	6.89 m-asl			
PVC Stick-up:	0.00 m		Hole Diameter:	152.0 mm
Piezometer Depth:	17.30 m		Piezometer I.D.:	50.0 mm
Length of Pocket:	4.08 m			
Static Water Depth:	5.120 m			
Initial Excess Head (H_o):	-0.823 m			

Current excess head (h): Varies with time (difference between current and static water depths)

Date	Elasped Time (min)	Reading Depth (m)	Water Depth (m-bGL)	Water Elev. (m-asl)	Residual Head h/H_o (m/m)
10/27/2017	0.000	4.297	4.297		1.000
	0.017	4.492	4.492		0.764
	0.033	4.961	4.961		0.194
	0.050	4.946	4.946		0.211
	0.067	4.972	4.972		0.180
	0.083	5.001	5.001		0.145
	0.100	5.019	5.019		0.123
	0.117	5.038	5.038		0.100
	0.133	5.053	5.053		0.081
	0.150	5.068	5.068		0.063
	0.167	5.079	5.079		0.050
	0.183	5.089	5.089		0.037
	0.200	5.101	5.101		0.023
	0.217	5.106	5.106		0.017
	0.233	5.112	5.112		0.010
	0.250	5.117	5.117		0.004

CALCULATION

$K = d^2(\ln(2m^{0.5}L/D))/8LTi$

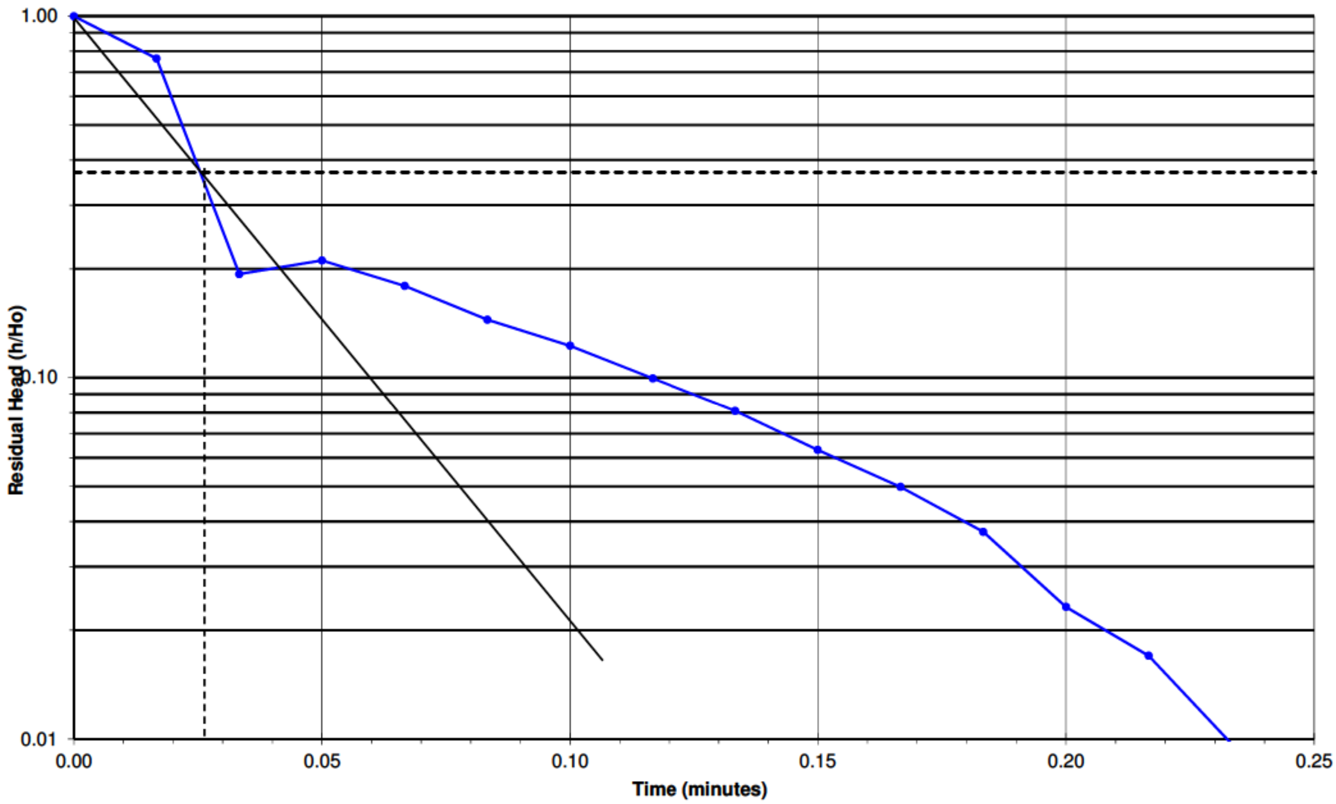
where

K= Hydraulic conductivity
D= Hole Diameter (m)
d= Tube Diameter (m)
m= Anisotropy (K_h/K_v)
L= Test Pocket Length (m)
Ti= Time for 63% drop on residual head plot (i.e. from 1 to 0.37 on y axis)
all above variables in consistent units

D= 0.152 m
d= 0.050 m
m= 10
L= 4.1 m
Ti= 0.026 min

K= 1.5E-02 m/min
K= 2.5E-04 m/s
Calculation from Hvorslev (1951)

RESIDUAL HEAD VS. ELAPSED TIME



FALLING HEAD TEST IN MW17-2

Hole: MW17-2
Datum Elevation: 6.50 m
Lithology: Fine Sand
Ground Elevation: 6.50 m-asl
PVC Stick-up: 0.00 m
Hole Diameter: 152.0 mm
Piezometer Depth: 19.80 m
Piezometer I.D.: 50.0 mm
Length of Pocket: 3.96 m
Static Water Depth: 4.643 m
Initial Excess Head (H_o): 0.075 m
Current excess head (h): Varies with time (difference between current and static water depths)

Date	Elasped Time (min)	Reading Depth (m)	Water Depth (m-bGL)	Water Elev. (m-asl)	Residual Head h/H_o (m/m)
10/27/2017	0.000	4.718	4.72		1.000
	0.001	4.734	4.73		1.215
	0.002	4.705	4.70		0.820
	0.004	4.707	4.71		0.853
	0.005	4.696	4.70		0.705
	0.006	4.690	4.69		0.632
	0.014	4.693	4.69		0.668
	0.015	4.681	4.68		0.509
	0.017	4.676	4.68		0.443
	0.018	4.674	4.67		0.412
	0.019	4.669	4.67		0.352
	0.020	4.668	4.67		0.328
	0.022	4.664	4.66		0.277
	0.023	4.660	4.66		0.227
	0.031	4.655	4.66		0.165
	0.032	4.653	4.65		0.136
	0.033	4.651	4.65		0.104
	0.035	4.647	4.65		0.056
	0.036	4.647	4.65		0.051

CALCULATION

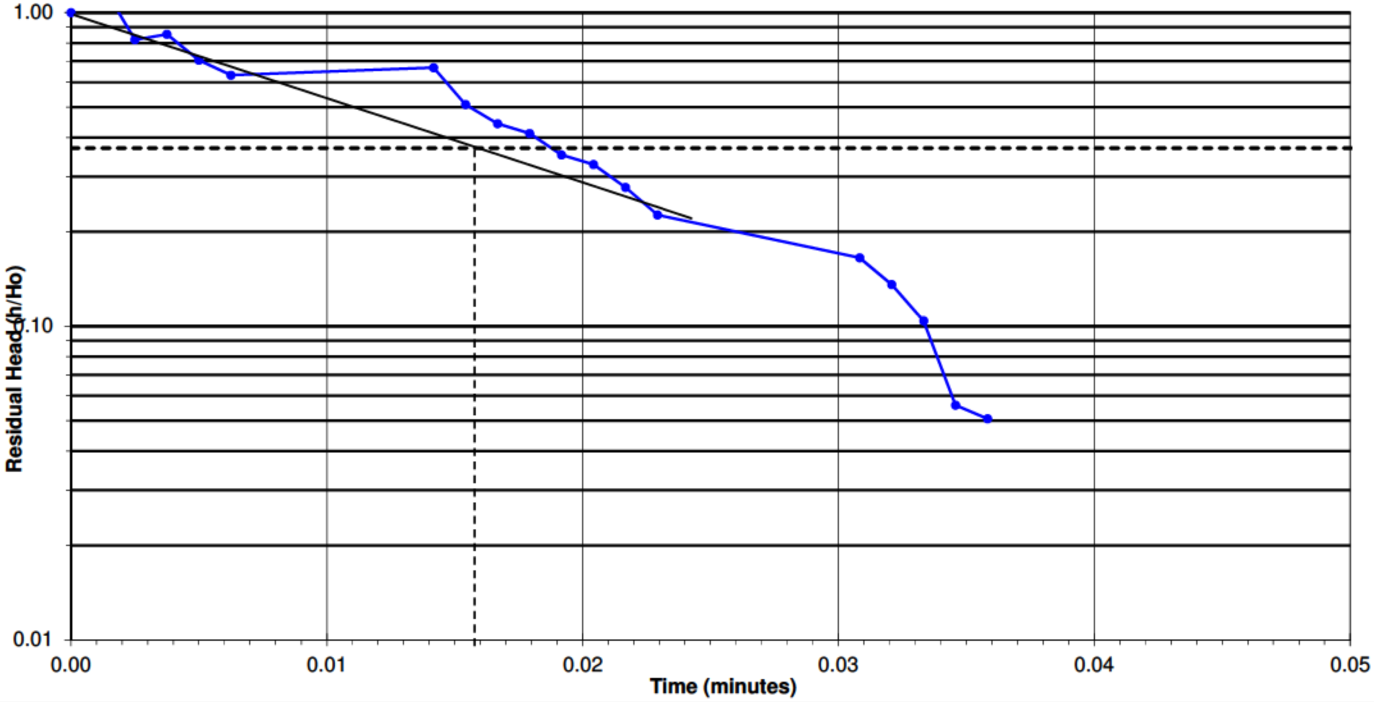
$K = d^2(\ln(2m^{0.5}L/D))/8LTi$

where
K= Hydraulic conductivity
D= Hole Diameter (m)
d= Tube Diameter (m)
m= Anisotropy (K_h/K_v)
L= Test Pocket Length (m)
Ti= Time for 63% drop on residual head plot (i.e. from 1 to 0.37 on y axis)
all above variables in consistent units

D= 0.152 m
d= 0.050 m
m= 10
L= 4.0 m
Ti= 0.0159 min

K= 2.5E-02 m/min
K= 4.2E-04 m/s
Calculation from Hvorslev (1951)

RESIDUAL HEAD VS. ELAPSED TIME



RISING HEAD TEST IN MW17-2

Hole: MW17-2
Datum Elevation: 6.50 m
Lithology: Fine Sand
Ground Elevation: 6.50 m-asl
PVC Stick-up: 0.00 m
Hole Diameter: 152.0 mm
Piezometer Depth: 19.80 m
Piezometer I.D.: 50.0 mm
Length of Pocket: 3.96 m
Static Water Depth: 4.643 m
Initial Excess Head (H_o): -0.067 m
Current excess head (h): Varies with time (difference between current and static water depths)

Date	Elapsed Time (min)	Reading Depth (m)	Water Depth (m-bGL)	Water Elev. (m-asl)	Residual Head h/H_o (m/m)
10/27/2017	0.000	4.576	4.576		1.000
	0.001	4.577	4.577		0.978
	0.003	4.581	4.581		0.924
	0.010	4.588	4.588		0.813
	0.012	4.589	4.589		0.796
	0.013	4.592	4.592		0.759
	0.014	4.593	4.593		0.740
	0.015	4.597	4.597		0.682
	0.017	4.597	4.597		0.681
	0.018	4.597	4.597		0.679
	0.019	4.600	4.600		0.643
	0.027	4.605	4.605		0.559
	0.028	4.609	4.609		0.508
	0.030	4.614	4.614		0.438
	0.031	4.618	4.618		0.376
	0.032	4.622	4.622		0.309
	0.033	4.624	4.624		0.281
	0.035	4.626	4.626		0.253
	0.036	4.628	4.628		0.217
	0.044	4.632	4.632		0.168

CALCULATION

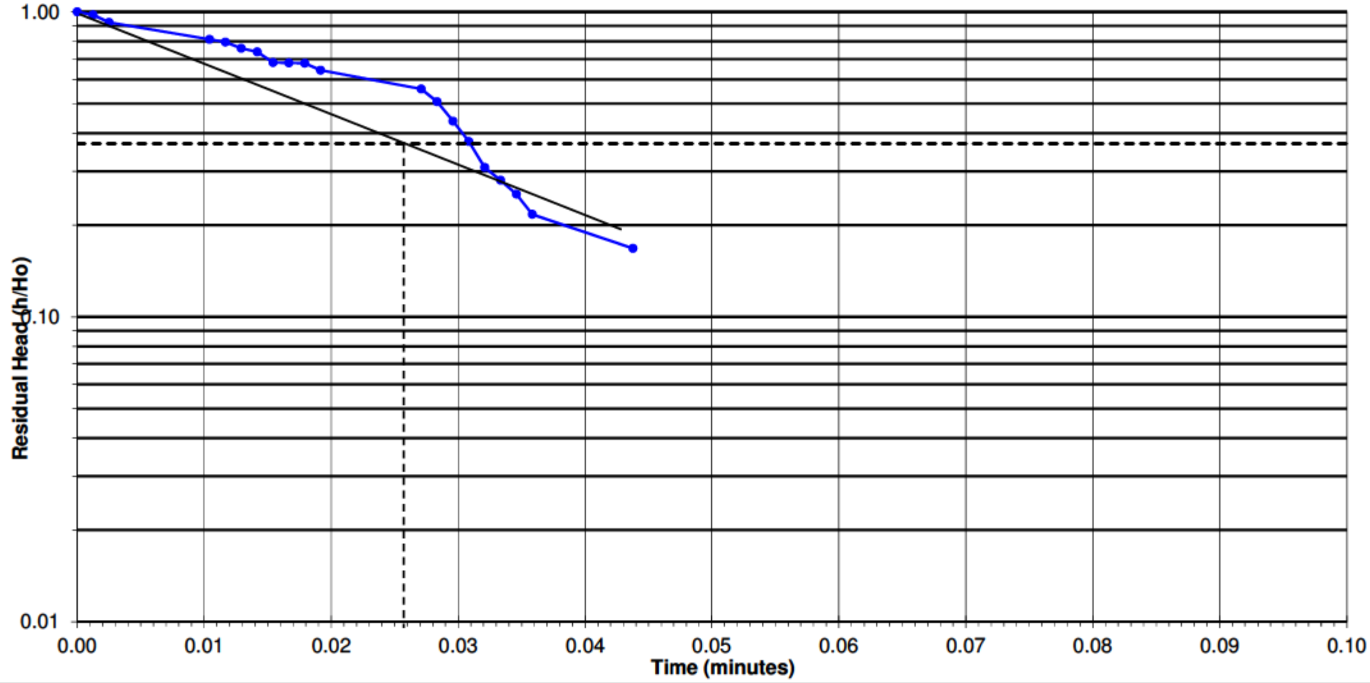
$K = d^2(\ln(2m^{0.5}L/D))/8LTi$

where
K= Hydraulic conductivity
D= Hole Diameter (m)
d= Tube Diameter (m)
m= Anisotropy (K_h/K_v)
L= Test Pocket Length (m)
Ti= Time for 63% drop on residual head plot (i.e. from 1 to 0.37 on y axis)
all above variables in consistent units

D= 0.152 m
d= 0.050 m
m= 10
L= 4.0 m
Ti= 0.0258 min

K= 1.6E-02 m/min
K= 2.6E-04 m/s
Calculation from Hvorslev (1951)

RESIDUAL HEAD VS. ELAPSED TIME



FALLING HEAD TEST IN MW17-3

Hole: MW17-3

Datum Elevation: 5.11 m

Lithology: Fine Sand

Ground Elevation: 5.11 m-asl

PVC Stick-up: 0.00 m

Hole Diameter: 152.0 mm

Piezometer Depth: 21.00 m

Piezometer I.D.: 50.0 mm

Length of Pocket: 3.04 m

Static Water Depth: 3.855 m

Initial Excess Head (H_o): 0.158 m

Current excess head (h): Varies with time (difference between current and static water depths)

Date	Elasped Time (min)	Reading Depth (m)	Water Depth (m-bGL)	Water Elev. (m-asl)	Residual Head h/H_o (m/m)
10/27/2017	0.000	4.013	4.01		1.000
	0.002	3.980	3.98		0.791
	0.004	3.989	3.99		0.846
	0.006	3.959	3.96		0.655
	0.008	3.959	3.96		0.659
	0.010	3.975	3.98		0.760
	0.012	3.981	3.98		0.797
	0.014	3.967	3.97		0.706
	0.016	3.944	3.94		0.564
	0.018	3.948	3.95		0.589
	0.020	3.938	3.94		0.527
	0.022	3.944	3.94		0.565
	0.024	3.932	3.93		0.489
	0.026	3.922	3.92		0.423
	0.028	3.918	3.92		0.399
	0.030	3.923	3.92		0.427
	0.032	3.909	3.91		0.344
	0.034	3.907	3.91		0.329
	0.036	3.900	3.90		0.282
	0.038	3.901	3.90		0.288

CALCULATION

$K = d^2(\ln(2m^{0.5}L/D))/8LTi$

where

K= Hydraulic conductivity

D= Hole Diameter (m)

d= Tube Diameter (m)

m= Anisotropy (K_h/K_v)

L= Test Pocket Length (m)

Ti= Time for 63% drop on residual head plot (i.e. from 1 to 0.37 on y axis)

all above variables in consistent units

D= 0.152 m

d= 0.050 m

m= 10

L= 3.0 m

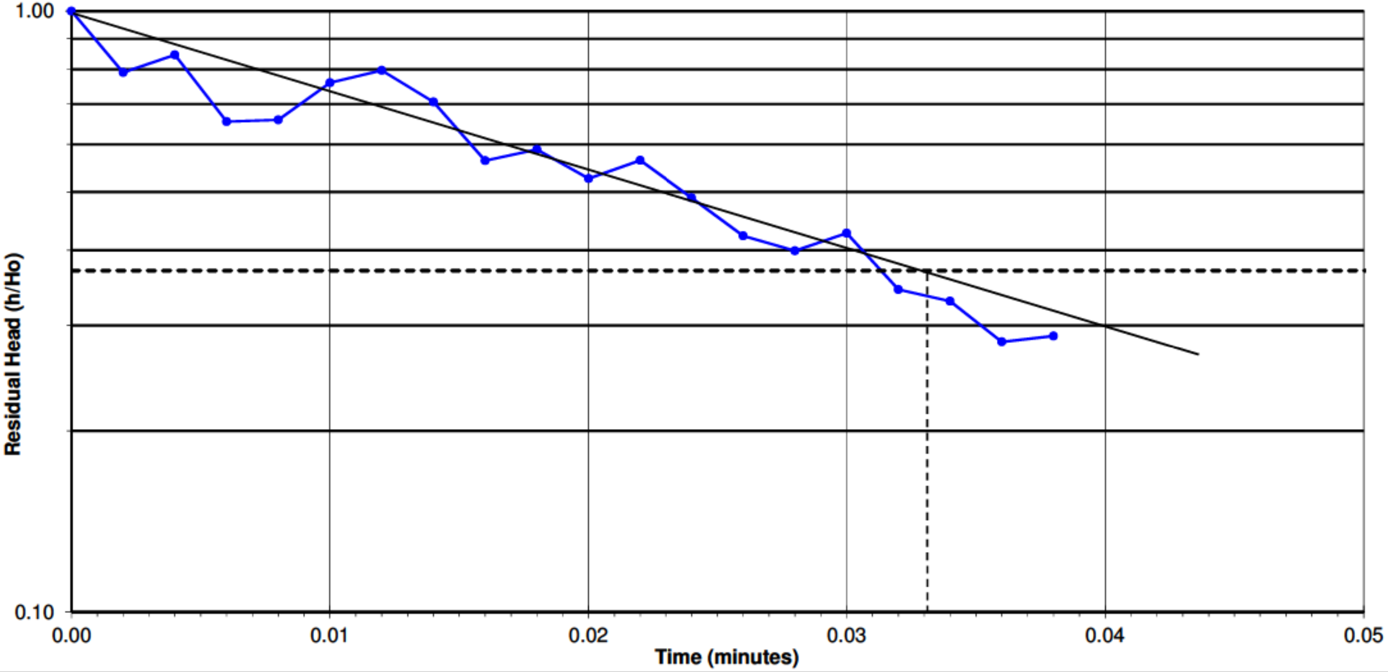
Ti= 0.0332 min

K= 1.5E-02 m/min

K= 2.5E-04 m/s

Calculation from Hvorslev (1951)

RESIDUAL HEAD VS. ELAPSED TIME



RISING HEAD TEST IN MW17-3

Hole: MW17-3
Datum Elevation: 5.11 m
Lithology: Fine Sand
Ground Elevation: 5.11 m-asl
PVC Stick-up: 0.00 m
Hole Diameter: 152.0 mm
Piezometer Depth: 21.00 m
Piezometer I.D.: 50.0 mm
Length of Pocket: 3.04 m
Static Water Depth: 3.855 m
Initial Excess Head (H_o): -0.013 m
Current excess head (h): Varies with time (difference between current and static water depths)

Date	Elasped Time (min)	Reading Depth (m)	Water Depth (m-bGL)	Water Elev. (m-asl)	Residual Head h/H_o (m/m)
10/27/2017	0.000	3.842	3.842		1.000
	0.005	3.843	3.843		0.902
	0.010	3.846	3.846		0.682
	0.015	3.847	3.847		0.621
	0.020	3.849	3.849		0.492
	0.025	3.850	3.850		0.417
	0.030	3.850	3.850		0.371
	0.035	3.852	3.852		0.242
	0.040	3.852	3.852		0.227
	0.045	3.852	3.852		0.220
	0.050	3.853	3.853		0.144
	0.055	3.854	3.854		0.098
	0.060	3.853	3.853		0.121
	0.065	3.855	3.855		0.038
	0.070	3.854	3.854		0.098
	0.075	3.855	3.855		0.023
	0.080	3.854	3.854		0.076

CALCULATION

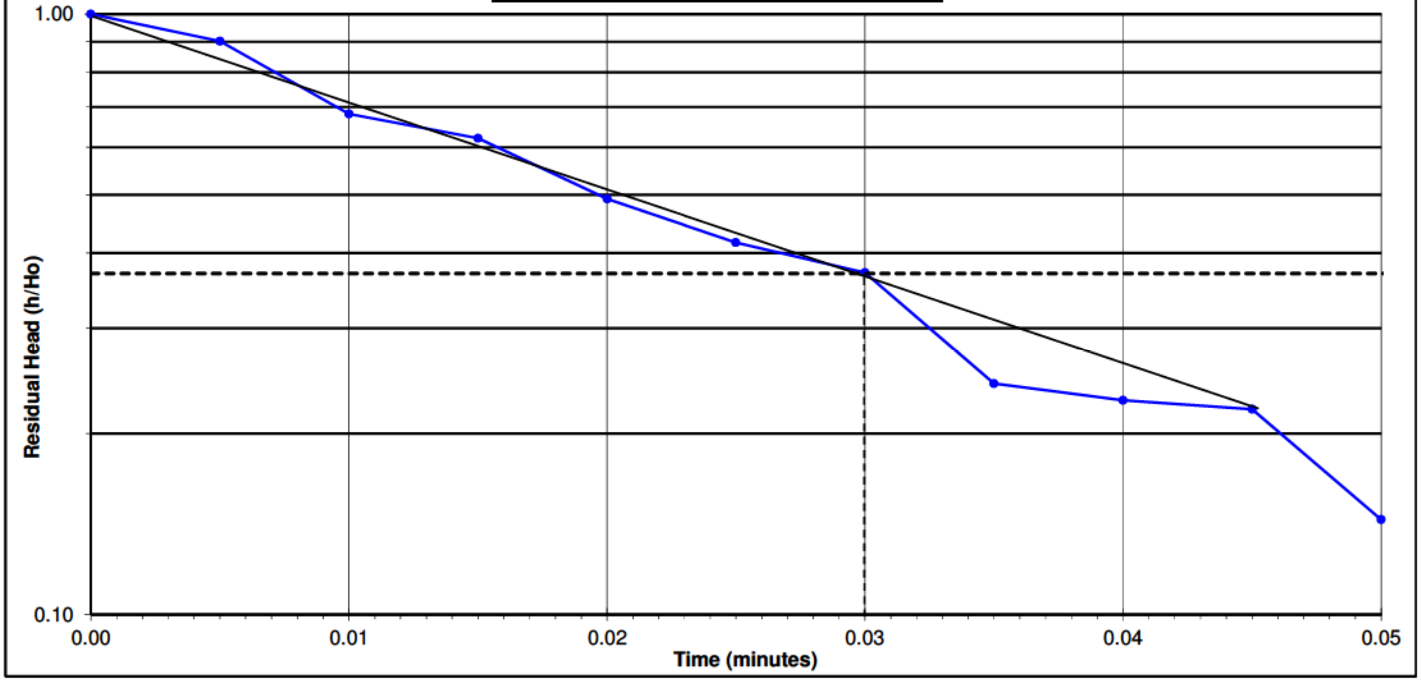
$K = d^2(\ln(2m^{0.5}L/D))/8LTi$

where
K= Hydraulic conductivity
D= Hole Diameter (m)
d= Tube Diameter (m)
m= Anisotropy (K_h/K_v)
L= Test Pocket Length (m)
Ti= Time for 63% drop on residual head plot (i.e. from 1 to 0.37 on y axis)
all above variables in consistent units

D= 0.152 m
d= 0.050 m
m= 10
L= 3.0 m
Ti= 0.03 min

K= 1.7E-02 m/min
K= 2.8E-04 m/s
Calculation from Hvorslev (1951)

RESIDUAL HEAD VS. ELAPSED TIME



FALLING-HEAD TEST IN MW17-4

Hole: MW17-4
Datum Elevation: 5.75 m
Lithology: Fine Sand
Ground Elevation: 5.75 m-asl
PVC Stick-up: 0.00 m
Hole Diameter: 152.0 mm
Piezometer Depth: 16.00 m
Piezometer I.D.: 50.0 mm
Length of Pocket: 3.04 m
Static Water Depth: 4.340 m
Initial Excess Head (H_o): 1.059 m
Current excess head (h): Varies with time (difference between current and static water depths)

Date	Elasped Time (min)	Reading Depth (m)	Water Depth (m-bGL)	Water Elev. (m-asl)	Residual Head h/H_o (m/m)
10/27/2017	0.000	3.281	3.28		1.000
	0.001	3.321	3.32		0.962
	0.003	3.523	3.52		0.771
	0.010	3.810	3.81		0.500
	0.012	3.902	3.90		0.414
	0.013	3.995	3.99		0.326
	0.014	4.083	4.08		0.243
	0.015	4.162	4.16		0.168
	0.017	4.194	4.19		0.138
	0.018	4.232	4.23		0.102
	0.019	4.259	4.26		0.076
	0.027	4.285	4.28		0.052
	0.028	4.293	4.29		0.044
	0.030	4.305	4.30		0.033
	0.031	4.312	4.31		0.026
	0.032	4.321	4.32		0.018
	0.033	4.324	4.32		0.015
	0.035	4.327	4.33		0.012
	0.036	4.329	4.33		0.010
	0.044	4.333	4.33		0.007

CALCULATION

$K = d^2(\ln(2m^{0.5}L/D))/8LTi$

where

K= Hydraulic conductivity
D= Hole Diameter (m)
d= Tube Diameter (m)
m= Anisotropy (K_h/K_v)
L= Test Pocket Length (m)
Ti= Time for 63% drop on residual head plot (i.e. from 1 to 0.37 on y axis)

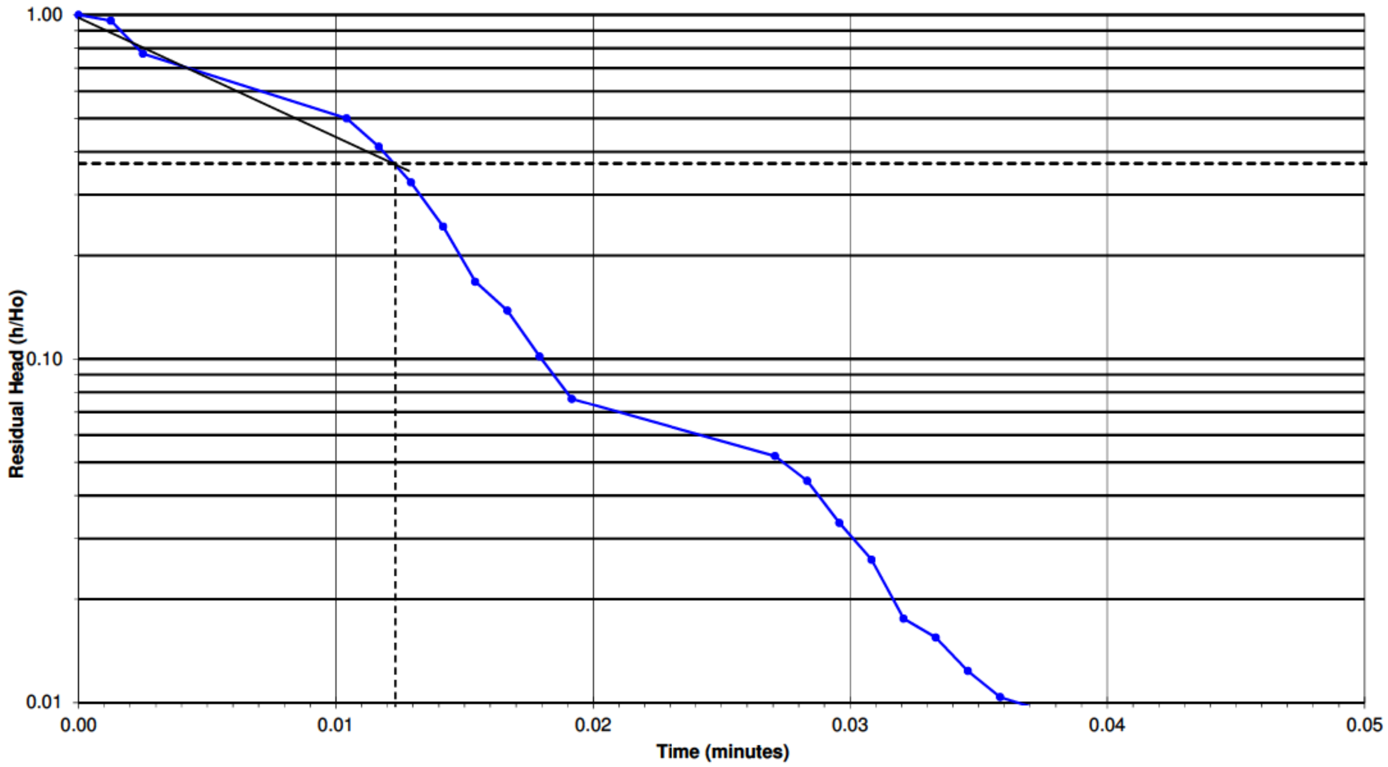
all above variables in consistent units

D= 0.152 m
d= 0.050 m
m= 10
L= 3.0 m
Ti= 0.0122 min

K= 4.1E-02 m/min
K= 6.8E-04 m/s

Calculation from Hvorslev (1951)

RESIDUAL HEAD VS. ELAPSED TIME



APPENDIX D

WATER QUALITY CERTIFICATE OF ANALYSIS

PITEAU ASSOC. ENGINEERING LTD.
ATTN: Arnd Burgert
#300-788 Copping Street
North Vancouver BC V7M 3G6

Date Received: 08-DEC-17
Report Date: 18-JAN-18 10:34 (MT)
Version: FINAL

Client Phone: 604-986-8551

Certificate of Analysis

Lab Work Order #: L2033220
Project P.O. #: NOT SUBMITTED
Job Reference: 3694
C of C Numbers: 17-675640
Legal Site Desc:

Comments: ADDITIONAL 10-JAN-18 14:44

Brent Mack, B.Sc.
Account Manager

	Sample ID	L2033220-1	L2033220-2	L2033220-3	L2033220-4	
	Description	Water	Water	Water	Water	
	Sampled Date	08-DEC-17	08-DEC-17	08-DEC-17	08-DEC-17	
	Sampled Time					
	Client ID	MW17-1	MW17-2	MW17-3	MW17-4	
Grouping	**Analyte**					
WATER						
Physical Tests	UV Absorbance (254 nm) (Abs/cm)		0.0520			
	Hardness (as CaCO3) (mg/L)	178	194	156	197	
	Transmittance, UV (254 nm) (%T/cm)		88.7			
Anions and Nutrients	Ammonia, Total (as N) (mg/L)	0.537	0.507	0.114	0.151	
	Bromide (Br) (mg/L)	0.111	<0.050	<0.050	0.069	
	Chloride (Cl) (mg/L)	4.54	7.64	10.2	6.07	
	Fluoride (F) (mg/L)	0.229	0.094	0.100	0.223	
	Nitrate (as N) (mg/L)	<0.0050	<0.0050	<0.0050	3.59	
	Nitrite (as N) (mg/L)	<0.0010	<0.0010	<0.0010	0.0148	
	Silicate (as SiO2) (mg/L)		24.6			
	Sulfate (SO4) (mg/L)	21.0	1.64	21.7	58.1	
	Sulphide as S (mg/L)		<0.018			
Organic / Inorganic Carbon	Dissolved Organic Carbon (mg/L)		2.51			
	Total Organic Carbon (mg/L)		3.13			
Total Metals	Aluminum (Al)-Total (mg/L)		0.0551			
	Antimony (Sb)-Total (mg/L)		<0.00010			
	Arsenic (As)-Total (mg/L)		0.00712			
	Barium (Ba)-Total (mg/L)		0.0842			
	Beryllium (Be)-Total (mg/L)		<0.00010			
	Bismuth (Bi)-Total (mg/L)		<0.000050			
	Boron (B)-Total (mg/L)		0.019			
	Cadmium (Cd)-Total (mg/L)		<0.0000050			
	Calcium (Ca)-Total (mg/L)		45.8			
	Cesium (Cs)-Total (mg/L)		0.000011			
	Chromium (Cr)-Total (mg/L)		0.00024			
	Cobalt (Co)-Total (mg/L)		0.00019			
	Copper (Cu)-Total (mg/L)		<0.00050			
	Iron (Fe)-Total (mg/L)		33.3			
	Lead (Pb)-Total (mg/L)		<0.000050			
	Lithium (Li)-Total (mg/L)		0.0028			
	Magnesium (Mg)-Total (mg/L)		18.3			
	Manganese (Mn)-Total (mg/L)		1.24			
	Mercury (Hg)-Total (mg/L)		<0.0000050			
	Molybdenum (Mo)-Total (mg/L)		0.00123			
	Nickel (Ni)-Total (mg/L)		<0.00050			
	Phosphorus (P)-Total (mg/L)		0.227			

* Please refer to the Reference Information section for an explanation of any qualifiers detected.

	Sample ID	L2033220-1	L2033220-2	L2033220-3	L2033220-4	
	Description	Water	Water	Water	Water	
	Sampled Date	08-DEC-17	08-DEC-17	08-DEC-17	08-DEC-17	
	Sampled Time					
	Client ID	MW17-1	MW17-2	MW17-3	MW17-4	
Grouping	**Analyte**					
WATER						
Total Metals	Potassium (K)-Total (mg/L)		1.34			
	Rubidium (Rb)-Total (mg/L)		0.00165			
	Selenium (Se)-Total (mg/L)		<0.000050			
	Silicon (Si)-Total (mg/L)		15.7			
	Silver (Ag)-Total (mg/L)		<0.000010			
	Sodium (Na)-Total (mg/L)		5.43			
	Strontium (Sr)-Total (mg/L)		0.184			
	Sulfur (S)-Total (mg/L)		0.70			
	Tellurium (Te)-Total (mg/L)		<0.00020			
	Thallium (Tl)-Total (mg/L)		<0.000010			
	Thorium (Th)-Total (mg/L)		<0.00010			
	Tin (Sn)-Total (mg/L)		0.00016			
	Titanium (Ti)-Total (mg/L)		0.00180			
	Tungsten (W)-Total (mg/L)		<0.00010			
	Uranium (U)-Total (mg/L)		0.000040			
	Vanadium (V)-Total (mg/L)		<0.00050			
	Zinc (Zn)-Total (mg/L)		<0.0030			
	Zirconium (Zr)-Total (mg/L)		0.000073			
Dissolved Metals	Dissolved Mercury Filtration Location	FIELD	FIELD	FIELD	FIELD	
	Dissolved Metals Filtration Location	FIELD	FIELD	FIELD	FIELD	
	Aluminum (Al)-Dissolved (mg/L)	0.0239	0.0047	0.0053	0.0037	
	Antimony (Sb)-Dissolved (mg/L)	<0.00010	<0.00010	<0.00010	0.00011	
	Arsenic (As)-Dissolved (mg/L)	0.00815	0.00707	0.00201	0.00244	
	Barium (Ba)-Dissolved (mg/L)	0.0905	0.0905	0.0663	0.0546	
	Beryllium (Be)-Dissolved (mg/L)	<0.00010	<0.00010	<0.00010	<0.00010	
	Bismuth (Bi)-Dissolved (mg/L)	<0.000050	<0.000050	<0.000050	<0.000050	
	Boron (B)-Dissolved (mg/L)	0.072	0.022	0.014	0.031	
	Cadmium (Cd)-Dissolved (mg/L)	<0.0000050	<0.0000050	<0.0000050	<0.0000050	
	Calcium (Ca)-Dissolved (mg/L)	47.8	46.8	36.3	45.2	
	Cesium (Cs)-Dissolved (mg/L)	0.000010	<0.000010	<0.000010	<0.000010	
	Chromium (Cr)-Dissolved (mg/L)	0.00123	0.00010	<0.00010	<0.00010	
	Cobalt (Co)-Dissolved (mg/L)	0.00278	0.00018	0.00033	0.00133	
	Copper (Cu)-Dissolved (mg/L)	0.00043	0.00095	<0.00020	<0.00020	
	Iron (Fe)-Dissolved (mg/L)	37.7	36.9	10.3	4.57	
	Lead (Pb)-Dissolved (mg/L)	<0.000050	0.000058	<0.000050	<0.000050	
	Lithium (Li)-Dissolved (mg/L)	0.0068	0.0029	0.0025	0.0034	
	Magnesium (Mg)-Dissolved (mg/L)	14.3	18.8	16.0	20.5	

* Please refer to the Reference Information section for an explanation of any qualifiers detected.

ALS ENVIRONMENTAL ANALYTICAL REPORT

	Sample ID	L2033220-1	L2033220-2	L2033220-3	L2033220-4	
	Description	Water	Water	Water	Water	
	Sampled Date	08-DEC-17	08-DEC-17	08-DEC-17	08-DEC-17	
	Sampled Time					
	Client ID	MW17-1	MW17-2	MW17-3	MW17-4	
Grouping	**Analyte**					
WATER						
Dissolved Metals	Manganese (Mn)-Dissolved (mg/L)	1.89	1.22	1.45	1.00	
	Mercury (Hg)-Dissolved (mg/L)	<0.0000050	<0.0000050	<0.0000050	<0.0000050	
	Molybdenum (Mo)-Dissolved (mg/L)	0.00480	0.00153 DTC	0.000955	0.00965	
	Nickel (Ni)-Dissolved (mg/L)	0.00546	<0.00050	<0.00050	0.00155	
	Phosphorus (P)-Dissolved (mg/L)	0.245	0.213	0.099	<0.050	
	Potassium (K)-Dissolved (mg/L)	2.32	1.43	1.70	2.52	
	Rubidium (Rb)-Dissolved (mg/L)	0.00178	0.00157	0.00103	0.00138	
	Selenium (Se)-Dissolved (mg/L)	0.000253	<0.000050	<0.000050	0.000140	
	Silicon (Si)-Dissolved (mg/L)	26.2	16.9	21.8	11.2	
	Silver (Ag)-Dissolved (mg/L)	<0.000010	<0.000010	<0.000010	<0.000010	
	Sodium (Na)-Dissolved (mg/L)	37.7	5.45	5.21	30.7	
	Strontium (Sr)-Dissolved (mg/L)	0.204	0.194	0.148	0.225	
	Sulfur (S)-Dissolved (mg/L)	7.34	0.61	7.50	19.8	
	Tellurium (Te)-Dissolved (mg/L)	<0.00020	<0.00020	<0.00020	<0.00020	
	Thallium (Tl)-Dissolved (mg/L)	<0.000010	<0.000010	<0.000010	<0.000010	
	Thorium (Th)-Dissolved (mg/L)	<0.00010	<0.00010	<0.00010	<0.00010	
	Tin (Sn)-Dissolved (mg/L)	0.00071	<0.00010	<0.00010	<0.00010	
	Titanium (Ti)-Dissolved (mg/L)	0.00162	<0.00030	<0.00030	<0.00030	
	Tungsten (W)-Dissolved (mg/L)	<0.00010	<0.00010	<0.00010	<0.00010	
	Uranium (U)-Dissolved (mg/L)	0.00107	0.000035	0.000030	0.000172	
	Vanadium (V)-Dissolved (mg/L)	0.00126	<0.00050	<0.00050	<0.00050	
	Zinc (Zn)-Dissolved (mg/L)	0.0015	0.0015	<0.0010	<0.0010	
	Zirconium (Zr)-Dissolved (mg/L)	0.000548	<0.000060	<0.000060	<0.000060	
Pharmaceuticals & Personal Care Products	Acesulfame K (ug/L)		<0.010 PEHT			
	Acetaminophen (ug/L)		<0.020 PEHT			
	Albuterol (ug/L)		<0.0010 PEHT			
	Amitriptyline (ug/L)		<0.0050 PEHT			
	Amlodipine (ug/L)		<0.0050 PEHT			
	Amphetamine (ug/L)		<0.010 PEHT			
	Ampicillin (ug/L)		<0.020 PEHT			
	Atenolol (ug/L)		<0.0050 PEHT			
	Atorvastatin (ug/L)		<0.0050 PEHT			
	Azithromycin (ug/L)		<0.10 PEHT			
	Benzoylecgonine (ug/L)		<0.0020			
	Bezafibrate (ug/L)		<0.010 PEHT			
	Carbadox (ug/L)		<0.10 PEHT			

* Please refer to the Reference Information section for an explanation of any qualifiers detected.

ALS ENVIRONMENTAL ANALYTICAL REPORT

	Sample ID	L2033220-1	L2033220-2	L2033220-3	L2033220-4	
	Description	Water	Water	Water	Water	
	Sampled Date	08-DEC-17	08-DEC-17	08-DEC-17	08-DEC-17	
	Sampled Time					
	Client ID	MW17-1	MW17-2	MW17-3	MW17-4	
Grouping	**Analyte**					
WATER						
Pharmaceuticals & Personal Care Products	Carbamazepine (ug/L)		<0.0020 PEHT			
	Cimetidine (ug/L)		<0.0050 PEHT			
	Clarithromycin (ug/L)		<0.0010 PEHT			
	Clinafloxacin (ug/L)		<0.20 PEHT			
	Clofibric Acid (ug/L)		<0.0020			
	Clotrimazole (ug/L)		<0.050 PEHT			
	Cloxacillin (ug/L)		<0.0020 PEHT			
	Codeine (ug/L)		<0.010 PEHT			
	Cotinine (ug/L)		<0.0050 PEHT			
	Cyclophosphamide (ug/L)		<0.0050 PEHT			
	Dehydronifedipine (ug/L)		<0.0020 PEHT			
	Diazepam (ug/L)		<0.0050 PEHT			
	Diclofenac (ug/L)		<0.010			
	Diethylstilbestrol (ug/L)		<0.0050			
	Digoxigenin (ug/L)		<0.050			
	Diltiazem (ug/L)		<0.0020 PEHT			
	1,7-Dimethylxanthine (ug/L)		<0.0050			
	Diphenhydramine (ug/L)		<0.0010 PEHT			
	Enrofloxacin (ug/L)		<0.010 PEHT			
	Erythromycin (ug/L)		<0.0010 PEHT			
	Erythromycin Anhydrate (ug/L)		<0.010 PEHT			
	Fenoprofen (ug/L)		<0.050			
	Flumequine (ug/L)		<0.050 PEHT			
	Fluoxetine (ug/L)		<0.0020 PEHT			
	Furosemide (ug/L)		<0.010			
	Gemfibrozil (ug/L)		<0.0020			
	Glipizide (ug/L)		<0.010 PEHT			
	Glyburide (ug/L)		<0.0050 PEHT			
	Hydrochlorothiazide (ug/L)		<0.010			
	2-Hydroxy Ibuprofen (ug/L)		<0.40			
	Ibuprofen (ug/L)		<0.050			
	Indomethacin (ug/L)		<0.010 PEHT			
	Ketoprofen (ug/L)		<0.020 PEHT			
	Lidocaine (ug/L)		<0.00050 PEHT			
	Lincomycin (ug/L)		<0.010 PEHT			
	Lomefloxacin (ug/L)		<0.020 PEHT			

* Please refer to the Reference Information section for an explanation of any qualifiers detected.

	Sample ID	L2033220-1	L2033220-2	L2033220-3	L2033220-4	
	Description	Water	Water	Water	Water	
	Sampled Date	08-DEC-17	08-DEC-17	08-DEC-17	08-DEC-17	
	Sampled Time					
	Client ID	MW17-1	MW17-2	MW17-3	MW17-4	
Grouping	**Analyte**					
WATER						
Pharmaceuticals & Personal Care Products	Metoprolol (ug/L)		<0.010 PEHT			
	Miconazole (ug/L)		<0.0050			
	Naproxen (ug/L)		<0.010			
	Norfloxacin (ug/L)		<0.50 PEHT			
	Norgestimate (ug/L)		<0.050 PEHT			
	Novobiocin (ug/L)		<0.0050 PEHT			
	Ofloxacin (ug/L)		<0.050 PEHT			
	Ormetoprim (ug/L)		<0.0010			
	Oxacillin (ug/L)		<0.0020 PEHT			
	Oxolinic Acid (ug/L)		<0.020 PEHT			
	Penicillin G (ug/L)		<0.020 PEHT			
	Penicillin V (ug/L)		<0.020 PEHT			
	Pentoxifylline (ug/L)		<0.0020			
	Ranitidine (ug/L)		<0.0010 PEHT			
	Roxithromycin (ug/L)		<0.0050 PEHT			
	Sarafloxacin (ug/L)		<0.020 PEHT			
	Sucralose (ug/L)		<0.050 PEHT			
	Sulfabenzamide (ug/L)		<0.0050			
	Sulfacetamide (ug/L)		<0.020			
	Sulfachloropyridazine (ug/L)		<0.010			
	Sulfadiazine (ug/L)		<0.0050			
	Sulfadimethoxine (ug/L)		<0.0050			
	Sulfaguanidine (ug/L)		<0.020			
	Sulfamerazine (ug/L)		<0.0050			
	Sulfameter (ug/L)		<0.0050			
	Sulfamethazine (ug/L)		<0.0050			
	Sulfamethizole (ug/L)		<0.0050			
	Sulfamethoxazole (ug/L)		<0.0050			
	Sulfamethoxypyridazine (ug/L)		<0.0050			
	Sulfamoxole (ug/L)		<0.0050			
	Sulfanilamide (ug/L)		<0.25			
	Sulfaphenazole (ug/L)		<0.0050			
	Sulfapyridine (ug/L)		<0.0050			
	Sulfaquinoxaline (ug/L)		<0.0050			
	Sulfathiazole (ug/L)		<0.0050			
	Sulfisoxazole (ug/L)		<0.0050			

	Sample ID	L2033220-1	L2033220-2	L2033220-3	L2033220-4	
	Description	Water	Water	Water	Water	
	Sampled Date	08-DEC-17	08-DEC-17	08-DEC-17	08-DEC-17	
	Sampled Time					
	Client ID	MW17-1	MW17-2	MW17-3	MW17-4	
Grouping	**Analyte**					
WATER						
Pharmaceuticals & Personal Care Products	Thiabendazole (ug/L)		PEHT <0.0050			
	Triclocarban (ug/L)		PEHT 0.0088			
	Triclosan (ug/L)		PEHT 0.064			
	Trimethoprim (ug/L)		PEHT <0.0020			
	Tylosin (ug/L)		PEHT <0.050			
	Warfarin (ug/L)		<0.0010			
	10-Hydroxy-Amitriptyline (ug/L)		PEHT <0.0010			

* Please refer to the Reference Information section for an explanation of any qualifiers detected.

Reference Information

QC Samples with Qualifiers & Comments:

QC Type Description	Parameter	Qualifier	Applies to Sample Number(s)
Matrix Spike	Diltiazem	K	L2033220-2
Matrix Spike	Enrofloxacin	K	L2033220-2
Matrix Spike	Norfloxacin	K	L2033220-2
Matrix Spike	Oxolinic Acid	K	L2033220-2
Laboratory Control Sample	Aluminum (Al)-Dissolved	MES	L2033220-2
Matrix Spike	Dissolved Organic Carbon	MS-B	L2033220-2
Matrix Spike	Dissolved Organic Carbon	MS-B	L2033220-2
Matrix Spike	Calcium (Ca)-Dissolved	MS-B	L2033220-1, -3, -4
Matrix Spike	Magnesium (Mg)-Dissolved	MS-B	L2033220-1, -3, -4
Matrix Spike	Strontium (Sr)-Dissolved	MS-B	L2033220-1, -3, -4
Matrix Spike	Aluminum (Al)-Total	MS-B	L2033220-2
Matrix Spike	Barium (Ba)-Total	MS-B	L2033220-2
Matrix Spike	Barium (Ba)-Total	MS-B	L2033220-2
Matrix Spike	Boron (B)-Total	MS-B	L2033220-2
Matrix Spike	Calcium (Ca)-Total	MS-B	L2033220-2
Matrix Spike	Calcium (Ca)-Total	MS-B	L2033220-2
Matrix Spike	Magnesium (Mg)-Total	MS-B	L2033220-2
Matrix Spike	Magnesium (Mg)-Total	MS-B	L2033220-2
Matrix Spike	Manganese (Mn)-Total	MS-B	L2033220-2
Matrix Spike	Manganese (Mn)-Total	MS-B	L2033220-2
Matrix Spike	Potassium (K)-Total	MS-B	L2033220-2
Matrix Spike	Sodium (Na)-Total	MS-B	L2033220-2
Matrix Spike	Sodium (Na)-Total	MS-B	L2033220-2
Matrix Spike	Strontium (Sr)-Total	MS-B	L2033220-2
Matrix Spike	Strontium (Sr)-Total	MS-B	L2033220-2
Matrix Spike	Sulfur (S)-Total	MS-B	L2033220-2
Matrix Spike	Silicate (as SiO2)	MS-B	L2033220-2
Matrix Spike	Ampicillin	RRQC	L2033220-2

Qualifiers for Individual Parameters Listed:

Qualifier	Description
DTC	Dissolved concentration exceeds total. Results were confirmed by re-analysis.
K	Matrix Spike recovery outside ALS DQO due to sample matrix effects.
MES	Data Quality Objective was marginally exceeded (by < 10% absolute) for < 10% of analytes in a Multi-Element Scan / Multi-Parameter Scan (considered acceptable as per OMOE & CCME).
MS-B	Matrix Spike recovery could not be accurately calculated due to high analyte background in sample.
PEHT	Parameter Exceeded Recommended Holding Time Prior to Analysis
RRQC	Refer to report remarks for information regarding this QC result.

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**
BR-L-IC-N-VA	Water	Bromide in Water by IC (Low Level)	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

CARBONS-DOC-VA	Water	Dissolved organic carbon by combustion	APHA 5310B TOTAL ORGANIC CARBON (TOC)

This analysis is carried out using procedures adapted from APHA Method 5310 "Total Organic Carbon (TOC)". Dissolved carbon (DOC) fractions are determined by filtering the sample through a 0.45 micron membrane filter prior to analysis.

CARBONS-TOC-VA	Water	Total organic carbon by combustion	APHA 5310B TOTAL ORGANIC CARBON (TOC)

This analysis is carried out using procedures adapted from APHA Method 5310 "Total Organic Carbon (TOC)".

CL-IC-N-VA	Water	Chloride in Water by IC	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

EC-SCREEN-VA	Water	Conductivity Screen (Internal Use Only)	APHA 2510

Qualitative analysis of conductivity where required during preparation of other tests - e.g. TDS, metals, etc.

F-IC-N-VA Water Fluoride in Water by IC EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

HARDNESS-CALC-VA Water Hardness APHA 2340B

Hardness (also known as Total Hardness) is calculated from the sum of Calcium and Magnesium concentrations, expressed in CaCO3 equivalents. Dissolved Calcium and Magnesium concentrations are preferentially used for the hardness calculation.

HG-D-CVAA-VA Water Diss. Mercury in Water by CVAAS or CVAFS APHA 3030B/EPA 1631E (mod)

Water samples are filtered (0.45 um), preserved with hydrochloric acid, then undergo a cold-oxidation using bromine monochloride prior to reduction with stannous chloride, and analyzed by CVAAS or CVAFS.

HG-T-CVAA-VA Water Total Mercury in Water by CVAAS or CVAFS EPA 1631E (mod)

Water samples undergo a cold-oxidation using bromine monochloride prior to reduction with stannous chloride, and analyzed by CVAAS or CVAFS.

MET-D-CCMS-VA Water Dissolved Metals in Water by CRC ICPMS APHA 3030B/6020A (mod)

Water samples are filtered (0.45 um), preserved with nitric acid, and analyzed by CRC ICPMS.

Method Limitation (re: Sulfur): Sulfide and volatile sulfur species may not be recovered by this method.

MET-T-CCMS-VA Water Total Metals in Water by CRC ICPMS EPA 200.2/6020A (mod)

Water samples are digested with nitric and hydrochloric acids, and analyzed by CRC ICPMS.

Method Limitation (re: Sulfur): Sulfide and volatile sulfur species may not be recovered by this method.

NH3-F-VA Water Ammonia in Water by Fluorescence J. ENVIRON. MONIT., 2005, 7, 37-42, RSC

This analysis is carried out, on sulfuric acid preserved samples, using procedures modified from J. Environ. Monit., 2005, 7, 37 - 42, The Royal Society of Chemistry, "Flow-injection analysis with fluorescence detection for the determination of trace levels of ammonium in seawater", Roslyn J. Waston et al.

NO2-L-IC-N-VA Water Nitrite in Water by IC (Low Level) EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

NO3-L-IC-N-VA Water Nitrate in Water by IC (Low Level) EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

PPCP-NG-1-DI-LCMS-WT Water PPCP by LC/MS-MS (Negative Mode) EPA 1694

Water: If the sample is not clear filter a portion of the sample using a RC filter. An aliquot of the sample is taken and internal standard is added. The sample is analyzed by LC/MS/MS.

PPCP-NG-2-DI-LCMS-WT Water PPCP by LC/MS-MS (Negative Mode) EPA 1694

Water: If the sample is not clear filter a portion of the sample using a RC filter. An aliquot of the sample is taken and internal standard is added. The sample is analyzed by LC/MS/MS.

PPCP-POS1-DI-LCMS-WT Water PPCP by LC/MS EPA 1694

An aliquot of the water sample is filtered and internal standards are added. The water sample is analyzed by LC-MS/MS using electron ionization source with direct injection without sample cleanup.

PPCP-POS2-DI-LCMS-WT Water PPCP by LC/MS EPA 1694

An aliquot of the water sample is filtered and internal standards are added. The water sample is analyzed by LC-MS/MS using electron ionization source with direct injection without sample cleanup.

PPCP-POS3-DI-LCMS-WT Water PPCP by LC/MS EPA 1694

An aliquot of the water sample is filtered and internal standards are added. The water sample is analyzed by LC-MS/MS using electron ionization source with direct injection without sample cleanup.

S2-T-COL-VA Water Total Sulphide by Colorimetric APHA 4500-S2 Sulphide

This analysis is carried out using procedures adapted from APHA Method 4500-S2 "Sulphide". Sulphide is determined using the methlyene blue colourimetric method.

SILICATE-COL-VA Water Silicate by Colourimetric analysis APHA 4500-SiO2 E.

This analysis is carried out using procedures adapted from APHA Method 4500-SiO2 E. "Silica". Silicate (molybdate-reactive silica) is determined by

Reference Information

the molybdosilicate-heteropoly blue colourimetric method.

SO4-IC-N-VA	Water	Sulfate in Water by IC	EPA 300.1 (mod)

Inorganic anions are analyzed by Ion Chromatography with conductivity and/or UV detection.

UV-ABS-VA	Water	UV Absorbance (Spectrometry)	APHA 5910B UV ABSORPTION METHOD

Test method is adapted from APHA Method 5910B. A sample is filtered through a 0.45 um filter and it's UV Absorbance is measured in a quartz cell at 254 nm and reported as UV Absorbance per cm. The analysis is carried out without pH adjustment.

UV-TRANS-CALC-VA	Water	UV Transmittance (Calculated)	APHA 5910B UV ABSORPTION METHOD

Test method is adapted from APHA Method 5910B. A sample is filtered through a 0.45 um filter and it's UV Absorbance is measured in a quartz cell at 254 nm. UV Transmittance is calculated from the UV Absorbance result and reported as UV Transmittance per cm. The analysis is carried out without pH adjustment.

** ALS test methods may incorporate modifications from specified reference methods to improve performance.

The last two letters of the above test code(s) indicate the laboratory that performed analytical analysis for that test. Refer to the list below:

Laboratory Definition Code	Laboratory Location
WT	ALS ENVIRONMENTAL - WATERLOO, ONTARIO, CANADA
VA	ALS ENVIRONMENTAL - VANCOUVER, BRITISH COLUMBIA, CANADA

Chain of Custody Numbers:

17-675640

GLOSSARY OF REPORT TERMS

Surrogate - A compound that is similar in behaviour to target analyte(s), but that does not occur naturally in environmental samples. For applicable tests, surrogates are added to samples prior to analysis as a check on recovery.
mg/kg - milligrams per kilogram based on dry weight of sample.
mg/kg wwt - milligrams per kilogram based on wet weight of sample.
mg/kg lwt - milligrams per kilogram based on lipid-adjusted weight of sample.
mg/L - milligrams per litre.
< - Less than.
D.L. - The reported Detection Limit, also known as the Limit of Reporting (LOR).
N/A - Result not available. Refer to qualifier code and definition for explanation.

Test results reported relate only to the samples as received by the laboratory.
UNLESS OTHERWISE STATED, ALL SAMPLES WERE RECEIVED IN ACCEPTABLE CONDITION.
Analytical results in unsigned test reports with the DRAFT watermark are subject to change, pending final QC review.

ALS Environmental
www.alsglobal.com

Chain of Custody (COC) / Analytical Request Form

Canada Toll Free: 1 800 668 9878

L2033220-COFC

COC Number: 17 - 675640

Page 1 of 1

Report To	Contact and company name below will appear on the final report
Company:	Fitean Associates
Contact:	Anna Burgert
Phone:	
	Company address below will appear on the final report
Street:	
City/Province:	
Postal Code:	

Report Format / Distribution

Select Report Format: ☐ PDF ☐ EXCEL ☐ EDD (DIGITAL)
Quality Control (QC) Report with Report ☐ YES ☐ NO
☐ Compare Results to Criteria on Report - provide details below if box checked
Select Distribution: ☒ EMAIL ☐ MAIL ☐ FAX
Email 1 or Fax
Email 2
Email 3

Select Service Level Below - Contact your AM to confirm all E&P TATs (surcharges may apply)

Regular [R] ☒ Standard TAT if received by 3 pm - business days - no surcharges apply

PRIORITY (Business Days)
4 day [P4-20%] ☐
3 day [P3-25%] ☐
2 day [P2-50%] ☐

EMERGENCY
1 Business day [E-100%] ☐
Same Day, Weekend or Statutory holiday [E2-200% (Laboratory opening fees may apply)] ☐

Date and Time Required for all E&P TATs: dd-mmm-yy hh:mm

For tests that can not be performed according to the service level selected, you will be contacted.

Invoice To
Same as Report To ☐ YES ☐ NO
Copy of Invoice with Report ☐ YES ☐ NO
Company:
Contact:

Invoice Distribution
Select Invoice Distribution: ☐ EMAIL ☐ MAIL ☐ FAX
Email 1 or Fax
Email 2

Project Information
ALS Account # / Quote #:
Job #: 3694
PO / AFE:
LSD:

Oil and Gas Required Fields (client use)
AFE/Cost Center:
PO#
Major/Minor Code:
Routing Code:
Requisitioner:
Location:

ALS Lab Work Order # (lab use only):

ALS Contact: Brent Mack
Sampler: Rob Bulger

Analysis Request
Indicate Filtered (F), Preserved (P) or Filtered and Preserved (F/P) below

ALS Sample # (lab use only)	Sample Identification and/or Coordinates (This description will appear on the report)	Date (dd-mmm-yy)	Time (hh:mm)	Sample Type	Anions	Dissolved Metals	Total Metals	Nutrients TKN NH3	Pharmaceuticals	TOC	DOC	UV transmittance	Silicate	Sulfide						SAMPLES ON HOLD	Sample is hazardous (please provide further details)	NUMBER OF CONTAINERS
	MW 17-1	08/12/17		Water	X	X		X														
	MW 17-2	"			X	X	X	X	X	X	X	X	X	X								
	MW 17-3	"			X	X		X														
	MW 17-4	"		↓	X	X		X														

Drinking Water (DW) Samples[1] (client use)
Are samples taken from a Regulated DW System?
☐ YES ☐ NO
Are samples for human consumption/ use?
☐ YES ☐ NO

Special Instructions / Specify Criteria to add on report by clicking on the drop-down list below (electronic COC only)

SAMPLE CONDITION AS RECEIVED (lab use only)
Frozen ☐ SIF Observations Yes ☐ No ☐
Ice Packs ☐ Ice Cubes ☐ Custody seal intact Yes ☐ No ☐
Cooling Initiated ☐

INITIAL COOLER TEMPERATURES °C			FINAL COOLER TEMPERATURES °C		
		7.6			

SHIPMENT RELEASE (client use)			INITIAL SHIPMENT RECEPTION (lab use only)			FINAL SHIPMENT RECEPTION (lab use only)		
Released by: J. Bulger	Date: Dec 8/17	Time:	Received by: TP	Date: Dec 8	Time: 16:15	Received by:	Date:	Time:

REFER TO BACK PAGE FOR ALS LOCATIONS AND SAMPLING INFORMATION

WHITE - LABORATORY COPY YELLOW - CLIENT COPY

JULY 2017 FRONT

Failure to complete all portions of this form may delay analysis. Please fill in this form LEGIBLY. By the use of this form the user acknowledges and agrees with the Terms and Conditions as specified on the back page of the white - report copy.

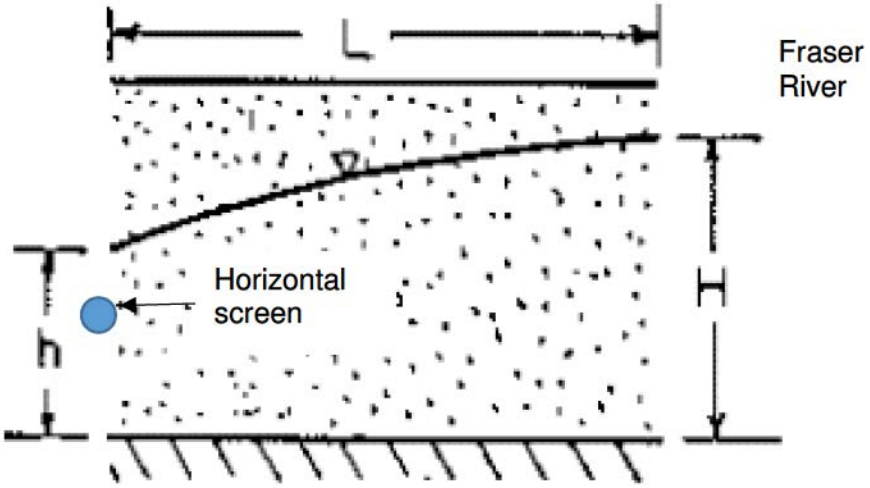
[1] If any water samples are taken from a **Regulated Drinking Water (DW) System**, please submit using an **Authorized DW COC form.**

APPENDIX E

PRELIMINARY FLOW CALCULATIONS FOR HORIZONTAL GROUNDWATER COLLECTOR

APPENDIX E

PRELIMINARY FLOW CALCULATIONS FOR HORIZONTAL GROUNDWATER COLLECTOR



Equation for steady state flow from line source (river) to a line sink (horizontal screen) in unconfined aquifer:

$$\frac{Q}{X} = \frac{K(H^2 - h^2)}{2L}$$

Symbol	Description	Unit	Assumed Value	Calculated Value
K	Hydraulic conductivity	m/s	7E-04	
H	Saturated thickness at river	m	30	
h	Saturated thickness at collector	m	20	
L	Distance between collector and river	m	30	
Q/X	Groundwater inflow per unit length	m^2/s		0.0057
X	Length of collector parallel to river	m	52	
Q	Groundwater inflow	m^3/s		0.29
		L/s		295
		MLD		25

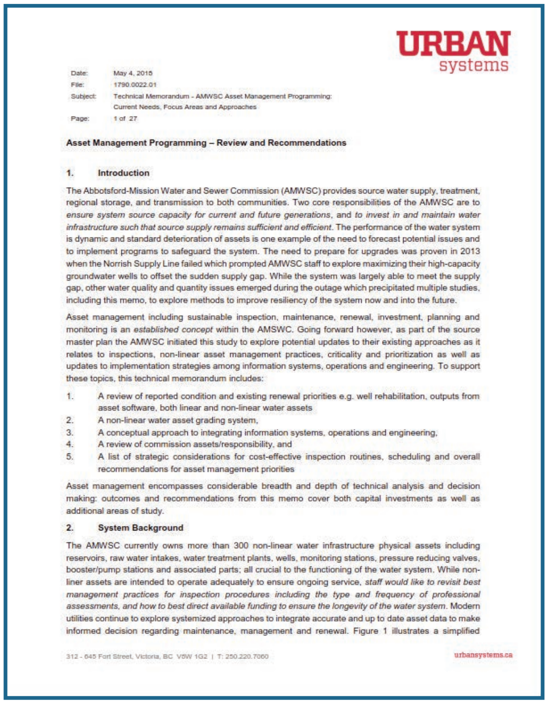
JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN

Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#12

ASSET MANAGEMENT PROGRAM REVIEW



URBAN systems

Date: May 4, 2016
File: 1790.0022.01
Subject: Technical Memorandum - AMWSC Asset Management Programming: Current Needs, Focus Areas and Approaches
Page: 1 of 27

Asset Management Programming – Review and Recommendations

1. Introduction

The Abbotsford-Mission Water and Sewer Commission (AMWSC) provides source water supply, treatment, regional storage, and transmission to both communities. Two core responsibilities of the AMWSC are to *ensure system source capacity for current and future generations*, and *to invest in and maintain water infrastructure such that source supply remains sufficient and efficient*. The performance of the water system is dynamic and standard deterioration of assets is one example of the need to forecast potential issues and to implement programs to safeguard the system. The need to prepare for upgrades was proven in 2013 when the Norrish Supply Line failed which prompted AMWSC staff to explore maximizing their high-capacity groundwater wells to offset the sudden supply gap. While the system was largely able to meet the supply gap, other water quality and quantity issues emerged during the outage which precipitated multiple studies, including this memo, to explore methods to improve resiliency of the system now and into the future.

Asset management including sustainable inspection, maintenance, renewal, investment, planning and monitoring is an *established concept* within the AMSWC. Going forward however, as part of the source master plan the AMWSC initiated this study to explore potential updates to their existing approaches as it relates to inspections, non-linear asset management practices, criticality and prioritization as well as updates to implementation strategies among information systems, operations and engineering. To support these topics, this technical memorandum includes:

1. A review of reported condition and existing renewal priorities e.g. well rehabilitation, outputs from asset software, both linear and non-linear water assets
2. A non-linear water asset grading system,
3. A conceptual approach to integrating information systems, operations and engineering,
4. A review of commission assets/responsibility, and
5. A list of strategic considerations for cost-effective inspection routines, scheduling and overall recommendations for asset management priorities

Asset management encompasses considerable breadth and depth of technical analysis and decision making: outcomes and recommendations from this memo cover both capital investments as well as additional areas of study.

2. System Background

The AMWSC currently owns more than 300 non-linear water infrastructure physical assets including reservoirs, raw water intakes, water treatment plants, wells, monitoring stations, pressure reducing valves, booster/pump stations and associated parts; all crucial to the functioning of the water system. While non-liner assets are intended to operate adequately to ensure ongoing service, *staff would like to revisit best management practices for inspection procedures including the type and frequency of professional assessments, and how to best direct available funding to ensure the longevity of the water system*. Modern utilities continue to explore systemized approaches to integrate accurate and up to date asset data to make informed decision regarding maintenance, management and renewal. Figure 1 illustrates a simplified

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urbansystems.ca

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Figure 1: Asset Condition: Integrating Data Sources into Capital Plans

Note: The same process is typically mirrored for capacity-based drivers for capital plans (separate memo).

While some utilities may be adequately sized to have dedicated resources to exclusively retain specialists to assess asset condition and performance, funding realities for most systems ultimately dictate data collection priorities and the result is that there is greater reliance on system-wide tools and operator knowledge for asset-repair decisions. Our experience is that 80% of asset renewal decisions are based on operator knowledge and system-wide tools and only 20% of replacement decisions are based on external personnel visiting a site to determine next steps. These ratios may shift a little for non-linear assets, but the overarching message remains: *asset condition programs must blend multiple data sources in order to cost-effectively prioritize asset investments*. The context for this memo is similar in that outcomes should reflect recommendations and next steps in all of these areas.

2.1 System-wide Tools: Riva Applications

A core asset condition tool for AMWSC is the Riva © software system. Assets are inventoried and categorized using the asset management software to provide AMWSC with a means of estimating asset replacement year and cost. Asset costs are divided into structural, electrical, generator, instrumentation and mechanical categories which provides a snapshot of asset values and pending areas of investments. These segmented results (i.e. summarized by asset type) provide the ingredients for large-scale facility upgrades. Each asset component is assigned a service life and a replacement value, both of which can be adjusted as new information is received (although it’s not common nor recommended to make frequent adjustments to each or all assets unless adequately justified). As an asset ages it approaches the end of its service life and eventually the software will *recommend* that the funding be directed to the asset for its renewal. This approach triggers multiple investments each year, often scattered throughout the system as assets age. Figure 2 summarizes estimated replacement costs for the 20-year horizon based on the databases.

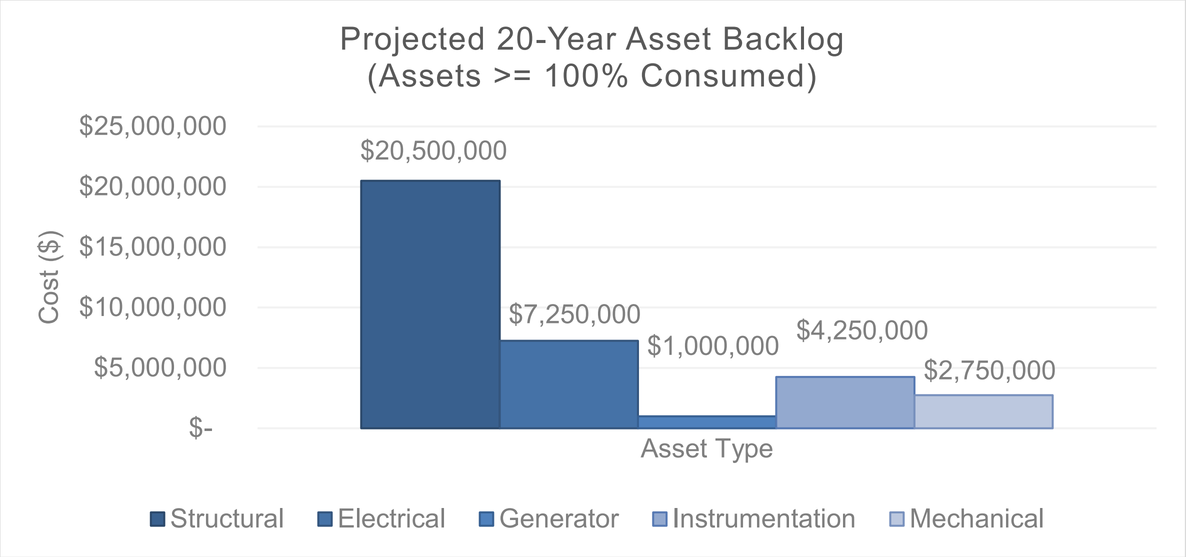


Figure 2: Riva Report for 20-Year Asset Renewal Investment Level

The above costs are based on Riva Asset Management's methodology of defining each asset in terms of consumed life, represented as ratio of physical age over estimated life. Unless otherwise stated, all cost figures presented are from 2017 Riva system outputs and that confirmation is required by Commission Staff per suitability of Riva projections for use in budget planning or construction scheduling.

Generally, structural assets are the most expensive to replace, but they also have the longest service lives. During periods of structural renewal, the utility will be faced with extraordinary renewal needs: the next 20 years of capital projections coupled with existing backlog will trigger larger-than-normal spending levels on existing assets. For example, assets like Cell 1 and Cell 2 at Maclure Reservoir and some wells are at the end of their estimated service lives and together, these assets represent approximately 60% of total replacement costs prior to 2030 for non-linear assets. Another 20% of pending costs relate to more frequently replaced electrical and instrumentation assets.

Based on age of assets in relation to their consumed life ratios, over 48% of all non-linear assets will be backlogged (greater than or equal to 100% consumed) by 2030 (a looming 10 year+ horizon to plan for), amounting to almost $24,750,000 in foreseeable replacement costs. While backlogged costs may not be reflective of actual system condition, they provide a conservative baseline as to where investment bottlenecks exist and where additional information is required in order to decide on actual capital projects. A breakdown of backlogged costs projected to 2030 (the projects triggered by consumed life ratio in 2030) can be seen in Figure 3 below. In effect, the Riva table builds a request for funds for asset management and renewal, but what is currently unknown – and ultimately creates the context for this memo – is the need to sensibly deploy funding resources to assets in need.

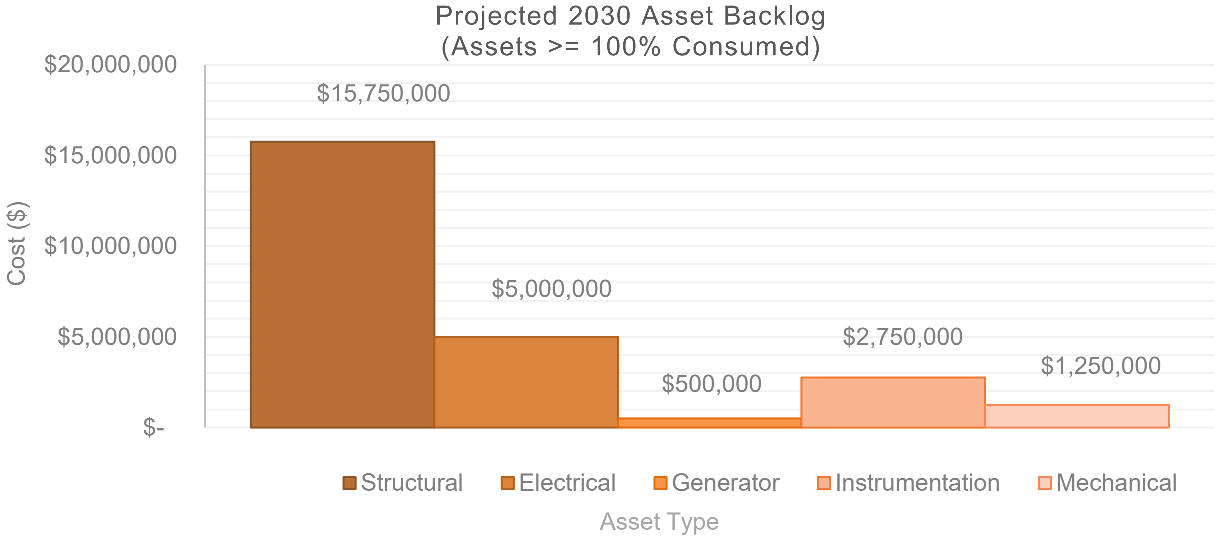


Figure 3: Riva Report on Backlogged Assets at 2030

A key observation from the comparison of Figure 3 to Figure 2 is that 2030 backlogged assets make up 70% of the 20-year horizon (up to 2038) for asset renewal. Figure 4 illustrates backlog assets and Figure 5 illustrates the relationship of three backlog reports: today, 2030 and 20-year.

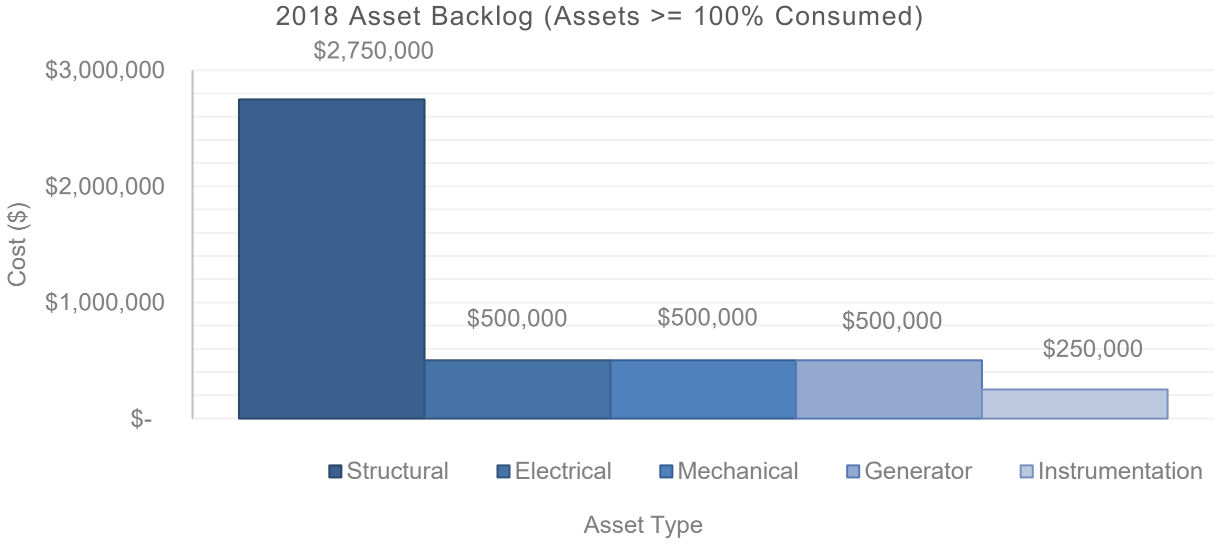


Figure 4: Riva Report on Backlogged Assets for 2018

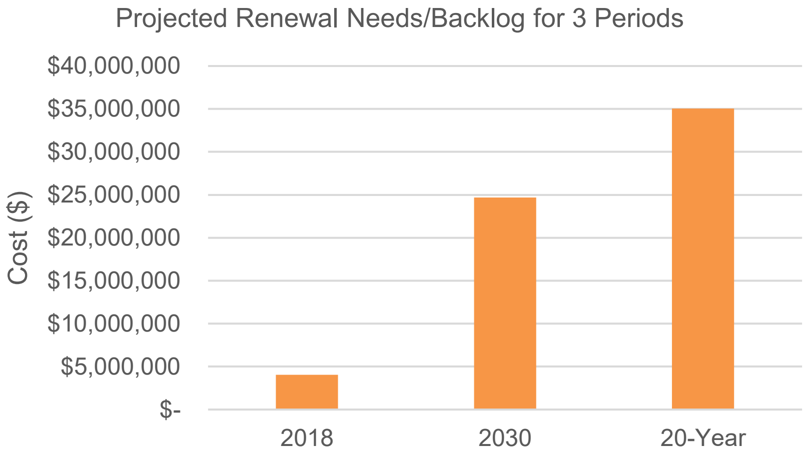


Figure 5: Comparison of Projected Backlog Assets over 3 Periods

The increase in backlog as time progresses is inevitable with water infrastructure, and, the average annual spending over the next 20 years is rather constant at $1.5M/yr based on consumed life ratio. Yet, these preliminary projections require further review and implementation details if they are to result into annual budgets and defined capital projects (*which* assets, *which* upgrades, *which* year). In that way and building onto the system-wide projections, Table 1 summarizes the five largest reported priorities (from Riva) based on consumed life ratio up to 2030.

Table 1: Five Largest Non-Linear Priorities by 2030

Asset Name/Location	2030 Reported Costs			Comments
	Structural	Non-Structural	**Total Cost**	
MacLure Reservoir	$5,250,000	$3,250,000	**$8,500,000**	*Inspection*
Townline Well Field	$2,750,000	$250,000	**$3,000,000**	*Addressed within short-term well renewal study (outlined later)*
Bevan Well Field	-	$2,750,000	**$2,750,000**	
Riverside Well Field	$2,725,000	$25,000	**$2,750,000**	
Marshall Well Field	$2,750,000	$25,000	**$2,775,000**	
Total	$13,500,000	$6,300,000	**$19,800,000**	

Not all of these assets or asset types are necessarily in-need of imminent funding or replacement, therefore there must be further engineering review to effectively decide on next steps in renewal and capital budgeting. In light of the Riva reports, three emerging priorities for asset renewal for the Commission include:

1. to investigate the accuracy of established consumed life ratios, or service lives, for most assets, and updated accordingly,
2. to contemplate risk-tolerances for certain assets or asset-types as to when to act based on their status beyond consumed life ratio, and also,
3. to inspect the most critical backlogged items to determine whether they are in need of urgent repair and to budget accordingly.

Akin to non-linear infrastructure, AMWSC tabulates and tracks linear water infrastructure using Riva systems. Prior to entering assets into the system, an estimated lifespan is identified, primarily based on asset material. Once this lifespan has been reached, the software *recommends* replacement, without knowledge of actual asset condition. In terms of linear water infrastructure, this approach is generally more acceptable when compared to non-linear infrastructure. Linear infrastructure such as pipes and transmission mains are often much harder to inspect as they are a primarily buried utility. Unlike non-linear infrastructure, linear infrastructure is usually replaced when one of two events occur:

a) There is a definite failure in the system which requires immediate replacement (also known as reactive asset management)
b) Or, an asset management schedule (like Riva) suggests replacement.

In certain cases, especially with larger pipes (transmission mains), the cost-prohibitive replacement warrants inspection from a specialist to determine actual pipe condition. For an outline of various popular linear inspection methods, see Table 2 in Appendix A.

It is important for AMWSC to budget funds to prepare for scheduled pipe replacements (case b), as well as maintain surplus funds in the event that failure occurs (case a). Further, there are very few backlogged costs by pipe material up to the 2030 horizon: the only significant project is the 400mm diameter Cannell pipe made of Asbestos Concrete, with an estimated replacement cost of $1,575,000. While there appear to be a few smaller replacement projects are required for asbestos concrete pipes and cast iron pipes on McConnell and Pine Street, respectively, there is little to no urgency to assess these small pipes in the near term.

In terms of Riva Asset management, linear assets are in relatively good condition with the majority of pipes constructed after 1980. Compared to backlogged costs for non-linear infrastructure, linear infrastructure represents approximately 8% of total 2030 backlog costs.

In order to properly allocate system funding, utilities frequently adhere to standardized asset management practices which promote multiple tactics to determine the remaining life of a given asset, including capacity, frequency of use and condition of connected-to-infrastructure (adjacent assets) which do not always correspond with its consumed life ratio. As such, assets may have multiple condition indicators that can be used to rate the condition-performance of an asset, such as:

1. Projected **Condition** – Inferred/Empirical estimate of condition after lifespan.
2. Rated **Performance** – Performance rating received after inspection which incorporates the condition as well as other functionality characteristics e.g. pump efficiency and pump replacement.
3. **Actual Condition** – True functioning condition of asset.

The latter two condition indicators relate directly to Figure 1 (schematic for integrating data sources) and can be collected by either operations staff or asset specialists such as engineers or manufacturers. Additional considerations and recommendations with regards to Riva are summarized into the concluding section of this document. The following sections review and outline key factors related to asset inspections by way of either operations staff or specialists. The integration of Riva with updated inspection programming, coupled by criticality and risk, positions the Commission for enhanced capital planning.

3. Asset Management Data Sources: Guidelines for Inspections – Operators and Specialists

With hundreds of assets, each with its own function and service life factors, there is a significant challenge in managing the regional system to prevent major outages and to optimize information, funding sources and decision-making. AMSWC operators work with assets and visit key facilities to perform maintenance and testing procedures on a regular basis to confirm functionality. The data and information collected from operators can be significant, in particular if, it is collected in a *systemized manner* and effectively relayed, then integrated, with system-wide resources. The culmination of all data sources can be incorporated into risk and analysis and funding reviews.

3.1 Systemized Condition Templates: Operators and Specialists

The state and performance of water assets is constantly changing and Commission staff are regularly interfacing with key facilities to provide service to thousands of customers; it's critical for the Commission to create linkages between operator duties and information collection to enhance utility asset management. Based on interviews with Commission staff and a review of available reports and studies, there is a core need to improve management templates and practices for:

- Assigning criticality to non-linear facilities for use in risk-analyses
- Defining performance grades and corresponding actions based upon visual inspections by operators; note: this includes performance thresholds where specialists are required for detailed reviews
- Implementation procedures to better relay field information toward system-wide tools and ultimately toward capital planning
- Completing asset-type studies on one or many assets to develop a custom renewal plan

Further guidelines and related materials are provided below for each management area.

Assigning Asset Criticality

Asset criticality is a core factor in determining the priority of a given repair or investment against all other potential projects. For the Commission (and most modern water utilities), criticality is typically determined by potential impact on health, the number of customers without adequate service, and the overall safety and financial outcomes resulting from asset failure. Scales of criticality often range from scores of 1 to 5 which typically corresponds to condition scores as well: this approach of layering scores between 1 and 5 allows for cross-functional assessments whereby multiple factors and multiple assets can be linked along a consistent scale. The same 1 to 5 rating was chosen here. Assigning criticality allows for concise knowledge of which assets are of most importance to the water system. Criticality ratings will also ease decision making when multiple assets are concurrently set for repair/replacement. Table 3 summarizes criticality ratings to be applied to all non-linear assets.

Table 3: Criticality Summary for Non-Linear Assets

Criticality Rating	Description of Impact due to Water Asset Failure
1	**Low impact on system in event of failure.**
2	**Moderate impact on system in event of failure**
3	**Significant impact on systems in event of failure**
4	**Vital to functionality of system**
5	**Broad scale system losses upon failure**

Table 4 outlines the application of the criticality grading scale for Commission assets.

Table 4: Criticality Summary for Commission Non-Linear Assets

Asset Types	Criticality Rating	Value of Assets in Criticality Grade (%)	Value of Projected Backlog by 2030
Water Intake, Reservoirs, Water Treatment [1]	**5**	**$18,000,000 (30%)**	**$8,825,000**
Pump Station/Booster, Groundwater Wells, Dam Valves	**4**	**$35,250,000 (59%)**	**$14,100,000**
Pressure Reducing Valves, SCADA Components, Line Valves	**3**	**$1,000,000 (2%)**	**$250,000**
Hydrometric Stations, Flow Meters,	**2**	**$100,000 (0.2%)**	**$75,000**
Chemical Production (Ammonia, Soda Ash)	**1**[2]	**$5,000,000 (8%)**	**$1,500,000**
Total		**$59,250,000**	**$24,750,000**

[1] Asset values should be developed for the Dickson/Norrish and Cannell Lake open-air dam systems, where required.

[2] Provided that adequate redundancy is available, and that catastrophic failure does not occur.

Important takeaways from Table 4 include:

- The majority of overall asset value (90%) is rated as having a criticality rating of 4 or 5;
- There is significance to effectively maintaining and investing in groundwater wells (covered later in this memo) to fulfill capacity needs but also based on financial best practice as this asset type amounts to 98% ($34,500,000) of the value in criticality rating 4 (ongoing asset-type studies for wells are likely required in an ongoing manner).

Given the weighting of asset value and the regularity of Commission staff visiting and working at non-linear assets with criticality ratings of 3, 4 or 5, it is advisable to complete performance grade templates in descending order such that the highest, most critical assets are understood first.

Defining Performance Grades

Visual assessments are a cost-effective method to inspect key aspects of the condition of infrastructure. This approach allows operators to identify any major concerns through obvious wear, corrosion, cracking, spalling and loss of integrity. In-field condition inspections can significantly increase the reliability of consumed life ratios (projected) because they can help to determine the actual condition of assets, identify asset faults, provide a record or trend of asset status over time, identify if specialist assessments are necessary, recommend urgent or high-priority repairs (or renewal) or validate the consumed life ratios estimated through system-wide tools.

Tables 5 and 6 outline the proposed grading methodology for non-linear assets including visual inspection sample (Table 5, for civil works; all other templates are enclosed) as well as how that corresponds to follow-up actions (Table 6).

Table 5: Sample Visual Inspection Template: Civil Works

Civil Works: Reservoirs, tanks, structural components			**Date:** ________
Feature: ______________	**Action**	**Comment**	**Recommended Grade**
No damage or deterioration	None		**1**
Surface staining or discolouration	None	*May need attention*	**1**
Deterioration or damage that presently has little effect on performance and not presently a safety hazard	Monitor	*Includes minor surface deterioration and damage*	**2**
Damage that may have some effect on performance but substantially functional and not presently a safety hazard. Includes signs of minor leaks	Specialist Assessment	*Likely to progress*	**3**
Damage likely to affect function but not presently a safety hazard. Includes active leakage.	Replace/Repair	*Likely to progress*	**4**
Severe corrosion or damage, does not work, missing component or safety hazard.	Replace/Repair	*Urgent Attention*	**5**
Grade: ___	**Comments:**		

Table 6: Follow-Up Practices based on Results of Visual Inspections

Grade	Classification	Action	Timescale for Long Life Assets	Timescale for Short Life Assets
1	Very Good	**Reinspect**	< 20 years	< 10 years
2	Good	**Monitor**	< 20 years	< 10 years
3	Moderate	**Specialist**	< 10 years	< 3 years
4	Poor	**Specialist**	< 3 years	< 1 year
5	Very Poor	**Replace/Repair**	< 1 year	Immediately

Additional templates (Appendix A) include inspection methods for materials and facility types. Further consideration to integrating the results of the inspections with system-wide tools and the overall capital planning process are outlined below.

Risk management is the concept of appreciating the likelihood and consequence of a catastrophic event and in turn, making decisions based on the information made available for asset performance assessments. For condition inspections in particular, likelihood and consequence can be represented by grading and criticality. The combination of these factors can be used to report a risk score per asset that can be used to prioritize next steps into either further asset inspections or renewal planning, as outlined in Table 7.

Table 7: Asset Replacement Risk Matrix

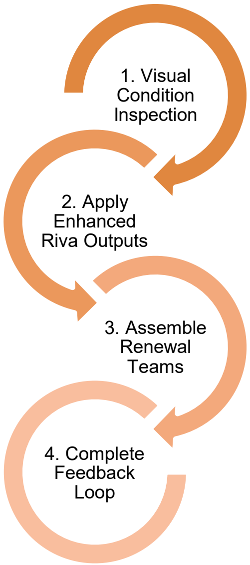
ASSET REPLACEMENT RISK MATRIX		Assigned Grade (1-5)				
		1 (LOW)	2	3	4	5 (HIGH)
		ASSET IS IN VERY GOOD CONDITION		SPECIALIST ASSESSMENT NECESSARY		ASSET IS IN VERY POOR CONDITON
Criticality (1-5)	5 (HIGH) CRUCIAL TO FUNCTIONALITY OF SYSTEM	PRIORITY B	PRIORITY B	PRIORITY A	PRIORITY A	PRIORITY A
	4	PRIORITY C	PRIORITY B	PRIORITY A	PRIORITY A	PRIORITY A
	3	PRIORITY C	PRIORITY B	PRIORITY A	PRIORITY A	PRIORITY A
	2	PRIORITY C	PRIORITY C	PRIORITY B	PRIORITY B	PRIORITY A
	1 (LOW) LOW IMPACT ON SYSTEM	PRIORITY C	PRIORITY C	PRIORITY B	PRIORITY B	PRIORITY B

Once affirmed, this risk table or one similar to it can become a fundamental tool for assessing risk and assigning financial and technical resources to pending upgrades.

Implementation Narrative: Linking Riva with Visual Inspections and Deploying Funds

Commission staff point to a critical information need to complement Riva reports: there is no in-field validation for use (how, when, what) of the funds and no feedback loop between condition reviews and the funding allocations. The implementation of enhanced in-field templates for visual inspections and overall condition performance requires direct links with Riva so that staff can effectively triangulate the information sources of system-wide tools, operator knowledge and the results of specialist assessments.

Implementation for the revised asset management programming in the Commission centers on a suite of prioritized actions:



1. ***Conduct visual inspections for all non-linear assets.***
   a. Refine and adopt templates to suit staff requirements
   b. Reconfirm the inventory of assets assigned to the Commission and the completeness of their description (note: further discussion on regional versus municipal asset ownership is outlined later)
   c. Conduct inspections in descending order of criticality (Table 3)
   d. Conduct inspections as part of regular operator activities in 2019 and upload data in geospatial (GIS) format
2. ***Apply enhanced Riva reports toward asset renewal priorities.***
   a. Sum the automatically-generated total value (for a given year) of funds triggered by backlogged assets i.e. those reaching their consumed life ratio
   b. Manually add additional layers for performance grade, criticality and risk rating to prioritize renewal tactics
   c. Filter down to only the assets that can be addressed given the annual funds
3. ***Assemble renewal teams for pending projects***
   a. Organize specialists to confirm previously recorded grading (if required)
   b. Initiate renewal project plan including scheduling, scope and cost estimates
   c. Revisit modified Riva report (with new layers) if any funds remaining
4. ***Complete feedback loop***
   a. Meet with operators to provide renewal/prioritization update
   b. Update Riva using GIS tools (so that it's geospatially correct and automated) so that remaining life and next *inspection* fields are up to date based on assessments
   c. Report the proposed projects for budgeting in priority sequence using risk ratings

Implementation of the proposed templates and manuals will require additional effort in terms of engaging with operators and developing tailored policy and procedures to ultimately establish a local protocol for in-field inspections that lead to effective renewal planning.

Completing Asset-Type Studies: Groundwater Well Renewal

In select instances, typically due to the scale or complexity of the asset-type, a utility manager may complete a study that examines the renewal needs, risks and costs for a suite of facilities. Groundwater wells are an example of an asset-type with sufficient complexity and scale (19 wells which are critical to supplying peak-demands) and in 2014, the Commission retained a specialist consultant to review a select list of the utility's 19 groundwater wells.

Water supply for customers in Abbotsford-Mission comes from a stable portfolio of sources including Cannell Lake, Norrish Creek and the 19 groundwater wells. Utility staff acknowledge the increased responsibility of managing and operating multiple sources while accepting the benefits that a diverse source portfolio can offer. Groundwater supply is likely to remain a core source for water in the region for decades to come and the management of these assets requires careful consideration.

When the Norrish creek source was unavailable due to pipe failure in 2013, the utility maximized a handful of high-capacity wells to offset the supply gap: however, the performance of the wells was concerning as staff observed issues related to water quality, mechanical and electrical systems and difficulties maintain chlorine residuals. The 2014 groundwater well review[1] focused on the condition, capacity and supply constraints for certain wells as part of a study that prioritized renewal needs to extend the life of the wells and ultimately result in more reliable, high-quality water provision. Table 8 summarizes the results of the study by way of well name, priority ranking (among the wells reviewed), upgrades and Class D costs. The proposed schedule for the upgrades was to complete all projects by 2020.

Table 8: Groundwater Renewal Summary

Well Name	**Renewal Categories**			
	Well and/or Treatment?	Site and Building?	Mechanical and Electrical?	2014 Class D Costs?
Marshall 2&3	--	--	Y	$ 302,000
Farmer 1	Y	Y	Y	$ 426,000
Industrial B&C	Y	--	--	$ 91,000
Townline 2	--	--	Y	$ 89,000
Townline 1	Y	Y	Y	$ 253,000
Riverside 1&2	Y	Y	Y	$ 777,000
Farmer 3	--	--	Y	$ 78,000
Farmer 2	Y	Y	Y	$ 523,000
Industrial A	Y	--	--	$ 30,000
Pine	--	--	Y	$ 103,000
				$ 2,672,000

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[1] Abbotsford Groundwater System Renewal Study, Associated Engineering, 2014.

While the order of the wells in the table denotes their priority, the actual implementation of the upgrades was driven by setting up practical contracts and finding synergies among similar projects. Overall, the outcomes of the study reveal important insights about the role of inspections, performance reviews and facility-specific renewal plans[2]. Key takeaways for application to next steps for the Commission are:

1. That operating the equipment at their design capacity for an extended period and observing their performance can reveal emerging upgrades,
2. That ordinary asset inspections by staff can help to fend off some expected or unexpected failure, but that reports by inspection professionals can consolidate information into a straightforward plan
3. That the most critical infrastructure (such as supply sources) should be proactively and regularly upgraded as they are the foundation for regional water services,
4. That non-condition (e.g. capacity or regulatory, such as GARP – *groundwater at risk of containing pathogens*) upgrades should be synched with condition upgrades wherever possible (i.e. either delaying or fast-tracking upgrades to suit instances where there are multiple drivers
5. That prioritizing assets among the same asset class provides direct links to budgeting and implementation, and
6. That there is a role for system-wide, broad-based review systems (such as Riva and asset databases) but that on the ground information increases accuracy and confidence in capital priorities.

Building on the above, when applying the results of the 2014 study along with key sentiments stemming from recent interviews with Commission staff, there become some clear consistencies about the role of condition reviews, asset management and prioritization, and how there is a need to integrate specialist findings, operator knowledge and system-wide tools for ongoing asset management.

This memo factors in the groundwater findings, with the preliminary results from Riva and applies the performance grading templates to support next steps in enhanced asset management.

4. Study Outcomes: Short Term Priorities

4.1 Review of Project Objectives

Asset management including sustainable inspection, maintenance, renewal, investment, planning and monitoring is an established concept with the AMSWC. Going forward however, the AMWSC initiated this study to explore potential updates to their existing approaches in particular as it relates to inspections, non-linear asset management practices, criticality and prioritization as well as updates to implementation strategies among information systems, operations and engineering. To support these topics, this technical memorandum includes a review of system-wide tools, operator knowledge-applications, the role of specialist assessments and implementation narratives to initiate integrated information processes. Two remaining items for discussion in regards to short term priorities include: **a review of ownership definitions as it relates to Commission assets/responsibilities**, and **a list of strategic recommendations for non-linear asset management priorities**. Each of these topics is explored below.

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[2] Groundwater well renewal plans (historic) should be integrated with upcoming GARP assessments which may trigger additional works that should be factored into a well upgrade projects.

4.2 Regional Service Delivery: Two Priorities to Enhance Asset Management

Asset Ownership and Functional Definitions

The distinction between regional and municipal assets is critical for service delivery effectiveness and overall service reliability. For almost all assets in the AMWSC, staff understand the ownership, operational responsibility, potential liability and funding requirements. In select circumstances, asset classification is either unknown or inconsistent with established rules or practices. In 2010, the Commission explored the topic of ownership and *functional distinction* of all assets. Reports were received for information however some aspects of the reports required further study or at least, further discussion by Commission members given the potential financial and operational impacts of reassigning select facilities. Preliminary criteria stemming from that study include:

1. Regional trunks: any asset that extends through one municipality to service another; any asset required for operational efficiency or to provide redundancy for reliability and security of the regional system
2. Facilities (non-linear assets): any asset which taken off-line affects a municipality other than the one in which it is located; any operational asset benefits both municipalities under regular operating condition[3]

Recommendations from the 2010 report span each major asset type. In some instances, there appears to be the need for additional dialogue and analysis in order to a) more clearly define asset ownership criteria for existing and future assets and b) assess the effective role of major existing assets considered as *regional or partially regional/municipal* to better appreciate their alignment (technically/hydraulically/operationally) with the criteria. Further study should consider the theme areas outlined below as a starting point in the review process.

Table 9: Asset Ownership Criteria

Regional Trunks	• *Assets that are required for operational efficiency or to provide redundancy to the regional system (benefits to both municipalities)* • *Assets that feed a regional asset and act as a conduit to regional customers from a regional facility or source (all regional sources or facilities should have a regional trunk supply or transmission main, including groundwater wells)* • *Assets that extend through a municipality to service another*
Sources	• Any directly related infrastructure for the following assets: 19 groundwater wells, Cannell Lake, Norrish Creek (Dickson Lake), Collector Well (future)
Reservoirs	• Any directly related infrastructure for the following *assets*: Mary Ann, MacLure Reservoirs, and *Zone* 4 Reservoir (part of master plan; because it provides a grandfathered redundancy to Mission customers in the event of Cannell Lake unplanned outage)
Pressure Reducing Stations	• For only those stations located on regional trunks that manage the regional supply system or that *interface* with the municipal system(s) • The operating set points for each station are crucial to *regional* hydraulics and should be the *responsibility* of the commission. Changes to set points require further operating protocols between regional service delivery and local supply expectations.

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[3] *Other criteria provided in the 2010 report that doesn't appear to directly distinguish asset ownership.*

Pump Stations	• *Assets* that are required for transmission of supply services for both *municipalities* • *Assets* that are required for operational efficiency or to provide *redundancy* to regional system • *Only* the low-lift and high-lift (proposed) at new collector well and Best Avenue Pump station proposed for regional purposes;
Future Projects	• *Expansion* projects in the master plan must meet the *agreed* upon criteria and be designed accordingly. • *Existing* assets that are classified incorrectly given the *above* criteria (or whichever criteria ultimately chosen) should be assessed in order to weigh the option(s) of reclassification and the impacts on the system (operationally and financially) so that reassignments are completed with sufficient information.
Other assets	• *Land, financial, information (archives) and human resources were not reviewed as part of this study*

These preliminary ownership definitions and criteria require technical analysis and likely some iterative refinement in order to arrive an agreed upon framework by all parties. Ultimately, ownership and operational responsibilities including liabilities and emergency operations require clear decisions and detailed procedures.

4.3 Asset Management and Long-Term Investment Policies

Each year the Commission selects capital projects for renewal or expansion, and often, those projects stem from the endorsed Joint Water Master Plan. Governance terms for the Commission, based on agreements in place suggest that all projects are funded annually based on contributions from each municipality. This approach is consistent with the governance terms of the Commission agreement has carried on with few drawbacks since 2005 which has allowed the system to meet the needs of customers throughout that time. Moving forward however, there are four distinct drivers to establish a long-term investment policy to be led by the Commission, including:

1. Pending large-scale capital projects, such as the collector well, which may trigger borrowing by one or both municipalities
2. Ongoing annual investments into asset management and the fundamental need to maintain consistent renewal funds for long-term reliability
3. Changes in rates including conservation-oriented pricing, reserve building, asset renewal or other metrics for water financial sustainability
4. Interest in system wide tools, resources, policies and procedures for asset management

Based on the Commission agreement and related governance terms, there is some potential to co-develop a long-term investment policy and to either a) append it to the Water Master Plan or b) include it as a schedule within updated agreements at the time of next ratification. The benefits of completing the policy would be long-term assurances for adequate funding for regional system upgrades and maintenance.

4.4 Short-term Asset Management Priorities

The particular circumstances of the AMWSC require custom methods for enhanced asset management. The scale of the infrastructure, the regional-nature of the utility, the type of existing practices and the opportunities to explore potential updates to asset management culminate into a broad-ranging list of short term priorities. Given the review above as well as results of discussions with Commission staff throughout the project, there are six recommended initiatives to undertake to take meaningful and tangible steps forward with regional, non-linear asset management, including:

1. Introduce the criticality, grading and risk performance methods for refinement and ultimately future adoption as asset condition monitoring policy
2. Review and update the inputs to Riva based on the latest results of asset performance and identify risk tolerances with respect to consumed life ratio and criticality (conduct annual or semi-annual database reviews to assess the accuracy of asset factors and to update based on new data)
3. Conduct a facility-specific review of the Norrish Creek Water Filtration plant to develop a renewal plan (e.g. regular consumed life renewal; opportunity to explore seismic) for implementation beyond 2020
4. Revisit the asset ownership definitions and confirm policy through reporting and discussion with the Commission or sub-committee
5. Undertake a strategic process to establish long-term investment policy for implementation by the Commission and each municipality
6. Complete the groundwater renewal program and simultaneously initiate inspection of the MacLure reservoir for potential upgrade

The results of asset management planning and infrastructure reviews typically also reveal other priorities that require near-term repair or upgrades. In light of the work to date throughout the development of the Joint Water Master Plan, a short-list of asset-management related priorities emerged which require implementation as part of the Plan. Table 10 outlines the short-list of studies or upgrades required to deliver on the objective of a comprehensive understanding of asset renewal initiatives for the Commission.

Asset Topic	*Drivers/Objectives for the Project*	*Budget*
SCADA Systems Upgrades	• *Remote monitoring and automated operation are critical for water systems that cover large geographies into remote locations* • *Requires new SCADA infrastructure and communications*	**$150,000**[4]
Seismic Review + Design Guidelines	• *Pending asset renewal (e.g. Norrish WTP) and new infrastructure (e.g. collector well) requires in-depth knowledge and recommendations for seismic resilience including impacts from major events and how they relate to emergency preparedness*	**$250,000**
Emergency Response Plans	• Typical plans, common to most utilities, provide core operations strategies and system instructions in the event of an unplanned or catastrophic event e.g. seismic, power outage, flood.	**$100,000**
	Total	**$500,000**

These studies are critical efforts to enhance strategic operations that comply with best practices to ensure reliable, consistent water supply through a range of risks and potential service disruptions. Preliminary capital allowances for seismic upgrades to Norrish Creek WTP ($5,000,000) have been included in the overall capital plan. SCADA upgrades for automation and remote operations is included in the budget

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[4] *Part of the SCADA budget is allocated to the security requirements addressed under separate cover (Viva, 2018); overall, the total budget for security upgrades and SCADA is $450,000.*

above. Beyond these items and connecting these results back to asset management priorities, the recommended short terms capital projects based on this plan include:

1. Groundwater Renewal: 1-3 years
2. Norrish Creek Water Plant: facility renewal plan: 1-3 years; upgrades/renewal: 5-10 years
3. Linear infrastructure replacements:
    a) Dewdney Trunk asbestos concrete pipes: inspect 1-3 years; upgrades/replacement 3-5 years
4. MacLure Reservoir: inspect 1-3 years; upgrades/renewal ~10 years
5. PRVs, Pumpstations, mechanical/electrical: regular annual investment
6. Implement the studies in Table 10 to effectively maintain service and manage assets.

Based on the items above and the value of assets scheduled for renewal over the next 20 years, the AMWSC should prepare for annual investment levels of $1.5M to $2.5M depending on the results of comprehensive inspections to be undertaken in the next 1-3 years.

Sincerely,

URBAN SYSTEMS LTD.

Ehren Lee, P.Eng.
Principal

/el/cf
Enclosure

APPENDIX A

INSPECTION TABLES

Table 1: Linear Pipeline Inspections Techniques

			Technique	Material	Assessment	Service Interruption	Commercialized
Pipeline Assets	Physical Property Testing	Non-Destructive	Barcol Hardness	Plastics and cementitious	Material hardness	No	Yes
			Carbonation testing and petrographic examination	Cementitious	Depth of carbonation in mm	No	Yes
			Corrosion burial test	Ferrous	Soil corrosivity	No	-
			Schmidt hammer	Concrete and brick	Compressive strength	No	Yes
		Destructive	Condition assessment of plastic pipes	Plastics	Material properties	Offline	Lab Testing
			Core/coupon sampling	Any	-	No	Test dependent
			Cut-out sampling	Any	-	Offline	Test dependent
			Fracture toughness C-ring	PVC	Fracture toughness	Offline	Lab Testing
			Indirect tensile strength test	AC and Conc	Tensile strength	Offline	Lab Testing
			Methylene Chloride Gelation	PVC	Level of gelation	Offline	Lab Testing
			Slow crack growth resistance	PE	Resistance to slow crack growth	Offline	Research Tool
			Pit depth measurement	Ferrous	Pit depth to infer rate of corrosion	Offline	Yes
			Phenolphthalein Indicator	Cementitious	Carbonation depth	Offline	Yes
		In-pipe (non-man entry)	Broad band electromagnetic	Steel, cast iron, and ductile iron	Remaining wall thickness	Offline	Yes
			CCTV	Any	Qualitative structural condition	Lowflow or Offline	Yes
			Fiberscope Inspection	Any	Qualitative	Online or Offline	Yes
			In-pipe acoustic inspection tools (sonar)	Any	Defects or geometry	No	Yes
			In-pipe hydrophone	Any	Leak detection	No	Yes
			Intelligent pigs	Steel	Corrosion or geometry	Offline	Limited use
			Magnetic flux leakage	Iron and Steel	Loss of metal	Offline	Specialist

Table 2: Plastics Material Inspection

Plastics: Fibreglass tanks, pipes, PE, PP, PVC			
Feature	**Action**	**Comment**	**Recommended Grade**
No damage or deterioration.	None		1
Surface staining or discolouration.	No Action	No Action	2
Holes, splitting or perforation - not water holding area.	Monitor	May reduce strength	2
Deformed or misaligned – not water holding area.	Monitor	Monitor for worsening conditions	2
Severe discolouration, cracking or blistering.	Specialist Assessment	May progress to splitting/perforation	3
Damaged or loose fixings – operational issue.	Repair/Replace	Fixing prevents component from operating	4
Holes, splitting or perforation - water holding area.	Repair ASAP	Needs Repair ASAP if threat to water quality/safety	5
Deformed or misaligned – water holding area.	Repair ASAP	Needs Repair ASAP if threat to water quality/safety	5
Damaged or loose fixings – water holding area or safety issue.	Repair ASAP	Needs Repair ASAP if threat to water quality/safety	5
Major damage Major deterioration Major perforation, missing or clearly failed.	Repair/Replace	Urgent Attention Required	5
Grade: ___	**Comments:**		

Table 3: Concrete Material Inspection

Concrete: Holes/breaks in the concrete or evidence of damage in steel reinforcement			
Feature	**Action**	**Comment**	**Recommended Grade**
No damage or deterioration.	None		1
Staining: Surface deposit only.	No Action		1
Staining: Actual staining of material.	Monitor	Possible Rusting reinforcement	2
Cast- in voids.	Monitor	May reduce strength. Possible reinforcement corrosion	2
Cracking No evidence of leakage.	Monitor	Cracks may self heal	2
Corroded Surface softening Erosion.	Specialist Assessment		3
Cracking Evidence of leakage.	Specialist Assessment		3
Spalling reinforcement not exposed.	Specialist Assessment	Weakens concrete, can expose reinforcement	3
Cracking Currently leaking.	Specialist Assessment	Needs repair	4
Exposed reinforcement, Loss of material.	Specialist Assessment	Will need repair	4
Major cracking, Major leakage, Major loss of material Structure looks unstable Corroded reinforcement Failed.	Specialist Assessment	Urgent Attention Required	5
Grade: ___	**Comments:**		

Table 4: Metal Material Inspection

Metals: Build up of rust on steel, loss of material, holes and damage to coating			
Feature	**Action**	**Comment**	**Recommended Grade**
No damage or deterioration.	Monitor		1
Surface staining or discolouration, surface rust.	Monitor	Will need cleaning/repainting in future	2
Deformed – not water holding area.	Monitor		2
Rusting affecting more than surface.	Clean/Repair		3
Holes and perforation.	Repair	May reduce strength	3
Substantial flaking rust.	Replace/Repair		4
Damaged or loose fixings – operational issue.	Replace/Repair		4
Deformed – water holding area.	Repair ASAP	Needs repair if threat to water quality	5
Damaged or loose fixings – water holding area or safety issue.	Repair ASAP	Will need repair if threat to water quality/safety	5
Severe corrosion Extensive perforation, Substantial metal loss Missing or clearly failed.	Replace/Repair	Urgent Attention Required	5
Grade: ___	**Comments:**		

Table 5: Civil Structures Inspection

Surface Operational Assets – Civil Structures: Water Intake			
Feature	**Action**	**Comment**	**Recommended Grade**
No damage or deterioration.	None		1
Surface staining or discolouration, surface rust.	None	May need repainting	1
Deterioration or damage that presently has little effect on performance and not presently a safety hazard.	Monitor	Likely to progress	2
Damage that may have some effect on performance but substantially functional and not presently a safety hazard.	Replace/Repair	Likely to Progress	3
Damage likely to affect function but not presently a safety hazard.	Replace/Repair	Likely to progress	4
Severe corrosion or damage, does not work, missing component or safety hazard.	Replace	Urgent Attention	5
Grade: ___	**Comments:**		

Table 6: Manhole/Inspection Covers

Manholes/Inspection Covers: Breaking/corrosion, settlement and general safety

Feature	**Action**	**Comment**	**Recommended Grade**
No damage or deterioration.	None		1
Surface staining or discolouration, surface rust.	None	May need repainting	1
Cover uneven or corroded but not presently a safety hazard.	Monitor	Will need repair/resetting	2
Cover displaced, or unstable but not presently a safety hazard.	Clean/Repair or monitor	Will need urgent repair/resetting	3
Damaged surround but substantially functional and not presently a safety hazard.	Replace/Repair	Likely to progress	4
Damaged cover but substantially functional and not presently a safety hazard.	Replace	Likely to progress	4
Severe corrosion or damage, missing component or safety hazard.	Replace	Urgent attention	5
Grade: ___	**Comments:**		

Table 7: Electrical/Mechanical Assets

Surface Operational Assets – Electrical/Mechanical: Electrical components, pumps, dosing station, associated pipeworks, control cabinets, WTP mechanical components			
Feature	**Action**	**Comment**	**Recommended Grade**
No damage or deterioration.	None		1
Surface staining or discolouration.	None	May need repainting	1
Deterioration or damage that presently has little effect on performance and not presently a safety hazard.	Monitor	Includes minor surface rusting, deterioration of coating	2
Damage that may have some effect on performance but substantially functional and not presently a safety hazard.	Replace/Repair	Likely to progress	3
Damage likely to affect function but not presently a safety hazard.	Replace/Repair	Likely to progress	4
Severe corrosion or damage, does not work, missing component or safety hazard.	Replace	Urgent Attention	5
Grade: ___	**Comments:**		

Table 8: Civil Works Assets

Civil Works: Reservoirs, tanks, structural components			
Feature	**Action**	**Comment**	**Recommended Grade**
No damage or deterioration.	None		1
Surface staining or discolouration.	None	May need attention	1
Deterioration or damage that presently has little effect on performance and not presently a safety hazard.	Monitor	Includes minor surface deterioration and damage	2
Damage that may have some effect on performance but substantially functional and not presently a safety hazard. Includes signs of minor leaks.	Specialist Assessment	Likely to progress	3
Damage likely to affect function but not presently a safety hazard. Includes active leakage.	Replace/Repair	Likely to progress	4
Severe corrosion or damage, does not work, missing component or safety hazard.	Replace/repair	Urgent Attention	5
Grade: ___	**Comments:**		

Table 9: Pipeworks and Valves Inspection

Pipeworks/Valves: Pressure Reducing Valves, Inline Valves			
Feature	**Action**	**Comment**	**Recommended Grade**
No damage or deterioration.	None		1
Surface staining or discolouration.	None	May need attention	1
Deterioration or damage that presently has little effect on performance and not presently a safety hazard.	Monitor	Includes minor surface deterioration and damage	2
Damage that may have some effect on performance but substantially functional and not presently a safety hazard. Includes signs of minor leaks.	Repair	Likely to progress	3
Damage likely to affect function but not presently a safety hazard. Includes active leakage.	Replace/Repair	Likely to progress	4
Severe corrosion or damage, does not work, missing component or safety hazard.	Replace/repair	Urgent Attention	5
Grade: ___	**Comments:**		

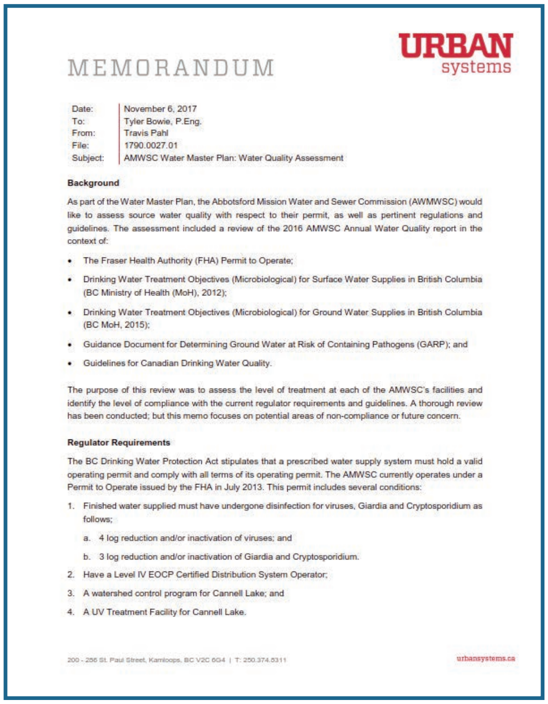
JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN

Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#13

WATER QUALITY TRANSMISSION ASSESSMENT



MEMORANDUM

URBAN systems

Date: November 6, 2017
To: Tyler Bowie, P.Eng.
From: Travis Pahl
File: 1790.0027.01
Subject: AMWSC Water Master Plan: Water Quality Assessment

Background

As part of the Water Master Plan, the Abbotsford Mission Water and Sewer Commission (AWMWSC) would like to assess source water quality with respect to their permit, as well as pertinent regulations and guidelines. The assessment included a review of the 2016 AMWSC Annual Water Quality report in the context of:

- The Fraser Health Authority (FHA) Permit to Operate;
- Drinking Water Treatment Objectives (Microbiological) for Surface Water Supplies in British Columbia (BC Ministry of Health (MoH), 2012);
- Drinking Water Treatment Objectives (Microbiological) for Ground Water Supplies in British Columbia (BC MoH, 2015);
- Guidance Document for Determining Ground Water at Risk of Containing Pathogens (GARP); and
- Guidelines for Canadian Drinking Water Quality.

The purpose of this review was to assess the level of treatment at each of the AMWSC's facilities and identify the level of compliance with the current regulator requirements and guidelines. A thorough review has been conducted; but this memo focuses on potential areas of non-compliance or future concern.

Regulator Requirements

The BC Drinking Water Protection Act stipulates that a prescribed water supply system must hold a valid operating permit and comply with all terms of its operating permit. The AMWSC currently operates under a Permit to Operate issued by the FHA in July 2013. This permit includes several conditions:

1. Finished water supplied must have undergone disinfection for viruses, Giardia and Cryptosporidium as follows;
   a. 4 log reduction and/or inactivation of viruses; and
   b. 3 log reduction and/or inactivation of Giardia and Cryptosporidium.
2. Have a Level IV EOCP Certified Distribution System Operator;
3. A watershed control program for Cannell Lake; and
4. A UV Treatment Facility for Cannell Lake.

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    a. 4 log reduction and/or inactivation of viruses; and
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2. Have a Level IV EOCP Certified Distribution System Operator;
3. A watershed control program for Cannell Lake; and
4. A UV Treatment Facility for Cannell Lake.

The AMWSC water supply system is currently in compliance with the permit conditions. A groundwater at risk of containing pathogens (GARP) study should be completed to determine if the first condition would apply to the groundwater wells.

Drinking Water Treatment Objectives (BC)

In addition to the regulatory requirements of a permit, water providers should consider best practices for treatment objectives and water quality parameters that are of concern to public health. These objectives and health parameters should be considered as they protect consumers and provide the basis of operating permit requirements issued by the governing health authority.

Treatment Objectives

The BC MoH provides treatment objectives for surface and ground water sources. The treatment objectives focus on the removal/inactivation of microbiological parameters. Turbidity reduction is also incorporated as a measure to improve the effectiveness of microbiological removal/inactivation. The general objectives for surface water treatment are as follows:

1. 4-log reduction or inactivation of viruses;
2. 3-log reduction or inactivation of Giardia and Cryptosporidium;
3. Two treatment processes for surface water;
4. Less than or equal to (≤) one nephelometric turbidity unit (NTU); and
5. No detectable *E. Coli*, fecal coliform and total coliform.

The majority of these items are included in the operating permit, with which the AWMSC is in compliance. A GARP screening level assessment is recommended to determine if these treatment objectives would apply to groundwater sources.

Source Compliance

It is worthy to note that treatment at Cannell Lake does not include filtration, which is typically required to meet the third objective of two treatment processes for surface water. The AMWSC has been granted filtration avoidance by the FHA for Cannell Lake and filtration is not required at this location.

In 2017, the BC MoH issued a document titled “Guidance Document for Determining Groundwater at Risk of Containing Pathogens (GARP)”. This provides a framework for determining the level of risk that a groundwater source may contain pathogens.

It is recommended that a hydrogeologist be engaged to assess if AMWSC groundwater wells are considered GARP. The first step is to conduct a screening level assessment in order to determine if more detailed investigations are recommended. If the groundwater wells are determined to be GARP, the above

BC MoH treatment objectives would apply and additional treatment may be required. The AMWSC has also indicated wells may be decommissioned depending on requirements.

Guidelines for Canadian Drinking Water Quality (GCDWQ)

Water quality for each source, as well as distribution system data, was reviewed in the context of the GCDWQ. Since microbiological and filtration requirements are covered under the BC MoH treatment objectives, this review will focus on other parameters.

The AMWSC regularly tests their sources and distribution system and summarizes this data in an annual water quality report. The AMWSC 2016 Water Quality Report was used as the basis of this assessment.

Surface Water (Norrish Creek and Cannell Lake)

In general, water quality at Norrish Creek and Cannell Lake is relatively good and meets guidelines following treatment. Norrish Creek includes a slow sand filtration and UF membrane filtration plant followed by chlorination. Cannell Lake includes UV and chlorination. Chloramination is completed at a secondary site allowing residence time for disinfection of viruses by chlorine. Note that detailed disinfection requirement calculations were not completed as part of this review. One parameters of note with respect to water quality of surface sources is colour.

Colour can be an indication of the presence of organic matter (total or dissolved organic carbon) and is primarily considered an aesthetic issue. However, organic matter can react with chlorine to form disinfection by products (DBPs). Filtration can remove organic particulate but not dissolved organic matter (unless the water is chemically pretreated) which is more likely to form DBPs. Further testing or results for UV transmittance (UVT), total organic carbon (TOC) and dissolved organic carbon (DOC) at Norrish and Cannell would provide additional context on DBP formation potential. Simulated distribution system (SDS) testing could also be conducted to evaluate DBP formation potential.

The AMWSC currently tests the distribution system for common DBPs including haloacetic acids (HAAs) and trihalomethanes (THMs). Levels are below guidelines; however, there could be higher formation potential in areas of the distribution system adjacent to certain sources, as opposed to locations with blended sources. This is discussed further in the distribution system section.

Groundwater

Parameters of concern noted for AMWSC groundwater wells include arsenic, iron, manganese, nitrate and nitrite. Testing or results for TOC, DOC and UVT in groundwater would assist with evaluating potential DBP formation potential from groundwater sources. SDS testing could also be conducted to evaluate DBP formation potential. The AMWSC has indicated that they have also tested wells for parameters that may be present in agricultural areas such as pesticides.

Testing has noted elevated arsenic levels in wells Industrial B and C. Industrial B has exceeded the maximum acceptable concentration stipulated in the GCDWQ. Well operation is controlled to provide blending and reduce arsenic concentrations to below GCDWQ limits.

Elevated levels of iron have been noted in several of the groundwater wells. Elevated iron can react with chlorine and precipitate out of water as a reddish sludge. This can result in taste and odour complaints from consumers. In general, the average concentration for wells with elevated iron are below the aesthetic objective of 0.3 mg/L stipulated by the GCDWQ. Wells that exceed the aesthetic objective are not used. The AMWSC has indicated that only the Pine Wells appear to have naturally occurring iron and that results for iron from other wells are typically from corrosion and insufficient flushing prior to sampling.

Elevated manganese levels have been noted in several wells. The GCDWQ currently recommends an aesthetic objective for manganese of 0.05 mg/L. Manganese also reacts with chlorine to form a sludge, resulting in taste and odour issues. While manganese is currently an aesthetic objective, recent studies have shown an association between manganese in drinking water and neurological effects in children[1]. A new GCDWQ for manganese is currently being developed to reflect these findings. The new guideline proposes a maximum acceptable concentration of 0.10 mg/L and an aesthetic objective of less than 0.02 mg/L. Further consideration should be given to implementing blending, treatment or not using wells containing elevated manganese levels in the future.

It is recommended that the AWMSC continue to monitor the groundwater quality with respect to arsenic concentration and adjust operation of wells based on levels of arsenic, iron and manganese.

Nitrate and nitrite are a health concern as their presence in drinking water has been linked to Methaemoglobinaemia (blue baby syndrome) in bottle fed infants and is also classified as a potential carcinogen. Nitrate and nitrite are a primary concern in systems that are susceptible to agricultural runoff and systems that utilize chloramines as a secondary disinfectant. The GCDWQ recommend maximum acceptable concentrations for nitrate and nitrite of 45 mg/L (10 mg/L nitrate-nitrogen) and 3 mg/L (1 mg/L nitrite-nitrogen) respectively. Recent data indicates the well sources are below the maximum acceptable concentrations for nitrate and nitrite, nitrite levels are generally low or non-detect. However, nitrification can occur in distribution systems that utilize chloramination, resulting in increased levels of nitrate and nitrite. It is recommended that the AMWSC test the distribution system for nitrates and nitrites and that wells continue to be monitored.

Distribution System

AMWSC tests for chlorine residuals, microbiological activity and disinfection by-products in the distribution system. In general, levels are within limits recommended by the GCDWQ.

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[1] "Manganese in Drinking Water." *Government of Canada, Health Canada and the Public Health Agency of Canada*. N.p., 03 June 2016. Web. 06 Nov. 2016.

Industry guidelines recommend minimum residual chlorine levels of 0.5 mg/L chloramines[2]. While residuals are below this level in some Abbotsford system extremities, microbial results are acceptable. Low residuals can result in microbial growth and can also be an indication of high water age and elevated DBPs. It is recommended the AMWSC consider adjusting chloramine dosages or review water age management practices to improve residual levels. Water age modelling is being completed as part of the Water Master Plan, which can inform this review.

Testing for common DBPs such as THMs and HAAs indicated levels were below limits recommended by the GCDWQ. Depending on organic levels in source water, localized testing could be recommended for areas with higher potential for DBPs. Testing for nitrates and nitrates throughout the distribution system is also recommended as there is an increased potential with chloramination.

The pH of AMWSC water sources is relatively low, 6.5-6.8 for surface water and 6.7-8 for wells. The GCDWQ recently provided an updated guideline for pH with a recommended range of 7-10.5. The guideline’s primary focus is on distribution system corrosion control and increased leaching of metals into water (e.g. lead, iron and copper) at low pH. The AMWSC includes a message in the annual water quality report from the FHA that advises the public to flush residential water pipes prior to use to minimize exposure to lead. Low pH is also aggressive towards asbestos cement pipes; however, testing conducted by the AMWSC indicated non-detect results for asbestos fibers. It is recommended that the AMWSC start a monitoring plan to determine the extents and impacts of low pH. This could include monitoring for metals throughout the distribution system. If corrosion control in the distribution system is a concern, the AMWSC may want to consider pH stabilization or alkalinity addition for surface water sources.

pH stabilization could include the addition of alkalinity or caustic to increase pH and buffer pH changes. The addition of soda ash (sodium bicarbonate - Na_2CO_3) is generally preferable as a source of alkalinity as it is safer to handle. The carbonate ions provide buffering capacity, are more stable and are less susceptible to rapid changes in pH. Soda ash does contain sodium, which can limit the amount that can be dosed. Depending on the extent of pH adjustment, other sources of alkalinity such as caustic soda could be considered. A review of alkalinity addition and pH stabilization is outside the scope of this review. These items could be reviewed in detail through a separate study that could also evaluate the potential to utilize or upgrade the Bell Road Soda Ash Station.

Summary and Recommendations

The AMWSC has a comprehensive water quality monitoring program. In general, water quality is in compliance with permit requirements, but there are areas of potential concern. The following items are recommended for consideration:

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[2] “EPA Guidance Manual: Alternate Disinfectants and Oxidants” *USA Environmental Protection Agency*. N.p., April, 1999. Web. 12 Oct. 2017.

1. Continue to monitor Cannell Lake source quality to confirm existing treatment remains adequate in accordance with FHA filtration avoidance;
2. Review organic water quality parameters with respect to DBP formation potential in water sources;
3. Conduct GARP screening level assessment for groundwater wells to confirm if more detailed analysis if recommend to inform any additional microbial treatment requirements;
4. Continue to monitor groundwater wells for iron, manganese, arsenic, nitrates and nitrites. Adjust operational practices accordingly based on water quality results. Be aware of upcoming guideline changes to manganese concentrations in drinking water;
5. Review practices around maintaining chloramine residuals and water age management;
6. Conduct SDS testing for DBPs depending on organic concentrations in source waters. Consider localized DBP testing in distribution system, adjacent to sources with high DBP formation potential and/or areas with high water age;
7. Chloramination may result in nitrification and elevated levels of nitrate and nitrite in the distribution system. Monitor distribution system for nitrates and nitrites, including in vicinity of groundwater wells; and
8. Start a monitoring plan to determine impacts of low pH such as distribution system testing for metals. Review pH stabilization/adjustment for surface water sources if distribution system corrosion control is a concern.
    a) A conceptual design is recommended to assess options for implementing pH stabilization/adjustment. The estimated capital cost associated with these upgrades is anticipated to be in the range of $15,000,000.
9. The additional water quality monitoring will result in additional costs. Discussions with AMWSC indicate a budget increase of $100,000 for the water quality monitoring program would be suitable.

Please contact the undersigned for any questions, comments or future considerations.

Sincerely,

URBAN SYSTEMS LTD.

Travis Pahl

Travis Pahl, P.Eng
Process Engineer

Peter Coxon

Peter Coxon, P. Eng
Senior Reviewer

/TP

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JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN

Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#14

SOURCE WATER MANAGEMENT

URBAN systems

TECHNICAL MEMORANDUM

Date: May 2, 2018
To: Tyler Bowie, P. Eng
cc: Steve Brubacher
From: Ehren Lee
File: 1790.0027.01
Subject: Source Water Management: Methods and Strategies Update

1. Introduction

The Abbotsford Mission Water and Sewer Commission (the Commission) owns and governs the shared water supply system for both of its municipalities. The Commission's water supply system consists of two surface water sources, Norrish Creek (fed predominantly by Dickson Lake) and Cannell Lake, along with 19 groundwater wells that augment the two surface water systems to meet year-round demands. While there are both drawbacks and advantages to operating a suite of sources, the diversity of supply for the Commission provides long-term resiliency benefits in that among a range of conventional source risks, there are multiple ways to provide adequate supply.

Overall, the Commission's sources are exposed to a mix of anthropogenically and naturally caused quantity and quality challenges such as: growing service population, occasional seasonal turbidity spikes at Norrish Creek, groundwater concentrations of manganese, nitrates and arsenic (natural sources) and seasonal drought and climate factors for all sources (e.g. increasing drought risks and or intense rainfall patterns which create turbidity issues). Amongst the challenges and opportunities for service delivery, the Commission's objectives for source water quality and quantity are well known:

- Being able to provide adequate supply through most servicing scenarios; and
- Being able to deliver water to a quality that meets regulatory requirements.

This memorandum reviews existing management practices and identifies any gaps or recommended practices to bolster water quality and quantity at existing sources for current and future customers.

Each supply source is characterized below along with a concise review of existing management practices. The memo culminates with a brief assessment of the current framework and recommends ways to increase water quality and quantity reliability moving forward.

2. Norrish Creek including Dickson Lake (reservoir)

The largest source for the Commission is Norrish Creek, fed predominantly by Dickson Lake, which includes water filtration to enhance water quality to meet public health requirements as dictated by the system permit. Norrish Creek can supply 89 MLD (megaliters per day) and can independently meet 100% of ADD (average daily demands) during periods of regular source water quality. Norrish Creek is unable to meet MDD (maximum daily demands) independently due to pipe size limitations of the main Norrish Creek supply line. Whether to upgrade the supply line, improve watershed management programs, expand Dickson Lake or increase capacity of the filtration plant are historic questions that relate to how best to meet resiliency needs for the Commission over the long-term.

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TECHNICAL MEMORANDUM

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2.1 Water Supply Issues – Quality and Quantity

The Norrish Creek raw water quality can be described as generally good, being low in turbidity and natural organic material. Impurities are filtered out of the water through both slow sand and membrane filtration. Occasionally Norrish Creek experiences high-turbidity events that reduce plant capacity to 45 MLD, as slow sand filters are taken offline during these periods. Turbidity spikes are typical during any intense summer storm, which often occur in winter. There is concern that the frequency and intensity of extreme storm events will increase with climate change creating longer term water quality and capacity (quantity) issues. A common cause of high turbidity events are intense storms and their interaction with forestry roads leading to erosion and increased instability of some slopes. During the winter season of 2006-2007 winter, 23 landslides occurred within the watershed, with all but one initiated from old forestry roads. While the Ministry of Forests has deactivated many of the forestry roads in the community watershed, there is speculation that roads deactivated in the 1990's may not have been performed with current knowledge and standards (Madrone, 2007). During a 2007 watershed review, it was observed that three previously deactivated logging roads had failed due to instability (Madrone, 2007).

Dickson Lake levels are controlled by the Dickson Dam, which was built on a rocky landslide deposit. The amount of storage capacity, previous water demand history, weather/climate and allocations for other users/uses dictates the reliability and adequacy of storage. At present the Norrish Creek water licences provide for a maximum storage of ~15,900 ML per year in Dickson Lake and a maximum withdrawal of 141.5 ML per day. There are two fish related flow requirements, Conditional Licence C126131 and C126189, that mandate minimum flow releases. There are no other licensees on either Norrish Creek or Dickson Lake and Norrish Creek and its tributaries are fully licensed as of 1995.

In addition to instream fish flow requirements, there are risks of Dickson Lake not refilling completely with probabilities have been estimated at 1 in 25 years, calling for a storage expansion of around 20% for year-over-year capacity safeguards. Overall, drought, instream fish flows and long-term water use by the Commission suggest that an expansion to Dickson Lake is prudent to maintain existing capacities.

Management techniques for water quality and water quantity are outlined in **Section 5.0**.

3. Groundwater Wells - Abbotsford Sumas Aquifer

The Abbotsford-Sumas Aquifer is one of the largest unconfined aquifers in the Fraser Valley, with an areal extent of 200 km^2. The aquifer straddles the Canada-United States border and has an annual groundwater recharge rate of 114 M m^3/yr, 30% of which is withdrawn in Canada (Piteau, 2004). The AMWSC currently owns and operates 19 wells that are generally located in the southern portion of the Abbotsford area, fed by the Abbotsford-Sumas aquifer. The first of these wells was developed as the primary water supplies for the former District of Abbotsford and District of Matsqui. Norrish was developed while other wells were constructed in the 1980's and 1990's. More recently, the four Bevan wells were added in 2008. The wells play a critical role in reinforcing the integrity of the AMWSC water supply in two primary areas: they augment the two surface water systems during periods of peak demand and, they are critical to maintaining supply, should the Norrish system, either of the two river crossings or either of the trunk mains conveying water from the surface water systems, be compromised. This criticality was demonstrated in 2013 when the Norrish Creek Water trunk main was out of service for seven weeks after being damaged by a rock slide (AE, 2014). Further consideration to the groundwater quality and quantity characteristics are outlined below.

3.1 Quality Concerns

There are several concerns with the wells with respect to water quality as well as general engineering/design standards and regulatory compliance. Primary water quality concerns are elevated levels of nitrates, arsenic and manganese. While most of the wells achieve secondary disinfection, there have been issues with maintaining system disinfection residuals during extended periods of exclusive groundwater supply. There is concern that anthropogenic factors such as certain farm practices have increased historic nitrates levels beyond natural levels in the aquifer; however, recent trends show the concentrations are declining, largely a result of improved farm practices. Contaminants in groundwater can pose significant health and operational problems, including:

- Nitrates in drinking water are attributed to methemoglobinemia which can cause anoxia (absence of tissue oxygen) in newborns;
- Long-term exposure to arsenic can be detrimental to human health and increases the risk of skin, lung, liver and kidney cancers (Ratnaike, 2003);
- Prolonged exposure to manganese may result in intellectual impairment in school-age children (Bouchard et. al, 2011) and aesthetic issues such as discolouration of water; manganese also creates significant deposits in pipelines and associated water infrastructure, which reduces the efficiency and quantity of the water supply system; and
- Pathogens emerge from a variety of vectors and lead to minor and major maladies including infection and disease.

Land use activities and regulations play a critical role in the quality and quantity of water within an unconfined aquifer. Roughly 80% of the Canadian portion of the Abbotsford-Sumas aquifer is agricultural. The practice of using fertilizer can significantly contribute to elevated nitrate levels in the aquifer (Piteau, 2004). Studies from Environment Canada have also displayed a clear causation between select farming practices and elevated nitrate levels in groundwater. It is expected that the nitrates primarily originate from raspberry production and poultry barns, which are predominant agricultural practices in the Abbotsford-Sumas region. Findings from Environment Canada studies reveal that nitrate concentrations fluctuate seasonally, and that nitrate concentrations are higher at shallow depths (Piteau, 2004). Occasionally elevated arsenic levels in groundwater, specifically the Industrial B well, had a maximum concentration of 12.7 µg/L in 2015, over the 10 µg/L Maximum Allowable Concentration (MAC) within the Canadian Guidelines for Drinking Water Quality. In the event that arsenic levels were above the MAC, the water was diluted with other sources (Annual Water Quality Report, 2016).

3.2 Quantity Concerns

The 19 wells are generally recognized to currently have a combined capacity of 55 MLD. However, a recent report prepared by Piteau (April 2017) indicates that the yield could be as high as 69.9 MLD (see Table 1 in report). This is, however, based upon pump tests and pump performance curves and has not been demonstrated under a real demand scenario. Unlike surface waters supplies, well capacities do reduce with time and wells have to be redeveloped every 5 – 10 years to maintain their yield. Also, depending upon aquifer recharge and seasonal variations, both of which are related to precipitation, geotechnical conditions, and runoff, interference from adjacent wells can significantly impact and reduce sustainable well yields. In particular:

- Well extraction rates over the last 14 years include a maximum supply rate of 48.1 MLD (as needed to meet demands but not a reflection of the total yield for groundwater supply).
- The Commission is working through licensing approvals with the Province for a 60.2 MLD peak day withdrawal rate, accompanied by an annual volume of 8,000 ML.
- There are six wells with water quality concerns which would reduce ultimate groundwater supply capacity by 20% if these wells were eliminated from supply.

Overall, due to water quality concerns and the lack of certainty for groundwater quality trending, the ultimate, theoretical combined well yield is assumed to be 55 MLD. There is room to expand groundwater capacity by adding wells, however, the amount of expansion potential is not accurately known. Theoretical capacity expansion is estimated at 43 MLD (aquifer wide) without consideration for competing withdrawals from other purveyors (meaning only a portion, if any, of the theoretical increase is available for extraction by the Commission). The recent experience in obtaining licensing of the Bevan Wells has shown that the regulatory approval and monitoring requirements for additional groundwater expansion adds a further level of uncertainty at the available groundwater expansion potential. Given the operational and regulatory complexity of groundwater supply, it is generally believed that the Commission will optimize existing assets and pursue source expansion into other areas e.g. collector wells adjacent the Fraser River.

Further consideration to overall water quality and quantity management practices for groundwater are outlined in **Section 5.0**.

4. Cannell Lake

Cannell Lake is a complementary source to Norrish Creek and the system of groundwater wells. It is located approximately 13 km north of Mission’s town centre and provides 10-15% of the AMWSC’s annual water supply. When Norrish Creek is off-line, it provides a greater percentage of the instantaneous supply and has a licensed capacity to provide 69 MLD for a short duration (days or weeks, not months). The source water quality is consistently high on a year-round basis. Treatment includes UV-disinfection and chloramination. Any long-term source planning includes Cannell Lake for current and future water needs as a complementary source only because Cannell Lake is limited by inflow (based on overall watershed area of 2.1 km^2) and cannot be reasonably expanded. The Cannell Lake watershed consists primarily of Crown Land and holds a Provincial status as “watershed reserve” (AMWSC, 2014) which protects the watershed area in part through the statutes and legislation under the Provincial Land Act. Being a watershed reserve, the lands can not be sold to private corporations and there are further provisions against commercial logging and public trespassing.

4.1 Quality Concerns

Unlike Norrish Creek, Cannell Lake is less susceptible to seasonal water quality spikes and provides high quality water that is typically low in turbidity. In 2013, Fraser Health Authority granted the Commission with the *Cannell Lake Filtration Avoidance Permit*, allowing the Commission to disinfect the water from Cannell Lake without filtration. To maintain the permit, Fraser health stipulates that water delivered to customers must achieve 3-log (99.99%) inactivation of Cryptosporidium and Giardia and a 4-log inactivation on all viruses. After a full year study of water quality analyses it was determined that the previous chloramine disinfection would need to be augmented by ultraviolet (UV) irradiation in order to achieve 3-log and 4-log inactivation.

4.2 Quantity Concerns

Cannell Lake is the sole source for Mission Pressure Zone 4 and primary concerns regarding Cannell Lake are in regard to water quantity. Drought and climate factors reduce long-term resiliency as Cannell experiences a risk of deficiency every 5 to 10 years. While Cannell Lake's license states it can provide up to 69 MLD, it currently produces a sustained reliable yield of 11.8 MLD and does not have the capacity to increase withdrawals. Cannell Lake is recommended to remain a complementary source for current and future supply systems for the Commission.

5. Management Considerations and Recommended Actions

The Commission through its technical staff and operators implement a range of best management practices to consistently deliver safe water to both Abbotsford and Mission. Each source-type is outlined below through concise summary tables which identify the issues, the status and expected effectiveness management practises and the level of impact-effort.

5.1 Norrish Creek Watershed Practices Review

Norrish Creek and Dickson Lake remain the largest source for the AMWSC. Historical challenges to maintaining consistent water quality and water supply trigger the need to re-establish management objectives and identify renewed tactics to achieve them. Each objective and supporting tactics are outlined below including budgeting and preliminary resource needs.

Objective: *Establish a coordinated watershed management program to preserve water quality*

Activities + Resources:

- Reactivate an informal association of stakeholders who are committed or obliged to manage watershed areas and practices
- Complete an integrated watershed management plan with comprehensive emphasis on: management practices, governance, funding, monitoring, oversight and coordination; examples include:
  - Consult legislative requirements for drinking water protection plans and source water assessments and apply modules as warranted e.g. complete a hazard inventory and manage risk such as pathogens;
  - Limit access to select sections of the watershed including new protocols for the yellow gate;
  - Increase security systems and monitoring of visitors and activities; and
  - Enhance the relationship with the Forest Practices Board for operational activities
- Update the plan regularly and conduct regular engagement with elected officials, the public and senior government to emphasise the importance of watershed management in Norrish Creek; consider grant applications for new capital works e.g. new works to implement the plan

- Maintain existing staff resources to prepare the plan and consider additional responsibilities/roles as needed to implement the plan; budget $250,000 for the plan including $150,000 for the initial plan and $100,000 for occasional updates over the plan horizon

Objective: *Achieve lowest turbidity levels at reasonable costs*

Activities + Resources:

- Collate historic survey, roads (active and deactivated), landslides, geotechnical features, basic attribute data (condition, purpose, age, etc) and streams to establish a baseline for management activities.
- Continue to conduct annual watershed tours and inspections and include, for 2018, a list of hot-spot locations for ongoing monitoring
- Partner with senior government to link hydrometric monitoring with turbidity monitoring to develop a water quantity/quality response-model for watershed management
- Engage with logging permit holders, Teal and Ministry of Forests, Lands, Natural Resource Operations and Rural Development to share water quality data and management practices and make a cooperative inventory of works installed to lower turbidity
- Study the link between turbidity and productivity and costs at the Norrish Creek Water Treatment Plant so as to prepare for cost-benefit decisions at a future date
- Use the objective to lower turbidity as a core element in establishing the integrated watershed management plan (item 1 above)
- Include $15,000 (as part of the $250,000 above) for inventory building and GIS mapping to establish a watershed baseline; no additional staff resources are forecasted at this time

Objective: *Achieve consistent, adequate supply and storage*

Activities + Resources:

- Revaluate the hydrometric monitoring program, climate/weather data collection program and consider a new station near to the outlet of Dickson Lake; include snow pillow upgrades and automation for enhanced data management
- Review the proposed weir adjustment as part of the proposed integrated watershed management plan and with consideration to the future need to expand Dickson Lake
- Involve senior government (i.e. DFO, MoE) in designing the weir, new intakes and reservoir expansions given their jurisdiction over fish flows and management thereof; look for senior government funding opportunities/grants for capital and operational upgrades
- Budget $10,000,000 for expansion to Dickson Lake near 2041 to maintain consistent supplies for Commission water demands and for fish flows however timing and scope of work to be dependent on results of monitoring program results;

To complement the Norrish Creek source, groundwater is increasing supply resiliency for peak demands and in the event of an unplanned watershed issue.

5.2 Groundwater Management Practices Review

Groundwater sustainability and aquifer management have been a priority for the Commission for many decades. Primary concerns for groundwater at this time include maintaining adequate quality among many anthropogenic and natural challenges, and, managing groundwater withdrawals throughout the aquifer within reasonable recharge capacities. Each groundwater management objective below includes specific management tactics to protect supply quality and quantity. Recommended tactics often include other parties given their jurisdictional interest in the issue e.g. development permit areas by the City of Abbotsford.

Objective: *Achieve compliant, adequate groundwater supply*

Activities + Resources:

- Complete well licensing program with the Province for existing and future groundwater sources
- Establish information sharing protocols and regular communications with senior government in regards to new wells including large-scale producers that require licenses (e.g. develop referral guidelines) and small-scale producers
- Enhance infiltration (groundwater recharge) through improved storm water management and strategic controls/guidelines for impervious areas in new development and land uses.
- Complete groundwater at risk of containing pathogens (GARP) assessment for each well in order to confirm recommended practices.
- Complete groundwater licensing and budget for $400,000 for ongoing groundwater source compliance including for new collector well, recognizing that less than half of that amount may be required in the next 10 years and the remaining $200,000 is a conservative budget amount in the event of unexpected aquifer supply issues
- Budget $100,000 for GARP assessments

Objective: Manage hazards to groundwater quality

Activities + Resources:

- Request that Abbotsford review and update (as warranted) development permit areas (as part of Official Community Plan amendments) corresponding to municipal well capture zones (within the City of Abbotsford) or sensitive parts of the aquifer to restrict land use and/or activities (may include provisions for storm water management, best management practices, and monitoring).
- Request that Abbotsford review quality of storm water recharging the aquifer and identify low-barrier techniques through development to enhance treatment (wetlands, biofiltration, oil-water separators) for urban aquifer recharge.
- Maintain existing groundwater quality and groundwater quantity monitoring program.
- Coordinate with first responder agencies to increase awareness and containment protocols within sensitive groundwater areas such as municipal well capture zones and specific provisions within those areas such as restrictions on the use of hazardous fire-retardant chemicals.
- Request that Abbotsford restrict land use and/or chemical storage and use in municipal capture zones or sensitive groundwater areas through municipal zoning bylaws (prohibit high-risk commercial and industrial activity and/or impose controls).

- Request that Abbotsford stipulate as a requirement for any sand and gravel mining – best management plans with provisions for fill characterization, drainage control, groundwater monitoring, closure plans; prohibit sand and gravel mining in sensitive areas.
- Request that Abbotsford review the suitability and prevalence of environmental farm plans within the aquifer area and consider partnership programs (e.g. incentives, extension services) to increase the number and extent of Environmental Farm Plans in Abbotsford
- Engage stewardship groups (partnership between City of Abbotsford, the Commission and senior agencies) and local agricultural stakeholders to review opportunities for external service providers to assist with the formation and implementation of management plans.
- In collaboration with the Fraser Health Authority and City of Abbotsford review the effectiveness and implementation requirements to enhance on-going inspection/maintenance of approved septic systems
- In collaboration with the Fraser Health Authority and City of Abbotsford provide public education on well maintenance, septic system maintenance, and proper use and disposal of household hazardous materials, lawn and garden chemicals and automotive repair chemicals, and consider whether advanced treatment systems are required where there are high-risk to groundwater quality

There is a long-list of groundwater protection and management practices already in place and careful reflection on ways to enhance the management regime will be further tackled by 2020 as the collector well begins development phases.

5.3 Cannell Lake Management Practices Review

Objective: *Maintain filtration deferral status*

Activities + Resources:

- Continue to implement the Cannell Lake Watershed Control Program Plan and submit annual filtration roadmap report
- Continue existing water quality monitoring practices: on-line raw water turbidity measurements; weekly raw water coliform testing; monthly raw water protozoa testing; and annual physical-chemical parameter testing.
- Continue to fund the filtration deferral reporting and monitoring through operational budgets

Objective: *Prevent contamination within the watershed*

Activities + Resources:

- Continue visual checks for watershed contamination as part of the operator’s Cannell Lake weekly site visit logsheet.
- Continue to maintain watershed access gates & fences to discourage vehicular entry into the watershed.
- Continue to conduct annual helicopter inspection of the watershed to identify any changes that may increase contamination risk.

- Conduct electronic surveillance devices including required telemetry/wiring (e.g. install fibre lines as needed as part of security budgets) to monitor human entry to the watershed
- Maintain existing signage at watershed access points to alert the public that entry is restricted.
- If financially viable, run electrical power up to the lake to eliminate the need for the diesel generator; acknowledge that there is adequate water supply in the source portfolio in the event of a power outage at Cannell (only) in absence of a diesel generator
- Security infrastructure is included in the budget recommendation of the Viva memorandum, *System Operation and Security Assessment*, as part of the Joint Water Master Plan.

For Cannell Lake, it is in the best interest of the Commission to maintain the Cannell Lake Filtration Avoidance Permit, as filtration systems are often expensive to implement and maintain. Each objective and actions outlined below position the Commission to maintain or enhance existing programs to manage source water quality and quantity.

In closing, the objectives and actions outlined above, in addition to the collaborative process with staff to better understand the efforts and management practices in place, provide a solid foundation for source water quality for decades to come. Many of the recommendations herein reflect affirmation of, our expansion to, practices and procedures. Table 1 summarizes the budget requests to implement these updates.

Table 1: Summary of Budget Items*

Item	Budget + Approx. Schedule
Norrish Creek Integrated Watershed Management Plan incl. GIS baseline and plan updates each 5 years	$250,000 (first Plan by 2024)
Dickson Lake reservoir expansion	$10,000,000 (2041)
Groundwater Licensing, Modelling and Supply Sustainability	$400,000
GARP Review	$100,000

(does not include existing operational costs or in-kind resources)

If you have any questions on the content of this memo or in regards to source water management, please do not hesitate to contact the undersigned.

URBAN SYSTEMS LTD.

Steve Brubacher, P.Eng.
Principal, Water Practice Leader

Ehren Lee, P.Eng.
Principal, Policy and Strategy

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6. Selected References and Reports

Watershed Assessment: Norrish Creek Community Watershed and Norrish Creek Drainage, 2007. Madrone Environmental Services, Ltd.

Assessment of Groundwater Source Options – Abbotsford and Hatzic Valley Areas, B.C. 2004. Piteau Associates

Technical Memorandum 1: Assessment of Abbotsford-Sumas Aquifer for Emergency Water Supply, 2017. Piteau Associates

Abbotsford Groundwater System Renewal Study, 2014. Associated Engineering

Annual Water Quality Report, 2016. Abbotsford Mission Water & Sewer Services

Cannell Lake Watershed Control Program Plan, 2014. Abbotsford Mission Water & Sewer Services

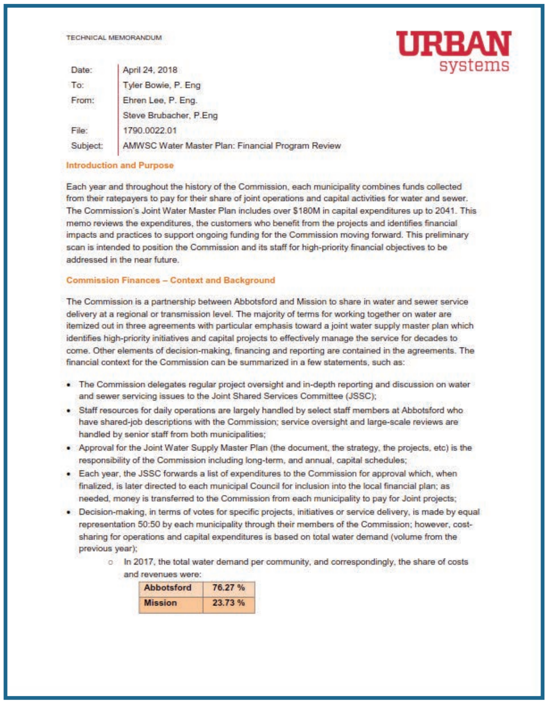
Acute and chronic arsenic toxicity, 2003. Ratnaike

Intellectual Impairment in School-Age Children Exposed to Manganese from Drinking Water. Environmental Health Perspectives, 2011. Bouchard et. al

REFERENCE TECHNICAL MEMORANDUM

#15

WMP FINANCIAL REVIEW



TECHNICAL MEMORANDUM

Date:	April 24, 2018
To:	Tyler Bowie, P. Eng
From:	Ehren Lee, P. Eng. Steve Brubacher, P.Eng
File:	1790.0022.01
Subject:	AMWSC Water Master Plan: Financial Program Review

Introduction and Purpose

Each year and throughout the history of the Commission, each municipality combines funds collected from their ratepayers to pay for their share of joint operations and capital activities for water and sewer. The Commission's Joint Water Master Plan includes over $180M in capital expenditures up to 2041. This memo reviews the expenditures, the customers who benefit from the projects and identifies financial impacts and practices to support ongoing funding for the Commission moving forward. This preliminary scan is intended to position the Commission and its staff for high-priority financial objectives to be addressed in the near future.

Commission Finances – Context and Background

The Commission is a partnership between Abbotsford and Mission to share in water and sewer service delivery at a regional or transmission level. The majority of terms for working together on water are itemized out in three agreements with particular emphasis toward a joint water supply master plan which identifies high-priority initiatives and capital projects to effectively manage the service for decades to come. Other elements of decision-making, financing and reporting are contained in the agreements. The financial context for the Commission can be summarized in a few statements, such as:

- The Commission delegates regular project oversight and in-depth reporting and discussion on water and sewer servicing issues to the Joint Shared Services Committee (JSSC);
- Staff resources for daily operations are largely handled by select staff members at Abbotsford who have shared-job descriptions with the Commission; service oversight and large-scale reviews are handled by senior staff from both municipalities;
- Approval for the Joint Water Supply Master Plan (the document, the strategy, the projects, etc) is the responsibility of the Commission including long-term, and annual, capital schedules;
- Each year, the JSSC forwards a list of expenditures to the Commission for approval which, when finalized, is later directed to each municipal Council for inclusion into the local financial plan; as needed, money is transferred to the Commission from each municipality to pay for Joint projects;
- Decision-making, in terms of votes for specific projects, initiatives or service delivery, is made by equal representation 50:50 by each municipality through their members of the Commission; however, cost-sharing for operations and capital expenditures is based on total water demand (volume from the previous year);
    - In 2017, the total water demand per community, and correspondingly, the share of costs and revenues were:

Abbotsford	76.27 %
Mission	23.73 %

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- DCC related capital projects are based on municipal policy and they are the exception to the demand share formula for cost-sharing or cost-offsetting
- The Commission has informal definitions for what is a joint project versus what is a municipal project in order to ensure that there is clarity around costs and benefits for joint assets;
- That staff provide regular updates to the Commission on the state of expenditures and pending financial needs;
- That staff prepare and maintain a 20-year and a 10-year financial plan including funding suggestions; there is also an expectation that staff prioritize capital plans based on criticality or need;
- Expenditures are generally separated into two categories: operations and capital. Projects that trigger external, construction contracts or for large studies that encompass a number of assets or issues (e.g. greater than $50,000) are typically categorized as capital; operations expenditures typically relate to maintenance, fleet, minor repairs, regular upgrades to mechanical/electrical systems, salaries and administration;
- Over-usage fees exist when projected capacity-cost-allocations do not meet actual targets and there is a need to resettle benefiting-payments;
- There are multiple cost-sharing formulas for use in cost-allocations and funding estimates (note: these have not been reviewed as part of this study);
- Annual spending levels for Joint initiatives range from $6M to $9M over the last 10 years; projects slated for 2018 were projected to amount to just over $9M; and,
- Any reserve building or use of debt is typically decided upon by each municipality to suit its cost-share of the pending budget for the year.

Financial operations of the Commission are generally considered adequate based on recent expenditures, however there remains some recognition that refinements to financial policy may be needed for the implementation of the Joint Water Master Plan.

Commission Finances – Joint Water Master Plan Investments

Table 1 outlines the fundamental attributes of each investment category of the Joint Master Water Supply Plan.

Title/Amount	Timing	Purpose	Funding
Expand Source Capacity **$76.0M**	*2020, 2041*	• New collector well; two phases; needed for supply resiliency • Benefits all customers, current and future	• *Pursue senior government grants for 2/3rd funding of Phase 1* • *Proportional DCC eligibility:* • *Consider debt to manage first 7 years of investments of the overall plan* • *Conventional revenue for remainder and any debt payments*

Title/Amount	Timing	Purpose	Funding
Update Asset Management **$55.0M**	*2019, ongoing*	• New asset management program; annual renewal projects	• *Conventional revenue*
System Vulnerabilities **$5.6M**	*2019-2024*	• Update response plans; seismic upgrades; system communications	• *Conventional revenue*
Enhanced Security **$0.45M**	*2020, 2023*	• Increase security systems and monitoring	• *Conventional revenue*
Quality & Compliance **$15.5M**	*2019-2022, 2032*	• Update watershed/aquifer management plans; long-term potability upgrades; licensing	• *Conventional revenue + pH/water quality project DCC eligible (proportional)*
Optimization **$27.0M**	*2024-2025*	• Install storage tank near Cannell, upgrade Best PS; expand Dickson Lake • Benefits to all customers as well as senior government environment ministries i.e. fish flows (Dickson Lake)	• *Cannell tank and Best PS DCC eligible (share toward development TBD)* • *Pursue senior government grants for 2/3rd funding (or more) for Dickson Lake i.e. fish flows and climate change triggers*

Table 2 and Figure 1 (enclosures) summarize the spending profile for the Joint Water Master Plan from 2018 to 2041. Important highlights from the long-term investment profile include:

- Almost 60% of the long-term projections are proposed in the first 7 (of 23) years which should cause a review of debt usage to finance projects and keep rates predictable, year over year;
- Many projects are scheduled in one calendar year yet the actual implementation of the project may spread out over multiple years; the reason for reporting investments on a per year basis is to trigger the appropriate financial tool (budgeting, reserve building or reserve drawdown, or debt use) as a complement to regular cash-flow financing
- Asset renewal spending is projected to fluctuate from year to year which may warrant a review of consistent municipal contributions year over year and the use of short-term reserves to balance the annual variability;
- Future demand splits at the 2041 horizon are estimated at 22% and 78% for Mission and Abbotsford, respectively, based on future average daily demand statistics (demand projections reviewed as part of a separate memo; the change in demand split in 2041 from today represents a marginal but largely insignificant change)
- That $179.6M over 22 years equates to an annual investment level of almost $8.2M which is in line with the average capital spending over the last eight years; and,

- That approximately $118M of the total is considered DCC eligible with a modest-share (likely less than half) potentially allocated toward development.

It's also important to note that water conservation funding falls under the operations category and may require a modest increase to accommodate the proposed direction in reductions and water loss management.

Next Steps in Master Water Supply Plan Funding

Moving forward, the Commission should undertake further review and decision-making in order to address and implement the following initiatives:

- Review the strengths and drawbacks of the existing funding requisition process and consider the benefit of establishing long-term financial policy that structures municipal finances to meet the long-term joint system needs, including topics such as debt use, reserve building, development cost charges (best practice at the municipal level to support joint capital finance), asset renewal spending, large-project procurement policy and the pursuit of grants;
- Review municipal DCC Bylaws to assess the opportunity to incorporate the eligible projects from Table 1 into local rates and update accordingly to ensure that looming development-oriented capital projects can be effectively funded by both communities;
- Initiate the background work required to support upcoming grant processes for the collector well, including business case review, risk registry and project development and phasing (already underway);
- Update asset-ownership definitions to ensure that there is clear policy for existing and future assets of the joint water system;
- Review the role of the Community Works Fund for each municipality as a funding source for water supply projects (one-time or ongoing);
- Review other equities or assets not required for the function of the water system (e.g. land, archives, etc) and confirm their ownership and proper accounting;
- Ensure water rates and revenue sources for joint supply projects meet cost pressures from inflation, construction cost-escalation and or unplanned changes in the rate of growth (up or down) and to adjust the spending plan as appropriate; and,
- Utilize the Joint Water Supply Master Plan and priority-sequenced capital plan to meet the operational-reporting needs for the Commission.

We trust the foregoing offers additional insights into next steps for implementing the Joint Water Supply Master Plan, and that this memo and its content will further in-depth discussions and outcomes from each municipality to meet the funding expectations for the plan.

Please contact the undersigned for future considerations on this matter including a process map for Commission to local strategy development.

URBAN SYSTEMS LTD.

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Principal, Water Practice Leader	Principal, Policy and Strategy

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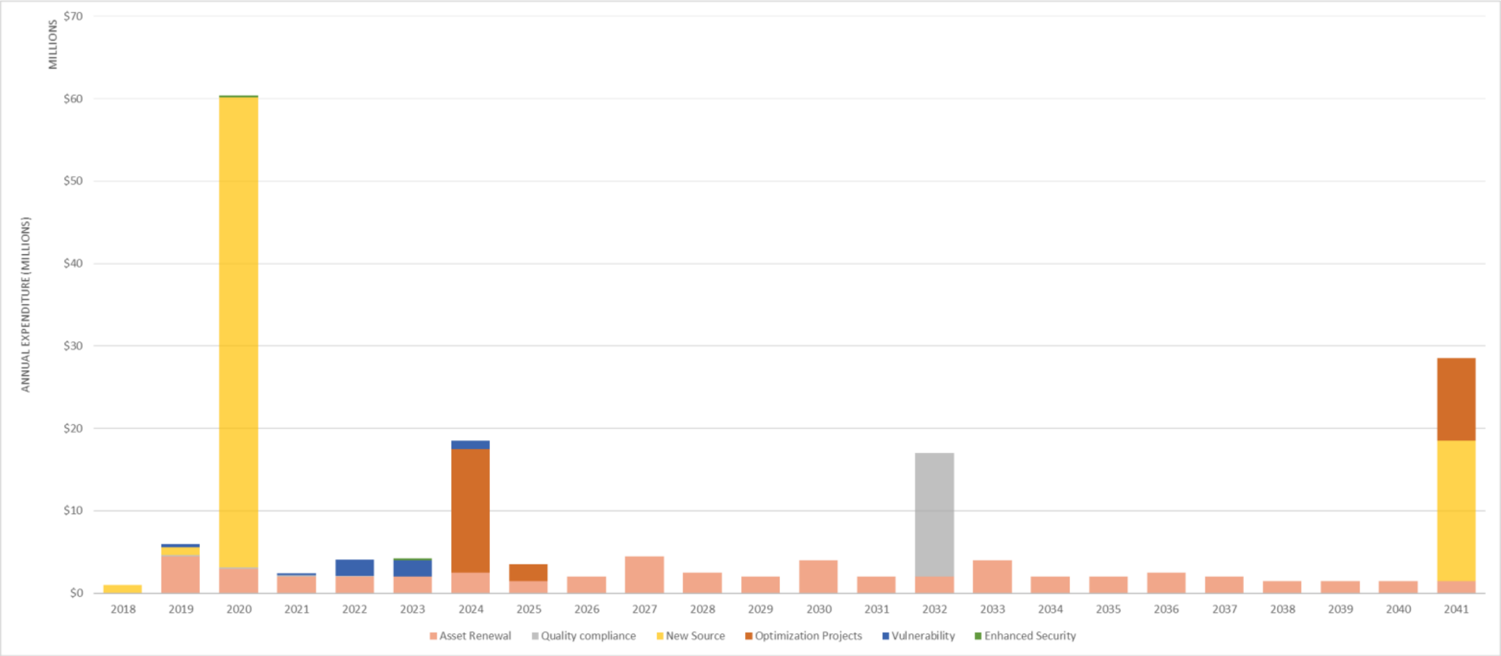
Table 2: Spending Profile

Year		Enhanced Security	Quality compliance	Vunerability	Optimization	New Source	Asset Renewal
2018						$ 1,000,000.00	
2019			$ 100,000.00	$ 350,000.00		$ 1,000,000.00	$ 4,500,000.00
2020		$ 250,000.00	$ 150,000.00			$ 57,000,000.00	$ 3,000,000.00
2021			$ 150,000.00	$ 250,000.00			$ 2,000,000.00
2022			$ 100,000.00	$ 2,000,000.00			$ 2,000,000.00
2023		$ 200,000.00		$ 2,000,000.00			$ 2,000,000.00
2024				$ 1,000,000.00	$ 15,000,000.00		$ 2,500,000.00
2025					$ 2,000,000.00		$ 1,500,000.00
2026							$ 2,000,000.00
2027							$ 4,500,000.00
2028							$ 2,500,000.00
2029							$ 2,000,000.00
2030							$ 4,000,000.00
2031							$ 2,000,000.00
2032			$ 15,000,000.00				$ 2,000,000.00
2033							$ 4,000,000.00
2034							$ 2,000,000.00
2035							$ 2,000,000.00
2036							$ 2,500,000.00
2037							$ 2,000,000.00
2038							$ 1,500,000.00
2039							$ 1,500,000.00
2040							$ 1,500,000.00
2041					$ 10,000,000.00	$ 17,000,000.00	$ 1,500,000.00
total		**$ 450,000.00**	**$ 15,500,000.00**	**$ 5,600,000.00**	**$ 27,000,000.00**	**$ 76,000,000.00**	**$ 55,000,000.00**
							$ 179,550,000.00

Figure 1: Spending Profile 2018-2041

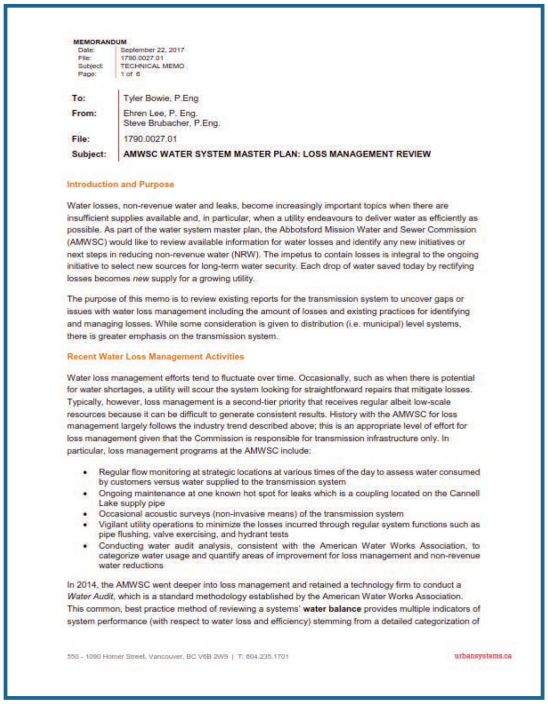


JOINT ABBOTSFORD-MISSION
WATER MASTER PLAN
Master Plan Summary | May 2018

REFERENCE TECHNICAL MEMORANDUM

#16

WATER LOSS MANAGEMENT



MEMORANDUM
Date: September 22, 2017
File: 1790.0027.01
Subject: TECHNICAL MEMO
Page: 1 of 6

To: Tyler Bowie, P.Eng
From: Ehren Lee, P. Eng.
Steve Brubacher, P.Eng.
File: 1790.0027.01
Subject: **AMWSC WATER SYSTEM MASTER PLAN: LOSS MANAGEMENT REVIEW**

Introduction and Purpose

Water losses, non-revenue water and leaks, become increasingly important topics when there are insufficient supplies available and, in particular, when a utility endeavours to deliver water as efficiently as possible. As part of the water system master plan, the Abbotsford Mission Water and Sewer Commission (AMWSC) would like to review available information for water losses and identify any new initiatives or next steps in reducing non-revenue water (NRW). The impetus to contain losses is integral to the ongoing initiative to select new sources for long-term water security. Each drop of water saved today by rectifying losses becomes *new* supply for a growing utility.

The purpose of this memo is to review existing reports for the transmission system to uncover gaps or issues with water loss management including the amount of losses and existing practices for identifying and managing losses. While some consideration is given to distribution (i.e. municipal) level systems, there is greater emphasis on the transmission system.

Recent Water Loss Management Activities

Water loss management efforts tend to fluctuate over time. Occasionally, such as when there is potential for water shortages, a utility will scour the system looking for straightforward repairs that mitigate losses. Typically, however, loss management is a second-tier priority that receives regular albeit low-scale resources because it can be difficult to generate consistent results. History with the AMWSC for loss management largely follows the industry trend described above; this is an appropriate level of effort for loss management given that the Commission is responsible for transmission infrastructure only. In particular, loss management programs at the AMWSC include:

- Regular flow monitoring at strategic locations at various times of the day to assess water consumed by customers versus water supplied to the transmission system
- Ongoing maintenance at one known hot spot for leaks which is a coupling located on the Cannell Lake supply pipe
- Occasional acoustic surveys (non-invasive means) of the transmission system
- Vigilant utility operations to minimize the losses incurred through regular system functions such as pipe flushing, valve exercising, and hydrant tests
- Conducting water audit analysis, consistent with the American Water Works Association, to categorize water usage and quantify areas of improvement for loss management and non-revenue water reductions

In 2014, the AMWSC went deeper into loss management and retained a technology firm to conduct a *Water Audit*, which is a standard methodology established by the American Water Works Association. This common, best practice method of reviewing a systems' **water balance** provides multiple indicators of system performance (with respect to water loss and efficiency) stemming from a detailed categorization of

550 - 1090 Homer Street, Vancouver, BC V6B 2W9 | T: 604.235.1701 urbansystems.ca

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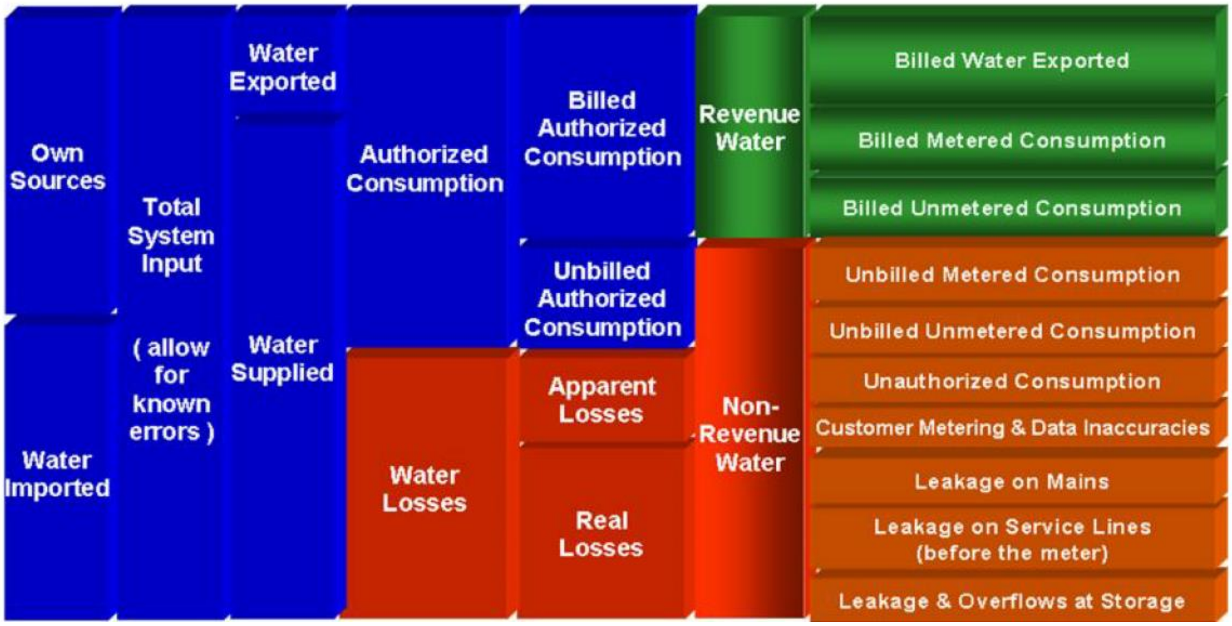


The report reviewed each category in detail and concluded that the system is performing very well; specific indicators that support this conclusion are listed below.

Financial: NRW as a % of System Input Volume (AwwaRF ref. WLPI 1, IWA ref. Fi36) **= 0.1%**
NRW % of System Input by Value (AwwaRF ref. WLPI 5, IWA ref. Fi37) **= 0.1%**[10]
Operational: Real Losses: m^3/km of main/day (AwwaRF ref. WLPI 3, IWA ref. Op27) **= 2.7**
Real Losses: Infrastructure Leakage Index (ILI) (AwwaRF ref. WLPI 6, IWA ref. Op29) **= 1.3**

Economic Unreported Real Losses = ILI 1.0 = 2.1 m^3/km/day = 0.2 MLD

Further discussion of these performance results is included throughout the memo. Based on the results of the latest review, that leakage levels are low and because no additional data (of significance) is available, there is no need to conduct additional water audit analysis at this time.

The AMWSC's overall approach is generally consistent with best management practices identified throughout North America. On top of regular programming, about every 3-5 years, a utility will conduct a thorough review of practices and loss reduction tactics and write a report on the status and effectiveness of the existing program.

Status for Water Loss Management in the Transmission System

In 2014, the AMSWC commissioned a loss management status report on the transmission infrastructure only, which outlined multiple findings and trends of the transmission system, such as:

- Additional meters, meter calibration, and monitoring efforts are creating more accurate loss estimates which has resulted in less significant assumptions within water balances; overall, the

increased resources toward monitoring has, in turn, increased confidence in the results of loss management analysis and reporting; also, there could be
  - greater effort expended toward the Maclure, Sandon, and Hyde-Buker meters will further converge analysis and increase reliability of loss management information
  - discrepancies between meter accuracies and actual loss/leakage events; this may never be fully addressed and recent efforts to minimize inaccuracies should continue
- Only one leak was identified, which is pre-existing and relates to a single coupling within the 400mm supply pipe on Cannell Lake; furthermore,
  - tightening the coupling will reduce leakage significantly, however, the mitigation is not permanent and creates a regular, low-scale maintenance requirement;
  - an upgraded coupling should be considered given the knowledge of the leak and existing operational burden
  - overall loss management is considered excellent given that only one known location exists for losses and the meter results affirm that leaks are not a notable source of non-revenue water
  - ELL is a technical term for leakage and overall loss performance; ELL ILI (index form) for AMWSC is rated as 1, the best theoretical score available
- Low connection densities (typical for regional transmission systems) reduce the risk of distributed, low-volume, and high-cost leaks; conversely, there is greater emphasis on the distribution systems to monitor and identify leaks
- *Deferral potential analysis* characterizes the significance of losses by considering the cost-benefit of repairing leaks in an effort to build system capacity without expanding infrastructure; deferral potential analysis is common when leaks and losses are relatively high; the analysis was not undertaken and is likely unwarranted because the amount of loss is estimated to be very low
- Surface level acoustic surveys were preferred at the time of report writing; recommendations to the AMWSC include $11,000/year to maintain the high-performing ELL results.

In summary, losses throughout the transmission system are low and demonstrate the best theoretical efficiency possible within the current rating systems. There is little justification to make major program changes and the existing approaches should generally remain as they are with a dual focus towards a) maintaining the existing performance and to b) stay on top of any new leaks that arise (as they are prone to do over time). Consider the best practice guidelines () for setting loss reduction targets which reinforce that current losses are low and that the transmission system demonstrates high performance in water efficiency.

Recognizing the status of loss management and the overall efficiency of the transmission system, there is more cause to consider the role that distribution (municipal) losses effect the overall Commission supply regime. Moving forward, there should be greater emphasis on achieving results at the distribution level as expanding the distribution focus will result in overall improvements in water efficiency for both the communities and the Commission. The motivation to expand efforts into loss management at the distribution level is similar to the regional approach which is to reduce the need (i.e. defer it; reduce the scale) for unnecessary energy and infrastructure expenditures for the AMWSC.

Path Forward: Considerations for Both Transmission and Distribution System Loss Management

The status of losses and non-revenue water in Abbotsford and Mission is summarized below.

Abbotsford		Mission	
2016 Estimate for Non-Revenue Water	14%	**2016 Estimate for Non-Revenue Water**	9%
2010 Previous Estimate for Non-Revenue Water	18%	**2010 Previous Estimate for Non-Revenue Water**	18%
High-Level Status • *Abbotsford's AMI program is effective at targeting leakage for all customers and staff comments suggest that leakage/loss management is stable and trending positive* • *There is a conceptual case to suggest that Abbotsford's NRW should actually be lower on a relative basis (relative to service population) to Mission* • *Available data from the AMI program should be reapplied at the local level to create updated estimates for NRW*		**High-Level Status** • *Lack of customer meters at all connections makes it impossible to accurately quantify losses, including overall, public-side, and private-side; historic/emerging leaks may go unnoticed, especially on the private side* • *Mission's public-side leakage program started in 2008 and has resulted in many fixed leaks, estimated at 73ML of leaks corrected per year* • *Previous study purports that leakage in the regional mains may be the cause for why per capita consumption rates in Mission are relatively high; however, AMWSC's 2014 study on the regional transmission system addresses that notion*	

Estimates for non-revenue water appear to have decreased from 2010 to 2016 which aligns with the overall reductions witnessed for the entire supply system. However, the comparison of transmission losses to distribution losses justifies that further efforts into loss management may occur through a Commission-to-municipal program. Considerations for that program include:

1. *A strong need to establish the '**why**' behind distribution loss management including objectives and goals such as the targeted NRW reduction as part of the high demand reduction scenario for water conservation (i.e. 10% reduction over 30 years, or 1% overall as a minimum); a clear purpose for any initiatives will add staying power and lead to longer term results and stable funding*
2. *Initiate on a political and administrative process to uncover important focus areas for loss management, that will likely include:*
    - *Quantifying the problem through enhanced monitoring, data collection, and information review*

  - *Reviewing strategies and best practices for municipal-scale loss management and developing a sequence of initiatives that show the greatest potential for loss-reduction in an incremental and cost-effective manner; if universal metering proceeds in Mission then there could be an added requirement for leak-detection technologies to significantly advance the potential for loss management*

  - *Exploring regulatory tools and financial incentives at the Commission level to be applied to each municipality including the strategic resource allocation of funds from the AMWSC and each municipal utility*

Enhanced discussions between operations and engineering staff should be initiated at each municipality to share insights, pool information, advise on program options, measure progress, present results and track achievements towards any targets; this initiative can be started right away through the existing meetings.

Loss management must be an ongoing practice that endeavours to make the most effective use of water resources. While overall losses in the transmission system are low, the estimate for non-revenue water at the municipal level is almost 15%. Moving forward, efforts for the AMWSC should include:

- **Maintaining the existing loss management program for the transmission system and conducting water audit analysis and reporting about every 5 years**

- **Initiating a loss management strategy through the Commission which sets out the purpose, strategies, actions, and resource allocations for activities at the municipal level**

The AMWSC is in a solid position to implement the above path forward given its strong performance on loss management to date. There should additional confidence in a distribution-side loss management program given the apparent willingness of each municipality in developing their own leakage programs and on top of the renewed focus of demand management in the overall water master plan.

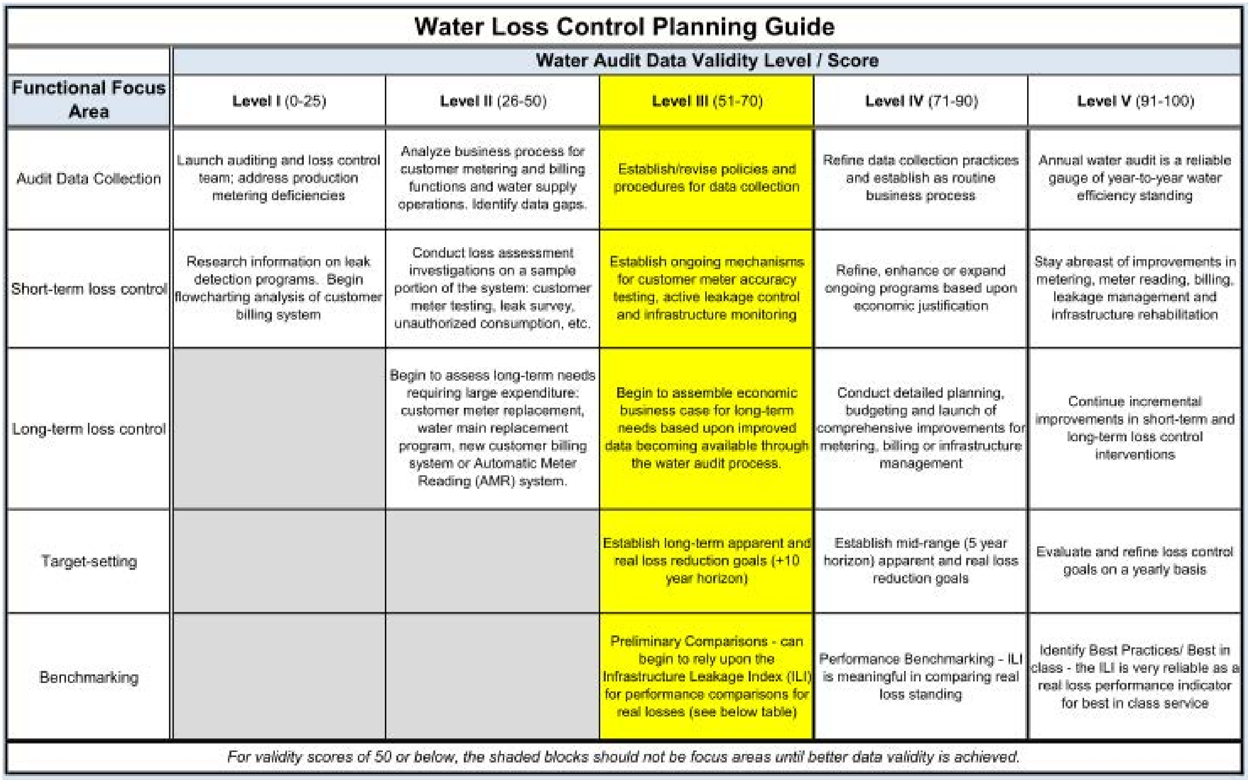
Please contact the undersigned for future considerations on this matter including a process map for Commission to local strategy development.

URBAN SYSTEMS LTD.

Steve Brubacher, P.Eng. Principal, Water Practice Leader	Ehren Lee, P.Eng. Principal, Policy and Strategy

Encl:

Enclosure: AWWA Best Practice Guidelines for Water Loss Control Planning and Target Setting



Water Loss Control Planning Guide

Functional Focus Area	Water Audit Data Validity Level / Score				
	Level I (0-25)	**Level II** (26-50)	**Level III** (51-70)	**Level IV** (71-90)	**Level V** (91-100)
Audit Data Collection	Launch auditing and loss control team; address production metering deficiencies	Analyze business process for customer metering and billing functions and water supply operations. Identify data gaps.	Establish/revise policies and procedures for data collection	Refine data collection practices and establish as routine business process	Annual water audit is a reliable gauge of year-to-year water efficiency standing
Short-term loss control	Research information on leak detection programs. Begin flowcharting analysis of customer billing system	Conduct loss assessment investigations on a sample portion of the system: customer meter testing, leak survey, unauthorized consumption, etc.	Establish ongoing mechanisms for customer meter accuracy testing, active leakage control and infrastructure monitoring	Refine, enhance or expand ongoing programs based upon economic justification	Stay abreast of improvements in metering, meter reading, billing, leakage management and infrastructure rehabilitation
Long-term loss control	▨	Begin to assess long-term needs requiring large expenditure: customer meter replacement, water main replacement program, new customer billing system or Automatic Meter Reading (AMR) system.	Begin to assemble economic business case for long-term needs based upon improved data becoming available through the water audit process.	Conduct detailed planning, budgeting and launch of comprehensive improvements for metering, billing or infrastructure management	Continue incremental improvements in short-term and long-term loss control interventions
Target-setting	▨	▨	Establish long-term apparent and real loss reduction goals (+10 year horizon)	Establish mid-range (5 year horizon) apparent and real loss reduction goals	Evaluate and refine loss control goals on a yearly basis
Benchmarking	▨	▨	Preliminary Comparisons - can begin to rely upon the Infrastructure Leakage Index (ILI) for performance comparisons for real losses (see below table)	Performance Benchmarking - ILI is meaningful in comparing real loss standing	Identify Best Practices/ Best in class - the ILI is very reliable as a real loss performance indicator for best in class service

For validity scores of 50 or below, the shaded blocks should not be focus areas until better data validity is achieved.

General Guidelines for Setting a Target ILI
(without doing a full economic analysis of leakage control options)

Target ILI Range	Financial Considerations	Operational Considerations	Water Resources Considerations
1.0 - 3.0	Water resources are costly to develop or purchase; ability to increase revenues via water rates is greatly limited because of regulation or low ratepayer affordability.	Operating with system leakage above this level would require expansion of existing infrastructure and/or additional water resources to meet the demand.	Available resources are greatly limited and are very difficult and/or environmentally unsound to develop.
>3.0 -5.0	Water resources can be developed or purchased at reasonable expense; periodic water rate increases can be feasibly imposed and are tolerated by the customer population.	Existing water supply infrastructure capability is sufficient to meet long-term demand as long as reasonable leakage management controls are in place.	Water resources are believed to be sufficient to meet long-term needs, but demand management interventions (leakage management, water conservation) are included in the long-term
>5.0 - 8.0	Cost to purchase or obtain/treat water is low, as are rates charged to customers.	Superior reliability, capacity and integrity of the water supply infrastructure make it relatively immune to supply shortages.	Water resources are plentiful, reliable, and easily extracted.
Greater than 8.0	Although operational and financial considerations may allow a long-term ILI greater than 8.0, such a level of leakage is not an effective utilization of water as a resource. Setting a target level greater than 8.0 - other than as an incremental goal to a smaller long-term target - is discouraged.		
Less than 1.0	If the calculated Infrastructure Leakage Index (ILI) value for your system is 1.0 or less, two possibilities exist. a) you are maintaining your leakage at low levels in a class with the top worldwide performers in leakage control. b) A portion of your data may be flawed, causing your losses to be greatly understated. This is likely if you calculate a low ILI value but do not employ extensive leakage control practices in your operations. In such cases it is beneficial to validate the data by performing field measurements to confirm the accuracy of production and customer meters, or to identify any other potential sources of error in the data.		