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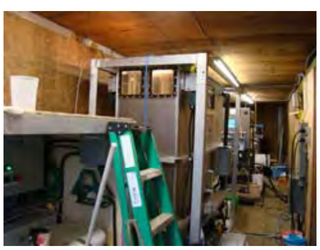
TECHNICAL REPORT 2

Englishman River Water Service

Phase 2 - Water Treatment Pilot Testing and Aquifer Storage and Recovery Feasibility Analysis



May 2014

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Executive Summary

1 BACKGROUND

Water supply to areas surrounding the City of Parksville (CoP) has historically been provided by a combination of municipally owned and operated wells and bulk water from the Englishman River. The intake and treatment facilities for the Englishman River are located in Parksville and are operated and managed by the Arrowsmith Water Service (AWS), a joint partnership between the CoP, the Town of Qualicum Beach (TQB), and the Regional District of Nanaimo (RDN). The Englishman River source is only used seasonally, primarily in the summer, to supplement the groundwater supplies.

In 2009 the AWS decided to take a fresh look at its water supply program, driven by factors such as a need to update water demand projections due to changing population composition and water conservation initiatives, the intent to plan for a broader future design horizon, the evolution of more stringent drinking water quality standards, and the need to consider the impact of climate change on water resources. A key component to the water supply program will be a significant expansion to the Englishman River intake and water treatment facilities.

Phase 1 – Conceptual Planning, Budgeting and Scheduling was initiated in 2009 to complete a broad and comprehensive study of potential river intake locations, water treatment requirements and associated infrastructure. The work completed under Phase 1 included workshops with the various stakeholders, a multi-stage site evaluation to determine the optimal location for the intake and treatment plant along a 10 km reach of the Englishman River, a hydraulic assessment of the Englishman River watershed, and an assessment of the Englishman River water quality based on historical data.

During Phase 1, the option to implement Aquifer Storage and Recovery (ASR) was identified as a potential option for the AWS water resource strategy. Simply put, ASR is the process of injecting and storing water in an aquifer during times of excess supply, such as during the winter and drawing this water back out during periods of high demand to supplement water supplies. The successful development of an ASR system depends on finding a suitable aquifer. Field work and site testing is required to verify that the desired hydrogeological conditions are available and that injected water still meets potable standards when it is pumped back out.

2 THE ROLE OF ERWS

Upon completion of Phase 1, the TQB withdrew from the partnership to develop the bulk water supply system. The Englishman River Water Service (ERWS) was formed in 2011 as a joint venture between the CoP and the RDN. Water supply and demand forecasts were updated to account for the new partnership and revised assessments of the groundwater supplies. Based on this information the Englishman River Water Treatment Plant is proposed to be constructed in two phases:

- Phase 1: Plant constructed in 2016 with a treatment capacity of 25.8 ML/d
- Phase 2: Plant expanded in 2035 to a total treatment capacity of 38.9 ML/d

In 2011 the ERWS initiated Phase 2 – Water Treatment Pilot Testing and Aquifer Storage and Recovery Feasibility Analysis to act on some of the key recommendations made at the end of Phase 1. The Phase 2 scope included:

- Conducting a 12-month water quality monitoring program to fill in gaps in the historical data and to more fully characterize the Englishman River.
- Performing reduced-scale field testing of the potential water treatment processes appropriate for the Englishman River.
- Conducting a preliminary field investigation and testing program for an ASR system.

This technical report summarizes the results of the Phase 2 work.

3 WATER QUALITY MONITORING

Historical water quality data reviewed in Phase 1 indicated that the primary drinking water treatment objective for the Englishman River are:

- Turbidity removal.
- Protection from microbiological activity.

Turbidity levels were typically low but would experience sudden, intense spikes, usually in the winter. There were other parameters flagged as potential concerns but with not enough data to confirm. In addition, there was insufficient data to be able to map out seasonal changes in water quality. As water flows in the Englishman River are high in the winter and low in the summer, it is reasonable to expect changes to the chemical makeup of the water.

The ERWS ran a 12-month monitoring program from the fall of 2011 to the late summer of 2012, using a combination of automated monitoring instruments and regular grab sampling and private laboratory analysis. The study monitored not only parameters flagged in Phase 1, but also parameters that can impact treatment efficiencies or that have been a concern in similar water sources elsewhere.

The study confirmed that turbidity levels were normally below 5 NTU, with a general increase in the winter and spring. Turbidity spikes occur quickly and unexpectedly throughout the year, although most frequently and with the most intensity during the winter, as shown in Figure 1. The source of the turbidity appears to be sediment from the riverbank. Significant mobility of riverbank sediment can occur during the first heavy rainfalls after a period of dry weather or when a riverbank partially collapses, and leads to very large turbidity spikes. Events like riverbank collapses can also mobilize metal particles from the soil that become suspended in the water.

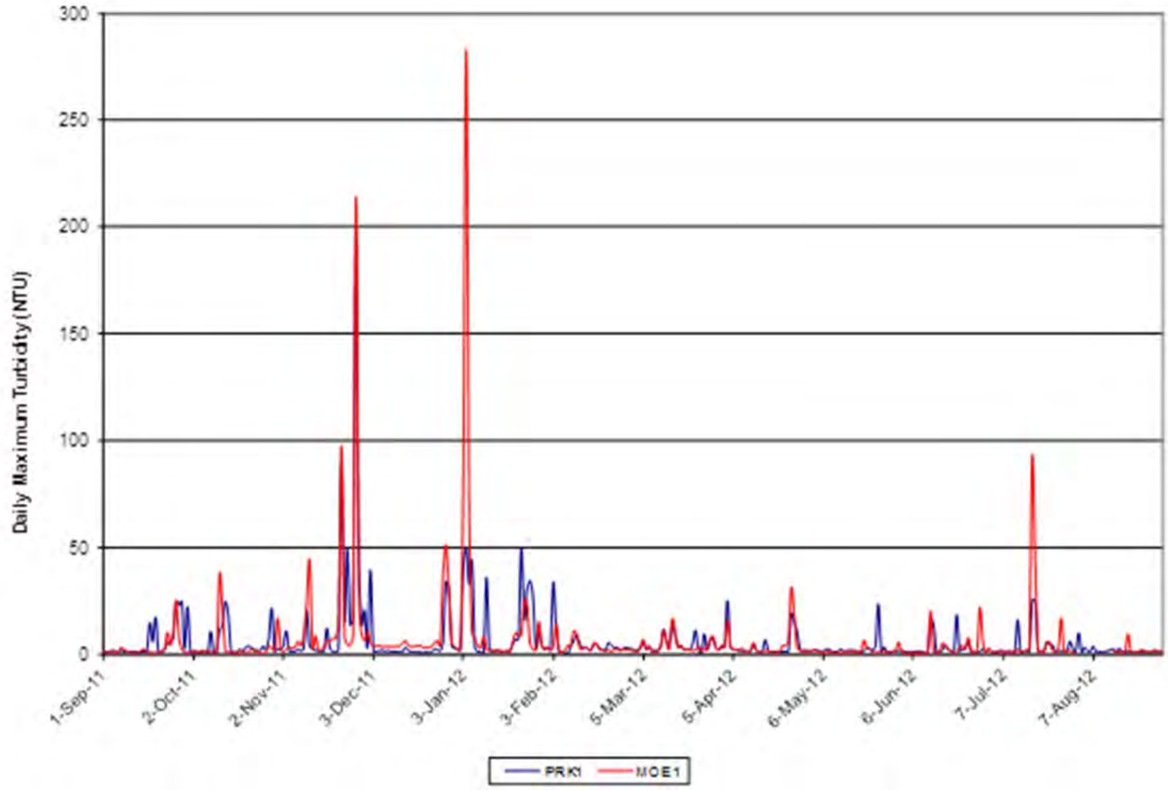

Figure 1 – Englishman River Turbidity

Aside from turbidity, true colour in the river frequently exceeded the aesthetic objective for drinking water (15 TCU). Above this level, the water can appear discoloured and be unappealing to consumers. Elevated levels of true colour occurred regularly throughout the year, and while a relationship between heavy rainfall and colour levels is suspected, the collected data could not confirm this.

The water quality data was reviewed to see whether filtration deferral or avoidance could be applied to this water source. In terms of water quality, the Englishman River failed to satisfy two of the criteria that must be met before filtration avoidance will be considered by the Health Authority: turbidity must not exceed 5 NTU for more than two days in a 12-month period, and *Escherichia coli* (*E.coli*) bacteria levels must never exceed 20 counts/ 100 mL. The turbidity requirement is because of turbidity's ability to potentially interfere with disinfection processes and because high turbidity can be an indicator of high levels of bacteria, viruses, and protozoa. The *E.coli* requirement is because *E.coli* bacteria can have a potent impact on human health, and therefore a double-barrier of filtration and disinfection is desired, as security, to ensure the bacteria are removed. Englishman River water will require filtration to meet current drinking water objectives.

Englishman River water must undergo treatment to address the following drinking water objectives:

- Reduce turbidity to 1 NTU or less, depending on the treatment selected.
- Reduce true colour to 15 TCU or less.
- During turbidity events, reduce total iron levels to less than 0.3 mg/L and total manganese levels to less than 0.05 mg/L.
- Achieve a minimum 3-log (99.9%) removal or inactivation of *Cryptosporidium parvum* and *Giardia lamblia*, and a minimum 4-log (99.99%) removal or inactivation of viruses.

All of these objectives can be achieved by using a combination of filtration and disinfection as treatment.

4 WATER TREATMENT TEST PILOTING

Each water source is unique, and will respond to treatment differently than another source. For a treatment system of this scale, it is important to simulate the proposed treatment processes at a reduced scale ahead of time. A piloting program was therefore considered using Englishman River water as its raw water source. In Phase 1, five different filtration processes were identified as potential options for particulate removal. In Phase 2 the options were narrowed down to two: conventional treatment and membrane filtration. The other options were rejected either because they would struggle to adequately treat sudden turbidity spikes, or were not cost-effective for the river's otherwise low turbidity conditions. Both short-listed options were piloted during the winter (2011/12), when sudden changes in Englishman River turbidity are most frequent.

Conventional treatment consists of coagulation, flocculation, sedimentation, and filtration. A coagulant is added first to encourage the agglomeration of smaller particles into larger floc that are easier to remove later. The coagulated water then passes through the flocculation phase, where the water is gently mixed to allow the formation of even larger floc. The floc settles out of the water during the sedimentation stage. The supernatant water then passes through a media filter that removes the remaining aggregate particles.

The membrane filtration process involves a pre-filtration stage where larger particles are removed by a large porosity filter, such as a steel filter screen, a bag filter or a cartridge filter. A coagulant is then added to enhance colour and turbidity removal. Water is then drawn through the membrane, where particles are physically strained out of the water.

During the pilot program, the conventional treatment system could not consistently lower turbidity levels to meet the drinking water objectives; the key reasons being the low alkalinity of the Englishman River and the sudden nature of the turbidity spikes. Alkalinity is used as part of coagulation reactions to encourage particle aggregation, thus in low alkalinity waters coagulation efficiency may be hindered. Coagulants specifically tailored for low alkalinity waters are sometimes used to compensate for this inefficiency, but for the Englishman River, low alkalinity remained an issue regardless of coagulant or coagulant-aid used. When turbidity levels were less than 5 NTU, conventional treatment struggled to form visible aggregate floc that could then be removed via sedimentation or filtration. Conversely, when a turbidity spike occurred, the change in turbidity was too rapid for the coagulation system to adequately react. While visible floc would form, a significant amount of turbidity was still able to pass through the filters. Filter backwashes had to be performed frequently to prevent filter breakthrough.

The membranes were able to consistently reduce turbidity to less than 0.01 NTU without any chemical aid. However, to reduce true colour a coagulant was required. The pilot showed that the use of aluminum chlorohydrate (ACH) as a coagulant allowed the membranes to successfully reduce colour to an acceptable level.

It is recommended that membranes be used at the Englishman River Water Treatment Plant. For microbiological protection, the combination of membranes followed by chlorine disinfection is recommended to achieve the desired removal of *Cryptosporidium*, *Giardia*, and viruses. The recommended treatment processes are therefore as follows:

- Pre-filtration
- Coagulation using ACH
- Membrane ultrafiltration
- Chlorination

5 AQUIFER STORAGE AND RECOVERY

An important focus of Phase 2 was a greater investigation into the feasibility of ASR for the ERWS system, which included a comprehensive aquifer study and field testing of an ASR pilot well. In Phase 1, three particular areas of the Nanoose Creek Aquifer were identified as the most suitable for ASR development, as shown in Figure 2. In Phase 2, a pilot ASR well was proposed to be developed in the western-most area, closest to the proposed water treatment plant site. Part of this aquifer's desirability was that it was accessed by relatively few wells. The drawback of this is that the area of the aquifer was not already comprehensively mapped out. Mapping of the aquifer was conducted using existing well records, newly drilled test wells, air and satellite photos, and site investigations. Based on this information it was determined that the target aquifer sits on a relatively flat section of till and bedrock, meaning water injected into the aquifer would likely not move away. The aquifer is confined from above by a layer of clay and silt, as well as an upper aquifer hydraulically isolated from the target aquifer. The target aquifer is thus protected from surface contamination sources. Of the test wells developed, one well along Kaye Road was identified as the most suitable location for developing a pilot ASR well. This pilot well, ASR-1 was developed and subjected to cycle testing.

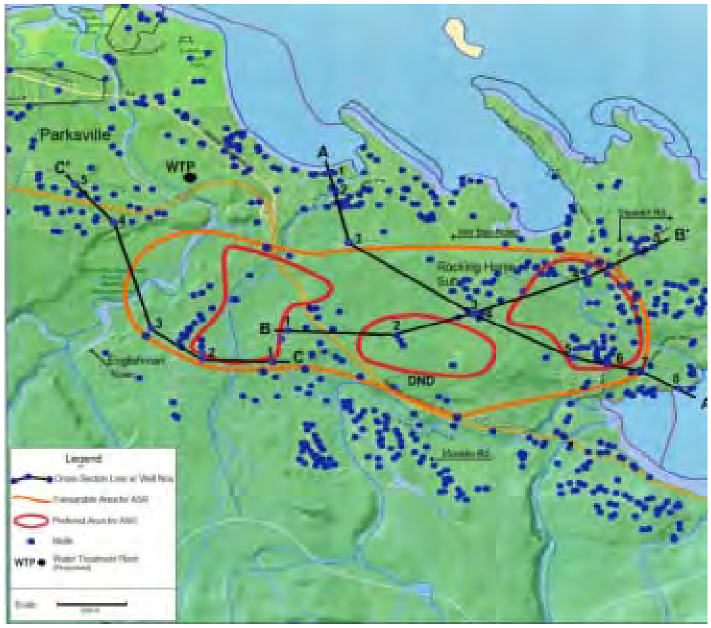

Figure 2 – Recommended ASR Locations

Cycle testing consists of a period of injecting treated water into the target aquifer via the target well followed by a period of recovery where the injected water is pumped back out of the well. The purpose of cycle testing is to, much like piloting the treatment processes, determine the reaction of the aquifer to the injected water in terms of injection and withdrawal capacity, total volume storage capability, stored water mobility, and chemical interactions between the stored water and the aquifer itself. Cycle testing also serves the purpose of conditioning the aquifer for ASR operations, such that each cycle test performs better than the last. A pilot ASR well is typically run for several cycles before it is incorporated into a drinking water system.

Two cycle tests were performed at ASR-1. For Cycle Test 1, a maximum sustainable injection rate of 9 L/s and a maximum sustainable recovery rate of 5 L/s was achieved. Performance improved in Cycle Test 2. The sustainable injection rate was increased to 10 L/s and the recovery rate to 8 L/s, although the data indicates that recovery could have been sustainably increased to 9 L/s.

Water injected and recovered from ASR-1 was analyzed to determine any changes in water quality during storage. The native aquifer water contains high levels of iron and ammonia. The water recovered from the aquifer contained trace amounts of iron and low levels of ammonia, indicating that the perimeter of the injected water “bubble” was acting as a buffer area, mostly protecting the injected water within the bubble from blending with the native water. However, during storage the injected water would interact with minerals in the aquifer soil matrix that mobilized manganese and arsenic. Water recovered from ASR-1 contained manganese levels exceeding the aesthetic objectives, and arsenic levels exceeding the health-based maximum acceptable concentrations for drinking water. Typically, arsenic, manganese and ammonia levels in ASR systems decrease with continued injection and recovery of the wells. Short-term remediation strategies were proposed to address the elevated levels until they fall to drinking water standards.

At this time, it is anticipated that three ASR wells could be developed with a total recovery capacity of 27 L/s. A cost analysis concluded that the costs required to develop, cycle test, treat, and connect the ASR wells in the Kaye Road area to the ERWS bulk water system were significantly greater than the savings that could be achieved by reducing the Englishman River Water Treatment Plant by 27 L/s.

However, in Nanoose, wells near Claudet Road were identified as potential candidates for conversion to an ASR well system. If successful, the wells could be used to replace three conventional wells nearby that require treatment for manganese and ammonia removal. A capital cost analysis indicated that developing ASR wells at this location would provide a net saving over treating the native groundwater and would reduce the Englishman River Water Treatment Plant by 25 L/s.

Different water supply options were compared based on their cost of implementation versus the amount of water they could produce. This comparison, shown in the table below, illustrates that the Englishman River is the most economically feasible supply option examined, followed by an ASR system at Claudet Road. The cost of developing ASR at Kaye Road was significantly greater, but was still more economically feasible over using native groundwater supplies requiring ammonia and manganese removal. It is believed that there are other sites near the CoP and Nanoose where ASR could be implemented at more competitive costs than the Kaye Road site.

Water Source	Direct Capital Cost per Unit Capacity ($ million / ML/d)
Englishman River Water Treatment Plant (Phase 1)	0.63
ASR at Claudet Road	0.87
ASR at Kaye Road	1.33
Treatment for Nanoose Wells	1.82

It is recommended that the ERWS proceed with cycle testing an ASR pilot system at the Claudet Road site, and determine other potential sites that are close to existing water system infrastructure for future ASR development prior to further development near Kaye Road. While this work will not impact sizing of Phase 1 construction of the water treatment plant, additional ASR systems will supplement the existing water sources during periods of severe drought, and will delay the need to expand the treatment plant under Phase 2.

6 PROJECT BUDGET

Class 'C' estimates in 2014 dollars for the proposed river intake, water treatment plant, and related water system upgrades are shown below.

Item	Cost ($ million)	
	Phase 1 To 2016	Phase 2 2035-2050
Direct Costs		
Intake	1.7	0.1
Raw Water Pipeline	0.8	-
Water Treatment Plant	16.1	1.8
Water Distribution Mains (incl. Pump Stations and Reservoir Tie-ins)	5.5	3.7
ASR Development at Claudet Road	2.6	-
Subtotal	26.7	5.6
Contingencies – Design and Construction	6.7	1.4
Total Direct Cost	33.4	7.0
Indirect Costs		
Engineering	2.9	0.7
Administration	1.0	0.2
Miscellaneous	0.7	0.1
Total Indirect Cost	4.6	1.0
GST Allowance (5%)	1.9	0.4
Total Capital Cost	39.9	8.4
	48.3	

The accuracy of the cost estimates will improve as site specifics are more closely examined and infrastructure layouts become more detailed.

7 RECOMMENDATIONS

1. Treatment at the future Englishman River Water Treatment Plant should consist of coagulation and membrane filtration, followed by chlorine disinfection. Membrane filtration was demonstrated to consistently reduce turbidity levels to potable standards under various and rapidly changed raw water conditions. Coagulation is recommended to aid in the removal of true colour. Membrane filtration followed by chlorine disinfection is sufficient to achieve the required disinfection credits for microbiological control.

2. A full-scale ASR system at Kaye Road should not be pursued. The relatively thin aquifer and treatment requirements at this particular location result in a high capital cost for the amount of water produced. ASR at Kaye Road would seasonally reduce the amount of water that would be

withdrawn from the Englishman River, but the capital costs associated with this reduction do not offset the ASR development costs.

3. Cycle testing of an ASR pilot at Claudet Road should be pursued. This site could potentially reduce the groundwater treatment infrastructure required in Nanoose and produce a net saving in capital costs. Cycle testing is required to confirm aquifer storage characteristics and potential changes to the water quality during aquifer storage.

4. Opportunities for ASR at other locations should be pursued in the future. In addition to the Claudet Road site, there are multiple sites between Parksville and Nanoose where an ASR system in the Nanoose Creek Aquifer could be developed. These locations would be further from the water treatment plant but could tie in directly to the distribution system. The development of any future ASR systems in the ERWS water system would allow the ERWS to draw less water from the Englishman River during the summer, providing the ERWS an extra margin of safety during drought periods where Englishman River flows are low.

5. The ERWS should continue to acquire the required property and easements for the new intake and water supply mains. The updated conceptual design shows the approximate location of the future intake, new water supply mains and pump station to Nanoose. Discussions should be held throughout 2014 with property owners with a view to acquire the required properties and easements not already in possession by the ERWS.

6. Continue with the preliminary design of the Englishman River intake, The ERWS should proceed with the next stage of design to achieve their target completion date of 2016. The ERWS should continue dialogue with VIHA, the Ministry of Environment, and the Department of Fisheries and Oceans to keep the approval agencies current on the project's progression.

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1 Introduction

1.1 BACKGROUND

Water supply assessment and planning activities for the communities located within the Regional District of Nanaimo (RDN) on Vancouver Island have been on-going for nearly 40 years. The region is blessed with several sources of water including upland lakes and reservoirs typically as shared resources supporting industry, fisheries and hydroelectric generation. The region also has an abundance of groundwater aquifers.

Based on work performed in the early 1990's (Koers and Ford, 1992), the Englishman River was identified as a key element of a long term water supply strategy for the City of Parksville (CoP), the Town of Qualicum Beach (TQB) and the nearby Regional District areas.

1.2 ARROWSMITH WATER SERVICE

In 1997, the Arrowsmith Water Service (AWS) joint venture was formed between the CoP, TQB and RDN with the objective of securing a bulk water supply from a new intake on the Englishman River for the member communities to supplement existing and individually owned groundwater sources. The Province of British Columbia also recognized the value of this bulk water supply and supported the construction of Arrowsmith Dam at the headwaters of the Englishman River to increase Arrowsmith Lake storage and therefore improve base flows in the river for fisheries enhancements.

Since the late 1990's, the AWS has achieved a number of significant milestones identified in its bulk water supply plan, including:

- Securing a Conditional Water Licence (#110050) on the Englishman River for a maximum withdrawal of 48,000 m^3/day (1997).
- Developing a Provisional Operating Rule for the proposed new Arrowsmith Lake storage of 9,000,000 m^3 and use of existing City of Parksville river intake (1997).
- Commissioning Arrowsmith Dam (1999).
- Expanding the City of Parksville Englishman River Intake and Pump Station (1999).
- Constructing Nanoose Bulk Water Supply Main (2001).
- Commissioning Top Bridge Reservoir (2007).

To date, AWS has successfully operated this bulk water system. From 2000 to 2008 performance of the AWS system was monitored and the infrastructure was managed using tools such as updated AWS capital plans (Koers, 2008).

1.3 ENGLISHMAN RIVER INTAKE AND WATER TREATMENT PLANT – PHASE 1

In 2009, AWS decided to take a fresh look at the bulk water supply program for the Englishman River. This was precipitated by a number of new and emerging factors and issues:

- Since 2005, additional significant groundwater wells have been added in the Nanoose area and the City of Parksville.
- Population growth predictions needed to be updated to reflect changes in expected population growth and demographics.
- The previous design horizon of 2021 was less than 15 years away and needed to be extended to at least 25 to 50 years in the future for appropriate bulk water system planning.
- Several water conservation initiatives had been implemented in the bulk water system service area since 1995 reducing peak water demands.
- Vancouver Island Health Authority (VIHA) imposed a policy change to require enhanced drinking water treatment for surface water supplies like the Englishman River.
- The question of whether the large privately operated French Creek water system would be included or excluded in AWS future planning needed to be resolved.
- Hydrology modeling for the Englishman River, in support of the water licence application, was carried out in the early 1990's. Subsequent dry summers and the extended time period over which water had to be released from Arrowsmith Lake have presented difficulties in meeting low river flow targets specified in the Arrowsmith Dam provisional operating rule. The watershed hydrology needed to be revisited in light of these difficulties to determine how climate change might affect future yields from the watershed and to determine potential mitigative strategies.

In 2009 Phase 1 – Conceptual Planning, Budgeting and Scheduling was initiated to complete a broad and comprehensive study of potential river intake locations, water treatment requirements and associated infrastructure. The work conducted by Associated Engineering (Henney *et al.,* 2011) under Phase 1 included:

- Workshops with the various stakeholders, including environmental groups, approval agencies, forestry companies, and First Nations.
- Update of population projections, water demands, and available groundwater supply capacity.
- Multi-stage site evaluations looking at a 10 km reach of the Englishman River, including Triple-Bottom-Line (TBL) + Risk evaluations, and conceptual layouts of the plant and intake.
- Hydrogeological assessment of projected changes to river flows, including drought and climate change scenarios.
- Characterization of Englishman River raw water quality based on historical data.
- Preliminary water treatment options evaluation and conceptual level intake selection.

During Phase 1, the potential of Aquifer Storage and Recovery (ASR) was identified as a water resource management strategy that could effectively provide a new 'third' water source for the AWS. Hydrogeological work completed under Phase 1 concluded that there was indeed potential for ASR using the local aquifers.

1.4 ENGLISHMAN RIVER WATER SERVICE

Upon completion of the work in Phase 1, the Town of Qualicum Beach withdrew from the partnership to develop the bulk water supply system. As a result, the Englishman River Water Service (ERWS) was formed in 2011 as a joint venture between the City of Parksville and the RDN recognizing the need for additional water for these two partners by about 2016. The ERWS would continue the objectives of the AWS in developing a bulk water supply for its partners. The ERWS also retained a full time Program Manager to address the complexity and public educational needs of the water system. A seven-phase program was developed, with the upgrades to the bulk water supply system scheduled to be fully operational in 2016.

In 2011 the ERWS successfully acquired the property for the proposed site of the future water treatment plant. In 2013 the Ministry of Forests, Lands and Natural Resource Operations approved the proposed ERWS water license amendment to divert water via the future intake from upstream of Highway 19, as opposed to the current intake location downstream of Highway 19A.

1.5 PHASE 2 OBJECTIVES

In 2011 Phase 2 – Water Treatment Pilot Testing and Aquifer Storage and Recovery Feasibility was initiated, focusing on the following tasks:

- Examine the feasibility of ASR in one of three potentially suitable aquifer zones.
- Development of a 12-month comprehensive water quality monitoring program of the Englishman River to fill in gaps in the historical water quality data set.
- Develop and operate pilot scale simulations for the two most viable surface water treatment processes for the Englishman River.

Technical Report 1 presents the results of the first task. Technical Report 2 presents the results of these tasks, and updates the conceptual design of the proposed intake, water treatment plant, and related water system upgrades based on the results of the study.

1.6 REPORT FORMAT

Technical Report 2 provides a summary of the water quality monitoring program (Section 2), treatment process piloting (Section 3), and the ASR piloting program (Section 4). An update to the conceptual plan proposed in Phase 1 is then provided (Section 5). The report concludes with recommendations for long term planning (Section 6) and more immediate “next step” tasks (Section 7).

Technical Report 2 is written as a stand-alone document that provides the reader with a general overview of the work completed under Phase 2. For the reader wishing additional detail, the technical memoranda detailing the water quality monitoring and treatment process piloting programs are appended to this report. Details of the ASR exploration program are provided in Technical Report 1.

2 Water Quality Monitoring Program

2.1 OBJECTIVE

As part of Phase 1 an assessment of the Englishman River was made using the data available from federal, provincial, and municipal monitoring stations, published river assessment reports, and from the ERWS monitoring logs for an approximate 10 km stretch of the river. A 12-month monitoring program was recommended to fill in the following gaps in the data set:

- Measure key water quality parameters that had been measured infrequently in the past.
- Determine changes in key water quality parameters under different seasonal conditions.

The monitoring program was developed by Associated Engineering and executed by the ERWS from September 2011 to August 2012. Continuous sampling equipment was positioned at the existing intake and chlorination facility, while manually collected samples were taken along the proposed reach of the river where the new intake will be installed. Details of the monitoring program can be found in Technical Memorandum WQ1 (Appendix A).

2.2 WATER QUALITY CHARACTERIZATION

Based on the results of the monitoring program, the following characterization of the Englishman River can be made:

- The water has low alkalinity, common for Vancouver Island surface waters.
- Turbidity remains below 5 NTU under typical river conditions.
- A general increase in the average turbidity occurs during the winter and spring.
- The river experiences periodic turbidity spikes that can occur quickly and unexpectedly throughout the entire year.
- Although occurring in all four seasons, the intensity and frequency of the turbidity spikes are greatest in the winter.
- The source of turbidity appears to be sediment released along the riverbank. High loading from this source can occur during periods of heavy rainfall or when parts of the riverbank erode and collapse.
- When a particularly intense turbidity event occurs, an increase in metals such as iron, manganese, and aluminum can be observed. Organic concentrations may also increase.
- A lull in turbidity events was observed in an unusually dry period of the winter; however, a direct relationship could not be defined between heavy rainfall or river flow and turbidity events.
- True colour concentrations exceeded treatment objectives regularly throughout the year, with no apparent relationship to season, precipitation or river flows. Monitoring during treatment system piloting found that colour levels tended to coincide with rises in turbidity.
- Under typical raw water conditions the majority of colour was from dissolved substances. During turbidity events, the apparent colour was primarily from suspended particles.
- Organic concentrations increased during the summer, accompanied by a proportional decrease in Ultraviolet Transmittance (UVT).

- Total coliform and *Escherichia coli* (*E. coli*) counts were also greater in the summer.
- Total Dissolved Solids (TDS) concentrations, hardness, pH, and conductivity decreased during the winter.
- A slight increase in aluminum concentrations was observed in the winter.

2.3 TREATMENT REQUIREMENTS

The monitoring program provided a more complete profile of the Englishman River water quality, and confirmed that the following water quality parameters will need to be addressed by treatment to meet potable standards:

- Turbidity: less than 1 NTU in the distribution system. Further requirements based on treatment).
- True colour: less than 15 TCU .
- Spikes in suspended metals during turbidity events.
- Iron: less than 0.3 mg/L.
- Manganese: less than 0.05 mg/L.
- Microbiological parameters associated with surface water:
  - A minimum 3-log (99.9%) removal or inactivation of *Cryptosporidium parvum.*
  - A minimum 3-log (99.9%) removal or inactivation of *Giardia lamblia*.
  - A minimum 4-log (99.9%) removal or inactivation of viruses.

All of these parameters can be addressed using a combination of filtration and disinfection as treatment.

The filtration avoidance criteria were reviewed to determine whether filtration of Englishman River water could be deferred past 2015. Part of the criteria as defined by Health Canada and by the BC Ministry of Health requires that turbidity not exceed 5 NTU for more than two days in a 12-month period, and that E. coli levels never exceed 20 counts/100 mL in the raw water. The Englishman River does not satisfy either of these criteria, and therefore an application for filtration deferral would likely be rejected.

Additional turbidity objectives are applied to surface water treatment plants that are dependent on the type of technology used for particulate removal, defined as follows:

- For chemically-assisted filtration, that is, filter beds that use media such as anthracite/sand, treated water levels must be 0.3 NTU or less in at least 95% of all monthly measurements made, and never exceed 1.0 NTU.
- For slow sand or diatomaceous earth filtration, treated water levels must be 1.0 NTU or less in at least 95% of measured samples and never exceed 3.0 NTU.
- For membrane filtration, treated water effluent must be 0.1 NTU or less in at least 95% of monthly measurements made and never exceed 0.3 NTU.

3 Pilot Testing Program

3.1 INTRODUCTION

As the characteristics of each water source are unique, reduced scale physical testing of the particulate removal processes was desired to determine their performance specific to the Englishman River. Bench-scale tests were conducted first to confirm the viability of the treatment process, while larger, pilot-scale tests were run to determine details on treatment performance, such as identify unanticipated reactions, chemical consumption rates and energy requirements, and response to varying raw water conditions. Details of the pilot testing program are provided in the report *"Treatability Testing of Englishman River Water"* (Appendix B).

3.2 PROCESS SELECTION

Table 3-1 lists the treatment process options that were identified during Phase 1 and the maximum influent turbidity tolerated by these processes. If these processes are run beyond these turbidity limits, maintenance requirements may increase and the quality of treated water can be negatively impacted. In general, processes with a lower maximum treatable turbidity level tend to have lower capital or operating costs than their more robust counterparts. Figure 3-1 contrasts these turbidity tolerances to the turbidity collected during the monitoring program.

Table 3-1
Influent Turbidity Tolerance of Selected Processes

Process	Maximum Turbidity Tolerance (NTU)	Percent of Raw Water Data Exceeding Maximum Tolerance [2]
In-Line Filtration	10	10 – 15 %
Direct Filtration	25	4 - 5%
High-Density Membranes	50	1 - 2%
DAF	100	< 1%
Low-Density Membranes	>100	0%
Conventional Treatment [1]	>100	0%
Actiflo [1]	>100	0%

Notes:
1- Coagulation, flocculation, sedimentation and filtration.
2- Percent annual exceedances of maximum turbidity tolerances, based on the turbidity data collected during the monitoring program.

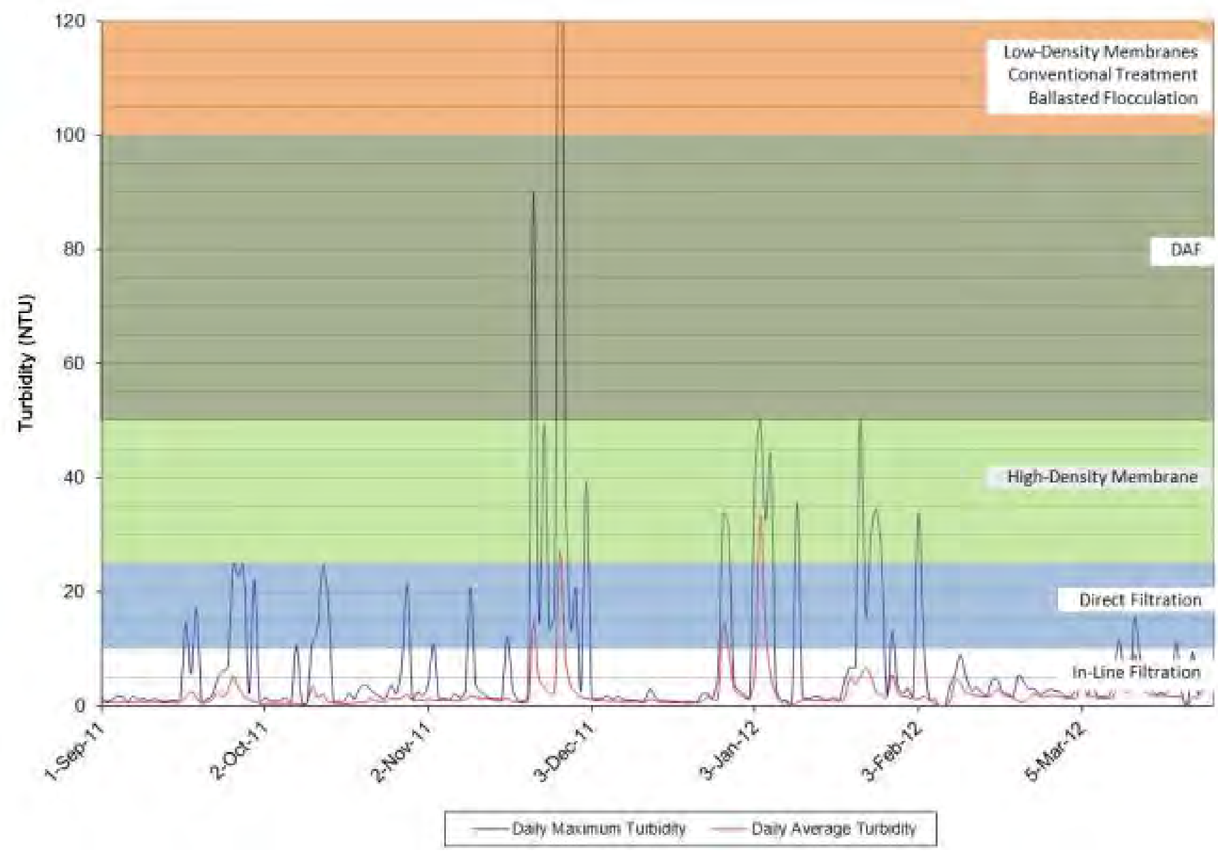

Figure 3-1 - Englishman River Turbidity, 2011/2012

3.2.1 Operational Considerations

The new treatment plant could be operated in a similar manner as the existing intake and chlorination facility, that is, the plant would temporarily shut down when a turbidity spike exceeds the maximum turbidity level for a given treatment process. However, the ERWS will be increasingly challenged to meet the population's growing water demands using only their groundwater and reservoir supplies, particularly if multiple turbidity spikes occur in a single week. In addition, if ASR is incorporated into the overall bulk water system, the new treatment plant will need to provide a large volume of water to the ASR system during the winter to ensure adequate reserves are available for summer demands. In this scenario the new treatment plant would need to run regularly and would not have significant flexibility to allow shut downs due to turbidity spikes. Therefore, it is recommended that the treatment processes that cannot efficiently treat a minimum turbidity event of at least 50 NTU, namely in-line filtration, direct filtration, and high-density membrane filtration not be considered further.

Another way of managing the turbidity spike would be to construct a raw water reservoir. A few days of raw water storage may reduce the turbidity spikes entering the water treatment facility therefore allowing low-turbidity tolerant processes such as in-line or direct filtration viable. However, raw water reservoir construction costs and algae control related operating issues may negate the benefit of a raw water reservoir. Limited site availability and hydraulic considerations would also be a challenge, and therefore the construction of raw water reservoirs were not considered further for this application.

3.2.2 Ballasted Flocculation

Ballasted flocculation treatment systems like Actiflo® are effective for very turbid waters because particulates agglomerate to the heavy particle carriers that are injected into the water after coagulation. Actiflo® is capable of adopting swiftly to pre-treatment chemical dose regime changes due to sudden high turbidity spikes. However, with the exception of the short-lived, elevated turbidity events, Englishman River turbidity is typically below 5 NTU. For these normally low turbidity raw water conditions, ballasted flocculation technology would be excessive and overly intensive. The injection and subsequent removal of the particle carriers would translate to higher capital, and operation and maintenance costs than necessary. Therefore ballasted flocculation is not recommended for this application.

3.2.3 Dissolved Air Flotation (DAF)

Dissolved air flotation (DAF) is typically used to remove particulates that do not readily settle, such as particles containing algae or natural organic matter. However, the main source of turbidity in the Englishman River comes from riverbank erosion. This type of sediment generally settles more readily than floats.

Parallel to this piloting work, Associated Engineering had piloted a DAF unit to treat water from the South Fork Reservoir for the City of Nanaimo. South Fork water quality is similar to the Englishman River, particularly in terms of the low alkalinity, which impedes flocculation, although South Fork water contains traces of algae and has turbidity spikes only in the order of 25 to 50 NTU. It was determined that the DAF pilot had difficulty forming a suitable floating floc and could not readily adjust to sudden changes in water quality. Based on these experiences it was recommended to not pilot a DAF system. However, a bench-scale DAF test was undertaken for the ERWS to confirm the floatable nature of the water.

3.2.4 Dual-media Filtration

It was anticipated that conventional treatment, using sedimentation and granular media filters, would have difficulty operating effectively due to the low alkalinity and sudden changes in raw water quality. Experience with similar pilots suggested that these two factors also contribute to shorter run times before the filters require backwashing. However, if viable, conventional treatment can be implemented at a lower capital cost than low-density membranes. Therefore it was decided to pilot conventional treatment.

3.2.5 Membrane Filtration

Membrane filtration offers the advantages of being able to remove high levels of turbidity and to continue operating effectively when a sudden change in feed water quality occurs. The potential vendors for membrane piloting have indicated that their membranes could adequately treat the turbidity spikes in the

Englishman River without any form of chemical/physical pre-treatment by using only microscreens as pre-filtration. However, pre-treatment would be required to reduce true colour levels. It was decided to pilot a membrane unit.

3.2.6 Final Pilot Selection

Conventional treatment and membrane filtration were selected for piloting. The anticipated challenges for conventional treatment were the low-alkalinity of the water inhibiting the formation of suitably-sized floc, and the ability of conventional treatment to adjust to sudden changes in raw water quality. The anticipated challenge for membrane filtration was finding a suitable chemical additive upstream of the membranes to assist with the removal of colour.

3.3 BENCH-SCALE TESTING

3.3.1 DAF Results

Bench-scale simulations of the DAF system (Figure 3-2) were conducted using a range of aluminum chlorohydrate coagulant doses. All of the simulations failed to produce a floating floc to remove. Therefore, DAF was deemed not a suitable treatment option for the Englishman River.

Figure 3-2 - DAF Bench-Scale Apparatus

3.3.2 Pre-oxidation for Colour Removal Results

Raw Englishman River water was dosed with either potassium permanganate ($KMnO_4$) or hydrogen peroxide (H_2O_2) at the bench-scale level to determine whether pre-oxidation would be an effective means to reduce colour concentrations upstream of the membranes. Potassium permanganate was able to achieve some reduction in colour levels, while hydrogen peroxide had no significant impact. Neither oxidant was able to reduce true colour concentrations to below the aesthetic objective of 15 TCU.

It was concluded that pre-oxidation was not an effective method for removing colour from Englishman River water.

3.3.3 Coagulants for Colour Removal

Conventional coagulants and polymers are not recommended for use with membranes as the chemicals can rapidly foul the membranes and reduce their performance. The membrane pilot vendor approved the use of two aluminum chlorohydrate (ACH) coagulants. These two coagulants were first tested at the bench-scale level to gauge their impact on colour. Both coagulants achieved a significant reduction in true colour concentrations. One of the coagulants (Isopac 80) successfully reduced colour levels to well below the 15 TCU aesthetic objective. Further reduction is anticipated to occur when the chemically-enhanced floc reaches the membranes. It was therefore recommended to use ACH upstream of the membranes for colour removal.

3.4 PILOTING

The pilot was stationed at the existing Englishman River intake. Piloting was conducted from November of 2011 to February of 2012, with the intent of testing the treatment processes under the worst raw water conditions, where turbidity events were historically the most frequent and the most intense.

3.4.1 Conventional Treatment

Process Description

The conventional treatment pilot consisted of coagulation, flocculation, sedimentation and media filtration. For the coagulation step a variety of coagulants and coagulant aids were tested throughout the course of piloting to determine the best combination of additives to produce a removable particulate floc. Table 3-2 lists the different chemicals that were tested. Two media configurations were run in parallel for the filtration process. The first filter column contained a dual media mix of anthracite on top of sand. The second column was a mono-media of anthracite. Pictures of the conventional treatment pilot are shown as Figures 3-3 and 3-4.

Table 3-2
Chemicals Trialed for Conventional Treatment Pilot

Name	Chemical Type	Tested Doses (mg/L)
Aluminum sulphate (Alum)	Coagulant	5 – 60
Polyaluminum chloride (PACL)	Coagulant	10 – 40
Aluminum chlorohydrate (ACH)	Coagulant	10 – 40
Soda ash	Coagulant aid	0 – 20
Anionic polymers – proprietary	Coagulant	0.1 – 0.2
Cationic polymers – proprietary	Coagulant	0 – 0.2

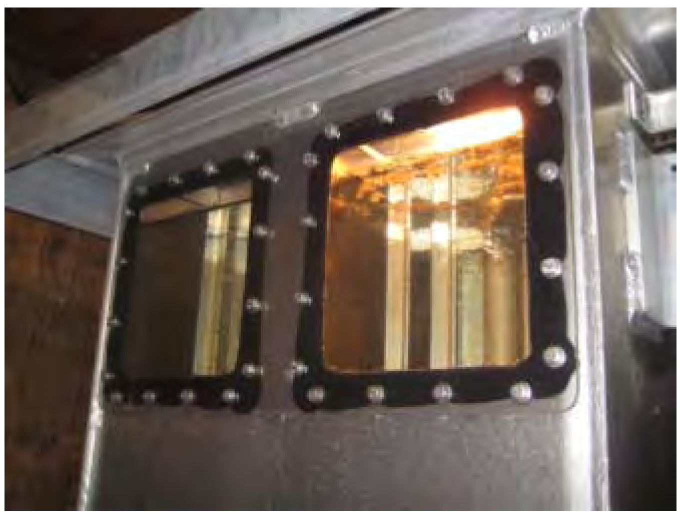

Figure 3-3 - Conventional Treatment Pilot – Flocculation/Sedimentation Basin

Figure 3-4 - Conventional Treatment Pilot – Filter Columns

Performance

For conventional treatment, it is generally desired for water leaving the coagulation/flocculation/ sedimentation (pre-treatment) process to achieve a turbidity of 2 NTU or less before entering the filters. When raw water turbidity was low, the pre-treatment processes struggled to form significant floc that would settle. Conversely, during a turbidity event, larger floc would form but not enough to reduce pre-filter turbidity to below 2 NTU because the pre-treatment processes could not adjust rapidly enough to sudden changes in turbidity levels. The pre-treatment system performed best when raw water turbidity was between 5 and 15 NTU.

The dual-media and mono-media filters performed similarly to each other, achieving similar levels of turbidity removal and having similar length filter runs. The filters were found to perform poorly. The unit filter run volumes (UFRV) were low, meaning that a relatively small volume of water could be treated by the filters before the media would require to be taken offline for backwashing. UFRV values for the pilot ranged from 125 m^3/m^2 to 174 m^3/m^2, below the minimum desired UFRV of 200 m^3/m^2. Filter backwashing had to be done frequently to prevent rapid filter breakthrough.

The filters could not consistently achieve the “chemically assisted filtration” objectives of lowering filter effluent turbidity to 0.3 NTU or less 95% of the time, and turbidity regularly exceeded the maximum turbidity objective of 1.0 NTU.

Poor filter performance was attributed to the difficulty of the pre-treatment processes producing sufficiently large floc for settling or filtration. This is in turn is attributed to the low alkalinity of the Englishman River and the rapid changes in turbidity during an event that the conventional treatment system could not respond to. Based on the results of the pilot study, conventional treatment does not appear to be able to reliably treat Englishman River water to potable standards.

3.4.2 Membrane Filtration

Process Description

A pressurized membrane system was used to pilot membrane performance for the Englishman River. The pilot consisted of pre-filtration using bag filters to remove large particles, followed by coagulation using ACH and membrane filtration. Figure 3-5 shows a photo of the membrane filtration pilot.

Figure 3-5 - Membrane Pilot

Performance

The membrane piloting program was divided into two Cycles. In Cycle 1, the membrane was run while testing different settings for filtrate flux, filtered water recovery, cleaning frequency, and cleaning intensity to determine the optimal combination of these parameters for an efficient membrane system. Cycle 1 ran from November 2011 to January 2012.

In Cycle 2, the membrane was run with only the pre-treatment coagulant dose being varied to test the pilot's ability to remove colour and to determine the impact of coagulant dose on filter run length before the membrane would require cleaning. Cycle 2 ran from January to February of 2012.

The results of Cycle 1 demonstrated that the membranes could consistently reduce turbidity to potable water objectives. During Cycle 1 Englishman River turbidity varied from less than 1 NTU to 100 NTU, and in Cycle 2 turbidity varied from less than 1 NTU to 66 NTU. While turbidity events would often cause the membrane to perform a 30-minute auto-cleaning (Enhanced Flux Maintenance) more frequently, filtered water turbidity continued to meet potable water objectives: Filtered permeate water from Cycle 1 and 2 had a turbidity of 0.01 NTU or less in 99% of all measured samples.

Without a coagulant, the membranes were not able to reduce true colour levels to 15 TCU or less. The addition of ACH achieved a reduction in true colour levels in the membrane permeate. The level of removal appeared proportional to the coagulant dose provided, that is, a higher dose of ACH was needed as raw water colour levels increased, with 5 mg/L of ACH being able to capably treat raw water colour levels of up to 30 TCU.

The addition of ACH also improved the UV Transmittance (UVT) of the water and lowered the formation potential of disinfection byproducts. However, it should be noted that actual disinfection byproduct formation of unfiltered Englishman River water, as measured in the City of Parksville distribution system, is already well below maximum safety thresholds.

The greatest vulnerability of the membrane pilot was the pre-filtration step. The bag filters would typically become clogged and need replacement during the turbidity events. In the full scale system, this can be addressed by implementing self-cleaning screens as part of membrane pre-filtration.

3.5 CONCLUSIONS

The recommended treatment process for the Englishman River is a membrane system, consisting of pre-filtration, coagulant addition in the form of ACH, and membrane filtration. A pressurized membrane system was piloted, and based on piloting of similar waters on Vancouver Island, it is anticipated that a submerged membrane system would perform similarly. It is projected that an ACH dose of 5 to 10 mg/L will be required under typical operation.

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The membrane system will provide the removal credits required for *Cryptosporidium* and *Giardia* inactivation. It is recommended that the membrane system be followed by a chlorination system to achieve the required destruction of viruses and to provide chlorine residual in the distribution system. It is assumed that the ERWS will apply an average chlorine dose of 0.8 mg/L, as is currently used at the existing intake.

4 Aquifer Storage and Recovery Feasibility Analysis

Aquifer Storage and Recovery (ASR) is the process of injecting and storing treated water in an aquifer, and withdrawing this water at a later date. Creating this underground reservoir of treated water would provide the ERWS a “third” water source in addition to the Englishman River and their groundwater supplies. In this concept, as illustrated in Figure 4-1, treated water from the Englishman River would be treated and injected into a suitable aquifer during the winter months when a surplus of water is available in the river. This would then be withdrawn from the aquifer during the dry summer months and pumped into the water distribution system. While all the water still comes from the Englishman River, ASR could allow the ERWS to change the timing of their water withdrawals and lessen the amount of water needed from the river during periods of drought. The intake and water treatment plant would be operated at a more constant rate through the year, reducing both the needed capacity and cost of the water treatment system.

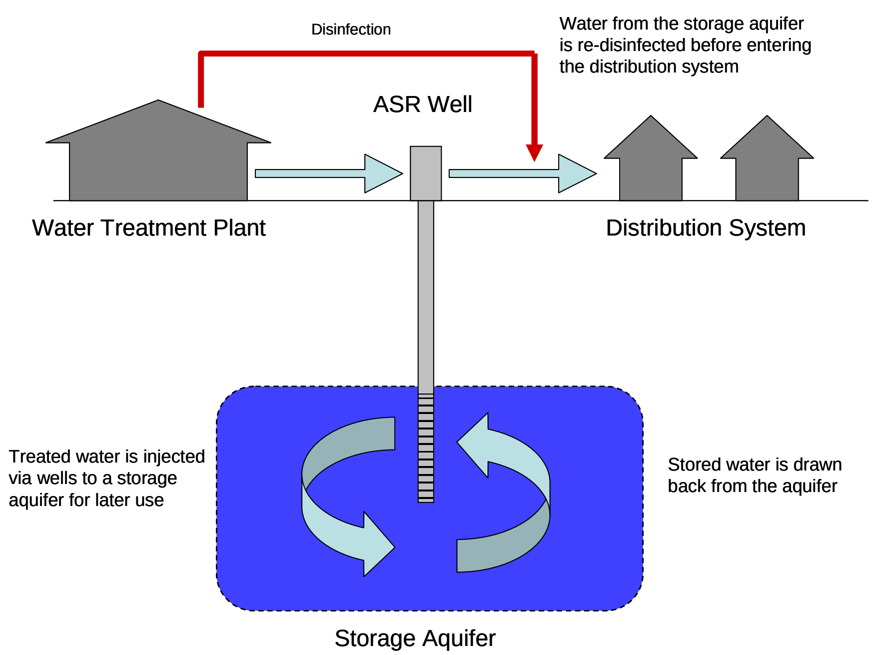
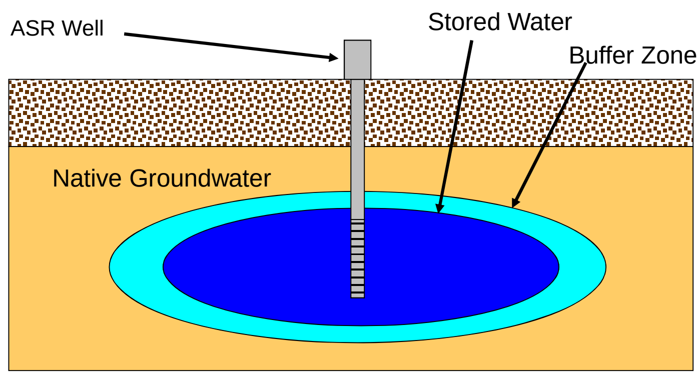


Figure 4-1 - ASR Process Diagram

Most of the water injected into the ASR aquifer remains in an isolated “bubble”, as schematically shown in Figure 4-2. When this water is recovered it typically does not need additional treatment except for secondary disinfection to re-establish a chlorine residual. However, post-ASR treatment requirements need to be determined on a case-by-case basis.



Buffer zone remains through each injection/recovery cycle. Once the buffer zone is established, new stored water does not interact with native groundwater

Figure 4-2 - ASR Stored Water Concept

4.1 ASR LOCATION

The key to the ability to implement ASR are the right series of conditions. First there needs to be a situation where surplus water is available part of the year and peak water demands occurring at a different time. For the ERWS, there is abundant water to be withdrawn from the Englishman River during the winter, when river levels are high and water demands are low. Second, suitable aquifer conditions must exist. Generally, the most favourable site is in a semi-confined aquifer that exhibits surplus storage capacity. A desirable aquifer should have an underlying horizontal confining layer as well as an overlying layer that prevents contamination from surface infiltration. The aquifer should also exhibit moderate lateral permeability to reduce mobility of the water bubble.

As part of Phase 1, thirteen aquifers in the ERWS region were identified and evaluated for their suitability for an ASR system. Five of the thirteen aquifers scored more than 50 points out of a 100 in the evaluation criteria scoring system, indicating that there are a number of potentially viable locations for ASR in the area. The most suitable candidate is the Nanoose Creek Aquifer, located between Parksville and Nanoose, with three particular areas within the aquifer identified as preferred locations. The Nanoose Creek Aquifer and the three areas are shown in Figure 4-3.

As part of Phase 2 the decision was made to focus on the western-most area of the aquifer, closest to the proposed water treatment plant site. An advantage of this area of the Nanoose Creek Aquifer is that it is accessed by relatively few wells. The drawback is that the aquifer was therefore not comprehensively mapped out. Therefore, the aquifer was better delineated using existing well records, air and satellite photos, and site investigations. Cross-sections were developed, an example section perpendicular to the Englishman River shown in Figure 4-4. The target aquifer sits on a relatively flat section of till and bedrock.

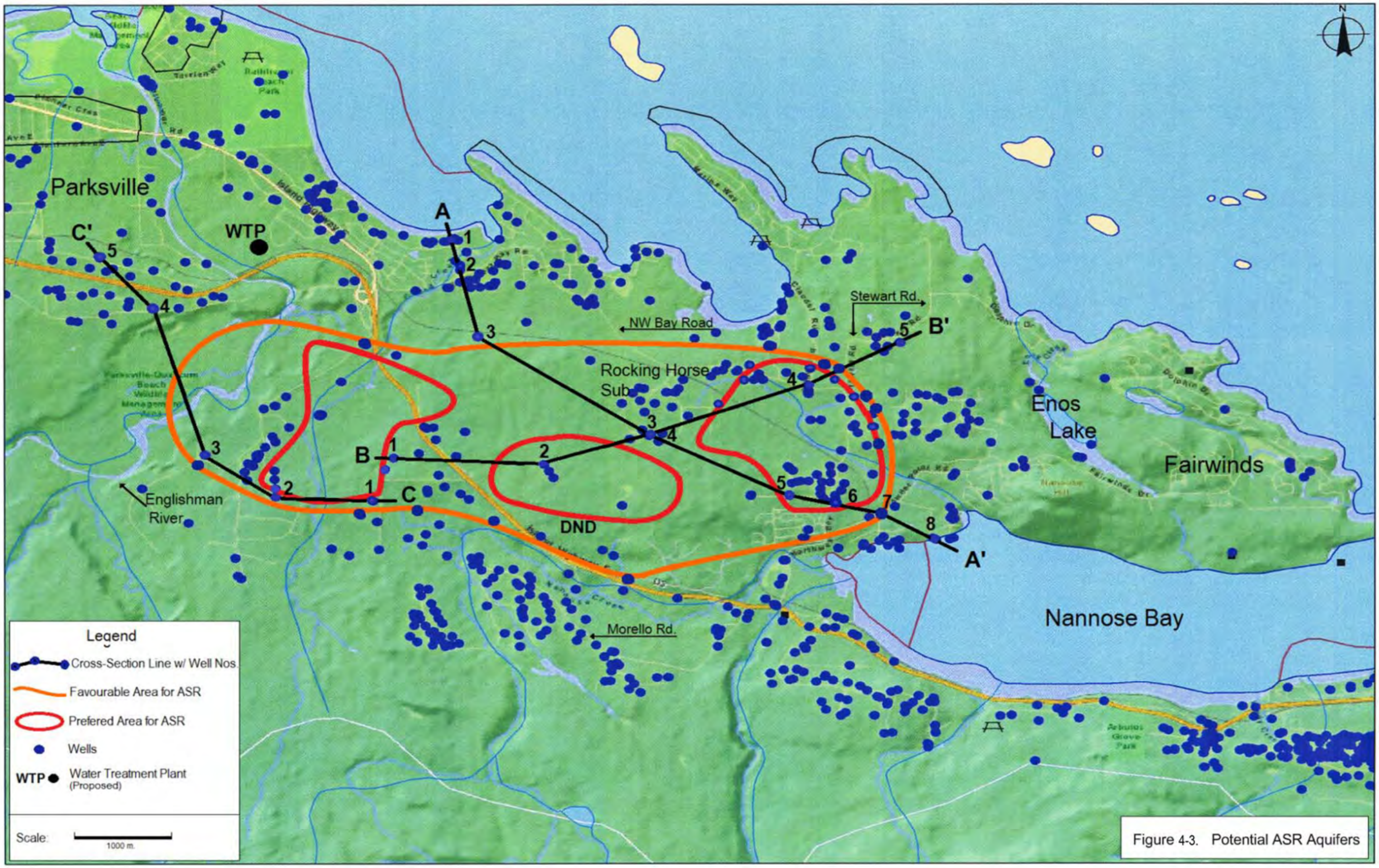


Figure 4-3. Potential ASR Aquifers

Above it is a confining layer of clay and silt, on top of which is an upper aquifer, hydraulically isolated from the lower aquifer.

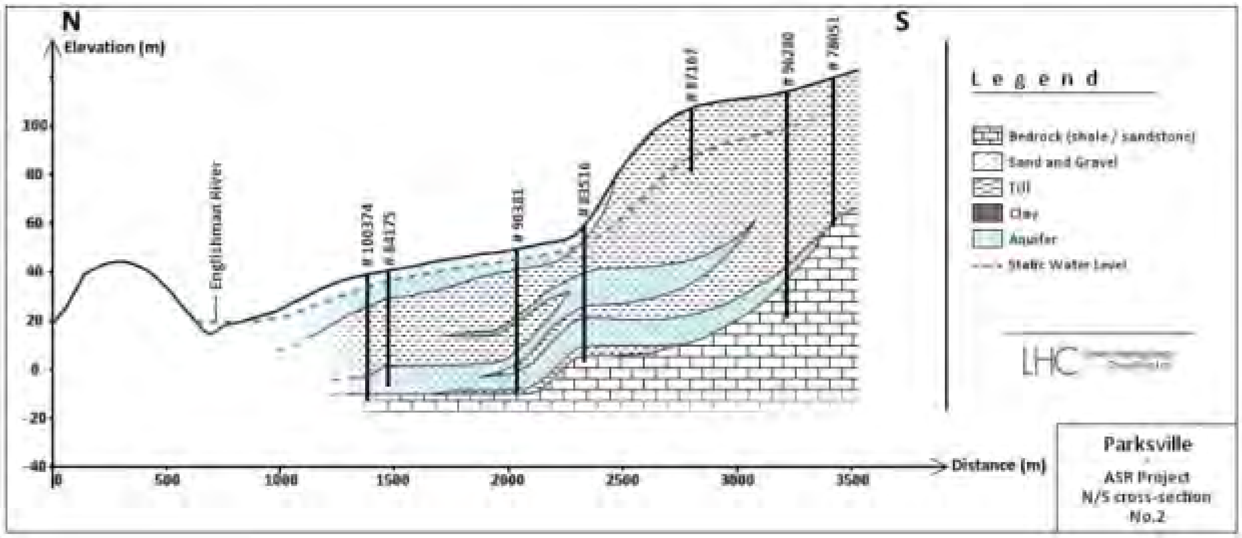


Figure 4-4 - Example Cross-section of the Nanoose Creek Aquifer

With a preliminary profile of the Nanoose Creek Aquifer completed, sites were selected to develop test wells. Test well location selection was based on anticipated aquifer capacity, land ownership, and access to power. The test wells were used to confirm geological conditions and aquifer characteristics such as aquifer thickness, static water levels, hydraulic conductivity and the presence of boundary conditions. The location of the optimal test well was used to drill the ASR pilot well, labelled ASR-1. ASR-1 was developed near test well DS-3, on Kaye Road just south of the Parksville weigh scale. Details on the test wells are provided in Technical Report 1. Figure 4-5 shows an updated model of aquifer thickness across the Nanoose Creek Aquifer based on data collected for this report.

4.2 ASR PILOT TESTING

4.2.1 Capacity

After development and an initial pump test, cycle testing of the pilot well ASR-1 was conducted. The cycle tests simulate the injection and recovery steps, and condition the aquifer for larger injection and recovery operations. Two cycle tests were conducted at ASR-1:

- *Cycle Test 1:* a small volume (22,000 m^3) of water was injected into the aquifer and 5600 m^3 (25%) of the water was pumped back out of the well. The objective was to determine whether the ASR concept was conceptually feasible, gauge the capacity of ASR-1, identify any critical geochemical reactions between injected and native groundwater, and to determine whether the “bubble” of injected water could be reasonably recovered.

- *Cycle Test 2:* a larger volume (67,000 m^3) of water was injected into the aquifer and 37,000 m^3 (57%) of the water was recovered. The objective was to test the integrity of the injection "bubble" in terms of dispersion/recovery and in terms of maintaining a consistent water quality, to improve injection/withdrawal capacity, to gauge operational requirements over a longer operating cycle, and to expand the injection "bubble" to the Target Storage Volume should the well be used in a full-scale ASR system in the future.

For Cycle Test 1, the sustainable injection rate was 9 L/s and the recovery rate was 5 L/s. A common operational challenge for ASR systems is that, over time, material will accumulate on the well screen and begin to clog passage into the well, resulting in an increase in wellhead pressure during injection and a drop in water level inside the well casing during recovery. This was observed at ASR-1. When either pressure or casing water level exceeded a defined threshold, a backflush was triggered. The backflush consisted of reversing flow through the well for a period of 30 to 120 minutes to dislodge the material accumulating on the screen. During Test Cycle 1, backflushing was conducted in ASR-1 on an average of every two to three days during injection.

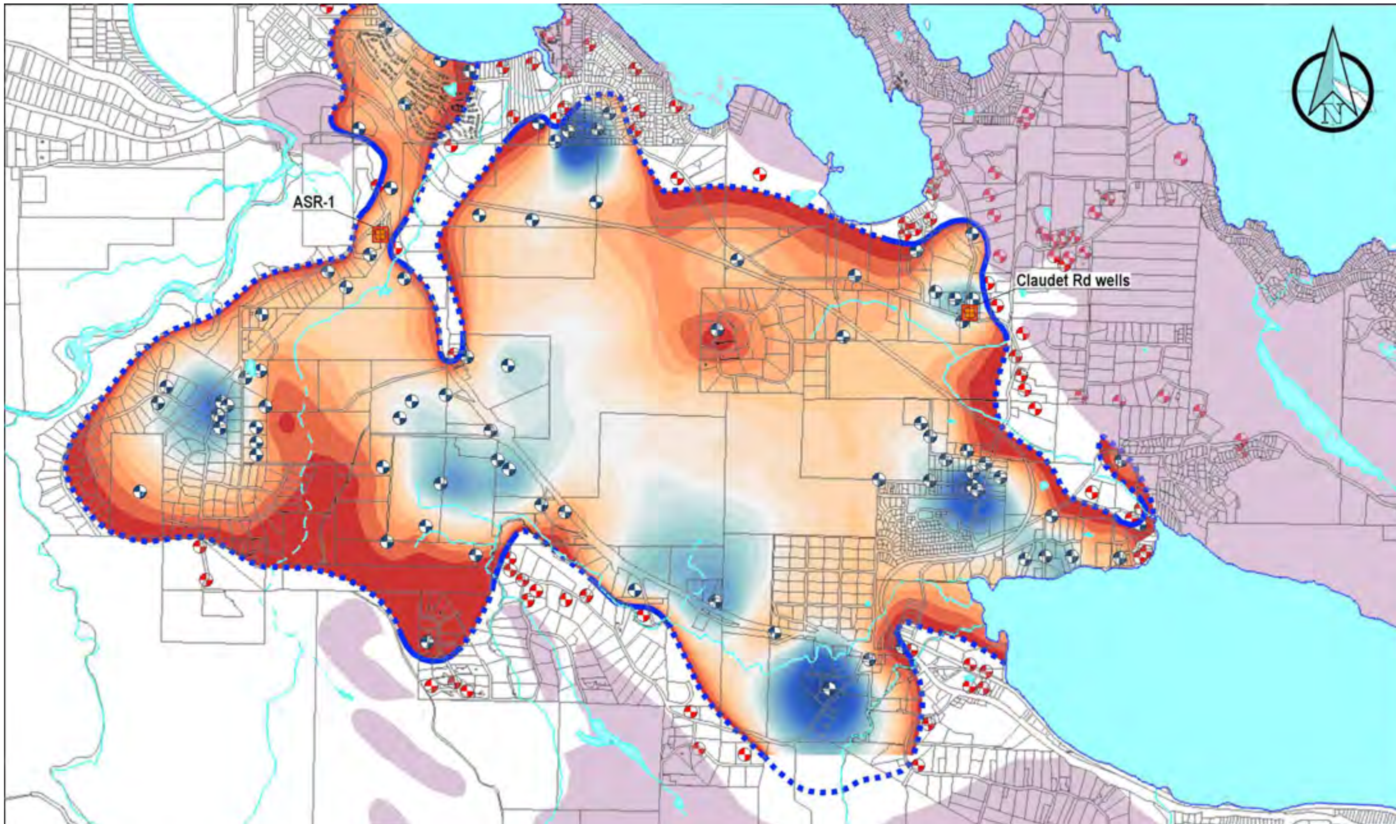
In general, it is anticipated that the injection and withdrawal capacity of an ASR system are at their lowest during the initial few cycles and improve with subsequent cycles. This was found to be the case for ASR-1, where system performance during Cycle Test 2 improved over Cycle Test 1. The Cycle Test 2 sustainable injection rate was increased to 10 L/s and the recovery rate to 8 L/s. The data indicates that recovery could have been sustainably increased to 9 L/s.

4.2.2 Water Quality

A summary of key parameters during the cycle testing process are provided in Table 4-1. The key parameters that will have an impact on the treatment of recovered ASR water are arsenic, manganese, and ammonia.

Table 4-1
ASR Cycle Testing Water Quality Summary[1]

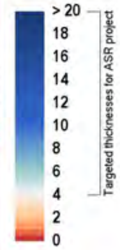
Parameter	Drinking Water Objective	Native Aquifer[2]	Injected Water Quality	Recovered Water Quality	
				Cycle Test 1[3]	Cycle Test 2
pH	6.5 – 8.5	8.4	7.3	7.6	8.1
Turbidity (NTU)	< 1	12	0.2	0.3	0.1
Total Arsenic (mg/L)	< 0.010	0.003	0.0003	-	0.031
Total Iron (mg/L)	< 0.3	2.9	0.01	0.009	0.003
Total Manganese (mg/L)	< 0.05	0.76	0.002	0.10	0.11
Nitrate (mg/L as N)	< 10	0.2	0.8	0.09	< 0.02



LEGEND

Aquifer mapping

Lower aquifer thickness (m.)



Aquifer boundary
High degree of confidence

Aquifer boundary
Low degree of confidence

Water well
Included

Water well
Excluded

Surface water

Bedrock outcrop

Cadastral

Scale

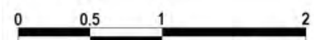


Figure 4-5. Depth Profile of the Nanoose Creek Aquifer

Electoral Area E / G
City of Parksville / Nanoose Bay, B.C.

05/11/2013
File No.: 1306
Drawing: MD
Review: DL

Lowen Hydrogeology Consulting Ltd.

NOTES

Kriging interpolation was used in this model. Manual corrections were applied where necessary.

KEY MAP

Parameter	Drinking Water Objective	Native Aquifer[2]	Injected Water Quality	Recovered Water Quality	
				Cycle Test 1[3]	Cycle Test 2
Total Dissolved Solids	< 500	249	205	197	242
Dissolved Sulphate (mg/L)	< 500	6	7	24	15
Ammonia (mg/L as N)	-	0.6	< 0.005	0.05	0.2

Notes:

1 – For brevity of presentation, parameters in table are averages of multiple measurements.

2 – Native groundwater as measured at ASR-1, MW-1, and MW-2 prior to ASR injection via bailer samples.

3 – Due to short duration of the Cycle Test 1 recovery phase, all parameters except turbidity and pH are based on one grab sample taken October 1, 2013.

The native aquifer into which ASR injection occurs is high in iron and manganese, exceeding the AO for iron (0.3 mg/L) and manganese (0.05 mg/L). Water recovered from the ASR system had iron levels well below the AO, indicating that the buffer zone was effective at preventing iron from entering the stored water "bubble". However, manganese concentrations, while reduced, still exceeded the AO. As shown in Figure 4-6, manganese concentrations were observed to gradually decrease with continued pumping.

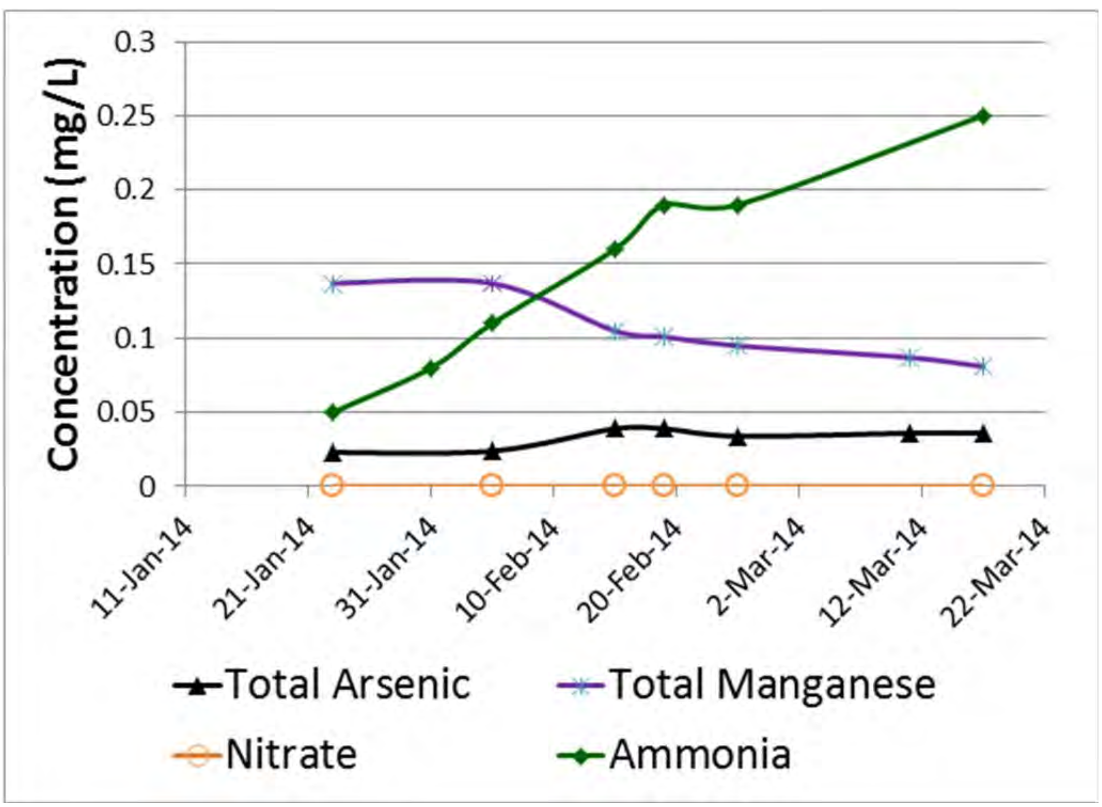


Figure 4-6 - Cycle Test 2 ASR Recovered Water Quality

Total arsenic concentrations were close to non-detectable in the native aquifer, but were present at levels exceeding the MAC of 0.010 mg/L in the recovered water.

Ammonia concentrations in the recovered water were several times less than levels observed in the native aquifer. However, as shown in Figure 4-6, a gradual increase in ammonia concentrations was observed as the ASR recovery stage progressed. Ammonia is not a potable water concern in terms of health impacts or even aesthetic appeal, but is significant to treatment in it that in can exhibit a high chlorine demand. It is projected that up to 1.8 mg/L of free chlorine may be required to overcome the ammonia demands near the end of the recovery phase.

It is believed that the metals are leaching from the matrix in this area of the aquifer. Minerals in the aquifer that stabilized when exposed to native groundwater reacted with the exposure to water of a different quality. The leaching is believed to occur predominantly near ASR-1, where the injected water still contains a chlorine residual and a greater level of dissolved oxygen. Based on the performance of ASR systems elsewhere in North America, such as Florida, it is anticipated that the concentrations of these parameters will decrease with each injection/recovery cycle or as the ASR buffer zone increases. To decrease arsenic and manganese to potable standards, it is proposed to execute multiple short-term injection and recovery cycles and to inject additional water into ASR-1 to expand the buffer zone. Should this not fully remediate the situation, a temporary treatment facility is proposed to remove arsenic and manganese from the recovered water. A more detailed discussion on the water quality changes and possible remediation strategies are provided in Technical Report 1.

4.2.3 Ultimate Siting

Based on the results of the cycle tests and aquifer exploration, a conservative projection of a fully developed ASR system in this area would consist of three to four ASR wells parallel to Kaye Road, each producing an average yield of 9 L/s. The shape of the aquifer would allow an additional four ASR wells to be developed further south, in River Edge, provided that property within the community could be secured as well sites. It is assumed that wells within the River Edge area would not be used for potential ASR development.

4.3 CLAUDET WELL

In parallel to the work at Kaye Road, a well site along Claudet Road in Nanoose that also accesses the Nanoose Creek Aquifer was investigated as a potential ASR site. Initial pump tests suggest that an ASR system consisting of a single well could be developed here with a 15 L/s capacity and 255,000 m^3 of available storage. Cycle testing has not been done at this site. The three Nanoose wells located nearby, currently producing elevated levels of manganese and ammonia, were also flagged as potential ASR candidates. No recent pump testing has been done to confirm this assessment, but it is estimated that two to three of these wells could be converted into ASR wells, each with a 10-15 L/s capacity.

5 Implications on Stage 1 Conceptual Planning

In this section the conceptual plan for the ERWS bulk water system was updated and the viability of incorporating ASR at the investigated areas was investigated.

5.1 REVISED DEMANDS

Drinking water supply and demand projections were updated to apply to the ERWS partners and current performance of their groundwater resources. The revised maximum day demands are listed in Table 5-1 and annual consumption rates are listed in Table 5-2.

Table 5-1
Maximum Day Demands

Area	Maximum Day Groundwater Supply Capacity (ML/d)	Projected Maximum Day Demand (ML/d)							
		2015	2020	2025	2030	2035	2040	2045	2050
RDN Nanoose	4.3	7.6	8.5	9.5	10.6	11.8	13.2	14.8	16.5
City of Parksville	7.5	17.7	19.5	21.4	23.5	25.8	28.3	31.1	34.2
Total Demands		25.3	28.0	30.9	34.1	37.6	41.5	45.9	50.7
Bulk Water Supply Requirements[1]	11.8	13.5	16.2	19.1	22.3	25.8	29.7	34.1	38.9

Notes:
1 – The Bulk Water Supply Requirements are the total water demands from each area minus the total groundwater supply capacity.

Table 5-2
Annual Water Demands

Area	Annual Groundwater Supply Capacity (million m^3)		Projected Annual Water Consumption (million m^3)							
	Current Volume	Potential Volume	2015	2020	2025	2030	2035	2040	2045	2050
RDN				1.24	1.38	1.54	1.73	1.93	2.16	2.41
Nanoose	0.63	0.63 [1]	1.11							
City of Parksville	0.93	1.40 [2]	2.59	2.84	3.12	3.43	3.77	4.14	4.55	5.00
Total Consumption			3.70	4.08	4.50	4.97	5.50	6.07	6.71	7.41
Bulk Water Supply Requirements[3]	1.56	2.06	1.64	2.02	2.44	2.91	3.44	4.01	4.65	5.35

Notes:
1 – Nanoose currently runs their wells all year-round. There is no potential for increasing the frequency of running the pumps.
2 – The City of Parksville runs their wells predominantly from late fall to early spring. There is potential to run the wells at least 50% more often to increase the total volume of groundwater used.
3 – Total volume of water required minus the potential volume of water that can be extracted from existing wells.

The 2050 projected maximum day bulk water supply requirement is lower than the 48 ML/d license that the ERWS has for drawing water from the Englishman River. However, it is likely that the ERWS will want to draw water to their full licensed amount at some point past 2050. It is recommended that the intake for the new water treatment plant be sized for the full 48 ML/d so that construction within the river is limited to the single, initial construction period. In other words, without considering ASR, it is recommended that the future infrastructure be sized for the following capacities:

- Intake: 48.0 ML/d
- Water Treatment Plant
  - Phase 1 construction (2015-2035): 25.8 ML/d
  - Phase 2 construction (2035-2050): 38.9 ML/d

Hydraulic modelling of the Englishman River, reported in DP6-1 of Phase 1, was not updated to reflect the change in ERWS surface water demands. A preliminary review indicates that the Englishman River should be adequate to meet these demands under typical conditions, but would not be able to mutually support ERWS demands and minimum fish flows under severe climate change scenarios or under 100-year return drought conditions. The ERWS is recommended to continue exploring options for supplementary water supply during these extreme conditions.

5.2 TREATED WATER DELIVERY

To incorporate the proposed intake and water treatment plant into the ERWS bulk water system, it is proposed that the treatment plant use dedicated mains to pump treated water directly to Reservoir #4 near Springwood and to Reservoir #5 near Top Bridge, and expand the ability of Reservoir #5 to provide water to the ERWS partners. The advantage of connecting the treatment plant to Reservoir #4 and Reservoir #5 is that it provides a simple way to control treatment plant operation via Reservoir #4 and Reservoir #5 water levels. It also minimizes the amount of new water main or water main upgrades required within the ERWS core area.

A conceptual design of the tie-in for the proposed supply mains to Reservoir #5 and connection to the Nanoose Peninsula Water System is shown in Figure 5-1. Water would gravity flow from Reservoir #5, hydraulic grade line (HGL) 74 m, to the Parksville distribution system. To provide water to Nanoose, water pressure will need to be boosted to match Nanoose's HGL 125m. A new pump station would be added to the main to Nanoose, located between Highway 19 and 19A and just east of Parksville's Industrial Park.

If the ASR option along Kaye Road proceeds, the pump station would also connect to the ASR system. While it is anticipated that the water leaving the treatment plant will have sufficient pressure for proper injection into the ASR wells, the pump house would be able to boost pressure if needed. Water recovered from the ASR system would be pumped at sufficient pressure to allow the water to flow to Nanoose.

The pump house would also contain a connection allowing water from Nanoose or from the ASR wells along Kaye Road to provide water to Parksville. This connection would include a pressure reducing valve to match the lower HGL 74m in Parksville. Alternatively the pump house could be located in the WTP, however this would require the supply main from Nanoose to continue along Highway 19. The suction for the pumps would be off the supply to Reservoir #5 and thus Reservoir #5 could be short circuited with the supply to Nanoose.

Downstream of the pump house, a 450 mm diameter supply main would be added to connect the bulk water system to Craig Bay. Similarly, a 2.5 km long 300 mm diameter supply main would be added in Nanoose from Stewart Road to Anchor Way to maintain required flows to the Fairwinds Reservoir.

Reservoir #5 would supply roughly a third of Parksville's water demands. The remaining demands would be supplied from Reservoir #4, west of Springwood Park. Treated water from the treatment plant would be pumped back towards the intake and cross the Englishman River to continue west along Forneau Road, Wildgreen Way, and the E&N Railway. For the river crossing it is assumed that the pipe would be installed on either the Highway 19 or the railway bridge. Appropriate permits would be required. The proposed pipe route is shown in Figure 5-2.

5.3 REVISED TREATMENT PLANT CAPITAL COSTS

In addition to the change in design capacity, the treatment plant layout and cost estimate must be revised to reflect the change in treatment processes to a membrane filtration system. The design developed in Phase 1 was based on conventional treatment, as conventional treatment has the greatest footprint requirements of the options considered. Figure 5-3 shows a revised conceptual treatment plant layout based on a membrane filtration system, with an updated capital cost estimate in Table 5-3. Details of the estimate are provided in Appendix C, and all capital costs are in 2014 dollars. This estimate does not factor in the impacts of ASR and thus acts as a base comparison.

Table 5-3
Intake and Treatment Plant Capital Costs – Membrane Filtration

Item	Cost ($ million)	
	Phase 1 To 2016	**Phase 2 2035-2050**
Direct Costs		
Intake	1.7	0.1[1]
Raw Water Pipeline	0.8	-
Water Treatment Plant	16.1	2.7
Water Distribution Mains (incl. Pump Stations and Reservoir Tie-ins)	5.5	3.7
Subtotal	24.1	6.5
Contingencies – Design and Construction	6.0	1.6
Total Direct Cost	30.2	8.1

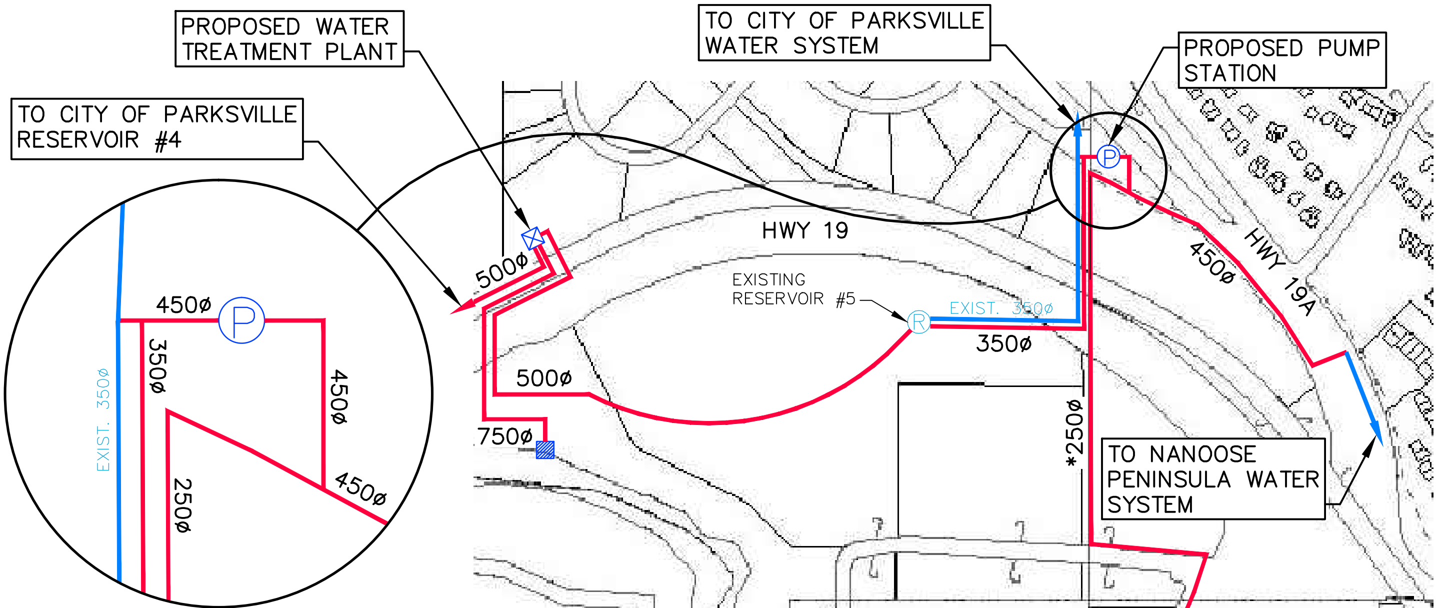
Notes: 1 – All of the intake structure would be constructed under Phase 1. Additional pumps required to expand the intake capacity would be deferred to Phase 2.

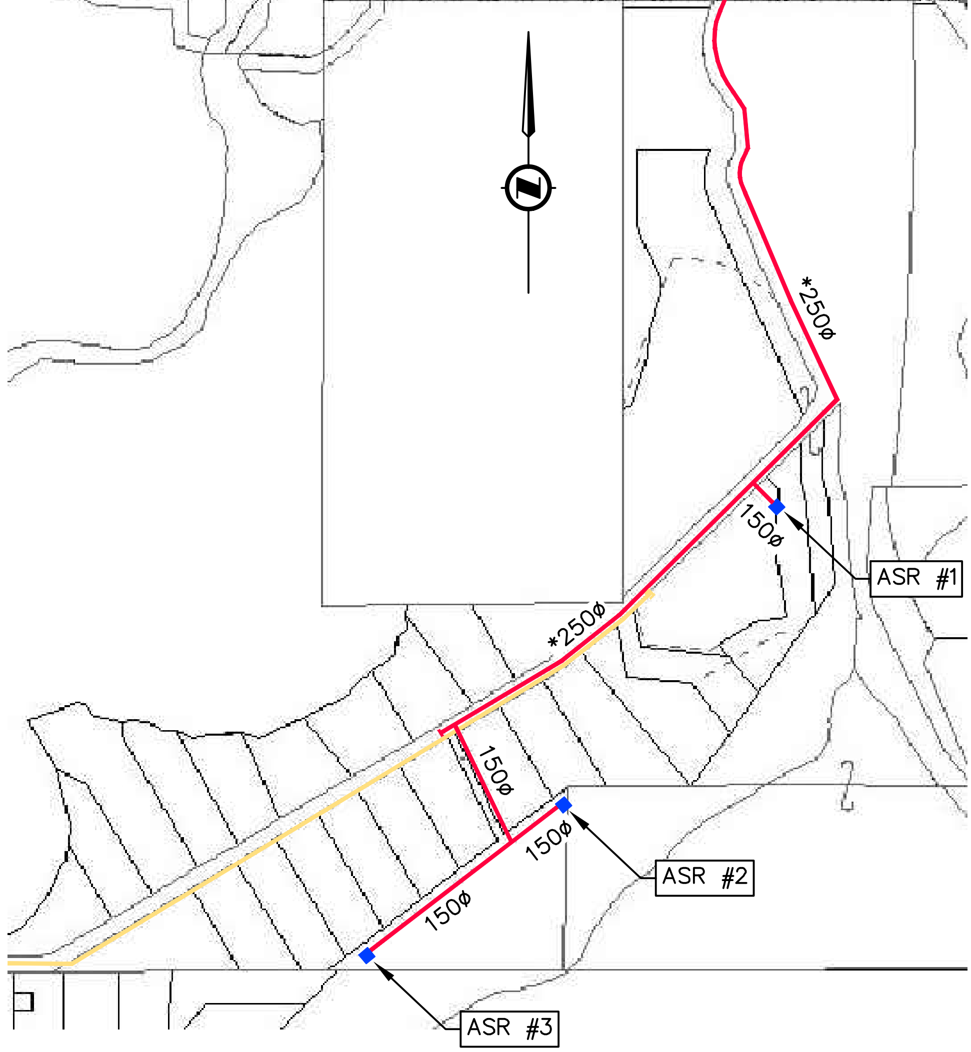
5.4 VIABILITY OF ASR

Two potential locations have been identified for full-scale development of ASR system within the ERWS service area. Other locations may be considered in the future. The two locations are distinct from each other and would connect at different locations in the bulk water system. They are discussed separately in the sections below.

5.4.1 Kaye Road

At this stage of design, it is assumed that an ASR system along Kaye Road would consist of ASR-1 and two additional wells (ASR-2 and ASR-3) to the south. Because of ASR spacing requirements, any more wells would need to be developed in the future at available properties in River Edge. A buried transmission





LEGEND

EXIST. WATERMAIN	EXIST. 350ø (blue line)
PROPOSED WATERMAIN	350ø (red line)
EXIST. RESERVOIR	Ⓡ
PROPOSED PUMP STATION	Ⓟ
PROPOSED ASR WELL	■
PROPOSED WATER TREATMENT PLANT	⊠
PROPOSED RIVER INTAKE	▨

NOTE:

*250ø BASED ON ULTIMATE OF 6–9 ASR WELLS (200ø ACCEPTABLE UP TO A MAXIMUM OF 6 WELLS)

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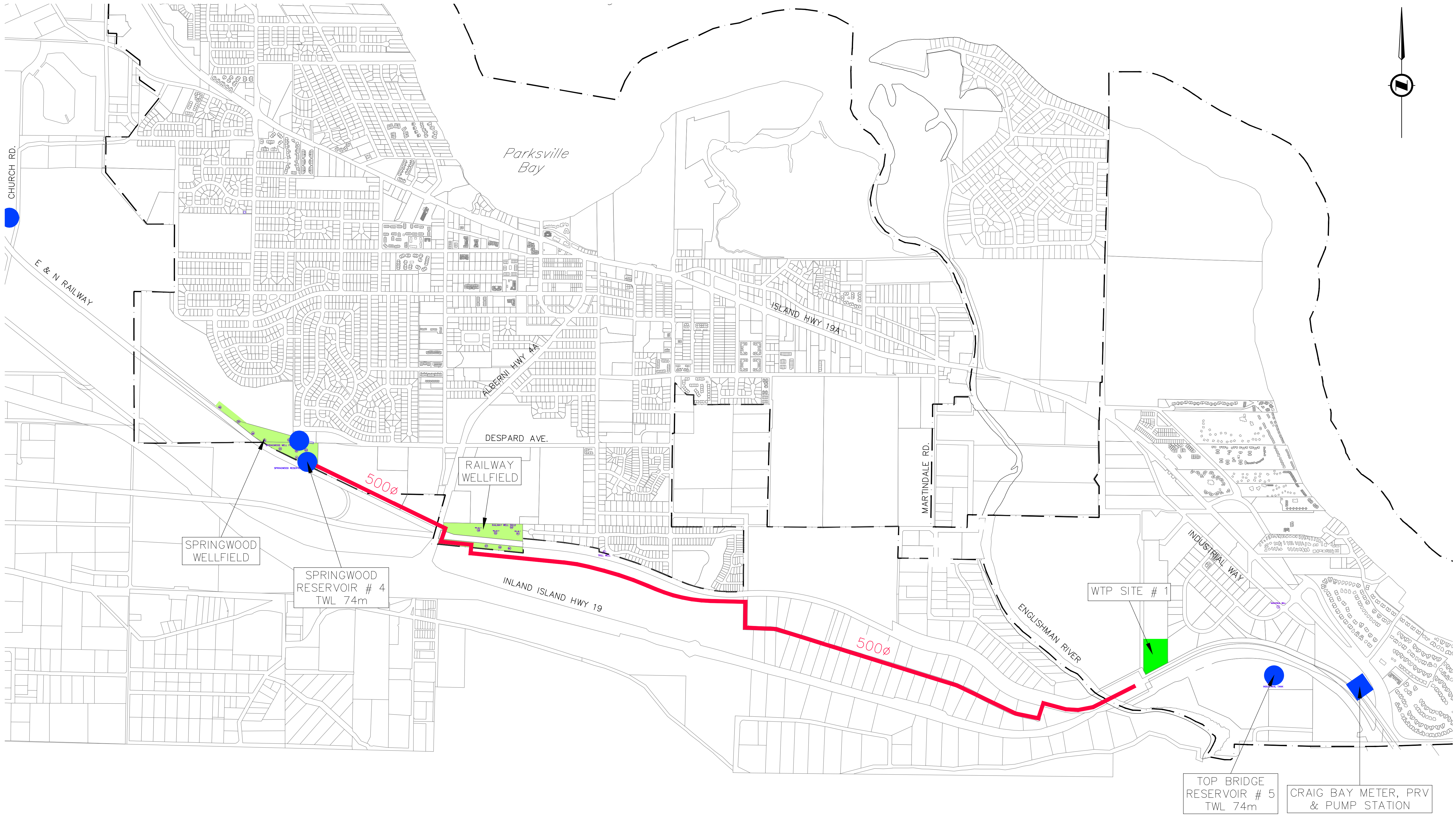
CLIENT	ENGLISHMAN RIVER WATER SERVICE	TITLE	PROPOSED PIPING TO ASR WELLS ON KAYE ROAD
PROJECT	ASR/WTP CONFIGURATION OPTIONS	APPROVED	CD
		DATE	18 FEB 2014
		JOB No.	0942–121
		SCALE	1:10000
		DWG No.	Figure 5–1



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CLIENT: ASSOCIATED ENGINEERING (BC) LTD.

PROJECT: ENGLISHMAN RIVER INTAKE STUDY

TITLE: TRANSMISSION MAIN IMPACTS INTAKE / W.T.P. SITE #1B

APPROVED:

SCALE: 1:30000

DATE: APR. 2010

JOB No.: 0942-121

DWG No.: Figure 5-2

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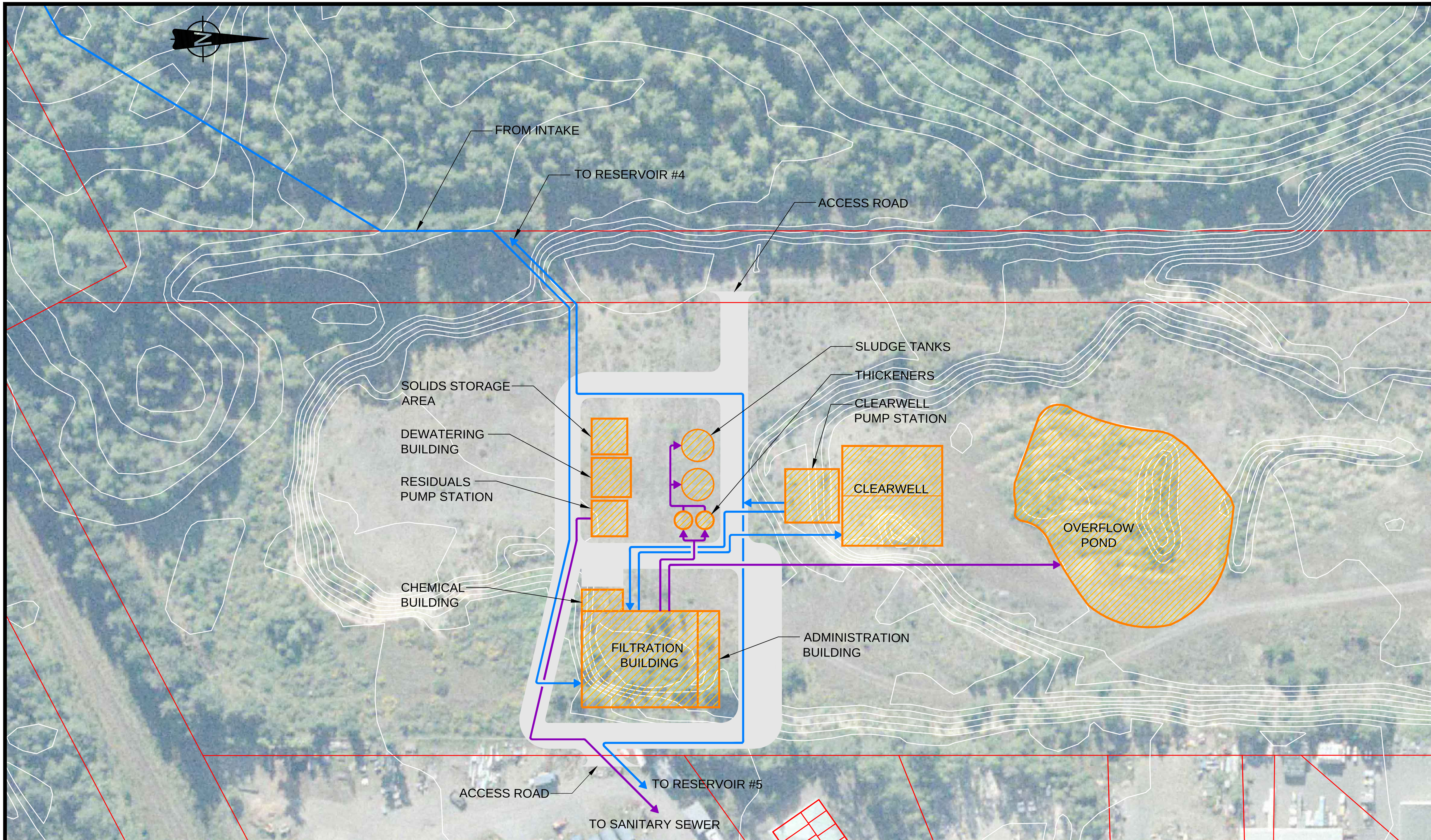


NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

PRELIMINARY
NOT FOR CONSTRUCTION

Associated Engineering

PROJECT No.	20092356	
SCALE	1:500	
DRAWN	S. KE	
DESIGNED	K. KOHUT	
CHECKED		
APPROVED		
DATE		INITIALS

ARROWSMITH WATER SERVICES

CIVIL
TREATMENT PLANT SITE PLAN
SITE #1

ARROWSMITH WATER SERVICES
ENGLISHMAN RIVER INTAKE
STUDY

DRAWING NUMBER	REV. NO.	SHEET
FIGURE 5-3		

main would connect the proposed pump station at Highway 19 and 19A to the ASR wells, allowing water to flow from the pump station to the ASR wells during injection, and from the wells to Nanoose and the pump station during ASR recovery. If only three ASR wells are to be developed in the area, a 200 mm diameter main would be sufficient. However, a 250 mm diameter buried main was assumed to allow flexibility should the ERWS chose to develop more ASR wells further south in the future.

Monthly water demand balances were prepared for 2035 and 2050, based on the projected ASR yields on Kaye Road, and are provided in Appendix D and summarized in Table 5-4. The addition of three ASR wells along Kaye Road would essentially reduce the required treatment plant size by 2.3 ML/d.

Table 5-4
Impact of Kaye Road ASR System on Plant Capacity

Treatment Plant Construction Phase	Phase 1 (2015-2035)	Phase 2 (2035-2050)
Design Capacity, without ASR (ML/d)	25.8	38.9
Design Capacity, with ASR on Kaye Road (ML/d)	23.5	36.6

While decreasing the surface water treatment plant capacity, the incorporation of ASR into the bulk water system will require some additional infrastructure, in particular:

- Adding permanent pump, wellhead, and related piping and valving to ASR-1.
- Drilling, developing, cycle testing, and completing two additional ASR wells.
- Constructing well control pump buildings to house non-buried mechanical equipment, instrumentation and controls.
- Installing process equipment to treat the ASR recovered water before it is introduced back into the distribution system.

At this stage it is anticipated that all three ASR wells will initially produce water containing elevated levels of arsenic, manganese and ammonia. It is assumed that the following remediation strategies proposed in Technical Report 1 would all be implemented at each well and successfully reduce the iron and manganese concentrations to target levels:

- Conduct multiple, short-term injection and recovery cycles.
- Expand Target Storage Volume injected into the aquifer.
- Install temporary treatment for arsenic and manganese until the metal concentrations recede over time to drinking water levels.

A free chlorine dose would be applied to the recovered water to oxidize any ammonia that may remain, and to provide secondary disinfection.

Table 5-5 provides a Class "D" capital cost estimate comparison of constructing Phase 1 and Phase 2 of the water treatment plant without ASR versus including an ASR system along Kaye Road.

Table 5-5
Capital Cost Estimates – ASR at Kaye Road

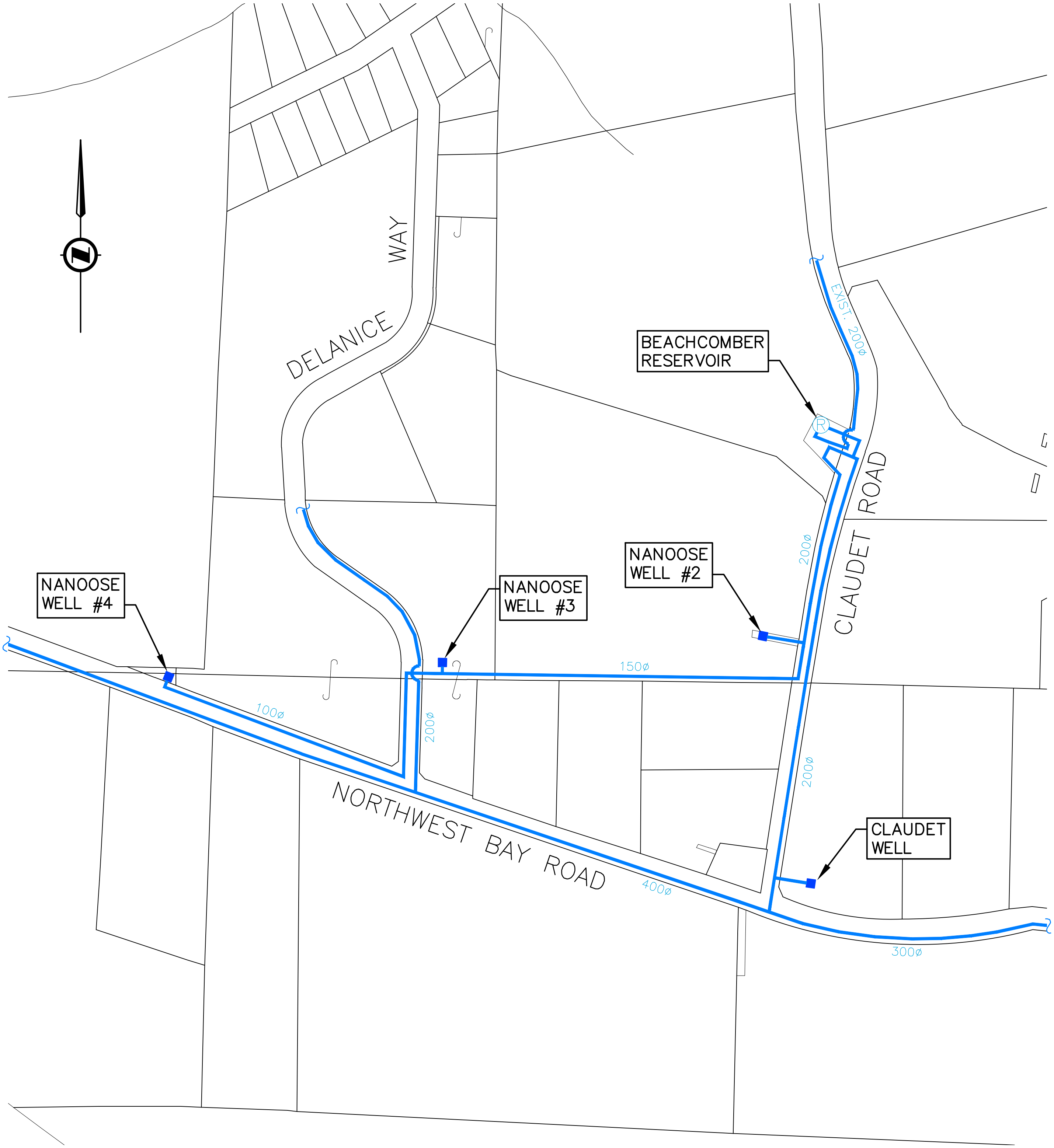
Description	No ASR ($ million)		ASR at Kaye Road ($ million)	
	Phase 1	Phase 1 & 2	Phase 1	Phase 1 & 2
Direct Costs				
Intake	1.7	1.7	1.7	1.7
Raw Water Pipeline	0.8	0.8	0.8	0.8
Treatment Plant	16.1	18.9	15.1	17.8
Water Distribution Mains	5.5	9.2	5.5	9.2
ASR System	-	-	3.1	3.1
Subtotal	*24.1*	*30.6*	*26.1*	*32.7*
Contingency (Des. & Eng.)	6.0	7.7	6.5	8.2
Total Direct Costs	**30.2**	**38.3**	**32.7**	**40.8**

From a capital cost perspective, the cost savings resulting from reducing the required Englishman River treatment plant capacity are not offset by the cost of fully developing the ASR system along Kaye Road. The greatest cost items for the ASR system at this location are the installation of the buried mains connecting to the ASR wells, the groundwater exploration and cycle testing for each well, and the remediation steps that are assumed to be required to lower arsenic and manganese concentrations. The feasibility of an ASR system along Kaye Road is examined in a broader context in Section 5.4.3.

5.4.2 Claudet Road

Wells #2, #3, and #4 in Nanoose currently contain elevated levels of ammonia and manganese and will require treatment in order to meet drinking water standards. There is an opportunity to convert the well sites in this area into an ASR system. The site is shown in Figure 5-4. Relatively little construction work would need to be done to incorporate an ASR well at this site. The work would essentially consist of adding small buildings to house the above-ground control valves and instruments, replacement or modification of the wells, and decommissioning work. Water could be injected directly from the Nanoose supply mains into the wells, and when recovered could be pumped into the same piping to make its way to the Beachcomber and Fairwinds Reservoirs.

Pump testing confirmed that a recovery yield of 15.3 L/s from an ASR well at the Claudet Road well site is expected (Lowen, 2013). At this stage of design it is assumed two of the Nanoose wells would be



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CLIENT: ENGLISHMAN RIVER WATER SERVICE

PROJECT: ASR/WTP CONFIGURATION OPTIONS

TITLE: PROPOSED ASR WELLS ON NORTHWEST BAY RD AND CLAUDET RD

APPROVED	CD	SCALE	1:5,000
DATE	18 FEB 2014	DWG No.	Figure 5-4
JOB No.	0942-121		

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developed into ASR wells, each with a 10 L/s capacity. Because these ASR wells would need to offset the groundwater supply provided by Wells #2, #3 and #4 (10.7 L/s), it would be desirable to expand the use of the ASR system so that water could be recovered from the wells more often throughout the year instead of exclusively in the summer. Based on the calculated water balances for this option, provided in Appendix D, the estimated ASR well yield and storage capacity would allow for the ASR system to contribute recovered water to Nanoose for six months of the year, with injection of excess water from the ERWS bulk water system occurring the other six months. The impact of developing an ASR system by Claudet Road on water treatment plant design capacity is shown in Table 5-6.

Table 5-6
Impact of Claudet Road ASR System on Plant Capacity

Treatment Plant Construction Phase	Phase 1 (2015-2035)	Phase 2 (2035-2050)
Design Capacity, without ASR (ML/d)	25.8	38.9
Design Capacity, with ASR on Claudet Road (ML/d)	23.7	36.8

In addition to impacting the required capacity of the Englishman River water treatment plant, replacing the three Nanoose wells would eliminate the need for a manganese and ammonia treatment facility in Nanoose, and potentially yield cost savings. A cost analysis was done, comparing the cost of a bulk water system with no ASR and treatment for the Nanoose wells to the cost a bulk water system that included an ASR system at Claudet Road, and is shown in Table 5-7. The assumptions used in developing the cost estimates are as follows:

- New ASR wells would be drilled and developed. Alternatively, the existing Claudet Road and Nanoose wells could be inspected and redeveloped, but new wells would allow for more optimally positioned screens that would maximize water injection and recovery rates. For example, a longer screen in the Claudet Road well would access a greater portion of the aquifer.
- At this stage it is assumed that the ASR wells will require conditioning to reduce arsenic and manganese concentrations in the recovered water, using the same techniques as was recommended for Kaye Road.
- A small structure would be constructed by the new well to house the ASR valving and controls, and the chlorination equipment.
- The third Nanoose well that is not converted to an ASR system would be used as a monitoring well.
- Water used for the injection phase of the cycle tests would come from the ERWS bulk water supply.

Table 5-7
Capital Cost Estimate – ASR at Claudet Road

Description	No ASR ($ million)		ASR at Claudet Road ($ million)	
	Phase 1	Phase 1 & 2	Phase 1	Phase 1 & 2
Direct Costs				
Intake	1.7	1.7	1.7	1.7
Raw Water Pipeline	0.8	0.8	0.8	0.8
Treatment Plant	16.1	18.9	15.2	17.9
Water Distribution Mains	5.5	9.2	5.5	9.2
ASR System	-	-	2.6	2.6
Nanoose Well Treatment	1.6	1.6	-	-
Subtotal	*25.7*	*32.2*	*25.8*	*32.3*
Contingency (Des. & Eng.)	6.4	8.1	6.5	8.1
Total Direct Costs	**32.2**	**40.3**	**32.2**	**40.4**

The capital cost comparison indicates that the development of an ASR system along Claudet Road would be roughly the same cost as constructing a treatment facility for the three Nanoose wells. It should be noted that the ASR cost estimates are based on the most conservative scenario, specifically:

- Only three ASR wells would be developed on site while Technical Report #1 indicated potential for a fourth.
- Each Nanoose well was assumed to produce 10 L/s of recovered water but could potentially produce 15 L/s.
- Remediation for arsenic and manganese during the initial cycle test was included in the ASR estimate, but it is unknown at this stage whether an increase in arsenic and manganese counts will occur at this site.

Should any of these assumptions prove to be overly conservative, ASR capital costs would be less than the presented estimate. The feasibility of an ASR system along Claudet Road, in comparison to other water supply options available, is examined in Section 5.4.3.

5.4.3 Summary

Ideally, the simplest water supply configuration for the ERWS would be to rely primarily on the groundwater supply of its partners and supplement community demands using the bulk water supply from the Englishman River. While the bulk water demands are within the ERWS's licensed amount that can be pumped from the Englishman River, the river may not be able to provide the licensed amount and protect fish flows during severe drought conditions. To minimize the risk to water supply capacity, the ERWS is recommended to diversify their sources of water supply. Work conducted under Technical Report 1 considered ASR as one such source.

The preceding sections of this report presented the net difference between the cost of developing ASR systems and the savings that would be achieved through the resulting decrease in treatment plant size. Another method to evaluate supply options is to compare the cost per unit of water produced. The direct capital cost per unit capacity is shown for each option in Table 5-8.

Table 5-8
Water Supply Options – Capital Cost per Unit Capacity

Description	Capacity Provided (ML/d)	Direct Capital Cost ($ million)	Cost per Unit Capacity ($ million / ML/d)
Englishman River Water Treatment Plant, Phase 1	25.8	16.1	0.63
Englishman River Water Treatment Plant, Phase 1&2	38.9	18.9	0.48
ASR at Claudet Road	3.0	2.5	0.87
ASR at Kaye Road	2.3	3.1	1.33
Treatment for Nanoose Wells #2, #3, #4	0.9	1.6	1.82

The cost estimates are based on a conservative performance of the ASR systems. Particularly, the ASR estimate at Claudet Road may improve if the converted Nanoose wells provide a recovery capacity greater than the assumed 10 L/s, as Technical Report 1 indicates that these wells may be able to produce up to 15 L/s each. Such an increase would reduce the cost per unit capacity at Claudet Road to $0.59 million/ML/d.

Based on Table 5-8 the most cost effective drinking water supply for the ERWS bulk water system would be treated water from the Englishman River. However, under severe drought conditions, the Englishman River may not be able to support all of the demands, and a supporting water source would be desired. The next most cost effective supply source considered is an ASR system along Claudet Road.

While the work completed under Phase 2 has led to a greater level of information of the Nanoose Creek Aquifer at the Kaye Road area, an ASR system along Kaye Road would be significantly more expensive than at Claudet Road for the amount of water produced. It is recommended that ASR development along Claudet Road be explored before continuing any development along Kaye Road. The primary differences in projected capital investments between the two sites is the comparatively low yield from the Kaye Road wells and the need for a dedicated water main from the Kaye Road wells to the proposed Nanoose pump station. With this in mind the ERWS is encouraged to review other locations close to existing water supply mains in Parksville and in the RDN to develop localized ASR systems. Minimizing the distance between ASR wells and their tie-in points will reduce connecting water main costs and improve their cost per unity capacity ratio.

ASR at Kaye Road will be less cost effective than at Claudet Road. However both ASR options are more cost effective than building a treatment facility for Nanoose wells #2, #3, and #4. It is recommended that the three wells not be used as conventional wells, in favour of the development of an ASR system.

6 Looking Forward

6.1 TREATMENT

Following the recommendation that membrane filtration be used as the Englishman River particulate removal treatment process, the ERWS is now faced with several configuration options.

The first relates to treatment plant residuals management. Simply put, the majority of raw water entering the membrane system will pass through as filtered membrane permeate, while a percentage of the raw water will not pass through the membrane and will be membrane reject. The ERWS has the option of either releasing the reject streams as waste, via direct discharge to sewer or to a wetland artificially enhanced as part of the project. The ERWS can alternatively choose to direct the membrane reject to a secondary membrane, to further extract permeate from the waste stream. The reject flows from the secondary membrane would be significantly reduced from the primary membrane, leading to lower reject flows leaving the treatment plant. Secondary membranes will add capital and operating costs to the water treatment plant, but would increase the percentage of raw water entering the facility that leaves as treated water to approximately 99%.

Another option to consider is the opportunity to use the changes in ground elevation throughout the site to manipulate water pressure and the HGL through the treatment plant. While a typical membrane system requires permeate pumps to drive water through the membrane, a siphon system would reduce the required permeate pump head requirements or eliminate the need for a permeate pump altogether, reducing power consumption at the plant.

At this stage both pressurized and submerged membrane configurations are equally viable. As design progresses, a specific membrane selection will be required. To aid in the selection, the membranes can be procured ahead of the main treatment plant construction contract via competitive bid. The pre-purchase will also allow the ERWS to work directly with membrane supplier via the design consultant to optimize plant design.

The procurement contract should include a performance guarantee, and to that end the membrane system may require another round of pilot testing. The piloting would be run by staff of the awarded membrane vendor, but will require coordination with the ERWS in setting up the raw water supply to test, power supply and waste disposal options. The pilot could be sited by the existing intake, where the preliminary round of piloting was conducted.

6.2 WATER RESOURCE MANAGEMENT

The Nanoose-Parksville area continues to be an attractive place to live for both lifestyle and economic reasons. Population and tourism in these areas will continue to grow well past the planning horizon of 2050, which will create steadily greater water demands. An update to the ERWS partnership water demands and available groundwater resources indicates that the ERWS should be able to meet projected water demands through a combination of their well networks and treated, bulk water supply from the

Englishman River, provided that the ERWS can draw their licensed amount of water from the river. However, the future impacts of climate change may reduce the amount of water that can be withdrawn from surface water sources, particularly during the dryer, warmer periods of the summer when water demands are at their peak. To minimize these risks the ERWS is encouraged to continue improving their management of groundwater resources, including the potential development of ASR systems.

The use of groundwater supplies are not without their risks, as the performance and quality of individual wells can change over time. This may be the case with wells located at low elevations near Georgia Strait. Increasing sea level due to global warming and increased well pumping could lead to saltwater intrusion and well contamination. Also increased urbanization or long term over pumping of wells could lead to water quality changes requiring further water treatment or abandonment of wells.

Considering the water resources of the region as a whole and planning on a regional basis will ensure that the abundant and high quality water supplies that the area has today will continue for decades into the future.

6.3 GROUNDWATER MANAGEMENT

A key component that will dictate the operating capacity of the Englishman River Water Treatment Plant is management of community groundwater supplies. For aquifers that only require disinfection to meet potable standards, well water can be provided to consumers at a lower operating cost than surface water. For aquifers requiring more treatment, the operating costs are greater. The management of the well networks are the mandate of the individual ERWS partners, which can lead to different strategies as to how the wells are operated.

As design of the Englishman River Water Treatment Plant continues, the ERWS should consider conducting a detailed assessment of their well network inventory to optimize operation and maintenance costs in the future. An assessment would include the following:

- Confirm current sustainable yields of individual wells, and projections of anticipated changes to yields over time.
- Determine whether individual wells could be run more regularly at an optimal cost or, conversely, if they should be run less to avoid over-pumping or to optimize operating costs.

An inventory assessment of this nature will allow the ERWS to maintain an optimal balance of groundwater and surface water use during typical seasonal conditions, and will allow the ERWS to determine how much they can stress their groundwater supplies during periods of severe drought.

6.4 ASR

A preliminary ASR investigation led to the development of an ASR pilot along Kaye Road, one of the potential sites closest to the future WTP. Cycle testing of an ASR pilot and a detailed characterization study of the Nanoose Creek Aquifer found that an ASR system along Kaye Road would consist of multiple wells in a relatively thin aquifer, producing recovered water with elevated levels of arsenic, manganese, and ammonia during its initial operation. The combination of aquifer thickness, water quality impacts, and distance from existing infrastructure will lead to a high cost per unit of water produced. Even with these limitations, developing an ASR system at Kaye Road is more cost effective than constructing a treatment facility for native groundwater supplies with elevated ammonia and manganese levels, as is the case for the Nanoose wells.

The Nanoose-Creek aquifer is quite large and there are numerous alternative locations near Parskville and Nanoose where ASR wells could be developed. Claudet Road was identified as a promising site for ASR development. The estimated costs per unit capacity at Claudet are lower than the estimates for Kaye Road and are more on par with the cost of treated surface water. It is recommended that the development of an ASR system at Claudet Road be further explored, beginning with the installation of a pilot ASR well and cycle testing. It is also recommended that the ERWS consider other potential ASR sites close to existing water infrastructure in Parskville and the RDN for development in the long term.

At this stage there is insufficient time in the project schedule to test alternative sites for an ASR system that would impact sizing of the treatment plant's Phase 1 of construction. However, the ERWS can still benefit from the development of ASR wells within the ERWS service area. In terms of security, an ASR system can serve as a third water source, to supplement water demands during a severe drought or if the treatment plant or the conventional groundwater supplies are offline. This third water source would also delay the need to expand the plant for Phase 2. An alternative use of ASR would be to develop an injection system near existing wells to enhance water levels in declining aquifers.

As public interest in the ASR concept grows, the ERWS is encouraged to look for opportunities where ASR can be incorporated in a cost-effective way, to supplement bulk water supply and to support the groundwater supplies.

6.5 PROJECT BUDGET

Updated capital costs, in 2014 dollars, for the recommended ERWS water supply work is summarized in Table 6-1. Phase 1 operation and maintenance costs for conceptual membrane water treatment plant and Nanoose pump station layouts are provided in Table 6-2. Details are provided in Appendix C. It is assumed that ASR development along Claudet Road would continue throughout Phase 1 construction of the water treatment plant and would not affect the Phase 1 plant design capacity. ASR at Claudet Road would decrease the required capacity of the plant in Phase 2.

Table 6-1
Class 'C' Capital Costs[1]

Item	Cost ($ million)	
	Phase 1 To 2016	Phase 2 2035-2050
Direct Costs		
Intake	1.7	0.1
Raw Water Pipeline	0.8	-
Water Treatment Plant	16.1	1.8
Water Distribution Mains (incl. Pump Stations and Reservoir Tie-ins)	5.5	3.7
ASR Development at Claudet Road	2.6	-
Subtotal	26.7	5.6
Contingencies – Design and Construction	6.7	1.4
Total Direct Cost	33.4	7.0
Indirect Costs		
Engineering	2.9	0.7
Administration	1.0	0.2
Miscellaneous	0.7	0.1
Total Indirect Cost	4.6	1.0
GST Allowance (5%)	1.9	0.4
Total Capital Cost	39.9	8.4
	48.3	

Notes:
1 – Class 'C' estimates are based on limited site information and probable conditions. These cost estimates are refined as design advances.

Table 6-2
Operation and Maintenance Cost Estimates

Description	Annual Cost ($/year)
General Staffing Payroll	600,000
Intake Operation and Maintenance	34,000
Water Treatment Plant	
Chemical Use and Membrane Use	86,000
Pump Operation and Maintenance	66,000
General Operation and Maintenance	44,000
Residuals Management and Disposal	18,000
Subtotal	**214,000**
Claudet Road ASR System	18,000
Total	**863,000**

Several possibilities for deferring capital costs from Phase 1 to Phase 2 have not been explored at this stage of design. A simplified staging of construction of the water supply main piping upgrades was assumed at this time but more of the construction may be able to be delayed until Phase 2. The size of the treatment plant could also be reduced for a smaller time frame, for example, sizing the Phase 1 plant capacity for 2030 as opposed to 2035. Further refinement of the design of the bulk water system upgrades will present further opportunities for capital cost deferral.

7 Recommendations

The recommendations arising from this study are as follows:

1. *Treatment at the future Englishman River Water Treatment Plant should consist of coagulation and membrane filtration, followed by chlorine disinfection*. Membrane filtration was demonstrated to consistently reduce turbidity levels to potable standards under various and rapidly changed raw water conditions. Coagulation is recommended to aid in the removal of true colour. Membrane filtration followed by chlorine disinfection is sufficient to achieve the required disinfection credits for microbiological control.

2. *Cycle testing of an ASR pilot at Claudet Road should be pursued*. This site could potentially reduce the groundwater treatment infrastructure required in Nanoose and produce a net saving in capital costs. Cycle testing is required to confirm aquifer storage characteristics and potential changes to the water quality during aquifer storage.

3. *Opportunities for ASR at other locations should be pursued in the future*. In addition to the Claudet Road site, there are multiple sites between Parksville and Nanoose where an ASR system in the Nanoose Creek Aquifer could be developed. These locations would be further from the water treatment plant but could tie in directly to the distribution system. The development of any future ASR systems in the ERWS water system would allow the ERWS to draw less water from the Englishman River during the summer, providing the ERWS an extra margin of safety during drought periods where Englishman River flows are low.

4. *A full-scale ASR system at Kaye Road should be pursued only after alternative locations are considered*. ASR at Kaye Road would reduce the amount of water that would be withdrawn from the Englishman River, and is more cost effective than treating native groundwater that is high in manganese and ammonia. However, the relatively thin aquifer, treatment requirements, and distance from existing water infrastructure at this particular location result in a high capital cost for the amount of water produced. Other locations may be more economically feasible to develop.

5. *The ERWS should continue to acquire the required property and easements for the new intake and water supply mains*. The updated conceptual design shows the approximate location of the future intake, new water supply mains and pump station to Nanoose. Discussions should be held throughout 2014 with property owners with a view to acquire the required properties and easements not already in possession by the ERWS.

6. *Continue with the preliminary design of the Englishman River intake.* The ERWS should proceed with the next stage of design to achieve their target completion date of 2016. The ERWS should continue dialogue with VIHA, the Ministry of Environment, and the Department of Fisheries and Oceans to keep the approval agencies current on the project's progression.

8 References

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TECHNICAL REPORT 2

Certification Page

This report presents our findings regarding the Englishman River Water Service Phase 2 - Water Treatment Pilot Testing and Aquifer Storage and Recovery Feasibility Analysis.

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Appendix A - Water Quality Monitoring Review: September 2011 to August 2012

Technical Memorandum - WQ1

Associated Engineering

GLOBAL PERSPECTIVE.
LOCAL FOCUS.

Englishman River Water Service

Water Quality Monitoring Review September 2011 to August 2012

April 2013

ASSOCIATED ENGINEERING
QUALITY MANAGEMENT SIGN-OFF
Signature
Date April 10/13 02-13-047

Table of Contents

TECHNICAL MEMORANDUM - WQ1

Englishman River Water Service

Water Quality Monitoring Review
September 2011 to August 2012

Issued:	April 5, 2013
Previous Issue:	January 3, 2013

1 Introduction

In September of 2011, the Englishman River Water Service began an intensive 12-month water quality monitoring program on the Englishman River. The water quality data was periodically reviewed and the monitoring program was modified to ensure that the optimal amount of data was collected throughout the four seasons. This memorandum summarizes the data collected during the monitoring period, and identifies water quality trends and parameters of concern. The outcome of this review was used to characterize overall water quality of the Englishman River throughout the four seasons of a given year, and discuss the impact of specific water parameters on the treatment processes proposed for the future water treatment plant.

1.1 Background

Historical water quality data for the Englishman river was examined in Discussion Paper 4-1 (DP 4-1) of Phase 1 of the Englishman River Water Intake, Treatment Facilities and Supply Mains project, completed in April of 2011. The water quality profile presented in DP 4-1 for the Englishman river highlighted some inconsistencies and gaps in the data. As such, the DP 4-1 recommendations included a 12-month water quality monitoring program implemented by the Englishman River Water Service to confirm the accuracy and completeness of the data. A list of the recommended parameters to monitor and sampling frequency was developed as a sampling protocol (Appendix A).

1.2 Data Source

The water quality data were collected using a combination of online analyzers, field measurements and third-party laboratory analyses from grab samples. Sample collection and field measurements were conducted by City of Parksville staff. An additional water quality sample was taken by Associated Engineering staff in January of 2012 during the membrane pilot study.

River flow and turbidity data was provided by the Ministry of Environment (MOE) from water monitoring station 08HB002. Precipitation data was provided by the City of Parksville, as measured from a rainfall gauge installed at the Public Works Yard.

2 Water Quality Description

The following section highlights the key observations made from the compiled monitoring data. More detailed water quality information is provided in Appendix B.

2.1 Reference Water Quality Standards

The drinking water quality objectives for the EWRS are based on meeting the Guidelines for Canadian Drinking Water Quality (GCDWQ). GCDWQ standards can be divided into the following categories:

- Health-based criteria, listed as Maximum Acceptable Concentrations (MAC);
- Aesthetic criteria, listed as the Aesthetic Objectives (AO);
- Criteria related to operational standards, listed as Operational Guidance Values (OG).

In addition the Vancouver Island Health Authority (VIHA) applies an operating rule to the Englishman River intake. Part of the operating rule stipulated a minimum 0.2 mg/L chlorine residual and a maximum 5 NTU turbidity entering the distribution system. In 2009 VIHA updated the operating rule, requiring that the turbidity of water entering the distribution system from the intake be less than 1 NTU. This was in agreement with similar changes to the GCDWQ.

2.2 Grab Samples

Table 2-1 provides a summary of the key water quality parameters measured from the grab samples taken between September 1, 2011 and August 31, 2012.

Table 2-1
Englishman River Grab Sample Water Quality Summary

Parameter	GCDWQ Objective	Type (MAC/AO/OG)	Minimum	Maximum	Average	Median	No. Samples
General Parameters							
Turbidity (NTU)	≤ 1	OG	0.07	104	2.15	1.10	207
Alkalinity (mg/L as $CaCO_3$)	-	-	9	24	17	17	15[1]
Hardness (mg/L as $CaCO_3$)	≤ 200	OG	13	30	21	19	15[1]
pH	6.5 – 8.5	AO	6.58	7.91	7.25	7.23	209
True Colour (TCU)	≤ 15	AO	< 5	77	22	20	210
TDS (mg/L)	≤ 500	AO	16	56	41	44	15[1]
TOC (mg/L)	-	-	0.7	6.7	2.1	1.9	24[2]

Parameter	GCDWQ Objective	Type (MAC/AO/OG)	Minimum	Maximum	Average	Median	No. Samples
DOC (mg/L)	-	-	0.7	3.7	2.2	2.2	24[2]
UVT (%)	-	-	69.8	98.9	87.3	86.4	23[2]
Nitrate (mg/L as N)	≤ 10	MAC	0.03	0.80	< 0.02	< 0.02	15[1]
Total Coliforms (count /100 mL)	0	MAC	110	1100	326	240	13[1]
E. coli (count /100 mL)	0	MAC	1	100	20	12	13[1]
Metals							
Aluminum (mg/L)	≤ 0.1[4]	OG	0.014	1.510	0.226	0.061	15[1]
Arsenic (mg/L)	≤ 0.010	MAC	<0.0001	0.0009	0.0002	0.0001	15[1]
Cadmium (mg/L)	≤ 0.005	MAC	< 0.00001	0.00007	< 0.00001	< 0.00001	15[1]
Chromium (mg/L)	≤ 0.05	MAC	< 0.001	0.006	< 0.001	<0.001	15[1]
Copper (mg/L)	≤ 1.0	AO	0.0005	0.012	0.002	0.0008	15[1]
Iron (mg/L)	≤ 0.3	AO	0.048	2.64	037	0.074	15[1]
Lead (mg/L)	≤ 0.01	MAC	< 0.0002	0.001	< 0.0002	< 0.0002	15[1]
Manganese (mg/L)	≤ 0.05	AO	0.002	0.069	0.013	0.005	15[1]
Uranium (mg/L)	≤ 0.02	MAC	< 0.0001	< 0.0001	< 0.0001	< 0.0001	15[1]

Notes:

1 – Samples collected monthly by City of Parksville staff.

2 – Samples collected bi-weekly by City of Parksville staff.

The data collected from the monitoring program is consistent with the data compiled in DP4-1: "Raw Water Quality Evaluation". The Englishman River raw water quality during the monitoring period generally met the criteria of the GCDWQ with the exception of turbidity, true colour, total coliforms, and *E.coli*. Spikes in aluminum, iron and manganese (GCDWQ-AO) were also observed on two occasions.

Turbidity

Turbidity does not have a direct impact on health, but can interfere with disinfection processes and reduce their effectiveness at destroying or inactivating microbiological parameters. Turbidity adds a cloudiness to water that reduces its visual appeal. Turbidity is also commonly used as an indicator of how well a filtration process is performing. Turbidity as measured in the grab samples at the proposed intake site was less than 5 NTU in 96% of the samples collected, but was less than 1 NTU in only 42% of the samples.

True Colour

Colour can have a detrimental impact on the visual appeal of drinking water but does not directly impact human health. Colour can be caused by both organic and inorganic sources.

True colour as measured in the field and in the laboratory did not agree. Figure 2-1 demonstrates that the field measurements were generally greater than the laboratory measurements, in the order of 10 to 30 TCU. No correlation was readily apparent, and it is uncertain whether the measurements are not as accurate in the field, whether the field measurements and the samples for the laboratory were taken at different times of the day, or whether changes to the chemical composition of the water changed for the collected samples while in transit to the laboratory. The field measurements indicate that true colour regularly exceeded the AO of 15 TCU, while the laboratory data suggests that colour was often below the AO but exceeded this limit during the winter and periodically throughout the rest of the year.

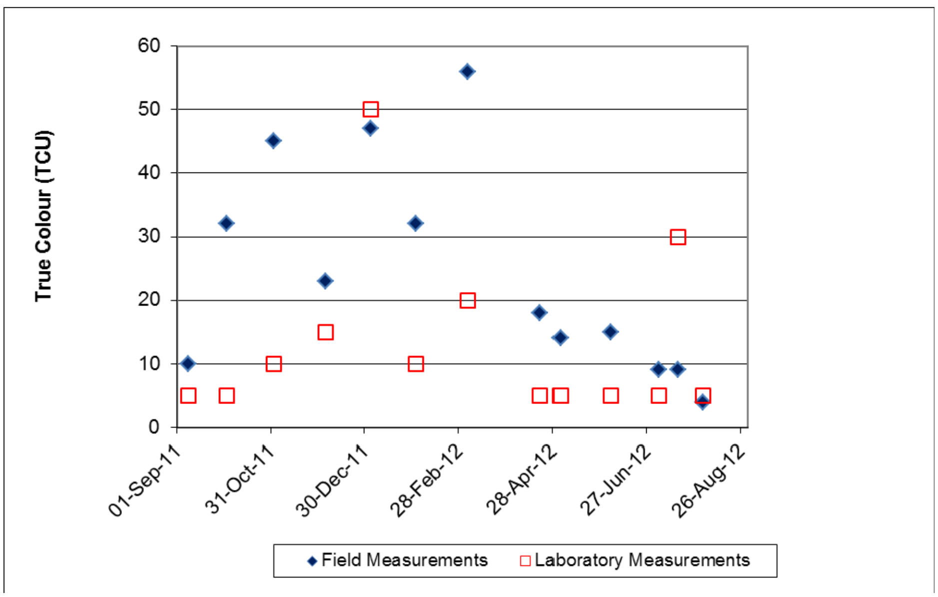

Figure 2-1 - Comparison of True Colour Data

Bacteria

Total coliforms measurements are used as a gauge of microbiological activity, while *E.coli* bacteria exposure is a risk to human health.

Related to bacteria, protozoans such as *Cryptosporidium parvum* and *Giardia lamblia* can be significant when determining treatment objectives because of their resilience to chlorine disinfection. A multi-barrier treatment approach, consistent of both disinfection and filtration, is typically employed to protect against protozoan activity.

Cryptosporidium parvum and *Giardia lamblia* were not monitored as part of this program, due to the sample method challenges in collecting representative samples and in achieving accurate and reproducible analytical measurements. However, measurable levels of *Cryptosporidium* and *Giardia* were noted in the historical data collected along the Englishman River. *E.coli* is commonly used as a surrogate to indicate the presence of the two protozoans, as all three are commonly found in faeces and therefore migrate to surface water sources. *E-coli* monitoring is accepted in lieu of expensive protozoa monitoring for small communities in many jurisdictions. However, *Cryptosporidium* and *Giardia* can survive in the environment for a much longer time than *E*.coli, thus the absence of detectable levels of *E.coli* does not guarantee the absence of these protozoans. Common practice is to assume that *Cryptosporidium* and *Giardia* will be present in raw surface water sources, which in the case of the Englishman River, has been confirmed via the historical data.

Metals

The spikes in aluminum, iron and manganese are shown in Figure 2-2. The first spike was observed in January, and the second in July. The possible causes of these peaks in metal concentrations are discussed in Sections 3.4 and 3.5. Iron and manganese have AO levels set on their impact on the visual appeal of water. High concentrations of iron can cause a red/yellow discolouration of the water, staining laundry and plumbing fixtures. Similarly, high concentrations of manganese can cause a dark discolouration of the water. The GCDWQ states that aluminum concentrations should not increase by more than 0.100 mg/L during treatment, but does not set a limit for aluminum in raw water. However, the spike in aluminum concentrations was highlighted in this document because of the increase was so large in both of the spike events. Beyond these two events iron, manganese and aluminum were measured at levels acceptable for drinking water.

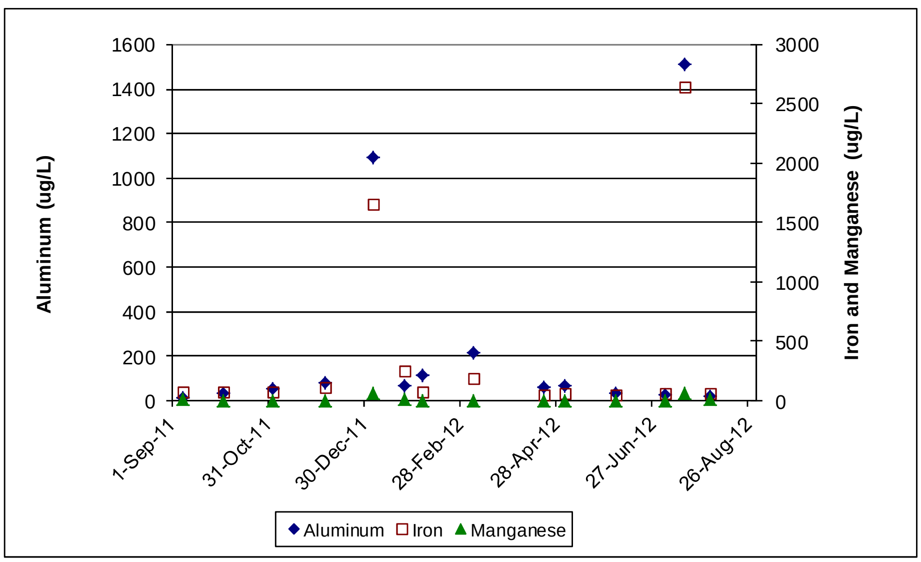

Figure 2-2 - Aluminum, Iron and Manganese Concentrations

Disinfection Byproducts

Throughout the monitoring program samples were taken from the distribution system and measured for disinfection by-product (DBP) concentrations, namely trihalomethanes (THMs) and haloeacetic acids (HAAs). Raw water samples were also taken from the Englishman River and tested for DBP formation potential. The Standard Method for the formation potential test involves dosing the water sample with a high dose, 5 mg/L or greater as opposed to a typical distribution concentration of 0.2 to 1.0 mg/L, and held for a week to allow the chlorine to react with the organics in the water sample.

It is worth emphasizing that DBP and DBP formation potential indicate different characteristics of a water system. High concentrations of DBPs in the distribution system would be a concern because of their potential risk to human health. In contrast, DBP formation potential is used to determine the amount of DBP potential precursors that are present in the water. Measurements of DBP formation potential can be used to monitor the change of specific organics in the Englishman River over time, or can be compared to DBP formation potential measurements taken downstream of treatment facilities to monitor treatment effectiveness. In other words, DBP formation potential information can be used to gauge treatment performance, while DBP concentrations are monitored because of their potential impact on human health.

Table 2-2 Summarizes the DBP concentrations measured in the distribution system as well as the maximum formation potential in the raw water.

Table 2-2
Measured DBP and DBP Formation Potential

Parameter		GCDWQ MAC (mg/L)	Measured Concentration		
			Average (mg/L)	Maximum (mg/L)	Count
Total THMs	Observed	0.100	0.013	0.021	5
	Formation Potential	-	0.330	0.490	3
Total HAAs	Observed	0.080	< 0.005	0.022	4
	Formation Potential	-	0.048	0.095	2

These measurements indicate that there are DBP precursors present in the raw water, but at the levels of chlorine currently used in the ERWS drinking water system, the level of DBPs actually formed are well below the GCDWQ limits.

2.3 Continuous Turbidity Monitoring

Turbidity data, recorded in 15 minute intervals, was collected from online turbidimeters at the existing intake (PRK1) and at the MOE Station near the Highway 19A bridge (MOE1), roughly 400 m upstream of PRK1. The daily maximum turbidity as measured by these two instruments is shown in Figure 2-3, and the daily average turbidity is shown in Figure 2-4. The turbidity samples taken at the location of the proposed future intake were included on Figure 2-4.

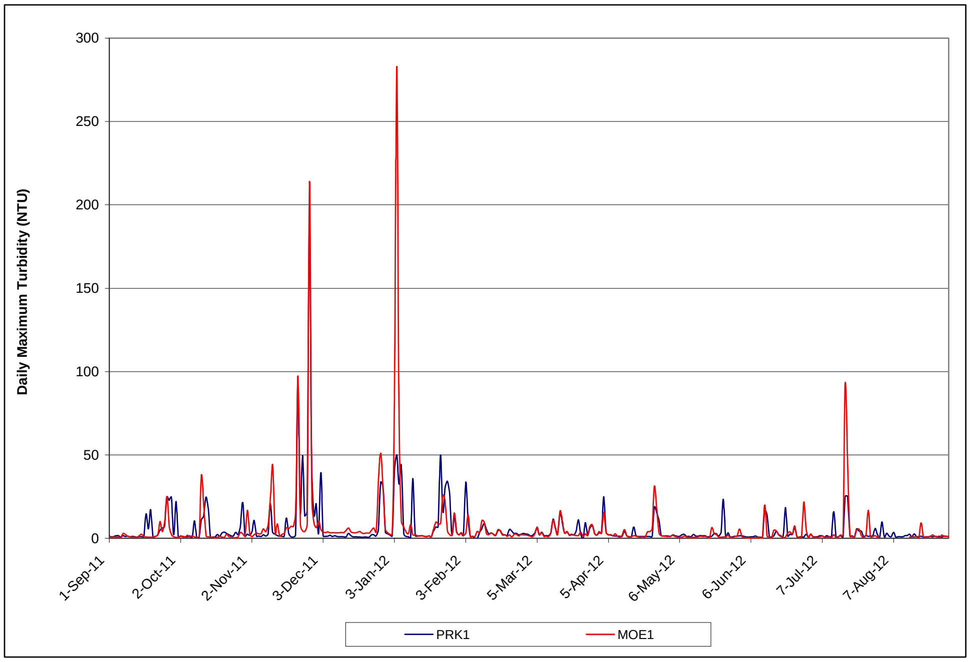

Figure 2-3 - Daily Maximum Turbidity

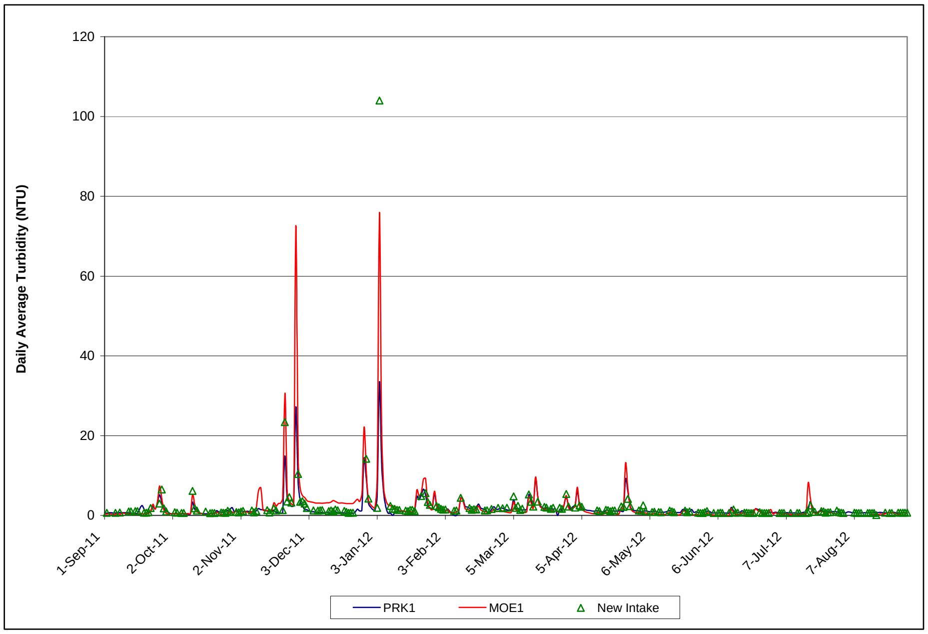

Figure 2-4 - Daily Average Turbidity

Turbidity was relatively low for a surface water source the majority of the time, but the Englishman River experienced sudden, short-duration, and intense turbidity spike events, where turbidity could increase from less than 1 NTU to 50 NTU or greater within hours. It is apparent from the observed data that the turbidity spike events with the greatest intensity generally occur during the winter months, while lesser intensity turbidity spike events were observed in other periods of the year.

The City of Parksville turbidimeter encountered accuracy errors during two of the measured spikes. On November 22, 2011, the turbidimeter read 498 NTU, while notes from the daily grab sampling log indicated that turbidity for that event peaked at 90 NTU. The higher turbidity value of 498 was replaced with 90 NTU for this day in the figure. On January 4 the turbidimeter could not read higher than 50 NTU, while the MOE turbidimeter captured peak readings of 282 NTU. The Parksville turbidimeter was replaced in the first week of February to more accurately capture turbidity spikes.

The two sets of continuous data are generally in alignment, in that the majority of the turbidity spike events were captured by both monitoring stations. The maximum turbidity measured at each event was the same at both monitoring station with a few exceptions, while daily average turbidity was more often measured at higher levels at MOE1 than at PRK1. This may be due to slower velocities at the wider and shallower section of the river by PRK1, allowing for some of the turbidity to settle, or that differences in sampling location, sampling method, and instrument calibration have led to variability between the two data sets. The replacement of a new turbidimeter at PRK1 in February did not noticeably affect how the two data sets aligned. The grab samples taken near the location of the proposed intake were lower than the daily averages taken at both monitoring stations downstream, with the exception of a turbidity spike event that was captured mid-process in early January.

When looking at the data, it is useful to compare raw water turbidity to the previous and current turbidity operating rule of 5 and 1 NTU, respectively. The number of times that 1 or 5 NTU were exceeded during the monitoring program is quantified in Table 2-3, using PRK1 data, and Table 2-4, using MOE1 data.

Table 2-3
Monthly Exceedences of the Turbidity Operating Rule Requirement – PRK1 data

Date	Daily Maximum Turbidity		Daily Average Turbidity	
	Percent of days > 5 NTU (Previous Rule)	Percent of Days > 1 NTU (Current Rule)	Percent of days > 5 NTU (Previous Rule)	Percent of Days > 1 NTU (Current Rule)
September	30%	73%	3%	37%
October	23%	68%	0%	29%
November	40%	93%	10%	63%
December	13%	61%	6%	35%
January	42%	87%	26%	71%
February	21%	93%	0%	79%
March	29%	97%	6%	97%
April	17%	100%	10%	93%
May	3%	84%	0%	35%
June	13%	60%	0%	27%
July	16%	71%	0%	19%
August	3%	48%	0%	0%
Total	21%	78%	5%	49%

Table 2-4
Monthly Exceedences of the Turbidity Operating Rule Requirement – MOE1 data

Date	Daily Maximum Turbidity		Daily Average Turbidity	
	Percent of days > 5 NTU (Previous Rule)	Percent of Days > 1 NTU (Current Rule)	Percent of days > 5 NTU (Previous Rule)	Percent of Days > 1 NTU (Current Rule)
September	13%	47%	3%	23%
October	10%	42%	3%	16%
November	57%	97%	27%	77%
December	29%	100%	10%	100%
January	42%	100%	29%	87%
February	14%	93%	0%	66%
March	23%	97%	3%	68%
April	17%	77%	10%	40%
May	3%	45%	0%	6%
June	17%	47%	0%	17%
July	16%	58%	3%	6%
August	5%	47%	0%	0%
Total	21%	71%	8%	44%

Both tables indicate that the less than 1 NTU objective was not met at least once a day for the majority of each month. Furthermore, raw water turbidity exceeded the 1 NTU objective for the majority of most days in the fall and spring, and exceeded 1 NTU almost permanently from January to April. Turbidity levels were at their lowest in August.

It should be noted that the existing intake uses an infiltration gallery which reduces the turbidity of the water drawn into the intake, thus the water entering the distribution system has lower turbidity than what is measured in raw Englishman River water.

2.4 Continuous Chlorine Residual Monitoring

The chlorine residual was measured in 15 minute increments, at the location where the intake connects to the distribution system, and is shown in Figure 2-5. As a constant chlorine dose was applied to the water, significant changes to the residual act as an indicator that the water has undergone some form of change. It is part of typical operations that the City of Parksville brings the existing intake offline during the winter when turbidity in the Englishman River exceeds 1 NTU and relies solely on the well supply. In 2011 the intake was brought offline on October 29 and brought back online May 16, 2012. Therefore, the chlorine residual in the distribution system was not examined during this timeframe.

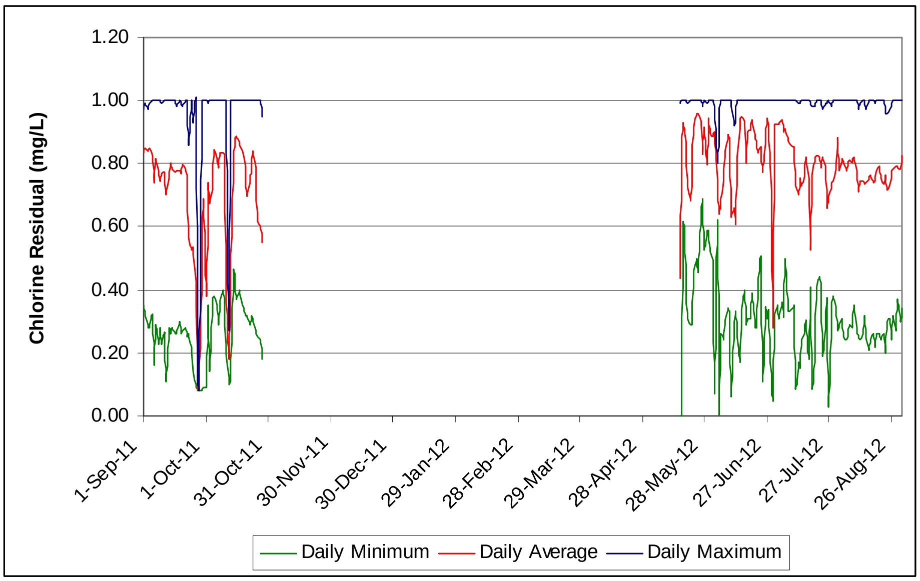

Figure 2-5 - Free Chlorine Residual

The chlorine residual typically varied throughout the day from 1.0 mg/L to 0.2 mg/L, with an average of 0.8 mg/L. A noticeable drop in chlorine residual occurred for several days around September 28, October 13, and June 30. Both of the drops in September and October were preceded the day before by the first sharp increases in flow in the monitoring program. None of the monitored parameters could explain the drop in June.

3 Water Quality Trends

Each of the monitored water quality parameters was examined to determine whether a relationship was apparent between the parameters and time, river discharge, or precipitation. Plots of the comparisons involving turbidity, water temperature, pH, DOC, TOC, colour, conductivity and UVT are available in Appendix B.

3.1 Seasonal Changes

The collected data was examined in quarterly periods, corresponding to the four seasons of the year.

River Flow and Precipitation

Figures 3-1 and 3-2 show daily Englishman River flow rates and precipitation. During the fall months of September and October river flow rates are relatively low, averaging 7 m^3/s. In early November, river flow rates increased dramatically to the order of 24 m^3/s and remained at these levels until March, where the spring flow rates decreased to an average river flow rate of 14 m^3/s. In June, flow rates further decreased to less than 4 m^3/s for the summer. This seasonal change correlates with the overall seasonal changes in precipitation. Rainfall intensity and frequency were at their greatest from the months of November to January. From April to June the daily amount of rainfall fell but the frequency increased, reflecting a relatively wet spring. Rainfall intensity and frequency fell to its lowest levels throughout July and August.

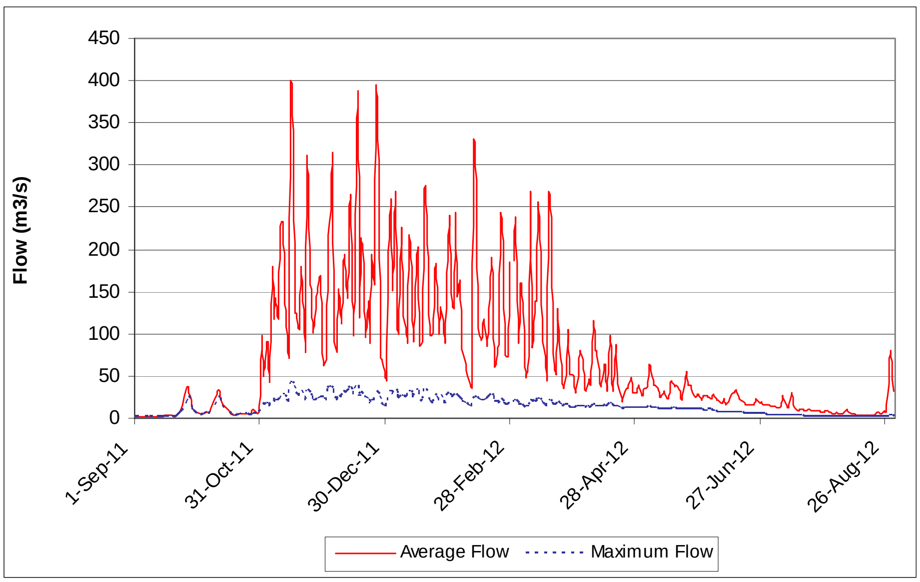

Figure 3-1 - River Flow Rates

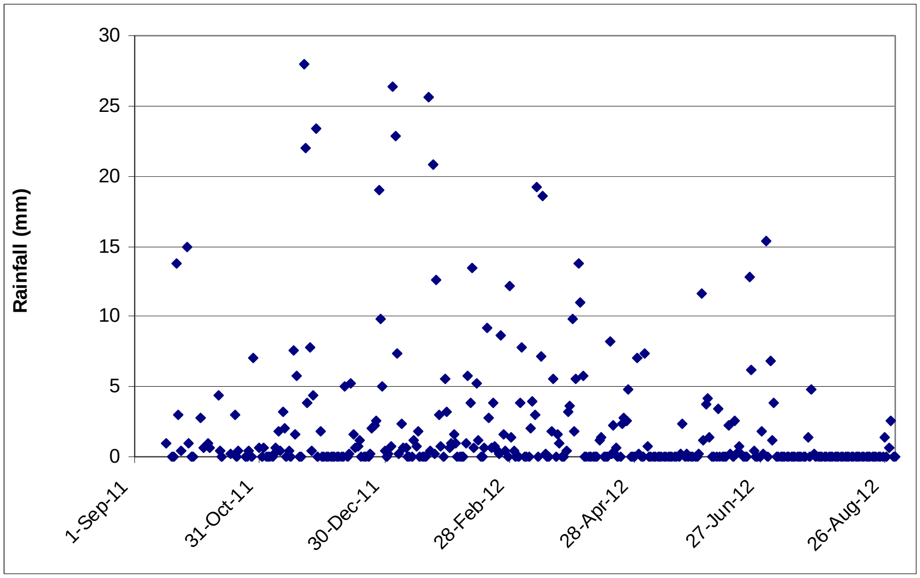

Figure 3-2 - Parksville Precipitation

Turbidity

As shown in Figure 2-3 and Table 2-4, the greatest turbidity spike events occurred between November and January, typically in the order of 20 to 50 NTU. The greatest spikes occurred near the end of November and early January, ranging between 90 NTU and 280 NTU in magnitude. From February to April the turbidity spike events ranged from 20 to 50 NTU. From November to April, turbidity was consistently greater than 1 NTU the majority of the time. Beyond this six month period the turbidity levels dropped. Turbidity from March to August behaved similarly to September and October conditions, with turbidity generally being less than 1 NTU and spiking to no more than 20 NTU. One exception was when a clay bank collapse on July 17 resulted in a significant summer turbidity spike event, which is discussed in Section 3.5.

Temperature, pH & Conductivity

Figure 3-3 shows water temperature, pH and conductivity throughout the four quarters of the monitoring period. Water temperature decreased to its lowest value in January, and which point the temperature began to increase back to levels measured in September. The change in pH was very gradual and was at first believed to be due to calibration drift. However, pH began to increase from February to August.

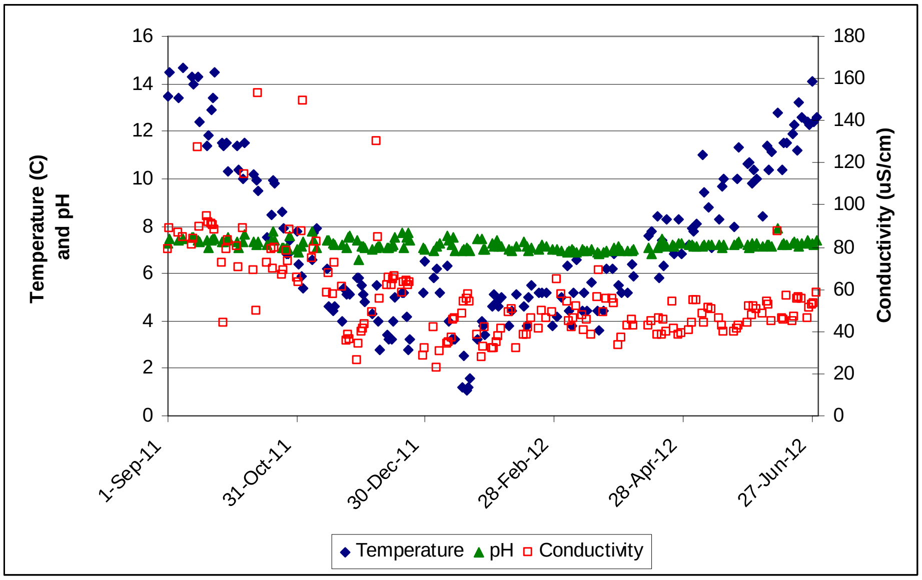

Figure 3-3 - Temperature pH and Conductivity

Organics & UV Transmittance

Figure 3-4 shows the measured values of total organic carbon (TOC), dissolved organic carbon (DOC) and UV Transmittance (UVT). The data shows that the three parameters oscillate over time, although there a slight increase in TOC and DOC was observed in the winter. The apparent increase in DOC was accompanied by a decrease in UVT in the spring, suggesting an inverse correlation between UVT and DOC. This relationship is commonly observed in surface water sources. However, plotting UVT directly against DOC, as shown in Figure 3-5, shows a poor correlation, even when the larger TOC value of 6.7 mg/L is omitted from the data set. A calculation of R2-values for this plot, which indicates on a scale of 0 to 1 how close the data points fall along a best-fit line, produced values of 0.2 to 0.6, which are well below the desired value of 0.9 or greater that would indicate a significant correlation. Qualitatively, it appears that a decrease measured on a UVT analyzer would indicate that an increase in DOC had occurred, but in the absence of a numerical correlation an accurate projection of organic concentrations based on UVT cannot be calculated.

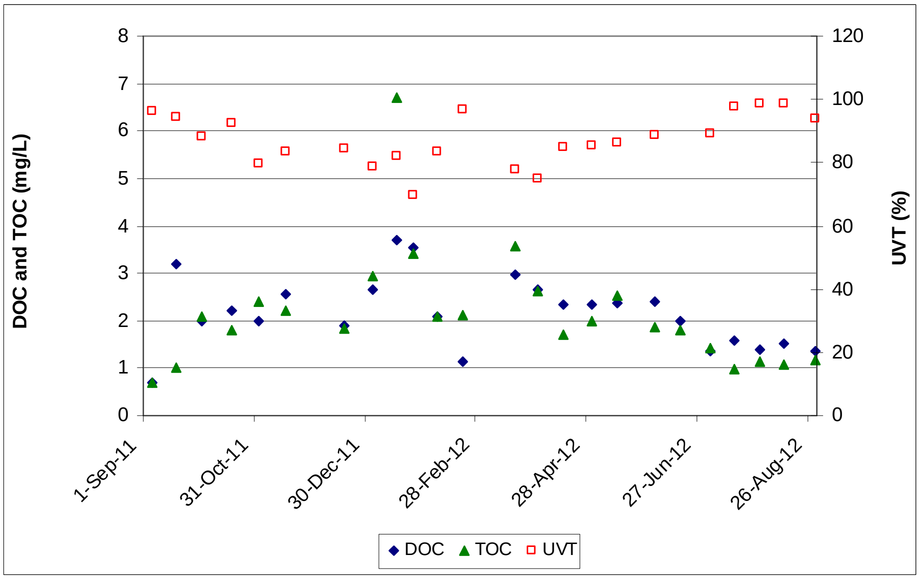

Figure 3-4 - Organic Concentrations and UVT

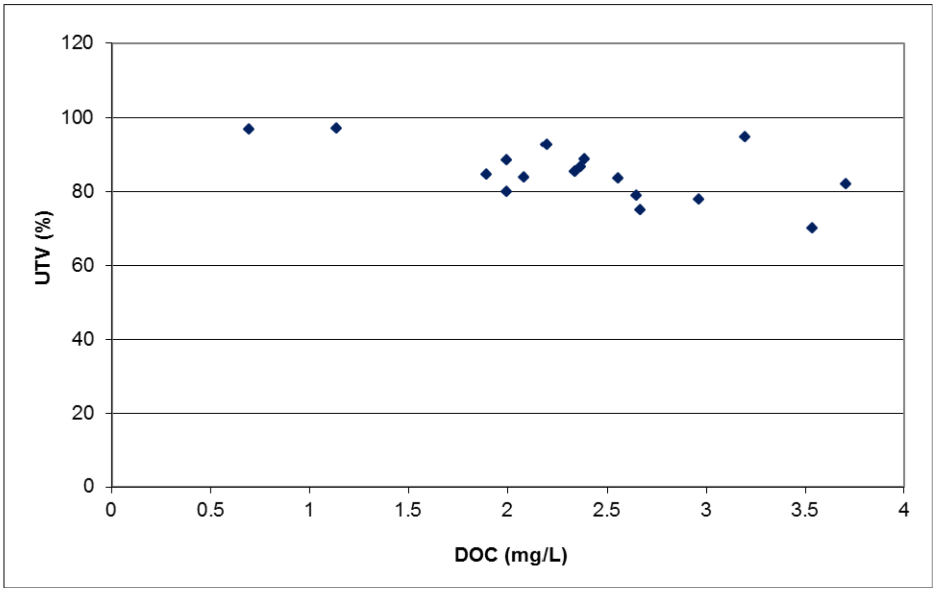

Figure 3-5 - DOC versus UVT

TDS & Hardness

Figure 3-6 shows hardness and total dissolved solids (TDS) as measured over time. Hardness appears to decrease from September to December, remain low from January to March, and increase back to original levels from April to August. TDS also appears to decrease in the fall and return to original levels in the spring and summer, although greater variation in the data makes this trend less apparent. Total hardness is a measure of ions such as calcium and magnesium, while

TDS is a measure of all dissolved ions. The two parameters follow similar trends implying that either a significant portion of the dissolved ions in the Englishman River are hardness ions or that the composition of ions in the river remains proportionally consistent throughout the year.

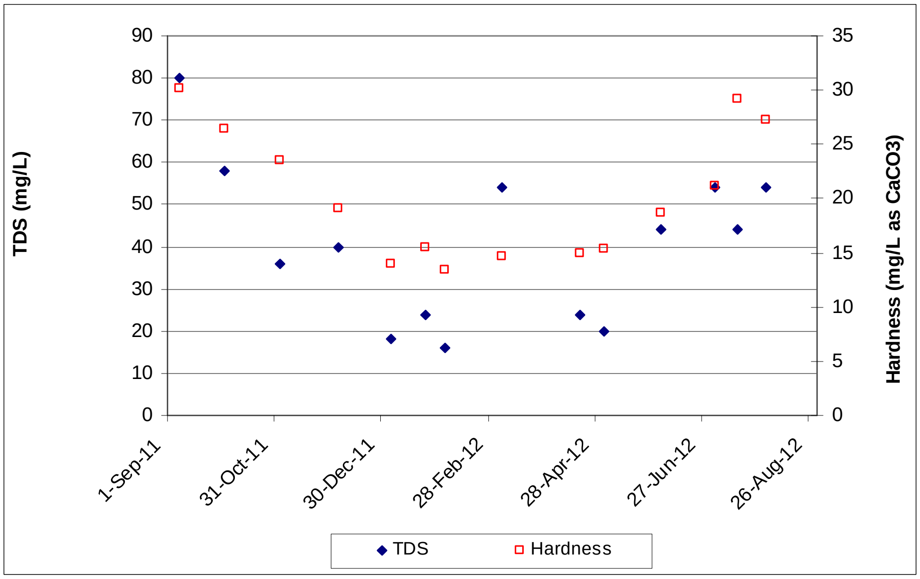

Figure 3-6 - TDS and Hardness

Aluminum

An examination of total aluminum concentrations over time, shown in Figure 3-7, suggests that aluminum concentrations increased from September to December and decreased in April to July. Two items of interest were noted: the first is that total aluminum concentrations increased at the same time that TDS decreased, indicating that the aluminum present in the Englishman River is predominantly in suspended form, not dissolved. The second item of interest is that none of the other metals such as iron, manganese, and copper had a similar trend.

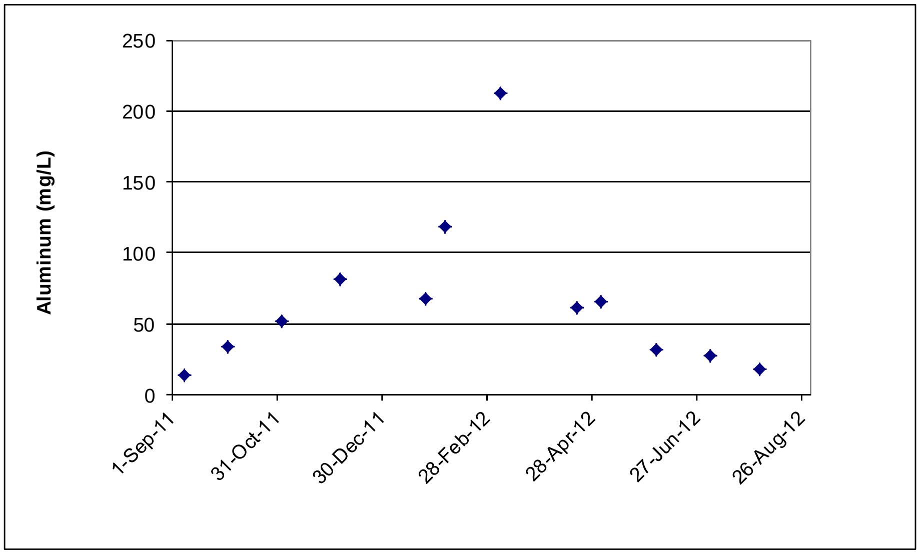

Figure 3-7 - Aluminum

Bacteriological Quality

Total coliforms were measured in their greatest concentrations in the summer, while *E.coli* counts peaked in July but were relatively low in August. No other relationships were identified for these two parameters. The *E.coli* and total coliform counts are shown in Figure 3-8.

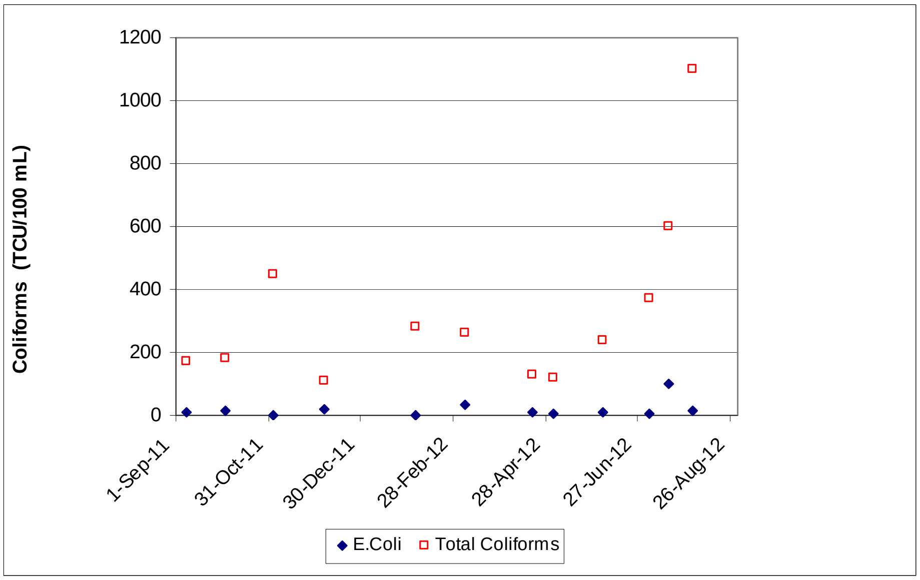

Figure 3-8 - Total Coliforms and *E.coli*

Chlorine Residual – Distribution System

The behaviour of the free chlorine residual in the distribution system does not appear to differ significantly in the fall and the spring, as shown in Figure 2-4. However, in the months of July and August, the average chlorine residual appeared to drop slightly and oscillate less from day to day. There does not appear to be a greater presence of organics or other parameters that have a chlorine demand. Typically ERWS brings their wells offline during this period to allow them to recharge. With just the intake adding new water to the distribution system, flow through the system is more uniform and therefore less likely to disturb biofilm inside the pipe that can have a chlorine demand. Alternatively, the warmer water temperatures in the river may accelerate the degradation of the chlorine residual to a small degree.

3.2 Changes with Flow

Reviewing the figures plotted in Section 3.1, potential relationships between several water quality parameters and flow are apparent and were examined below.

Precipitation

Despite expectations, a correlation between river flow and rainfall as measured at the Industrial Park is not readily apparent. This is likely because the river experiences different rates of precipitation at the Arrowsmith Dam, and that contributions to the river upstream of the rain gauge are large enough that precipitation contributions near Parksville to the river are insignificant.

Conductivity

Decreases in conductivity coincided with elevated flow but, as shown in Figure 3-9, a significant correlation could not be established, even when using logarithmic scales or polynomial equations to compare the data.

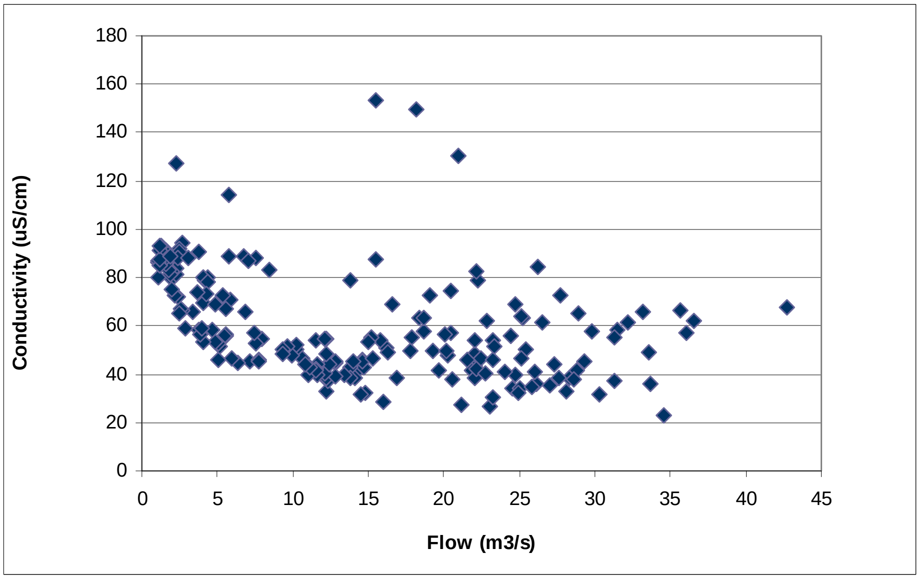

Figure 3-9 - Conductivity versus Flow

Organic Concentrations

Organic concentrations and UVT experienced general changes that coincided with changes in flow, as shown in Figure 3-10, but not at any consistency that could be considered significant.

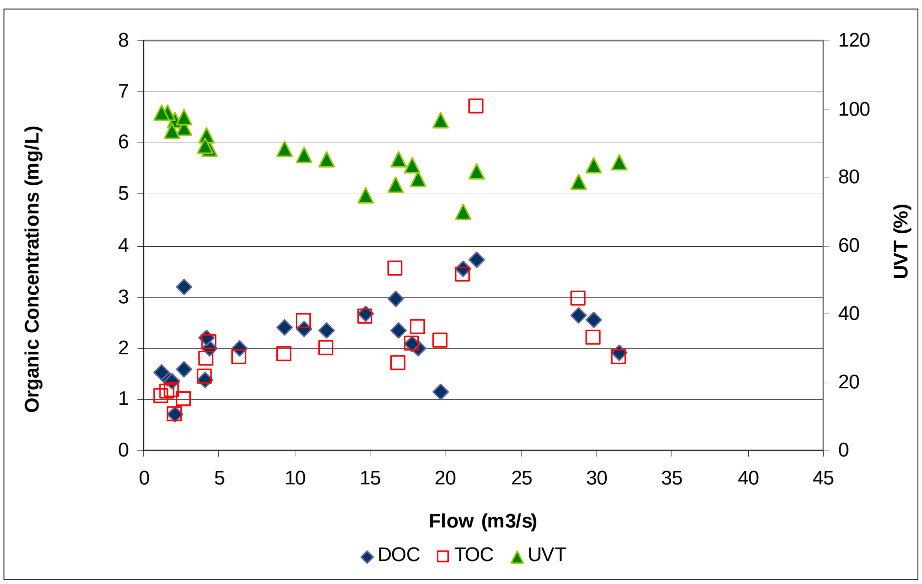

Figure 3-10 - Organic Concentrations and UVT versus Flow

Chlorine Residual - Distribution System

A comparison of flow to average chlorine residual, shown in Figure 3-11, reveals that a sudden dip in the chlorine residual occurred whenever flows exceeded 15 m^3/s. This is likely due to the greater flows carrying more organic and inorganic matter that consume a portion of the chlorine residual.

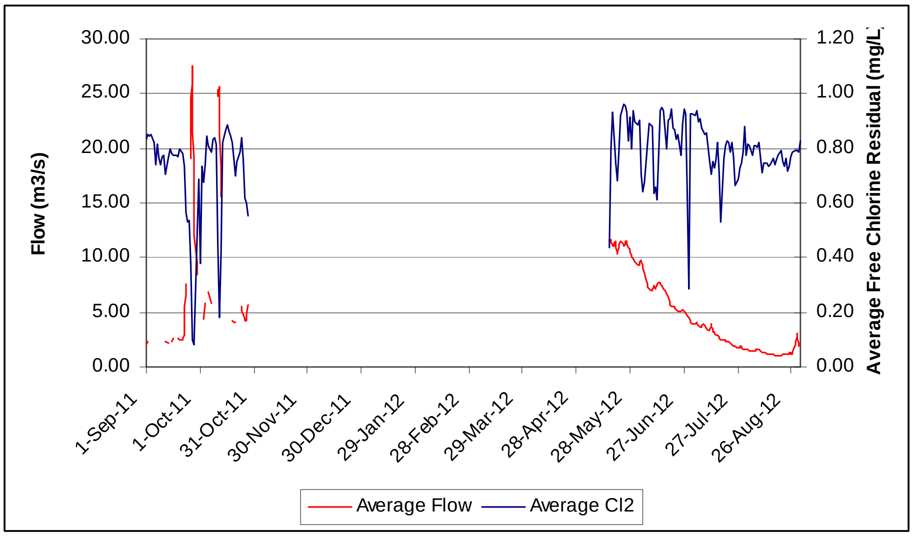

Figure 3-11 - Flow and Chlorine Residual

In summary, an increase in river flows was typically accompanied by a decrease in conductivity and UVT, and an increase in TOC and DOC. Greater flows also coincided with temporary drops in chlorine residual. However, a direct, quantitative equation relating these parameters together could not be established to a significant degree.

3.3 Changes with Precipitation

Alongside river flow rates, precipitation patterns changed throughout the year, reaching their peak in the winter. The water quality dataset was examined to determine whether a relationship was apparent between precipitation and any of the water quality parameters.

Organic Concentrations

As illustrated in Figure 3-12, the highest measured organic concentrations coincided with a rainfall spike that occurred in late January, and a local spike occurred in March, several days after a heavy rainfall. However, as illustrated in Figure 3-13, a direct correlation could not be between rainfall and measured TOC or DOC.

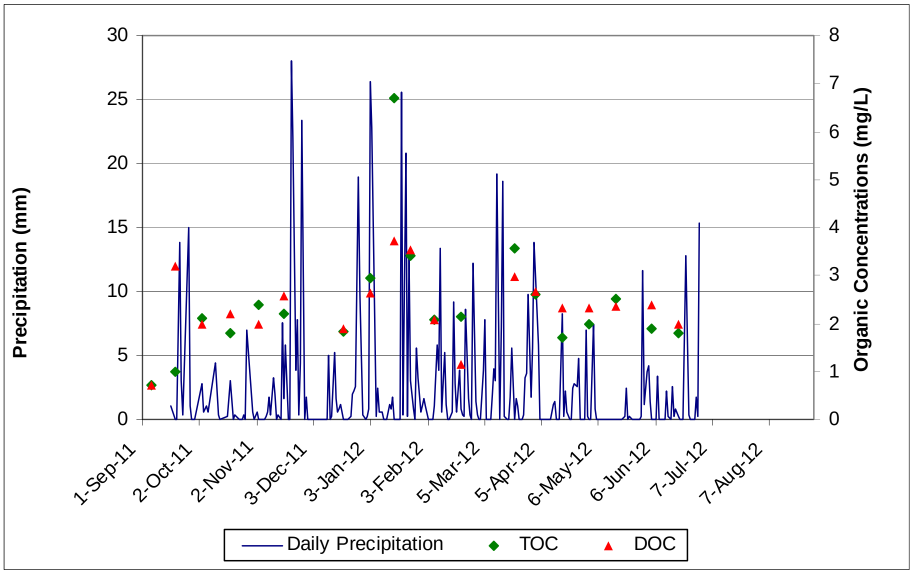

Figure 3-12 - Organic Concentrations and Precipitation

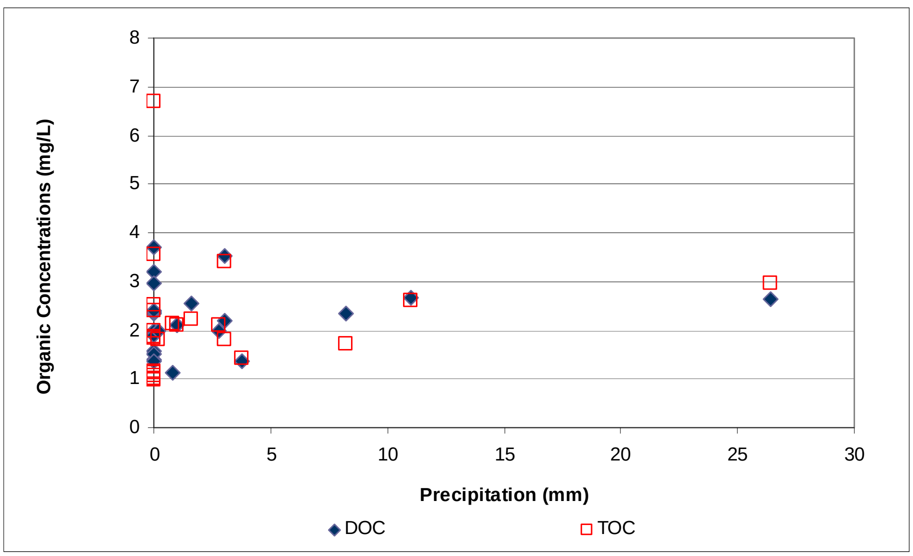

Figure 3-13 - Organic Concentrations versus Precipitation

Conductivity

Examining the data collected during the winter, localized dips in conductivity occurred whenever rainfall exceeded 13 mm/day, but not for smaller rain events. This relationship was also observed in the month of April, but not in the final periods of rain in June, as illustrated in Figure 3-14. A plot of conductivity versus precipitation, shown in Figure 3-15, showed no direct relationship between conductivity and precipitation could be significantly quantified.

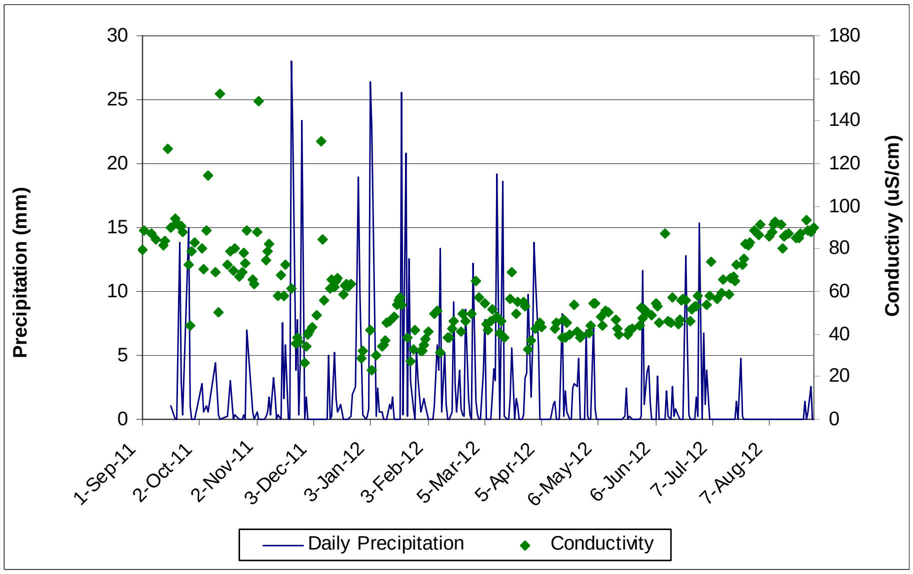

Figure 3-14 - Conductivity and Precipitation

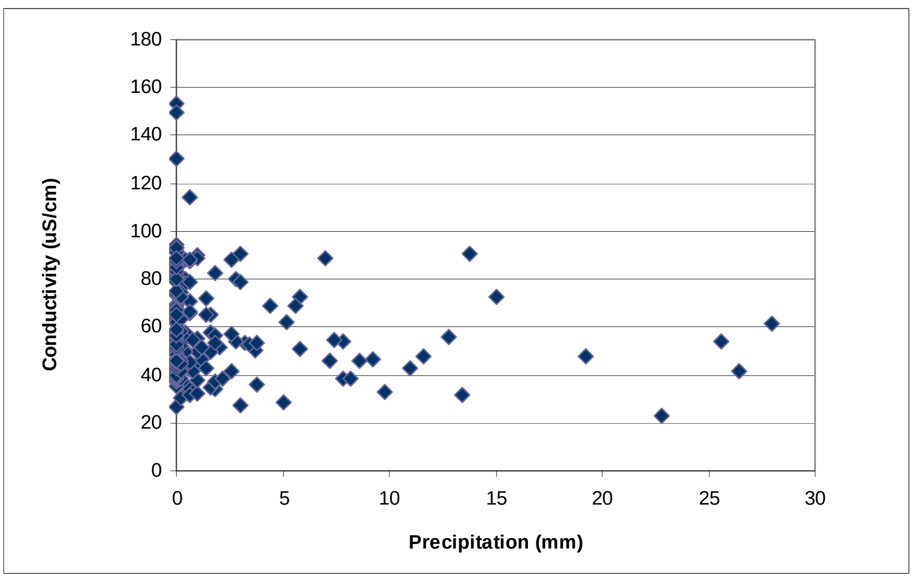

Figure 3-15 - Conductivity versus Precipitation

Turbidity

The data collected from the PRK1 turbidimeter, illustrated in Figure 2-3, showed a lull in turbidity spike events near the end of December. The rest of December, and all of January, was characterized by multiple high-magnitude turbidity spike events, so this calm period was unexpected. During this time period, river flow was unchanged, but there was a drop in precipitation. It is suspected that the reduction in precipitation resulted in less sediment contributions to the river during this time period. However, a direct relationship between precipitation and Englishman River turbidity could otherwise not be identified.

3.4 Turbidity Spike Event - January

Between January 16 and 24 of 2012, a temporary but significant change occurred for a number of Englishman River water quality and physical characteristics, summarized as follows:

- Iron, manganese, and aluminum were measured in concentrations greater than what was typically present. Iron and manganese concentrations exceeded the GCDWQ aesthetic objectives.
- DOC and TOC concentrations peaked at the same time as a dip in UVT occurred.
- Water temperature dropped to its lowest value in the 12-month data set.
- Turbidity spiked to 50 NTU, followed by spikes in the order of 30 NTU on subsequent days.
- A period of high precipitation, roughly 20 mm per day as rain, was experienced.

A review of local weather conditions indicated that this coincided with the only period this winter where daily temperatures remained below 0°C. It is possible that the significantly high volumes of precipitation and/or sub-zero temperatures contributed to the spikes in metal concentrations. Daily precipitation was less than 20 mm for the remainder of the monitoring program. No other spikes in metal concentrations were captured, with the exception of the event in July described in the section below.

3.5 Riverbank Collapse Impact

On July 17, 2012 a portion of a clay bank upstream of the sampling locations collapsed into the Englishman River. In response the ERWS brought their existing intake offline and relied solely on their groundwater supplies until the turbidity spike event caused by the bank collapse had passed. ERWS staff were able to capture a sample of the event for analysis. The following observations were made:

- *E.coli* counts increased from the order of 10 counts/100 mL to 100 counts/100 mL.
- Total coliform counts increased from roughly 300 counts/100 mL to 600 counts/100 mL, although this was not the greatest concentration of total coliforms measured in the monitoring program.
- Turbidity spiked to 122 NTU.
- Aluminum, iron, manganese, copper and lead concentrations increase significantly from previously measured levels. Iron and manganese concentrations exceeded their AO levels and aluminum concentrations by over almost two orders-of-magnitude.

What is particularly important to note about this event is that it occurred during the summer, when significant changes to raw water quality are generally not anticipated, and that it occurred at a time of year when community water demands are at their greatest. Additionally, this event consisted solely of riverbank contributions, and therefore can be compared to the rest of the monitoring data to see if other events bear similar characteristics, which would indicate whether these other events are also caused by riverbank contributions.

4 Discussion

4.1 Data Review

Total coliforms and E. coli were detected in all river samples taken. This is not surprising, as these bacteria are commonly detected in most surface water sources. The greatest concentrations of total coliforms and *E.coli* were detected in the summer. Combined with the lack of a correlation with flow or precipitation, it is believed that these greater concentrations are due to the increased activity in the river and the warmer summer temperatures which are more favourable to bacterial growth.

For the majority of the year turbidity was at levels of 1 NTU or lower, but one could expect periodic turbidity spikes, particularly during the winter. A general rule of thumb is that a turbidity event can be anticipated during periods of sudden, heavy flow in the river or rainfall. However, no parameter could be identified to help confidently predict the date and magnitude of future events. Based on the available data, it appears that riverbank sediment is the primary contributor to the river's turbidity.

True colour was measured to exceed the drinking water aesthetic objectives on several occasions throughout the monitoring period, although no trend could be identified to predict when colour levels could rise.

The chlorine residual oscillated between 0.2 and 1.0 mg/L on a typical day, and appeared qualitatively sensitive to a number of factors. When river flows exceeded 15 m^3/s, it is believed that the river would carry additional organic and inorganic matter that exerted a natural chlorine demand, hence reducing the chlorine residual for a short time. Warmer water temperatures also coincided with a decrease in chlorine residual, believed to be due to the warmer temperatures accelerating the residual's degradation rate. Even whether the groundwater system was running or not may have impacted residual concentrations.

Conductivity, TDS levels, hardness and pH all decreased during the winter. The four parameters are related in that they all measure ion activity or ion concentrations in the water. It is believed that elevated flows and water levels in the river dilute the dissolved ions in the water, lowering their overall concentrations in the river. This dilution means that additional ions are not introduced into the water at great enough level to offset the dilution caused by the additional water in the river. As water levels lower in the summer, these ions become more concentrated. Therefore it appears that the total amount of dissolved ions in the water do not significantly change throughout the year, only their concentration.

Aluminum concentrations increased slightly during the winter. The aluminum appears to be present in the suspended form, as TDS concentrations were decreasing as aluminum concentrations increased. A significant spike in aluminum concentrations occurred when a portion of a clay bank collapsed in the summer, suggesting that the river banks are a natural source of metals. Other metals, such as iron, manganese, and copper, increased in concentrations when the clay bank collapsed but did not change over time. This suggests that aluminum along the riverbank is either more readily mobile under wet conditions, or is present in greater concentrations than the other monitored metals.

In addition to the riverbank collapse in July, a second spike in metal concentrations was observed in January during a period of heavy rainfall and during the only period in the monitoring program where air temperatures constantly remained below 0°C. It is believed that the heavy precipitation, possibly combined with the freezing temperatures, encouraged a significant erosion of the riverbanks upstream.

It is not surprising that greater organic matter, in the form of TOC and DOC, would be in the water during the winter, as large amounts of dead vegetative matter are available along the riverbanks at this time, and the large amount of rainfall during the winter provides ample opportunities for this matter to be carried to the river. Typical of surface water, UVT appeared to be inversely related to DOC concentrations.

Analysis and comparison of DBP formation potential in Englishman River raw water, and actual DBP concentrations measured in the distribution system indicate that DBP precursors are present in the river, but at the amount of chlorine added to the ERWS drinking water system do not form in sufficient levels to be a health concern. The DBP concentrations measured in the distribution system were well below the MAC limits.

Overall, it is believed that high river flows or heavy rainfall lead to changes to some of the water quality parameters as listed above. However, the relationship between these parameters and flow or precipitation are not simple and a numerical equation that would allow water quality data to be predicted based on measured flows and precipitation could not be produced. The high flow rates and precipitation contribute to the erosion and collapse of the river bank, which appears to be the primary contributor of turbidity and suspended metals in the water.

The changes in water quality that occurred during the July event were similar to the changes observed during the January event. This suggests that heavy rain and cold air temperatures produce a result similar to a collapse in the riverbank, that is, by carrying a large contribution of riverbank sediment into the river in a short period of time.

4.2 Implications on Treatment Requirements

4.2.1 Reference Water Quality Standards

Based on the results of the monitoring program, the following parameters in Englishman River water will require treatment in order to meet drinking water quality standards:

- Turbidity: the overall turbidity of water entering the distribution system must remain below 1 NTU. Additional requirements are dependent on the type of filtration used. The treatment process used would need to rapidly adjust to sudden spikes in turbidity that can occur at any time of the year.
- True colour: colour concentrations must be reduced to less than 15 TCU.
- Microbiological: as indicated by the regular detection of total coliforms and *E.coli*, a combination of filtration and disinfection would be required to achieve the following:
  - Minimum 4-log (99.99%) removal or inactivation of viruses.
  - Minimum 3-log (99.9%) removal or inactivation of *Cryptosporidium parvum* and *Giardia lamblia*.
  - A minimum 0.2 mg/L chlorine residual to maintain the integrity of the water as it travels through the distribution system.
- Metals: spikes of suspended iron and manganese to be reduced to less than 0.3 mg/L and 0.05 mg/L, respectively. Although not required, it is recommended that the spikes in suspended aluminum also be removed to maintain a consistent water quality.

4.2.2 Treatment Implication

The existing treatment system consists of chlorination only, and cannot meet the water quality objectives listed above. However, all of the treatment objectives can readily be achieved through a combination of filtration and disinfection. A detailed discussion of the filtration and disinfection options is provided in Discussion Paper 4-3, prepared under Phase 1 of the Englishman River Water Intake, treatment Facilities and Supply Mains project. Based on an evaluation documented in the October 7, 2011 memorandum titled "Selection of Treatment Processes to Pilot", the following treatment processes were recommended for further study, based on their ability to meet the treatment objectives listed above and their ability to react to sudden changes in water quality:

- Conventional filtration followed by chlorination and possibly UV irradiation
- Membrane filtration followed by chlorination and possibly UV irradiation

While not addressed in Discussion Paper 4-3, these two treatment options can readily remove suspended metals, and can reduce colour if the appropriate coagulant is used.

5 Conclusions

The 12-month monitoring program successfully confirmed which water quality parameters in the Englishman River water were of concern, as well as identified a parameter that had not originally been identified as a concern from the historical data. These parameters are as follows:

- Turbidity
- True colour
- Spikes in suspended metals
- Microbiological parameters associated with surface water

All of these parameters can be properly addressed to meet drinking water standards by using a combination of filtration and disinfection as treatment.

The monitoring program also identified how the characteristics of the Englishman River water change throughout the seasons, namely:

- Turbidity spike events happen quickly and unexpectedly throughout the entire year.
- Turbidity spike events are greater in intensity during the winter.
- Average turbidity is greater during the winter and spring.
- True colour concentrations oscillate throughout the year without any identifiable pattern.
- Organic concentrations increased slightly during the summer.
- UVT decreased during the winter, in a proportional inverse correlation to dissolved organic concentrations.
- TDS, hardness, pH and conductivity increased during the winter.
- Aluminum concentrations increased slightly during the winter.
- Total coliforms and E. coli concentrations were at their greatest in the summer.

This information can be used to refine the refine the design of the future Englishman River intake and water treatment plant.

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Appendix A - Water Sampling Protocol

Recommended sampling protocol

Frequency	Parameter	Measurement Method
Continuously	• Turbidity • Chlorine residual	Online analyzer Online analyzer
Daily/every 2nd day	• pH • True colour	• Field but could not hurt for occasional lab confirmation • Field
Weekly		
Biweekly	• TOC – grab more frequently when high flows/significant rain storm occurs • DOC – for the first few months only • UVT • Temperature – field measured • Conductivity – lab	• Lab • Lab • Lab • Field • Lab
Monthly	• General potability test – includes metals	• Lab
Quarterly	• THM, HAA – from distribution system	• Lab

Appendix B - Water Quality Data

Parameter	**Unit**	8-Sep-11	3-Oct-11	3-Nov-11	6-Dec-11	5-Jan-12	24-Jan-12	4-Feb-12	7-Mar-12	20-Apr-12	3-May-12	4-Jun-12	5-Jul-12
Microbiological													
Total Coliforms	CFU/100mL	170	180	450	110			280	260	130	120	240	370
E.coli	CFU/100mL	10	14	<100	19			1	33	8	4	10	6
Chemical Parameters													
Alkalinity (Total as CaCO3)	mg/L	24	23	20	14.1	9.13	11.8	11.6	13.4	13.3	12.8	17	20.4
Alkalinity (PP as CaCO3)	mg/L	<0.5	<0.5	<0.5	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Nitrate (N)	mg/L	<0.02	<0.02	0.799	0.03	<0.020	0.069	0.026	0.041	<0.020	<0.020	<0.020	<0.020
Nitrite (N)	mg/L	<0.005	<0.005	0.011	<0.005	0.016	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Nitrate plus Nitrite (N)	mg/L	<0.02	<0.02	0.81	0.03	<0.020	0.069	0.026	0.041	<0.020	<0.020	<0.020	<0.020
Colour	Col. Unit	<5	5	10	15	50	30	10	20	5	5	5	<5.0
Turbidity	NTU	<0.4	0.5	0.5	1.22	57.5	5.33	1.33	3.44	0.57	0.64	0.48	0.38
Conductivity	uS/cm	86	76	62	52.4	27.1	43.7	38.7	39.6	39.2	38.8	48.7	58.2
pH		7.56	7.41	7.49	7.2	7.11	7.1	7.17	7.35	7.32	7.41	7.41	7.43
Total Disolved Solids	mg/L	80	58	36	40	18	24	16	54	24	20	44	54
Hardness (CaCo3)	mg/L	30.1	26.4	23.5	19.1	14	15.5	13.4	14.7	14.9	15.3	18.7	21.2
Sulphate (SO4)	mg/L	1.5	<0.5	0.5	1.68	<0.50	<0.50	0.84	0.99	1.62	0.87	1.26	1.68
Bicarbonate (HCO3)	mg/L	29	28	25	17.2	11.1	14.4	14.1	16.3	16.3	15.7	20.8	24.9
Carbonate (CO3)	mg/L	<0.5	<0.5	<0.5	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Hydroxide (OH)	mg/L	<0.5	<0.5	<0.5	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Metals													
Aluminum (Al)	ug/L	14	34	52	81.9		67.3	118	213	61	65.3	31.3	26.9
Antimony (Sb)	ug/L	<0.5	<0.5	<0.5	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Arsenic (As)	ug/L	0.1	0.1	0.1	0.15	0.57	0.16	<0.10	0.17	0.14	0.13	0.11	0.13
Barium (Ba)	ug/L	6	6	5	4.3	15.2	4.6	3.5	4.4	3.6	3.1	3.2	3.8
Boron (B)	ug/L	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Cadmium (Cd)	ug/L	<0.01	<0.01	0.02	<0.010	0.027	0.011	<0.010	<0.010	<0.010	<0.010	<0.010	0.011
Calcium (Ca)	mg/L	11	8.72	7.81	6.14		4.7	4.28	4.71	4.76	5.1	6.26	9.09
Chloride (Cl)	mg/L	11	8.9		5	1.3	4.5	2.8	3.3	2.9	2.2	3	4.4
Chromium (Cr)	ug/L	<1	<1	<1	6.3	3.5	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Cobalt (Co)	ug/L	<0.5	<0.5	<0.5	<0.50	1.16	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.57
Copper (Cu)	ug/L	0.5	0.7	0.7	1.2	9.26	2.46	0.63	1.04	3.62	0.59	0.65	0.57
Fluoride (F)	mg/L	0.02	0.02		0.012	0.015	0.019	0.017	0.019	0.015	0.014	0.014	0.015
Iron (Fe)	ug/L	72	77	74	114	1660	258	78.9	185	55.1	57	48	65.2
Lead (Pb)	ug/L	<0.2	<0.2	<0.2	<0.20	1.05	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Magnesium (Mg)	mg/L	1.2	1.11	0.97	0.909	0.842	0.918	0.668	0.721	0.732	0.62	0.73	
Manganese (Mn)	ug/L	9	6	5	4.7	63.6	6.8	2.1	4.5	1.6	1.6	2.1	3.1
Mercury (Hg)	ug/L	<0.05	<0.05	<0.05	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Molybdenum (Mo)	ug/L	<1	<1	<1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Nickel (Ni)	ug/L	<1	<1	<1	3	5	<1	<1	<1	<1	<1	<1	<1
Potassium (K)	mg/L	0.13	0.14	0.15	0.124	0.124	0.169	0.098	0.123	0.074	0.082	0.077	0.091

Parameter	Unit	8-Sep-11	3-Oct-11	3-Nov-11	6-Dec-11	5-Jan-12	24-Jan-12	4-Feb-12	7-Mar-12	20-Apr-12	3-May-12	4-Jun-12	5-Jul-12
Selenium (Se)	ug/L	<0.1	<0.1	<0.1	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	
Silver (Ag)	ug/L	<0.02	<0.02	<0.02	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	
Sodium (Na)	mg/L	4.42	3.82	3.55	2.86	1.1	2.45	1.83	1.92	1.83	1.58	2.03	2.5
Sulphur (S)	mg/L	<3	<3	<3	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0
Uranium (U)	ug/L	<0.1	<0.1	<0.1	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	
Vanadium (V)	ug/L	<5	<5	<5	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	
Zinc (Zn)	ug/L	<5	<5	<5	<5.0	7.4	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	
THM													
Chloroform	ug/L	7			7.8							21	
Chlorodibromoethane	ug/L	3			4.1							<1	
Bromodichloromethane	ug/L	4			3.8							<1	
Bromoform	ug/L	1			1.7							<1	
Total THM	ug/L				17.4							<1	
HAA													
MCAA	ug/L	<5			<5							<5	
MBAA	ug/L	<5			<5							11	
DCAA	ug/L	<5			<5							11	
TCAA	ug/L	<5			<5							<5	
BCAA	ug/L	<5			<5							<5	
DBAA	ug/L	<5			<5							22	
Total HAA	ug/L	<5			<5								
THM FORMATION POTENTIAL													
Chloroform	ug/L					530	420						
Chlorodibromoethane	ug/L					<3	<3						
Bromodichloromethane	ug/L					3	6						
Bromoform	ug/L					<3	<3						
Total THM	ug/L					550	430						
HAA FORMATION POTENTIAL													
MCAA	ug/L						<5						
MBAA	ug/L						<1						
DCAA	ug/L						46						
TCAA	ug/L						49						
BCAA	ug/L						0.7						
DBAA	ug/L						<0.5						
Total HAA	ug/L						95						

Parameter	Unit	17-Jul-12	2-Aug-12	5-Sep-12	9-Sep-12	10-Sep-12	13-Sep-12
Microbiological							
Total Coliforms	CFU/100mL	600	1100	230			
E.coli	CFU/100mL	100	13	21			
Chemical Parameters							
Alkalinity (Total as CaCO3)	mg/L	23.7	22.3	22.9			
Alkalinity (PP as CaCO3)	mg/L	<0.50	<0.50	<0.50			
Nitrate (N)	mg/L	<0.020	<0.020	<0.020			
Nitrite (N)	mg/L	0.0547	<0.005	<0.005			
Nitrate plus Nitrite (N)	mg/L	0.06	<0.020	<0.020			
Colour	Col. Unit	30	5	<5.0			
Turbidity	NTU	122	0.35	0.42			
Conductivity	uS/cm	67.6	81.3	86.4			
pH		7.51	7.55	7.55			
Total Disolved Solids	mg/L	44	54	56			
Hardness (CaCo3)	mg/L	29.2	27.3	28.7			
Sulphate (SO4)	mg/L		<0.50	1.68			
Bicarbonate (HCO3)	mg/L		27.2	27.9			
Carbonate (CO3)	mg/L		<0.50	<0.50			
Hydroxide (OH)	mg/L		<0.50	<0.50			
Metals							
Aluminum (Al)	ug/L	1510	17.9	13.5			
Antimony (Sb)	ug/L	<0.50	<0.50	<0.50			
Arsenic (As)	ug/L	0.93	0.14	0.12			
Barium (Ba)	ug/L	17.2	5.9	5.6			
Boron (B)	ug/L	<50	<50	<50			
Cadmium (Cd)	ug/L	0.048	0.067	<0.010			
Calcium (Ca)	mg/L		9.09	9.56			
Chloride (Cl)	mg/L		10	12			
Chromium (Cr)	ug/L	2.3	<1.0	<1.0			
Cobalt (Co)	ug/L	1.46	<0.50	<0.50			
Copper (Cu)	ug/L	12	0.95	0.79			
Fluoride (F)	mg/L		0.013	0.015			
Iron (Fe)	ug/L	2640	68	71.1			
Lead (Pb)	ug/L	0.63	<0.20	<0.20			
Magnesium (Mg)	mg/L	1.58		1.18			
Manganese (Mn)	ug/L	69.1	7.1	8.8			
Mercury (Hg)	ug/L	<0.050	<0.050	<0.050			
Molybdenum (Mo)	ug/L	<1.0	<1.0	<1.0			
Nickel (Ni)	ug/L	2.9	<1	<1			
Potassium (K)	mg/L	0.287		0.136			

Parameter	Unit	17-Jul-12	2-Aug-12	5-Sep-12	9-Sep-12	10-Sep-12	13-Sep-12
Selenium (Se)	ug/L	<0.10	<0.10	<0.10			
Silver (Ag)	ug/L	<0.020	<0.020	<0.020			
Sodium (Na)	mg/L	3.1		4.76			
Sulphur (S)	mg/L	<3.0	<3.0	<3.0			
Uranium (U)	ug/L	<0.10	<0.10	<0.10			
Vanadium (V)	ug/L	6.1	<5.0	<5.0			
Zinc (Zn)	ug/L	6.3	<5.0	<5.0			
THM							
Chloroform	ug/L			1.3	2.4		
Chlorodibromoethane	ug/L			2.4	3.2		
Bromodichloromethane	ug/L			1.6	2.4		
Bromoform	ug/L			1.2	1.4		
Total THM	ug/L						
HAA							
MCAA	ug/L			<5			
MBAA	ug/L			<5			
DCAA	ug/L			<5			
TCAA	ug/L			<5			
BCAA	ug/L			<5			
DBAA	ug/L			<5			
Total HAA	ug/L						
THM FORMATION POTENTIAL							
Chloroform	ug/L					10	
Chlorodibromoethane	ug/L					4.6	
Bromodichloromethane	ug/L					5	
Bromoform	ug/L					<3	
Total THM	ug/L					20	
HAA FORMATION POTENTIAL							
MCAA	ug/L						<5
MBAA	ug/L						<1
DCAA	ug/L						1.5
TCAA	ug/L						<1
BCAA	ug/L						<0.5
DBAA	ug/L						<0.5
Total HAA	ug/L						<5

Date	Flow (m3/s)		Rainfall (mm)	Turbidity (NTU) - Existing Intake			New Intake	Temp	True Colour	pH	Conductivity	DOC	UVT	TOC	
	Max	Average	Works Yard	Min	Max	Ave	Location (NTU)	°C	mg/L Pt Co		µs/cm				
1-Sep-11	2.18	2.00						13.5	9	7.27	79.3				
2-Sep-11	2.37	2.27					0.65	14.5	36	7.45	88.6				
6-Sep-11	2.18	2.13					0.63	13.4	6	7.41	87	0.7	96.5	0.7	
8-Sep-11	2.25	2.18					0.72	14.7	10	7.47	84.7				
12-Sep-11	2.32	2.26					1.02	14.3	14	7.54	81.4				
13-Sep-11	2.29	2.25					1	14	19	7.51	83.6				
15-Sep-11	2.60	2.27					1.08	14.3	19	7.41	127.1				
16-Sep-11	2.69	2.63	1				1.08	12.4	2	7.31	89.8				
19-Sep-11	2.74	2.67	0				0.68	11.4	0	7.42	94.3	3.2	94.6	1	
20-Sep-11	2.53	2.44	0				0.69	11.8	9	7.06	91.8				
21-Sep-11	2.83	2.47	13.8				0.8	12.9	4	7.43	90.8				
22-Sep-11	4.60	3.75	3				1.86	13.4	12	7.48	90.5				
23-Sep-11	9.82	7.52	0.4					14.5	37	7.49	88.2				
26-Sep-11	37.67	19.05	15				2.97	11.5	43	7.35	72.4				
27-Sep-11	33.06	27.35	1				6.5	11.4	44	7.31	43.8				High flows/heavy rains
28-Sep-11	18.32	13.81	0				1.76	11.5	31	7.38	79.1				
29-Sep-11	10.33	8.47	0				1.01	10.3	25	7.53	83.1				
3-Oct-11	5.22	4.33	2.8				0.82	11.4	32	7.35	80.1	2	88.4	2.1	
4-Oct-11	6.06	5.82	0.6				0.7	10.4	17	7.07	70.7				
6-Oct-11	7.22	6.79	1				0.6	10	8	7.36	88.9				
7-Oct-11	6.25	5.78	0.6				0.61	11.5	24	7.64	114.5				
11-Oct-11	33.83	24.74	4.4				6.14	10.2	43	7.31	68.8				
12-Oct-11	29.01	25.45	0.4				1.77	9.9	24	7.19	50.1				
13-Oct-11	19.69	15.52	0				1.22	9.5	25	7.33	153.1				
17-Oct-11	5.81	5.37	0.2				0.98	7.5	8	7.18	72.5				
19-Oct-11	4.42	4.21	3				0.55	8.5	24	7.4	78.7	2.2	92.4	1.8	
20-Oct-11	4.16	4.04	0				0.6	9.9	21	7.81	69.6				
21-Oct-11	5.95	4.09	0.4				0.6	9.8	15	7.41	79.9				
24-Oct-11	5.98	5.54	0				0.71	8.6	11	7.1	67				
25-Oct-11	5.20	4.85	0				0.69	7.9	26	7.07	69				
26-Oct-11	4.62	4.39	0.4				0.65	6.8	28	7.07	78.4				
27-Oct-11	4.62	4.27	0				1.16	6.8	37	7.04	73				
28-Oct-11	10.74	5.74	7				0.85	7.4	14	7.57	88.5				
31-Oct-11	7.37	6.82	0.6				0.86	7.8	36	7.03	65.8				
1-Nov-11	98.3	18.332	0	0.70	1.80	0.96	0.78	6.4	28	6.87	63.2				
2-Nov-11	49.4	15.482	0.6	0.80	3.90	1.14	0.98	5.9	29	7.14	87.7				
3-Nov-11	90	18.224	0	0.00	10.80	1.00	1.12	5.4	45	7.34	149.3	2	79.7	2.4	
4-Nov-11	88.8	17.113	0	0.80	1.30	0.98									
5-Nov-11	46.1	14.474	0	0.70	1.40	1.04									
6-Nov-11	177	23.546	0	0.80	1.10	0.92									
7-Nov-11	118	20.426	0.2	0.70	2.10	0.94	1.25	6.6	14	7.78	74.7				
8-Nov-11	142	22.226	0.6	0.80	1.40	0.94	0.76	7.7	19	7.37	79.1				
9-Nov-11	119	22.192	1.8	0.90	2.40	1.14	1.11	7.9	26	7.11	82.5				
10-Nov-11	227	23.234	0.4	1.10	20.80	1.73									
11-Nov-11	233	27.81	3.2	0.00	3.80	1.47									
12-Nov-11	153	27.827	2	1.20	2.50	1.44									
13-Nov-11	121	22.627	0	0.90	1.70	1.28									
14-Nov-11	76.4	18.682	0.4	0.90	1.30	1.08	1.33	4:48	41	7.38	58				
15-Nov-11	392	42.755	0	0.70	1.30	0.88	0.74	4.6	6	7.37	67.9				
16-Nov-11	303	38.597	7.6	0.90	1.30	0.99									
17-Nov-11	127	29.81	1.6	0.90	12.10	1.33	1.79	4.4	16	7.25	57.9	2.56	83.4	2.21	
18-Nov-11	125	27.763	5.8	0.60	3.00	0.73	1.23	4.6	29	7.19	72.6				
19-Nov-11	107	26.504	0	0.60	1.00	0.71									

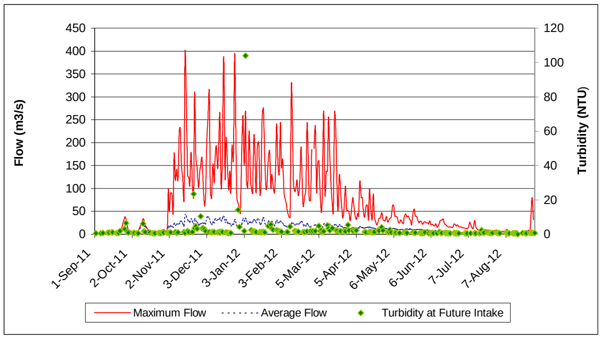
20-Nov-11	179	33.741	0	0.40	0.80	0.58									
21-Nov-11	110	26.484	28	0.40	1.90	0.78	1.33	4	16	7.21	61.2				
22-Nov-11	81.7	22.196	22				23.4	5.4	10						High turbidity event. Up to 90 NTU
23-Nov-11	310	33.716	3.8	3.40	15.20	4.64	3.5	5.1	34	7.09	35.7				
24-Nov-11	165	28.307	7.8	0.00	49.40	3.28	4.6	5.2	43	7.51	38.4				
25-Nov-11	145	26.099	0.4	1.70	13.40	2.24	3.2	5.1	44	7.56	36				
26-Nov-11	102	21.069	4.4	1.80	16.30	2.45									
27-Nov-11	138	21.787	23.4		198										
28-Nov-11	149	23.013	0	4.50	43.30	8.69	10.4	5.8	56	7.38	26.5				
29-Nov-11	167	24.585	1.8	2.80	13.80	3.56	3.42	5.8	77	6.58	34.3				
30-Nov-11	101	24.731	0	1.70	20.60	2.47	3.57	5.5	66	7.17	40				
1-Dec-11	61.5	24.084	0	1.30	2.90	1.48	2.98	5.1	25	7.12	41				
2-Dec-11	75	22.079	0	1.30	39.30	1.43	1.87	4.8	41	7.09	43.3				
3-Dec-11	197	36.459	0	0.90	1.50	1.09									
4-Dec-11	259	37.541	0	0.90	1.20	0.93									
5-Dec-11	310	33.6	0	0.80	1.30	0.94	1.26	4.3	23	7	49.1				
6-Dec-11	98	24.899	0	0.70	1.80	0.86									
7-Dec-11	77.5	20.927	0	0.70	1.10	0.76	1.19	5.5	23	7.1	130.2				
8-Dec-11	153	26.242	0	0.70	1.60	0.82	1.27	4	15	7.15	84.5				
9-Dec-11	112	24.401	0	0.60	1.10	0.73	1.33	2.8	16	7.13	55.7				
10-Dec-11	169	33.668	0	0.60	1.00	0.66									
11-Dec-11	193	30.546	5	0.70	1.00	0.80									
12-Dec-11	143	32.235	0	0.60	0.90	0.68	1.1	3.4	26	7.08	61.7				
13-Dec-11	215	33.153	0.2	0.60	0.90	0.68	1.25	3.2	13	7.11	65.7				
14-Dec-11	261	36.58	5.2	0.60	2.90	1.15	1.02	3.2	22	7.17	61.8				
15-Dec-11	100	28.944	1.6	0.70	1.70	0.94	1.47	4	16	7.2	64.9				
16-Dec-11	188	35.629	0.6	0.60	0.90	0.70	1.29	5	15	7.53	66.2				
17-Dec-11	387	38.439	0.8	0.60	0.90	0.72									
18-Dec-11	124	25.832	1.2	0.60	0.80	0.64									
19-Dec-11	211	31.531	0	0.60	0.80	0.65	1.11	5.2	10	7.71	58.3	1.9	84.5	1.83	
20-Dec-11	168	25.22	0	0.50	0.60	0.57	0.88	5.2	18	7.1	63.1				
21-Dec-11	96.1	25.17	0	0.40	0.80	0.50	0.65	4.2	6	7.52	63.7				
22-Dec-11	138	22.863	0	0.50	0.70	0.52	0.7	2.8	22	7.72	61.9				
23-Dec-11	90	18.669	0.2	0.50	0.70	0.54	0.7	3.2	16	7.43	63.4				
24-Dec-11	194	22.01	2	0.50	2.10	0.82									
25-Dec-11	161	21.777	2.2	1.20	2.10	1.55									
26-Dec-11	393	32.215	2.6	0.80	1.40	1.11									
27-Dec-11	262	26.623	19	0.80	5.49	1.29									
28-Dec-11	77.4	18.072	9.8												
29-Dec-11	68.1	16	5	3.80	31.20	9.53	14.2	5.2	44	7.07	28.7				High river flows. Turb up to 40 NTU
30-Dec-11	56	14.773	0.4	2.60	3.80	3.04	4.23	6.5	39	7.05	32.1				
31-Dec-11	46.2	14.307	0	1.80	2.70	2.13									
1-Jan-12	168	22.122	0.2	1.30	2.00	1.50									
2-Jan-12	259	34.464	0.8	1.20	1.40	1.29									
3-Jan-12	151	28.84	26.4	1.20	40.20	5.22	1.88	5.8	47	6.93	41.7	2.65	78.8	2.95	
4-Jan-12	269	34.561	22.8	0.00	50.00	33.48	104	6.2	55	7.16	23				High Turb Event
5-Jan-12	117	28.665	7.4	8.10	32.60	13.59									
6-Jan-12	101	23.263	0.2	0.00	43.40	5.44		5.2	50	7.3	30.3				
7-Jan-12	226	26.37	2.4	1.00	3.00	1.96									
8-Jan-12	131	26.748	0.6	0.20	1.10	0.56									
9-Jan-12	103	25.075	0.6	0.10	1.00	0.57	2.37	6.3	37	7.6	34.1				
10-Jan-12	90.2	27.019	0	0.00	0.30	0.05	1.7	4	34	7.42	35.1				
11-Jan-12	216	31.307	0	0.00	35.80	0.59	1.64	3.2	23	7.18	37				
12-Jan-12	160	29.351	0	0.90	1.70	1.07	1.4	3.2	24	7.54	45.5				
13-Jan-12	91	25.164	1.2	0.90	1.30	1.05	1.38	3.2	37	6.96	46.3				
14-Jan-12	194	33.568	0.8	0.90	1.50	1.00									
15-Jan-12	201	32.08	1.8	0.80	1.60	1.01									

16-Jan-12	85.4	22.032	0	0.90	1.20	0.98	1.22	1.2	21	6.93	48.4	3.71	81.9	6.7
17-Jan-12	96.5	22.075	0	0.80	1.00	0.87	1.09	2.5	12	7	53.9			
18-Jan-12	259	31.277	0	0.70	1.50	0.91	1.38	1.1	14	7.1	55.5			
19-Jan-12	275	36.099	0	0.70	1.00	0.84	1.39	1.2	45	6.99	57.3			
20-Jan-12	162	23.274	25.6	0.80	4.40	1.31	1.09	1.6	14	6.98	54			
21-Jan-12	97.7	18.863	0.4	3.40	6.80	4.79								
22-Jan-12	105	18.335	20.8	2.40	6.80	3.93								
23-Jan-12	161	27.654	0.2	1.20	50.00	5.10	4.85	3.2	50	7.44	38.4			
24-Jan-12	182	26.217	12.6	2.90	16.00	6.60								
25-Jan-12	101	21.2	3	2.10	30.00	5.18	5.59	4	43	7.44	27.4	3.54	69.8	3.42
26-Jan-12	131	28.116	0.8	1.60	34.30	2.40	3.38	3.8	36	7.03	32.7			
27-Jan-12	108	21.815	0	1.60	26.70	2.01	2.67	3.4	34	7.03	41.8			
28-Jan-12	90.8	18.476	5.6	1.40	2.20	1.52								
29-Jan-12	147	25.945	3.2	1.60	13.10	5.42								
30-Jan-12	241	30.268	0.6	1.70	3.90	2.48	2.38	4.6	28	7.26	31.9			
31-Jan-12	160	24.885	1	1.40	2.10	1.65	2.04	5.1	28	7.15	32.3			
1-Feb-12	132	25.834	1.6	1.30	3.10	1.55	1.65	4.8	32	7.38	34.8			
2-Feb-12	244	28.617	1	1.10	1.70	1.22	1.45	4.6	25	7.16	37.8			
3-Feb-12	146	26.059	0	0.90	33.70	1.12	1.48	5	23	7.15	41			
4-Feb-12	164	23.405	0	0.90	11.40	1.61								
5-Feb-12	89.8	20.284	0	0.90	1.30	1.03								
6-Feb-12	77.2	19.094	0	0.00	1.20	0.39								
7-Feb-12	64.6	17.818	1	0.00	0.00	0.00	1.17	3.8	28	7.02	49.4	2.09	83.6	2.09
8-Feb-12	49.7	16.232	5.8	0.00	0.00	0.00	1.24	4.4	22	6.96	50.7			
9-Feb-12	38.4	14.815	3.8	0.00	3.49	0.83								
10-Feb-12	36.3	14.539	13.4	3.40	5.70	4.42	4.42	5.1	31	7.12	31.7			
11-Feb-12	322	23.64	0.6	2.50	8.90	3.93								
12-Feb-12	255	24.492	5.2	1.90	5.32	2.25								
13-Feb-12	107	22.242	1.2	1.80	2.70	2.14								
14-Feb-12	92.6	20.559	0	1.60	3.20	1.80	1.84	4.6	32	7.36	38.1			
15-Feb-12	104	22.088	0	1.40	2.40	1.61	1.4	3.8	55	7.17	38.7			
16-Feb-12	118	22.178	0.6	1.40	1.90	1.58	1.56	5	26	6.95	42.3			
17-Feb-12	84.8	22.403	9.2	1.40	4.50	1.88	1.49	5.5	27	7.1	46.3			
18-Feb-12	111	24.578	2.8	2.20	4.50	2.86								
19-Feb-12	191	27.915	0.6	1.70	2.40	1.94								
20-Feb-12	137	27.243	3.8	1.50	2.10	1.67								
21-Feb-12	62.3	19.699	0.8	1.30	1.70	1.45	1.26	5.2	18	7.04	41.5	1.14	96.9	2.13
22-Feb-12	83.2	19.297	0.4	0.00	5.30	0.84	1.3	5.2	17	7.18	49.7			
23-Feb-12	92.8	17.342	0.2	0.00	4.20	0.69								
24-Feb-12	241	23.211	8.6	1.10	2.90	1.47	1.59	5.2	28	7.12	46.1			
25-Feb-12	191	19.935	1.6	1.70	3.00	2.17								
26-Feb-12	74.3	16.463	0.4	1.40	2.00	1.56								
27-Feb-12	73.6	16.269	0	1.20	2.40	1.55	1.91	3.8	20	7.01	49.3			
28-Feb-12	185	19.789	12.2	1.30	2.90	1.83								
29-Feb-12			1.4	1.60	2.60	1.79	1.82	4.2	23	7.03	65			
1-Mar-12	187	19.252	0.4	1.40	2.40	1.60								
2-Mar-12	234	20.49	0	1.30	1.60	1.40	1.92	5	12	6.97	57.4			
3-Mar-12	90.9	15.702	0	1.20	1.70	1.30								
4-Mar-12	154	16.8	3.8	1.20	3.20	1.43								
5-Mar-12	160	15.838	7.8	1.80	6.00	4.03	4.78	6.3	56	6.89	54.3			
6-Mar-12	85.9	12.833	0	1.70	2.00	1.83	1.88	4.4	32	6.97	44.9			
7-Mar-12	47.6	14.269	0	1.50	3.70	1.74	2.4	3.8	35	7.02	41.8			
8-Mar-12	87.2	14.607	0	1.30	1.60	1.38	1.37	5.2	56	6.96	46.1			
9-Mar-12	269	23.377	2	1.30	1.70	1.37	1.68	6.6	24	6.92	51.8			
10-Mar-12	87.5	19.209	4	1.30	1.60	1.39								
11-Mar-12	138	21.598	3	1.30	3.60	1.62								
12-Mar-12	138	20.267	19.2	1.60	11.60	5.22	5.25	4.4	30	7.01	48			
13-Mar-12	256	22.707	0	2.80	6.10	3.83	3.42	5.2	27	6.98	40.6			

14-Mar-12	173	21.53	7.2	2.30	3.10	2.46	2.22	4.4	25	6.95	45.8			
15-Mar-12	104	18.067	18.6	2.40	15.40	9.13								
16-Mar-12	66.2	14.145	0.2	3.20	8.80	4.74	3.47	5.6	46	7	38.3			
17-Mar-12	46.4	13.996	0	2.10	3.20	2.54								
18-Mar-12	263	21.595	0	1.80	3.90	2.05								
19-Mar-12	218	20.103	1.8	1.50	1.90	1.64	2.15	4.4	18	6.92	56.3			
20-Mar-12	93.2	16.581	5.6	1.60	2.40	1.92	1.97	3.6	28	6.86	68.8			
21-Mar-12	51.8	16.664	0	1.60	2.10	1.77						2.97	77.7	3.56
22-Mar-12	130	20.162	1.6	1.50	4.50	1.59	1.64	4.4	13	6.92	49.4			
23-Mar-12	90	17.908	1	1.50	11.10	1.54	1.92	6.2	26	6.94	55.4			
24-Mar-12	55.1	16.716	0	1.40	2.40	1.58								
25-Mar-12	35.2	14.038	0	0.00	0.00	0.00								
26-Mar-12	59.8	15.246	0.4	1.20	9.40	1.52	1.92	6.2	26	6.94	55.4			
27-Mar-12	105	14.986	3.2	1.20	2.00	1.40	1.65	6.8	71	7.06	53.1			
28-Mar-12	51.2	12.274	3.6	1.50	6.10	2.66								
29-Mar-12	51.4	12.198	9.8	2.80	7.40	4.60	5.41	5.5	15	7.17	33.1			
30-Mar-12	48.1	12.286	1.8	1.90	3.00	2.28	2.2	5.2	40	6.93	37.3			
31-Mar-12	29.4	12.166	5.6	1.50	1.90	1.66								
1-Apr-12	56.1	13.561	13.8	1.60	3.30	2.21								
2-Apr-12	80.4	14.699	11	2.20	3.40	2.70	1.98	5.2	46	6.98	42.6	2.67	74.9	2.61
3-Apr-12	63.4	14.608	5.8	3.20	24.90	6.10								
4-Apr-12	40.9	12.773	0	2.20	3.50	2.65	2.49	6.4	36	6.97	45.5			
5-Apr-12	31.8	12.134	0	1.70	2.20	1.89	2.19	5.9	44	7.01	43			
6-Apr-12	45.6	13.747	0	0.00	1.90	1.53								
7-Apr-12	39	13.242	0	1.30	1.50	1.38								
8-Apr-12	116	15.989	0	1.20	1.40	1.24								
9-Apr-12	80.1	14.389	0	1.10	1.30	1.19								
10-Apr-12	80.1	14.824	0	1.00	1.30	1.10								
11-Apr-12	49.3	13.689	1.2	1.10	1.20	1.10								
12-Apr-12	37.3	13.805	1.4	1.00	4.10	1.16	1.25	7.6	22	7.07	42.8			
13-Apr-12	61.6	14.651	0	0.90	1.50	1.14	1.08	7.8	25	6.86	45.1			
14-Apr-12	63.7	15.189	0	0.90	1.10	0.92								
15-Apr-12	31.2	13.705	0	0.80	1.10	0.88								
16-Apr-12	98.1	16.933	8.2	0.80	6.70	1.29	1.39	8.4	41	7.08	38.5	2.34	85.1	1.71
17-Apr-12	61.1	15.318	0.2	1.10	1.80	1.28	1.34	5.8	31	7.16	46.5			
18-Apr-12	31.3	13.772	2.2	1.10	1.10	1.10	1.04	7.4	14	7.48	38.4			
19-Apr-12	88	14.012	0.6	1.10	1.10	1.10	1.21	6.3	7	7.23	45.4			
20-Apr-12	40.9	13.424	0	1.10	1.10	1.10	1.26	8.3	18	7.16	39.5			
21-Apr-12	27.8	12.365	0	1.10	1.10	1.10								
22-Apr-12	20.1	11.43	2.4	1.10	1.10	1.10								
23-Apr-12	27.2	11.523	2.8	1.10	1.10	1.10	2.26	7	32	7.21	53.9			
24-Apr-12	34.7	11.995	2.6	1.10	1.10	1.10	2.14	6.8	23	7.15	41.5			
25-Apr-12	35.9	11.613	4.8	1.10	18.60	9.19								
26-Apr-12	47.2	12.207	0	2.80	15.40	6.09	4.14	8.3	21	7.25	38.7			
27-Apr-12	32.9	12.856	0	1.70	10.50	2.24	2.32	6.8	28	7.26	38.8			
28-Apr-12	30	12.672	0	1.30	1.80	1.46								
29-Apr-12	29.6	12.713	7	1.10	1.40	1.22								
30-Apr-12	39.4	12.542	0.2	1.10	1.50	1.25								
1-May-12	26.4	12.149	0	1.00	1.40	1.14	1.25	7.2	56	7.19	40.6	2.34	85.3	1.98
2-May-12	31.1	12.38	0	0.80	1.10	0.85	1.17	7.9	19	7.19	44.1			
3-May-12	34.8	12.219	7.4	0.70	2.00	1.03	2.54	7.8	14	7.12	54.7			
4-May-12	37.1	12.099	0.8	1.00	1.60	1.11	1.1	8.1	21	7.12	54.6			
5-May-12	63.6	13.367	0	0.90	1.20	1.01								
6-May-12	61.4	12.963	0	0.90	1.20	0.92								
7-May-12	39.6	12.243	0	0.90	2.10	0.93	0.85	11	12	7.14	48.2			
8-May-12	38.8	11.615	0	1.00	2.30	1.07	0.91	9.4	21	7.18	43.8			
9-May-12	36	10.941	0	0.80	1.20	0.92								
10-May-12	25.2	10.04	0	0.70	1.20	0.82	0.84	8.8	12	7.18	51.1			

11-May-12	25.2	10.233	0	0.70	1.00	0.82	0.82	7.1	13	7.24	50.3			
12-May-12	31.7	11.09	0	0.70	2.30	0.82								
13-May-12	26.2	10.891	0	0.80	1.40	0.86								
14-May-12	23.5	10.114	0	0.90	1.30	1.01								
15-May-12	39.7	10.638	0	0.90	1.70	1.20	1.2	8.3	24	7.22	46.5	2.37	86.4	2.52
16-May-12	44.3	11.477	0	0.90	1.50	1.07	1	9.7	22	7.11	42.4			
17-May-12	37.7	11.589	0	0.70	1.60	0.85	0.8	10	15	7.19	39.7			
18-May-12	39.5	11.013	0	0.60	0.90	0.72								
19-May-12	33.3	11.057	0	0.60	1.00	0.71								
20-May-12	30.9	11.557	0.2	0.70	1.30	0.82								
21-May-12	20.8	10.337	2.4	0.90	2.80	1.49								
22-May-12	47.4	10.981	0	0.90	2.60	1.36	1.2	8	10	7.22	39.5			
23-May-12	55.2	11.479	0.2	0.80	1.40	0.94	0.8	10	6	7.3	41.6			
24-May-12	39.6	11.123	0	0.80	3.60	0.93	1	11.3	5	7.34	42.6			
25-May-12	38.8	11.358	0	0.30	23.40	1.49								
26-May-12	30.9	11.528	0	0.70	1.10	0.76								
27-May-12	25.5	10.851	0	0.80	3.30	0.94								
28-May-12	27.8	10.83	0	0.60	0.90	0.72	0.69	10.6	18	7.2	43.9			
29-May-12	27.8	10.244	0.2	0.60	0.90	0.64	0.6	10.7	38	7.09	52.1			
30-May-12	21.6	9.939	11.6	0.60	1.30	0.67	0.6	9.8	6	7.26	47.6			
31-May-12	26.6	9.665	1.2	0.60	1.30	0.72	0.8	10.4	7	7.15	51.7			
1-Jun-12	27.3	9.385	3.7	0.70	1.50	1.04	1.1	10	26	7.26	50.4			
2-Jun-12	25.5	9.407	4.2	0.80	1.60	1.04								
3-Jun-12	25	9.802	1.4	0.60	1.20	0.70								
4-Jun-12	22.4	9.38	0	0.60	0.80	0.61	0.6	8.4	15	7.16	48.5	2.39	88.5	1.88
5-Jun-12	29	8.649	0	0.60	0.80	0.61								
6-Jun-12	21.2	7.957	0	0.50	0.90	0.60	0.6	11.4	20	7.22	54.4			
7-Jun-12	21.5	7.533	3.4	0.50	1.00	0.63	0.7	10.4	10	7.23	52.8			
8-Jun-12	19.3	7.118	0	0.60	1.40	0.63	0.6	11.1	10	7.15	45.1			
9-Jun-12	18.5	7.01	0	0.50	0.80	0.59								
10-Jun-12	22.8	7.396	0	0.50	0.70	0.60								
11-Jun-12	15.5	7.083	0	0.50	0.70	0.60	0.6	12.8	2	7.91	87.2			
12-Jun-12	19.2	7.393	2.2	0.60	16.40	2.00								
13-Jun-12	25.2	7.762	0.2	0.90	13.90	1.18	1.5	10.4	6	7.22	45.9			
14-Jun-12	30.6	7.776	0	0.60	1.10	0.77	0.7	11.5	27	7.26	45.2			
15-Jun-12	30.6	7.474	2.6	0.60	0.90	0.71	0.7	11.5	23	7.21	57.2			
16-Jun-12	33.4	7.141	0.2	0.60	1.48	0.76								
17-Jun-12	22.8	6.654	0.8	0.80	4.20	1.16								
18-Jun-12	21.4	6.381	0.2	0.70	2.20	0.84	0.7	11.9	20	7.27	45	2.00		1.81
19-Jun-12	19	5.926	0	0.60	1.20	0.73	0.7	12.3	11	7.36	46.7			
20-Jun-12	15.8	5.595	0	0.60	1.10	0.69	0.6	11.2	8	7.26	55.8			
21-Jun-12	15.4	5.569	0	0.60	18.40	0.89	0.6	13.2	7	7.17	56.3			
22-Jun-12	16.3	5.464	12.8	0.60	1.40	0.73	0.6	12.6	5	7.25	55.6			
23-Jun-12	15.7	5.211	6.2	0.80	2.50	1.63								
24-Jun-12	15.5	5.03	0.4	1.00	2.30	1.53								
25-Jun-12	22.5	5.114	0	0.80	6.50	1.33	0.8	12.4	31	7.38	45.9			
26-Jun-12	21	5.178	0	0.70	1.00	0.78	0.6	12.3	11	7.3	51.5			
27-Jun-12	18.1	5.093	0	0.60	0.80	0.64	0.6	14.1	17	7.3	52.9			
28-Jun-12	20.4	4.916	1.8	0.60	1.00	0.66	0.6	12.4	2	7.24	53.3			
29-Jun-12	15.9	4.67	0.2	0.60	0.80	0.64	0.6	12.6	19	7.38	58.1			
30-Jun-12	15.9	4.445	15.4	0.70	2.40	0.85								
1-Jul-12	15.9	4.445	0	0.60	0.80	0.66								
2-Jul-12	15.9	4.215	6.8	0.60	2.40	0.81								
3-Jul-12	14.2	4.003	1.2	0.60	1.00	0.71								
4-Jul-12	14.2	3.992	3.8	0.60	0.90	0.70	0.60	13.7	22	7.29	53.6	1.37	89.3	1.43
5-Jul-12	13.4	4.031	0	0.60	1.00	0.67	0.60	11.8	9	7.38	58.2			
6-Jul-12	12.5	3.761	0	0.60	1.60	0.63	0.60	15.7	8	7.37	73.9			
7-Jul-12	12.5	3.63	0	0.60	1.50	0.69								

8-Jul-12	14.8	3.629	0	0.60	0.80	0.63								
9-Jul-12	26.4	3.988	0	0.60	1.60	0.65	0.60	17.8	10	7.34	56.6			
10-Jul-12	21	3.84	0	0.50	1.00	0.62								
11-Jul-12	13.8	3.484	0	0.50	1.10	0.63								
12-Jul-12	12.8	3.394	0	0.00	16.00	0.58	0.60	19.1	7	7.48	59			
13-Jul-12	29.8	3.926	0	0.50	1.10	0.62	0.60	18.0	20	7.33	65.7			
14-Jul-12	16.1	3.407	0	0.50	0.90	0.65								
15-Jul-12	12.4	3.176	0	0.60	1.70	0.81								
16-Jul-12	9.25	2.932	0	0.60	0.90	0.68	0.60	19.7	18	7.76	58.7			
17-Jul-12	9.82	2.888	0	0.60	25.00	1.48	0.70	16.2	9	7.38	66.5	1.57	97.7	0.99
18-Jul-12	10.5	2.713	0	0.30	24.90	3.52	2.50	18.0	11	7.35	67.3			
19-Jul-12	9.99	2.544	0	0.90	1.50	1.03	0.90	18.7	13	7.52	64.9			
20-Jul-12	9.64	2.46	1.4	0.70	1.50	0.87	0.90	17.0	41	7.27	72.3			
21-Jul-12	10.1	2.373	0	0.60	0.90	0.70								
22-Jul-12	9.91	2.311	4.8	0.60	5.70	1.08								
23-Jul-12	9.35	2.367	0.2	0.80	4.30	1.29	1.10	15.1	17	7.5	72.5			
24-Jul-12	9	2.196	0	0.80	4.20	1.13	1.00	18.0	13	7.47	75.4			
25-Jul-12	8.68	2.027	0	0.70	1.10	0.83	0.70	18.3	14	7.37	82.5			
26-Jul-12	8.16	1.939	0	0.70	1.70	0.95	0.80	18.5	5	7.4	81.6			
27-Jul-12	6.99	1.871	0	0.70	1.20	0.87	0.80	18.3	9	7.37	83			
28-Jul-12	7.03	1.805	0	0.70	1.40	0.96								
29-Jul-12	7.83	1.905	0	0.70	1.60	0.95								
30-Jul-12	8.42	1.826	0	0.00	5.90	0.89	1.20	18.7	14	7.47	88.7			
31-Jul-12	7.18	1.663	0	0.60	2.30	0.75	0.80	18.1	13	7.41	87.3	1.40	98.9	1.14
1-Aug-12	6.25	1.613	0	0.60	0.80	0.70	0.70	19.3	7	7.4	86.4			
2-Aug-12	6.07	1.608	0	0.00	9.90	0.78	0.60	17.0	4	7.4	91.2			
3-Aug-12	5.84	1.555	0	0.60	0.90	0.66								
4-Aug-12	6.46	1.487	0	0.60	3.00	0.87								
5-Aug-12	6.21	1.439	0	0.70	1.50	0.84								
6-Aug-12	6	1.465	0	0.60	1.00	0.70								
7-Aug-12	6.18	1.452	0	0.60	3.60	0.74	0.70	17.3	4	7.49	85.8			
8-Aug-12	8.5	1.594	0	0.60	0.80	0.63	0.60	17.3	3	7.58	88			
9-Aug-12	10.7	1.593	0	0.50	1.00	0.62	0.60	18.1	9	7.39	91.2			
10-Aug-12	6.79	1.444	0	0.50	0.90	0.63	0.60	17.9	12	7.42	93			
11-Aug-12	4.46	1.326	0	0.50	0.90	0.66								
12-Aug-12	4.45	1.256	0	0.60	1.60	0.66								
13-Aug-12	4.13	1.21	0	0.60	1.70	0.64	0.60	18.7	2	7.51	91.2	1.51	98.9	1.06
14-Aug-12	3.83	1.179	0	0.60	2.40	0.68	0.60	18.8	7	7.66	80			
15-Aug-12	3.77	1.129	0	0.60	0.90	0.68	0.60	19.1	17	7.41	86.1			
16-Aug-12	3.63	1.094	0	0.60	2.60	0.77	0.60	18.0	10	7.52	86.2			
17-Aug-12	3.37	1.095	0	0.60	1.10	0.75	0.07	18.0	2	7.51	86.9			
18-Aug-12	3.35	1.062	0	0.60	1.00	0.71								
19-Aug-12	3.82	1.051	0	0.60	1.30	0.78								
20-Aug-12	3.7	1.055	0	0.60	0.80	0.67								
21-Aug-12	3.58	1.07	0	0.60	0.90	0.65	0.70	16.7	8	7.49	85			
22-Aug-12	4.21	1.168	0	0.60	0.90	0.64								
23-Aug-12	5	1.191	0	0.60	1.10	0.66	0.60	16.9	10	7.61	85.2			
24-Aug-12	7.96	1.215	0	0.50	0.90	0.66	0.60	13.1	12	7.46	87.3			
25-Aug-12	5.3	1.195	0	0.60	1.20	0.75								
26-Aug-12	6.39	1.232	1.4	0.60	0.90	0.65								
27-Aug-12	9.27	1.268	0	0.60	1.20	0.66	0.70	15.4	9	7.55	93.4			
28-Aug-12	6.49	1.232	0.6	0.60	0.80	0.61	0.70	15.4	10	7.6	88.3			
29-Aug-12	51.7	2.39	2.6	0.60	1.40	0.67	0.70	15.1	9	7.56	88.2			
30-Aug-12	80.4	3.076	0	0.60	1.20	0.64	0.70	14.6	4	7.59	89	1.35	93.8	1.16
31-Aug-12	32.1	1.865	0	0.60	1.00	0.64	0.70	15.3	10	7.52	89.9			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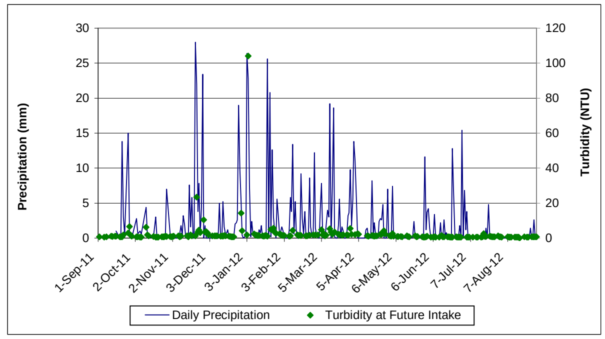
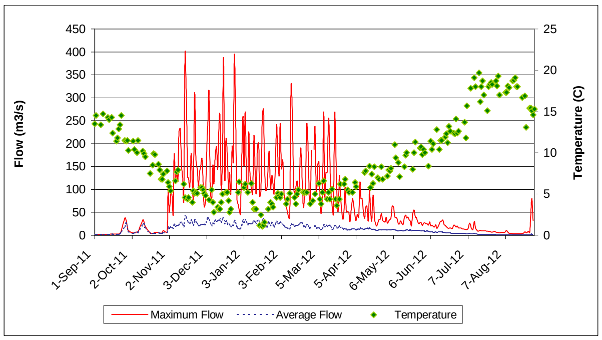
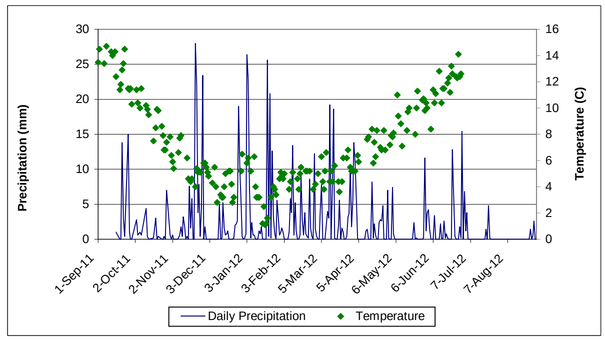
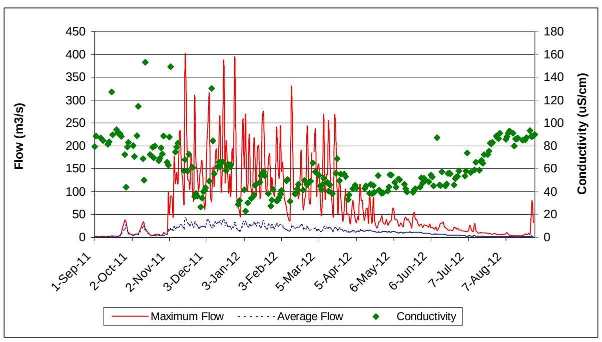
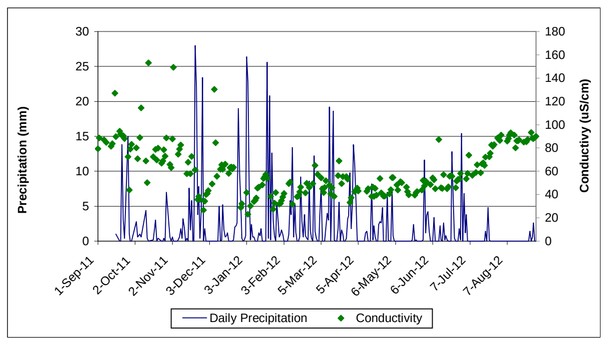
Turbidity (NTU)
Maximum Flow
Average Flow
Turbidity at Future Intake

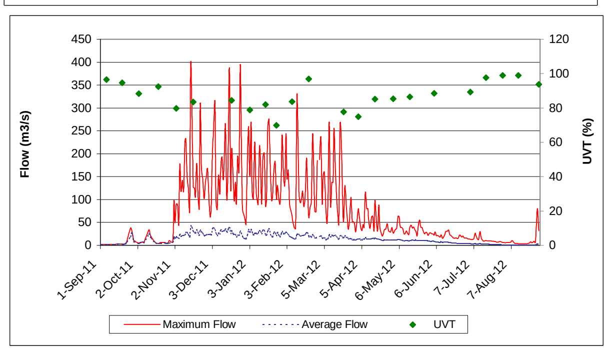

Precipitation (mm)
Turbidity (NTU)
Daily Precipitation
Turbidity at Future Intake

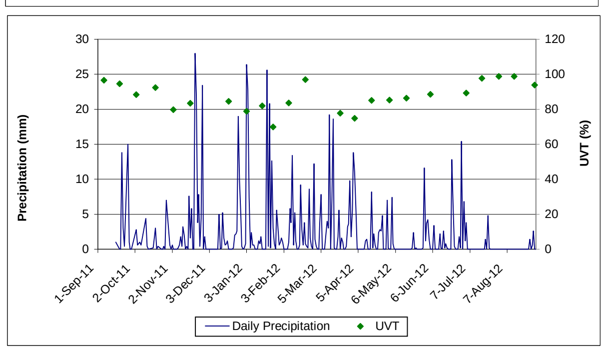

Flow (m3/s)
Temperature (C)
Maximum Flow
Average Flow
Temperature

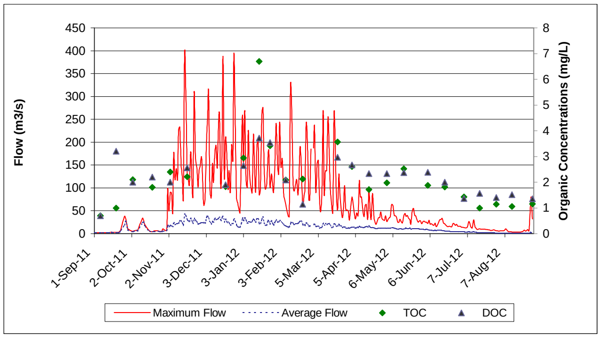

Precipitation (mm)
Temperature (C)
Daily Precipitation
Temperature

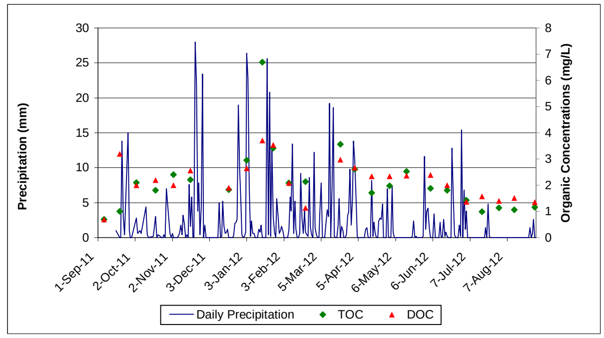

Flow (m3/s)
Conductivity (uS/cm)
Maximum Flow
Average Flow
Conductivity


Precipitation (mm)
Conductivy (uS/cm)
Daily Precipitation
Conductivity


Flow (m3/s)
UVT (%)
Maximum Flow
Average Flow
UVT


Precipitation (mm)
UVT (%)
Daily Precipitation
UVT


Flow (m3/s)
Organic Concentrations (mg/L)
Maximum Flow
Average Flow
TOC
DOC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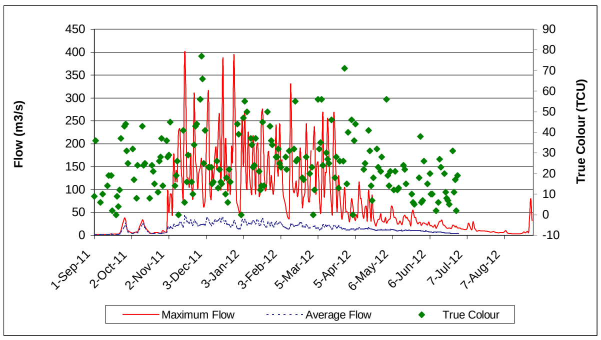
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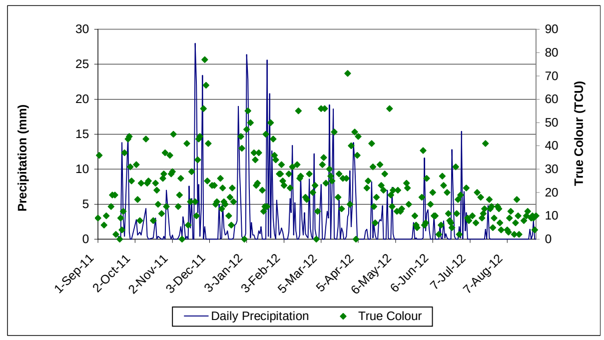
Maximum Flow
Average Flow
True Colour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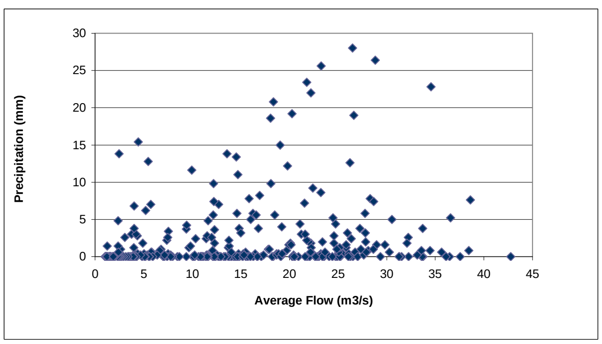
Daily Precipitation
True Colour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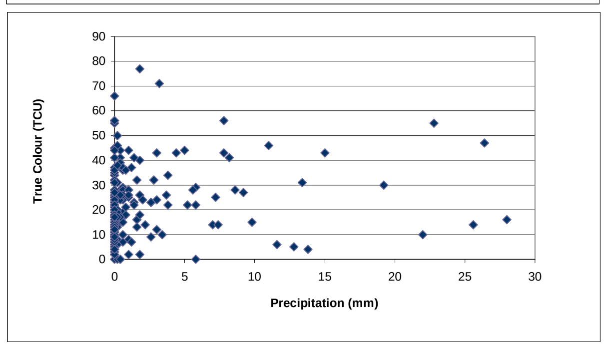
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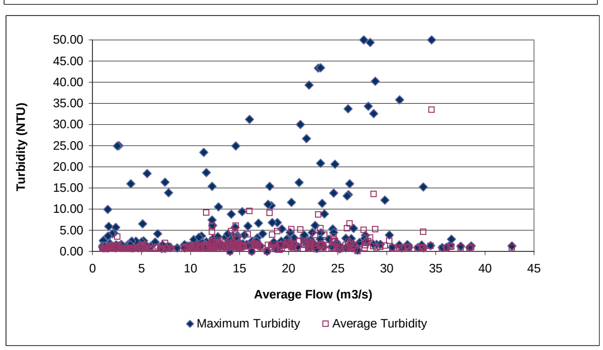
Precipitation (mm)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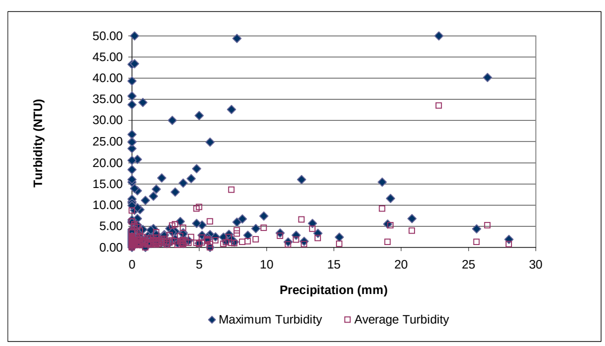
Maximum Turbidity
Average Turbidity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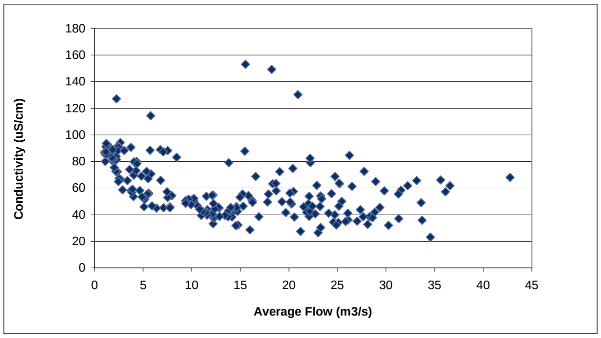
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Average Flow (m3/s)
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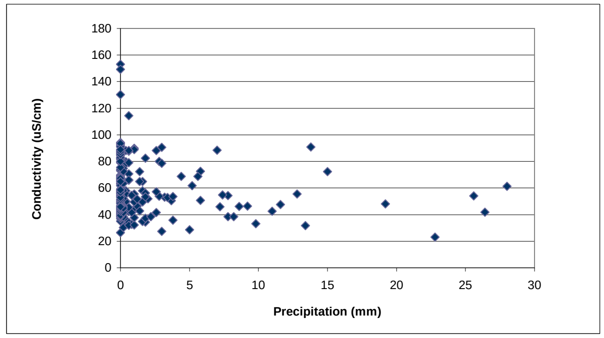
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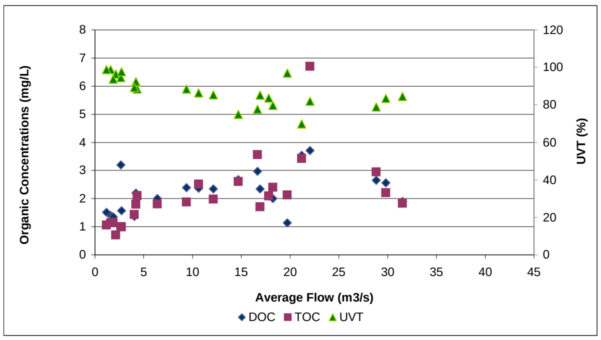
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UVT (%)
Average Flow (m3/s)
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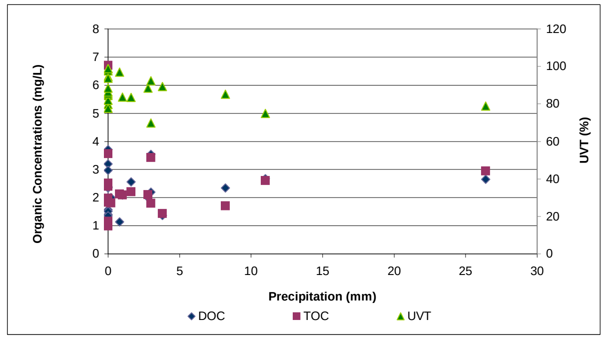
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UVT (%)
Precipitation (mm)
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UVT

Appendix B - Treatability Testing of Englishman River Water

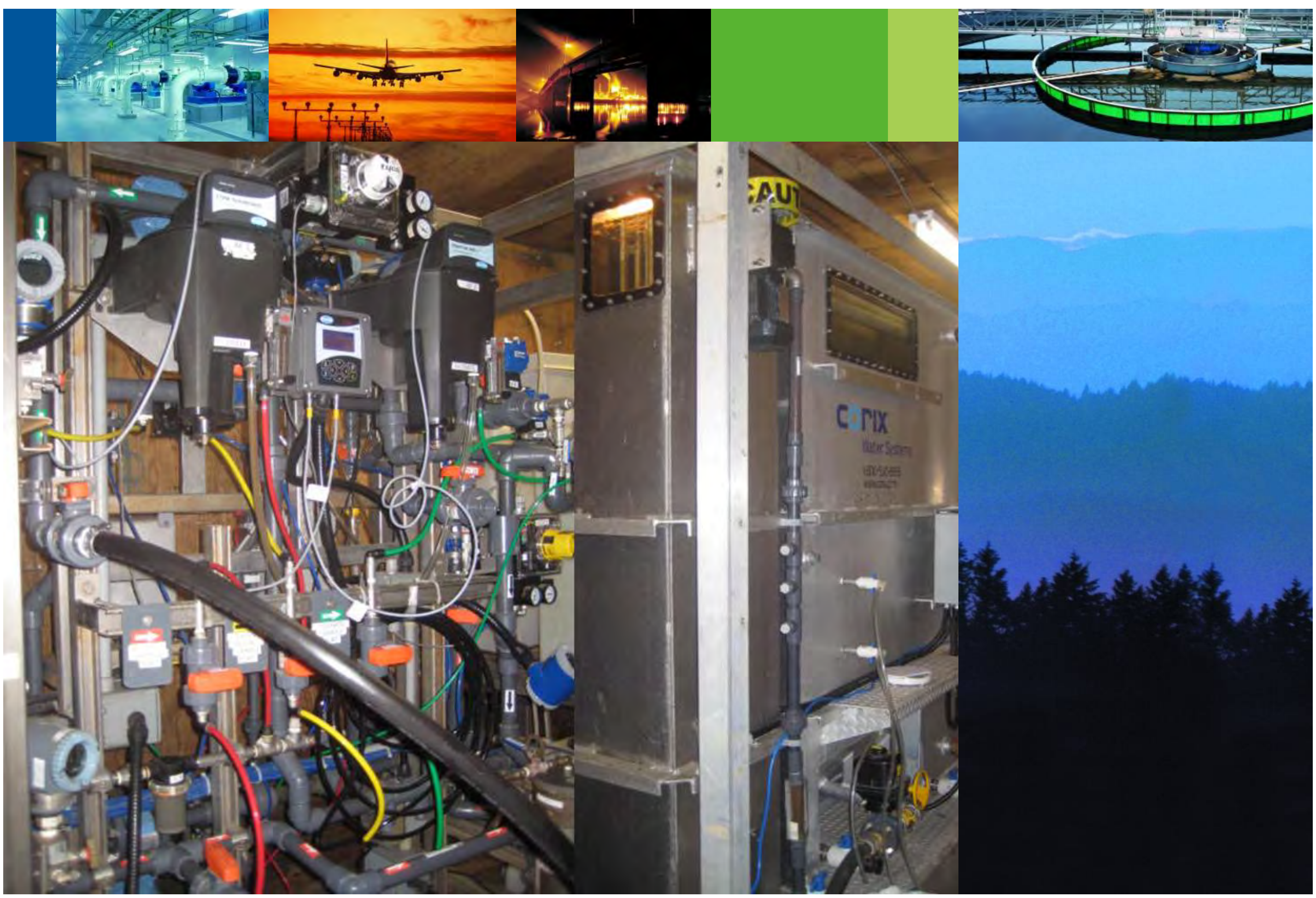
Report

Associated Engineering
GLOBAL PERSPECTIVE.
LOCAL FOCUS.

Englishman River Water Service

Treatability Testing of Englishman River Water

September 2013



ASSOCIATED ENGINEERING
QUALITY MANAGEMENT SIGN-OFF
Signature
Date Sept 19, 2013
07-13-110

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List of Abbreviations

ACH	Aluminum Chlorohydrate
ASRF	Air Scrub/Reverse Filtration
AWS	Arrowsmith Water Service
CIP	Clean-In-Place
DAF	Dissolved Air Flotation
DBP	Disinfection By-Product
DBPFP	Disinfection By-Product Formation Potential
DOC	Dissolved Organic Carbon
EFM	Enhanced Flux Maintenance
ERWS	Englishman River Water Service
GCDWQ	Guidelines for Canadian Drinking Water Quality
gfd	Gallons per square foot per day
gpm	Gallons per minute (US)
HAA	Haloacetic Acid
kPa	Kilopascals
L/min	Litres per minute
Lmh	Litres per square meter per hour
MAC	Maximum Acceptable Concentration
MF	Microfiltration
µg/L	Micrograms per litre
mg/L	Milligrams per litre
MSDS	Material Safety Data Sheets
NTU	Nephelometric Turbidity Units
PACL	Polyaluminum Chloride
ppm	Parts per million (equivalent to mg/L)
psi	Pounds per square inch
RDN	Regional District of Nanaimo
RF	Reverse Filtration
SDS	Simulated Distribution System
TCU	True Colour Units
THM	Trihalomethane
THMFP	Trihalomethane Formation Potential
TMP	Trans-Membrane Pressure
TOC	Total Organic Carbon
UFRV	Unit Filter Run Volume
VIHA	Vancouver Island Health Authority
WTP	Water Treatment Plant

1 Introduction

1.1 BACKGROUND

The Englishman River Water Service (ERWS), comprised of the City of Parksville (City) and the Regional District of Nanaimo (RDN), engaged Associated Engineering (AE) for the engineering services of Phase II of the Englishman River Water Intake, Treatment Facilities and Supply Mains project. This report describes the findings from a bench and pilot study conducted from November 2011 to late February 2012 in Parksville, BC.

1.2 SCOPE OF WORK

The treatability testing scope of work involved an evaluation of two potential treatment processes through water quality monitoring, bench-scale testing and pilot-scale testing. The objective of the bench-scale testing was to assess the effectiveness of chemical pre-treatment of the Englishman river water source for colour removal and to optimize the conventional pre-treatment pilot system for particulate removal. The main objective of the pilot study was to evaluate the treatment performance and determine optimal operating parameters of two treatment options to determine which treatment is most suitable for the ERWS system. The treatment options are:

- Conventional treatment (coagulation/flocculation/sedimentation and granular media filtration)
- Membrane Filtration (optional coagulation/microfiltration).

This information will be used to more accurately estimate process behaviour, challenges, and cost implications at full-scale design.

1.3 EXISTING WATER SYSTEM

Currently, the City of Parksville draws water out of the Englishman River via an infiltration gallery and disinfects the water using gas chlorination. The City also has a network of wells that undergo chlorination at a separate location. The City primarily relies on the surface water intake for supply during the summer and a combination of the intake and the wells during the winter. To comply with the Operating Permit granted by the Vancouver Island Health Authority (VIHA), the surface water intake is not allowed to deliver water to the distribution system when raw water turbidity levels exceed a specific limit. In 2009 the maximum turbidity allowed from the Englishman River was lowered from 5 NTU to 1 NTU, leading to more frequent periods where the intake would shut down and wait for turbidity levels to lower.

Recent monitoring work has indicated that true colour levels in the Englishman River may periodically exceed drinking water aesthetic objectives, that is, a characteristic that does not impact consumer health but may reduce the aesthetic appeal of the water. The current surface water treatment facilities are not adequate to ensure consistent colour removal.

2 Study Design

The bench and pilot study protocol was first detailed in an earlier memo to the ERWS (October 2011). The program was slightly modified from the original due to site-specific reasons outlined below.

2.1 PRE-TREATMENT CHEMICALS

The following chemicals were tested during the bench and/or pilot study:

Table 2-1
Bench and Pilot Study Chemicals

Chemical Type	Chemical Name	Treatment Process
Coagulant	Aluminum sulphate (Alum)	Conventional
Coagulant	Polyaluminum chloride (PACL)	Conventional
Coagulant	Aluminum chlorohydrate (ACH)	Conventional / Membrane
Coagulant Aid	Soda ash	Conventional
Polymer	Anionic – proprietary	Conventional
Polymer	Nonionic – proprietary	Conventional
Polymer	Cationic – proprietary	Conventional
Oxidant	Sodium hypochlorite	Membrane
Oxidant	Potassium permanganate	Membrane
Oxidant	Hydrogen peroxide	Membrane

Oxidants were used at bench-scale for the purpose of color removal upstream of the membrane system. ACH was the only chemical tested for colour removal at pilot-scale with the membrane based on the extensive bench-scale and pilot-scale tests conducted in similar water in the regions.

2.2 BENCH TESTING

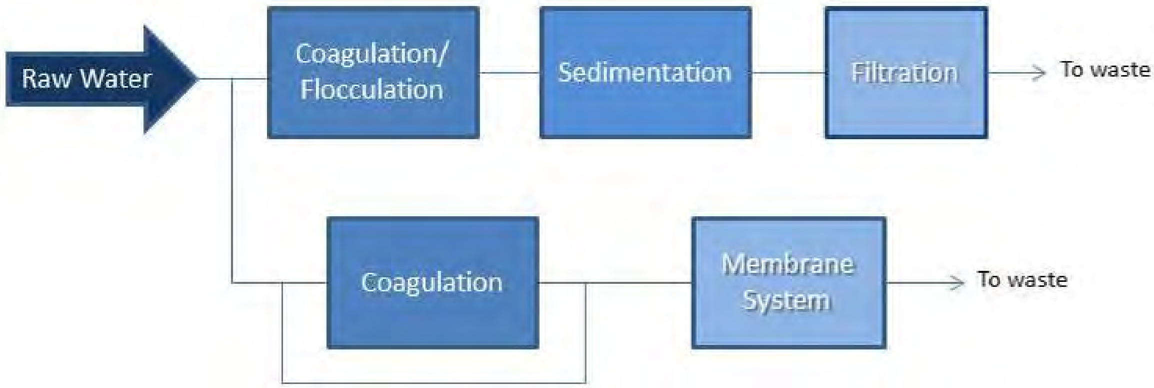
Bench-scale testing of the conventional treatment and DAF pre-treatment processes utilized a six-jar apparatus that could be used for both settling and flotation tests. The jar with the chemical dose that produced the best floc in terms of size and settleability was then applied at pilot-scale for the conventional system.

The effectiveness of oxidants to remove color from the raw water upstream of the membrane system was also tested at bench-scale. Three oxidants (chlorine, hydrogen peroxide, and potassium permanganate) were evaluated at various doses to the raw water.

2.3 PILOT TESTING

The pilot study commenced in early November and ran until late February, simulating conventional treatment and membrane treatment in parallel.

Figure 2-1
Pilot Process Schematic



The pilot process train is depicted in Figure 2-1. The conventional system was monitored, operated, and maintained by AE. The membrane was remotely monitored and operated by the membrane supplier, and maintained by AE.

Specific objectives for the pilot study were as follows:

- Evaluate operational and treatment performance of filters at different filtration rates.
- Evaluate operational and treatment performance of filters with different pre-treatment conditions.
- Evaluate operational and treatment performance of membranes at different flux.
- Evaluate operational and treatment performance of membranes with different pre-treatment conditions.
- Determine impact of pre-treatment conditions on membrane fouling through transmembrane pressure (TMP) monitoring.

2.3.1 Conventional System

The conventional treatment system was supplied by Corix. Raw water was pumped directly from the Englishman River by the City of Parksville to a raw water tank. The water was subsequently pumped to the two-stage flocculation basins equipped with variable speed mixers. Chemicals were dosed inline prior to the static inline mixer upstream of the floc tanks. Flocculated water then entered the sedimentation tank (Figure 2-2) where settling tubes assist in further removing the floc from the clarified water, which was collected on top of the sedimentation tank through a perforated pipe and discharged into the adjacent clarifier.

A portion of the clarified water was diverted to two 100 mm gravity filters columns for further removal of particulate matter. The pilot filters were capable of receiving flows from 0.2 L/min up to 2 L/min. Figure 2-3 shows the conventional pilot filter unit. Media configurations are described in Table 2-2.

Figure 2-2
Flocculation/Sedimentation Unit

Figure 2-3
Pilot Gravity Filters

Table 2-2
Gravity Filter Media Configurations

Filter	Media	Depth (mm)	Effective Size (mm)	Uniformity Coefficient
1	Anthracite	500	1.0-1.1	1.4
	Sand	350	0.45-0.55	≤ 1.5
2	Anthracite	860	1.0-1.1	1.4

The conventional system was equipped with online monitoring of turbidity (raw, clarified, and filtered), as well as filter headloss (pressure). Pre-treatment chemical doses were set manually and flow-paced to the raw water flow. A portion of the clarified water was used to feed two gravity filters and the rest was diverted to waste. Filter effluent was used for backwash supply.

Table 2-3
Conventional System Operating Parameters

Parameter	Range	Unit
Pre-Treatment Flows	8 - 15	L/min
Flocculation Tank Volume	0.27	m^3
Flocculation Detention Time	18 – 34	min
Sedimentation Tank Volume	1.02	m^3
Sedimentation Detention Time	68 – 128	min
Hydraulic Loading Rate	0.9 – 1.6	m/h
Clarifier Volume	0.7	m^3
Filter Flows	0.4 – 1.2	L/min
Filter Column Diameter	100	mm
Filtration Rates	3 - 9	m/h
Media Expansion during Backwash	30 – 40	%

2.3.2 Membrane Filter

Raw water from the Englishman River was pumped by the City into an equalization tank, where a submersible pump was used to feed the membrane system as needed, based on the level in the membrane raw water feed tank. During chemical pre-treatment, the coagulant was dosed directly to the suction side of the submersible pump, using the pump impeller to mix the chemical into the water. The contact time for the chemical from the point of injection to the membrane filter was approximately 12 minutes based on a membrane flow of 8.7 L/min (2.3 gpm).

The membrane system was operated remotely by the supplier at various operating parameters (i.e. flux, cleaning frequency, etc.) in order to determine the optimum parameters for full-scale design based on raw water conditions. These are summarized in Table 2-4 and further detailed in Appendix B – Pall Pilot Report.

Table 2-4
Membrane Filtration Operating Parameters

Parameter	Range	Unit	Comments
Flux	43 – 94 (25 – 55)	Lmh (gfd)	
Percent Recovery	91.7 – 96.9	%	Target of ≥95%
Air Scrub Interval	20 – 30.4	min	
EFM Frequency	1 – 2	Per day	Typically 1
Excess Recirculation	0 – 10	%	
CIP Frequency	≥ 30	day	
Coagulant Dose	0 – 14	mg/L	

2.4 PILOT PERFORMANCE ANALYSIS

2.4.1 Water Quality Objectives

The pilot study results were compared to the drinking water objectives set by VIHA, which adopts the Guidelines for Canadian Drinking Water Quality (GCDWQ) and the 4-3-2-1-0 Drinking Water Objective. A detailed discussion on drinking water guidelines and criteria was presented in Discussion Paper 4-2 (AE, 2009) in the Conceptual Planning stage of this project.

For the purpose of the pilot study, the following finished water quality objectives were used:

- Final effluent turbidity less than 0.1 NTU (for membrane filtration).
- Final effluent turbidity less than 0.3 NTU (for conventional media filtration).
- pH between 6.5 and 8.5.
- True colour less than 15 TCU (aesthetic objective).

2.4.2 Conventional Pre-Treatment

The conventional pre-treatment process was evaluated primarily on clarified water turbidity. The maximum clarified water turbidity goal was 2.0 NTU before entering the filter columns. Other factors considered in the evaluation included the following:

1. Robustness (with varying raw water quality)
2. Chemical requirements
3. Colour removal
4. Operation and maintenance requirements
5. Other observations (e.g. impact on filtration)

2.4.3 Conventional Filters

Conventional filter performance was evaluated based on turbidity (maximum 0.3 NTU) and headloss (maximum 1.4 m), which were used to determine the end of a filter run. The two filter columns were compared based on these criteria in relation to each other. Other factors considered in the data analysis and the media evaluation included the following:

1. Feed water quality from pilot pre-treatment process
2. Filter ripening characteristics
3. Robustness (with varying water quality)
4. Operation and maintenance requirements
5. Backwash frequency

2.4.4 Membrane Treatment

The membrane process was evaluated based on the following list of criteria:

1. Effluent turbidity (max 0.1 NTU)
2. Colour removal
3. Effluent particle counts
4. Robustness (with varying water quality)
5. Chemical requirements
6. Cleaning frequency
7. Operation and maintenance requirements
8. Membrane fouling

2.5 CLEANING PROCEDURES

The conventional filters and the membrane system required periodic cleaning to remove built-up materials in the filter bed and on the membrane.

2.5.1 Filter Backwash

Filter backwash was initiated when terminal headloss was reached or if turbidity breakthrough occurred. During the pilot study, filter backwash was conducted using a combined air/water wash (collapse-pulse technique). The flows and times were modified based on physical observations during backwash.

2.5.2 Membrane Cleaning

The following methods were used for cleaning the membranes:

1. Backflush – combined air scrub and reverse filtration (ASRF). This was a frequent (every 20-30 minutes), short-duration (60 seconds) cleaning to dislodge debris on the membrane surface.
2. Enhanced Flux Maintenance (EFM) – heated water and sodium hypochlorite (500 mg/L) wash. An EFM was triggered based on a pre-set trans-membrane pressure (TMP) or a set time (24 hours) for 30 minutes to maintain membrane performance and increase membrane permeability. During coagulant addition, a weekly EFM consisting of 2500 mg/L citric acid was added to enhance the membrane clean.
3. Clean in Place (CIP) – a more rigorous membrane cleaning to remove foulants and restore membrane permeability. A CIP was conducted at the end of each cycle and involved high concentrations of sodium hypochlorite (1000 mg/L) together with 1% caustic solution, followed by a 2% citric acid flush, for a total duration of 3 to 4 hours. A detailed CIP protocol is included in the Pall Pilot Report (Appendix B).

3 Results

3.1 RAW WATER QUALITY

During the pilot study, raw water quality was monitored on-site using online and bench-top instruments. During turbidity events and major operational changes, samples were also collected for analysis at an external laboratory (standard drinking water package – Maxxam Analytics). Key raw water quality parameters are shown in Table 3-1.

Table 3-1
Englishman River Raw Water Quality

Parameter	Units	Average	Median	Min	Max	95th Percentile	No. of Samples
Turbidity[1]	NTU	3.92	1.5	0.3	198	12.5	22430
Apparent Colour	CU	65	41	20	550[2]	145	42
True Colour	TCU	32	28	15	58	56	53
UVT	%	74	76	36	85	83	52
Temperature	°C	6.3	6.2	3.1	9	9	47
pH		7.1	7.1	6.7	7.8	7	51
Alkalinity	mg/L	17	15	13	20	20	13

[1] Combined online and grab samples. Max online reading was 100 NTU.
[2] Maximum colorimeter reading of 550 CU/TCU.

Additional parameters conducted by an external laboratory are included in Appendix C. These were collected during major operational changes (i.e. pre-treatment chemical dose change) and to capture the worst-case raw water quality during high turbidity events due to rainfall.

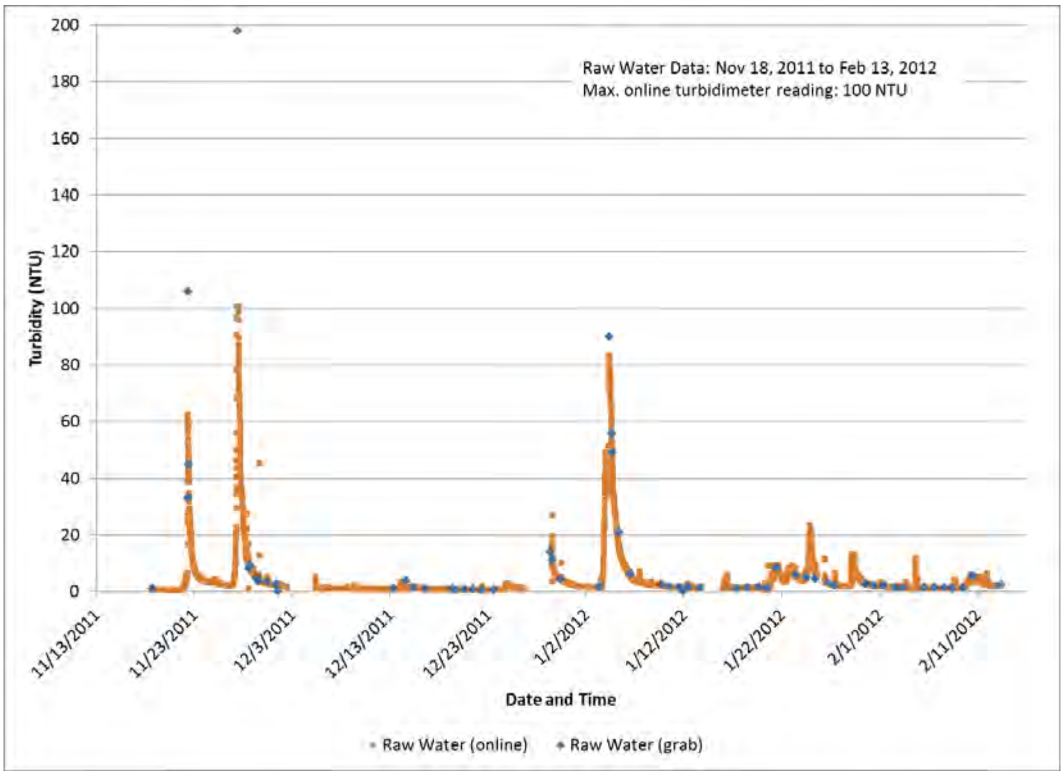
3.1.1 Turbidity

The raw water turbidity trend is shown in Figure 3-1. The turbidimeters supplied with the pilot equipment had a range of 0 to 100 NTU. For the majority of the pilot study, raw water was of good, but not of potable quality, with turbidity below 12.5 NTU. VIHA mandates a maximum turbidity of 1.0 NTU for potable water use (filter avoidance).

The Englishman River water source typically experiences higher turbidity from October to February. The cause of this turbidity increase was investigated in Discussion Paper 4-1 (AE, 2009), which listed potential causes as precipitation, river flow, and influence from other water sources. Historically, the challenging period is late fall and early winter, therefore the pilot study was scheduled for this time period to capture worst-case water quality conditions.

During the pilot study, five turbidity events were experienced where raw water spiked to > 20 NTU. Grab samples were taken to confirm actual turbidity values, and are included in Figure 3-1. Grab samples and online measurements were generally close, except where the actual turbidity exceeded 100 NTU, the limit of the online turbidimeters. In case of discrepancy, it was assumed the grab samples were more accurate.

Figure 3-1
Raw Water Turbidity

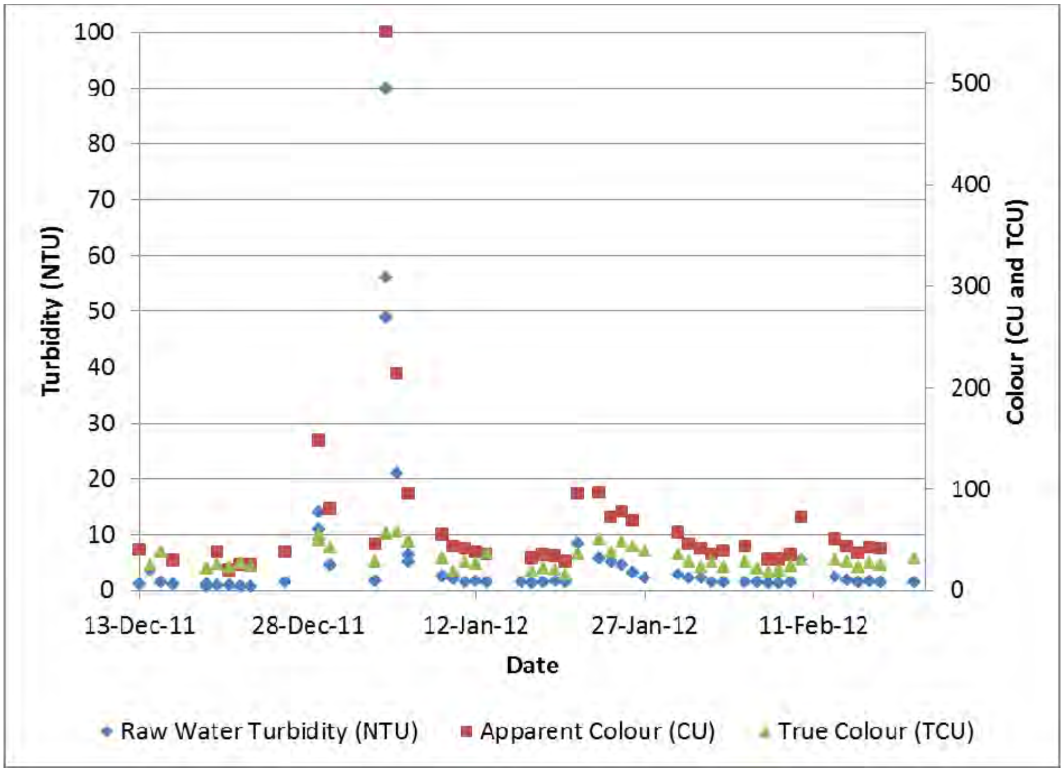


3.1.2 Colour

Another raw water quality parameter that was of interest in this study was colour. Both organic and inorganic constituents in raw water can contribute to colour. Colour removal during filtration is dependent on whether the constituents are suspended or dissolved. Suspended particles contributing to colour can be removed by filtration, whereas chemical pre-treatment is needed to remove dissolved material causing colour. True colour (dissolved) and apparent colour (dissolved plus suspended) were measured on-site.

Figure 3-2 shows that both colour trends generally follow the turbidity trend. During times of low turbidity, the difference between apparent colour and true colour was minimal, suggesting that the majority of the colour was due to dissolved substances. During high turbidity events however, the difference between apparent and true colour was greater, likely due to mainly suspended particles causing apparent colour. Therefore, pre-treatment for colour removal during high turbidity events will likely be required.

Figure 3-2
Raw Water Colour



3.1.3 Metals

A comprehensive water quality analysis was conducted during the pilot study. Water samples were collected during normal conditions and high turbidity events. During the first turbidity event, the concentration of three metals exceeded the Canadian Drinking Water Guidelines, as shown in Table 3-2. The aluminum limit is an operational standard while that for iron and manganese are aesthetic objectives. A more comprehensive list is provided in Appendix C.

Table 3-2
Metals in Englishman River Raw Water

Parameter	Units	Guideline	Jan 4 Event	Jan 24 Event	No Event
Total Aluminum	µg/L	100	**1090**	**214**	85
Total Iron	µg/L	300	**1660**	258	67
Total Manganese	µg/L	50	**64**	7	2

Red = Exceeded guideline value

3.1.4 Organics and DBP Formation Potential

Historical water quality data has shown that organic levels in the Englishman River are typically low, below 4 mg/L, as suggested from the recent results of the City's monitoring program. Raw water samples collected during the pilot study contained less than 2 mg/L dissolved organic carbon (DOC). Raw water haloacetic acid (HAA) formation potential was reported to be 95 µg/L and trihalomethane formation potential was reported to be 430 µg/L. It should be noted that the formation potential testing is an extreme measurement and much higher than the actual formation in the distribution system. This is further discussed in Section 3.5.5.

3.2 BENCH-SCALE CONVENTIONAL PRE-TREATMENT

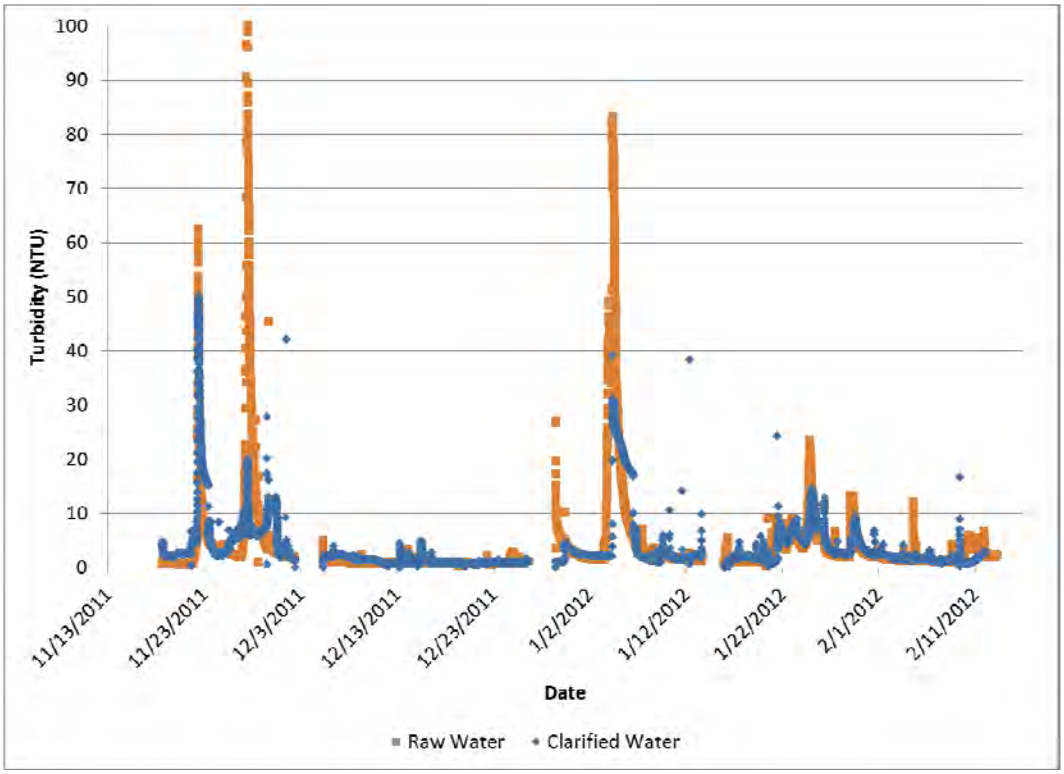
Jar tests were conducted to determine the appropriate dose of soda ash, coagulant, and polymer. The goal was to produce the best floc in the jars which would settle out in the shortest amount of time. The best result from each jar test was used to set chemical doses at pilot-scale. The floc formed did not settle well, if at all during the allotted settling period. The test results indicate poor settleability in all pre-treatment tests. A summary of bench-scale tests is shown in Appendix A.

3.3 PILOT-SCALE CONVENTIONAL SYSTEM PERFORMANCE

3.3.1 Pre-Treatment Process

Bench-scale jar test results did not always translate well to pilot-scale. Chemical doses that produced floc at bench-scale did not necessarily do so at pilot-scale. Pilot pre-treatment performance was gauged primarily on turbidity removal and chemical dosages were adjusted accordingly. During periods of low raw water turbidity of approximately 2 NTU or less, floc formation was difficult to achieve since there were fewer particles to form colloids in the water. Furthermore, the low alkalinity water presented a challenge to coagulation chemistry. Conversely, during periods of high turbidity, it was challenging to adjust the conventional process to the rapidly changing influent water quality. Although floc was formed during these turbidity spikes, the water leaving the clarifier to the filters was still above the 2 NTU objective. The conventional pre-treatment process performed best when raw water turbidity was between 5 and 15 NTU. Figure 3-3 shows the clarified water turbidity compared to the influent water turbidity.

Figure 3-3
Clarified Water Turbidity



3.3.2 Filtration

Filter performance was largely dependent on influent water quality from the conventional pre-treatment system, and less so by filtration rate and the type of media tested. Figure 3-4 shows how clarified water quality (light blue) impacted filter effluent quality (red, dark blue) during a filter run. The two filters performed similarly, as can be seen by the similarity in turbidity and headloss trends for each filter. In the graph shown, turbidity breakthrough occurred at approximately 41 hours for Filter 2 and 44 hours for Filter 1. Terminal headloss (1.4 m) was not reached. Although a 40 hour run-time is considered good by industry standards, the filtration rate (3 m/h) was low, with a calculated unit filter run volume (UFRV) of 125 m^3/m^2. UFRV values represent the volume of water filtered before backwashing is required, and values less than 200 m^3/m^2 are generally considered poor.

Figure 3-5 shows a filter run at a higher filtration rate of 9 m/h. This time, the turbidity breakthrough occurred at approximately 19 hours for Filter 2. An equipment malfunction caused the supply line to stop feeding Filter 1 before the end of the filter run, though the data indicates this filter would have performed longer than Filter 2. The UFRV for Filter 2 under these operating conditions was 174 m^3/m^2, still below the minimum goal of 200 m^3/m^2. Higher filtration rates and/or longer filter run times would be necessary to reach UFRV values above 200 m^3/m^2.

Although the results in Figures 3-4 and 3-5 show good filtered effluent water quality for this particular filter run, they were not typical results during the pilot study. In many cases, poor clarified water quality resulted in floc carryover onto the filters, causing high filter effluent turbidity (>0.3 NTU). In some cases, filter performance was poor even during good clarifier performance (<2.0 NTU), as shown in Figure 3-6. A full-scale conventional filtration system may undergo similar challenges in treating the Englishman River Water.

Coagulation chemistry was continuously adjusted throughout the pilot study to meet target clarified water goal of 2 NTU. However, for reasons described earlier in Section 3.2.1, this was a challenge given the nature of the raw water source. The increased solids loading onto the filters resulted in high headloss and turbidity breakthrough. Therefore, the filters were shut down when solids loading increased.

Figure 3-4
Filter Performance with Changing Influent Quality

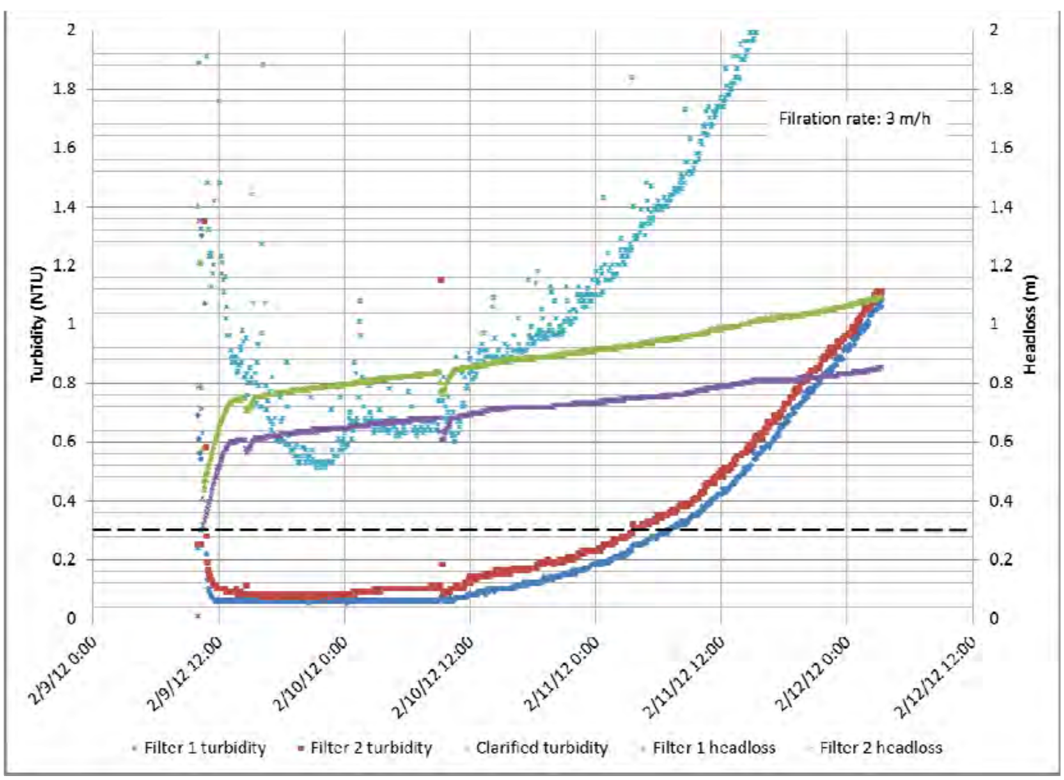


Figure 3-5
Filter Run November 24, 2011

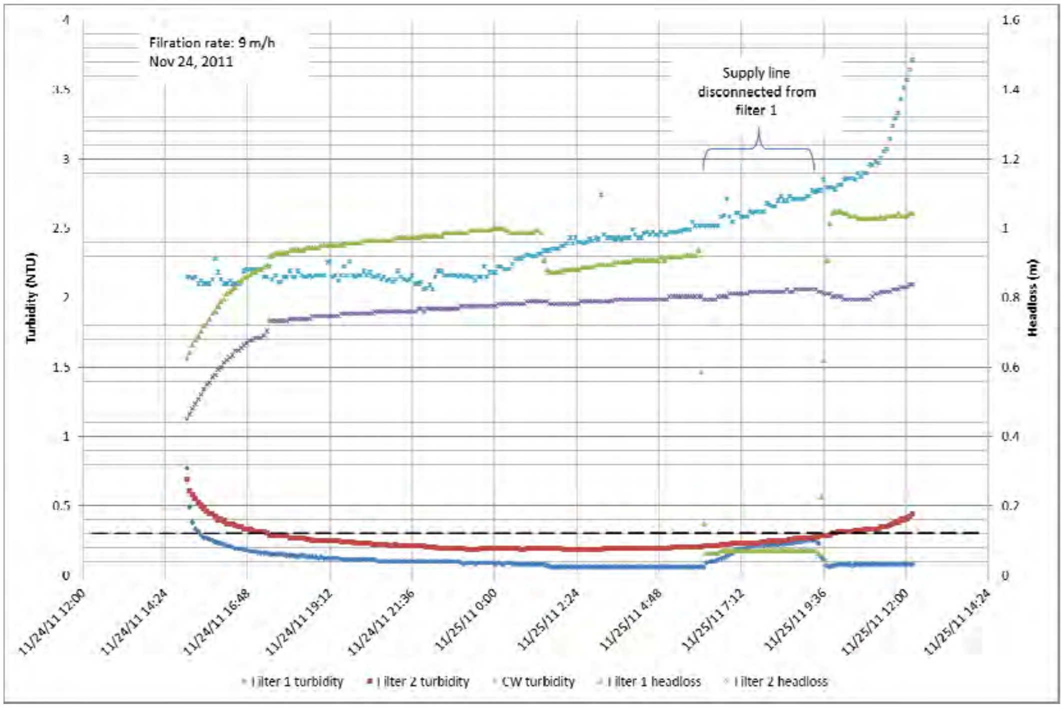
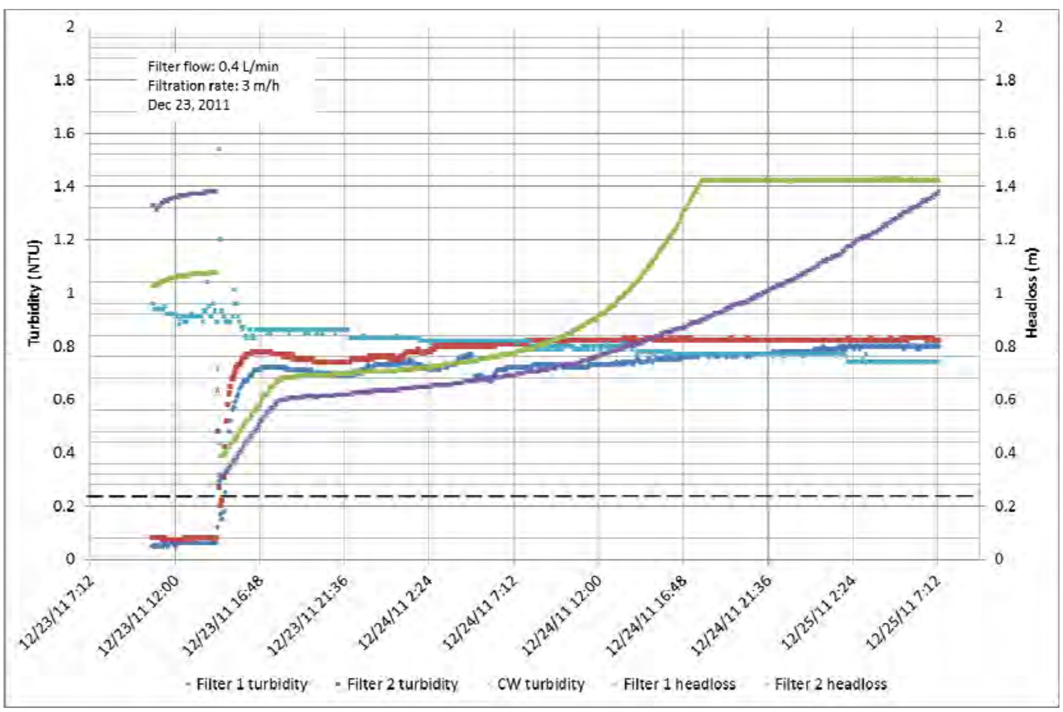


Figure 3-6
Filter Run December 23, 2011



3.4 BENCH-SCALE PRE-TREATMENT FOR MEMBRANE

3.4.1 Colour Removal with Oxidants

Without pre-treatment, membranes can remove suspended material but would not be able to remove colour when in its dissolved form. Two oxidants, potassium permanganate ($KMnO_4$) and hydrogen peroxide (H_2O_2), were tested at bench-scale to determine their efficacy in removing colour from the raw water. Since oxidant reactions are dose and time dependant, multiple doses were tested for up to 30 minutes of contact time. The maximum potassium permanganate dose tested was 0.2 mg/L, since higher doses caused a pink hue in the water. The results did not show a substantial decrease in true colour over the 30 minute contact time with potassium permanganate, as shown in Figure 3-7. A dose of 0.1 mg/L potassium permanganate seemed to reduce the true colour to near the target level of 15 TCU, though this cannot be confirmed since instrument precision is low (±10) according to the instrument manufacturer (HACH). No reduction in colour was seen with a dose of 0.2 mg/L.

Hydrogen peroxide was applied to the raw water at a dose of 1 mg/L, 5 mg/L, and 10 mg/L. Figure 3-8 shows that the dose of 1 mg/L had no impact on colour removal. Although there seemed to be a slight improvement in colour with a peroxide dose of 5 mg/L, the removal was not sufficient to lower the colour below the target of 15 TCU. Given the low instrument precision, the reduction of five colour units may not be significant. Increasing the dose to 10 mg/L did not further enhance colour removal.

3.4.2 Colour Removal with Coagulants

Two aluminum chlorohydrate (ACH) coagulants (CTI 4900 and Isopac 80) were also tested at bench-scale for comparison to the two oxidants mentioned above. The results are shown in Figure 3-9.

At the time of testing with CTI 4900, raw water colour was very high around 50 TCU. A CTI 4900 dose of 5 mg/L reduced the colour by half, to approximately 25 TCU. The increased dose of 10 mg/L reduced the colour to the target level of 15 TCU. When Isopac 80 was tested, the raw water colour was lower in comparison, at 21 TCU. A dose of 5 mg/L Isopac 80 reduced the true colour to approximately 5 TCU, well below the target of 15 TCU. The results show that the coagulants are far better at colour removal compared to the two oxidants tested. Contact time did not influence the colour removal by coagulants.

Figure 3-7
Efficacy of Potassium Permanganate ($KMnO_4$) for Colour Removal

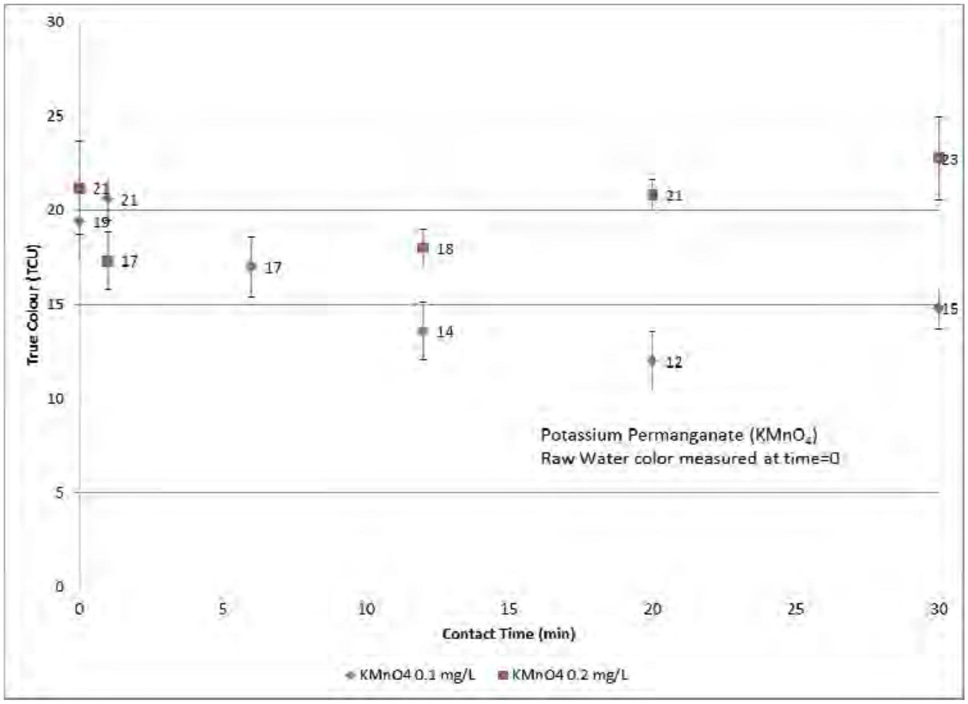


Figure 3-8
Efficacy of Hydrogen Peroxide for Colour Removal

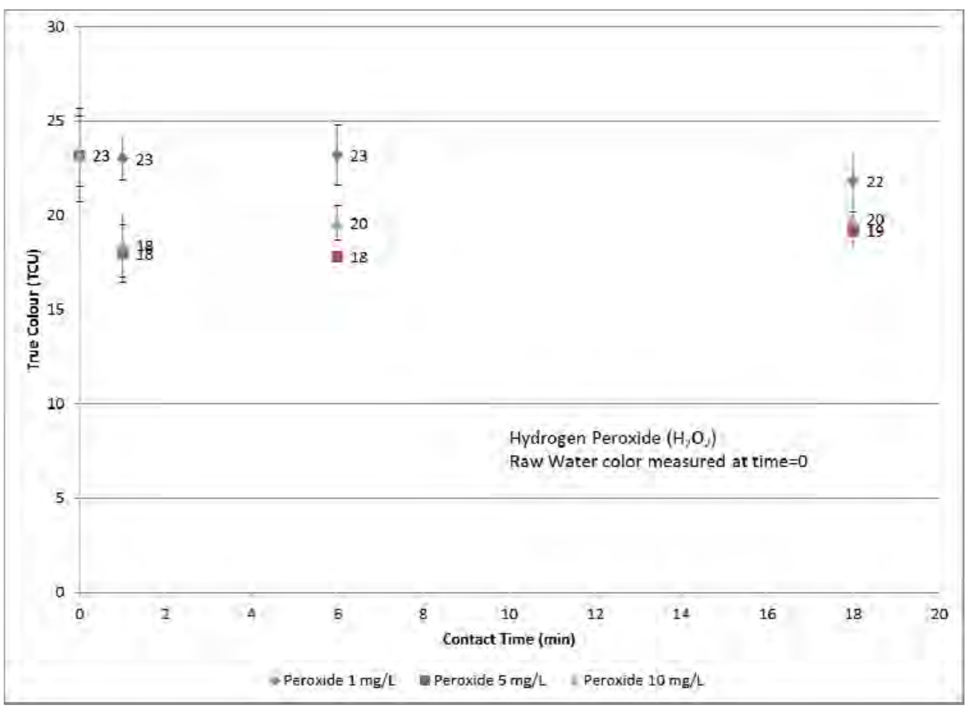
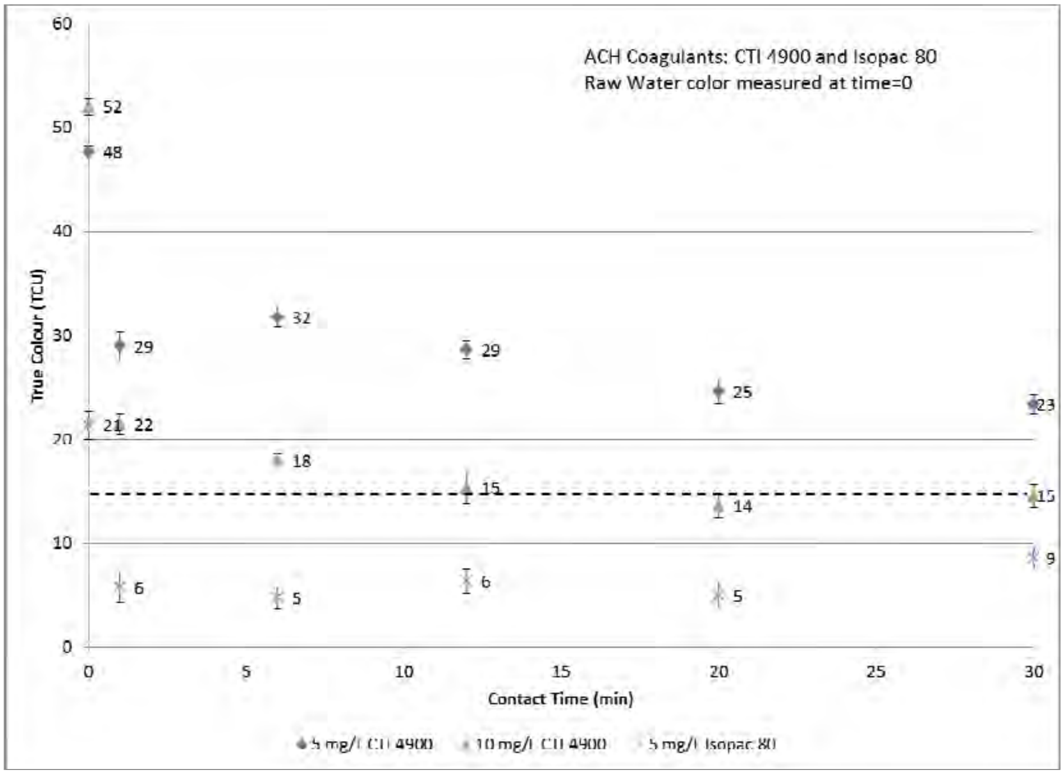


Figure 3-9
Colour Removal with ACH Coagulants (CTI 4900 and Isopac 80)



3.5 PILOT-SCALE MEMBRANE SYSTEM PERFORMANCE

3.5.1 Cycle 1

The first phase of piloting (Cycle 1) involved operating the membrane pilot at various flux without pre-treatment to help determine the optimum parameters for full-scale membrane design. Towards the end of this phase, 5 mg/L of ACH was added to enhance colour removal. Table 3-3 summarizes the operating parameters for Cycle 1.

Table 3-3
Cycle 1 Operating Parameters

Filtrate Flux		42-55 gfd (71-94 Lmh)
Recovery		>95%
Air Scrub / Reverse Filtration (ASRF)	Volume	284 L (75 gal)
	Frequency	30.3 minutes
	Duration	60 seconds
	Air flow	1.5 SCFM

	Water flow	3.8 L/min (1 gpm)
Forward Flush	Duration	30 seconds
	Flow	7.6 L/min (2 gpm)
Enhanced Flux Maintenance (EFM)	Frequency	Daily
	Duration	30 minutes
	Cleaning chemical	500 mg/L NaOCl
	Temperature	32-38°C (90-100°F)
Cycle length		64 days
Excess Recirculation		10%
Raw Water Pre-treatment		0-5 mg/L ACH

The membrane performance for Cycle 1 is illustrated in Figure 3-10. Trans-membrane pressure (TMP) and turbidity values are summarized in Table 3-4. The average raw water temperature during the Cycle 1 was 6.7°C. The first major turbidity event was experienced on November 22nd, where the flux was lowered from 94 Lmh (55 gfd) down to 43 Lmh (25 gfd) and the air scrub/reverse filtration (ASRF) frequency was changed from intervals of 26 minutes (95.9% recovery) to 20 minutes (91.7% recovery). An enhanced flux maintenance (EFM) wash was also necessary to slow down the rapid rise in TMP during the upset. After the first turbidity event, the system TMP was stabilized at 71 Lmh (42 gfd) and an ASRF interval of 30 minutes (96.4% recovery). Within a few days a second turbidity event was encountered on November 27th, with levels as high as 200 NTU in the raw water. This time the system was set to trigger an EFM when TMP climbed above 3 kPa (20 psi) while keeping the flux and ASRF unchanged. An EFM occurred 3 hours before the end of the 24 hour scheduled EFM cycle. This showed that short-term upsets in raw water quality could be effectively combatted without adjusting membrane operation settings.

Figure 3-10
Cycle 1 Membrane Performance

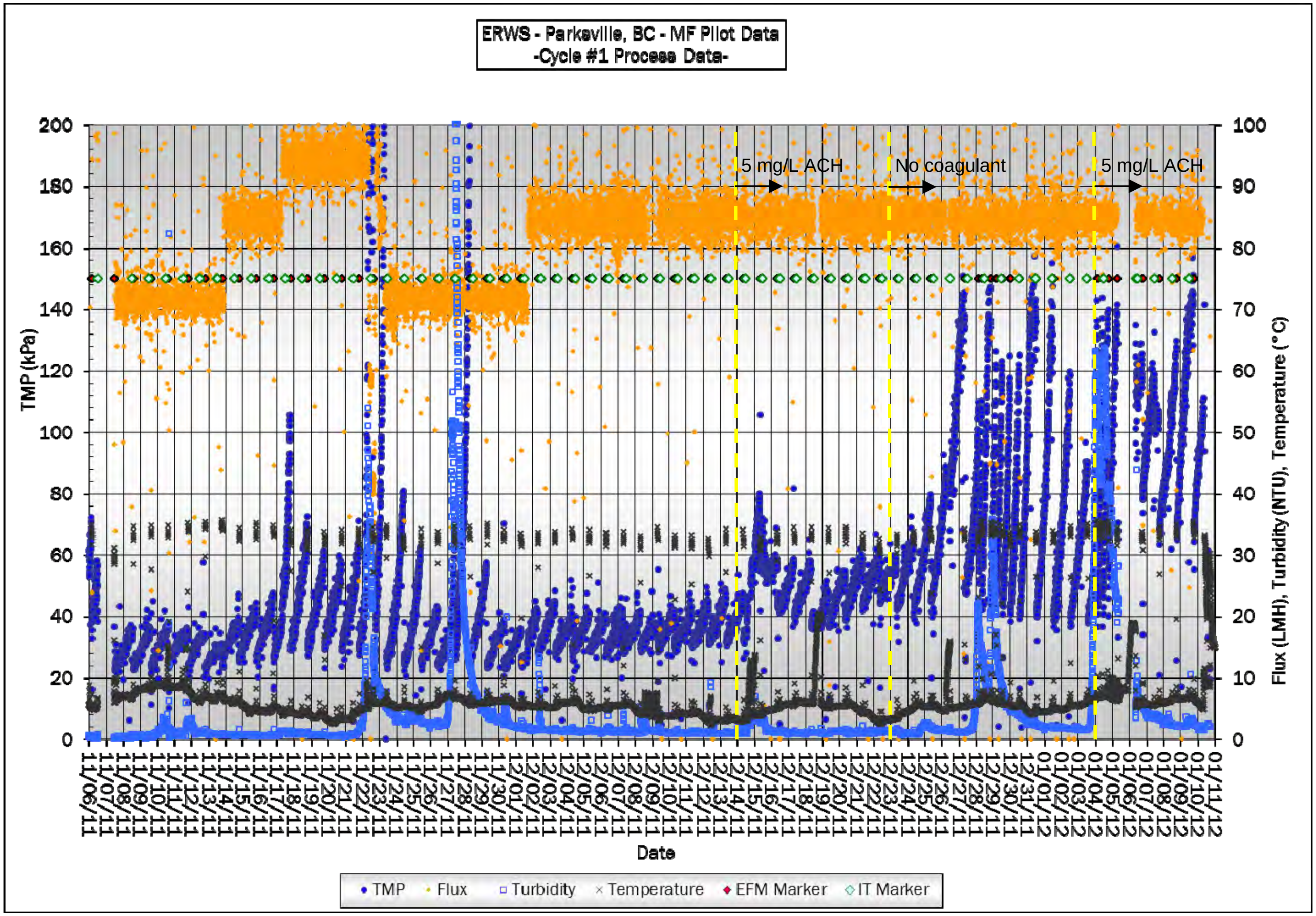


Table 3-4
Cycle 1 Transmembrane Pressure (TMP) and Turbidity

	Cycle 1			
	Average	Minimum	Maximum	99th Percentile
Ambient TMP (kPa)	5.96	0	46.18	-
Ambient TMP (psi)	0.89	0	6.9	-
Feed Turbidity (NTU)	2.96	0.23	99.98	8.41
Filtrate Turbidity (NTU)	0.0125	0	0.491[1]	0.0131

Note 1: Possible outlier

During the first two weeks of December, the membranes were operating with no coagulant at 85 Lmh (50 gfd) and ASRF intervals of 25 minutes (96.4% recovery). On December 15th, coagulant (ACH) was added for colour removal. Various coagulant doses were applied to optimize colour removal and to account for varying raw water colour values. The results are discussed later in Section 3.5.3. Addition of coagulant caused a rise in TMP (Figure 3-10); however the daily heated EFM helped to restore permeability and control TMP growth.

The last week of December and the first week of January were the most challenging in terms of influent raw water quality for the membrane system. On December 26th, the membrane system was automatically shut down due to raw water feed pump failure (intake strainer restricted flow due to high solids in the river). The system was restarted just prior to the third high turbidity event on December 28th, this time causing the membrane system to shut down due to clogging of the bag filter in the feed line. After re-starting the membrane unit, several EFMs were triggered until the third turbidity event subsided. After each EFM, the TMP was restored to approximately 0.7-1 kPa (5-7 psi).

A fourth turbidity event began on January 3rd, 2012. Raw water turbidity increased to 90 NTU and raw water true colour increased to 56 TCU. EFMs were triggered based on a TMP of 3 kPa (20 psi) and restored TMP to 0.7 kPa (5 psi). On January 5th, the membrane system shut down again due to clogged bag filter. After the system was brought back online, operation continued at a slightly elevated TMP until the first CIP was performed on January 10th.

Detailed membrane performance data for Cycle 1 can be found in Appendix B.

3.5.2 Cycle 2

Cycle 2 started January 11, 2012 and was terminated after 41 days when the pilot study ended. During this time, the membrane was operated with the parameters listed in Table 3-5.

Table 3-5
Cycle 2 Operating Parameters

Filtrate Flux		77-85 Lmh (45-50 GFD)
Recovery		95.3%
Air Scrub / Reverse Filtration	Volume	284 L (75 gal)
	Frequency	30.3 minutes
	Duration	60 seconds
	Air flow	1.5 SCFM
	Water flow	3.8 L/min (1 gpm)
Forward Flush	Duration	30 seconds
	Flow	7.6 L/min (2 gpm)
EFM	Frequency	Daily
	Duration	30 minutes
	Cleaning chemical	500 mg/L NaOCl
	Temperature	32-38°C (90-100°F)
Alternate EFM	Frequency	Weekly
	Duration	30 minutes
	Cleaning chemical	2500 mg/L citric acid
	Temperature	32-38°C (90-100°F)
Cycle length		41 days
Excess Recirculation		10%
Raw Water Pre-treatment		5-10 mg/L ACH

The primary goal in Cycle 2 was to evaluate the impact of pre-treatment with two coagulant doses, 5 mg/L and 10 mg/L, regardless of the raw water quality. This operating scenario was not intended to simulate actual operating conditions, but rather to see what impact a certain coagulant dose had over a period of time on the membranes. During periods of high colour in the raw water, the 5 mg/L may not have been enough to remove colour. Conversely, the 10 mg/L dose added to raw water of low colour may have resulted in unreacted coagulant build up on the membranes, potentially increasing the TMP at a faster rate. In addition to the regular daily EFM schedule, an alternate EFM was added during this cycle to enhance the cleaning efficiency of the membranes during coagulant addition. The alternate EFM was done on a weekly basis and consisted of a 2500 mg/L heated citric acid wash following a regular heated sodium hypochlorite EFM.

Coagulant addition (5 mg/L ACH) began on January 17th, 2012. Membrane performance was relatively stable at 77 Lmh (45 gfd), ASF interval of 20.9 minutes and a 95.3% recovery. On January 21st, a rainfall event caused an increase in raw water turbidity up to 10 NTU. The rise in TMP was controlled and permeability restored with regular daily and additional weekly citric acid EFMs.

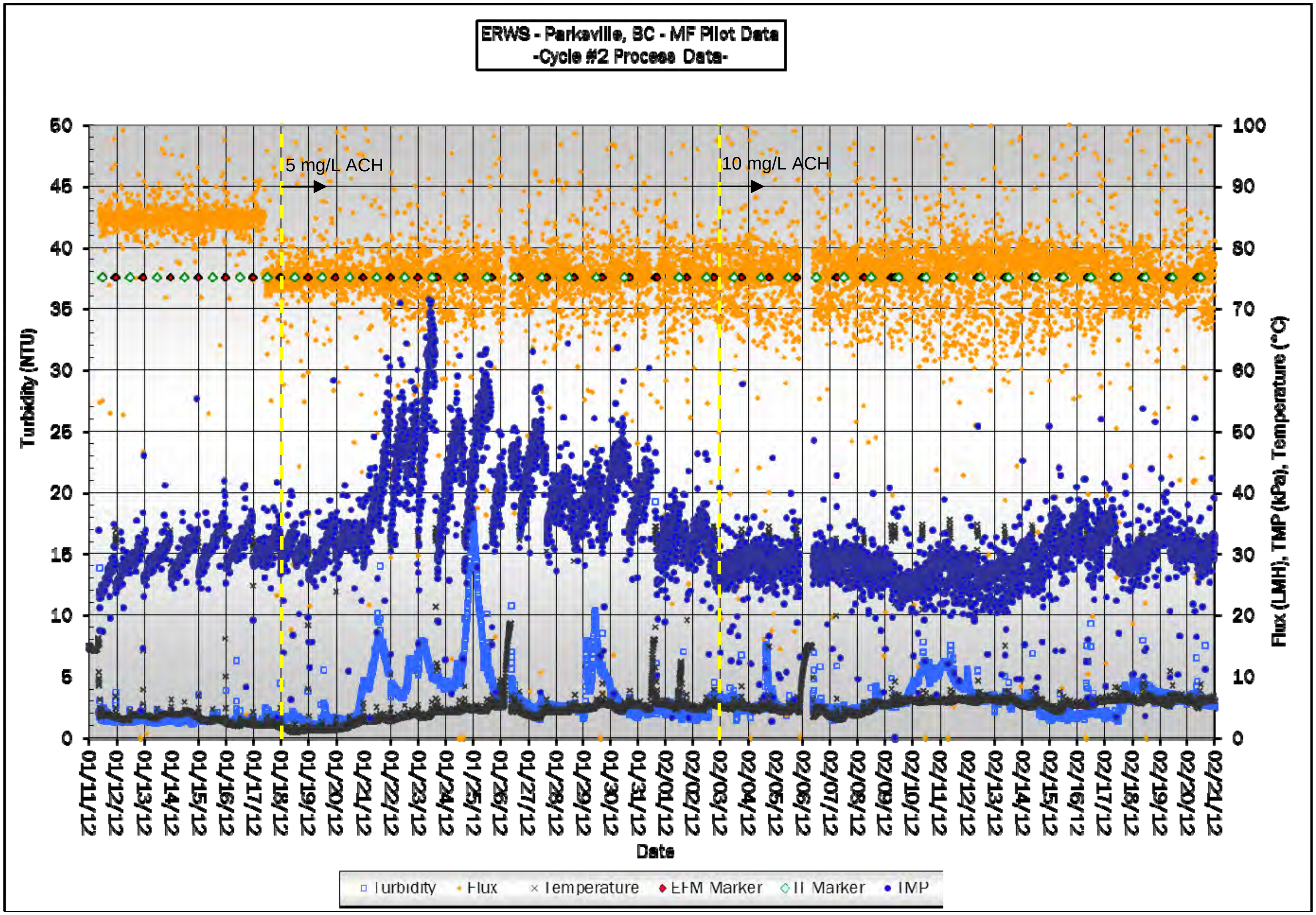
On February 2nd, coagulant dosing was increased to 10 mg/L of ACH. Membrane performance remained fairly stable with an average TMP of 0.9 kPa (6 psi). Daily regular EFMs and weekly citric EFMs were continued and were effective in controlling the rise in TMP with additional coagulant. The membrane operated with a TMP of approximately 0.6 kPa (4 psi). Since no significant turbidity events occurred during this time, it is likely that much of the 10 mg/L ACH was unreacted in the membrane feed. Although the full-scale membranes would not intentionally be operated with excess coagulant, the results showed that good membrane performance may still be achieved with the additional citric EFMs in the event coagulant is overdosed.

Table 3-6
Cycle 2 TMP and Turbidity

	Cycle 2			
	Average	Minimum	Maximum	99th
Ambient TMP (kPa)	4.8	0	10.4	-
Ambient TMP (psi)	0.7	0	1.5	-
Feed Turbidity (NTU)	3.02	0.94	65.66	11.60
Filtrate Turbidity (NTU)	0.012	0.011	0.087	0.013

Detailed membrane performance data for Cycle 2 can be found in Appendix B.

Figure 3-11
Cycle 2 Membrane Performance



3.5.3 Colour Removal

Once the membrane was optimized and operation was stabilized at 85 Lmh (50 gfd) and 96.4% recovery, colour removal efficacy was monitored at three scenarios: no coagulant addition (control), 5 mg/L ACH addition, and 10 mg/L ACH addition. The results are shown in Figure 3-12. Colour removal for both doses of coagulant was proportional to the raw water colour. During the addition of 5 mg/L of coagulant, a wide range of raw water colour was observed between 15 and 58 TCU. A dose of 5 mg/L was able to keep membrane effluent colour below the aesthetic target of 15 TCU with influent raw water colour values of up to 30-35 TCU. Raw water colour levels were already less than 15 TCU during the period that the 10 mg/L coagulant dose was used. However, membrane effluent colour level of less than 10 TCU was reasonably achieved.

3.5.4 Impact of Pre-Treatment on UVT

Coagulant addition upstream of the membranes also improved UVT of permeate, as shown in Figure 3-13. The level of improvement (i.e. increase in UVT) was dependant on the raw water UVT as well as the coagulant dose (5 mg/L vs. 10 mg/L). Although UVT is not a regulated parameter, it is an important factor in UV reactor design. Higher UVT values result in more efficient disinfection using UV, which may be considered in the overall future plant design.

3.5.5 DBP Formation Potential

During the pilot study, raw water and membrane effluent samples were analyzed for disinfection by-product haloacetic acid (HAA) formation potential as well as trihalomethane (THM) formation potential (HAAFP and THMFP, respectively). The raw water was pre-treated with 5 mg/L ACH coagulant. The laboratory results are shown in Table 3-7 and Table 3-8. The results indicate that the membrane reduced the formation potential of HAAs by up to 100 µg/L, and reduced the THMFP by 110 µg/L.

Figure 3-12
Impact of Coagulant Pre-Treatment on Colour Removal

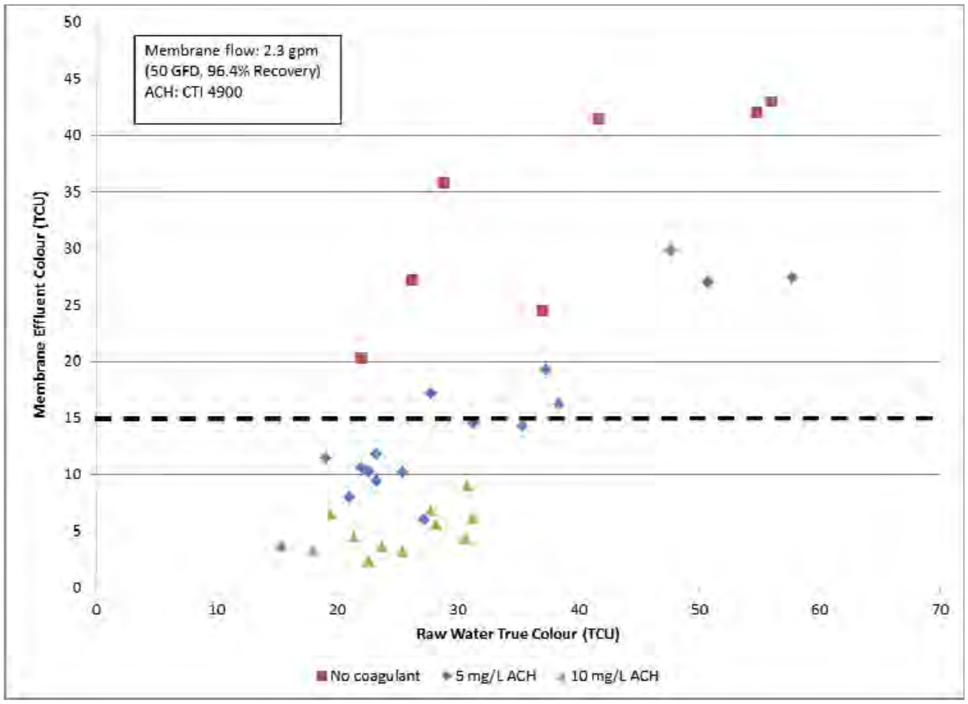


Figure 3-13
Impact of Pre-treatment on UVT

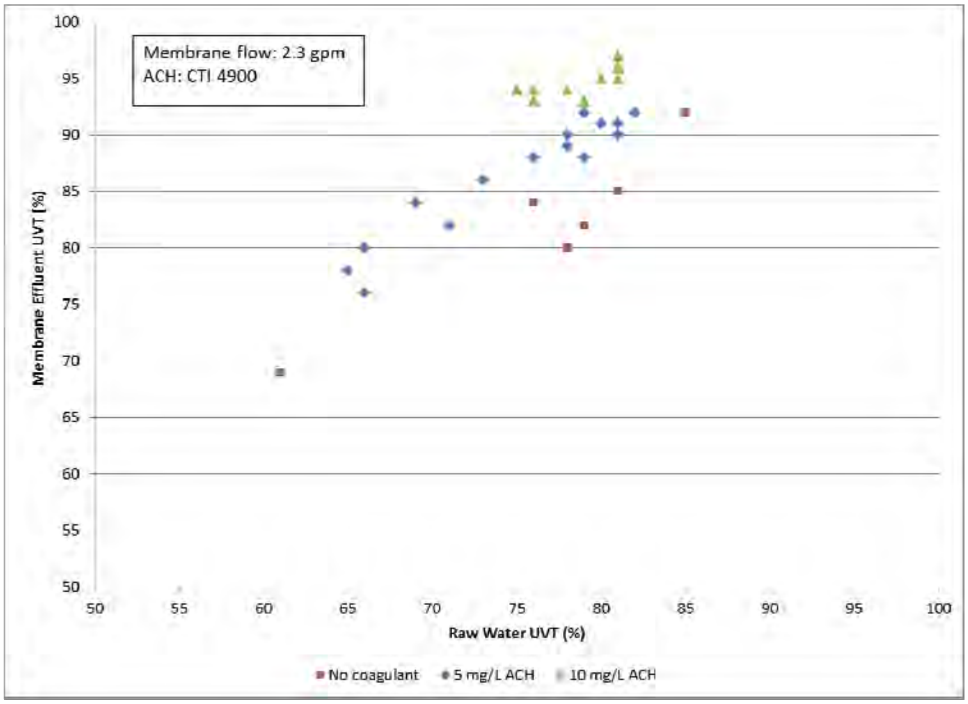


Table 3-7
HAA Formation Potential

HAA FORMATION POTENTIAL (F.P.)			Raw Water				Membrane Effluent			
Sodium hypochlorite dose:	units	DL[1]	5 ppm	10 ppm	20 ppm	40 ppm	5 ppm	10 ppm	20 ppm	40 ppm
Monochloroacetic acid F.P.	µg/L	5	<5	<5	<5	<5	<5	<5	<5	<5
Monobromoacetic acid F.P.	µg/L	1	<1	<1	<1	<1	<1	<1	<1	<1
Dichloroacetic acid F.P.	µg/L	0.5	46	85	100	108	47	66	78	68
Trichloroacetic acid F.P.	µg/L	1	49	127	150	167	62	100	126	105
Dibromoacetic acid F.P.	µg/L	0.5	<0.5	<0.5	<0.5	3	<0.5	<1	<0.5	5
Halo Acetic Acids 5 Total (calc.) F.P.	µg/L	5	95	212	250	278	109	166	204	178
Bromochloroacetic acid F.P.	µg/L	0.5	0.7	2	<0.5	3	1	1.5	2	3

[1]DL = Detection Limit

Table 3-8
THM Formation Potential

THM FORMATION POTENTIAL	units	DL	Raw Water	Membrane Effluent
Bromodichloromethane	µg/L	3	6	6
Bromoform	µg/L	3	<3	<3
Chlorodibromomethane	µg/L	3	<3	<3
Chloroform	µg/L	3	420	310
THM Formation Potential	µg/L	3	430	320

The formation potential tests are used to determine the extreme potential to form trihalomethanes and other DBPs when under the influence of direct chlorination. However, formation potential should not be confused with actual DBP concentrations measured in the distribution system. The THMFP and HAAFP analysis involves dosing the sample with a high concentration of chlorine and allowing the sample to react for seven days. Actual conditions would typically have much lower chlorine residual concentrations and may have significantly lower detention times. To illustrate, DBP concentrations as measured in the distribution system on Dec 5, 2011 were 17 µg/L total THMs and < 0.5 µg/L total HAAs.

4 Recommendations

4.1 KEY FINDINGS FROM BENCH STUDY

- ACH doses up to 10 mg/L were tested and deemed effective in removing colour from the raw water for both systems. Dose influenced colour removal more than contact time.
- Settleable floc formation was difficult to achieve when raw water quality was good (<5 NTU) using a combination of ACH (coagulant), soda ash, and polymer. At best, a pin floc was formed that was difficult to settle.
- Neither hydrogen peroxide nor potassium permanganate were able to significantly reduce colour below 15 units at doses of 10 mg/L and 0.2 mg/L, respectively (at contact times of up to 30 minutes).

4.2 KEY FINDINGS FROM PILOT STUDY

4.2.1 Conventional System

- The Englishman River raw water was a challenge for the conventional pre-treatment, clarification and filtration system. Even at times of good raw water quality, floc formation was difficult to achieve. During high turbidity events, the conventional treatment could not keep up with the fast-changing water quality.
- Conventional filters were sensitive to changes in clarified water quality and did not always meet the water quality treatment goal of 0.3 NTU or less with the media type and configuration tested.
- The conventional pre-treatment system was operator-intensive, requiring frequent monitoring and chemical adjustment based on changes in raw water quality.

4.2.2 Membrane System

- The membrane system showed to be a robust system that was capable of handling the variable raw water conditions from the Englishman River. Attention will be required on the membrane pre-treatment processes, to ensure that they do not clog with silt during a turbidity event. Proper design can effectively address this issue.
- Membrane effluent water quality met and exceeded the treatment goal of 0.1 NTU or less more than 99 percent of the time.
- Addition of ACH coagulant (up to 10 mg/L) was effective in reducing true colour to below the treatment goal of 15 TCU and increasing the UVT. The dose is dependent on raw water values.
- During turbidity events, the membranes were able to adequately treat the water without altering the operational parameters. Additional EFM cleans may be needed to limit TMP build-up during these events.
- Preliminary DBP formation potential testing showed that a coagulant dose of 5 mg/L

reduced DBP formation potential by approximately 100 µg/L during a small turbidity event (5-10 NTU). As with colour and UVT, the dose required to reduce DBPFP is likely dependent on raw water conditions. Future SDS testing should be undertaken to confirm the DBP compliance.

- The various cleaning methods (EFM and CIP) used in this pilot study were effective restoring membrane permeability. A CIP interval greater than 30 days should be achieved under full-scale design conditions.

4.3 RECOMMENDATIONS FOR ERWS

The results of the pilot study suggest that a membrane system is a more suitable process for the treatment of the Englishman River water source compared to conventional treatment. The membrane process showed that it can successfully remove turbidity to well below the health based limit of 0.1 NTU during normal and challenging conditions. Pre-treatment with aluminum chlorohydrate (ACH) coagulant would enhance treatment by removing the true colour from the water, to below the aesthetic objective of 15 TCU as well as increase UVT for a future UV disinfection process. Based on the pilot test findings, recommended design criteria for membrane filtration (specific to Pall Microfiltration system) are:

Pre-treatment Coagulant:	Aluminum Chlorohydrate (ACH)
Coagulant Dose:	0-10 mg/L based on raw water colour
Flux:	76.5 Lmh (45 GFD) at ambient temperature
EFM:	Minimum once per day, depending on raw water conditions
CIP:	Greater than 30 days

Please note that the above design criteria are based on Pall 0.1 µm microfiltration (MF) membrane system. If other membrane vendor equipment is to be chosen, a brief proof testing of the membrane using the recommended pre-treatment conditions should be completed.

REPORT

Certification Page

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PROFESSIONAL PROVINCE OF K. D. KOHUT # 33868 BRITISH COLUMBIA ENGINEER

sep 19/13

Keith Kohut, M.A.Sc., P.Eng.
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LW/SS/KK/lp

A Appendix A - Bench-Scale Test Results

		Raw Water			Coagulant		Polymer				
Date	Test	Turb (NTU)	Temp (°C)	Soda Ash	Type	Dose (mg/L)	Type	Dose (mg/L)	pH	Floc Size	Settleable
16-Nov-11	1	1	4.8	0	All	10 to 40	Anionic	0.1	6.5-7.3	none	N
17-Nov-11	2	2.22	7.7	0	Alum	40	Anionic	0.1	6.93	A	N
17-Nov-11	3	2.22	7.7	0	Alum	30	Anionic	0.15	6.43	B	N
18-Nov-11	4	1.48	4	0	ClearPac	5	Anionic	0.2	6.8	A	N
18-Nov-11	5	1.48	4	0	Alum	30	Anionic	0.2	7.09	B/C	N
22-Nov-11	6	84	8	0	Alum	60	Anionic	0.2	5.6	A	N
22-Nov-11	7	25	8	0	Alum	40	Anionic	0.1	6.21	B/C	N
23-Nov-11	8	6.48	6.2	0	Alum	40	Anionic	0.2	6.09	B/C	minimal
28-Nov-11	9	12	7.2	0	ClearPac	2 to 20	Anionic	0		none	N
28-Nov-11	10	12	7.2	0	ClearPac	50	Anionic	0	6.6	A/B	N
28-Nov-11	11	8.2	7.2	0	ClearPac	45	Anionic	0.2	6.78	B	minimal
29-Nov-11	12	4.85	7.3	0	ClearPac	40	Anionic	0.2	7.08	B	minimal
30-Nov-11	13	3.1	6	0	ACH	20	Anionic	0	7.35	A	N
30-Nov-11	14	3.1	6	0	ACH	20	Anionic	0.4	7.44	B	N
13-Dec-11	15	1	5	20	ACH	40	Anionic	0.2	9.59	B	N
19-Dec-11	16	1.1	8	20	Alum	5 to 60	Anionic	0.2	8.6-10.1	none	N
20-Jan-12	17	1.2	5.3	0	ACH	10	Cationic	0.2	6.94	A	N

SUMMARY - Jar Test Results
PARKSVILLE, BC
ENGLISHMAN RIVER WATER SOURCE

		Raw Water			Coagulant		Polymer				
Date	Test	Turb (NTU)	Temp (^oC)	Soda Ash	Type	Dose (mg/L)	Type	Dose (mg/L)	pH	Floc Size	Settleable
16-Nov-11	1	1	4.8	0	All	10 to 40	Anionic	0.1	6.5-7.3	none	N
17-Nov-11	2	2.22	7.7	0	Alum	40	Anionic	0.1	6.93	A	N
17-Nov-11	3	2.22	7.7	0	Alum	30	Anionic	0.15	6.43	B	N
18-Nov-11	4	1.48	4	0	ClearPac	5	Anionic	0.2	6.8	A	N
18-Nov-11	5	1.48	4	0	Alum	30	Anionic	0.2	7.09	B/C	N
22-Nov-11	6	84	8	0	Alum	60	Anionic	0.2	5.6	A	N
22-Nov-11	7	25	8	0	Alum	40	Anionic	0.1	6.21	B/C	N
23-Nov-11	8	6.48	6.2	0	Alum	40	Anionic	0.2	6.09	B/C	minimal
28-Nov-11	9	12	7.2	0	ClearPac	2 to 20	Anionic	0		none	N
28-Nov-11	10	12	7.2	0	ClearPac	50	Anionic	0	6.6	A/B	N
28-Nov-11	11	8.2	7.2	0	ClearPac	45	Anionic	0.2	6.78	B	minimal
29-Nov-11	12	4.85	7.3	0	ClearPac	40	Anionic	0.2	7.08	B	minimal
30-Nov-11	13	3.1	6	0	ACH	20	Anionic	0	7.35	A	N
30-Nov-11	14	3.1	6	0	ACH	20	Anionic	0.4	7.44	B	N
13-Dec-11	15	1	5	20	ACH	40	Anionic	0.2	9.59	B	N
19-Dec-11	16	1.1	8	20	Alum	5 to 60	Anionic	0.2	8.6-10.1	none	N
20-Jan-12	17	1.2	5.3	0	ACH	10	Cationic	0.2	6.94	A	N

B Appendix B - Pall Pilot Report

Pall Corporation

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Pall Water Processing Final Report
Project No. W-0560

PILOT-SCALE FILTRATION OF SURFACE WATER USING PALL MICROFILTRATION MEMBRANES FOR THE ENGLISHMAN RIVER WATER SERVICE LOCATED IN VANCOUVER ISLAND, PARKSVILLE, BC

For: Linda Wojcicka, Associated Engineering
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S. Toomey

March 26, 2012

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PURPOSE

The purpose of this pilot test is to demonstrate the performance of the Pall 0.1 µm Microfiltration (MF) membrane in treating a source of surface water from the Englishman River located in Parksville, BC. Pretreatment included direct coagulation into the raw stream feeding the Pall MF pilot system. This report summarizes the findings of the pilot test. Specific objectives of the pilot test included:

- Demonstration of the design criteria and operating parameters to be used in the full-scale 4 MGD MF system
- Demonstration of particulate and microbial removal capability via on-line turbidity and particle count measurement
- Confirmation of on-line integrity test procedures
- Evaluation of membrane flux and recovery
- Evaluation of membrane fouling, CIP intervals and effectiveness

SUMMARY

Pall Corporation began pilot testing in November 2011 to determine the performance characteristics of the Pall MF system for filtering surface water from the Englishman River. The timing of the pilot study was critical in an effort to capture seasonally high turbidity events from the surface water source. The variable raw water quality has recorded turbidity events as high as 250 NTU. These spikes occur rapidly and within 8 hours, return to stable turbidity levels. Cycle #1 experienced several turbidity events. During cycle #1, the MF pilot system started operations on raw water without any pretreatment process. The directed coagulation process would be introduced into the process on December 14. The strategy for this phase of testing was to determine the most effective method to operate the MF system with minimal production interruption and minimal operator intervention. It was found that the most effective way to operate the Pall MF system during such an upset was to use the typical NaOCl EFM process with an automated trigger based on a preset transmembrane pressure. During the pilot study, the automated trigger of which an EFM was initiated at was set at 20 PSI. Cycle #2 examined ACH (Aluminum Chlorohydrate) as a coagulant. During this phase of the study, the Pall MF system successfully operated on pretreated water (coagulation with 5-10 ppm ACH) from the Englishman River at 45 GFD with a 95.3% recovery, 10% XR, daily 500 ppm NaOCl EFM and weekly 2500 ppm citric acid EFM procedures. The MF filtrate turbidity produced during the pilot was consistently low, with an average of 0.012 NTU. The average feed water temperature measured during the pilot was 41°F. Throughout the pilot test, the Pall membrane demonstrated regenerative ability using EFM and CIP procedures. Membrane integrity was verified throughout the pilot with daily pressure hold tests.

TEST EQUIPMENT & OPERATION

Membrane Module

The system was equipped with a pre-conditioned UNV-3003 (S/N 030440909) hollow-fiber MF module. The module contains 6.97 square meters of active membrane surface area and operates in an outside-to-inside filtration mode. The membrane is a polyvinylidene fluoride (PVDF) hollow fiber type with a nominal pore size of 0.1 µm. PVDF fibers has excellent mechanical and chemical resistance. The physical characteristics of the membrane are described below in *Table 1*.

TABLE 1: TEST MEMBRANE UNV-3003 SPECIFICATIONS

Membrane Material	PVDF
Housing Material	PVC
Membrane Area (Outer Surface)	75 ft^2/6.97 m^2
Module Length	1 m
Module Diameter	7.62 cm

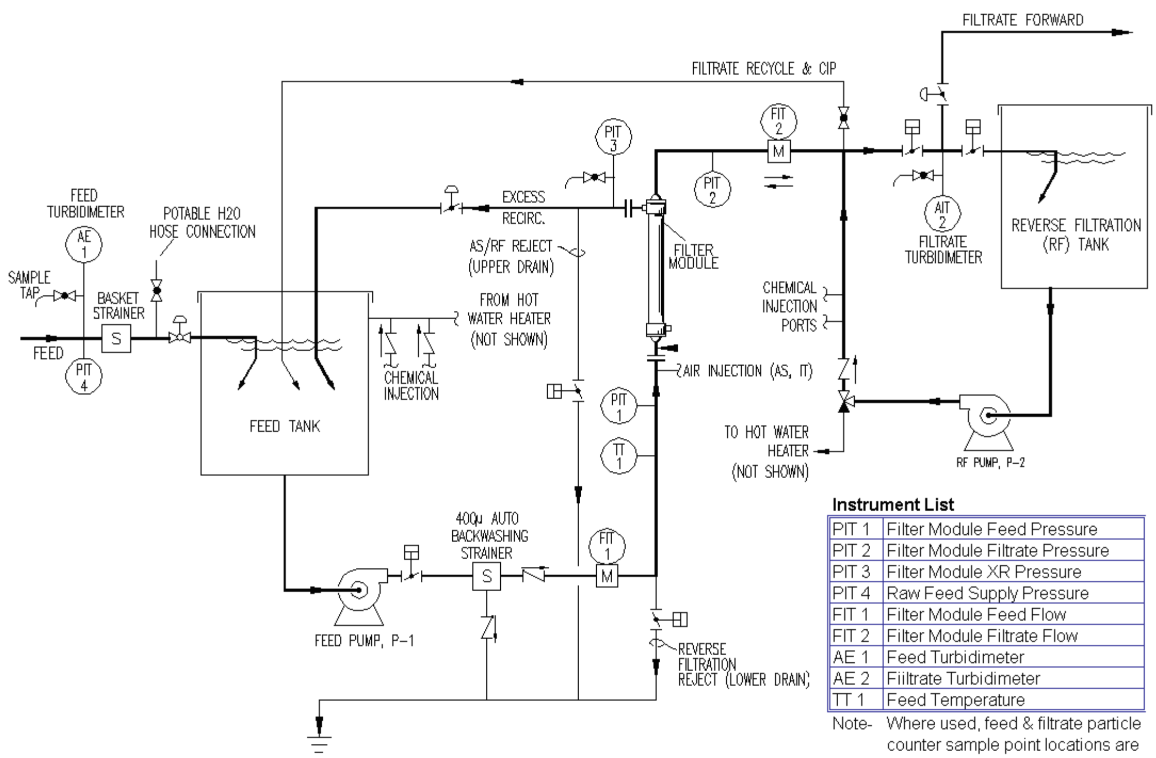
TABLE 2: FULL SCALE MEMBRANE UNA-620A SPECIFICATIONS

Module Type	UNA-620A
Membrane Material	PVDF
Housing Material	ABS
Membrane Area (Outer Surface)	538 ft^2/50 m^2
Module Length	2 m
Module Diameter	15.24 cm
Nominal Membrane Pore Diameter	0.1µm
Number of Fibers per Module	6400
Fiber Diameter (ID/OD)	0.7mm/1.3mm
Filtration Mode	Outside-In, Dead End
Maximum Permeation Transmembrane Pressure	43.5 psid
Typical Operating Transmembrane Pressure	5-43.5 psid
Maximum Air Pressure for Integrity Test	>30
Maximum Operating Temperature	40°C
Maximum Cleaning Temperature	40°C
Operating pH Range	1-10
Cleaning pH Range	1-13
Maximum OCl- Exposure (Lifetime Contact Time)	>7,200,000 ppm-hr
Maximum Concentration for OCl- Cleaning	10,000 ppm

Pall MF Pilot System

The Pall MF pilot system is a fully automated membrane system designed with a range of capacity and capability intending to be applied to a wide range of process conditions. An industrial computer and a PLC controlled the operation of the system during this pilot study. The system was also monitored and controlled remotely through a wireless cellular router and remote access software. Critical operational parameters were logged continuously at 5 minute intervals and recorded automatically on the system computer hard drive. A schematic of the Pall MF system is show below in ***Figure 1***. The pilot unit also included a hot water heater and chemical pumps for the direct coagulation and EFM processes.

FIGURE 1: SCHEMATIC OF PALL PILOT SYSTEM



Instrument List

PIT 1	Filter Module Feed Pressure
PIT 2	Filter Module Filtrate Pressure
PIT 3	Filter Module XR Pressure
PIT 4	Raw Feed Supply Pressure
FIT 1	Filter Module Feed Flow
FIT 2	Filter Module Filtrate Flow
AE 1	Feed Turbidimeter
AE 2	Fiiltrate Turbidimeter
TT 1	Feed Temperature

Note- Where used, feed & filtrate particle counter sample point locations are same as AE 1 & AE 2 respectively.

PROCESS DESCRIPTIONS

There are five basic modes of operation for the membrane pilot system:

1. **Forward Filtration (FF):** The feed pump draws water from the feed tank and pumps it into the feed port at the bottom of the module and through the membrane filter. The permeate exits through the filtrate port at the top end of the module. Excess recirculation (XR) entails circulating a small fraction of the feed water back to the feed tank to retain particulate suspension. This is performed by allowing a fraction of the feed flow to return to the feed tank through the horizontal XR port at the top of the module. The pilot unit is capable of operating with or without excess recirculation.
2. **Air Scrub (AS):** AS is a frequent, short-duration hydraulic cleaning of the membrane to maintain optimal performance. During the AS, air is injected into the module, on the feed side of the fibers while filtrate is pumped in the reverse direction through the module. All of the process waste created during an AS is discharged to drain. The combined water-air flow creates a strong turbulent and shearing force to dislodge dirt deposits on the membrane surface. The forward and reverse flow periods are used to flush out the solids dislodged during air scrubbing. The frequency and duration of the AS is user defined.
3. **Forward Flush (FL):** FL is another form of hydraulic cleaning for the membrane that follows an AS. The feed pump draws water from the feed tank and pumps it through the membrane housing in the same direction as that during forward filtration. The waste is discharged through the upper discharge port, flushing out the solids dislodged during air scrubbing.
4. **Reverse Filtration (RF):** The RF pump draws filtrate stored in the RF tank and pumps it through the filter in the opposite direction as that during forward filtration. RF is used as a form of hydraulic cleaning for the membrane and is discharged through both upper and lower discharge points to drain.
5. **Enhanced Flux Maintenance (EFM):** An EFM is a cleaning of membranes to maintain optimal performance. EFM process involves circulation of a chemical cleaning solution on the feed side of the membrane at an elevated temperature (~ 90°F) for 30 minutes before rinsing and returning the unit back to filtration mode.

CYCLE #1

Cycle #1 began on November 8, 2011 and ended on January 10, 2012. The Pall MF pilot system was supplied with a surface water stream delivered from the Englishman River. For this phase in the pilot test, there is no pretreatment process in operation. The intent is to operate the MF pilot system at a variety of flux rates to help determine the optimum parameters for design based on raw water only. The target recovery rate at each operational flux is greater than 95%. The average feed water temperature was 44.07°F. Below is an overview of the system performance at a variety of parameters and conditions.

- During the period of operation from 11/8 to 11/10, the ambient flux the MF pilot system operated at was 42 GFD, with an ASF (Air Scrub) interval of 20.7 minutes. Excess recirculation was operational at 10%. The MF membrane performance was stable with the average TMP measuring 4.3 PSI.
- During the period of operation from 11/10 to 11/13, the ambient flux the MF pilot system operated at was 42 GFD, with an ASF (Air Scrub) interval of 30.4 minutes with 96.4% recovery. Excess recirculation was not enabled during this period. The MF membrane performance was stable with the average TMP measuring 4.2 PSI.
- During the period of operation from 11/13 to 11/17, the ambient flux was increased to 50 GFD, with an ASF (Air Scrub) interval of 30.2 minutes with 96.9% recovery. Excess recirculation was not enabled during this period. The MF membrane performance was stable with the average TMP measuring 4.94 PSI.
- During the period of operation from 11/17 to 11/22, the ambient flux was increased to 55 GFD. The previous testing periods demonstrated stable performance and an overall good recovery. This test period would challenge the membrane performance more aggressively in order to achieve targeted recovery rates. At 55 GFD, an ASRF interval of 30 and 25 minutes proved to be too aggressive. At 55 GFD an ASRF interval of 20 minutes would prove to be appropriate. The system would operate at these parameters from 11/18 until 11/22.
- On Tuesday 11/22, the process experienced the first major upset. Raw water turbidity would be recorded as high as 50 NTU at the source. As indicated by the system data, it is likely that the upset began to occur around 4:30 AM. At 10:30 AM, the flux was lowered from 55 GFD to 42 GFD, with an ASRF interval of 26.3 minutes (95.9% recovery). At 11:30 AM the feed pressure reached approximately 45 PSI. The flux was lowered to 35 GFD with an ASRF interval of 20 minutes (93.9% recovery). At 2:00 PM a high TMP warning was logged. The flux was then lowered to 25 GFD with an ASRF interval of 20 minutes (91.7% recovery). At 3:20 PM, an EFM was triggered in an effort to intervene further in the process recovery. The EFM was effective in slowing down the rapid TMP growth due to the upset. Prior to the EFM, the TMP was closing in on terminal TMP limits (43.5 PSI). After the EFM, the TMP returned to stable levels (2-3 PSI). At 5:45 PM, the performance was stable and I began to increase the operating flux. At 50 GFD

and 55 GFD, the performance was not able to stabilize the TMP growth. On Wednesday 11/23, the system would continue operation at 42 GFD with an ASRF interval of 30 minutes (96.4% recovery).

- From Wednesday 11/23 through 11/28 the MF pilot system would continue to operate at 42 GFD with an ASRF interval of 30 minutes (96.4% recovery). As the first major upset passed through, the performance continues to stabilize. On Sunday 11/27 the MF pilot begins to experience another upset in the surface water source. The raw water turbidity begins to rise to 49 NTU. The TMP also begins to climb rapidly. The system was set to trigger an additional EFM if the pressure climbed above a 20 PSI increment. The system automatically triggered an additional EFM (just 3 hours short of the 24 interval) at 8:15 AM. This would demonstrate that the system could successfully combat short term upsets in the surface water source.

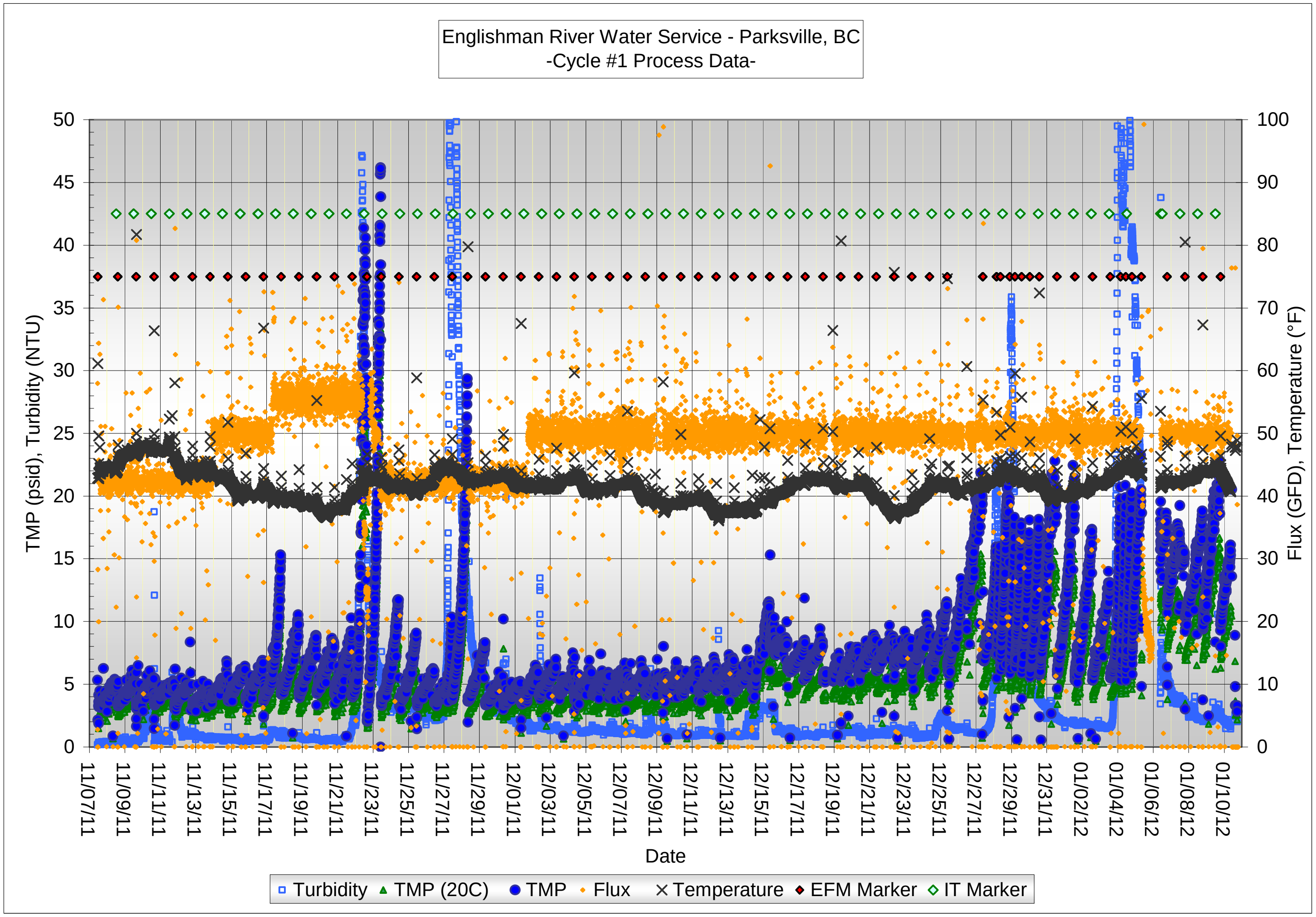
- From Thursday, 12/1 through 1/10/12 the MF pilot system would continue to operate at 50 GFD with an ASRF interval of 25 minutes (96.4% recovery). MF performance was stable from the 12/1 until 12/14. On 12/14, coagulant was introduced into the system. On 12/15 a noticeable rise in TMP occurred which is believed to be a result of the coagulant addition. The injection rate of the coagulant was lowered. Further details of coagulant addition will be provided at a later time. From 12/16 through 12/25, the TMP gradually rose, however the daily heated EFM helped to restore permeability and to control TMP growth. During this period of operation, the raw water quality was good as indicated by turbidity measurement. The gradual rise in the TMP is likely due to the coagulant injection process. This TMP increase would be expected. From 12/25 to 12/27, a rapid rise in the TMP occurred. This rise would be due to a brief interruption in operation on 12/26, which resulted in a missed daily EFM. An EFM is triggered on 12/27 and effectively recovers the TMP. From 12/28 through 1/5, the MF process experienced a series of high turbidity events. This provided the opportunity to test the effectiveness of process triggers using the ASRF and EFM processes during such events. For the purpose of this test, the effort was to control and limit the TMP to around 20 PSI. According to the online raw water turbidimeter, on 12/28 the turbidity rapidly rose to 22 NTU, retracted, then increased to 35 NTU. On 12/28, three EFMs were triggered. The first two EFMs were triggered with a TMP at approximately 16 PSI. The span was adjusted for the third EFM on 12/28 to trigger with a TMP closer to 20 PSI. From 12/29 through 12/30, the turbidity event declines. EFMs occurred twice with the time interval increasing after each cycle. This would suggest that it would take a few days for such an event to pass through the system. With the EFM used as the primary trigger, it can be seen that the TMP after each EFM has returned restores to approximately 5-7 PSI. On 12/31, the operational strategy changed to use an ASRF trigger at 20 PSI. This would quickly prove to not be very effective in restoring the TMP to reasonable levels. Essentially, when the TMP would reach 20 PSI, an additional ASRF was triggered. The ASRF would maintain 20 PSI, however, would reduce to overall recovery of the MF process. From 12/31 through 1/3, the raw water quality fed to the MF test rig gradually improves as indicated by on-line instruments. The EFM is triggered on a daily interval based on time rather than a trigger based on pressure. On 1/3 another high turbidity event occurs. Raw water turbidity measured on the MF test rig reached as high as 65 NTU. Three EFMs were triggered as the TMP reached 20 PSI. The EFMs restored the TMP to 5-6 PSI. On 1/5, the rig shutdown due to the rig being starved of raw water. The bag filter on the inlet of the rig was filled with solids. On 1/6 the strainer and drain lines were cleaned of any excess debris. The system is brought back on line and operated through 1/10 at a slightly elevated TMP.

A CIP was performed in conclusion of cycle #1 on January 10, 2012 per the protocol found in Appendix B. An integrity test was also performed after the CIP was completed and was successful with a less than 0.2 PSI/min drop in pressure over the five minute pressure hold duration. The integrity test procedure is detailed in Appendix A. The MF pilot rig was brought back into service Wednesday 1/12/12

TABLE 3: CYCLE #1 OPERATING PARAMETERS

Filtrate Flux		42 – 55 GFD
Recovery		> 95%
ASF	Interval (gallons)	75 Gallons
	Interval (minutes)	30.3 Minutes
	Filtration Duration	28.8 Minutes
	Duration	60 Seconds
	Air Flow (SCFM)	1.5 SCFM
	RF Flow (GPM)	1 GPM
FL	Interval (gallons)	75 Gallons
	Interval (minutes)	30.3 Minutes
	Filtration Duration	28.8 Minutes
	Duration	30 Seconds
	Water Flow (GPM)	2 GPM
EFM	Frequency	Daily
	Duration	30 Minutes
	Chemical	500 ppm NaOCl
	Temperature	90-100°F
Cycle Length		64 Days
Excess Recirculation		10% as determined
Raw Water Pretreatment		Direct Coagulation, 5 ppm ACH

FIGURE 2: CYCLE #1 PROCESS TREND



CYCLE #2

Cycle #2 began on January 11 and ended on February 21, 2012. The Pall MF pilot system was supplied with a surface water stream delivered from the Englishman River. The target recovery rate at each operational flux is greater than 95%. The average feed water temperature was 37.1 °F. Below is an overview of the system performance at the selected parameters and conditions.

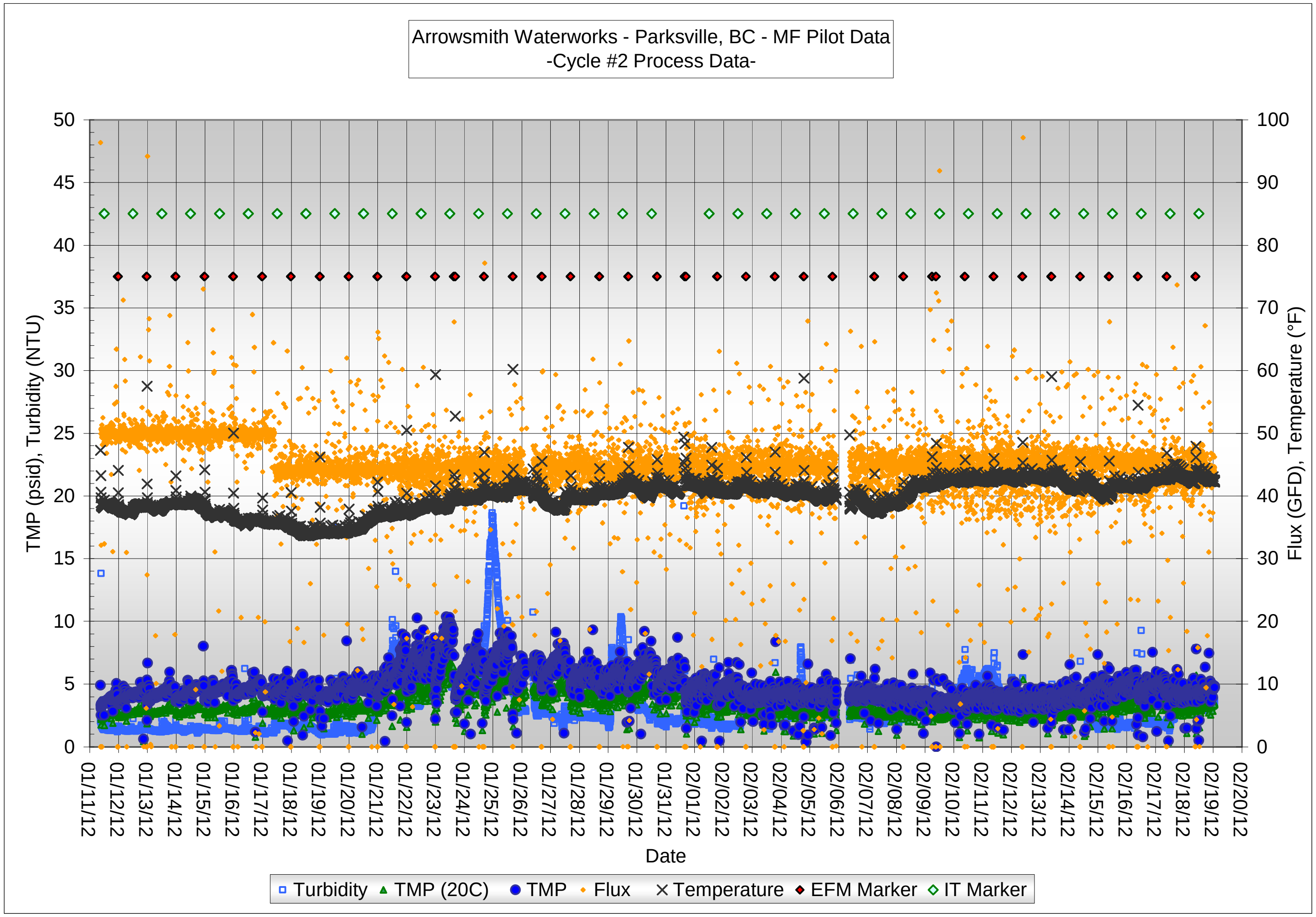
- During the period of operation from 1/11 to 1/17, the ambient flux the MF pilot system operated at was 50 GFD, with an ASF (Air Scrub) interval of 20.9 minutes with 95.3% recovery. The ASF (Air Scrub) utilizes the Forward Flush (FL). For this phase in the pilot test, there is no pretreatment process in operation. The intent is to operate the MF pilot system and observe the stability in treating raw water only. Excess recirculation was operational at 10%. The MF membrane performance was stable with the average TMP measuring 4.3 PSI.
- During the period of operation from 1/17 to 2/2, the ambient flux the MF pilot system operated at was 45 GFD, with an ASF (Air Scrub) interval of 20.9 minutes with 95.3% recovery. The ASF (Air Scrub) utilizes the Reverse Filtration (RF). Excess recirculation was operational at 10%. Direct coagulation into the raw stream that feeds the test rig was initiated at a rate of 5mg/L of ACH. The MF membrane performance was relatively stable with the average TMP measuring 5.7 PSI. On 1/21, a moderate rise in the TMP could be observed (1.3 to 8.2 NTU). The turbidity event is the likely cause of the slightly elevated TMP from 1/21 thru 1/31. Daily NaOCl (500 mg/L) EFMs coupled with a weekly citric acid (2500 mg/L) EFM has helped control the rise in the TMP and recover permeability. In addition to the daily NaOCl EFM a citric acid EFM was performed on 1/23 and 1/31 during this period of operation.
- During the period of operation from 2/2 to 2/21, the ambient flux the MF pilot system operated at was 45 GFD, with an ASF (Air Scrub) interval of 20.9 minutes with 95.3% recovery. The ASF (Air Scrub) utilizes the Reverse Filtration (RF). Excess recirculation was operational at 10%. Direct coagulation into the raw stream that feeds the test rig was increased from a rate of 5 mg/L to a rate of 10 mg/L of ACH. The MF membrane performance has remained stable with the average TMP measuring 5.7 PSI. The practice of daily NaOCl (500 mg/L) EFMs coupled with a weekly citric acid (2500 mg/L) EFMs has continued. This has a demonstrated benefit to the process which has helped control the rise in the TMP. During this period, the raw water has been stable. The MF membrane TMP has operated in the range of 3-5 PSI.

A CIP was performed in conclusion of the pilot study on February 21, 2012 per the protocol found in Appendix B. An integrity test was also performed after the CIP was completed and was successful with a less than 0.2 PSI/min drop in pressure over the five minute pressure hold duration. The integrity test procedure is detailed in Appendix A. At no time during this cycle did the TMP reach the terminal level (43.5 PSI).

TABLE 4: CYCLE #2 OPERATING PARAMETERS

Filtrate Flux		50, 45
Recovery		95.3%
ASF	Interval (gallons)	75 Gallons
	Interval (minutes)	30.3 Minutes
	Filtration Duration	28.8 Minutes
	Duration	60 Seconds
	Air Flow (SCFM)	1.5 SCFM
	RF Flow (GPM)	1 GPM
FL	Interval (gallons)	75 Gallons
	Interval (minutes)	30.3 Minutes
	Filtration Duration	28.8 Minutes
	Duration	30 Seconds
	FL Flow (GPM)	2 GPM
EFM	Frequency	Daily
	Duration	30 Minutes
	Chemical	500 ppm NaOCl
	Temperature	90-100°F
Alt. EFM	Frequency	Weekly
	Duration	30 Minutes
	Chemical	2500 ppm citric acid
	Temperature	90-100°F
Cycle Length		41 Days
Excess Recirculation		10%
Raw Water Pretreatment		5-10- ppm ACH

FIGURE 3: CYCLE #2 PROCESS TREND



TURBIDITY

The average MF feed water, and MF filtrate turbidity for the pilot is shown below in *Table 5*. Graphed turbidity data is shown in Appendix C. The turbidity data showed that the Pall MF membranes produced excellent water quality with the filtrate turbidity average of 12.4 mNTU

TABLE 5: TURBIDITY SUMMARY

	Average MF Feed Turbidity (NTU)	Average Filtrate Turbidity (mNTU)
Cycle 1	3.90	12.44
Cycle 2	3.01	12.32
All Data	3.55	12.39

PARTICLE COUNTS

The on-line particle count data is summarized in *Table 6*. Graphed particle count data is shown in Appendix C.

TABLE 6: PARTICLE COUNT SUMMARY

	Average MF Feed Particle Counts (counts/mL)	Average Filtrate Particle Counts (counts/mL)	99^{th} Percentilo Filtrate Particle Counts (counts/mL)
Cycle 1	2837	0.76	7.29
Cycle 2	6504	1.20	11.93
All Data	3916	0.92	10.84

CIP EFFECTIVENESS

A chemical CIP procedure was performed after each cycle during the pilot study using the protocol outlined in Appendix A. A typical measure of CIP effectiveness is the specific flux or permeability, reported in GFD/psid. Appendix C contains graphs displaying the specific flux during pilot. Additionally, ***Table*** provides a summary of permeability following each CIP.

TABLE 7: CIP EFFECTIVENESS

Cycle	Cycle Length (Days)	Date of CIP	Average Specific Flux GFD/psi
Initial	-	-	18.33
1	64	1/10/12	22.03
2	42	2/21/12	22.04

The MF pilot study was successful at demonstrating the ability to regenerate the membrane's permeability after each CIP. As listed above in ***Table 7***, the initial average specific flux value was 18.33 GFD/psi. At the completion of the CIP procedure following cycle #1, the average specific flux value was recorded at 22.03 GFD/psi. The CIP procedure following cycle #2 fully restored permeability, with the average specific flux value at 22.04 GFD/psi.

INTEGRITY TESTING

In order for a membrane treatment system to be an effective barrier against pathogens and particulate matter it must be free of breaches. The presence or breaches, or membrane integrity, can be demonstrated on an ongoing basis during system operation using pressure based tests. A pressure hold test was performed at the start of the pilot, daily during the pilot, and after each CIP. The procedure is outlined in Appendix B, and consists of pressurizing the wetted filtrate side of the membrane while exposing the feed side to atmosphere. The pressure decay rate is then monitored and compared to a standard to ensure breaches are not present. Each integrity test performed during piloting passed with an average pressure decay rate of 0.1 psi/min.

The upper control limit (UCL) of the PDR for a Pall pilot system is 0.2 psi/min or 1 psi per 5 minute direct integrity test (DIT). This UCL is based on empirical data from previous Pall fiber cuts and integrity tests. Experience has dictated that minor air leaks are inevitable in pilot systems, and this actuality needs to be considered when determining the PDR UCL. Transportation of piloting equipment can often contribute to air breaches in piping and instrument connections. Air leaks are less likely with a full scale plant that does not move once installed. Additionally, full scale plants have larger air hold up volumes than pilot units. The PDR of a larger volume of air has substantially less sensitivity from a single air leak, thus full scale systems are less sensitive to each individual air breach. The PDR of 0.2 psi/min is conservative enough to account for air leaks, but is still capable of verifying membrane integrity (based on previous Pall testing).

Under the Long-Term Stage 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), a direct integrity test must meet a resolution criterion (for the purpose of granting removal credit for *Cryptosporidium* from regulatory agencies). A direct integrity test is required to have sufficient resolution to detect an integrity breach of 3 μm or less. The resolution computation below shows that a minimum test pressure of 17.5 psi is required to meet this criterion. The pressure-hold procedure used by Pall for full scale systems typically applies testing pressures as high as 25 to 30 psi. All IT's performed during the pilot trial exceeded 25 psi. This high testing pressure not only ensures the resolution criterion specified in LT2ESWTR can be met, but also considerably increases the sensitivity of the test.

The minimum testing pressure required in order to achieve a resolution of 3μm (P_{test}) with the Pall pilot is calculated below using equation 4.1 from the US EPA's Membrane Filtration Guidance Manual (MFGM).

$$P_{test} = (0.193 \bullet \kappa \bullet \sigma \bullet \cos\theta) + BP_{\max} \quad \text{(MFGM Equation 4.1)}$$

κ	=	pore shape correction factor ($\kappa = 1$)
σ	=	surface tension at the air-liquid interface (σ = 74.9 dynes/cm @5°C)
θ	=	liquid-membrane contact angle ($\theta = 0°$)
BP_{max}	=	the sum of back pressure and static head (BP_{max} = 3.0 psid[1])

[1] BPmax is calculated by adding the back pressure (0 psi during an IT) and the static head pressure (module height is 2 meter resulting in 3 psi of hydrostatic head).

Therefore, P_{test} = 14.5 + 3 = 17.5 psi

The pilot's integrity test data is summarized in ***Table 8*** below. All integrity tests performed during the pilot had pressure decays less than 0.2 psi/min, implying the absence of membrane breaches and ensuring membrane integrity.

TABLE 8: INTEGRITY TEST DATA SUMMARY

	Minimum Value	Maximum Value	Average Value
Beginning Pressure, P_{test} (psi)	17.04	30.24	24.94
Ending Pressure (psi)	16.14	29.58	23.79
Change in Pressure (psi)	0.25	0.70	0.49
Change in Pressure (psi/min)	0.05	0.14	0.10

CONCLUSIONS

The conclusions of this pilot study proved to be valid under normal conditions and within the range of the ACH dose tested. The results of the pilot study indicated the following:

- The Pall MF pilot system was successfully operated at a design flux of 45 GFD (ambient temperature) treating surface water.
- The Pall membrane system produced excellent finished water quality, averaging 12.2 mNTU.
- The pilot confirmed that a CIP interval greater than 30 days could be achieved under design conditions.
- The chemical cleaning processes (EFM & CIP) effectively restored membrane permeability, indicating that the specified cleaning regime (chemical, duration, and frequency) is appropriate for this feed water source.
- Membrane integrity was successfully verified on a daily basis during the pilot study using a pressure-hold test.

Pall Corporation's *Water Processing* appreciates the opportunity to work with the Associated Engineers staff and the city of Parksville staff on this project. We will be happy to assist in the future implementation of the Pall MF technology.

Scott Toomey
Project Manager
Pall Water Processing
Pall Corporation

APPENDIX A: INTEGRITY TEST PROTOCOL

1. In Automatic Mode

1.1 Open the *Mode* view in the HMI

1.2 Select *Integrity Test* tab from the view. The integrity test sequence is automatically executed and the test data is logged into data file. If the pressure decay rate exceeds the set point (typically 0.2 psid/min.), an alarm is activated. If the system passes the integrity test, the system will return to the normal operation after integrity test.

2. In Manual Mode

2.1 Open the *Process* view in the HMI

2.2 Set the system in *Manua*l mode by clicking *Auto/Manual* button

2.3 Close valves on feed and excess recirc line and open the valve on the filtrate line by clicking valves on process flow diagram. The color Red indicates "Close" and Green indicates, "Open"

2.4 Open the air valve to pressurize the module to the set point (typically 25 – 30 psi).

2.5 Wait until pressure stabilizes and record the pressure reading on the feed pressure transmitter tag as initial pressure; close the air valve start the timer.

2.6 Record pressure reading every 30 seconds for 5 minutes.

2.7 If the pressure reading at the end of 5 minutes exceeds the set point (typically 1.0 psi), the module fails the test. Check for leaks from piping and valves and look at the clear plastic coupling at the top of the module for air bubbles. If a continuous stream of air bubbles is visible, then the module failure is positively confirmed.

2.8 If the pressure loss at the end of 5 minutes is within or less than the set point (typically 1.0 psi), the module passes the test. Proceed to the next step.

APPENDIX B: CIP PROTOCOL SPECIFIC TO PALL MICROFILTRATION (MF) MEMBRANES

1. System Preparation:

- 1.0 Initiate appropriate AS/RF sequence.
- 1.1 Close Feed valve to unit after ensuring that all secondary feed pumps to system is shut off.
- 1.2 Close valves to turbidimeters, particle counters and other instruments, as required.
- 1.3 Drain feed tank: Wipe sides and bottom of feed tank, floater valve, inside of cover, etc. Rinse and drain feed tank so it is clean.
- 1.4 Drain module and any prefilters.

2. Softened (Potable) Water Flushing:

- 2.0 Fill feed and filtrate tanks with softened water to 8 gal level
- 2.1 Recirculate feed through XR valve at 8 gpm for 5-10 minutes
- 2.2 Flush the feed to drain
- 2.3 Perform a RF with filtrate at 15 gpm for one minute
- 2.4 Drain feed and filtrate tanks.

3. 1% Caustic/1000 mg/l (ppm) Chlorine Cleaning:

- 3.0 Switch filtrate valve to tank (recirculation mode)
- 3.1 Fill feed and filtrate tanks with softened heated (90° F) water to 8 gal
- 3.2 Add 50% NaOH (400 ml in 8 gal) and 6% NaOCl (460 ml in 8 gal)
- 3.3 Recirculate with 3-4 gpm forward flow for 2 hrs
- 3.4 Stop the system and AS the chemical solution to drain
- 3.5 Perform a RF with filtrate at 15 gpm for one minute
- 3.6 Drain feed and filtrate tanks.

4. Softened (Potable) Water Flushing: see section 3 above

- 4.0 Fill feed and filtrate tanks with softened water to 8 gal level
- 4.1 Recirculate feed through XR valve at 8 gpm for 5-10 minutes
- 4.2 Flush the feed to drain
- 4.3 Perform a RF with filtrate at 15 gpm for one minute
- 4.4 Drain feed and filtrate tanks.

5. 2% Citric Acid Cleaning

- 5.0 Switch filtrate valve to tank (recirculation mode)
- 5.1 Fill feed and filtrate tanks with softened heated (90° F) water to 15 gal
- 5.2 Add 50% citric acid (976 ml in 8 gal)
- 5.3 Recirculate with 3-4 gpm forward flow for 1 hrs
- 5.4 Stop the system and AS the chemical solution to drain
- 5.5 Perform a RF with filtrate at 15 gpm for one minute
- 5.6 Drain feed and filtrate tanks.

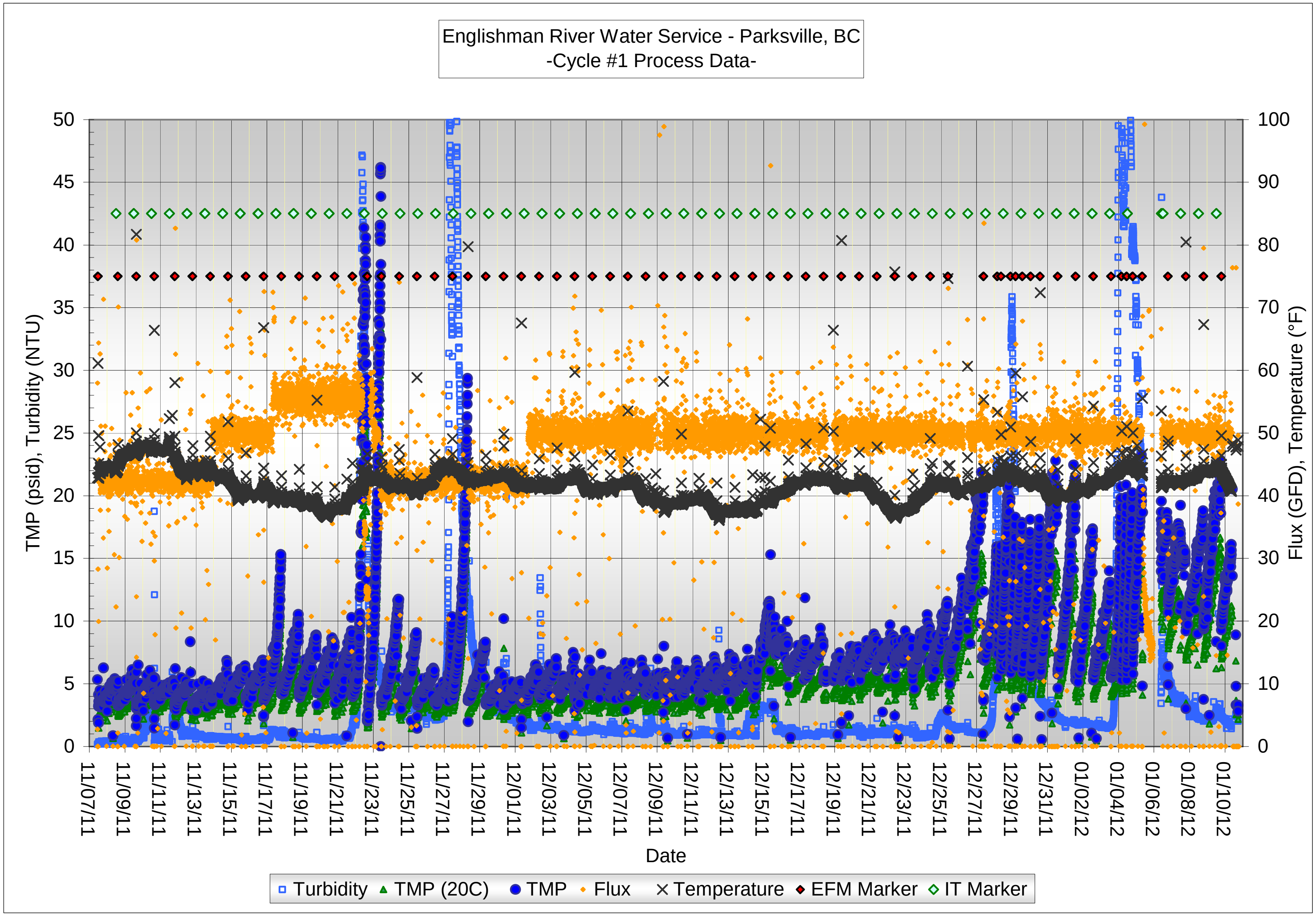
6. Softened (Potable) Water Flushing: see section 4 above

Water Processing

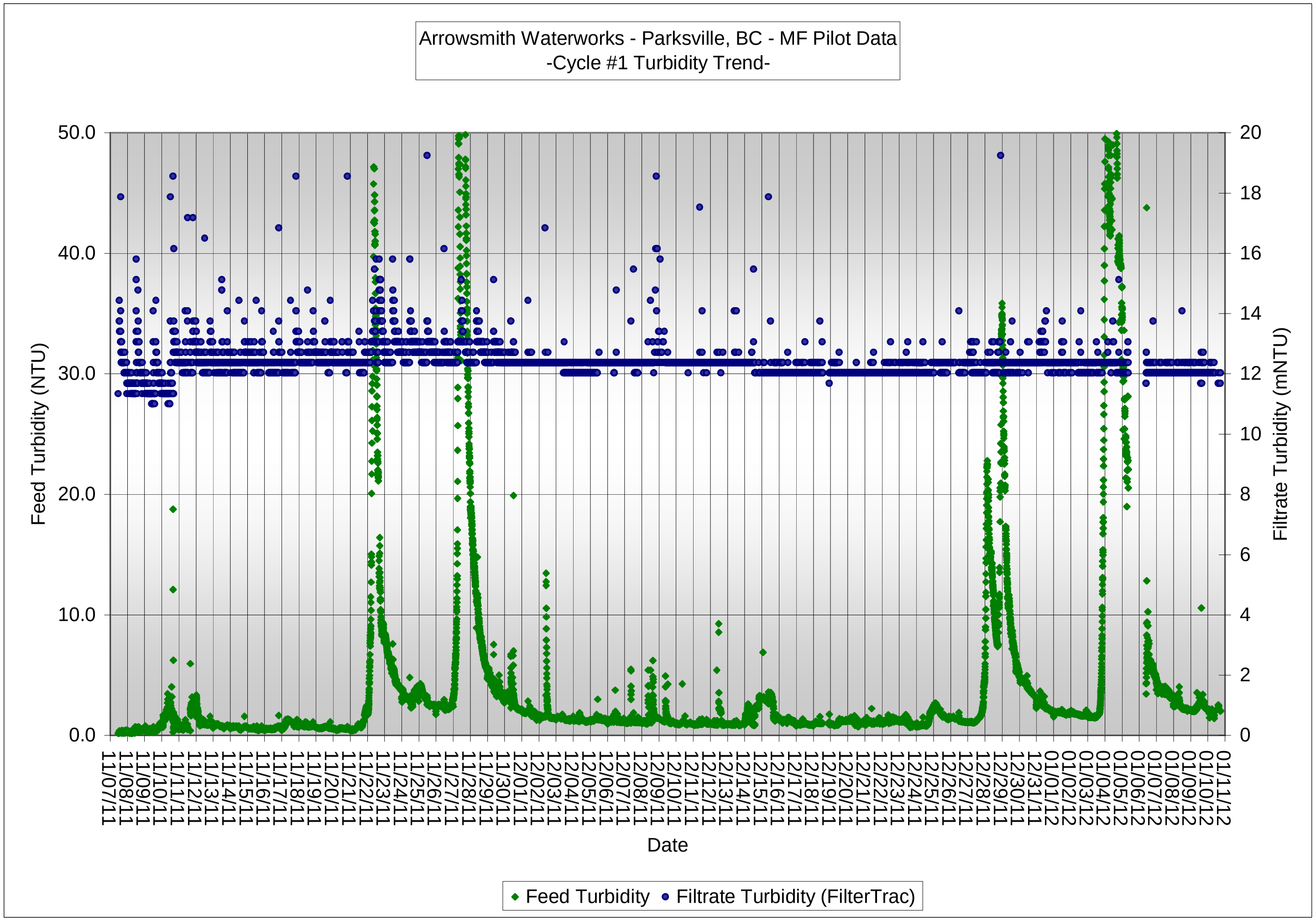
APPENDIX C: PILOT DATA CHARTS AND FIGURES

Appendix C Table of Contents

Water Processing



APPENDIX C


Arrowsmith Waterworks - Parksville, BC - MF Pilot Data
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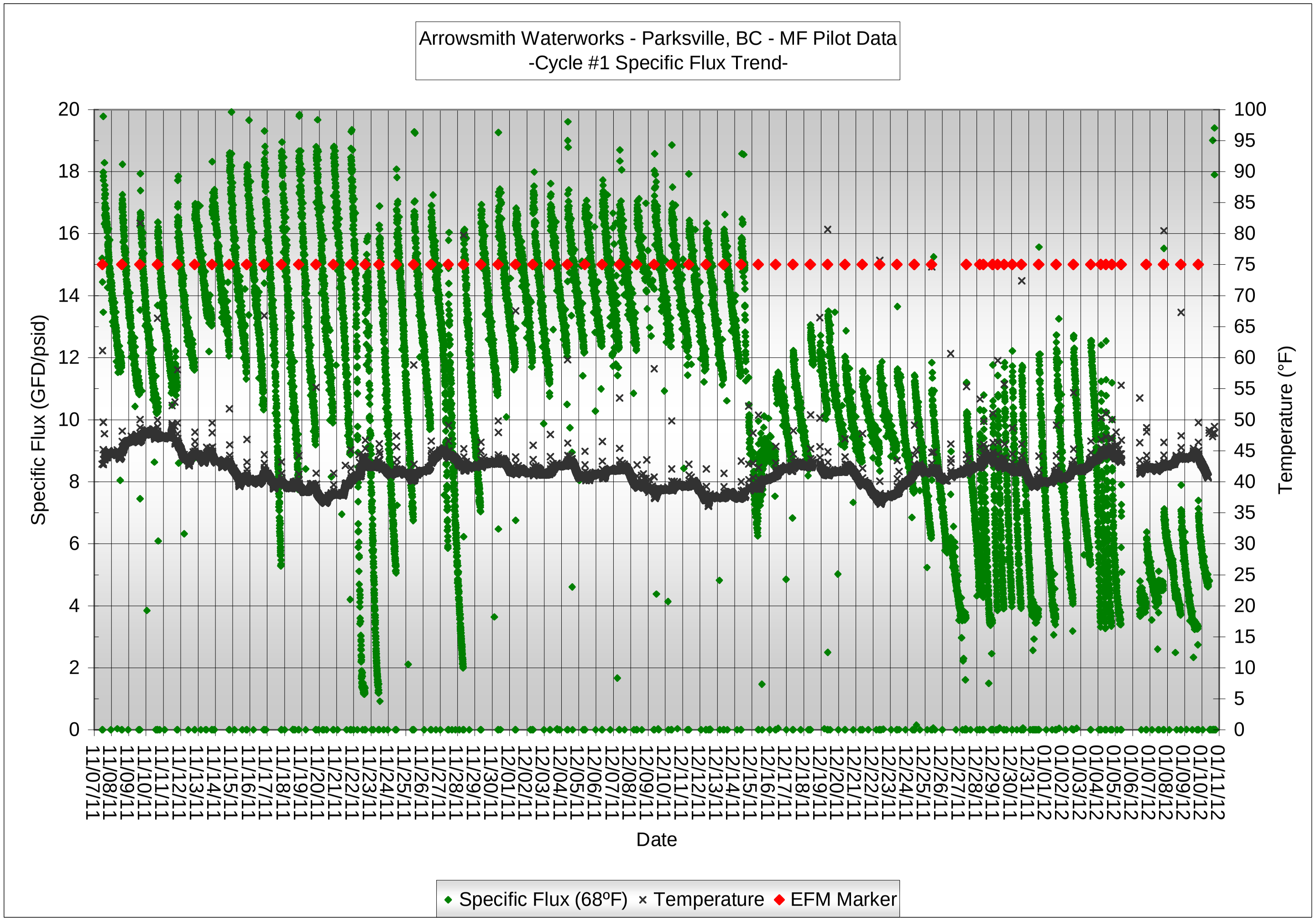
Filtrate Turbidity (mNTU)
Date
Feed Turbidity
Filtrate Turbidity (FilterTrac)


Arrowsmith Waterworks - Parksville, BC - MF Pilot Data
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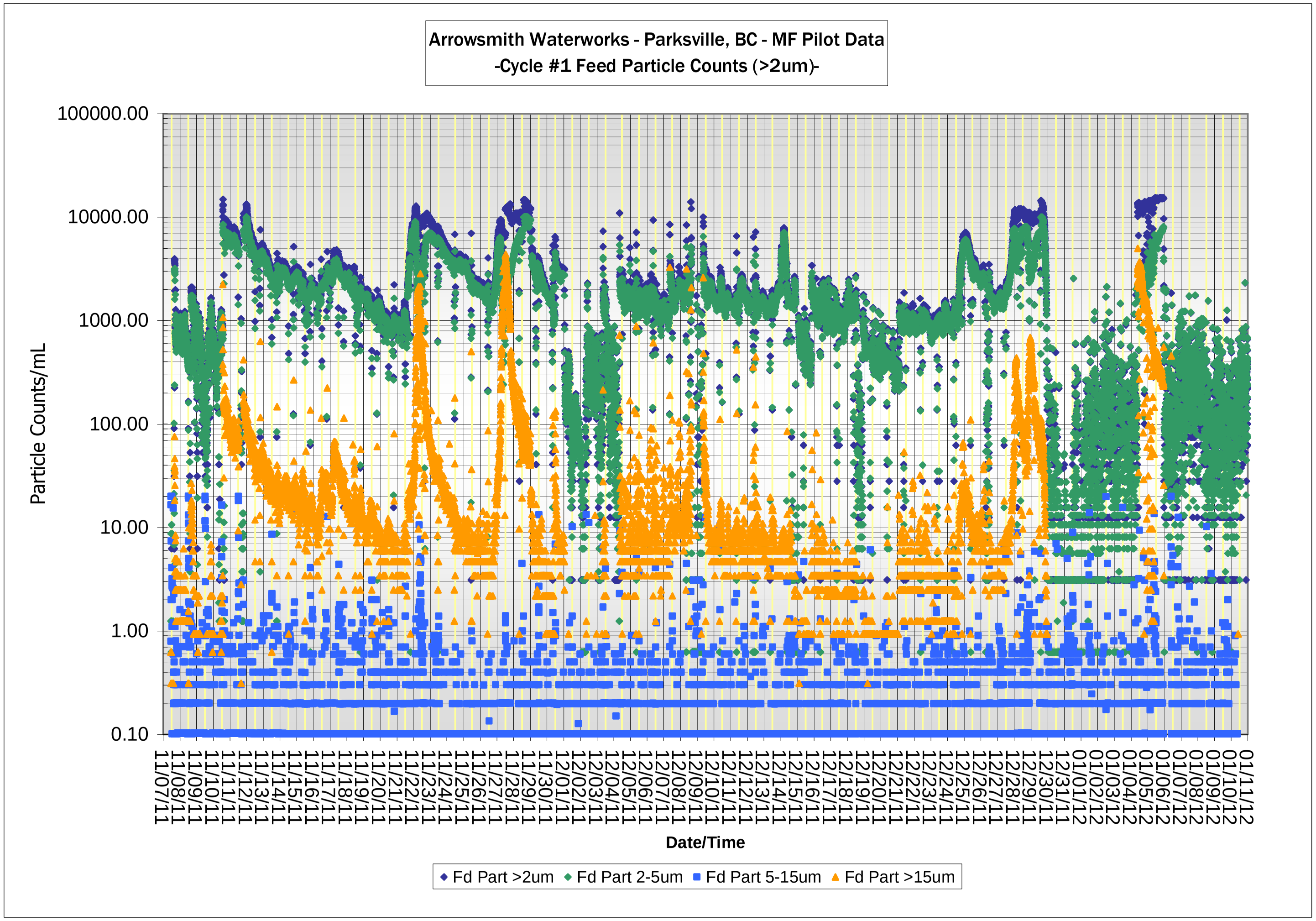
12/26/11
12/27/11
12/28/11
12/29/11
12/30/11
12/31/11
01/01/12
01/02/12
01/03/12
01/04/12
01/05/12
01/06/12
01/07/12
01/08/12
01/09/12
01/10/12
01/11/12
Specific Flux (68ºF)
Temperature
EFM Marker


Arrowsmith Waterworks - Parksville, BC - MF Pilot Data
-Cycle #1 Feed Particle Counts (>2um)-
Particle Counts/mL
100000.00
10000.00
1000.00
100.00
10.00
1.00
0.10
11/07/11
11/08/11
11/09/11
11/10/11
11/11/11
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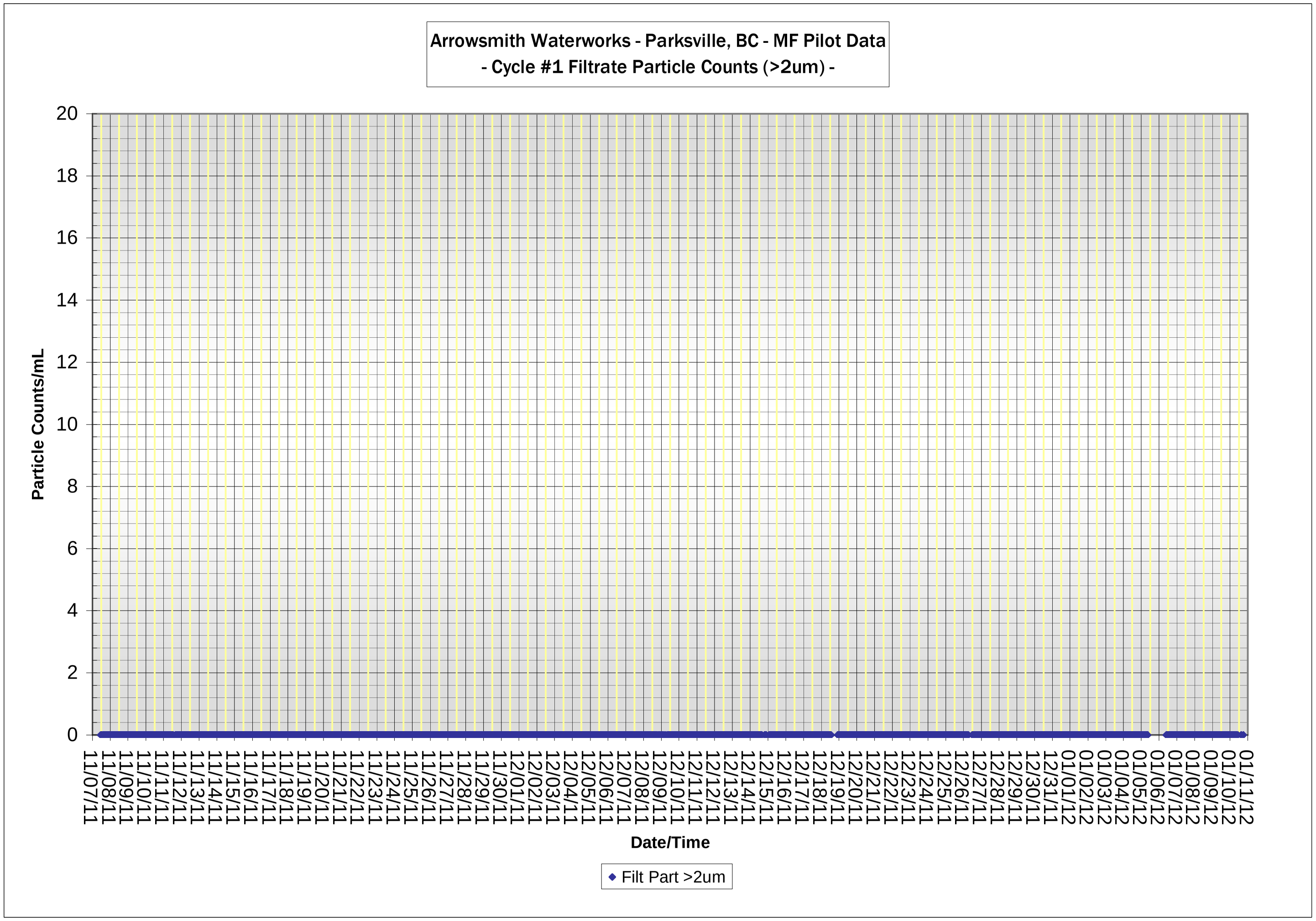
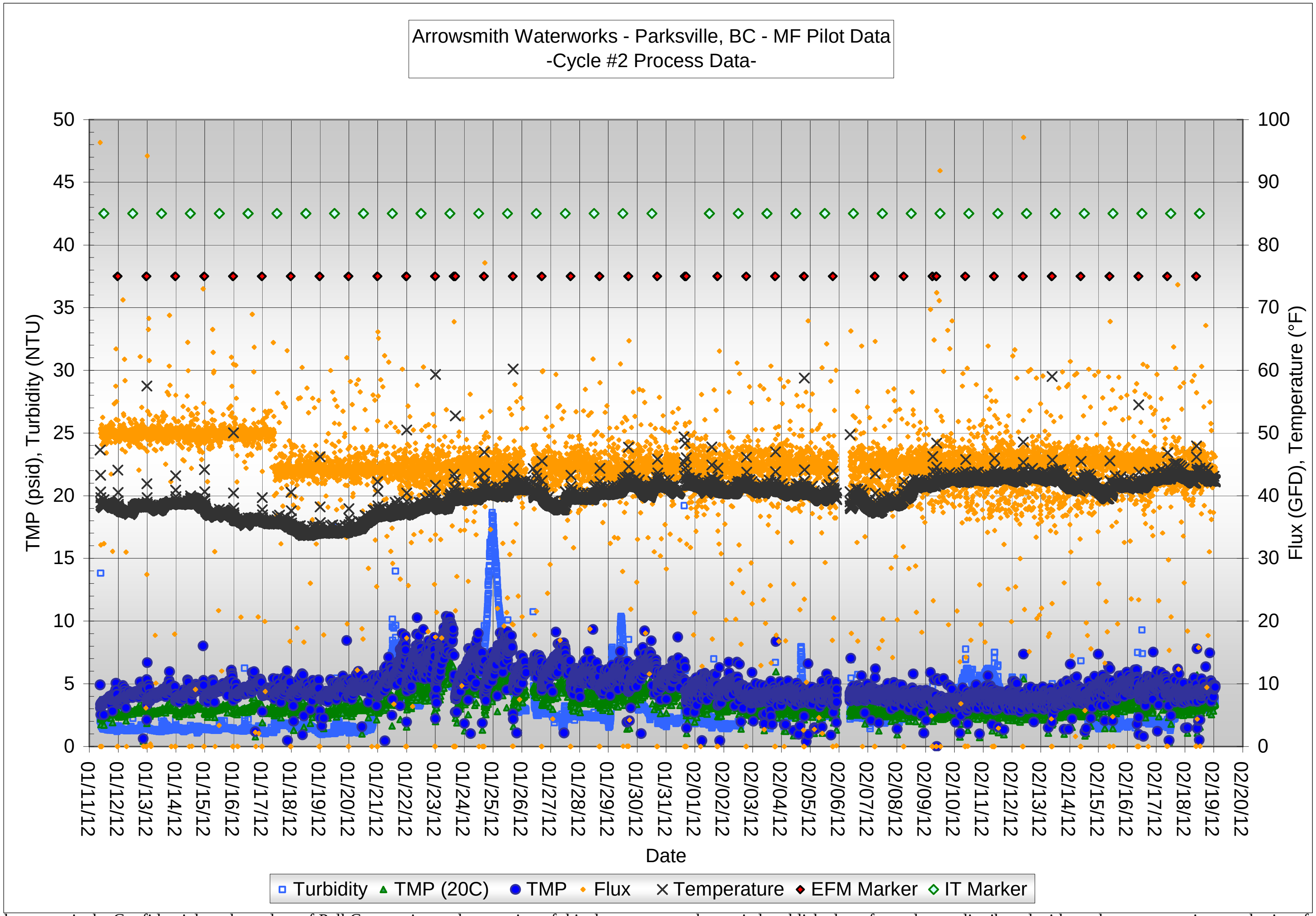
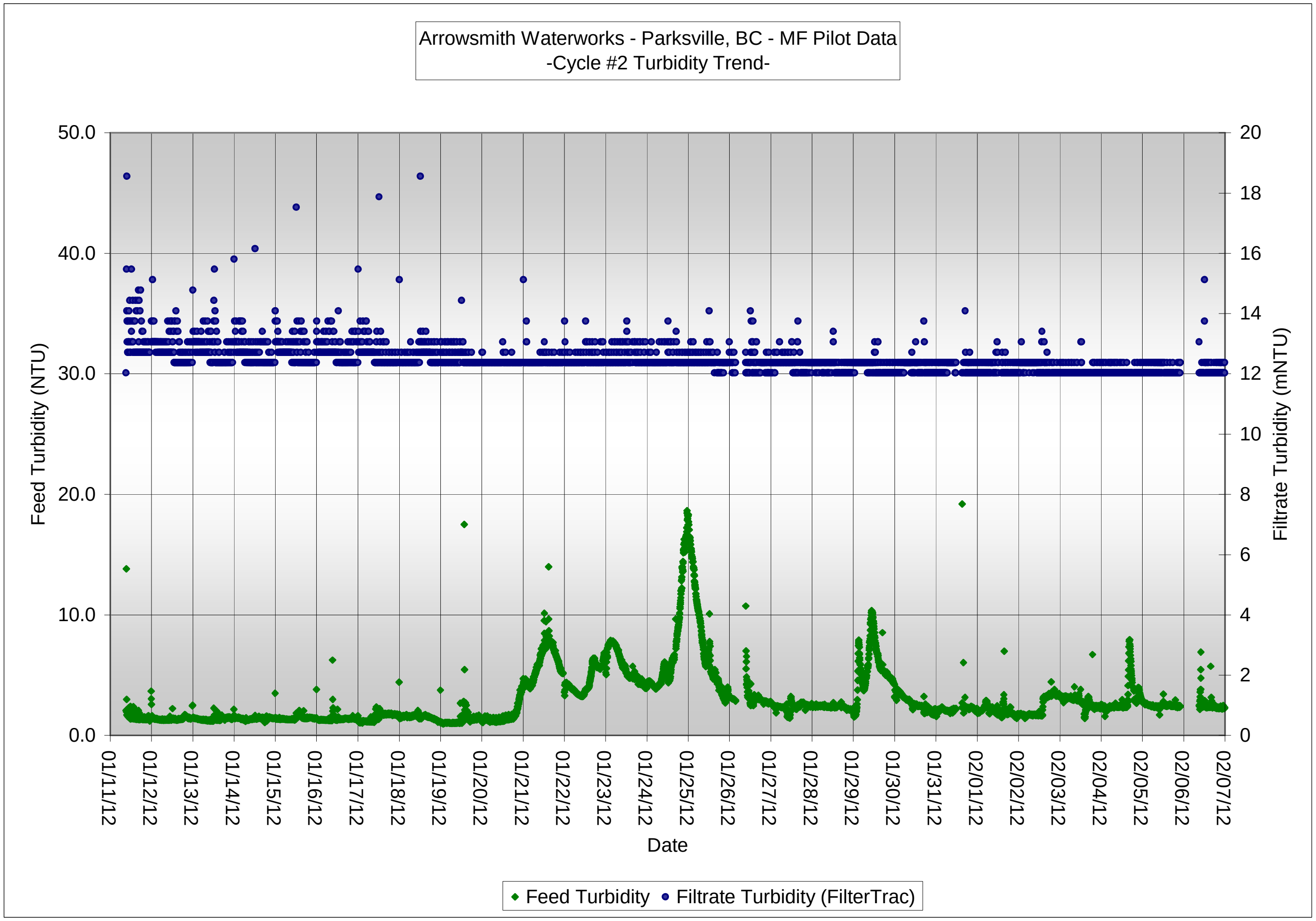
01/05/12
01/06/12
01/07/12
01/08/12
01/09/12
01/10/12
01/11/12
Date/Time
Fd Part >2um
Fd Part 2-5um
Fd Part 5-15um
Fd Part >15um


Arrowsmith Waterworks - Parksville, BC - MF Pilot Data
- Cycle #1 Filtrate Particle Counts (>2um) -
Particle Counts/mL
Date/Time
Filt Part >2um

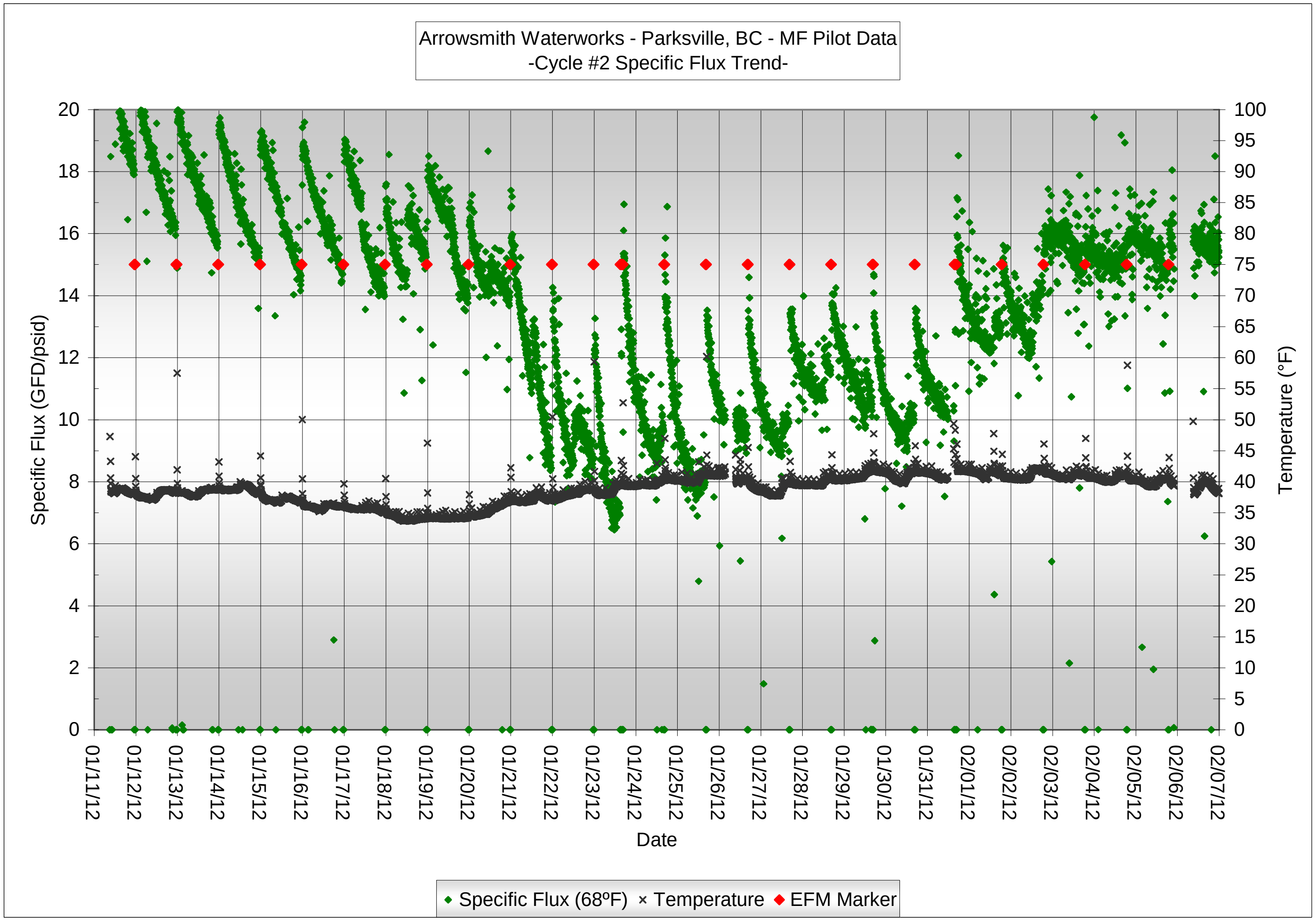
Water Processing



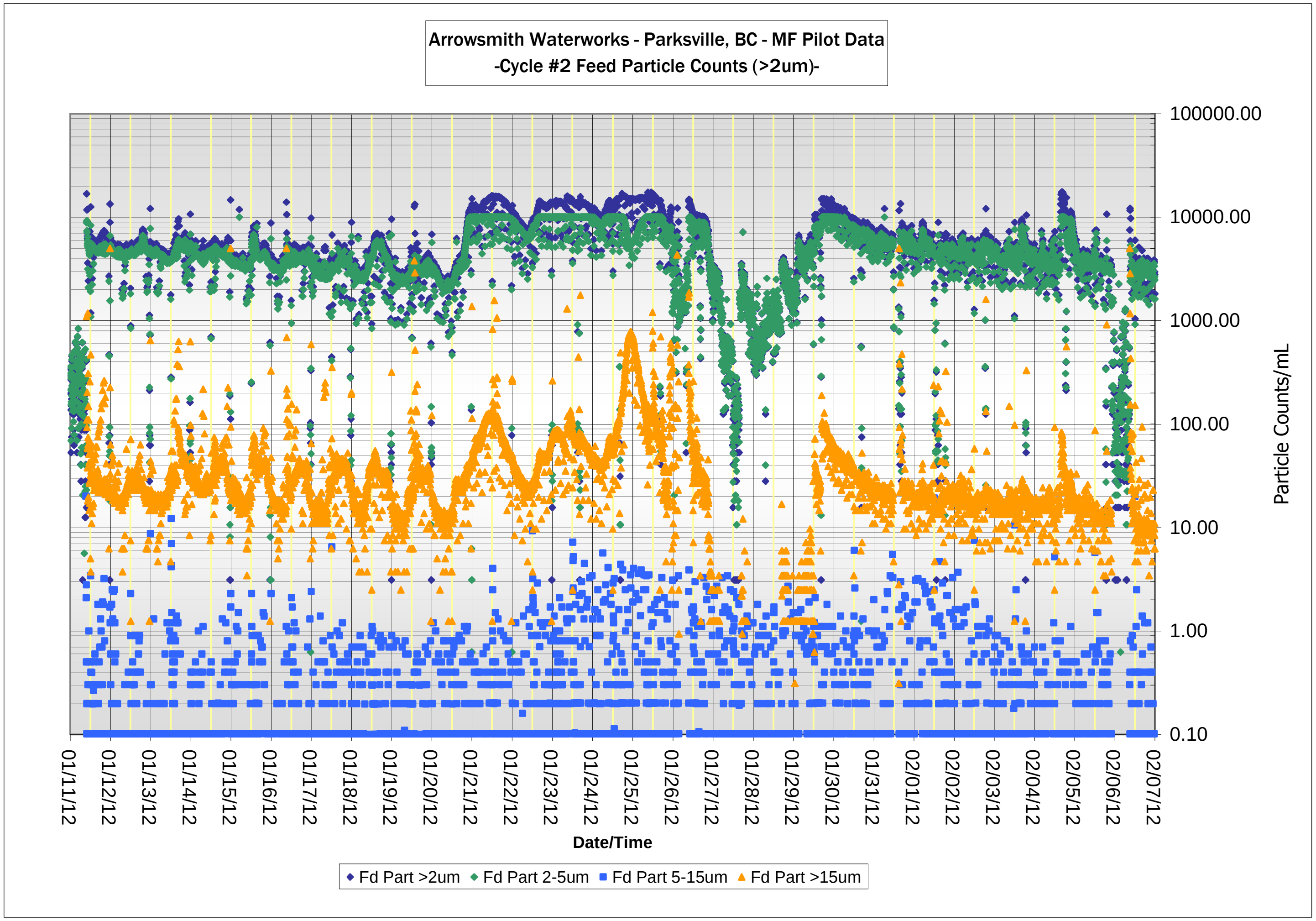
Water Processing



PALL Water Processing



APPENDIX C


Arrowsmith Waterworks - Parksville, BC - MF Pilot Data
-Cycle #2 Feed Particle Counts (>2um)-
100000.00
10000.00
1000.00
100.00
10.00
1.00
0.10
Particle Counts/mL
01/11/12
01/12/12
01/13/12
01/14/12
01/15/12
01/16/12
01/17/12
01/18/12
01/19/12
01/20/12
01/21/12
01/22/12
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01/24/12
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01/26/12
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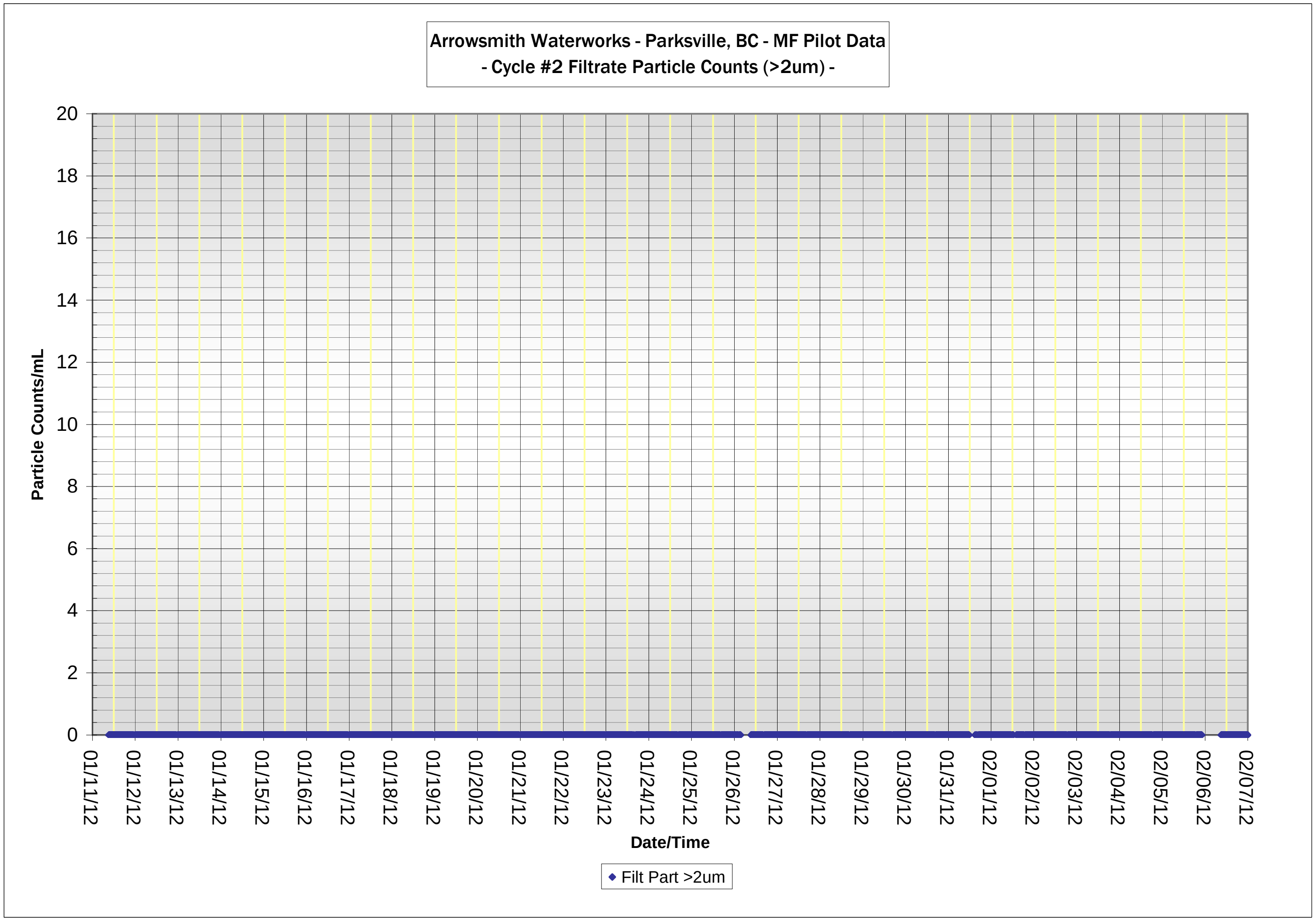
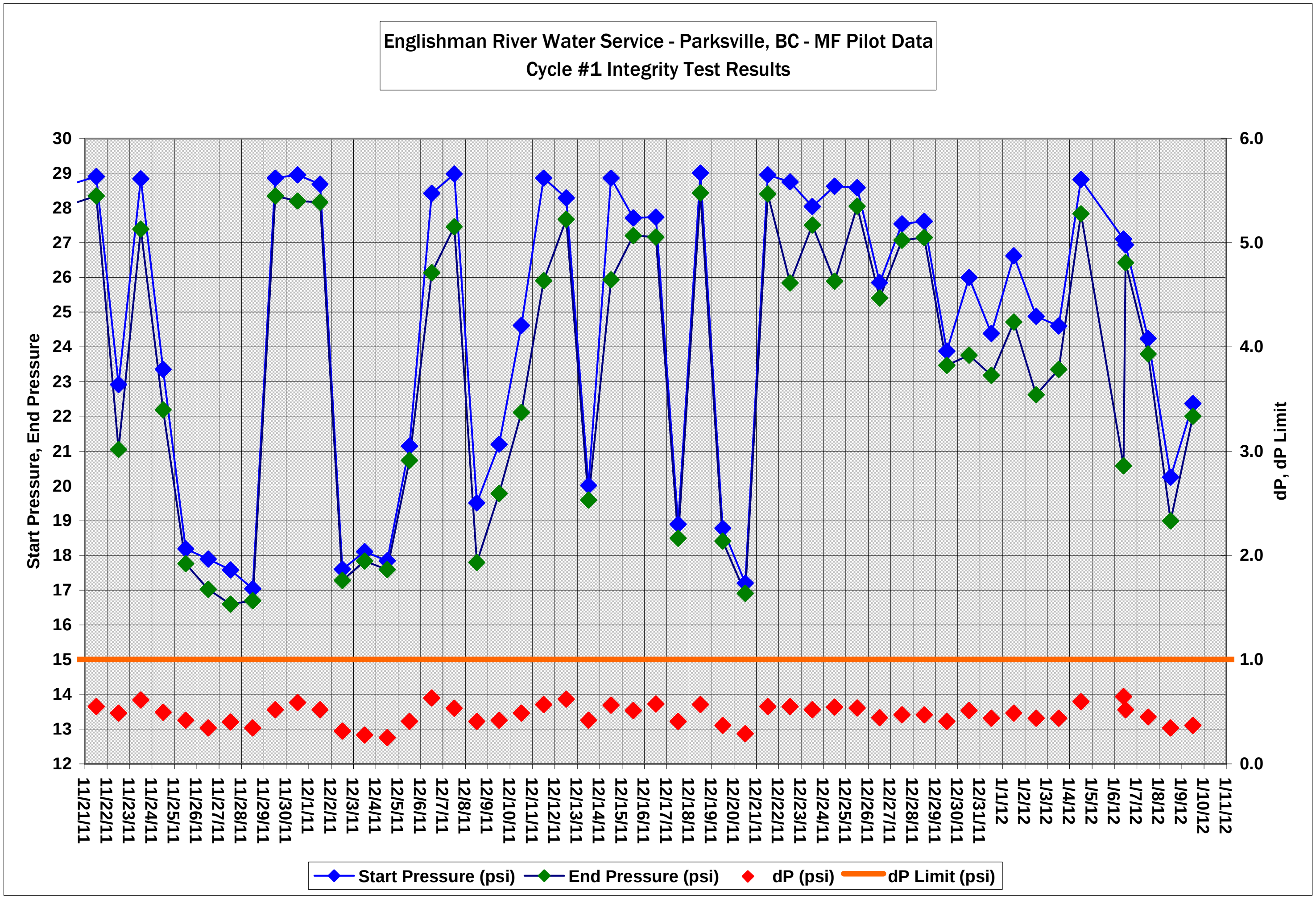
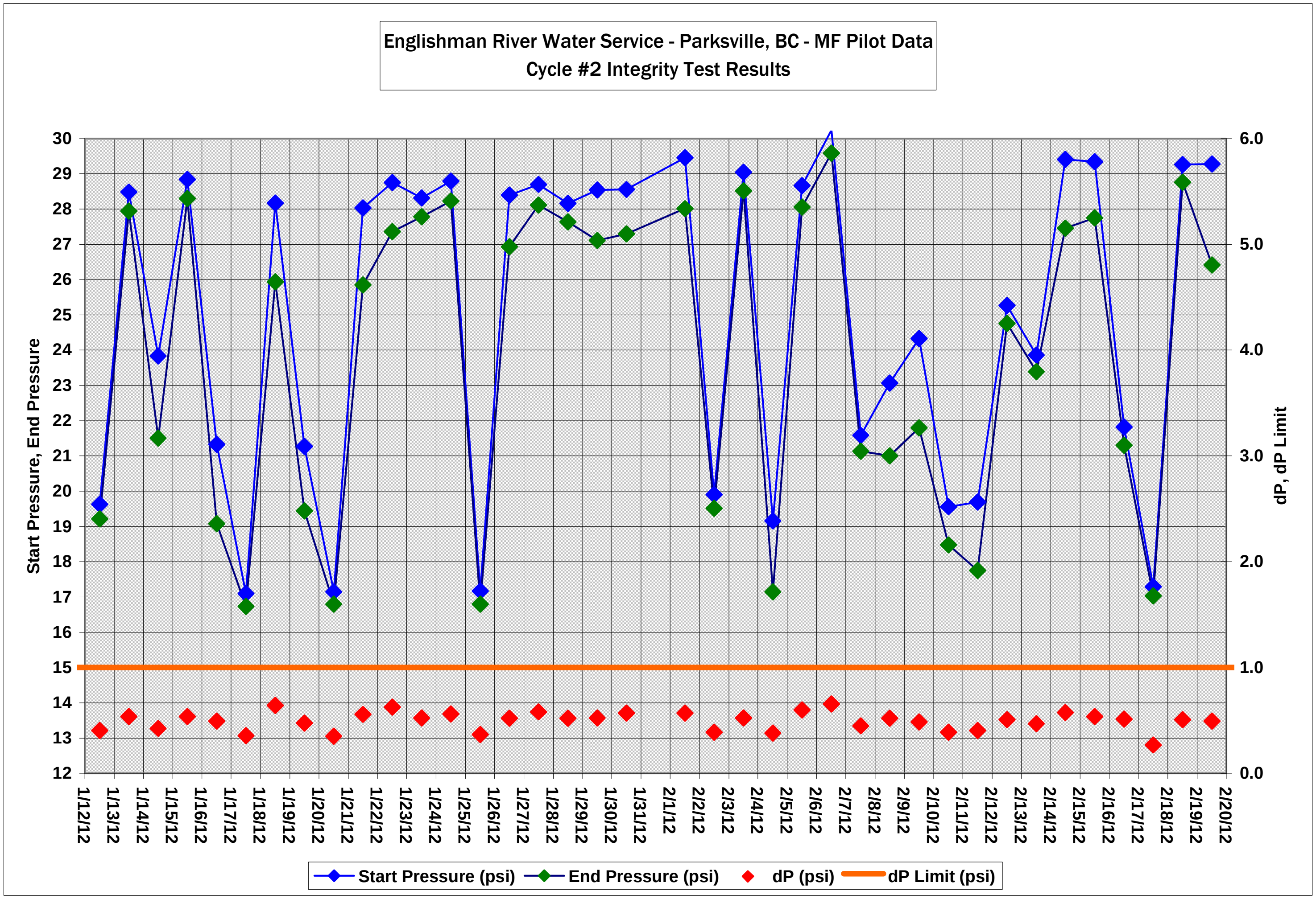
01/29/12
01/30/12
01/31/12
02/01/12
02/02/12
02/03/12
02/04/12
02/05/12
02/06/12
02/07/12
Date/Time
Fd Part >2um
Fd Part 2-5um
Fd Part 5-15um
Fd Part >15um

Water Processing




Englishman River Water Service - Parksville, BC - MF Pilot Data
Cycle #1 Integrity Test Results
Start Pressure, End Pressure
dP, dP Limit
Start Pressure (psi)
End Pressure (psi)
dP (psi)
dP Limit (psi)

Water Processing



C Appendix C - Lab Analysis

LAB ANALYSIS
PARKSVILLE, BC
ERWS PILOT STUDY

DRINKING WATER PACKAGE (WATER)

Maxxam ID			CL8495	CL8496	CL8497	CO4772	CO4773	CT1358	CT1359
Sampling Date			1/4/2012 8:50	1/4/2012 8:45	1/4/2012 10:45	1/24/2012 13:40	1/24/2012 13:45	2/16/2012 13:05	2/16/2012 13:10
COC Number			G047503	G047503	G047503	G047505	G047505	G047507	G047507
	Units	**RDL**	**RAW WATER**	**MEM. EFFLUENT**	**MEM EFF W/ ACH**	**RAW WATER**	**MEM. EFFLUENT**	**RAW WATER**	**MEM. EFF (10MG/L)**
ANIONS									
Nitrite (N)	mg/L	0.005	0.016	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Calculated Parameters									
Total Hardness (CaCO3)	mg/L	0.50	14.0	10.4	9.77	15.5	15.0	15.4	14.5
Nitrate (N)	mg/L	0.020	<0.020	0.021	<0.020	0.069	0.070	0.031	0.030
Misc. Inorganics									
Fluoride (F)	mg/L	0.010	0.015	0.014	0.014	0.019	0.019	0.018	0.018
Alkalinity (Total as CaCO3)	mg/L	0.50	9.13	8.52	7.66	11.8	12.6	16.2	14.5
Alkalinity (PP as CaCO3)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Bicarbonate (HCO3)	mg/L	0.50	11.1	10.4	9.35	14.4	15.3	19.7	17.7
Carbonate (CO3)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Hydroxide (OH)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Anions									
Dissolved Sulphate (SO4)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Dissolved Chloride (Cl)	mg/L	0.5	1.3	1.2	1.3	4.5	4.6	3.8	4.8
MISCELLANEOUS									
True Colour	Col. Unit	5	50	20	20	30	10	15	5
Nutrients									
Nitrate plus Nitrite (N)	mg/L	0.020	<0.020	0.021	<0.020	0.069	0.070	0.031	0.030
Physical Properties									
Conductivity	uS/cm	1.0	27.1	25.5	25.1	43.7	44.6	47.4	46.9
pH	pH Units		7.11	7.02	6.99	7.10	7.34	7.57	7.55
Physical Properties									
Total Dissolved Solids	mg/L	10	18	22	20	24	24	38	26
Turbidity	NTU	0.10	57.5	<0.10	<0.10	5.33	<0.10	1.13	0.18
Total Metals by ICPMS									
Total Aluminum (Al)	ug/L	3.0	1090	81.7	80.2	214	43.5	84.9	18.3
Total Antimony (Sb)	ug/L	0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Total Arsenic (As)	ug/L	0.10	0.57	0.11	0.11	0.16	0.12	0.13	<0.10
Total Barium (Ba)	ug/L	1.0	15.2	2.4	2.4	4.6	3.2	3.4	3.1
Total Boron (B)	ug/L	50	<50	<50	<50	<50	<50	<50	<50
Total Cadmium (Cd)	ug/L	0.010	0.027	<0.010	<0.010	0.011	<0.010	0.012	<0.010
Total Chromium (Cr)	ug/L	1.0	3.5	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Total Cobalt (Co)	ug/L	0.50	1.16	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Total Copper (Cu)	ug/L	0.20	9.26	1.88	1.73	2.46	1.30	1.84	0.63
Total Iron (Fe)	ug/L	5.0	1660	38.5	35.5	258	19.1	67.1	<5.0
Total Lead (Pb)	ug/L	0.20	1.05	<0.20	<0.20	<0.20	<0.20	0.40	<0.20
Total Manganese (Mn)	ug/L	1.0	63.6	2.8	4.1	6.8	2.7	2.2	1.4
Total Mercury (Hg)	ug/L	0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Total Molybdenum (Mo)	ug/L	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Total Nickel (Ni)	ug/L	1.0	5.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Total Selenium (Se)	ug/L	0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total Silver (Ag)	ug/L	0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Total Uranium (U)	ug/L	0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total Vanadium (V)	ug/L	5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Total Zinc (Zn)	ug/L	5.0	7.4	<5.0	<5.0	<5.0	<5.0	7.7	<5.0
Total Calcium (Ca)	mg/L	0.050	4.21	3.38	3.11	4.70	4.62	4.84	4.54
Total Magnesium (Mg)	mg/L	0.050	0.842	0.482	0.488	0.918	0.848	0.809	0.778
Total Potassium (K)	mg/L	0.050	0.242	0.146	0.175	0.169	0.156	0.099	0.093
Total Sodium (Na)	mg/L	0.050	1.10	1.07	1.09	2.45	2.40	2.26	2.48
Total Sulphur (S)	mg/L	3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0

RDL = Reportable Detection Limit
EDL = Estimated Detection Limit

LAB ANALYSIS
PARKSVILLE, BC
ERWS PILOT STUDY
EFM WASTE ONLY

DRINKING WATER PACKAGE (WATER)

Maxxam ID		CS9012		
Sampling Date		2/15/2012 9:15		
COC Number		G047506		
	Units	**EFM WASTE**	**RDL**	**QC Batch**
ANIONS				
Nitrite (N)	mg/L	0.044	0.005	5608856
Calculated Parameters				
Total Hardness (CaCO3)	mg/L	18.2	0.50	5603875
Nitrate (N)	mg/L	0.022	0.020	5602111
Misc. Inorganics				
Fluoride (F)	mg/L	0.034	0.010	5613494
Alkalinity (Total as CaCO3)	mg/L	269	0.50	5608547
Alkalinity (PP as CaCO3)	mg/L	<0.50	0.50	5608547
Bicarbonate (HCO3)	mg/L	329	0.50	5608547
Carbonate (CO3)	mg/L	<0.50	0.50	5608547
Hydroxide (OH)	mg/L	<0.50	0.50	5608547
Anions				
Dissolved Sulphate (SO4)	mg/L	39.4	0.50	5609301
Dissolved Chloride (Cl)	mg/L	440	5	5609084
MISCELLANEOUS				
True Colour	Col. Unit	30	5	5607191
Nutrients				
Nitrate plus Nitrite (N)	mg/L	0.066	0.020	5608855
Physical Properties				
Conductivity	uS/cm	1590	1.0	5608549
pH	pH Units	8.21		5608550
Physical Properties				
Total Dissolved Solids	mg/L	838	10	5616526
Turbidity	NTU	27.4	0.10	5605458
Total Metals by ICPMS				
Total Aluminum (Al)	ug/L	17600	3.0	5607348
Total Antimony (Sb)	ug/L	<0.50	0.50	5607348
Total Arsenic (As)	ug/L	1.15	0.10	5607348
Total Barium (Ba)	ug/L	14.1	1.0	5607348
Total Boron (B)	ug/L	<50	50	5607348
Total Cadmium (Cd)	ug/L	0.102	0.010	5607348
Total Chromium (Cr)	ug/L	2.7	1.0	5607348
Total Cobalt (Co)	ug/L	<0.50	0.50	5607348
Total Copper (Cu)	ug/L	21.0	0.20	5607348
Total Iron (Fe)	ug/L	1220	5.0	5607348
Total Lead (Pb)	ug/L	2.31	0.20	5607348
Total Manganese (Mn)	ug/L	12.1	1.0	5607348
Total Mercury (Hg)	ug/L	<0.050	0.050	5607348
Total Molybdenum (Mo)	ug/L	<1.0	1.0	5607348
Total Nickel (Ni)	ug/L	1.4	1.0	5607348
Total Selenium (Se)	ug/L	0.50	0.10	5607348
Total Silver (Ag)	ug/L	0.041	0.020	5607348
Total Uranium (U)	ug/L	0.24	0.10	5607348
Total Vanadium (V)	ug/L	<5.0	5.0	5607348
Total Zinc (Zn)	ug/L	13.8	5.0	5607348
Total Calcium (Ca)	mg/L	5.35	0.050	5601917
Total Magnesium (Mg)	mg/L	1.17	0.050	5601917
Total Potassium (K)	mg/L	0.201	0.050	5601917
Total Sodium (Na)	mg/L	328	0.050	5601917
Total Sulphur (S)	mg/L	<3.0	3.0	5601917

RDL = Reportable Detection Limit
EDL = Estimated Detection Limit

Appendix C - Cost Estimates

Revision Date:	18-Apr-14								
Previous Version Date:	-								
ARROWSMITH WATER SERVICES									
ENGLISHMAN RIVER INTAKE AND WATER TREATMENT PLANT									
ESTIMATE OF DIRECT AND INDIRECT COSTS									
Site	1A								
Description	No ASR			ASR at Kaye Road			ASR at Claudette Road		
	Treatment of Nanoose Wells			Treatment of Nanoose Wells			No change in Phase 1 WTP size		
Expansion	Phase 1	Phase 2	Total	Phase 1	Phase 2		Phase 1	Phase 2	
Capacity	26 ML/d	39 ML/d		24 ML/d	37 ML/d		26 ML/d	37 ML/d	
Intake	$ 1,656,688	$ 77,703	$ 1,734,390	$ 1,656,688	$ 77,703	$ 1,734,390	$ 1,656,688	$ 77,703	$ 1,734,390
Raw Water Main	$ 827,875	$ -	$ 827,875	$ 827,875	$ -	$ 827,875	$ 827,875	$ -	$ 827,875
Water Treatment Plant	$ 16,140,149	$ 2,720,978	$ 18,861,127	$ 15,059,941	$ 2,734,512	$ 17,794,453	$ 16,140,149	$ 1,763,941	$ 17,904,091
Distribution System Upgrades	$ 5,500,000	$ 3,718,750	$ 9,218,750	$ 5,500,000	$ 3,718,750	$ 9,218,750	$ 5,500,000	$ 3,718,750	$ 9,218,750
ASR Capital Costs	$ -	$ -	$ -	$ 3,100,394	$ -	$ 3,100,394	$ 2,619,200	$ -	$ 2,619,200
Nanoose Well Treatment	$ 1,600,000	$ -	$ 1,600,000	$ 1,600,000	$ -	$ 1,600,000	$ -	$ -	$ -
Subtotal	$ 25,724,712	$ 6,517,430	$ 32,242,142	$ 27,744,898	$ 6,530,964	$ 34,275,862	$ 26,743,912	$ 5,560,394	$ 32,304,306
Contingencies - Design and Construction (25%)	$ 6,431,178	$ 1,629,358	$ 8,060,535	$ 6,936,224	$ 1,632,741	$ 8,568,965	$ 6,685,978	$ 1,390,098	$ 8,076,076
			$ -			$ -			$ -
Total Direct Costs	$ 32,155,890	$ 8,146,788	$ 40,302,677	$ 34,681,122	$ 8,163,705	$ 42,844,827	$ 33,429,890	$ 6,950,492	$ 40,380,382
			$ -			$ -			$ -
Engineering (12%)	$ 2,894,965	$ 782,092	$ 3,677,057	$ 2,765,340	$ 783,716	$ 3,549,056	$ 2,894,965	$ 667,247	$ 3,562,213
Administration (3%)	$ 964,677	$ 244,404	$ 1,209,080	$ 1,040,434	$ 244,911	$ 1,285,345	$ 1,002,897	$ 208,515	$ 1,211,411
Miscellaneous (2%)	$ 643,118	$ 162,936	$ 806,054	$ 693,622	$ 163,274	$ 856,897	$ 668,598	$ 139,010	$ 807,608
			$ -			$ -			$ -
Total Indirect Costs	$ 4,502,760	$ 1,189,431	$ 5,692,191	$ 4,499,397	$ 1,191,901	$ 5,691,297	$ 4,566,460	$ 1,014,772	$ 5,581,232
GST Allowance 5%	$ 1,832,932	$ 466,811	$ 2,299,743	$ 1,959,026	$ 467,780	$ 2,426,806	$ 1,899,817	$ 398,263	$ 2,298,081
Total Capital Cost	$ 38,491,582	$ 9,803,030	$ 48,294,612	$ 41,139,545	$ 9,823,386	$ 50,962,931	$ 39,896,167	$ 8,363,527	$ 48,259,694

Revision Date:		18-Apr-14		Keith Kohut			
Previous Version Date:		-					
ARROWSMITH WATER SERVICES							
ENGLISHMAN RIVER INTAKE AND WATER TREATMENT PLANT							
SUMMARY OF DIRECT COST ESTIMATE							
Site	1A						
Description		No ASR		ASR at Kaye Road		ASR at Claudet Road	
Expansion		Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
Capacity		26 ML/d	39 ML/d	24 ML/d	37 ML/d	24 ML/d	37 ML/d
Intake	General & Sitework	$ 289,970	$ -	$ 289,970	$ -	$ 289,970	$ -
	Structural	$ 398,194	$ -	$ 398,194	$ -	$ 398,194	$ -
	Mechanical	$ 571,086	$ 55,162	$ 571,086	$ 55,162	$ 571,086	$ 55,162
	E, I&C	$ 66,100	$ 7,000	$ 66,100	$ 7,000	$ 66,100	$ 7,000
Raw Water Main		$ 662,300	$ -	$ 662,300	$ -	$ 662,300	$ -
WTP	General & Sitework	$ 953,350	$ 115,063	$ 940,139	$ 114,769	$ 941,950	$ 114,805
	Structural	$ 4,116,168	$ 850,028	$ 3,796,999	$ 964,174	$ 3,838,198	$ 949,248
	Mechanical	$ 7,024,702	$ 1,152,491	$ 6,524,116	$ 1,049,466	$ 6,571,930	$ 1,056,965
	E, I&C	$ 817,900	$ 59,200	$ 786,698	$ 59,200	$ 790,977	$ 59,200
Distribution System Upgrades							
	Connection to Reservoir 4	$ 3,170,000	$ 1,230,000	$ 3,170,000	$ 1,230,000	$ 3,170,000	$ 1,230,000
	Connection to Reservoir 5	$ 300,000	$ 600,000	$ 300,000	$ 600,000	$ 300,000	$ 600,000
	Pump Station for Nanoose	$ 930,000	$ -	$ 930,000	$ -	$ 930,000	$ -
	Connection to Craig Bay	$ -	$ 1,145,000	$ -	$ 1,145,000	$ -	$ 1,145,000
	Subtotal	$ 19,299,769	$ 5,213,944	$ 18,435,603	$ 5,224,771	$ 18,435,603	$ 5,224,771
	Contractor Profit and Overhead (25%)	$ 4,824,942	$ 1,303,486	$ 4,608,901	$ 1,306,193	$ 4,608,901	$ 1,306,193
	Contracted Construction Cost	$ 24,124,712	$ 6,517,430	$ 23,044,504	$ 6,530,964	$ 23,044,504	$ 6,530,964
ASR Capital Costs							
	ASR-1 finalization	$ -	$ -	$ 447,623	$ -	$ -	$ -
	ASR-2 & 3 development, testing and finalization	$ -	$ -	$ 1,695,022	$ -	$ -	$ -
	Water Mains for ASR-1, -2 & -3	$ -	$ -	$ 654,000	$ -	$ -	$ -
	Temporary treatment skid (metals removal)	$ -	$ -	$ 303,750	$ -	$ 303,750	$ -
	Claudet and Nanoose well ASR conversion	$ -	$ -	$ -	$ -	$ 2,310,400	$ -
	Monitoring well conversion and decommissioning	$ -	$ -	$ -	$ -	$ 5,050	$ -
	Subtotal Costs	$ 24,124,712	$ 6,517,430	$ 26,144,898	$ 6,530,964	$ 25,663,704	$ 6,530,964
	Total Phase Cost	$ 24,124,712	$ 6,517,430	$ 26,144,898	$ 6,530,964	$ 25,663,704	$ 6,530,964
	Total Base Cost	$ 30,642,142		$ 32,675,862		$ 32,194,668	

		Cost		Total Cost
	Division 1 - General Requirements	26 ML/d	39 ML/d	
	Subtotal	$ 105,000	$ 57,000	$ 162,000
	Division 2 - Site Work			
	Intake	$ 279,970	$ -	$ 279,970
	Water Main - Intake to Treatment Plant	$ 652,300	$ -	$ 652,300
	Water Treatment Plant	$ 868,350	$ 58,063	$ 926,413
	Subtotal	$ 1,800,620	$ 58,063	$ 1,858,683
	Division 3 - Concrete			
	Intake	$ 235,312	$ -	$ 235,312
	Water Treatment Plant	$ 3,338,323	$ 850,028	$ 4,188,351
	Subtotal	$ 3,573,635	$ 850,028	$ 4,423,663
	Division 4 - Masonry			
	Intake	$ 82,500	$ -	$ 82,500
	Water treatment plant	$ 511,200	$ -	$ 511,200
	Subtotal	$ 593,700	$ -	$ 593,700
	Division 5 - Metals			
	Intake	$ 14,720	$ -	$ 14,720
	Water Treatment Plant	$ 73,957	$ -	$ 73,957
	Subtotal	$ 88,677	$ -	$ 88,677
	Divison 6 - Wood and Plastics			
	Assume cost of wood included in concrete costs			
	Division 7 - Thermal and Mosture Protection			
	Intake	$ 25,972	$ -	$ 25,972
	Water Treatment Plant	$ 41,968	$ -	$ 41,968
	Subtotal	$ 67,940	$ -	$ 67,940
	Division 8 - Doors and Windows			
	Subtotal	$ 60,000	$ -	$ 60,000
	Division 9 - Finishes			
	Subtotal	$ 130,410	$ -	$ 130,410
	Division 10 - Specialties			
	Subtotal	$ 40,000	$ -	$ 40,000

		Cost		Total Cost
	Division 11 - Equipment			
	Intake	$ 457,486	$ 55,162	$ 512,648
	Water Treatment Plant	$ 5,891,252	$ 1,111,491	$ 7,002,743
	Subtotal	$ 6,348,738	$ 1,166,653	$ 7,515,391
	Division 12 - Furnishings			
	n/a			
	Division 14 - Cranes			
	Subtotal	$ 95,000	$ -	$ 95,000
	Division 15 - Mechanical			
	Intake	$ 93,600	$ -	$ 93,600
	Water Treatment Plant	$ 1,018,450	$ 41,000	$ 1,059,450
	Subtotal	$ 1,112,050	$ 41,000	$ 1,153,050
	Division 16 - Electrical and Controls			
	Intake	$ 66,100	$ 7,000	$ 73,100
	Water treatment plant	$ 817,900	$ 59,200	$ 877,100
	Subtotal	$ 884,000	$ 66,200	$ 950,200
	Cost Summary	**$ 14,899,769**	**$ 2,238,944**	$ 17,138,714

		Cost		Total Cost
	Division 1 - General Requirements	24 ML/d	37 ML/d	
	Subtotal	$ 105,000	$ 57,000	$ 162,000
	Division2 - Site Work			
	Intake	$ 279,970	$ -	$ 279,970
	Water Main - Intake to Treatment Plant	$ 652,300	$ -	$ 652,300
	Water Treatment Plant	$ 855,139	$ 57,769	$ 912,908
	Subtotal	$ 1,787,409	$ 57,769	$ 1,845,178
	Division 3 - Concrete			
	Intake	$ 235,312	$ -	$ 235,312
	Water Treatment Plant	$ 3,098,666	$ 964,174	$ 4,062,840
	Subtotal	$ 3,333,978	$ 964,174	$ 4,298,152
	Division 4 - Masonry			
	Intake	$ 82,500	$ -	$ 82,500
	Water treatment plant	$ 465,628	$ -	$ 465,628
	Subtotal	$ 548,128	$ -	$ 548,128
	Division 5 - Metals			
	Intake	$ 14,720	$ -	$ 14,720
	Water Treatment Plant	$ 67,363	$ -	$ 67,363
	Subtotal	$ 149,447	$ -	$ 149,447
	Divison 6 - Wood and Plastics			
	Assume cost of wood included in concrete costs			
	Division 7 - Thermal and Mosture Protection			
	Intake	$ 25,972	$ -	$ 25,972
	Water Treatment Plant	$ 39,760	$ -	$ 39,760
	Subtotal	$ 65,732	$ -	$ 65,732
	Division 8 - Doors and Windows			
	Subtotal	$ 60,000	$ -	$ 60,000
	Division 9 - Finishes			
	Subtotal	$ 105,271	$ -	$ 105,271
	Division 10 - Specialties			
	Subtotal	$ 40,000	$ -	$ 40,000

		Cost		Total Cost
	Division 11 - Equipment			
	Intake	$ 457,486	$ 55,162	$ 512,648
	Water Treatment Plant	$ 5,431,799	$ 1,010,595	$ 6,442,394
	Subtotal	$ 5,889,285	$ 1,065,757	$ 6,955,042
	Division 12 - Furnishings			
	n/a			
	Division 14 - Cranes			
	Subtotal	$ 95,000	$ -	$ 95,000
	Division 15 - Mechanical			
	Intake	$ 93,600	$ -	$ 93,600
	Water Treatment Plant	$ 977,317	$ 38,871	$ 1,016,189
	Subtotal	$ 1,070,917	$ 38,871	$ 1,109,789
	Division 16 - Electrical and Controls			
	Intake	$ 66,100	$ 7,000	$ 73,100
	Water treatment plant	$ 786,698	$ 59,200	$ 845,898
	Subtotal	$ 852,798	$ 66,200	$ 918,998
	Cost Summary	**$ 14,102,966**	**$ 2,249,771**	$ 16,352,738

		Cost		Total Cost
	Division 1 - General Requirements	24 ML/d	37 ML/d	
	Subtotal	$ 105,000	$ 57,000	$ 162,000
	Division 2 - Site Work			
	Intake	$ 279,970	$ -	$ 279,970
	Water Main - Intake to Treatment Plant	$ 652,300	$ -	$ 652,300
	Water Treatment Plant	$ 856,950	$ 57,805	$ 914,755
	Subtotal	$ 1,789,220	$ 57,805	$ 1,847,025
	Division 3 - Concrete			
	Intake	$ 235,312	$ -	$ 235,312
	Water Treatment Plant	$ 3,131,529	$ 949,248	$ 4,080,777
	Subtotal	$ 3,366,841	$ 949,248	$ 4,316,089
	Division 4 - Masonry			
	Intake	$ 82,500	$ -	$ 82,500
	Water treatment plant	$ 471,877	$ -	$ 471,877
	Subtotal	$ 554,377	$ -	$ 554,377
	Division 5 - Metals			
	Intake	$ 14,720	$ -	$ 14,720
	Water Treatment Plant	$ 68,268	$ -	$ 68,268
	Subtotal	$ 82,988	$ -	$ 82,988
	Divison 6 - Wood and Plastics			
	Assume cost of wood included in concrete costs			
	Division 7 - Thermal and Mosture Protection			
	Intake	$ 25,972	$ -	$ 25,972
	Water Treatment Plant	$ 40,063	$ -	$ 40,063
	Subtotal	$ 66,035	$ -	$ 66,035
	Division 8 - Doors and Windows			
	Subtotal	$ 60,000	$ -	$ 60,000
	Division 9 - Finishes			
	Subtotal	$ 106,152	$ -	$ 106,152
	Division 10 - Specialties			
	Subtotal	$ 40,000	$ -	$ 40,000

		Cost		Total Cost
	Division 11 - Equipment			
	Intake	$ 457,486	$ 55,162	$ 512,648
	Water Treatment Plant	$ 5,473,972	$ 1,017,811	$ 6,491,784
	Subtotal	$ 5,931,458	$ 1,072,973	$ 7,004,432
	Division 12 - Furnishings			
	n/a			
	Division 14 - Cranes			
	Subtotal	$ 95,000	$ -	$ 95,000
	Division 15 - Mechanical			
	Intake	$ 93,600	$ -	$ 93,600
	Water Treatment Plant	$ 982,958	$ 39,154	$ 1,022,112
	Subtotal	$ 1,076,558	$ 39,154	$ 1,115,712
	Division 16 - Electrical and Controls			
	Intake	$ 66,100	$ 7,000	$ 73,100
	Water treatment plant	$ 790,977	$ 59,200	$ 850,177
	Subtotal	$ 857,077	$ 66,200	$ 923,277
	Cost Summary	**$ 14,130,705**	**$ 2,242,379**	$ 16,373,084

		Cost		Total Cost
	Division 1 - General Requirements	26 ML/d	37 ML/d	
	Subtotal	$ 105,000	$ 57,000	$ 162,000
	Division 2 - Site Work			
	Intake	$ 279,970	$ -	$ 279,970
	Water Main - Intake to Treatment Plant	$ 652,300	$ -	$ 652,300
	Water Treatment Plant	$ 868,350	$ 46,405	$ 914,755
	Subtotal	$ 1,800,620	$ 46,405	$ 1,847,025
	Division 3 - Concrete			
	Intake	$ 235,312	$ -	$ 235,312
	Water Treatment Plant	$ 3,338,323	$ 666,968	$ 4,080,777
	Subtotal	$ 3,573,635	$ 666,968	$ 4,316,089
	Division 4 - Masonry			
	Intake	$ 82,500	$ -	$ 82,500
	Water treatment plant	$ 511,200	$ -	$ 471,877
	Subtotal	$ 593,700	$ -	$ 554,377
	Division 5 - Metals			
	Intake	$ 14,720	$ -	$ 14,720
	Water Treatment Plant	$ 73,957	$ 4,311	$ 68,268
	Subtotal	$ 88,677	$ 4,311	$ 82,988
	Divison 6 - Wood and Plastics			
	Assume cost of wood included in concrete costs			
	Division 7 - Thermal and Mosture Protection			
	Intake	$ 25,972	$ -	$ 25,972
	Water Treatment Plant	$ 41,968	$ -	$ 40,063
	Subtotal	$ 67,940	$ -	$ 66,035
	Division 8 - Doors and Windows			
	Subtotal	$ 60,000	$ -	$ 60,000
	Division 9 - Finishes			
	Subtotal	$ 130,410	$ -	$ 130,410
	Division 10 - Specialties			
	Subtotal	$ 40,000	$ -	$ 40,000

		Cost		Total Cost
	Division 11 - Equipment			
	Intake	$ 457,486	$ 55,162	$ 512,648
	Water Treatment Plant	$ 5,891,252	$ 600,532	$ 6,491,784
	Subtotal	$ 6,348,738	$ 655,694	$ 7,004,432
	Division 12 - Furnishings			
	n/a			
	Division 14 - Cranes			
	Subtotal	$ 95,000	$ -	$ 95,000
	Division 15 - Mechanical			
	Intake	$ 93,600	$ -	$ 93,600
	Water Treatment Plant	$ 1,018,450	$ 3,662	$ 1,022,112
	Subtotal	$ 1,112,050	$ 3,662	$ 1,115,712
	Division 16 - Electrical and Controls			
	Intake	$ 66,100	$ 7,000	$ 73,100
	Water treatment plant	$ 817,900	$ 32,277	$ 850,177
	Subtotal	$ 884,000	$ 39,277	$ 923,277
	Cost Summary	**$ 14,899,769**	**$ 1,473,316**	$ 16,373,085

Appendix D - Monthly Water Balances

Arrowsmith Water Services
Englishman River Intake and Water Treatment Plant
Water Balance - 2035

Maximum ASR injection/recovery = 27 L/s
2.3 ML/d
70 ML/month

Kaye Road ASR System

Month	Total Demand (ML)	GW Available (ML)	Amount Needed (ML)	Amount to Take from Surface Water (ML)	To ASR (ML)	From ASR (ML)	Water Lost (ML)	Balance (ML)
Oct	429	150	279	319	40	0	0	40
Nov	330	50	280	320	40	0	0	80
Dec	347	50	297	337	40	0	0	120
Jan	314	50	264	304	40	0	0	160
Feb	308	30	278	318	40	0	0	200
Mar	336	50	286	326	40	0	0	240
Apr	336	50	286	326	40	0	0	280
May	462	200	262	262	0	0	0	280
Jun	605	350	255	185	0	70	0	210
Jul	759	350	409	339	0	70	0	140
Aug	704	350	354	284	0	70	0	70
Sep	572	350	222	152	0	70	0	0
	5500	2030		3470				

Plant sizing estimate

Step 1: Winter MDD:	514.6 ML/30 d			
or	17.2 ML/d	Subtract GW output 11.8 ML/d	WTP min capacity =	5.4 ML/d
Step 2: Largest ADD:	339.0 ML/30 d or			11.3 ML/d
Step 3: Summer MDD:	1127.1 ML/30 d or			
	37.6 ML/d	Subtract GW output and ASR output of (11.8 + 2.3) = 14.1 ML/d	WTP min capacity =	23.5 ML/d

Therefore, minimum WTP capacity for this year is **23.5 ML/d**

Arrowsmith Water Services
Englishman River Intake and Water Treatment Plant
Water Balance - 2050

Maximum ASR injection/recovery = 27 L/s
2.3 ML/d
70 ML/month

Kaye Road ASR System

Month	Total Demand (ML)	GW Available (ML)	Amount Needed (ML)	Amount to Take from Surface Water (ML)	To ASR (ML)	From ASR (ML)	Water Lost (ML)	Balance (ML)
Oct	578	150	428	468	40	0	0	40
Nov	445	50	395	435	40	0	0	80
Dec	467	50	417	457	40	0	0	120
Jan	422	50	372	412	40	0	0	160
Feb	415	30	385	425	40	0	0	200
Mar	452	50	402	442	40	0	0	240
Apr	452	50	402	442	40	0	0	280
May	622	200	422	422	0	0	0	280
Jun	815	350	465	395	0	70	0	210
Jul	1023	350	673	603	0	70	0	140
Aug	948	350	598	528	0	70	0	70
Sep	771	350	421	351	0	70	0	0
	7410	2030		5380				

Plant sizing estimate

Step 1: Winter MDD: 693.2 ML/30 d
or 23.1 ML/d — Subtract GW output 11.8 ML/d — WTP min capacity = 11.3 ML/d
Step 2: Largest ADD: 602.6 ML/30 d or — 20.1 ML/d
Step 3: Summer MDD: 1519.6 ML/30 d or
50.7 ML/d — Subtract GW output and ASR output of (11.8 + 2.3) = 14.1 ML/d — WTP min capacity = 36.6 ML/d

Therefore, minimum WTP capacity for this year is **36.6 ML/d**

Arrowsmith Water Services
Englishman River Intake and Water Treatment Plant
Water Balance - 2035

Maximum ASR injection/recovery = 35 L/s
3.0 ML/d
91 ML/month

Claudet Road ASR System

Month	Total Demand (ML)	GW Available (ML)	Amount Needed (ML)	Amount to Take from Surface Water (ML)	To ASR (ML)	From ASR (ML)	Water Lost (ML)	Balance (ML)
Oct	429	150	279	299	20	0	0	20
Nov	330	70	260	350	90	0	0	110
Dec	347	80	267	357	90	0	0	200
Jan	314	50	264	354	90	0	0	290
Feb	308	40	268	358	90	0	0	380
Mar	336	70	266	356	90	0	0	470
Apr	336	10	326	306	0	20	0	450
May	462	120	342	252	0	90	0	360
Jun	605	260	345	255	0	90	0	270
Jul	759	320	439	349	0	90	0	180
Aug	704	320	384	294	0	90	0	90
Sep	572	240	332	242	0	90	0	0
	5500	1730		3770				

Plant sizing estimate

Step 1: Winter MDD: 514.6 ML/30 d
or 17.2 ML/d — Subtract GW output 10.9 ML/d — WTP min capacity = 6.3 ML/d
Step 2: Largest ADD: 358.0 ML/30 d or 11.9 ML/d
Step 3: Summer MDD: 1127.1 ML/30 d or 37.6 ML/d — Subtract GW output and ASR output of (10.9 + 3.0) = 13.9 ML/d — WTP min capacity = 23.7 ML/d

Therefore, minimum WTP capacity for this year is **23.7 ML/d**

Arrowsmith Water Services
Englishman River Intake and Water Treatment Plant
Water Balance - 2050

Maximum ASR injection/recovery = 35 L/s
3.0 ML/d
91 ML/month

Claudet Road ASR System

Month	Total Demand (ML)	GW Available (ML)	Amount Needed (ML)	Amount to Take from Surface Water (ML)	To ASR (ML)	From ASR (ML)	Water Lost (ML)	Balance (ML)
Oct	578	150	428	448	20	0	0	20
Nov	445	70	375	465	90	0	0	110
Dec	467	80	387	477	90	0	0	200
Jan	422	50	372	462	90	0	0	290
Feb	415	40	375	465	90	0	0	380
Mar	452	70	382	472	90	0	0	470
Apr	452	10	442	422	0	20	0	450
May	622	120	502	412	0	90	0	360
Jun	815	260	555	465	0	90	0	270
Jul	1023	320	703	613	0	90	0	180
Aug	948	320	628	538	0	90	0	90
Sep	771	240	531	441	0	90	0	0
	7410	1730		5680				

Plant sizing estimate

Step 1: Winter MDD:	693.2 ML/30 d			
or	23.1 ML/d	Subtract GW output 10.9 ML/d	WTP min capacity =	12.2 ML/d
Step 2: Largest ADD:	612.6 ML/30 d or			20.4 ML/d
Step 3: Summer MDD:	1519.6 ML/30 d or			
	50.7 ML/d	Subtract GW output and ASR output of (10.9 + 3.0) = 13.9 ML/d	WTP min capacity =	36.8 ML/d

Therefore, minimum WTP capacity for this year is **36.8 ML/d**