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Final Report

Water Distribution Corrosion Study

Internal Corrosion
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WHISTLER

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Executive Summary

The Resort Municipality of Whistler (RMoW) identified that there is potential for internal corrosion in their water distribution system because many of their 15 water sources have low pH and alkalinity levels. Their hypothesis is supported by high water loss in some areas such as Emerald Estates and complaints of green staining in other areas such as Cheakamus Crossing. Both of which can be indicative of internal corrosion.

The RMoW engaged Kerr Wood Leidal Associates Ltd. (KWL) to determine if internal corrosion is a risk, identify and evaluate potential mitigation strategies and provide recommendations. This report both identifies the internal corrosion risk within the RMoW system and evaluates mitigation strategies. It also presents overall conclusions and recommendations for upcoming installation and maintenance activities.

The water chemistry of each of the RMoW water sources was analyzed using the Rothberg, Tamburini and Winsor (RTW) Model for Corrosion Control and Process Chemistry to determine its corrosivity. This model was used to calculate both the Calcium Carbonate Precipitation Potential (CCPP) and Aggressiveness Index (AI) which are the corrosion indices best suited for waters that are acidic, soft and/or have low total dissolved solids (TDS) concentrations.

The analysis indicated that all water sources are corrosive to both metallic and Asbestos Cement (AC) pipe. Risk scorecards were then generated by cross referencing the water corrosivity against material sensitivities. These scorecards are intended to identify high-risk groups of pipes and fittings and have been appended to the report for easy reference.

Four high-risk sources were identified based on both water chemistry (CCPP and AI values) and anecdotal evidence of corrosion in each of the areas supplied by the wells. These sources are summarized in Table A.

Table A: High Risk Water Sources

Source	CCPP Value (1)	AI Value (2)	Anecdotal Evidence of Corrosion
Community Wells (Combined)	-106.17	9.92	Point failures of AC pipe in the Village area and valve cluster failures.
Emerald Estates Well #1	-100.38	9.42	Significant water loss in Emerald Estates area.
Emerald Estates Well #2 (3)	-48.76	9.78	
Cheakamus Crossing Well	-46.02	8.81	Complaints of green staining.

Notes:
1. CCPP of < -10 indicates that source water is corrosive to metallic pipes and fittings.
2. AI of < 10 indicates that source water is highly aggressive to AC pipe.
3. Emerald Estates Well #3 demonstrates similar source water characteristic to Well #2, but is currently offline due to poor water quality.

Given that there is a high-risk of internal corrosion in the RMoW distribution system, four different mitigation strategies were reviewed:

1. Alteration of water chemistry by adding chemicals (pH and alkalinity control);
2. Placement of a barrier or lining between the water and the pipe (corrosion inhibition and pipe lining);
3. Forcing the material to act as the cathode (cathodic protection); and
   Using pipe materials that are not corroded by the source water (pipe replacement).

It was determined that the first option (pH and alkalinity control) was the most appropriate mitigation strategy for this application. Three different chemicals which are commonly used for internal corrosion mitigation were reviewed:

1. Caustic soda (NaOH);
2. Hydrated lime ($Ca(OH)_2$); and
3. Soda ash (Na_2CO_3).

All of these chemicals add alkalinity to the water and increase the pH. Again using the RTW model, the concentrations of chemicals required to achieve a CCPP value of -4 were determined. The average annual chemical requirements for each source were calculated based on the average runtimes and flowrates for each of the well pump which were supplied by RMoW.

A comparative financial analysis was conducted to determine which chemical is the most cost effective. These chemicals are supplied in different forms (solution and powder) and therefore have different dosing system requirements. They also vary in cost and must be dosed at different rates. Table B provides a summary of the different chemicals reviewed and identifies their estimated Net Present Value (NPV) which is used for financial comparison.

Table B: Financial Comparison of Mitigation Chemicals [1]

[redacted]

Notes:
1. Estimates are based on the largest source, the combined Community Wells, to identify the largest difference between different chemicals
2. Soda ash and hydrated lime require chemical make-down systems which are more expensive and larger footprint than the injection pump setup required for caustic soda solutions
3. Based on average flow rates for combined Community Wells and required concentration calculated using RTW model.
4. Assumes that more operator time will be required for the chemical make-down systems. Lime dosing system is especially subject to clogging and must be checked daily.
5. To be used for comparison purposes only.

It was determined that 50% caustic soda is the most appropriate chemical because: it is the most cost effective; easiest to implement, operate and maintain; has the smallest footprint; and will not cause scaling in the Cheakamus Crossing District Energy System (DES).

A permanent 50% caustic soda dosing system would include the following components (refer to Figure A):

- Heated building (50% caustic freezes at 12^{o}C) with access;
- Tote or barrel (depending on volume required);
- Backup tote or barrel (1 or 2 depending on volume required);
- Spill containment (tote or barrel will sit on top of a spill containment device);
- Dosing pump;
- pH monitor;
- Local pump control (well pump starts the dosing system and pH alarm can shut it down);
- Sample port after chemical addition; and
- Safety shower and eyewash station with hot water heater.

A building would be constructed and the water distribution pipe downstream of chlorination would be diverted into the new building. The dosing location, pH sensor and manual sampling port would be located inside the building. This construction was estimated at $333,000 for the largest high-risk water source, the combined Community Wells. It is anticipated that all other systems would be constructed for less than this amount.

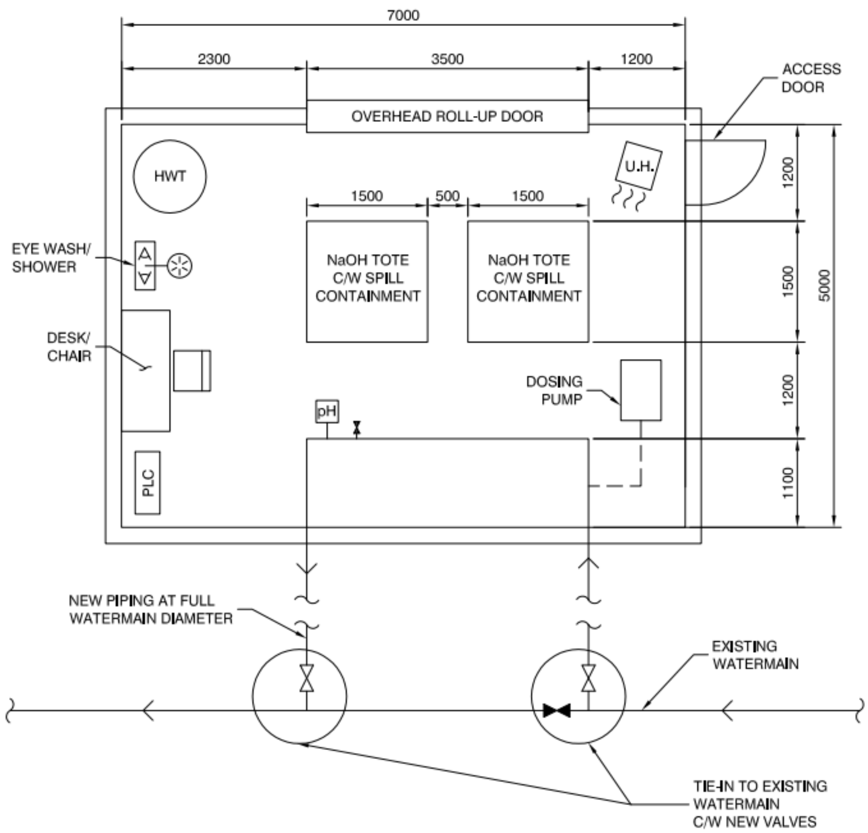

Figure A: Dosing System Schematic

Given the cost of implementing full systems and the inherent limitations of corrosion risk identification, it is recommend that the RMoW pilot a chemical dosing system at the Cheakamus Crossing Well before proceeding with chemical injection at all high-risk sources. This well was chosen for the pilot because it feeds an isolated system (there will be no contamination from other sources) which has newer pipes that are likely to be in good condition. A separate pilot plan will be developed to address corrosivity in the Cheakamus Crossing area.

It is also recommended that additional investigations be carried out to verify the internal corrosion risk. Destructive testing (collecting coupons or fittings) would represent significant cost to the RMoW; therefore it is recommended that the RMoW opportunistically collect samples in conjunction with other work on an ongoing basis. This other work could include installation of a new large service connection, road reconstruction work, routine replacement/maintenance of pipe or fittings, and repair of pipe/fitting break or leak. Both internal and external corrosion can be identified and documented using these samples in conjunction with potable water and soil/groundwater samples. A Field Validation Sample Collection Plan will be developed to assist staff with the collection and preservation of samples for analysis.

1. Introduction

The Resort Municipality of Whistler (RMoW) has several drinking water sources, with the main source being 21 Mile Creek. Water from the creek is disinfected and a chlorine residual is maintained throughout the distribution system. While the 21 Mile Creek is a high quality water source, its use is limited during periods of high turbidity.

To ensure continuity of water supply, the 21 Mile Creek source is supplemented by 14 groundwater wells that draw from underground aquifers, which are in turn slowly recharged from surface water. Due to this operational approach, the distribution water chemistry varies both geographically (throughout the distribution system) and chronologically (throughout the year).

While the treated water quality from all RMoW water sources complies with health regulations, RMoW staff have identified that there is potential for internal corrosion based on low pH and alkalinity levels found in some of the water sources. This hypothesis is supported by customer complaints of green staining around their water outlets, an indication of internal corrosion of copper piping and fittings within customer homes. The RMoW is concerned that internal corrosion may be reducing the lifetime of their water distribution infrastructure.

The RMoW engaged Kerr Wood Leidal Associates Ltd. (KWL) to determine if internal corrosion is a risk, identify and evaluate potential mitigation strategies and provide recommendations. This report identifies the internal corrosion risk within the RMoW system and evaluates mitigation strategies. It also presents overall conclusions and recommendations for upcoming installations and maintenance activities.

1.1 Purpose

The overall purpose of this report is to identify internal corrosion risk within the RMoW water distribution system and identify a preferred method for mitigating the risk.

More specifically this report aims to provide:

- Background information on internal corrosion;
- A summary of the findings of the internal corrosion analysis;
- Background on internal corrosion mitigation strategies;
- A summary of the findings of the internal corrosion mitigation analysis;
- A capital cost estimate for mitigation of the high-risk water sources within the RMoW system; and
- Overall conclusions and recommendations.

1.2 Background

Corrosion Indices

Iron corrosion of water distribution systems is one of the most costly and complicated problems facing drinking water utilities. For many years, water chemists, engineers, operators and utility owners have tried to predict water aggressiveness and corrosion risk by developing corrosion indices. In 1982 the US Environmental Protection Agency (UESPA) released a report entitled *Corrosion in Potable Water Systems*. This report identified several corrosion indices and indicated their limitations; several of the most widely used indices are summarized in Table 1-1.

Table 1-1: Corrosion Indices Summary

Corrosion Index	Basis	Target Value	Comment on Use
Langelier Saturation Index (LSI)	Based on theoretical tendency of water to deposit or dissolve calcium carbonate. It is a logarithm of the ratio of the hydrogen ion concentration that the water must have if saturated with calcium carbonate to the actual hydrogen ion concentration.	**>0** Value >0 indicates a tendency to form protective scale.	Inaccurate outside pH range of 6.5-9.5.
Ryznar Index (RI)	Also based on theoretical tendency of water to deposit or dissolve calcium carbonate.	**<6** Value <6 indicates a tendency to form protective scale.	Inaccurate in soft or saline waters.
Larson Index (LI)	Based on conductivity effects of specific ions rather than calcium carbonate precipitation.	**<0.5** Value <0.5 indicates that corrosive action may exist.	Inaccurate in soft or low total dissolved solids (TDS) waters.
Aggressiveness Index (AI)	Developed to determine what water can be transported in asbestos cement (AC) pipe without adverse structural effects.	**>12** Value >12 indicates nonaggressive water.	Does not incorporate temperature or TDS effects.
Calcium Carbonate Precipitation Potential (CCPP)	Based on theoretical quantity of $CaCO_3$ that can be precipitated from oversaturated waters or dissolved by under saturated waters.	**>0** Value >0 indicates a saturated water that will form a protective scale.	Accurate for all waters, but computationally cumbersome.
Source: USEPA Corrosion in Potable Water Systems Final Report			

When choosing a corrosion index for analysis, the source water characteristics must be considered. According to the 2013 RMoW annual drinking water report, the source waters are slightly acidic and soft and they have low Total Dissolved Solids (TDS) levels:

- pH as low as 6.0 was recorded (guideline is 6.5-8.5);
- Total hardness as low as 16.2 mg/L was recorded (soft water is defined as 0-60 mg/L); and
- TDS as low as 20.1 was recorded (aesthetic objective is <500 mg/L).

These water characteristics limit the choice of corrosion indices. As noted in Table 1-1, the Langelier Saturation Index (LIS), Ryznar Index (RI) and Larson Index (LI) are inaccurate for acidic, soft and/or low TDS waters. This leaves only the Aggressiveness Index (AI) and the Calcium Carbonate Precipitation Potential (CCPP) as potential candidates for this corrosion analysis.

The (AI) was developed to measure aggressiveness specific to AC pipes. It does not incorporate temperature or TDS effects, but it was used in this study to identify corrosion-associated risk for AC pipe specifically.

The CCPP is computationally cumbersome to calculate, but it is accurate for a broad range of water chemistries and is used in this study to identify corrosion risk. The CCPP can be determined graphically through the use of Caldwell-Lawrence diagrams, analytically through equilibrium equations or by computer analysis.

RTW Model

The Rothberg, Tamburini and Winsor (RTW) Model for Corrosion Control and Process Chemistry is a spreadsheet-based tool which was developed to provide the same pH and $CaCO_3$ equilibrium information as Caldwell-Lawrence (C-L) diagrams while also providing a numerical solution based on specific source water characteristics. The model has been updated over time and the current version is called the Tetra Tech (RTW) Model for Water Process and Corrosion Chemistry. This model also allows calculation of the effects of various chemical additions to a specific water sample.

This model was used to assess the source water aggressiveness and identify corrosion-associated risk to all other pipe materials (AC pipe excluded) by calculating CCPP. While the CCPP is considered to be the most accurate guide of water's tendency to dissolve or precipitate calcium carbonate ($CaCO_3$), it was noted by developers of the model that it may identify an unrealistically high corrosion risk for source waters with low alkalinity. As a result, CCPP is used in this study to rank sources from lowest to highest risk; the study also identifies a need to validate the results of the analysis through a chemical dosing pilot (see Section 11).

The model was also used to determine the impact of different mitigations chemicals on each source water.

Corrosion Mitigation Strategies

There are four approaches to controlling corrosion within a water distribution system:

1. Alter the water chemistry by adding chemicals (pH and alkalinity control);
2. Place a barrier or lining between the water and the pipe (corrosion inhibition and pipe lining);
3. Force the material to act as the cathode (cathodic protection); and
4. Use pipe materials that are not corroded by the source water (pipe replacement).

These approaches are described in greater detail below.

pH and Alkalinity Control

The most common method of corrosion control is pH adjustment; it is considered to be the least capital intensive and most easily implemented method of achieving corrosion control.

Both metallic pipes and the cement matrix of AC pipe or cement pipe lining are more soluble at low pH which leads to uniform corrosion of the surfaces. Increasing the pH reduces this overall material loss. Also, when calcium carbonate alkalinity is present increasing the pH reduces the solubility of this calcium carbonate; the material deposits on the interior pipe and fitting surfaces forming a scale that protects them from corrosion. Consideration will be given to any impact that calcium carbonate deposits can have on a residential district energy system in the area

Several chemicals are used to control pH; the following three are the most prevalent and were considered in this study:

1. Lime ($Ca(OH)_2$);
2. Caustic soda (NaOH); and
3. Soda ash (Na_2CO_3).

Each chemical has advantages and disadvantages which are included in Table 8-3 below.

In low alkalinity waters (below 40 mg/L) it is often beneficial to add carbonate to form insoluble carbonates. Soda ash (Na_2CO_3) or sodium bicarbonate ($NaHCO_3$) can be added to increase the carbonate alkalinity of the water and allow a protective calcium carbonate scale to form on the interior of pipe surfaces. While scale formation protects water distribution infrastructure impacts on other infrastructure like District Energy Systems (DES) must be considered during chemical selection.

Corrosion Inhibitors

Corrosion can be controlled by adding chemicals that form a protective film on the interior surface of the pipe. There are three classes of inhibitors:

1. Calcium carbonate: as noted above, calcium carbonate can be deposited on the interior surface of a pipe and serve as a protective coating.
2. Inorganic phosphates: inorganic phosphates form a protective film on the surface of the pipe. They also inhibit the deposition of $CaCO_3$ scale on pipe walls which is only advantageous in areas where excessive scaling occurs.
3. Sodium silicates (water glass): sodium silicates have been demonstrated to reduce corrosion in galvanized iron, yellow brass and copper plumbing system.

The success of any inhibitor depends on:

- Early application of the inhibitor before pitting has started;
- High initial concentration to build up a protective film quickly;
- Continuous application at a sufficiently high concentration; and
- Adequate flow rates throughout the system to distribute the inhibitor.

If a protective film is not quickly formed and maintained then the inhibitor will not be effective at controlling corrosion.

Pipe Linings

Pipes can be lined with a variety of materials to protect them from corrosion. Common pipe lining materials with associated advantages and disadvantages are included in Table 1-2.

Table 1-2: Pipe Linings

Material	Pros	Cons
Hot applied coal tar enamel	• Long service life (>50 years) • Erosion resistant • Resistant to biological attachment	• Need to apply to welded areas • Extreme temperatures can compromise coating • May cause an increase in trace organics in water • Potentially carcinogenic substance (Health & Safety concerns)
Epoxy	• Smooth surface (reduces pumping costs)	• Expensive • Less erosion resistant than tar enamel • Short service life (15 years)
Cement mortar	• Inexpensive • Easy to apply • Calcium hydroxide release from cement may protect uncoated metal at joints and fittings	• Lining is rigid and can crack • Lining is thick and reduces carrying capacity of pipes
Polyethylene	• Long service life (50 years) • Erosion resistant • Smooth surface (reduces pumping costs)	• Expensive
Source: USEPA Corrosion Manual for Internal Corrosion of Water Distribution Systems		

Cathodic Protection

Corrosion involves the formation of an electrical cell where material is lost at the anode and oxygen gas is converted to hydroxide at the cathode. For example, with iron the following reactions occur:

(Anode) $2Fe \rightarrow 2Fe^{2+} + 4e^-$

(Cathode) $O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$

The two ions (Fe^{2+} and OH^-) then recombine at the anode forming the corrosion product, in this case rust ($Fe(OH)_2$).

In cathodic protection, a separate anode material is electrically connected to the material that is being protected. This anode preferentially supplies electrons (either through an applied current or by dissolving) and allows the material that is being protected to act as the cathode.

Cathodic protection is typically employed to protect water storage tanks; it is expensive and not practical for use throughout a water distribution system.

Pipe Replacement

Certain materials are more resistant to corrosion (i.e. plastic and stainless steel). Replacing existing pipe with corrosion resistant pipe can reduce the risk within a water distribution system.

Is should be noted that plastic pipe is commonly installed with metal fittings which are susceptible to corrosion. Pipe replacement can therefore reduce, but not completely mitigate corrosion risk within a water distribution system.

Choice of Mitigation Strategy

The advantages and disadvantages of each mitigation strategy are outlined in Table 1-3.

Table 1-3: Corrosion Mitigation Strategy Summary

Mitigation Strategy	Pros	Cons
pH and Alkalinity Control	• Least capital intensive corrosion mitigation option • Protects all infrastructure fed by controlled water source	• Ongoing chemical costs • Health and safety concerns associated with chemical use and storage
Corrosion Inhibitors	• $CaCO_3$ corrosion inhabitation can be implemented as part of a pH and alkalinity control strategy	• Less effective in an old system • Potential health implications of chemical addition (with the exception of $CaCO_3$) • Ongoing chemical costs • Protective film can degrade if the supply of chemical is stopped
Pipe Linings	• Can be implemented gradually as part of an asset management program • Can be combined with other mitigation strategies	• Linings can be compromised by extreme temperatures and/or physical stress • Linings reduce carrying capacity of pipe • Lining effectiveness is dependent on quality of installation
Cathodic Protection	• Effective for large water containing vessels	• Expensive • Ineffective for distribution systems
Pipe Replacement	• Can be implemented gradually as part of an asset management program • Can be combined with other mitigation strategies	• Expensive to replace materials all at once • Metal fittings are still susceptible to corrosion
Source: USEPA Corrosion Manual for Internal Corrosion of Water Distribution Systems		

The 2014 Water Infrastructure Rehabilitation Study prepared for the RMoW recommended a short term program to replace AC and cast iron water mains within the next 10 years. These pipes are demonstrating effects of internal corrosion; AC pipes have lost wall strength and cast iron pipes are exhibiting tuberculation and producing turbid waters. The report also recommended corrosive soils investigations and ductile pipe condition assessment to target renewal (replacement) of assets that have reached the end of their service life.

Over time this pipe replacement will reduce the corrosion risk across the distribution system, but this will take time and will not address all corrosion risks. These risks include corrosion of metal fittings and corrosion of domestic piping in both municipal buildings and customer homes.

To address the immediate and long term corrosion risks it is recommended that the RMoW implement pH and alkalinity control at high-risk water sources.

2. Sampling Plan

To determine the areas of highest risk, water samples were collected and analyzed from each water source. The analysis allowed the project team to identify the most corrosive sources and work with RMoW staff to identify areas requiring mitigation.

The 2013 RMoW Annual Drinking Water Report identified 16 water sources that feed the RMoW water distribution system. An additional well (Rainbow Park) is not yet commissioned, but was tested as part of this program. Samples were collected from the locations identified in Table 2-1.

Table 2-1: Sampling Locations (Water Sources)

Water Source #	Water Source	Sample Location/Notes	Type
1	21-Mile Creek	P282, the Alta Lake Rd. PRV #2 during a period when only 21 Mile surface water has been entering the system	Surface Water
2	Blackcomb Creek	Is not currently being used; was not sampled	Surface Water
3	Emerald Estates Well #1	Chlorine injection analyzer feed	Groundwater
4	Emerald Estates Well #2[1]	Nearest possible sampling point	Groundwater
5	Emerald Estates Well #3[2]	Raw water sample	Groundwater
6	Alpine Well #1	Chlorine injection analyzer feed	Groundwater
7	Alpine Well #2	Currently offline, to be sampled when it comes online again	Groundwater
8	Alpine Well #3	Chlorine injection analyzer feed	Groundwater
9	Function Well #1	Chlorine injection analyzer feed	Groundwater
10	Function Well #2	Chlorine injection analyzer feed. Sampled after flushing for several hours to minimize introduction of manganese laden water to the system and to the sample	Groundwater
11	Community Well #1 [3]	Raw water (see note 3)	Groundwater
12	Community Well #2 [3]	Raw water (see note 3)	Groundwater
13	Community Well #3 [3]	Raw water (see note 3)	Groundwater
14	Community Well #4 [3]	Raw water (see note 3)	Groundwater
15	Combined Community Well Water[3]	Nearest possible sampling point following chlorination and combination	Groundwater
16	21 Mile Creek Well	Chlorine injection analyzer feed	Groundwater
17	Cheakamus Crossing Well	Chlorine injection analyzer feed	Groundwater
18	Rainbow Park Well [4]	Raw water sample	Groundwater

1. Emerald Estates Well #2 is currently off-line. It was sampled for a short period.
2. Due to poor water quality in Emerald Estates Well #3 it was not brought online during the study. Raw water samples were collected; if UV disinfection is implemented in the future it will be a useable source.
3. The wells in the community system run together in order to support the flow rate that the booster pump is capable of. It would be difficult to obtain separate, undiluted treated samples for the individual wells due to the nature of system therefore a combined sample was obtained.
4. Raw water sample was collected from the uncommissioned Rainbow Park Well.

Two (2) samples were collected from each location and tested for the water quality parameters identified in Table 2-2. These parameters were required for the internal corrosion analysis.

Table 2-2: Water Quality Parameters Measured

Water Quality Parameter	Units
Total dissolved solids (TDS)[1]	mg/L
Temperature	°C
pH	s.u.
Alkalinity (as $CaCO_3$)	mg/L
Calcium (as $CaCO_3$)[2]	mg/L
Chloride (Cl^-)	mg/L
Sulfate (SO_4^{-2})	mg/L

1. TDS is used to estimate the ionic strength of the initial water. If necessary, conductivity can be measured in the place of TDS.
2. If calcium concentration is not available directly, it can be derived from hardness data. This would require total and magnesium hardness.

At each sample location field staff also identified description and coordinates of sample location, sampling date and time. Two samples were collected at each location and the values were averaged.

3. Water Quality

The results of the water sampling program are included in Table 3-1.

Table 3-1: Water Quality Data

Source Number	Sample Number	Water Source	Sample Site (RMOW Bldg #)	Sample Date	Sample Time	Description of Sample Location	GIS Coordinates of Sample Location (Lat, Long)	Parameter						
								Total Dissolved Solids	Temperature	pH	Alkalinity as $CaCO_3$	Ca as $CaCO_3$	Cl	SO_4
								(mg/L)	deg C	s.u.	mg/L	mg/L	mg/L	mg/L
SURFACE SOURCES														
1	1	21-Mile Creek	**R231 Cl2** taken at P280 Lorimer Rd.	Aug. 14 2014	13:25	Lorimer Rd analyzer @ P280	50 9.639' N / 122 55.607' W	42	15.8	7.0	7	4	1	3
	2			Aug. 26 2014	12:15			<10	14.4	6.9	10	4	1	3
							Average	**42.0**	**15.1**	**7.0**	**8.5**	**4.0**	**1.2**	**2.9**
GROUNDWATER SOURCES														
2	1	Emerald Estates Well #1	W201-1	Aug.14 2014	14:10	Analyzer feedline	50 9.639' N/122 55.606' W	201	11.5	6.3	47	27	54	15
	2			Aug. 26 2014	9:50			176	11.5	6.3	49	27	53	15
							Average	**188.5**	**11.5**	**6.3**	**48.0**	**27.3**	**53.6**	**14.6**
3	1	Emerald Estates Well #2	W201-2	Aug. 15 2014	10:50	Analyzer feedline	50 9.639' N/122 55.606' W	88	10.5	6.7	51	24	9	12
	2			Aug. 26 2014	10:30			80	9.9	6.7	50	24	11	12
							Average	**84.0**	**10.2**	**6.7**	**50.5**	**23.9**	**9.7**	**11.5**
4	1	Emerald Estates Well #3	W201-3	Aug. 20 2014	8:35	Raw Water	50 9.020' N/122 57.714' W	117	10.0	6.8	43	25	22	15
	2			Aug. 26 2014	10:15			93	12.9	6.5	44	23	24	15
							Average	**105.0**	**11.5**	**6.7**	**43.5**	**24.1**	**22.9**	**15.0**
5	1	Alpine Well #1	W202	Aug. 14 2014	12:30	Analyzer feedline	50 8.639' N/122 57.555' W	42	10.8	6.4	16	9	1	7
	2			Aug. 26 2014	15:50			33	11.8	6.5	20	9	1	7
							Average	**37.5**	**11.3**	**6.5**	**18.0**	**9.0**	**0.6**	**7.2**
6	1	Alpine Well #3	W213	Aug. 19 2014	15:00	Analyzer feedline	50 7.346' N/122 59.180' W	149	8.8	6.1	35	40	8	60
	2			Aug. 28 2014	10:00			128	11.5	7.2	36	39	8	65
							Average	**138.5**	**10.2**	**6.7**	**35.5**	**39.2**	**7.8**	**62.3**
7	1	Function Well #1	W212-1	Aug. 13 2014	12:30	Analyzer feedline	50 6.906' N/122 57.159' W	188	12.9	6.1	33	18	56	14
	2			Aug. 21 2014	13:15			222	10.3	6.2	32	19	72	13
							Average	**205.0**	**11.6**	**6.2**	**32.5**	**18.6**	**64.2**	**13.5**
8	1	Function Well #2	W212-2	Aug. 15 2014	14:20	Special Setup downstream of Cl_2 injection point	50 6.889' N/122 57.165' W	299	9.8	6.0	39	20	114	11
	2			Aug. 25 2014	9:30			259	10.4	6.2	38	19	94	11
							Average	**279.0**	**10.1**	**6.1**	**38.5**	**19.6**	**103.9**	**11.0**
9	1	Community Well #1 - Raw	W205-1	Aug. 13 2014	10:10	Sample Port	50 6.984' N/122 57.141' W	279	9.1	6.2	52	59	35	93
	2			Aug. 26 2014	14:00			241	8.8	6.2	51	56	34	85
							Average	**260.0**	**9.0**	**6.2**	**51.5**	**57.3**	**34.4**	**89.0**
10	1	Community Well #2 - Raw	W205-2	Aug. 13 2014	10:20	Sample Port	50 7.012' N/122 57.109' W	388	9.6	6.3	65	80	47	113
	2			Aug. 26 2014	14:15			348	9.1	6.3	67	80	43	105
							Average	**368.0**	**9.4**	**6.3**	**66.0**	**79.6**	**44.9**	**109.0**
11	1	Community Well #3 - Raw	W205-3	Aug. 13 2014	10:30	Sample Port	50 5.253' N/123 2.170' W	207	9.8	6.2	62	48	28	61
	2			Aug. 26 2014	14:30			179	9.7	6.3	59	41	22	53
							Average	**193.0**	**9.8**	**6.3**	**60.5**	**44.4**	**24.7**	**57.0**
12	1	Community Well #4 - Raw	W211	Aug. 13 2014	10:40	Sample Port	50 5.253' N/123 2.162' W	257	9.1	6.2	65	52	38	64
	2			Aug. 26 2014	14:45			202	9.0	6.2	53	44	34	58
							Average	**229.5**	**9.1**	**6.2**	**59.0**	**48.2**	**35.7**	**61.1**
13	1	Combined Community Well Water	P247	Aug. 13 2014	9:30	P247 Analyzer feedline	Not supplied	290	10.0	6.3	59	64	38	87
	2			Aug. 26 2014	15:00			253	9.2	6.4	60	60	39	83
							Average	**271.5**	**9.6**	**6.4**	**59.5**	**61.8**	**38.2**	**84.6**
13	1	21 Mile Creek Well	W218	Aug. 14 2014	13:00	Clear well Cl_2 analyzer discharge line	Not supplied	68	9.5	6.2	15	13	2	21
	2			Aug. 27 2014	15:00			59	9.4	6.5	16	13	3	20
							Average	**63.5**	**9.5**	**6.4**	**15.5**	**12.6**	**2.6**	**20.9**
14	1	Cheakamus Crossing Well	W217	Aug. 14 2014	10:30	Analyzer feedline	50 7.382' N/122 58.815' W	49	9.5	6.4	22	12	6	11
	2			Aug. 21 2014	13:40			53	13.0	6.4	23	11	6	11
							Average	**51.0**	**11.3**	**6.4**	**22.5**	**11.4**	**6.0**	**11.0**
15	1	Rainbow Park Well	W219	Aug. 20 2014	15:00	Raw Water	Not supplied	60	7.4	6.4	22	12	2	14
	2			Aug. 26 2014	12:50			42	8.0	6.2	22	12	2	14
							Average	**51.0**	**7.7**	**6.3**	**22.0**	**11.7**	**2.0**	**13.6**

\\libra25.burnaby.kerrwoodleidal.org\0000-0999\0000-0099\029-237\300-Report\Phase I\FINAL Report\Tables\[Table 3-1.xlsx]Data

4. Internal Corrosion Analysis

Using the results of the water sampling program, the source water corrosivity was determined using the RTW model. The corrosivity was based on CCPP and AI as indicated in Section 1.2. Material sensitivity to corrosion was then reviewed. Risk score cards were developed by cross referencing water corrosivity and material sensitivity (see Section 4.2).

4.1 Source Water Corrosivity

The CCPP and AI for each of the water source were determined, then the water sources were ranked from most corrosive to least corrosive for each index and colour coded (see tables 4-1 and 4-2).

Table 4-1: Ranked Water Source Corrosivity Based on CCPP

Ranked Source	CCPP Value
Community Well #4	-143.52
Community Well #3	-132.30
Community Well #1	-130.23
Community Well #2	-129.71
Function Well #2	-127.57
Combined Community Wells	-106.17
Emerald Estates Well #1	-100.38
Function Well #1	-99.59
Rainbow Park Well	-60.17
Emerald Estates Well #2	-48.76
Emerald Estates Well #3	-46.26
Cheakamus Crossing Well	-46.02
Alpine Well #3	-38.88
21 Mile Creek Well	-37.78
Alpine Well #1	-34.26
21-Mile Creek	-9.72

Legend		
Corrosion state of water	**CCPP Value**	**Colour**
Scaling (protective)	> 0	
Passive	0 to -5	
Mildly Corrosive	-5 to -10	
Corrosive (aggressive)	-10 to -50	
	- 50 to -100	
	< -100	

Note: While corrosive waters are ranked based on CCPP values, all water sources with a CCPP value below -10 should be considered corrosive.

Table 4-2: Ranked Water Source Corrosivity Based on AI

Ranked Source	AI Value
21-Mile Creek	8.48
21 Mile Creek Well	8.64
Alpine Well #1	8.66
Rainbow Park Well	8.71
Cheakamus Crossing Well	8.81
Function Well #1	8.93
Function Well #2	8.98
Emerald Estates Well #1	9.42
Community Well #4	9.65
Community Well #2	9.67
Emerald Estates Well #3	9.67
Community Well #3	9.68
Community Well #1	9.69
Emerald Estates Well #2	9.78
Alpine Well #3	9.79
Combined Community Wells	9.92

Legend		
Corrosion state of water	**AI Value**	**Colour**
Nonaggressive	>12	
Moderately Aggressive	10-12	
Highly Aggressive	<10	

4.2 Material Sensitivity

A material's sensitivity to corrosion depends not only on its type, but also on its age and surface preparation.

Material Type

Table 4-3 outlines common distribution system materials and comments on their sensitivity/resistance to corrosion.

Table 4-3: Distribution System Materials' Sensitivity/Resistance to Corrosion

Distribution System Material	Corrosion Resistance
Steel	Subject to uniform corrosion.
Cast Iron (1)	Subject to surface erosion by aggressive waters.
Copper	Good overall corrosion resistance, but subject to corrosive attack from high velocities, soft water, chlorine, dissolved oxygen and low pH.
Asbestos Cement	Good corrosion resistance, but aggressive waters can leach calcium from cement.
Ductile Iron (2)	Resistant to corrosion, but coatings must be intact and continuous.
Polyethylene	Resistant to corrosion.
PVC	Resistant to corrosion.

Source: USEPA Corrosion Manual for Internal Corrosion of Water Distribution Systems.
1. All cast iron is assumed to be unlined.
2. All ductile iron is assumed to be cement mortar lined.

Material Age

The expected lifetime of various pipe materials are summarized in Table 4-4.

Table 4-4: Distribution System Materials' Expected Life

Distribution System Material	Expected Service Life of Mains
Steel	85 years (2)
Cast Iron	65 years (2, 3)
Copper (1)	50 years (4)
Asbestos Cement	50 years (2)
Ductile Iron	85 years (2, 5)
Polyethylene	85 years (2)
PVC	85 years (2)

1. Copper is not typically used for water mains; copper is included in this table as an estimate of domestic piping service life.
2. Source: AECOM Water Utility Infrastructure Rehabilitation Study Table 2-10.
3. All cast iron is assumed to be unlined.
4. Life expectancy of domestic piping is estimated at 50 years or more (U.S. Department of Housing and Urban Development Residential Rehabilitation and Inspection Guide).
5. All ductile iron is assumed to be cement mortar lined.

5. Risk Scorecards

Risk score cards were developed by cross referencing water corrosivity (CCPP and AI) and material sensitivity (see tables 5-1 and 5-2). These scorecards are intended to identify high-risk groups of pipes and fittings. Table 5-1 identifies corrosion associated risk based on CCPP (all pipes except AC) and Table 5-2 identifies corrosion associated risk for AC pipes based on AI. These scorecards are also appended for easy reference (see Appendix A).

Table 5-1: CCPP-Based Risk Scorecard

CCPP Range	Pipe/Fitting Material	Pipe Age	Risk of Failure Associated with Corrosion
> 0	All	All	Low
0 to -5	All	All	Low
-5 to -10	Steel	0-40	Low
		40-85	Low
		> 85	Medium
	Cast Iron (1)	0-35	Low
		35-65	Low
		>65	Medium
	Copper	0-25	Low
		25-50	Low
		> 50	Medium
	Ductile Iron (2)	0-45	Low
		45-85	Low
		>85	Low
	Plastic (Polyethylene or PVC)	0-45	Low
		45-85	Low
		>85	Low

CCPP Range	Pipe/Fitting Material	Pipe Age	Risk of Failure Associated with Corrosion
< -10	Steel	0-50	Medium
		50-100	High
		> 100	Very high
	Cast Iron (1)	0-35	Medium
		35-65	High
		>65	Very high
	Copper (3)	0-25	Medium
		25-50	High
		> 50	Very high
	Ductile Iron (2)	0-45	Low
		45-85	Medium
		>85	Medium
	Plastic (Polyethylene or PVC)	0-45	Low
		45-85	Low
		>85	Low

1. All cast iron is assumed to be unlined.
2. All ductile iron is assumed to be cement mortar lined. If the lining is compromised the unprotected area will be subject to corrosion as if it was steel, this could result in point failure.
3. All copper piping is assumed to be used as service or domestic piping.

Table 5-2: AI-Based Risk Scorecard

AI Range	Pipe/Fitting Material	Pipe Age	Risk of Failure Associated with Corrosion
> 12	AC	All	Low
10 - 12	AC	0-25	Low
		25-50	Medium
		> 50	High
< 10	AC	0-25	Medium
		25-50	High
		> 50	Very high

6. Potential Evidence of Corrosion

Without material evidence collected from the distribution system it is difficult to validate the internal corrosion analysis. However, there has been anecdotal evidence of internal corrosion in areas supplied by wells that were investigated in this study:

- There have been complaints of green staining in the Cheakamus Crossing area. Green staining is an indication of copper corrosion.
- The RMoW has identified that there is significant water loss in the Emerald Estates neighbourhood. This area's water supply is groundwater only; it is not diluted by mixing with 21-Mile Creek water which could decrease the water's aggressiveness. The identified water loss could be associated with fitting or pipe failures in the area. Based on GIS data supplied by the RMoW, the Emerald Estates have a combination of PVC and Ductile Iron pipes. Any metal pipes or fitting in this area could be subject to corrosion-associated failure.
- There have been many point failures of existing AC pipe in the village area. The RMoW will be replacing all remaining AC pipe in the area in the next 5 years. Samples from this piping could be helpful in correlating with AI results.
- A new strata in the Village area has experienced three valve cluster failures in the last three (3) years. These failed valve clusters have not been examined by KWL staff, but they could be evidence of corrosion in the Village area which is supplied by the community wells. RMOW staff have indicated that anecdotally these are attributed to external corrosion. If both external and internal corrosion are present in this area, they could explain the accelerated valve cluster failure.

7. Identification of High Risk Water Sources

High risk water sources were identified based on the potential evidence of corrosion identified in Section 6, on the source water distribution in the system, and on CCPP values for the water sources investigated. It was determined that the Cheakamus Crossing well, Emerald Estates wells and Community wells present the highest risk to the RMoW water distribution system infrastructure.

Figure 7-1: Cheakamus Crossing Pump Station

8. Corrosion Mitigation Analysis

A mitigation analysis for the five high-risk sources was conducted to determine what type and concentration of chemical would be required to achieve an acceptable CCPP value.

8.1 High Risk Source Water Corrosivity

The Community wells, Emerald Estates wells and Cheakamus Crossing well were identified as high-risk water sources. Given that the Community wells always operate together, the combined water would be treated instead of treating each well separately. The CCPP values for each these high-risk water sources are ranked from most corrosive to least corrosive in Table 8-1.

Table 8-1: Ranked Water Source Corrosivity Based on CCPP

Ranked Source	CCPP Value
Combined Community Wells	-106.17
Emerald Estates Well #1	-100.38
Emerald Estates Well #2	-48.76
Emerald Estates Well #3	-46.26
Cheakamus Crossing Well	-46.02

Legend		
Corrosion State of water	**CCPP Value**	**Colour**
Scaling (protective)	> 0	
Passive	0 to -5	
Mildly Corrosive	-5 to -10	
Corrosive (aggressive)	-10 to -50	
	- 50 to -100	
	< -100	

8.2 Mitigation Analysis

To achieve a passive water chemistry, three different chemicals were added in the RTW model:

- Caustic soda (NaOH);
- Hydrated lime ($Ca(OH)_2$); and
- Soda ash (Na_2CO_3).

All of these chemicals add alkalinity to the water and increase the pH.

A CCPP value of -4 was targeted and the concentrations of chemicals required to achieve this CCPP value were determined. These concentrations are outlined in Table 8-2.

Table 8-2: Required Chemical Concentrations for Internal Corrosion Mitigation

Water Source	Required Concentration (1)		
	Caustic Soda	Hydrated Lime	Soda Ash
Combined Community Wells	50 mg/L	44 mg/L	125 mg/L
Emerald Estates Well #1	46 mg/L	40 mg/L	118 mg/L
Emerald Estates Well #2	20 mg/L	18 mg/L	53 mg/L
Emerald Estates Well #3	19 mg/L	17 mg/L	49 mg/L
Cheakamus Crossing Well	19 mg/L	16 mg/L	49 mg/L

1. Calculated using the RTW model introduced in Technical Memorandum No 1.

Choice of Chemical

Table 8-3 outlines the advantages, disadvantages and equivalent costs of the chemicals used in the corrosion mitigation analysis. Both the base chemical cost and equivalent costs for each chemical are provided. The equivalent costs were calculated based on stoichiometry and on the concentration of liquid solutions.

Table 8-3: Chemical Advantages/Disadvantages

Chemical	Pros	Cons	Chemical Cost (1)	Cost per Caustic (NaOH) Equivalent (1)
Caustic soda (NaOH) 25%	• Liquid is available in drums and totes and can be dosed directly (no make-down required). • Freezes at -20°C. • RMoW has experience with this chemical. (2)	• Only adds hydroxide alkalinity • Purchased chemical is 75% water. • Chemical is the most expensive. • More chemical is required than 50% solution. • Health and safety concerns associated with chemical use and storage	$0.83/kg	$3.32/kg
Caustic soda (NaOH) 50%	• Liquid is available in drums and totes and can be dosed directly (no make-down required). • Less chemical is required than 25% solution. • RMoW has experience with this chemical. (2)	• Only adds hydroxide alkalinity. • Freezes at 12°C. • Purchased chemical is 50% water. • Chemical is the second most expensive. • Health and safety concerns associated with chemical use and storage	$1.07/kg	$2.14/kg

Chemical	Pros	Cons	Chemical Cost (1)	Cost per Caustic (NaOH) Equivalent (1)
Hydrated Lime ($Ca(OH)_2$)	• Chemical is the least expensive.	• Only adds hydroxide alkalinity. • Cost intensive make-down system is required. • Chemical can burn tissue (skin, eye, respiratory tract) causing irreversible damage • Lime is relatively insoluble in water therefore a dosing system would be feeding a slurry. It is difficult to maintain a consistent pH and concentration in this slurry. • Screw feeders and other equipment in the make-down system can become clogged easily therefore the system must be checked daily.	$1.00	$1.02/kg
Soda ash (Na_2CO_3)	• Adds carbonate alkalinity which can form protective scale on pipe interior. • Chemical is less expensive than 25% and 50% caustic solutions. • RMoW has experience with this chemical. (2)	• Sensitive to water ingress (hardens and becomes difficult to meter for solution make-down). Operators must check the system frequently to ensure it has not become clogged. • Cost intensive make-down system is required.	$1.01	$1.34/kg

1. Costs provided by ClearTech. Equivalent costs consider stoichiometry and concentration of liquid solutions.
2. RMoW uses caustic soda and soda ash for pH control at their wastewater treatment plant.

Comparative Financial Analysis

Each chemical has different chemical costs and dosing system requirements. For example: caustic soda is the most expensive chemical by weight, but requires no chemical make-down system while hydrated lime is the least expensive chemical, but requires the most equipment for chemical dosing. Required chemical doses also vary between chemicals.

To determine the most appropriate chemical for internal corrosion mitigation a comparative financial analysis was conducted. This analysis considered: capital costs, equipment lifetime, equipment footprint (and associated building cost), chemical costs and operating costs associated with operator time to determine the net present value (NPV) for each chemical over a 10 year period. This analysis was conducted for the water source with the largest flow and chemical demands (combined Community Wells) because this source would show the largest difference in NPV for each of the chemicals investigated.

Comparative financial analysis details are provided in Appendix B. The financial analysis was based on the following assumptions:

- NPV rate of 4%.
- Annual inflation rate of 2%.
- Dosing system equipment costs:
  - Caustic dosing system - $1,000 for containment pallet and $3,300 for pumps + $28,000 for overall electrical equipment (including BC Hydro connection).
  - Soda ash and lime systems - $100,000 (based on quotes from suppliers) + $28,000 for overall electrical equipment (including BC Hydro connection).
- Safety equipment cost of $4,500 for hot water heater, safety shower and eyewash.
- Service life: 15 year service life for chemical dosing equipment, 50 year service life for building (including mechanical and electrical equipment) and 75 year service life for yard piping
- Operations and maintenance:
  - Caustic Soda – operations time of 3 hours/week at $50/hour and maintenance time of 4 hours/month at $70/hour.
  - Soda Ash – operations time of 5 hours/week at $50/hour and maintenance time of 8 hours/month at $70/hour.
  - Lime – operations time of 8 hours/week at $50/hour and maintenance time of 8 hours/month at $70/hour.
  - Does not include heating costs.
- Building footprint and cost:
  - Caustic Soda – footprint of 7 m x 5 m and cost of $105,000.
  - Soda Ash and Lime – footprint of 7.5 m x 5 m and a cost of $125,000.
- Chemical costs:
  - 50% caustic soda - $2.14 / kg (of active chemical).
  - 25% caustic soda - $3.32 / kg (of active chemical).
  - Soda ash - $1.01 / kg (purchased as a powder).
  - Lime - $1.00 / kg (purchased as a powder).
- Chemical amounts were based on the concentrations calculated using the RTW model and average flow rates for each source. .

The analysis did not attempt to quantify the benefit of the chemical dosing system and assumed that all chemicals would provide the same corrosion mitigation benefit. The results of the financial analysis are presented in Table 8-4.

Table 8-4: Financial Analysis Results

Chemical	NPV	Rank
25% Caustic Soda	[redacted]	3
50% Caustic Soda		1
Soda Ash		4
Hydrated Lime		2

Chemical Recommendations

Given that chemical dosing will be implemented at individual well pump stations 50% caustic soda is recommended for the following reasons:

- It is the most cost effective chemical injection option for internal corrosion mitigation;
- It is easier to implement, operate and maintain than a lime make-down and dosing system;
- It is less capital intensive and smaller footprint than a lime make-down system;
- It is less expensive than the 25% caustic soda solution; and
- It only adds hydroxide alkalinity which will not create scaling (operational issue) in heat exchangers located in Cheakamus Crossing neighbourhood systems.

It should be noted that the 50% caustic soda solution freezes at 12°C. If the RMoW is concerned about freezing, it could use 25% caustic solution or dilute the solution during the winter months, or ensure that the temperature in all chemical dosing buildings remains above 15°C at all times.

9. Chemical Requirements

The corrosion model identified what concentration of chemicals are required to achieve a passive water, but the flow rates of the various sources were required to calculate the chemical dosing rate and storage requirements for each of the high-risk sources.

Three pieces of information were supplied by RMoW staff for the five high-risk sources:

1. Well pump flow rates;
2. Maximum daily volume; and
3. Monthly average volume.

This information is summarized in Table 9-1.

Table 9-1: Source Water Flow Rates

Water Source	Well Pump (1) Flow Rate	Max. Daily Volume (2)	Monthly Average Volume (3)
Combined Community Wells	70 L/s	3,024 m^3/d	25,034 m^3/month
Emerald Estates Well #1	13 L/s	1,123 m^3/d	25,335 m^3/month
Emerald Estates Well #2	10.5 L/s	605 m^3/d	2,964 m^3/month
Emerald Estates Well #3 (4)	26.67 L/s	739 m^3/d	10,796 m^3/month
Cheakamus Crossing Well	36.67 L/s	1,122 m^3/d	2,358 m^3/month

1. Well pump flow rates supplied by RMoW.
2. Max daily volume calculated based on longest runtime noted in 2014 supplied by RMoW.
3. Monthly average volume based on 2013 data supplied by RMoW with the exception of Emerald Estates Well #3 (see note 4).
4. Emerald Estates Well #3 has been offline since March 2012. The max daily and monthly average volumes are based on 2011 data supplied by RMoW.

Each piece of information was used to determine a different aspect of the chemical dosing system:

- **Well pump flow rates**: The well pumps are all fixed rate pumps which turn on and off based on reservoir levels. These pump flow rates were used to determine the dosing flow rate of 50% caustic solution required at each location.
- **Max daily volume**: Each well draws water based on demand in the system. The maximum daily volumes were used to determine the maximum daily amount of chemical required at each location. This information was used to determine chemical storage requirement.
- **Monthly average volume**: The monthly average volumes were used to determine the average amount of chemical used each month at each location. This information was used, with the maximum daily chemical requirement, to determine chemical storage requirements.

The caustic dosing rate, maximum daily volume and average monthly volume required for each source are summarized in Table 9-2.

Table 9-2: Required Dosing Rate and Volume

Water Source	Required Dosing Rate (1)	Max Daily Volume Required (1)	Average Monthly Volume Required (1)
Combined Community Wells	4.6 mL/s	199 L/d	1,647 L/month
Emerald Estates Well #1	0.8 mL/s	68 L/d	1,533 L/month
Emerald Estates Well #2	0.3 mL/s	16 L/d	78 L/month
Emerald Estates Well #3	0.7 mL/s	18 L/d	270 L/month
Cheakamus Crossing Well	0.9 mL/s	28 L/d	59 L/month
1. Assumes 50% caustic solution is used.			

10. Dosing System Requirements

A permanent chemical dosing system would include the following components:

- Heated building (50% caustic freezes at 12°C) with access;
- Tote or barrel (depending on volume required);
- Backup tote or barrel (1 or 2 depending on volume required);
- Spill containment (tote or barrel will sit on top of a spill containment device);
- Dosing pump;
- pH monitor;
- Local pump control (well pump starts the dosing system and pH alarm can shut it down);
- Sample port after chemical addition; and
- Safety shower and eyewash station with hot water heater.

10.1 Dosing Building Conceptual Design

Three concepts were considered for the dosing building design; these options generally include the items noted above. The three options are summarized below and conceptual layouts for each are provided in Figure 10-1.

- **Option 1** includes above ground mechanical piping inside the dosing building at the same diameter as the water main it ties into, with full flow from the water main diverted into the piping. The dosing location, pH sensor and manual sampling port are located inside the building.
- **Option 2** includes mechanical piping inside the dosing building that is at a reduced diameter of 50 mm. A circulation pump ensures flow through the 50 mm piping, and the pH sensor and manual sampling ports are located in a manhole outside of the building.
- **Option 3** includes two manholes, the first containing the tie-in from the dosing pump that discharges directly into the existing water main, and the second containing the pH sensor and manual sampling port.

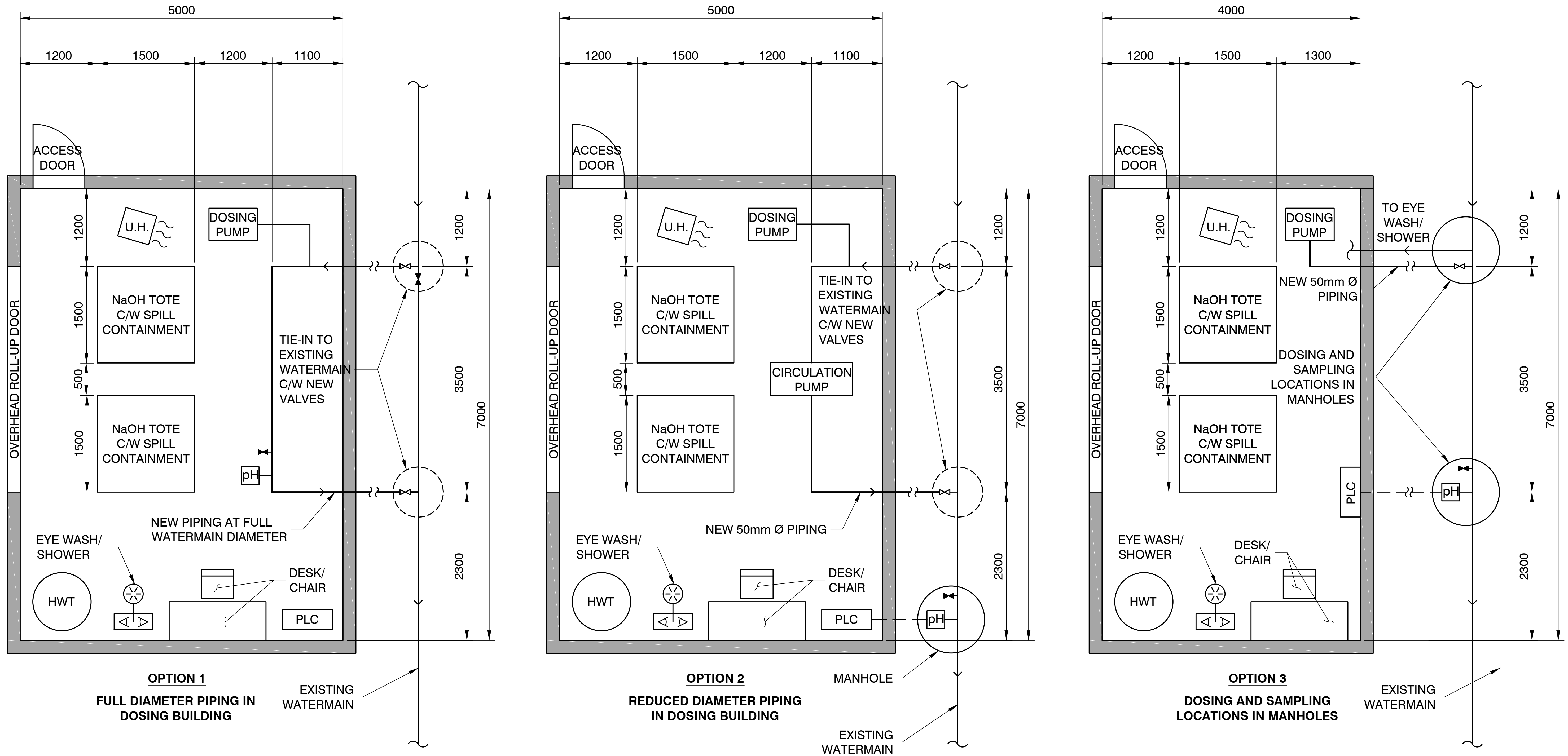

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FIGURE 10-1: DOSING BUILDING CONCEPTUAL DESIGN OPTIONS

A comparison of the advantages and disadvantages of the three options is included in Table 10-1.

Table 10-1: Dosing Building Conceptual Design Options

Option		Pros	Cons
1	Full diameter piping inside dosing building	• All dosing piping and instrumentation is accessible and visible in the building	• Potentially higher capital cost than Options 2 and 3 due to larger pipe and valves.
2	Reduced diameter piping inside dosing building	• Potentially lower capital cost than Option 1 due to smaller piping and valves • Potentially lower cost for the two water main tie-ins compared to Option 1 due to smaller piping	• Additional cost associated with circulation pump. • More O&M effort required than Options 1 and 3 due to the additional circulation pump. • pH sensor and sampling port are located in buried manholes and are susceptible to flooding by groundwater.
3	Dosing and sampling locations in manholes (outside building)	• Potentially lower capital cost than Options 1 and 2 due to smaller building area and less piping required	• Dosing piping with NaOH is buried, leak detection is limited and pipe / NaOH are susceptible to freezing. • pH sensor and sampling port are located in buried manhole where they are susceptible to flooding my groundwater. • Water piping connection is required for eye wash and shower.

Based on the analysis above, the preferred option was determined to be Option 1. The conceptual layout for Option 1 is included in Figure 10-1, the system is described in further detail below, and Class D Opinions of Probable Cost for liquid dosing and solid dosing is included in Table 10-2 and 10-3 respectively.

Recommended Option 1 – Full Diameter Piping in Dosing Building

The building size is based on the requirements for dosing the Combined Community Wells and assumes chemical totes are required, providing the largest building layout needed for the five proposed sites. For some of the other sources the total projected chemical usage is lower and chemical barrels may be used instead of totes. If barrels are used instead of totes less space would be required in the dosing station and subsequently construction costs would be reduced.

The conceptual design includes tie-ins to the existing water main adjacent to the chemical dosing station building and diverting all flow into above ground piping within the building. Isolation valves would be provided to allow the water main to bypass the building piping. The building piping would be sized to match the diameter of the existing water main.

A chemical dosing pump would discharge directly into the building's piping, and a pH meter downstream of the dosing location would monitor the pH levels of the outgoing water. The dosing pump would be supplied with liquid NaOH from portable totes located inside the building. An overhead rollup door would allow access to the building for delivery and removal of totes as required. A second doorway would be provided for primary access.

A local PLC would provide control to the dosing pump and receive SCADA signals from the existing flowmeter that monitors the existing well upstream of the building. The PLC would also provide local control of the building heat and ventilation to keep ambient temperatures within tolerable limits for the NaOH.

Safety considerations in the building include an eye wash station and shower with a hot water heater to provide tepid water.

A Class ‘D’ Cost Opinion was developed for Building Option 1 and is included as Table 10-2. The estimate includes capital cost only and does not consider Operation and Maintenance or chemical costs. Due to the limited information available for each site location, a contingency of 20% and an engineering line item of 20% were included.

The following assumptions have been made to develop the estimate:

- Building is cast-in-place concrete with a flat roof;
- Exterior architectural finishes are not included;
- Exterior landscaping is not included;
- Mechanical piping into the building is the same diameter as the water main which is assumed to be a maximum 300 mm diameter;
- The existing water main is in adequate condition to complete tie-ins;
- Flowmeter output on the existing water main can be relayed to the PLC inside the Dosing Building, no additional flowmeter is required; and
- Electrical service to the building can be obtained from a local location.

10.2 Next Steps – Pilot Testing

Based on source water chemistry and anecdotal evidence of corrosion it is recommended that the RMoW proceed with chemical dosing at the Combined Community Wells chlorination point, Emerald Estates Wells #1 and #2 (Well #3 is currently offline due to water quality concerns) and Cheakamus Crossing Well. It has been estimated that each dosing system would have a maximum capital cost of $333,000.

Given the cost of implementing a full system and the inherent limitations of corrosion risk identification, it is recommend that the RMoW pilot a chemical dosing system at the Cheakamus Crossing Well before proceeding with chemical injection at all high-risk sources. This well was chosen for the pilot because it feeds an isolated system (there will be no contamination from other sources) which has newer pipes that are likely to be in good condition.

The RMoW currently uses caustic soda and soda ash at its wastewater treatment plant (WWTP). A pilot system at Cheakamus Crossing could utilize both chemicals to test their individual and combined effectiveness. A dual chemical pilot could augment carbonate alkalinity in the form of soda ash and hydroxide alkalinity in the form of caustic soda to achieve a stable water that is capable of forming a protective $CaCO_3$ scale. Should a dual chemical system prove most effective, careful consideration would be given to potential impacts to the heat exchangers in the DES in the Cheakamus Crossing neighbourhood.

The dosing at this pilot would be optimized based on water chemistry (pH and CCPP) and validated over a period of several months by monitoring green staining or installing and monitoring a coupon in the distribution area and regularly testing and analyzing the water chemistry. When the system has been optimized and validated, detailed designs for dosing systems at other high-risk sources could be conducted. These systems could then be implemented at a rate that aligns with the RMoW's annual budgets.

11. Conclusions/Recommendations

High risk water sources were identified based on the potential evidence of corrosion identified in Section 7, on the source water distribution in the system, and on CCPP values for the water sources investigated. It was determined that the Cheakamus Crossing well, Emerald Estates wells and Community wells present the highest risks to the RMoW water distribution system infrastructure.

It is recommended that additional investigations be carried out to verify this risk. Destructive testing (collecting coupons or fittings) would represent significant cost to the RMoW; therefore it is recommended that the RMoW opportunistically collect samples in conjunction with other work on an ongoing basis. This other work could include installation of a new large service connection, road reconstruction work, routine replacement/maintenance of pipe or fittings, and repair of pipe/fitting break or leak. Both internal and external corrosion can be identified and documented using these samples in conjunction with potable water and soil/groundwater samples. The RMoW is planning to replace pipes in Spruce Grove, this could present an opportunity to collect material and validate the findings of this internal corrosion study. A material collection plan will be developed to assist staff with the collection and preservation of samples for analysis.

The implementation of corrosion mitigation systems at the high-risk water sources would represent a large capital expenditure (up to $333,000). It is recommended that the RMoW develop a Pilot Plan to test the corrosion chemistry prior to implementing the permanent solution at the high-risk water sources. Prior to pilot implementation, a baseline corrosion level should be determined by monitoring material loss from a coupon system installed downstream of a hot water source within a municipal building.

12. Report Submission

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

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S. M. ROBINSON
42192
BRITISH COLUMBIA
ENGINEER

Nov 18, 2015

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Statement of Limitations

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Revision History

Revision #	Date	Status	Revision	Author
1	November 20, 2015	Final	Final	SR/EV
A	January 23, 2015	Draft	For client review	SR/EV

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Appendix A

Internal Corrosion Risk Scorecards

CCPP-Based Risk Scorecard

CCPP Range	Pipe/Fitting Material	Pipe Age	Risk of Failure Associated with Corrosion
> 0	All	All	Low
0 to -5	All	All	Low
-5 to -10	Steel	0-40	Low
		40-85	Low
		> 85	Medium
	Cast Iron (1)	0-35	Low
		35-65	Low
		>65	Medium
	Copper	0-25	Low
		25-50	Low
		> 50	Medium
	Ductile Iron (2)	0-45	Low
		45-85	Low
		>85	Low
	Plastic (Polyethylene or PVC)	0-45	Low
		45-85	Low
		>85	Low
< -10	Steel	0-50	Medium
		50-100	High
		> 100	Very high
	Cast Iron (1)	0-35	Medium
		35-65	High
		>65	Very high
	Copper (3)	0-25	Medium
		25-50	High
		> 50	Very high
	Ductile Iron (2)	0-45	Low
		45-85	Medium
		>85	Medium
	Plastic (Polyethylene or PVC)	0-45	Low
		45-85	Low
		>85	Low

1. All cast iron is assumed to be unlined.
2. All ductile iron is assumed to be cement mortar lined. If the lining is compromised the unprotected area will be subject to corrosion as if it was steel, this could result in point failure.
3. All copper piping is assumed to be used as service or domestic piping.

AI-Based Risk Scorecard

AI Range	Pipe/Fitting Material	Pipe Age	Risk of Failure Associated with Corrosion
> 12	AC	All	Low
10 - 12	AC	0-25	Low
		25-50	Medium
		> 50	High
< 10	AC	0-25	Medium
		25-50	High
		> 50	Very high

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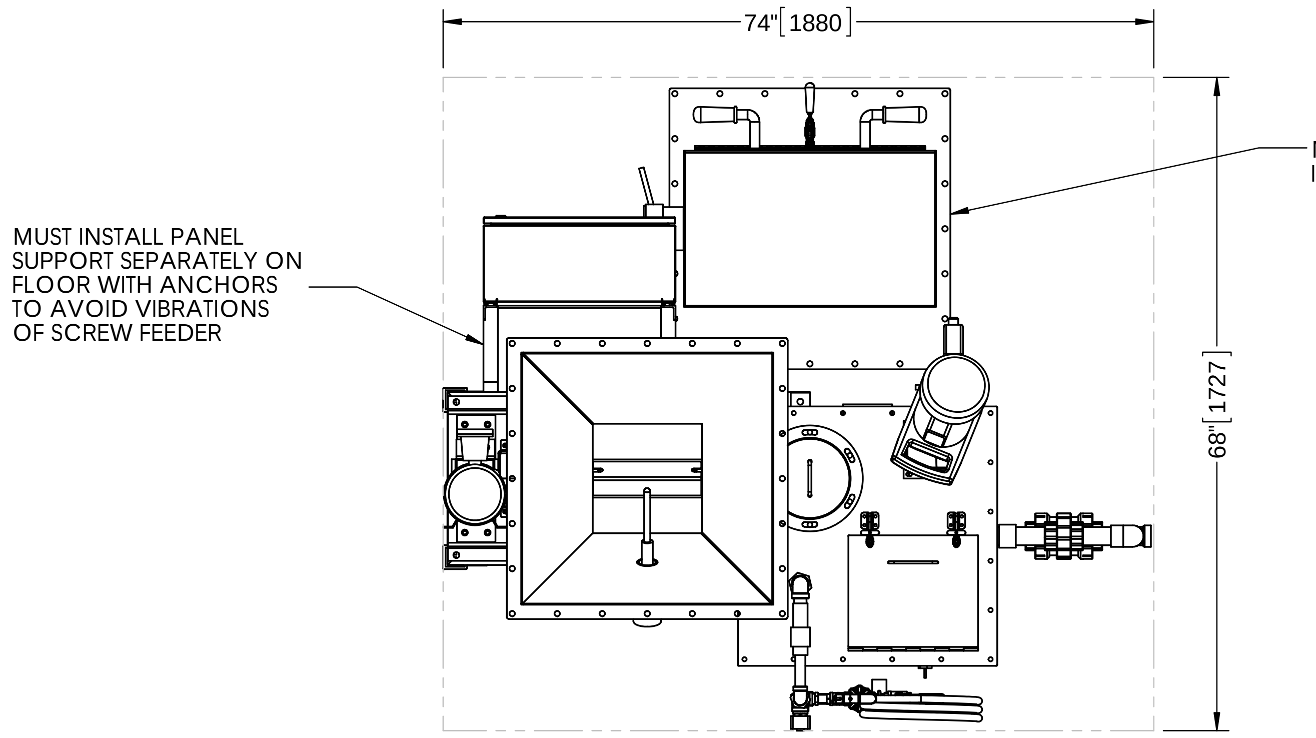
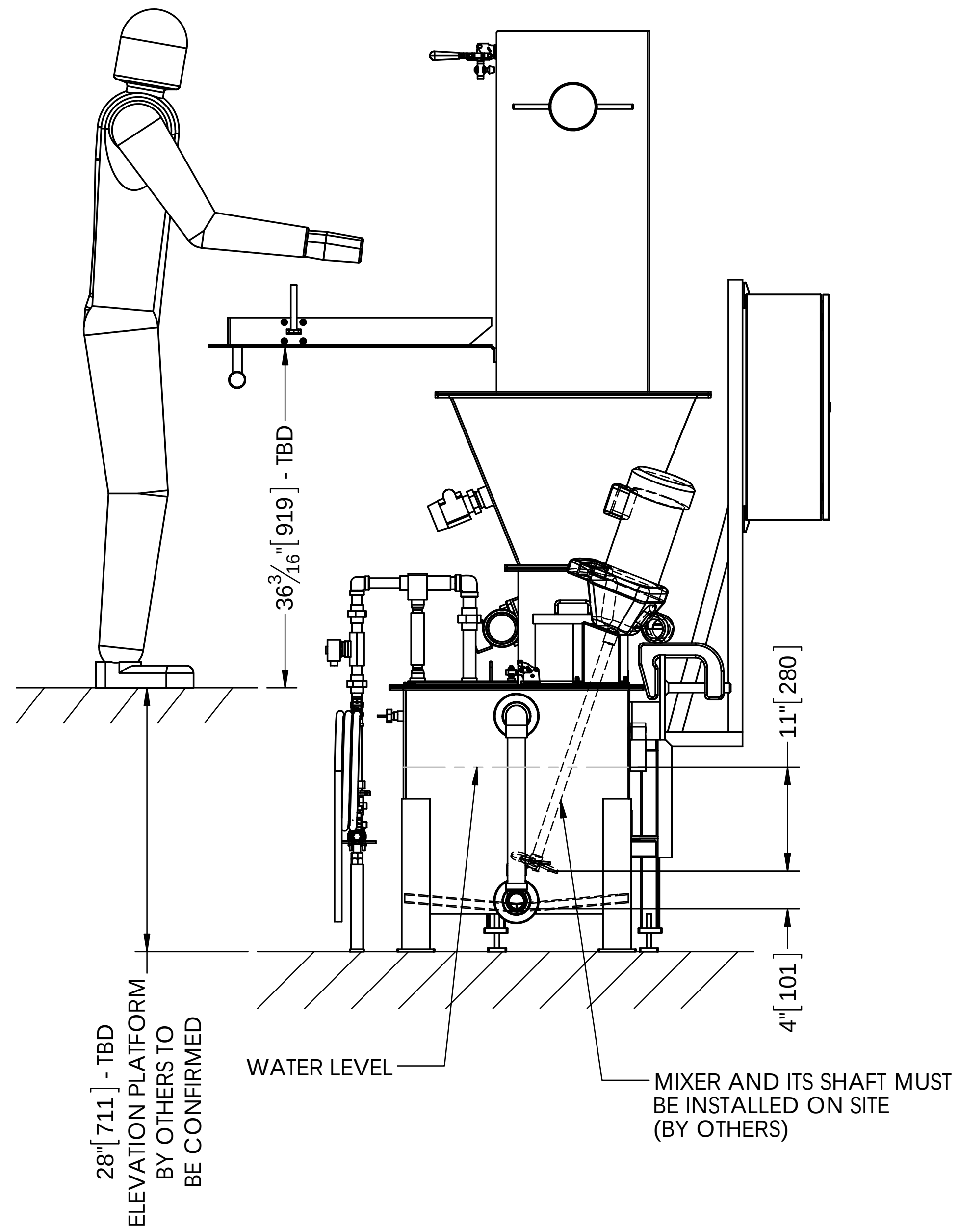
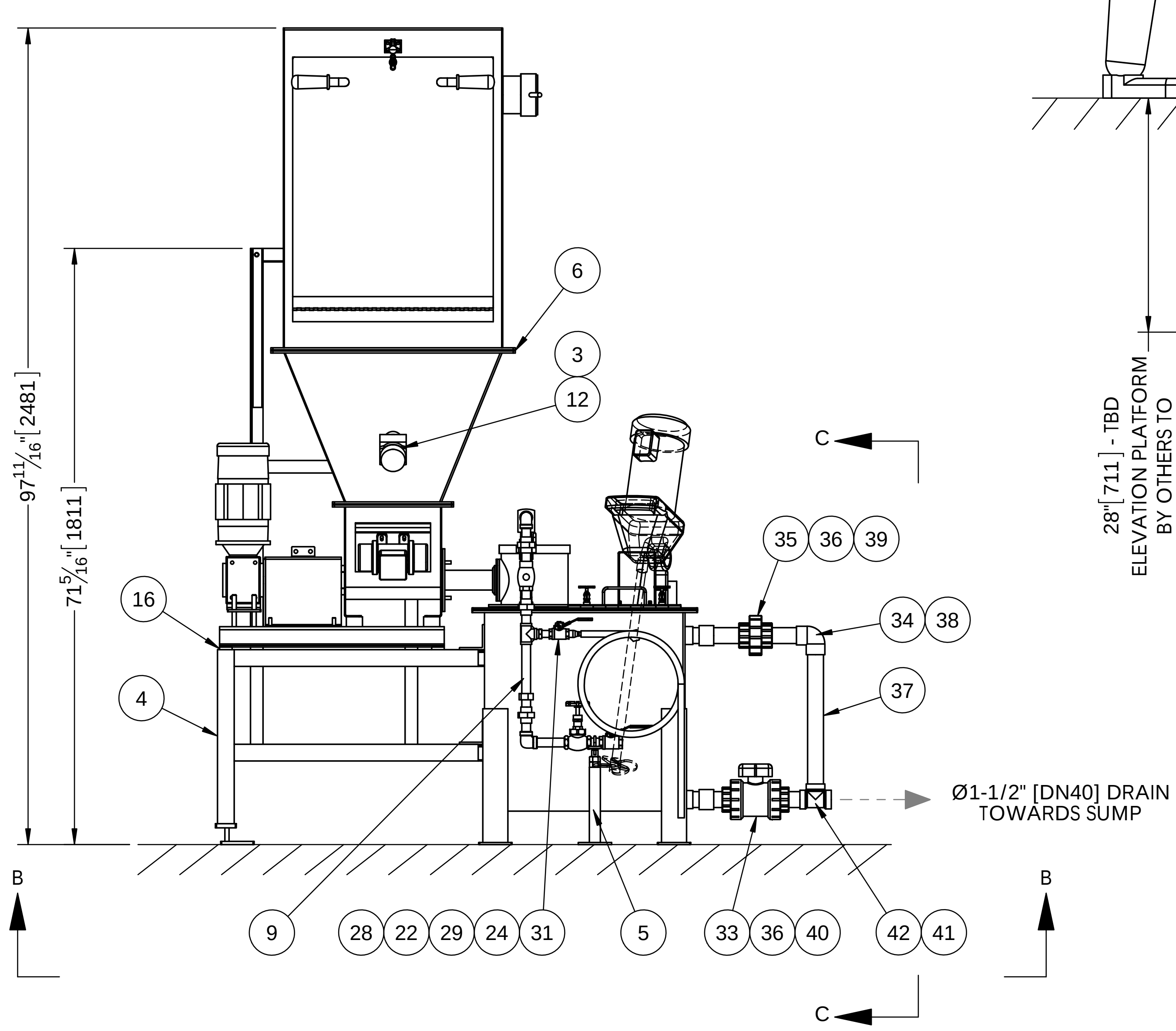
Appendix C

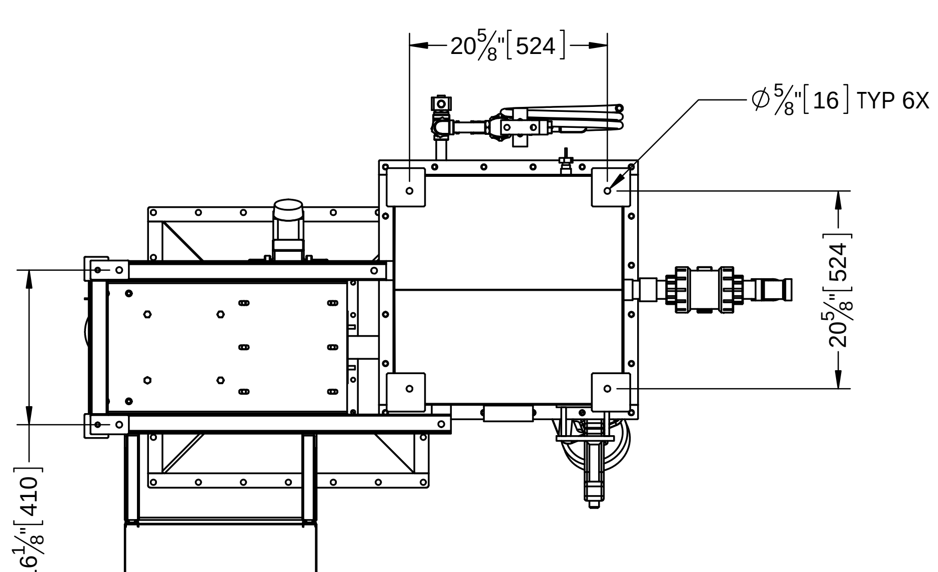
Chemical Make-down System

ITEM	QTY	DESCRIPTION	REFERENCE	TAG #	MATERIAL	WEIGTH (LBS)
1	1	MANUAL BAG DUMP STATION	10083-MBD100_02	MBD-100	SS304L	188
2	1	2' x 2' x 2' MIXING TANK	10084-MTC100_04	MTK-300	SS304L	211
3	1	Ø1-1/2" SCREW FEEDER. 3pi³ HOPPER. 90VDC. 1/2 HP	10085-SCF100_02	SF-200	SS316L	254
4	1	SCFREW FEEDER & PANEL MOUNT	10087-SUP100_01	-	CS	77
5	1	PIPING & ACCESORIES STAND		-	SS316	3
6	1	1/8" x 1-1/2" GASKET STRIP	-	-	EPDM	0.9
7	1	CONTROL PANEL	028147	CTP-500	CS	40.0
8	1	0.5 HP ELECTRIC AGITATOR	10XPC-0.5HP	MIX-301	SS316L	41
9	1	Ø3/4" [DN20] MNPT FLOW METER	H625-016	FI-402	-	1.0
10	1	Ø1/2" [DN15] MNPT FLOAT SWITCH	FH7-0001	LSH-302	-	0.1
11	1	Ø1" [DN25] HYDRO-EJECTOR. Ø3/4" [DN20] WATER INLET	NBTLS3	EJC-400	PVC	0.50
12	1	SOLIPHANT LEVEL SWITCH. Ø1-1/2" MNPT	FTM20-CN46A	LSL-203	SS316L	7
13	1	Ø3/4" [DN20] SOLENOID VALVE	8210	SOL-403	BRASS	2
14	1	Ø1" [DN25] REINFORCED FLEXIBLE HOSE	-	-	-	0.2
15	1	Ø1/2" [DN15] REINFORCED FLEXIBLE HOSE	-	-	-	1.1
16	4	5/16" ISOLATION PAD	899-050	-	EPDM	0.025
17	2	Ø3/4" [DN20] MNPT NIPPLE	-	-	SS316L	0.5
18	2	90° ELBOW. Ø3/4" [DN20] PIPE	-	-	SS316L	0.34
19	6	Ø3/4" [DN20] MNPT SHORT NIPPLE	-	-	SS316L	0.2
20	3	Ø3/4" [DN20] FNPT UNION	-	-	SS316L	0.63
21	1	Ø1-1/2" [DN40] MNPT NIPPLE	-	-	SS316L	0.3
22	1	Ø1/2" [DN15] MNPT NIPPLE	-	-	SS316L	0.1
23	1	Ø1" [DN25] MNPT NIPPLE	-	-	SS316L	0.9
24	1	Ø3/4" [DN20] MNPT x Ø1/2" [DN15] FNPT HEX. BUSHING	-	-	SS316L	0.1
25	1	90° ELBOW. Ø1" [DN25] PIPE	-	-	SS316L	0.54
26	1	Ø1" [DN25] PIPE UNION	-	-	SS316L	1.0
27	2	Ø1" [DN25] HOSE BARB x Ø1" [DN25] MNPT ADAPTER	-	-	SS316L	0.3
28	1	Ø1/2" [DN15] HOSE BARB x Ø1/2" [DN15] MNPT ADAPTER	-	-	SS316L	0.1
29	1	Ø3/4" [DN20] MNPT TEE	-	-	SS316L	0.5
30	1	Ø3/4" [DN20] FNPT BALL VALVE	-	BAV-401	SS316	1.3
31	1	Ø1/2" [DN15] FNPT BALL VALVE	-	BAV-404	SS316L	0.9
32	1	GLOBE VALVE Ø3/4" [DN20]	-	-	SS316L	2.92
33	1	Ø1-1/2" [DN40] SOCKET BALL VALVE	-	BAV-304	PVC	4
34	1	Ø1-1/2" [DN40] SOCKET 90° ELBOW		4880K25	PVC	0.27
35	1	Ø1-1/2" [DN40] SOCKET UNION	-	-	PVC	1.52
36	2	Ø1-1/2" [DN40] SOCKET x Ø1-1/2" [DN40] MNPT ADAPTER	-	-	PVC	0.2
37	1	Ø1-1/2" [DN40] PIPE SCH.40	-	-	PVC	1
38	1	Ø1-1/2" [DN40] PIPE SCH.40	-	-	PVC	0.21
39	1	Ø1-1/2" [DN40] PIPE SCH.40	-	-	PVC	0.20
40	1	Ø1-1/2" [DN40] PIPE SCH.40	-	-	PVC	0.12
41	1	Ø1-1/2" [DN40] PIPE SCH.40	-	-	PVC	0.12
42	1	Ø1-1/2" [DN40] SOCKET TEE	-	2389K15	PVC	0.21

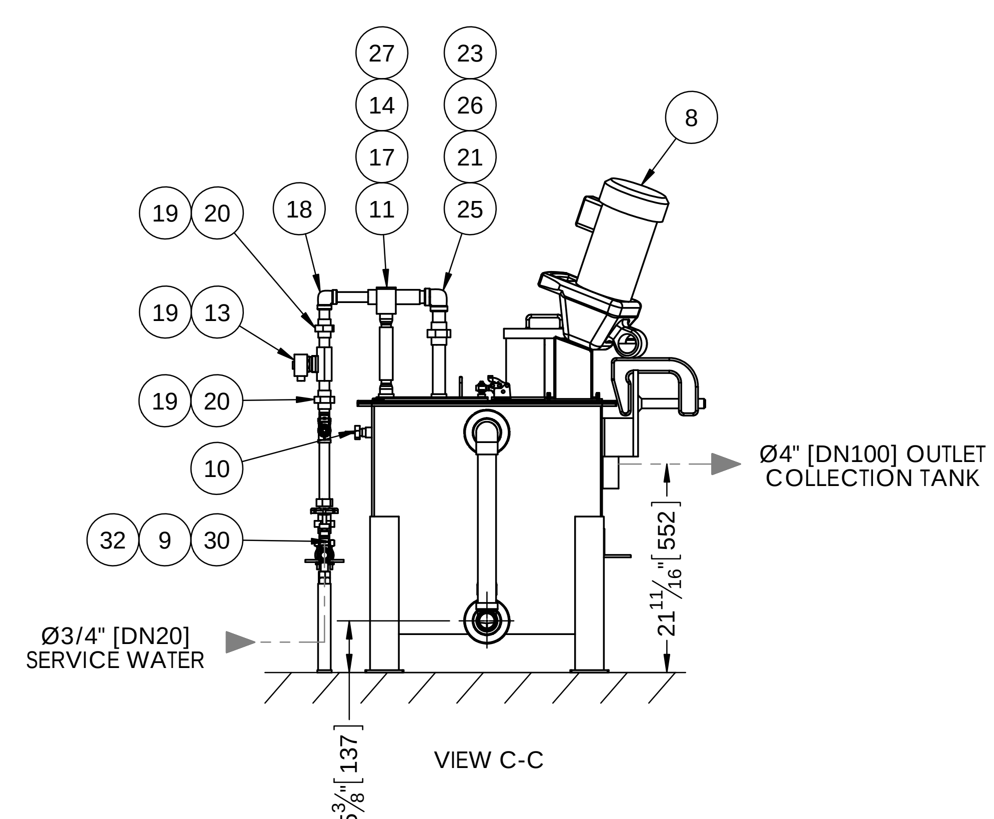




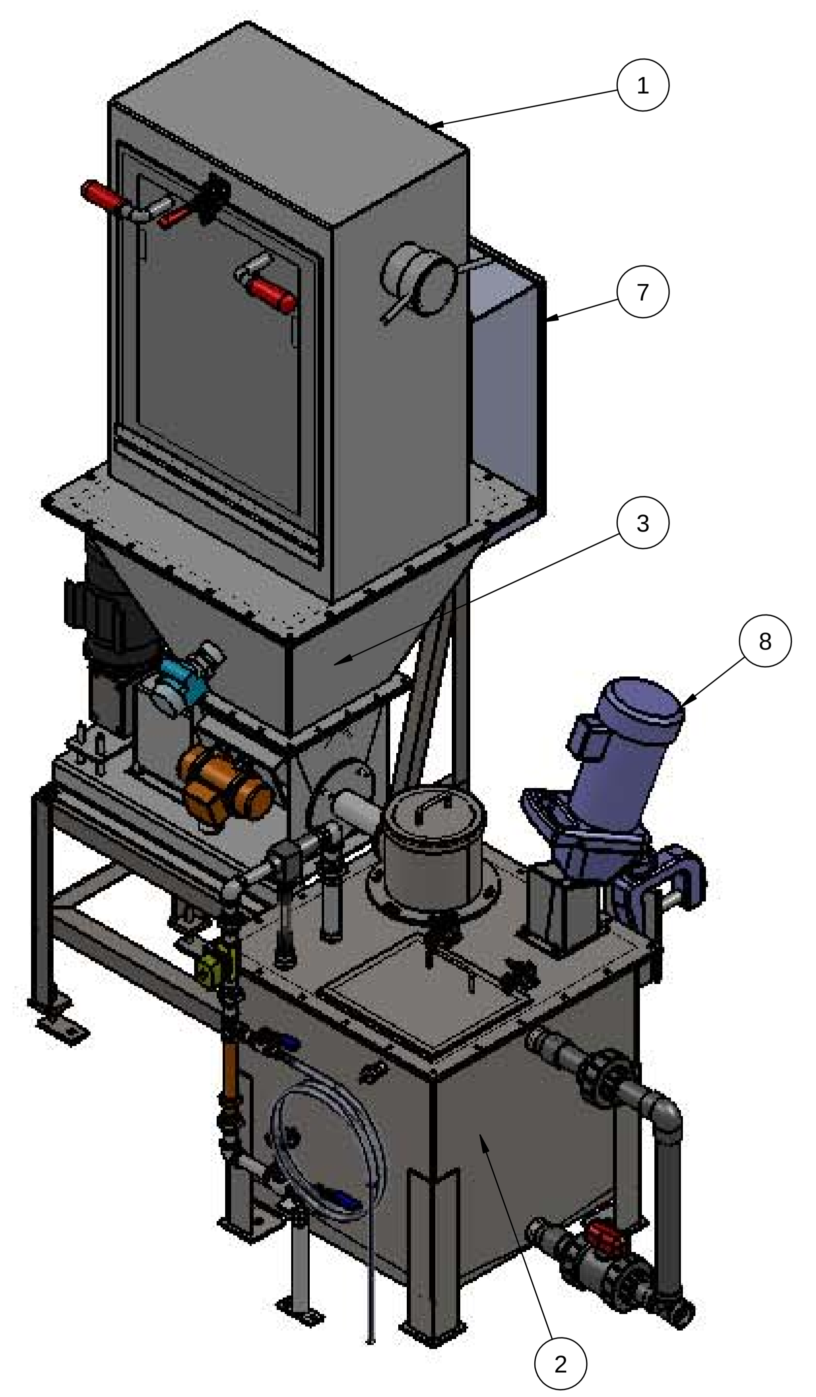




VIEW B-B



VIEW C-C



NOTES:
- ANCHORS TO BE SUPPLIED BY OTHERS;
- PLATFORM FOR BAGS BY OTHERS.

PRODUCT:

DENSITY:

FEED RATE:

WEIGHT:
850 lbs

QTY:
1

REV	DESCRIPTION	BY	DATE
0	DISCUSSION PURPOSE	P.O.	2015-01-15

TOLERANCES UNLESS OTHERWISE SPECIFIED

X.X	±.02	HOLE	
X.XX	±.01	DECIMAL +.001 -.000	FRACTION +1/64 -0
X.XXX	±.005		
FRACTION	±1/16	CLEAN ALL SHARP EDGE (R.015" MAX)	
ANGULAR	±1°		

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PROJECT:
HYDRATED LIME SYSTEM

TITLE:
SLURRY SYSTEM
GENERAL ASSEMBLY

DRAWN BY: P. OUELLET
VERIFIED BY:

DRAWING #: 10086-GEA100
REV: 0
DATE: 2015-01-15

PROJECT #:
SCALE: 1:20
SHEET: 1 / 1

SCALE VALID FOR A 17X22 FORMAT - DIMENSIONS ARE IN INCHES