Feasibility Study

Garden Bay Water Treatment Improvement

Final

Sunshine Coast Regional District (SCRD)- North Pender
February 17, 2023

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1 Introduction

1.1 Background

Pender Harbour, on the Sunshine Coast of British Columbia, includes two water service areas. North Pender Harbour Water Service Area (NPHWSA) serving the communities of Garden Bay and Irvines Landing, and South Pender Harbour Water Service Area (SPHWSA), serving the communities of Madeira Park and Francis Peninsula.

NPHWSA consists of two small water supply systems, which include: Garden Bay Water Treatment Facility supplied from Garden Bay Lake and Hotel Lake Water Supply Facility supplied from Hotel Lake. Hotel Lake Water Supply Facility has been taken out of service by Sunshine Coast Regional District (SCRD); Therefore, drinking water in the North Pender Area is provided and treated by Garden Bay Water Treatment Facility.

Water quality monitoring at the Garden Bay Water Treatment Facility has confirmed the presence of turbidity spikes. In addition, the colour level occasionally exceeds the aesthetic level of 15 TCU, which is indicative of high organic content in the water. This results in the formation of disinfection byproducts (DBPs) during chlorine disinfection, which have recommended maximum concentrations in the Canadian Drinking Water Quality Guidelines (CDWQG).

Due to the elevated turbidity and DBPs, a review of water treatment requirements has been initiated by SCRD.

1.2 Scope of the Work

Sunshine Coast Capital Regional District (SCRD) retained HDR corporation to perform a feasibility study to improve the treatment at the Garden Bay Water Treatment Plant. The scope of the work includes:

- Existing water system evaluation (water supply and water treatment),
- Conceptual overview of the potential improvement options according to the latest regulations and permits[1],
- Potential barriers that may be associated with the treatment improvements,
- Conceptual site plan,
- Evaluating the addition of a backup power generator, and
- Estimated constructional and operational costs.

[1] SCRD follows BC Drinking Water Protection Regulation and the BC Drinking Water Protection Act in addition to the Operating Permit issued by the VCH.

1.3 Historical Information

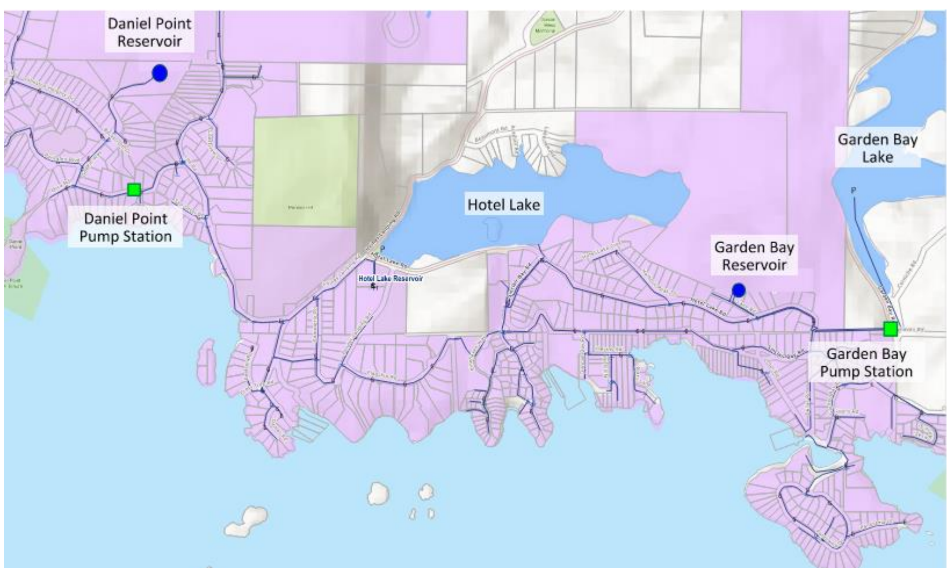
The following reports and documents were reviewed and used as data sources in preparing this report.

- Pender Harbour Water Treatment Feasibility Study (2008) by Kerr Wood Leidal associated LTD.,
- Garden Bay Lake Seasonal Turbidity Study (2022) by SCRD,
- DW-Sub Results in North Pender Harbour Water System (2009-2022),
- Sample Site Test Data (2015-2022), and
- Online Analyzer Data Log.

2 Existing System

Garden Bay Water Treatment Plant treats water diverted from Garden Bay Lake. The treated water is pumped to the distribution system via the Garden Bay Reservoir (250,000L). Daniel Point Pump Station also pumps water from the distribution system to the Daniel Point reservoir (460,000 L) to serve consumers in that area. Figure 2-1 shows existing NPHWSA.

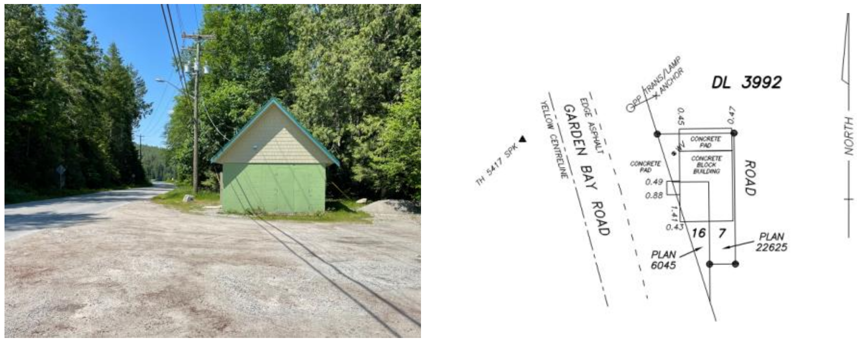
Figure 2-1. North Pender Harbour Water System Area



2.1 Water Treatment Plant/Pump Station

The Garden Bay Water Treatment Plant (Figure 2-2) was constructed in 1985 and upgraded with a UV disinfection system (Trojan LPHO UV) in 2010-2012. A small electrical room and chemical storage room are also located in the building. As part of the 2010-2012 UV upgrade, the roof was replaced with pre-engineered trusses and hatches added to remove the pumps in the building extension.

Figure 2-2. Garden Bay Water Treatment Plant/Pump Station



Three vertical turbine pumps (Table 2-1) located on the basement level of the facility pump water from the southeast side of Garden Bay Lake through the treatment system and the reservoir. The treatment consists of UV disinfection and sodium hypochlorite injection. Water is pretreated by screening larger particles (>5mm). Finished water is pumped from the plant to the reservoirs before distribution to the community.

Table 2-1. Existing Pumps Information

	Pump 1	Pump 2	Pump 3
Model	8M23-3	8M23-3	8M23-3
Serial Number	9708MV000516-1	9708MV000516-1	9708MV000516-1
Head	300 ft	300 ft	300 ft
RPM	3550	3550	3550
Flow	25 L/s	25 L/s	25 L/s

2.2 Garden Bay Lake Water Licence

Table 2-2 summarizes the existing Garden Bay water licences. Four waterworks licences allow for a maximum of 1,809 cubic meters per day (m^3/d) and 433,072 cubic meters per year (m^3/yr) to be diverted from Garden Bay Lake for potable water use.

Table 2-2. Existing Garden Bay Water Licences

Licence	Purpose	Max Annual Consumption Limit (m^3/year)	Max Daily Consumption Limit (m^3/day)	Comment
C036003	Waterworks	124,449	341	-
C057305	Waterworks	70,521	193	-
C121237	Waterworks	113,652	934	Flow (Nov15-Jan15) was 80 Gal/min and updated to 106 Gal/mi
F012402	Waterworks	124,449	341	The purpose previously was Power and Domestic.
Total		**433,072**	**1,809**	**-**

2.3 Water Demand

Water consumption data provided by SCRD is based on the flow meter totalizer values, which are recorded on a daily basis. There is a significant daily consumption variability due to the semi-random cycling of the pumps to fill the reservoir and the time of day that operations staff manually record the flow meter readings. Therefore, a 3-day moving average has been used to compensate for this daily variability, resulting in average day demands (ADD) and maximum day demands (MDD), as provided in Table 2-3. Figure 2-3 presents the daily flow trends between 2014 and 2021.

Figure 2-3. Three-Day Average Flow Data (2014-2021)

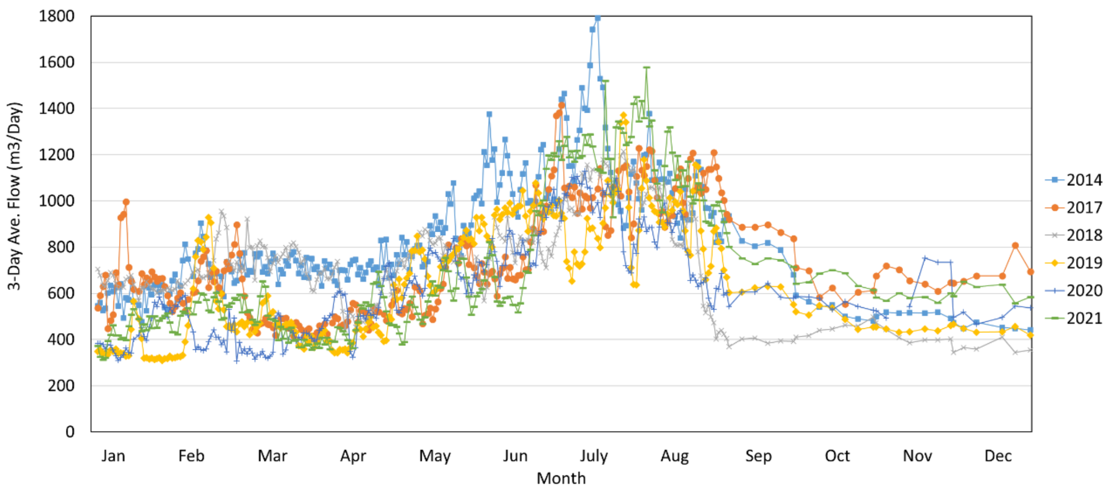


Table 2-3. Water Demand Over Time (2014-2021)

Year	Annual Consumption (m^3)	MDD (m^3/day)	ADD (m^3/day)	MDD/ADD
2014	280,932	1,792	847	2
2015	NA	NA	NA	-
2016	NA	NA	NA	-
2017	257,186	1,415	714	2
2018	235,595	1,213	644	1.9
2019	211,689	1,372	586	2.3
2020	217,406	1,129	597	1.9
2021	241,077	1,580	662	2.4
Average	**240,647**	**1,417**	**675**	**2.1**

ADD: Average Day Demand (3-Data Point Average)
MDD: Maximum Day Demand (3-Data Point Average)

The design flow rate for a treatment system is typically based on the MDD forecast of approximately 20 years in the future.

Population data for the NPHWSA is unavailable. However, Census Canada collects population data for the central Garden Bay area, which covers a smaller area than the NPHWSA. This data was available for 2006, 2011, 2016 and 2021, which were 323, 370, 364 and 395, respectively. These numbers indicate an average growth rate of 1.35% per year.

SCRD was able to provide the number of NPHWSA water service connections for 2021, which was 591 services. Additionally, Statistics Canada's Garden Bay data set noted an average dwelling size of 1.8 people per dwelling. Using the available SCRD water service data, the estimated service population in 2021 is approximately 1,064 people.

The 2021 maximum day demand was 1,580 m^3/d, equating to per capita maximum day demand of 1,485 cubic Litres per day per capita (L/d/c) and the average day consumption was 662 m^3/d, equating to 622 L/d/c. This compares to the historical average per capita consumption in Metro Vancouver, which ranges between 400 and 480 L/d/c, and SCRD's average day demand of around 600 L/d/c (2017).

Due to the limited data for forecasting future population in the service area and the ability to forecast future population growth, the use of the 2021 data provides a conservative estimate for future water consumption.

The proposed future capacity is as follows:

20-year assumed growth rate: 1.35% per year

2041 service population: 1,391 people

Table 2-4 summarizes the future proposed water demand for sizing the future facility.

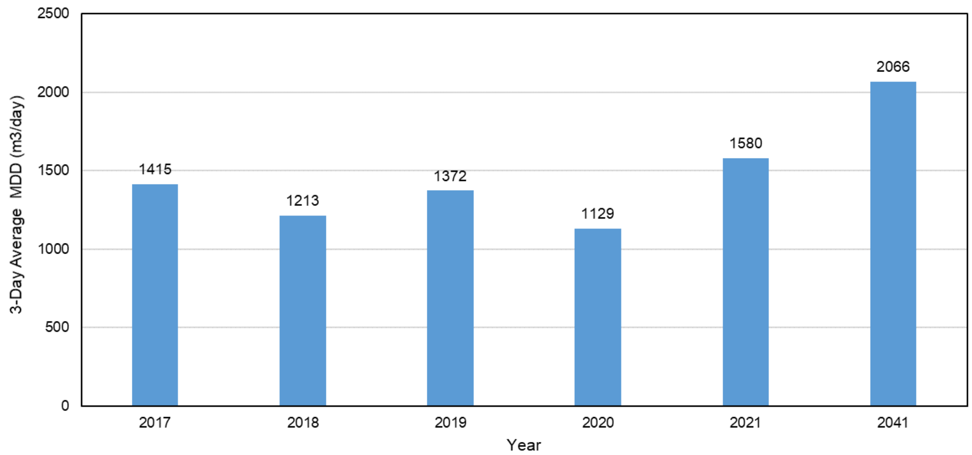
Table 2-4. Current and Estimated Water Demand

Year	ADD (m^3/day)	MDD (m^3/day)
2021	662	1,580
2041	866	2,066

It should be noted that this number exceeds the current water licences. It is proposed that since these treatment capacities are based on the future maximum day demands, the water licence amount be increased once the actual water demands start to approach the licence values. Until then, flow through the plant could be controlled not to exceed the daily water licence amount.

Figure 2-4 shows the historic and predicted MDD. No data for 2015 and 2016 were available.

Figure 2-4. Three-Day Average MDD Data (2017-2021) and forecasted MDD (2041)



2.4 Water Quality

The water quality for the NPHWSA for the period 2006-2022 was reviewed. The Historical results include:

- Online measurement for the chlorine concentration, UV transmittance and turbidity at the water treatment plant (2014-2022[2])
- Field measurement for chlorine residuals, pH, temperature, conductivity, and turbidity on site (2017-2022)
- Laboratory analyses for bacteriological, anions/cations and metals (2006-2022)

A summary of the raw water lab results and online analyzer data are presented in the following sections. The rest of the water quality monitoring results are provided in Appendix A.

[2] Information for the years 2015 and 2016 was not available.

Table 2-5. Garden Bay Lake Water Quality (Lab Test Results)

Parameter	Hardness (mg /L)	Alkalinity (mg/L)	Colour (TCU)	Conductivity (µS/cm)	pH (-)	Turbidity (NTU)	Iron (µg/L)	Manganese (µg/L)
CDWG	-	-	AO:15	-	7-10.5	1 NTU	300	120
27-July-06	18	-	<5	63	7.3	0.40	88	18
14-May-07	16	-	<5	64	7.4	0.30	18	3.0
18-Jul-07	17	-	10	61	7.2	0.40	52	2.0
11-Aug-08	17	16	5.0	63	7.2	0.30	16	3.0
01-Jun-09	17	17	ND	66	7.3	0.30	18	5.0
24-Feb-10	17	15	10	66	7.3	0.30	36	2.0
23-Aug-10	17	16	5	64	7.4	0.50	62	22
08-Dec-10	18	20	5	66	7.2	**1.40**	244	47
18-May-11	12	16	5	65	7.2	0.20	40	2.0
29-May-12	17	16	10	63	7.3	0.30	19	3.8
12-Dec-12	18	17	5	67	7.4	0.79	156	22
18-Jun-13	17	17	5	64	7.2	**2.07**	67	-
26-May-14	17	16	5	63	7.2	0.35	64	-
26-May-15	17	15	**18**	64	7.15	0.36	65	15
06-Sep-16	17	16	**16**	62	7.1	0.79	127	40
20-Dec-16	19	21	**18**	64	7.2	**3.33**	**564**	40
01-Mar-17	15	15	12	60	7.2	0.33	39	5.8
01-Aug-17	17	17	9	63	7.5	0.39	17	ND
10-Jul-18	18	20	ND	69	7.23	0.44	67	14
13-Feb-19	16	16	14	61	7.2	<0.10	10	**981**
21-Aug-19	17	10	10	-	6.9	0.90	100	46
10-Mar-20	15	15	12	-	7.1	0.19	38	11
17-Sep-20	16	16	6	-	7.2	0.26	10	<1
27-Jan-21	16	16	13	-	-	0.33	29	2.9
18-Aug-21	17	20	<5	-	-	0.51	98	22
23-Feb-22	16	15	<5	-	7.1	0.25	30	3.0
Average	**17**	**16**	**9**	**64**	**7.2**	**0.65**	**81**	**64**
Max	**19**	**21**	**18**	**67**	**7.5**	**3.33**	**564**	**981**

Table 2-6. Daniel Point Water Quality (Lab Test Results)

Parameter	Hardness (mg /L)	Alkalinity (mg/L)	Colour (TCU)	Conductivity (µS/cm)	pH (-)	Turbidity (NTU)	Iron (µg/L)	Manganese (µg/L)
CDWG	-	-	AO:15	-	7-10.5	1 NTU	300	120
1-Mar-17	17	17	11	73	7.2	**1.66**	171	6
1-Aug-17	17	20	5	83	7.4	0.34	71	12
18-Jul-18	19	24	ND	89	7.5	0.51	105	13
13-Feb-19	17	21	5	86	7.3	0.34	4	**905**
21-Aug-19	18	<5	<5	-	7.0	0.60	87	8
10-Mar-20	16	20	<5	-	7.2	0.23	78	3
17-Sep-20	18	21	<5	-	7.1	0.32	90	10
27-Jan-21	18	22	<5	-	-	0.48	174	9
18-Aug-21	18	21	<5	-	-	0.46	66	5
23-Feb-22	19	18	<5	-	7.3	0.29	97	5
Average	**18**	**20**	**7**	**81**	**7.2**	**0.52**	**93**	**107**
Max	**19**	**22**	**11**	**86**	**7.4**	**1.66**	**174**	**905**

2.4.1 Turbidity

Turbidity was recorded regularly by an online turbidimeter. It has also been measured by sending samples to the laboratory and in the field. The lab test results indicate that the average turbidity in Garden Bay Lake between 2017 and 2022 was around 0.52 NTU, with a maximum of 1.66 NTU. Except for a few samples, all the turbidity levels were below 1 NTU and acceptable according to the Canadian Drinking Water Quality Guidelines (CDWQGs) for unfiltered surface waters; however, the online turbidity analyzer at the plant recorded frequent spikes. The average online recorded turbidity between 2014 and 2021 was 0.5 NTU with a maximum of 13.14 NTU. Figure 2-5 demonstrates the online turbidity monitoring over time. Seasonal turbidity spikes and random spikes are observed in the data. Some of the random spikes are likely due to pump starts and the associated high flow rates.

2.4.2 UV Transmittance

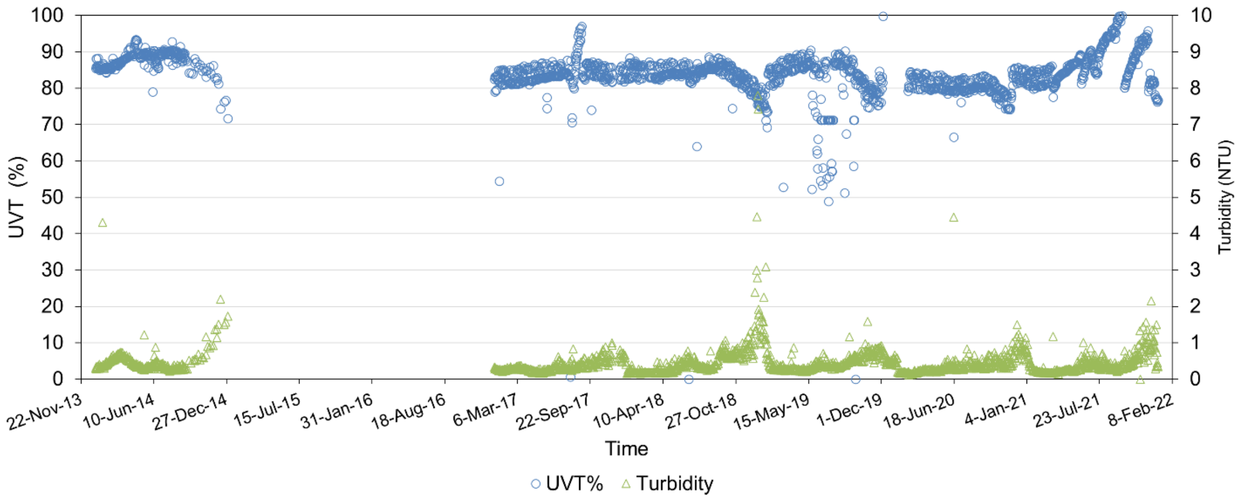
Ultraviolet (UV) transmittance is a key measurement when UV disinfection is part of the water treatment process. This parameter is related to the ability of the UV light to penetrate the water. In general, a consistent 90% UVT is desirable for efficient UV disinfection.

When chemically assisted filtration (i.e., conventional filtration) is part of the water treatment process, UV disinfection is typically downstream of filtration, where improved and more consistent UVT results are expected.

In addition, UVT is used as a surrogate for organic content in the source water. A lower UVT is associated with an increase in the total organic content in the water. The organic content can be correlated to increased DBPs following chlorination.

At Garden Bay Treatment Plant, UVT has been monitored since 2014. Figure 2-5 shows the online monitoring results over time.

Figure 2-5. Online UVT and Turbidity Measurements at Water Treatment Plant



2.4.3 Colour

According to the lab test results (Table 2-5), colour ranged from below the detection limit of the sampling method to 18 TCU. It is recommended that the colour be less than 15 TCU. Colour is typically caused by dissolved organics, which can react with chlorine in the disinfection process and increase the potential of DBP formation.

2.4.4 Total Organic Carbon

Total Organic Carbon (TOC) consists mainly of natural organic matter in the water. TOC can include humic and fulvic acids from decaying vegetation, known to react with chlorine in water treatment to form DBPs. While there are no guidelines for TOC, the organic levels should be minimal to avoid DBP formation and chlorine decay.

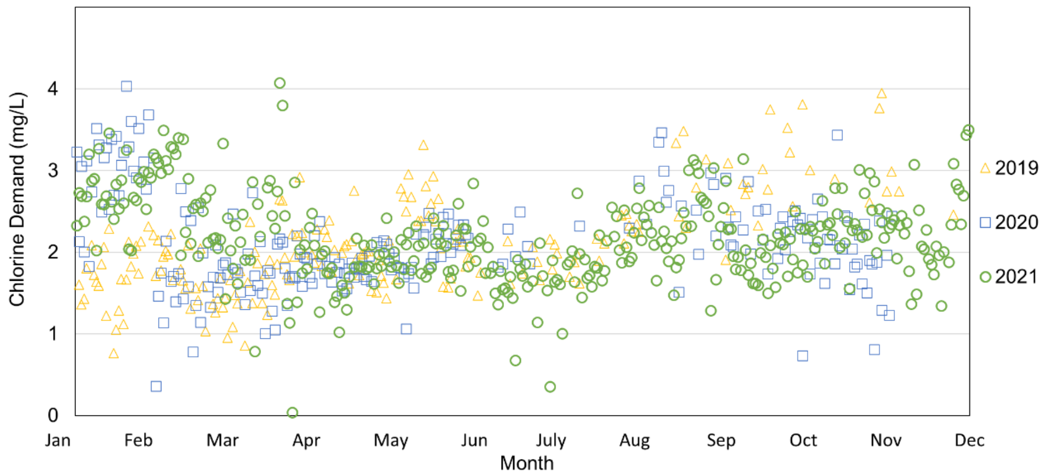
There was no TOC measurement on the Garden Bay Lake water; however, high colour levels and low UV transmittance are indicators that the raw water contains an elevated concentration of organic matter. The actual level of TOC in the raw water should be measured and considered in designing the treatment system.

2.4.5 Chlorine Demand

Chlorine is a highly reactive chemical, and chlorine demand indicates how much chlorine is consumed by reactions with constituents in the raw water. This typically includes inorganic material (e.g., iron, manganese), organic material (e.g., humic acids, tannins) and bacteria (e.g. coliform). The reaction with organic material results in DBPs which are known to produce carcinogenic compounds. Guidelines have been published to limit these products in treated water.

Figure 2-6 represents the chlorine demand of the Garden Bay Lake water. The chlorine demand ranges for the Garden Bay system, but the average is around 67% of the chlorine dose or approximately 2.2 mg/L. The higher the chlorine demand, the more reactive the organics and inorganics are in the water. This results in a higher potential for DBP formation and the more likely that the residuals at the end of the distribution system will not meet a target residual.

Figure 2-6. Garden Bay Lake Chlorine Demand



2.4.6 pH

According to the recent guidelines, the operational range for pH should be between 7 and 10.5 in finished drinking water. Low pH values can be associated with corrosive water, which increases the potential leaching of the metals into the potable water and rates of metal pipe and fixture corrosion.

According to the field measurements (Table A-1), the pH of Garden Bay Lake in 2021 typically ranges from 6.2 to 7.2, with an average of 6.7. pH in some of these samples is lower than the recommended range. Therefore, pH correction should be considered as part of the water treatment upgrade. However, lab test results (Table 2-5) confirmed an average of 7.2 for pH with a minimum point of 6.88.

2.4.7 Alkalinity

Alkalinity measures the capacity of water to neutralize acidity and, due to limited buffering, resist change in pH levels. Additionally, drinking water with alkalinity below 80 mg/L can be related to corrosive water. Adjusting the pH will also add alkalinity which is required to allow the effective operation of any future coagulant process. It is recommended that alkalinity be between 80-120 mg/L to provide sufficient buffering capacity and alkalinity for future coagulation. Alkalinity in the Garden Bay Lake water has an average of 16.4 mg/L as $CaCO_3$ and a minimum of 10 mg/L as $CaCO_3$.

2.4.8 Temperature

Garden Bay Lake's temperature appears to be within the expected range of 6 to 22 °C. The results are shown in Table A-1 in Appendix A.

2.4.9 Disinfection By-Products (DBPs)

The two most common chlorinated DBPs following chlorine disinfection (gas or liquid chlorine) are Trihalomethanes (THM) and Haloacetic acids (HAA). The standards for THM and HAA based on the CDWQGs are 100 µg/L and 80 µg/L, respectively. Figures 2-7 and 2-8 summarize the historical THM and HAA test results from 2018 to 2022 at two sampling points in the Garden Bay water distribution system, namely Daniel Point Reservoir (NP-07) and Garden Bay Treatment Plant (NP-08). THMs and HAAs concentrations typically increase based on the concentration of chlorine, exposure time to chlorine, water temperature and the concentration of organics in the source water. As a result, THMs and HAAs are typically highest at the end of the distribution systems.

As shown in the graphs, THM and HAA levels exceed the CDWQGs at the Daniel Point Reservoir sampling location. Treatment to remove organics and reduce the required chlorine dose would increase the safety of the water supply and provide compliance with the Health Canada Guidelines.

Figure 2-7. Trihalomethanes (THM) Readings in Garden Bay Lake and Daniel Point Reservoir

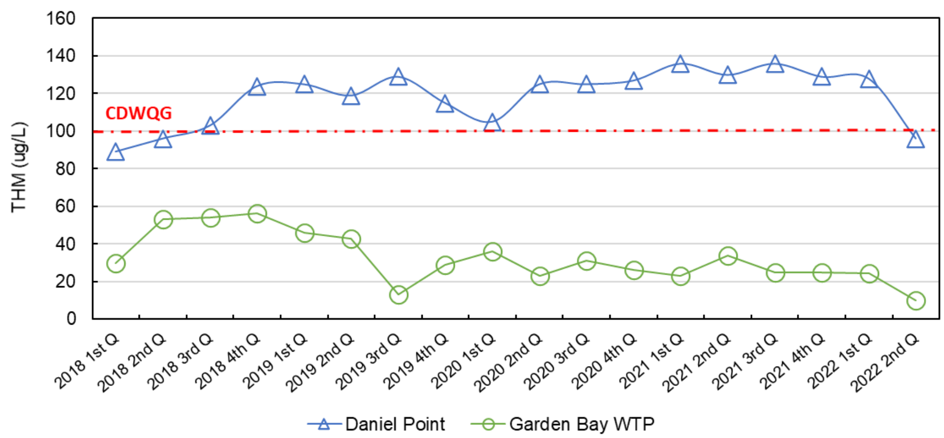
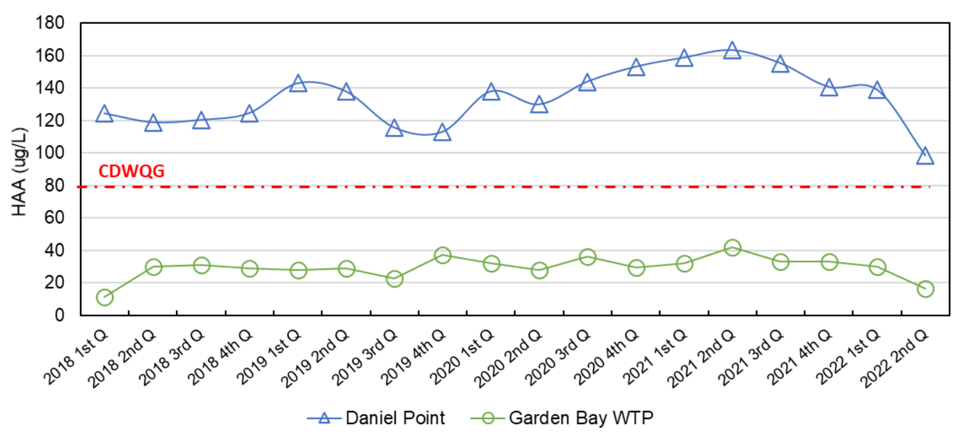


Figure 2-8. Haloacetic Acid (HAA) Readings in Garden Bay Lake and Daniel Point Reservoir



2.4.10 Iron and Manganese

According to the lab test results, iron and manganese levels are acceptable except for a few very high levels detected in Garden Bay Lake or Daniel point Reservoir samples. These elements generally are in a precipitate form in surface waters due to the positive oxidation-reduction potential. Therefore, these are typically removed during filtration. However, a review should be considered to measure the dissolved iron and manganese in the water as this could impact future filtration performance.

3 Treatment Objectives

Each water treatment system should meet the Province of BC's Drinking Water Treatment Objectives for Surface Water Supplies. This generally involves compliance with the 4-3-2-1-0 drinking water objective. For the existing Garden Bay Treatment System this would involve:

- 4 log inactivation of viruses,
- 3 log removal of Giardia,
- 2 treatment processes for surface water
- Less than 1 NTU for turbidity
- Zero E. Coli or coliform is detected in the water.

The use of 2 forms of treatment provides for the multibarrier system for drinking water treatment. These two forms of treatment can consist of a combination of filtration, UV or chlorination, depending on the specific source water characteristics. Presently, Garden Bay provides UV and chlorination.

Historically the Garden Bay source water complies with the BC Surface Water Treatment Objectives for filtration exemption, where the target turbidity should be less than 1 NTU and never to exceed 5 NTU. Typically, the Garden Bay raw water achieves this objective, with occasional spikes higher than 1 NTU, but less than 5 NTU. However, the BC Objectives and the CDWQGs also recommend that sources which are exempt from filtration should include a watershed protection plan, vulnerability assessment and contingency or emergency response plan to manage unanticipated turbidity events which cannot be controlled through the treatment process.

A critical concern in this system is the removal of DBP precursors in the source water to reduce the DBPs formation in the distribution system. The CDWQGs highlight DBP precursor removal as a basis for filtration on source waters which do not exceed the turbidity threshold identified in the guidelines. The addition of filtration under the CDWQGs typically triggers a 0.3 NTU or 0.1 NTU post filtration target for media filtration (sand) and membrane filtration, respectively. These objectives are set as they represent what should routinely be achieved in a well-maintained filtration process. The CDWQGs, Technical Documents for Turbidity does permit a variation on these requirements if the treatment objective is not for protozoa or turbidity, rather for systems such as the removal of DBP precursors. It should be noted that most DBP precursor treatment methods would achieve the turbidity goals and therefore should retain the same 0.3 and 0.1 NTU objectives in order to demonstrate suitable treatment system operation.

Table 3-1. Water Treatment Targets

Parameter	Target
Turbidity	0.3 NTU
Colour	<5 TCU
UVT	>90%
TOC	Low as achievable
pH	7.5-10.5
20-year- Maximum Day Demand	2066 m^3/day
Virus	4-log (99.99% removal)
Protozoa	3-log (99.9%)
Steps of Treatment	Dual Barrier Treatment
E.coli and coliform	-0-

Key factors to address long-term water quality considerations include:

- The type of treatment to mitigate the elevated DBP levels, elevated colour and turbidity, and low pH,
- Maximizing the use of the existing disinfection system,
- Integrating any new system with the available constraints, including the limited available land at the existing pump station and the pumping requirements necessary between the intake pumps, and
- The disposal of backwash water and the associated residuals.

4 Evaluation of Treatment System Options

4.1 Pender Harbour Treatment Plant Connections

Previous studies have reviewed the options of connecting the North Pender Harbour Water Treatment Plant with the South Pender Harbour Water Treatment Plant, specifically the Kerr Wood Leidal report[3] (2008). Based on the 2008 estimated costs, the report recommended retaining two separate plants as this provides the lowest life-cycle costs as the interconnecting cost exceeded the estimated capital expenditures. There are further additional benefits of two separate treatment plants, specifically an increase in the available catchment areas as the two systems will not have to rely on a single catchment, mitigating risks due to lower summertime rainfall or snow melt. Additionally, in the event of an emergency or loss of water in either North or South Pender Harbour, a local source of potable water would continue to be available.

[3] Pender Harbour Water Treatment Feasibility Study, Kerr Wood Leidal, September 2008

4.2 Treatment Options

4.2.1 Coagulation/Flocculation

Coagulation-flocculation is a treatment process where chemicals are added to produce a floc particle which removes the colour-causing substances. Common water treatment chemicals used for this purpose include alum, ferric chloride, poly-aluminum chloride (PAC) or aluminum chlorohydrate (ACH). Flocculation comprises a tank whereby the coagulated water is slowly mixed to generate removable ‘floc’ particles. A filtration step is always required following coagulation and flocculation.

4.2.2 Solids Separation

Solids separation includes sedimentation, flotation and filtration. Filtration is an essential barrier in the production of safe drinking water. Depending on the type of filtration technology, protozoa, bacteria, viruses and particles are removed by porous media through various methods, which include ionic attachment to the filter grains, physical straining or by biological mechanisms. Physical removal is important for enteric protozoa and viruses. Cryptosporidium oocysts are not effectively inactivated by chlorine disinfection, and the inactivation of Giardia cysts with free chlorine requires high concentrations or long contact times (Health Canada, 2012). Filtration is one of the practical methods for achieving high removals of these organisms.

Because of their small size, enteric viruses can easily pass through most filtration barriers. Chemical coagulants are often utilized to produce flocs that entrap viruses and can be more easily removed through filtration.

It has been demonstrated that good removal of Giardia cysts and Cryptosporidium oocysts can be achieved when low-turbidity water is produced, and therefore, a target of 0.3 NTU is recommended post filtration as a method to confirm filtration operation.

Sedimentation is not typically used for low-turbidity water as there is insufficient turbidity in the water to form a settleable solid (floc). Therefore, a technique which involves flotation is a more common process for low-turbidity water and is discussed below.

Slow Sand Filtration

Slow sand filtration is an older technology for small communities as it is relatively simple to operate, affordable, and produces minimal solids. However, it requires a larger area than other technologies and is not very practical for waters with a high colour or turbidity. It consists of passing water through a 600 mm to 1200 mm deep sand filter at loading rates between 0.1 and 0.4 m/hr. Treatment occurs at the sand water interface, where a Schmutzdecke layer forms.

Due to the elevated colour a slow sand filter is not recommended to treat the Garden Bay Lake water. Adding a pre-treatment is an option to remove colour but it is considered to negate the simplistic advantages of slow sand filtration over the other technologies considered.

Rapid Rate Filtration

In rapid rate filtration, using sand and/or anthracite media is a common method for filtration following coagulation/flocculation. This filtration method uses coarser sand (0.4-1.2 mm) and a higher filtration rate, typically 10 m/hr. This process is always downstream of coagulation and flocculation steps and is usually a clarification stage (using either sedimentation or flotation). In the case of the high organics and low turbidity (<1NTU) in the raw water, clarification using dissolved air flotation (DAF) is recommended as it is more effective at organic removal than sedimentation due to the lightweight floc which is formed.

Membrane Filtration

Membrane filtration works by passing water through immersed membrane fibres with nominal and absolute pore sizes typically less than 0.1 micron which removes particulate matter, including Giardia cysts and Cryptosporidium oocysts. Not all membranes (i.e. Microfiltration) are suitable for the removal of organic material unless preceded by a chemical flocculation process. The use of nanofiltration or reverse osmosis can remove organics without chemical pretreatment. Some ultrafiltration membranes, which can be considered a ‘tight ultrafiltration’ membrane which have a narrow pore size, closer to the lower range of ultrafiltration membrane pore size (0.005 to 0.1 micron) are suitable for the removal of larger organic molecules without the added system complexities of nano-filtration membranes. This type of system would be suitable for Garden Bay water without the addition of the chemical pre-treatment.

The membrane system produces water with lower turbidity than media filtration and would not require the addition of ultraviolet (UV) disinfection system to the overall treatment process. A membrane filtration system would be comparatively more complex and typically has higher capital and O&M costs than conventional filtration systems. Membrane replacement and cleaning must also be considered as an ongoing cost.

Dissolved Air Flotation (DAF)

DAF is a clarification method generally used to treat water with low turbidity and high organic/colour levels. In this method, particles are attached to micro air bubbles where they are floated to the water surface and removed. DAF is more efficient at removing colour and turbidity relative to sedimentation as the low turbidity water does not contain sufficient ballast to cause flocs to settle. Therefore, either very long sedimentation tanks are required, or ballast in the form of turbidity must be added.

DAF is a common technology for small systems with a quick start-up and relatively small footprint. In addition, the SCRD currently operates two DAF plants and is familiar with the process, has existing service capabilities and chemicals in its inventory.

4.3 Treatment Costs

The two technologies which are considered feasible for the Garden Bay system include membrane filtration with preliminary coagulation/flocculation for organic removal and DAF, also with preliminary coagulation/flocculation. Although several other technologies were reviewed (organic removal membranes and absorption clarification), they were considered less suitable for the Garden Bay system as they are either relatively new technologies or less effective relative to traditional UF membranes and DAF systems.

The base cost for membrane systems would be $2.0 to $2.5 million for the equipment and chemical cleaning system, whereas a DAF system is $1.4M for the process equipment (incl. coagulation and air saturator). Both systems would require similar building and piping infrastructure to provide the recirculation and solids thickening.

Membrane systems will also require ongoing membrane module replacement, which is not required with a DAF system. The major equipment replacement associated with DAF is a routine top-up of any sand/anthracite which will be lost during backwashing along with servicing of moving parts, notably the chain and flight system.

5 Recommended Treatment System

5.1 Filtration System

A treatment system consisting of conventional coagulation/ flocculation, DAF and rapid sand filtration is the recommended treatment technology and will be a lower capital and operational costs than a membrane system. These systems are designed to remove the water's organics/colour, turbidity, and other impurities. Treatment plants of this type are typically designed to have one operational train during average flows and all trains operational under maximum day demand, a duty assist type system. The configuration is usually based on system capacity, with the least number of trains being the most cost-effective.

According to the recommended design flow rate (2066 m^3/d), a conventional rapid rate filtration system with two DAF modules is recommended. Existing off-the-shelf DAF modules are available at either 800, 1,200 or 1,500 m^3/d flow rates. The use of two 1,200 m^3/d DAF modules is recommended to meet the future design flow along with extra space for an additional third module.

The existing UV disinfection system (2-D12 Trojan LPHO UV Units) and chlorine contact time in the pipeline to the reservoir provide the required 3-log protozoa and 4-log virus contact time. According to Trojan, the UV equipment manufacturer, each of the existing units in the plant have a validated capacity of 168 L/s at 90% UVT for 3 log Cryptosporidium removal. This flowrate is well above the design flow rate; therefore, the UV system is not a limiting factor to the water treatment plant expansion.

5.2 Residual Management

The proposed water treatment plant will produce residual wastewater (approximately 0.5% of the operational flow), which cannot be returned directly to the environment and must be disposed of. Different methods to manage residuals are discussed in the following.

To achieve the 0.5% waste flow, the system must be designed with a filter backwash recycling system; This requires filter backwash to be collected and slowly introduced to the raw water at a rate less than 10% of the inlet flow. As a result of filter backwash recycling, only the DAF float is wasted from the system.

5.2.1 Sewer

The simplest method to manage residual wastewater is to connect it to the sewer system to be treated at the wastewater treatment plant. However, the existing community is not serviced by a centralized sewer system, and there is no sewer connection at the existing Garden Bay facility. As such, sewer disposal is not an option.

5.2.2 Dewatering Ponds

through excavation and landfill/land application. Due to the coastal climate, drying ponds require multiple years of drying to produce solid waste, which can be hauled offsite. For the purpose of sizing a facility, the existing ponds at the South Pender Harbour DAF plant were scaled to the proposed North Pender plant.

Dewatering systems always require a minimum of two ponds as one is required for active operation and the other for drying which can extend through, and sometimes beyond, an entire summer season. With flow optimization, including recycling of backwash water to the head of the plant and mechanical dewatering of the waste float, the residuals transferred to the dewatering ponds can be reduced to less than 0.5% of the total plant flow, thus reducing the required dewatering pond area to around 459 m^2. The location of the ponds would be between the lake and the proposed treatment plant, permitting stormwater to overflow back into the environment.

Table 5-1. Pond Area Requirement

	Design Flow (m^3/day)	Assumed Waste Volume (m^3/day)	Storage Area (m^2)
South Pender Plant	2590	129.5 (5% of the designed flow)	5,750
North Pender Plant	2066	10.33 (0.5% of the designed flow)	459

5.2.3 Dewatering Bags/Geo tubes

Dewatering bags or geo tubes are designed to filter the water as it is pumped from the site. Once the bag is fully drained, its contents can be disposed of as solid waste. Also, if there is no hazardous material in the content, it can be converted to a soil amendment for re-use. Bags come in different materials and sizes. Filling and dewatering time, as well as sludge percentage, varies seasonally. In some areas, cold weather and precipitations prevent the bags from dewatering during winter and make them unfunctional. Figure 5-1 shows an example of a geo tube application.

Based on the equivalent-sized systems, it is anticipated that a geo tube with an area of approximately 180 m^2 could be filled throughout the year and dried the following summer. Two bags would be required (operational and drying).

In discussions with the Layfield group, they noted that the largest available dewatering bag is 20 m^2. As such, approximately 9 to 10 bags would be required to dewater the solids over one year. Although the cost of the bags is relatively inexpensive ($200 per bag), there is an operational consideration for handling the bags and offsite disposal.

Figure 5-1. A Geo Tube Application in a Small System

5.2.4 Pump and Haul

Pump and haul involves storing the residual waste stream in a holding tank to be pumped and hauled to a local liquid waste disposal site, typically an existing wastewater treatment plant owned by the Regional District. Based on the typical efficiency of a treatment plant, this would require daily disposal of the liquid waste due to the capacity of available pump trucks, 3000 gallons. Therefore, it is not viable without preliminary residual reduction, such as backwash recycling and mechanical dewatering. A rough estimation of hauling cost is shown in Table 5-2. The information is based on hauling to the South Pender Harbour DAF plant.

Table 5-2. Estimation of Hauling Cost for the Proposed Water Treatment Plant

Item	Value	Unit
Daily Produced Residual	10.33	m^3
Largest truck volume in the area	11.35	m^3
Hauling Time	1.5	hr
Hauling Cost	145	$/hr
Allowance for interface costs between services areas (10%)	10% of Hauling	$
Total Daily hauling Cost	**240**	**$**

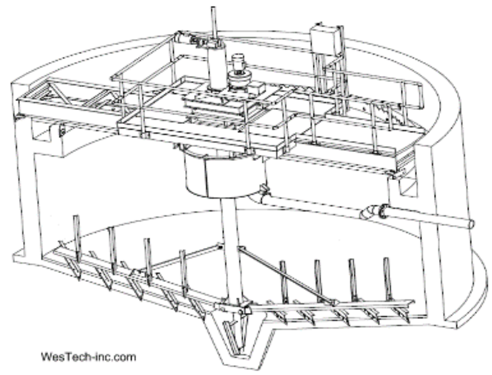
5.2.5 Mechanical Dewatering/Gravity Thickener

Mechanical dewatering involves treating the residuals in a secondary treatment process where an additional polymer is added to the waste stream; excess water is removed and recycled back to the treatment system where possible. The accumulated sludge can be either placed in a drying pond for ultimate off-site hauling or stored in a holding tank for pumping and disposal at the regional liquid waste disposal facility.

To minimize the size of the mechanical dewatering facility, the treatment process efficiency is required to be very high. This typically involves recycling backwash water to the head of the treatment plant and only mechanical dewatering of the sludge or float waste.

The relatively warm climate at the SCRD allows the thickener to be located outside the plant and protected from rainfall to minimize overflow. The estimated size of the thickener is 6-meter diameter and can be located to the north of the plant, between the lake and the proposed treatment plant.

Figure 5-2. A Thickener Designed for Continuously Thickening Solids



5.2.6 Recommended Residuals Management

To manage residuals produced from a filtration/flotation process, it is recommended that a high-efficiency plant be designed to minimize liquid waste. This would include:

1. Recycling filter backwash water, up to 10% of the plant flow.
2. Mechanical dewatering using a thickener or equivalent process.
3. Recycling of thickener supernatant to the raw water.
4. On-site storage and hauling to a regional WWTP of the thickened solids.

A mechanical thickener is assumed to develop a conceptual treatment plant.

5.3 Building Layout and Site Plan

A conceptual layout of a DAF plant was developed based on information from past projects and vendor-provided data (Attached drawing in Appendix B). Figure 5-3 shows the proposed building footprint next to the Garden Bay Water Treatment Plant. The land north of the existing building appears suitable for the upgrade. An access road extension would also be required to access the building and the thickener.

Figure 5-3. Proposed Building Footprint and Existing Garden Bay Water Treatment Plant

6 Generator

As part of this study, the addition of a generator to the existing building has also been evaluated. Table 6-1 shows the load information for specifying a generator for the current pump station. In total, 72 kW is required for the existing equipment. According to these numbers, a 150kW generator is required for the existing plant, which allows for inrush current allowance during pump start-up for a maximum of two pumps running and each pump started in sequence to minimize in-rush current. If all three pumps are intended to be simultaneously operated under backup power, then a 200kW generator would be required along with staged pump start-up. The generator itself would be loaded 70% with both pumps (qty = 2) running and all other loads but needs 150kW to support the starting of both pumps, similarly with a 200kW generator for three pumps. This assumes that the pumps are started sequentially. If both pumps start simultaneously, a 250kW or 300kW generator would be required for operation of two or three pumps, respectively.

Table 6-1. Exiting Treatment Plant Loading Information

Instrument	Load (KW)	Total (KW)
Vertical Turbine Pump (each)	33	66
UV Disinfection System	25	25
Dehumidifier	1.5	1.5
Heating	1.5	1.5
Misc. Loads	10	10
	Total (2-pumps running)	**104**

* There are three pumps with a maximum of two running at once.

Considering the additional load related to the proposed water treatment plant, a 300kW generator would be required in future. However, it should be noted that diesel generators should not operate below 30% of their capacity. It would therefore not be recommended to install a 300-kW generator without concurrently building the filtration system.

If the generator is an urgent need, the Reginal District could proceed with the installation of a 150-kW generator and add a parallel unit with the treatment plant in the future. Alternatively, the 150kW unit could be repurposed if a larger, single unit is preferred. Since the community already has a portable generator, this might not be a viable option.

As an alternative, a 300kW generator can be installed now while having a radiator-mounted automatic load bank to keep the load above 30% in the existing plant. However, the load bank would not be required after the new treatment system is in operation.

Preliminary pricing for outdoor standby generators is $80,000 and $150,000 for 150- and 300-kW units, respectively. Additional costs for the acoustic/weather enclosure and fuel base are in addition to these costs. In total, the installed cost is expected to be approximately $200,000 for the 150-kW unit and $320,000 for the 300-kW unit.

7 Cost Estimate

A Class “D” cost estimate for the proposed treatment plant upgrade, including the new building with a DAF system, a secondary treatment (thickener) for float treatment, and a generator, has been developed. Table 7-1 summarizes the cost estimate for a DAF plant. These estimates are based on the above-noted project information and past project experience. An updated cost estimate should be developed through preliminary and detailed designs as the project advances.

- Tenderer is to complete and submit as part of the Tender submission.
- Regarding the mobilization and demobilization, the price is to include temporary offices and conveniences, other temporary facilities, hoarding, reinstatement, and other items not required to form part of the permanent works (60% to be paid upon complete mobilization and 40% to be paid upon complete demobilization).
- Generator addition works included as Provisional Items shall not be performed by the contractor unless directed to do so by means of a Change Order.

Table 7-2 also, summarizes the cost estimate for membrane plants. The estimated Class D construction cost for the DAF and tight ultrafiltration, reinforced fibre membranes for organic removal systems are $9 million and $11.5 million, respectively. The membrane system has a higher initial cost due to the higher cost associated with the membrane equipment and electrical system as compared to the DAF system. In addition, the membrane system will require a high solids concentration on the membranes to increase the residual solids and reduce the wastewater generated to be comparable to the DAF float waste.

Table 7-1. Garden Bay Water Treatment Upgrade Estimate Cost (DAF System)

Item	Description	Unit Rate	Qty	Units	Budget
1	**General Requirements**				
1.1	Mobilization & Demobilization	$5,691,000	2%		$114,000
1.3	Cash Allowance for Testing and Inspection	$5,691,000	0.50%		$28,000
1.4	Commissioning	$5,691,000	2%		$114,000
1.5	Record Drawings	$5,691,000	0.50%		$28,000
1.6	O&M Manuals	$5,691,000	0.50%		$28,000
				Subtotal	**$312,000**
2	**Civil Works**				
2.1	Tree Clearing and Grubbing	$12	2000	m^2	$24,000
2.2	Stripping	$23	800	m^3	$18,000
2.3	Hauling and Disposal	$50	2263	m^3	$113,000
2.4	Foundation Excavation	$23	1463	m^3	$34,000
2.5	Site Access gravel (sub-base)	$45	250	m^3	$11,000
2.6	Yard Piping	$600	100	m	$60,000
2.7	Power / Communications to Site	$40,000	1	Allowance	$40,000
				Subtotal	**$300,000**
3	**Existing Pump Station**				
3.1	New sub-fed power	20,000	1	Allowance	$20,000
				Subtotal	**$20,000**
4	**Water Treatment Plant**				
4.2	Waste Residuals -Thickener	$436,000	1	LS	$436,000
4.3	Pumps (BW, Recycle, Waste, Low Lift)	$20,000	8	ea	$160,000
4.4	Mechanical Piping	$210,000	1	LS	$210,000
4.5	Water Treatment Plant Building, Foundation, Tanks and Walls	$4,000	500	m^2	$2,000,000
4.6	Chemical Metering Systems	Incl	0	each	
4.7	Chemical Day Tanks	Incl	0	each	
4.8	Treatment Equipment Supplier Scope of Supply	$1,659,000	1	LS	$1,659,000
4.9	Water Treatment Plant plumbing and HVAC	$100,000	1	LS	$100,000
4.10	Electrical Systems	$486,000	1	LS	$486,000
				Subtotal	**$5,051,000**
5	**Provisional Items**				
5.1	Standby Generator c/w exterior acoustic and weather enclosure	$320,000	1	LS	$320,000
				Subtotal	**$320,000**
				Total	**$6,003,000**
			Engineering	**15%**	**$900,000**
			Contingency	**35%**	**$2,101,000**
				Project Scope Total	**$9,004,000**

Table 7-2. Garden Bay Water Treatment Upgrade Estimate Cost (Membrane System)

Item	Description	Unit Rate	Qty	Units	Budget
1	**General Requirements**				
1.1	Mobilization & Demobilization	$7,305,000	2%		$146,000
1.3	Cash Allowance for Testing and Inspection	$7,305,000	0.50%		$37,000
1.4	Commissioning	$7,305,000	2%		$146,000
1.5	Record Drawings	$7,305,000	0.50%		$37,000
1.6	O&M Manuals	$7,305,000	0.50%		$37,000
				Subtotal	**$403,000**
2	**Civil Works**				
2.1	Tree Clearing and Grubbing	$12	2000	m^2	$24,000
2.2	Stripping	$23	800	m^3	$18,000
2.3	Hauling and Disposal	$50	2263	m^3	$113,000
2.4	Foundation Excavation	$23	1463	m^3	$34,000
2.5	Site Access gravel (sub-base)	$45	250	m^3	$11,000
2.6	Yard Piping	$600	100	m	$60,000
2.7	Power / Communications to Site	$40,000	1	Allowance	$40,000
				Subtotal	**$300,000**
3	**Existing Pump Station**				
3.1	New sub fed power	$20,000	1	Allowance	$20,000
				Subtotal	**$20,000**
4	**Water Treatment Plant**				
4.2	Waste Residuals -Thickener	$436,000	1	LS	$436,000
4.3	Pumps (BW, Recycle, Waste, Low Lift)	$20,000	8	ea	$160,000
4.4	Mechanical Piping	$318,000	1	LS	$318,000
4.5	Water Treatment Plant Building, Foundation, Tanks and Walls	$4,000	500	m^2	$2,000,000
4.6	Chemical Metering Systems	Incl	0	each	
4.7	Chemical Day Tanks	Incl	0	each	
4.8	Treatment Equipment Supplier Scope of Supply	$2,745,000	1	LS	$2,745,000
4.9	Water Treatment Plant plumbing and HVAC	$100,000	1	LS	$100,000
4.10	Electrical Systems	$906,000	1	LS	$906,000
				Subtotal	**$6,654,000**
5	**Provisional Items**				
5.1	Standby Generator c/w exterior acoustic and weather enclosure	$320,000.00	1	LS	$320,000
				Subtotal	**$320,000**
				Total	**$7,708,000**
			Engineering	**15%**	**$1,156,000**
			Contingency	**35%**	**$2,698,000**
				Project Scope Total	**$11,562,000**

7.1 Operating Costs

A comparison of operational costs was developed for the membrane and the DAF options (Table 7-3). Labour and general facility maintenance were considered comparable between the two options and not directly considered. The following costs, specific to each option, were included:

- Power for the process equipment and pumping
- Chemicals for cleaning (membranes), pH adjustment and coagulation
- Membrane replacement costs

Coagulant consumption for the membrane option was assumed to be lower than the DAF system as a smaller pin-floc is typically created as the membrane can filter a small particle. Membrane replacement was assumed based on a 10-year replacement frequency and $2,500 per module.

Table 7-3. Garden Bay Water Membrane and DAF Operating Cost Comparison

Description	Membrane	DAF	Units
Power			
Daily power consumption	74	34	kW/d
Cost of Power	$0.08	$0.08	$/kWhr
Subtotal	**$52,000**	**$23,000**	**$/yr**
Membrane Replacement			
Module Cost Allowance	$2,500	-	
Warranty	10	-	years
Number of Modules	60	-	modules
Subtotal	**$15,000**	**-**	$/yr
Cleaning Chemicals			
Volume per year	600	0	L/yr
Average Chemical Cost	$0.75	$0	$/L
Caustic Soda (pH)	$0.94	$0.94	$/kg
Caustic Dose	20	20	mg/L
Caustic Annual Dose	4,833	4,833	kg/yr
Annual NaOH Cost	$4,500	$4,500	$/yr
Coagulant Dose	5	25	mg/L
Coagulant Cost	$2.5	$2.5	$/kg
Annual Dose	1208	6041	kg/yr
Annual ACH Cost	$3,000	$15,000	$/yr
Subtotal	**$8,000**	**$20,000**	$/yr
Total Allowance for Power and Chemicals	**$76,000**	**$43,000**	

The estimated annual operating costs for the membrane system are considered higher as the servicing cost for the membrane is higher than the DAF option, as well as the power costs to operate the permeate pumps, which are not required with a DAF system.

8 Summary and Recommendations

The NPHWSA supplies water from Garden Bay Lake. It has been noted that there are elevated colour and turbidity events, increasing the risks of DBP formation. A critical consideration is that the post-treatment DBPs, notable THMs and HAAs, exceed Health Canada's recommended levels for drinking water. These by-products directly result from the reaction between the chlorine used for disinfection and the naturally occurring organics in the raw water. The historic turbidity levels are around 1 NTU which is at the recommended limit for unfiltered surface water. Furthermore, the SCRD would not have any alternative water supplies should the turbidity exceed 1 NTU due to a natural event such as lake turn-over or algae.

To remove organics and decrease turbidity, several water treatment options were considered. This included filtration processes, such as membrane and rapid rate filtration and clarification using flotation or sedimentation. The nature of the water, low turbidity and high organics are typically treated with a flotation process due to the relative simplicity and effectiveness for organic removal. Membranes can be used; however, the upfront equipment costs and operational costs are typically higher. As the existing plant currently has the necessary chlorination and UV treatment, the benefits of a membrane system are not achieved over a DAF system. An additional benefit of the DAF system is the ongoing operation of two DAF systems within the region, the Chapman Creek WTP and the South Pender Harbour WTP. Although Garden Bay is a smaller system, DAF is highly scalable and is suitable for even smaller plants. The readily available skid-mounted filter systems make this a cost-effective technology for smaller communities.

Since there is no option for a sanitary connection, and the plant capacity is too high to haul solids off-site, options for residual disposal at the plant are limited. To optimize plant efficiency, a backwash recycling system is recommended, along with a residual thickening process. The thickened solids can be hauled off-site for disposal at one of the region's existing dewatering ponds or landfill. This does result in added complexity within the plant as backwash holding tanks are required where the water can be fed into the raw water supply at a controlled rate.

There is limited space at the existing site for a new treatment system. However, there does appear to be sufficient space between the building and the lake. This area is currently a treed area where the lake previously drained. Some realigning of the existing driveway would be required. Discussions with the Ministry of Transportation should be initiated to confirm the ability to utilize this land for a future treatment plant. For sizing purposes, the plant has been assumed to include a provisional space for the future expansion to a 3-parallel train system.

In advance of preliminary or detailed design, additional water quality data should be collected. It is recommended that weekly or bi-weekly total organic carbon be sampled along with monthly dissolved iron and manganese samples. The iron and manganese can be field sampled using a HACH kit or completed at an off-site lab.

Prepared by:

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Maryam Dezfoolian, EIT
Junior Engineer

EGBC Permit to Practice No. 1001547

A

Historical Water Monitoring Data

Table A-1.Garden Bay Lake Water Site Test Results

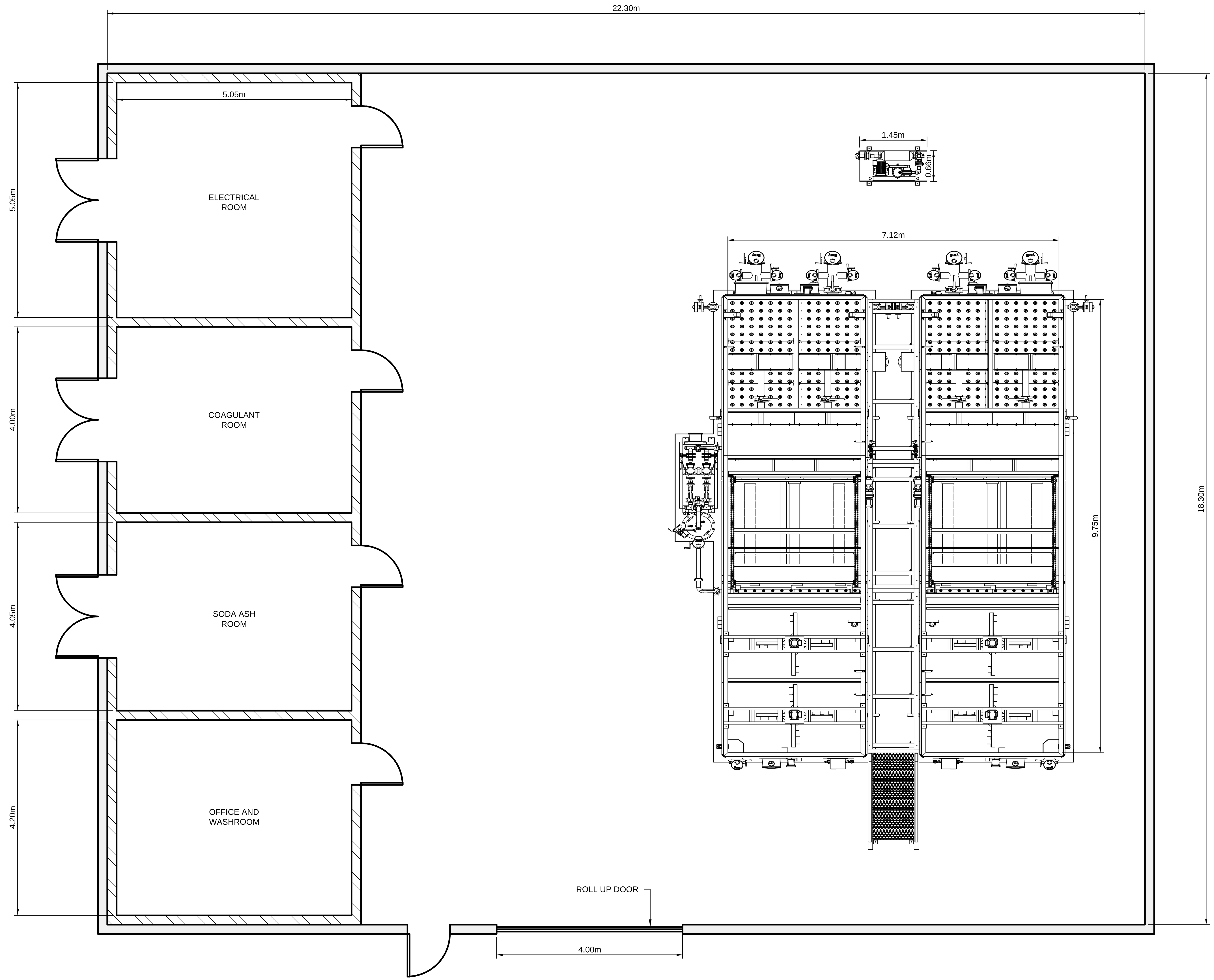
Parameter	Temperature			pH			Conductivity		
Year	°C			-			mS		
	Ave.	+/-	#	Ave.	+/-	#	Ave.	+/-	#
2017	13	3	12	6.3	0.5	12	-	-	-
2018	12	3	22	6.9	0.9	22	66.6	18.3	16
2019	11	3	26	6.9	0.5	25	77.4	19.7	26
2020	11	3	26	6.9	0.6	24	61.0	6.4	24
2021	10	2	24	6.7	0.5	25	62.0	4.9	17
2022	8	1	11	6.9	0.1	11	54.7	3.3	11

Table A-2. Daniel Point Water Site Test Results (NP05)

	Chlorine			Temperature			pH			Conductivity		
Year	mg/L			°C			-			mS		
	Ave	+/-	#	Ave.	+/-	#	Ave.	+/-	#	Ave.	+/-	#
2017	0.57	0.24	13	16	3	13	6.3	0.6	13	-		
2018	1.35	1.61	26	14	4	23	7.6	0.4	22	94.7	14.5	18
2019	1.01	0.15	25	13	4	24	7.4	0.5	25	97.7	11.0	24
2020	0.99	0.17	26	13	3	26	7.3	0.5	26	88.0	11.5	26
2021	0.99	0.18	26	12	4	24	7.1	0.4	26	81.5	17.9	22
2022	0.90	0.11	10	9	2	10	7.3	0.2	10	75.4	5.6	10

B

Proposed Building Layout



PROJECT MANAGER	-
CIVIL	-
STRUCTURAL	
ARCHITECTURAL	
PROCESS	
MECHANICAL	
ELECTRICAL	
INSTRUMENTATION	
PROJECT NUMBER	-

ISSUE DATE DESCRIPTION

GARDEN BAY WATER TREATMENT PLANT UPGRADE

DAF TREATMENT PLANT

PLAN

FILENAME Garden Bay Port Edward WTP.dwg

SCALE 1:50

1:50 0 1 2 m

2022

SHEET **SK-101**

C

Proposed Process Flow Diagram

PROJECT MANAGER W. BAYLESS

ISSUE	DATE	DESCRIPTION
A	SEPT 9, 2022	CONCEPTUAL

PROJECT NUMBER 10346720

GARDEN BAY WATER TREATMENT PLANT
DISSOLVED AIR FLOTATION PLANT CONCEPT

PROCESS FLOW DIAGRAM

FILENAME 10346720-C01-100-C001.dwg
SCALE NTS
SHEET C001

D

Proposed Site Plan

1 2 3 4 5 6 7 8

D C B A

ISSUE	DATE	DESCRIPTION	PROJECT MANAGER	W.BAYLESS
			PROJECT NUMBER	XXXXXXXXXXXXXXX

GARDEN BAY WATER TREATMENT PLANT
DISSOLVE AIR FLOTATION PLANT CONCEPT

SITE PLAN

1:250 0 5 10m

FILENAME

SCALE 1:250

SHEET C002