ASSESSMENT OF THE SUPPLY AND DEMAND OF COVE BAY WATER SYSTEM ON BOWEN ISLAND

Written by

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ABSTRACT

Water scarcity has been a popular occurrence on Bowen Island, British Columbia in the past and recent years. The situation is compounded by population growth, climate change, and increased summer water use. The study aimed at assessing the demand and supply of the largest water distribution system on Bowen Island – the Cove Bay Water System, using a water balance approach in Grafton Lake Watershed. From 2015-2019, it appears that more than 50% of the residents of the watershed used over 300L/P/D in the summer when there was limited precipitation. The study revealed that the regression of the summer precipitation versus summer water use is more significant than that of temperature. Therefore, the summer precipitation is a better determinant of summer water use.

A monthly estimate of drainage from the watershed into the lake was done, assuming 100% runoff. A sensitivity analysis that assumes 10% and 20% drainage loss to groundwater was done. It was found that the drainage was little to nothing in the summer but greater in the winter. The lake's water balance was also analyzed, and it returned negative for most summer months and high in the winter. The lake balance was used to review the lake's monthly storage for the 5-year period (2015-2019). For most winter months, there was a large spill as the lake reached its maximum storage capacity, but it fell short in almost all the summer months.

The present situation of demand and supply in the watershed seem adequate but there are concerns for future situations, especially when climate change and population growth are considered. Recommendations were provided to optimize supply and consciously to reduce demand. The projected climate change data from the Pacific Climate Impacts Consortium (PCIC) is now available for 2100. Therefore, this research could be taken further by using the current water supply and demand assessment to estimate the impact of climate and population growth on the water supply up to 2100. It is recommended that climate monitoring at the Bowen Island station should be resumed, as no calibration data was available from the island's station since 2012 so Vancouver Harbour's station (the closest match) was used in this project.

ACKNOWLEDGEMENT

I would like to thank my family for their unwavering support in my academic and career endeavours. They have been a source of motivation and blessings. My loving wife, Oluwadunsin, and my son, Oluwagbotemi for their understanding and being my greatest fans; my parents for their full support, financially and spiritually; and my siblings, Adetutu, Oluseyi, Itiade, Opeyemi, Ayoade, and Funmilade for supporting me in whatever I do.

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1.2 Background

Small island communities within and outside Canada are often surrounded by water (usually saline) which can not easily be used as freshwater (drinking and household use). In many cases, depending on the topography of the island and the aquifer hydraulic conductivity, the freshwater in an island's aquifer may mix with the seawater in what is popularly known as 'saltwater intrusion' (at the freshwater-saltwater interface) and renders it salty (Klassen et al, 2014). Therefore, in such an island, groundwater will no longer be a good source of freshwater and there would be overdependence on direct precipitation and other sources of freshwater like lakes and rivers.

Small islands are also known for their rich coastal amenities which attract tourists, especially in the summer (Gill, A. & Williams, P. 2008). This poses a lot of water resource challenges on islands as air temperature goes high against a drastically reduced precipitation. Loss of water to the atmosphere in the forms of evaporation on surface waters and evapotranspiration in forested areas become the order of the day during summer in a typical island community. The increased summer population requires a higher water demand than usual thereby making the limited freshwater resources of such island insufficient to meet the new demand.

1.3 Objectives

- To determine the water balance of supply and demand of the Cove Bay LAS (Grafton Lake) system on Bowen Island near Vancouver
- To examine the impact of population growth and climate change on the water system and evaluate the constraints and options to achieve long-term water sustainability.
- To make recommendations for how the system will be managed and operated, also taking into consideration seasonal variability.

1.4 Bowen Island and Water Challenges

Bowen Island is an island municipality which is a part of Metro Vancouver with a land area of about 659 ha. It is in Howe Sound (Figure 1). It is located about 6km west of Mainland British Columbia. It has a population of about 3,680 as of 2016, rising by 8.2 % from the 2011 figure (Figure 2); this figure increases by 1,500 every summer (Statistics Canada, 2017). The Population Density is about 73.4/Km2. It is worthy of note that the island receives thousands of day- and short-term tourists who access the island through ferry ride which takes about 20 minutes from West Vancouver - the BC ferries Horseshoe Bay Terminal and water taxis that depart from Horseshoe Bay and downtown Vancouver (Bowen Island Municipality, 2018)

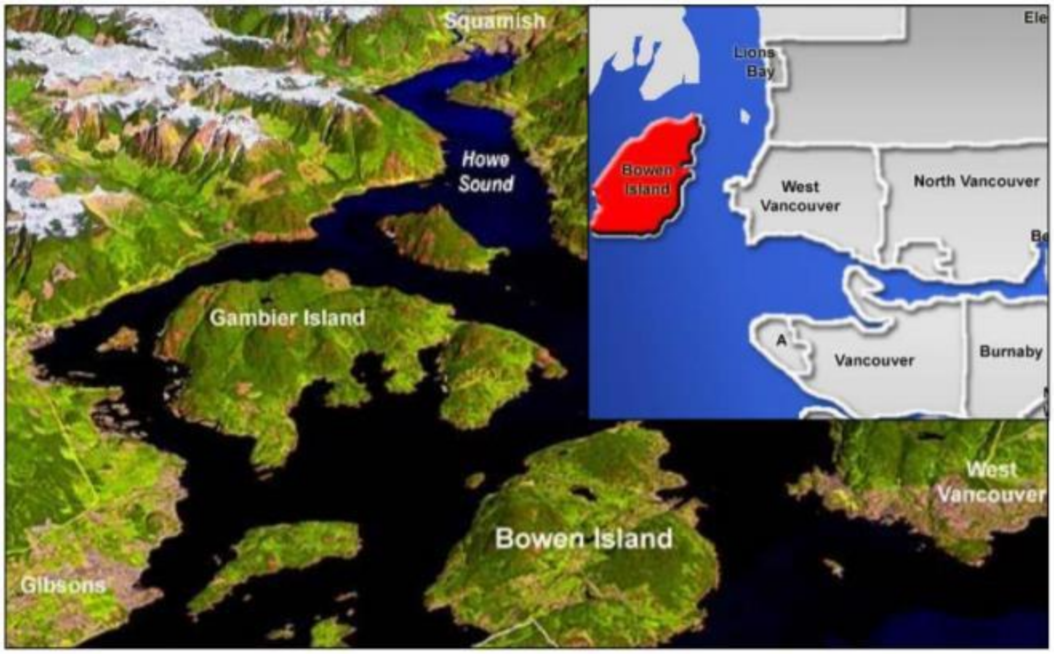


Figure 1: The geographic location of Bowen Island on the coast of British Columbia. Source: CRC Joint Venture (2007), Bowen Island Geo Library (2007). In: Bowen Island Municipality (2018)

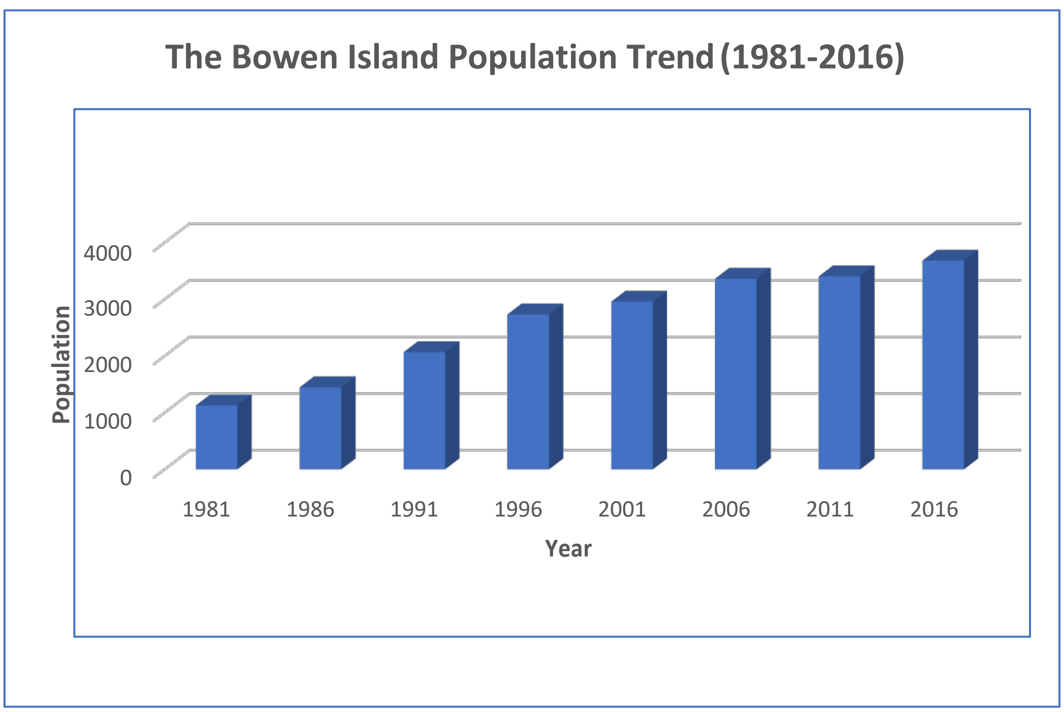


Figure 2: Graph showing the 35-Year Population Trend of Bowen Island

As the population grows and the climate changes, the water scarcity issue on Bowen Island is becoming more threatening despite conservation measures promoted by the Municipality. The island depends on a combination of groundwater and surface water. Groundwater wells are often deep in bedrock and are generally low rate producers. Each well tends to yield less than 15 gallons per minute. The surface water is sourced from Grafton Lake and Killarney Lake. These two lakes are primarily fed by direct precipitation, with some contribution from their watersheds. The Municipality owns and operates seven different water systems on the island (Blue Park, Bowen Bay, Cove Bay, Eagle Cliff, Hood Point, King Edward Bay, and Tunstall Bay Water Systems), four of which are served by groundwater wells alone, two that have both surface sources and wells, and one that is serviced by only a surface source; that is Grafton Lake servicing the largest water system – the Cove Bay Local Area Service (LAS). The Municipality is currently building a new water treatment plant to treat Grafton Lake water servicing Cove Bay. This plant is scheduled for completion in March 2021. Many of the water supplies on the island are being strained and the sustainable balance between supply and demand is in question across the island.

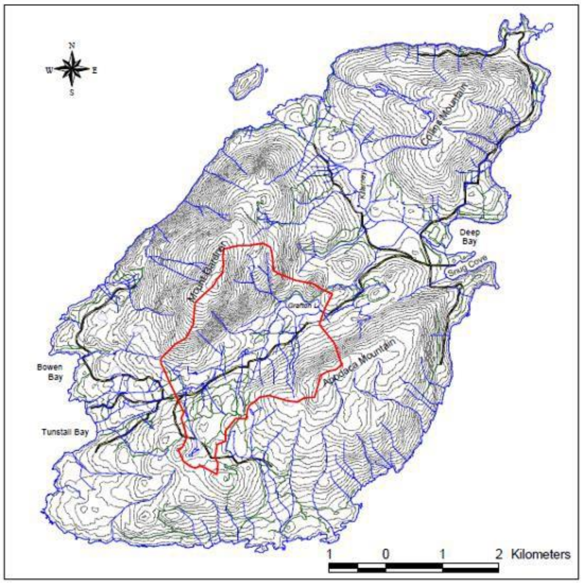
1.5 The Cove Bay Water System (CBWS)

This work aims to assess the demand and supply of the Cove Bay Water System, which is the largest of the 7 water systems on Bowen Island. This is intended to ultimately arrive at demand and supply management and strategic options that could be adopted for the system to yield an annual surplus that may be used to serve other more vulnerable parts of the island. The CBWS provides water to over 40% of the Bowen Island population (Whitehead Consultants Ltd, 2003). The system serves over 630 service connections mainly in the Millers Landing, Snug Cove, Queen Charlotte Heights, and Cates Hill areas of the island (Dayton and Knight Ltd Engineering Consultants, 2009).

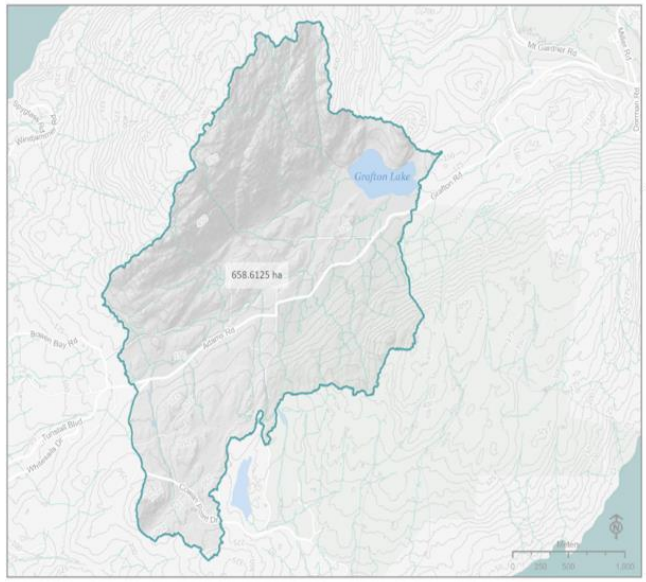
1.6 The Grafton Lake Watershed and Its Reservoir – The Grafton Lake

The source of water of the CBWS is the Grafton Lake watershed. It is the major surface source of drinking water on Bowen Island. Interestingly, it covers only about 16% of the surface area of the island. The watershed is located in the south-central part of the island (Figure 3A). About two-thirds of the Bowen Island residents whose water is supplied from the Grafton Lake Watershed live outside the topographic boundaries of the watershed (Whitehead Consultants Ltd, 2003). This means that the watershed provides water to a greater population than those that reside in it.

The watershed has an area of approximately 659 hectares while the lake has a surface area of about 151 hectares. The soils of the watershed are described as gravelly to coarse sands with poor water holding and storage capacity (Whitehead Consultants Ltd, 2015).



A: Map of Bowen Island Showing Grafton Lake Watershed in Red Outline. (Whitehead Consultants Ltd, 2003)



B: Map of the Grafton Lake Watershed showing the Grafton Lake in the NW area of the Watershed. (Bowen Island Municipality)

Figure 3: Showing maps of Bowen Island, Grafton Lake Watershed and Grafton Lake

2.1 WATER USE ANALYSIS IN COVE BAY 2015 – 2019

2.2 Data Analysis from the Cove Bay Treatment Plant 2015-2019

Table 1 below shows the monthly and annual water use based on the treatment Plant data (Some of the differences between the Urban Systems data and this data might be due to missing intervals in the 1 and 5-minute data set). One of the issues is the November, December, and January 2016-2017 data (all highlighted in yellow) which seems to be unusually high for winter consumption.

Table 1: Monthly and Annual Water Use Based on the Treatment Plant Data (All Values in m^3)

Monthly Water Use from Treatment Plant					
	2015	**2016**	**2017**	**2018**	**2019**
Jan	**13790**	**12810**	**20742**	**11202**	**11238**
Feb	**12289**	**7779**	**10501**	**11002**	**11002**
Mar	**15797**	**6876**	**11345**	**11997**	**13388**
Apr	**17455**	**14797**	**12433**	**14691**	**13975**
May	**22590**	**19330**	**14096**	**20001**	**18715**
Jun	**23911**	**16099**	**17059**	**18288**	**21054**
Jul	**21746**	**15913**	**23425**	**23331**	**19244**
Aug	**17697**	**18266**	**20885**	**23095**	**20720**
Sep	**13413**	**11071**	**15092**	**14546**	**15712**
Oct	**15144**	**17564**	**14434**	**15295**	**15785**
Nov	**11741**	**23644**	**10644**	**12477**	**14545**
Dec	**13464**	**24837**	**10702**	**12324**	**12683**
Annual	**199036**	**188970**	**181358**	**188249**	**188158**

If Average Values are used for November – January 2016 to 2017, then the second peak is removed (See Figure 4). The analysis of the monthly water use data from the Treatment Plant showed relatively little variability between the 5-years (average around 18800 m^3). The lowest water use values were observed in January and February, (around 11000 m^3), while July and August showed the highest water use values (around 20000 m^3). The fall period averaged around 14000 m^3. Seasonal water uses were lowest in Jan-Apr (around 5000 m^3), May-August (around 8000 m^3, and September – December (around 6000 m^3).

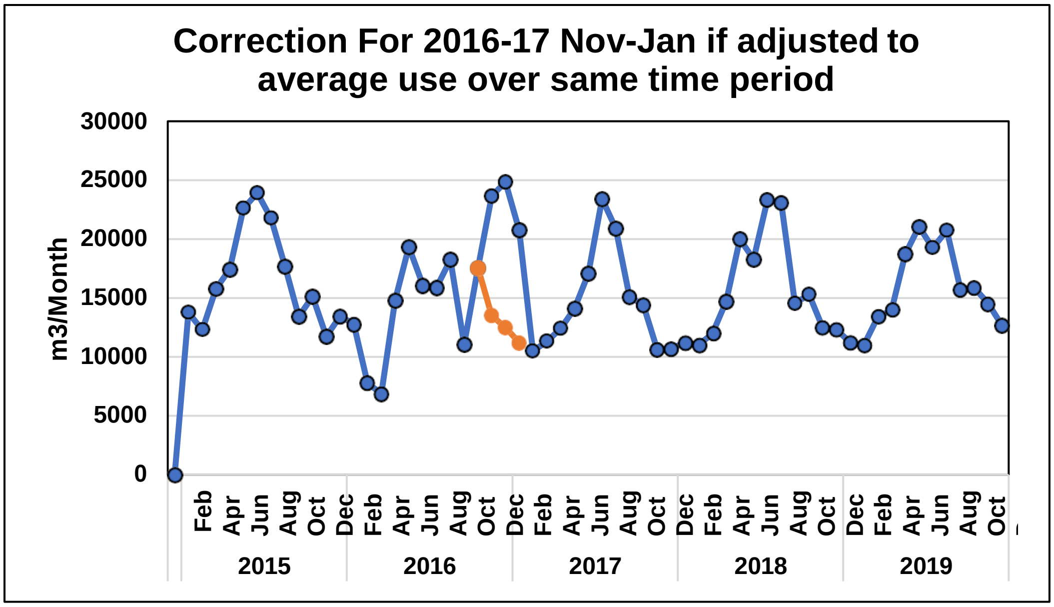


Figure 4: Corrected by Using Average Values for Nov-Jan 2016-2017

To compare the metered water use data from the treatment plant with the individual user data, the monthly data were combined into 3 seasons and Table 2 provides the seasonal values for the treatment plant data.

Table 2: Seasonal Summary of Water Use from the Treatment Plant

Seasonal Water Use from Treatment Plant					
	2015	2016	2017	2018	2019
Jan	**13790**	**12810**	**20742**	**11202**	**11238**
Feb	**12289**	**7779**	**10501**	**11002**	**11002**
Mar	**15797**	**6876**	**11345**	**11997**	**13390**
April	**17455**	**14797**	**12433**	**14691**	**13975**
Jan-Apr	**59330**	**42262**	**55021**	**48892**	**49606**
May	**22590**	**19330**	**14096**	**20001**	**18715**
June	**23911**	**16099**	**17059**	**18288**	**21054**
Jul	**21746**	**15913**	**23425**	**23331**	**19244**
Aug	**17697**	**18266**	**20885**	**23095**	**20722**
May-Aug	**85944**	**69607**	**75465**	**84715**	**79734**
Sep	**13413**	**11071**	**15092**	**14546**	**15712**
Oct	**15144**	**17564**	**14434**	**15295**	**15876**
Nov	**11741**	**23647**	**10644**	**12477**	**14548**
Dec	**13464**	**24839**	**10702**	**12324**	**12683**
Sep-Dec	**53762**	**77122**	**50872**	**54642**	**58818**

2.3 Metered Data Analysis for Cove Bay Water Distribution 2015 – 2019

Metered water use data is collected 3 times per year for the January-April, May-August, and September-December periods. The data was evaluated in three parts:

a) Total metered data

b) Metered Residential water use and

c) Metered Commercial and Institutional water use data (ICI)

a. Total metered data

The combined Table 3 and Figure 5 show the seasonal and total water use as well as the average volume per connection (m^3/ connection).

There was little annual variability in total water use (average around 16900 m^3). Average water use/connection varied between 63 -72 m^3 for the January-April period, 107-135 m^3 in May-August, and 68 -72 m^3/connection September-December.

Table 3: Summary of Seasonal and Total Water Used Based on all Metered Data

Year	All	Seasonal Total (m3)	No of Connection	Mean (m3/Connection)	Annual Total m3
2015	Jan-April	39239	619	63	
	May-Aug	84487	624	135	
	Sep-Dec	42466	628	68	166192
2016	Jan-April	44790	628	71	
	May-Aug	66791	628	106	
	Sep-Dec	49472	630	79	161053
2017	Jan-April	40579	632	64	
	May-Aug	82905	632	131	
	Sep-Dec	43184	640	67	166668
2018	Jan-April	41419	644	64	
	May-Aug	79370	647	123	
	Sep-Dec	49098	648	76	169887
2019	Jan-April	45643	648	70	
	May-Aug	77117	651	118	
	Sep-Dec	44660	652	68	167420

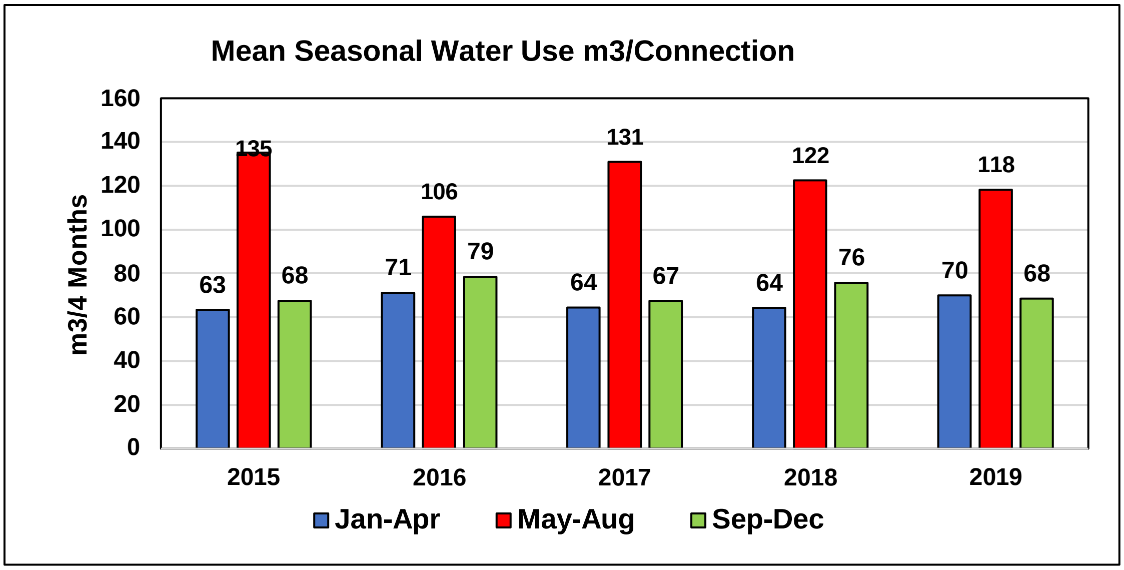


Figure 5: Average Seasonal Metered Water Use Data in m3/Connection

The data shows consistent values over the 5 years with the summer of 2016 being somewhat lower due to higher summer precipitation than in the other 4-year periods.

a) Metered Residential Water Use

The Residential water use/connection is summarized in Table 4 and Figure 6.

Table 4: Metered Residential Water Use

Year	All	Seasonal Total (m3)	No of Connection	Mean (m3/Connection)	Annual Total m3
2015	Jan-April	28354	557	51	
	May-Aug	60267	563	107	
	Sep-Dec	29042	566	51	117663
2016	Jan-April	31173	564	55	
	May-Aug	48554	563	86	
	Sep-Dec	36945	566	65	115772
2017	Jan-April	27695	568	49	
	May-Aug	57117	568	101	
	Sep-Dec	29888	574	52	114700
2018	Jan-April	28395	581	49	
	May-Aug	57997	581	100	
	Sep-Dec	34243	583	59	120635
2019	Jan-April	31077	583	53	
	May-Aug	56791	584	97	
	Sep-Dec	31954	587	54	119222

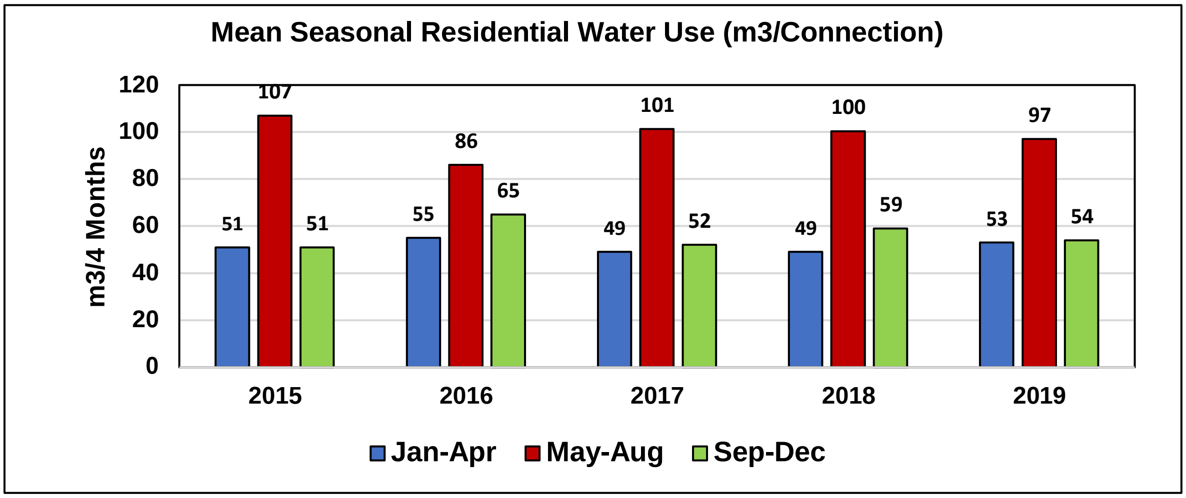


Figure 6: Average Seasonal Residential Water Use in m3/Connection

Again, the data was consistent with the summer water use about twice those for the other two seasons. The residential water use averaged around 50 m^3 per connection in January-April, around 100 m^3 in May-August, and around 50 m^3 per connection in September-December.

b) Metered ICI Water Use

The water used for the metered ICI users is summarized in Table 5 and Figure 7.

Table 5: Metered ICI Water Use

Year	All	Seasonal Total (m3)	No of Connection	Mean (m3/Connection)	Annual Total m3
2015	Jan-April	10340	54	191	
	May-Aug	23835	56	426	
	Sep-Dec	13231	55	241	47406
2016	Jan-April	13377	55	243	
	May-Aug	17747	57	311	
	Sep-Dec	13211	56	236	44335
2017	Jan-April	12719	57	223	
	May-Aug	25432	56	454	
	Sep-Dec	13101	58	226	51252
2018	Jan-April	12901	58	222	
	May-Aug	20974	58	362	
	Sep-Dec	14669	60	244	48544
2019	Jan-April	14042	60	234	
	May-Aug	20803	61	341	
	Sep-Dec	12613	61	207	47458

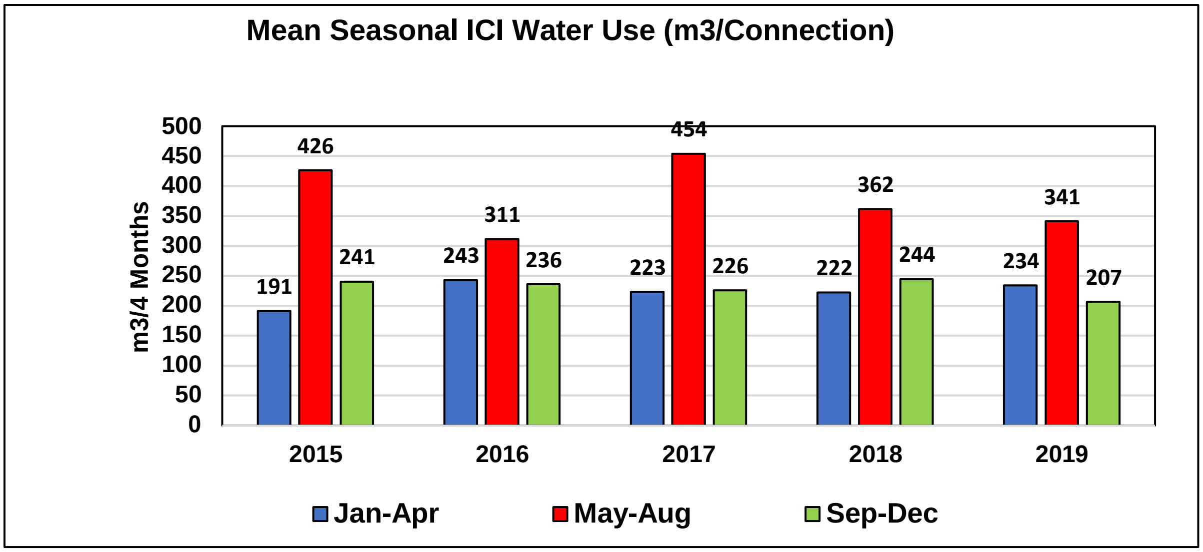


Figure 7: Average Seasonal ICI Water Use in m3/Connections

The average ICI water use has declined in the summer since 2017, but the average summer use is still about 2 times higher than the residential use. Similarly, the average ICI use in the fall and winter period is 4 times higher than the residential use.

Differences in ICI showed around 230 m^3 per connection in January-April, 350-400 m^3 for May-August, and around 230 m^3 per connection for September-December.

2.2 Comparison between the Treatment Plant Water Use and Metered Data

A summary of the total and seasonal water use between the treatment plant and the metered data is provided in Table 6.

The annual difference between the two data sets is between 8-16.5% and 11.3% in 2019. Seasonally, the variability between the years was much more variable, with -6 to 34% difference in Winter and 10-36% in the fall. The summer period shows the smallest difference ranging from 2-10%. These figures (in their actual volume) represent the amount of water that is not accounted for in the watershed and is considered non-revenue water and leakages.

Table 6: Comparison of the Treatment Plant and Metered Data

Comparison Between Treatment Plant and Metered Data						
Winter		2015	2016	2017	2018	2019
Treatment	Jan-Apr	59330	42262	55021	48892	49606
Metered	Jan-Apr	39239	44790	40579	41419	45643
Difference	Jan-Apr	20091	2528	14442	7473	3963
% Diff	Jan-Apr	34	-6	26	15	8
Summer		2015	2016	2017	2018	2019
Treatment	May-Aug	85944	69607	75465	84715	79734
Metered	May-Aug	84487	66791	82905	79370	77117
Difference	May-Aug	1457	2816	7440	5345	2617
	May-Aug	1.6	4	9.9	6.3	3.3
		2015	2016	2017	2018	2019
Treatment	Sep-Dec	53762	77122	50872	54642	58818
Metered	Sep-Dec	42466	49472	43184	49098	44660
Difference	Sep-Dec	11296	27650	7688	5544	14158
% Diff	Sep-Dec	21	35.9	15.1	10.4	24.1
Annual		2015	2016	2017	2018	2019
Treatment	Annual	199036	188990	181358	188249	188158
Metered	Annual	166192	161053	166668	169887	167420
Difference	Annual	32844	27937	14690	18362	20738
% Diff	Annual	16.5	14.8	8.1	9.8	11

2.3 Average Water Use in L/P/D and Frequency Distribution

To present the seasonal and annual water use by each sector (residential and ICI) in Litres per person per day, the metered values in (m^3) were multiplied by 1000 (to convert to litres), divided by 2.5 (average number of persons per connection) and divided by the number of days in each season. The results are summarized in Tables 7 and 8, indicating average values seasonally and annually for the combined data set (Residential Use and All metered data). The reason why a low 2.5 people/connection rate was used is that there are likely many retired people living on Bowen Island and many other residential owners only occupy their residences during the summer season.

Table 7: Average Seasonal and Annual Residential Water Use in L/P/D

Average Seasonal & Annual Residential Water Use (L/P/D)					
	2015	**2016**	**2017**	**2018**	**2019**
Jan-Apr	**170**	**184**	**163**	**163**	**178**
May-Aug	**348**	**280**	**327**	**325**	**316**
Sep-Dec	**168**	**214**	**171**	**193**	**178**
Mean Annual	**229**	**226**	**220**	**227**	**224**

Table 8: Average Total Seasonal and Annual Water Use in L/P/D

All (Residential & ICI) Average Water Use in L/P/D					
	2015	**2016**	**2017**	**2018**	**2019**
Jan-Apr	**211**	**238**	**214**	**214**	**235**
May-Aug	**440**	**346**	**427**	**399**	**385**
Sep-Dec	**222**	**257**	**221**	**248**	**225**
Mean Annual	**290**	**281**	**288**	**288**	**283**

The results show that the average annual residential water use is between 218-247 L/P/D which is considerably lower than the averages of values in Metro Vancouver. During the Fall and Winter Period, the residential values are generally below 200 L/P/D, but this is likely due to low or seasonal occupancy by several landowners.

An optimum range of domestic water use globally is between 150-200 L/P/D, hence there is some room for additional conservation. The key for conservation measures is in the summer when the residential values range between 279-347 L/P/D

2.3.1 Frequency Distribution of Residential Water Use

A more important consideration is the frequency distribution of residential water use in relation to different water use categories. The results in Figure 8 show that a large number of people use less than 150 L/P/D (about one-third of house owners). This is considered the lower limit of potential use in the developed world and suggests that these users do not live in Cove Bay on an annual basis. About 39-43% of the residents are in the 150-300 L/P/D range, which likely represents the bulk of the year-round residents. That leaves around 30% of the house owners that use excessive amounts of water (350-3200L/P/D range).

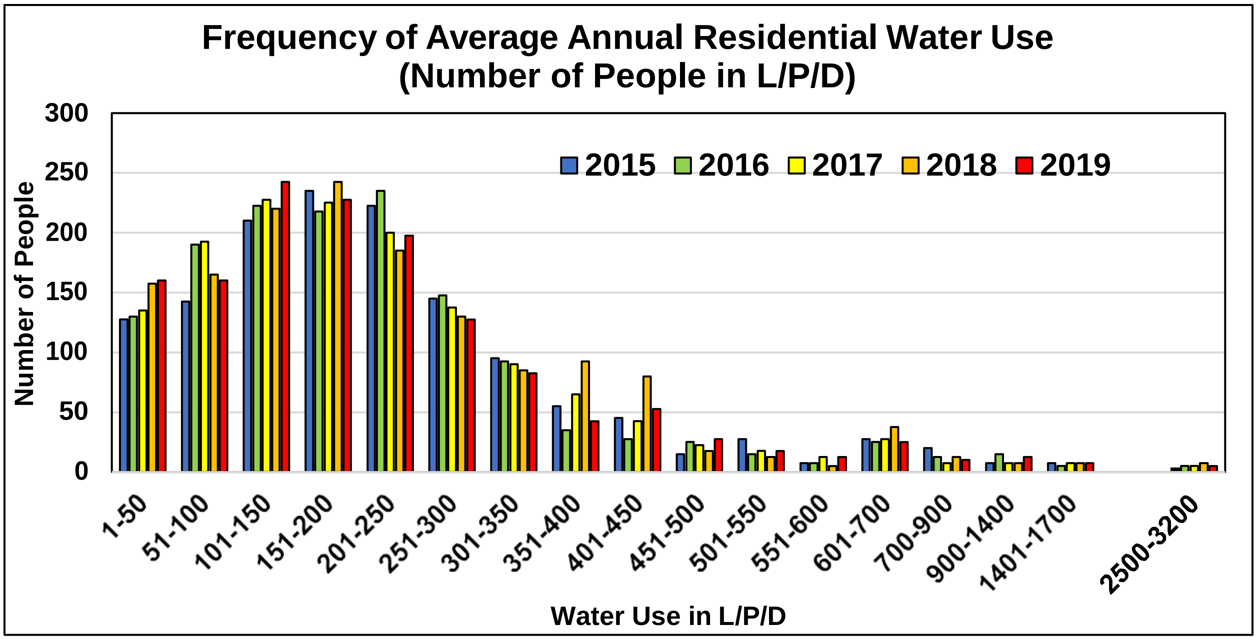


Figure 8: Average Annual Water Consumption in L/P/D

The key issue is summer water consumption which is shown in Figure 9. The less than 150 L/P/D group is much smaller than those that use more than 300 L/P/D which make up about 40-53% of the population.

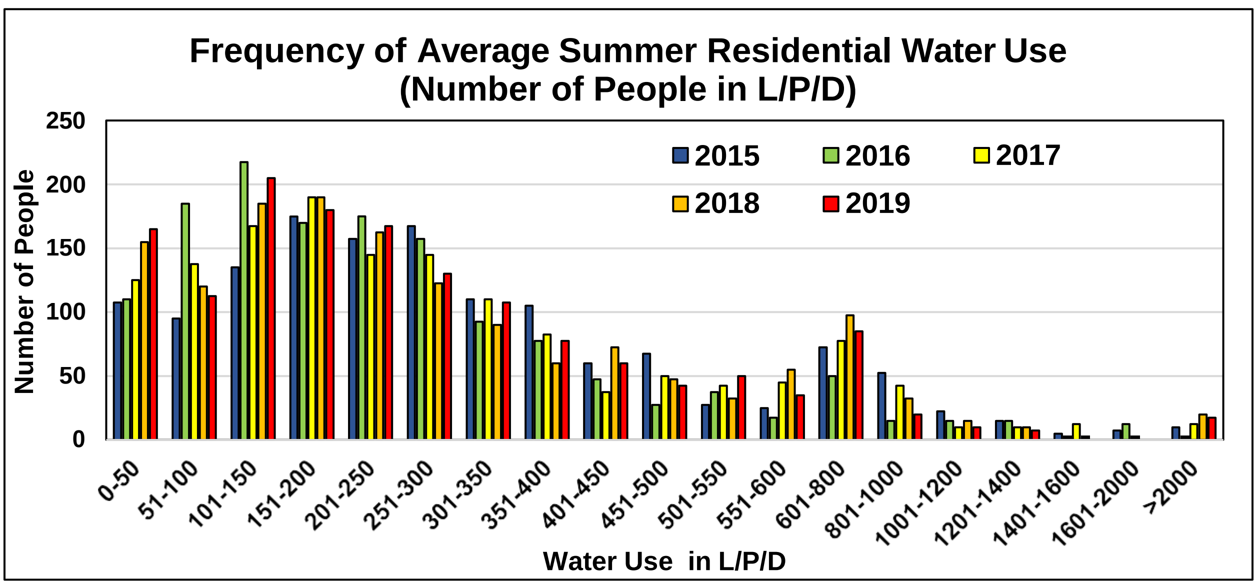


Figure 9: Average Summer Water Consumption in L/P/D

2.5 Water Consumption Versus Temperature and Precipitation

The climate data for Bowen Island is intermittent and only available for 1994-2003. A few local climate stations were evaluated to determine the best matching station to be used. The climate data for West Vancouver, Vancouver Harbour, and Gibsons were compared with the Bowen data in Figure 10.

Summer precipitation and temperatures are one of the key factors that result in higher summer water use. As shown below, the Vancouver Harbour station was the closest match to Bowen for both the annual and summer precipitation. As a result, the Vancouver Harbor station was used to determine the impact of summer temperatures and precipitation on water use.

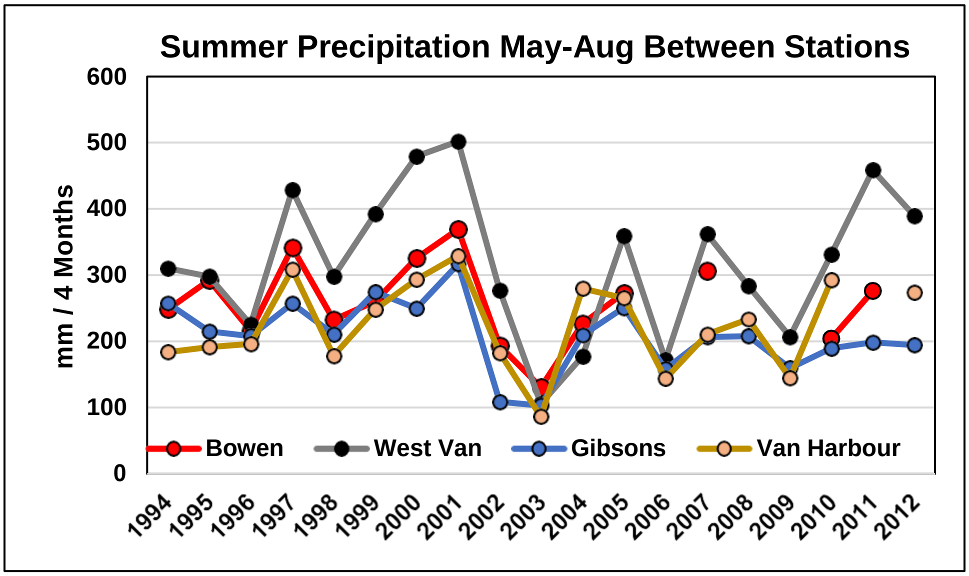


Figure 10: The Vancouver Harbour Station Shows the Closest Match to Bowen Island

The 1976-2019 historic precipitation and temperature for the summer (May-August) are provided in Figure 11, which shows that over the past 5 years temperatures were at the high end while precipitation was at the low end of the historic record.

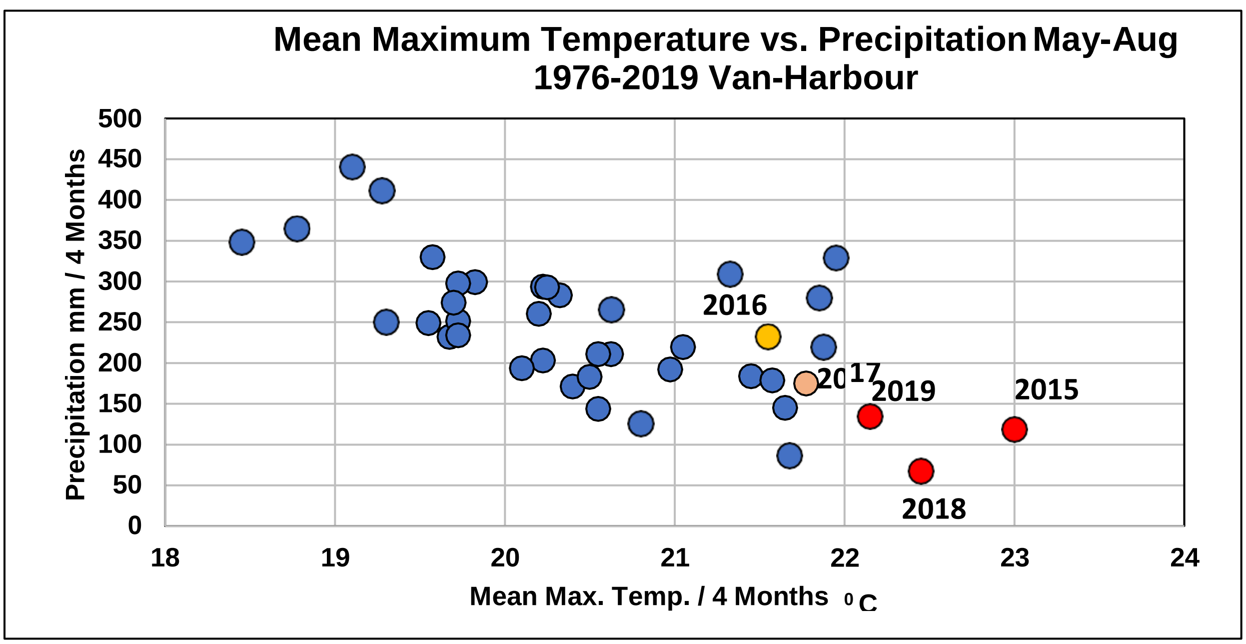


Figure 11: Historic Summer Precipitation versus Mean Maximum Summer Temperatures

The years 2015, 2018, and 2019 were some of the driest and hottest summers. The monthly water use from the Treatment Plant was compared with the monthly precipitation in Figure 12 for each of the five years from 2015-2019. The results show that 2016 had higher May-July precipitation and a corresponding reduction in water use compared to the other years.

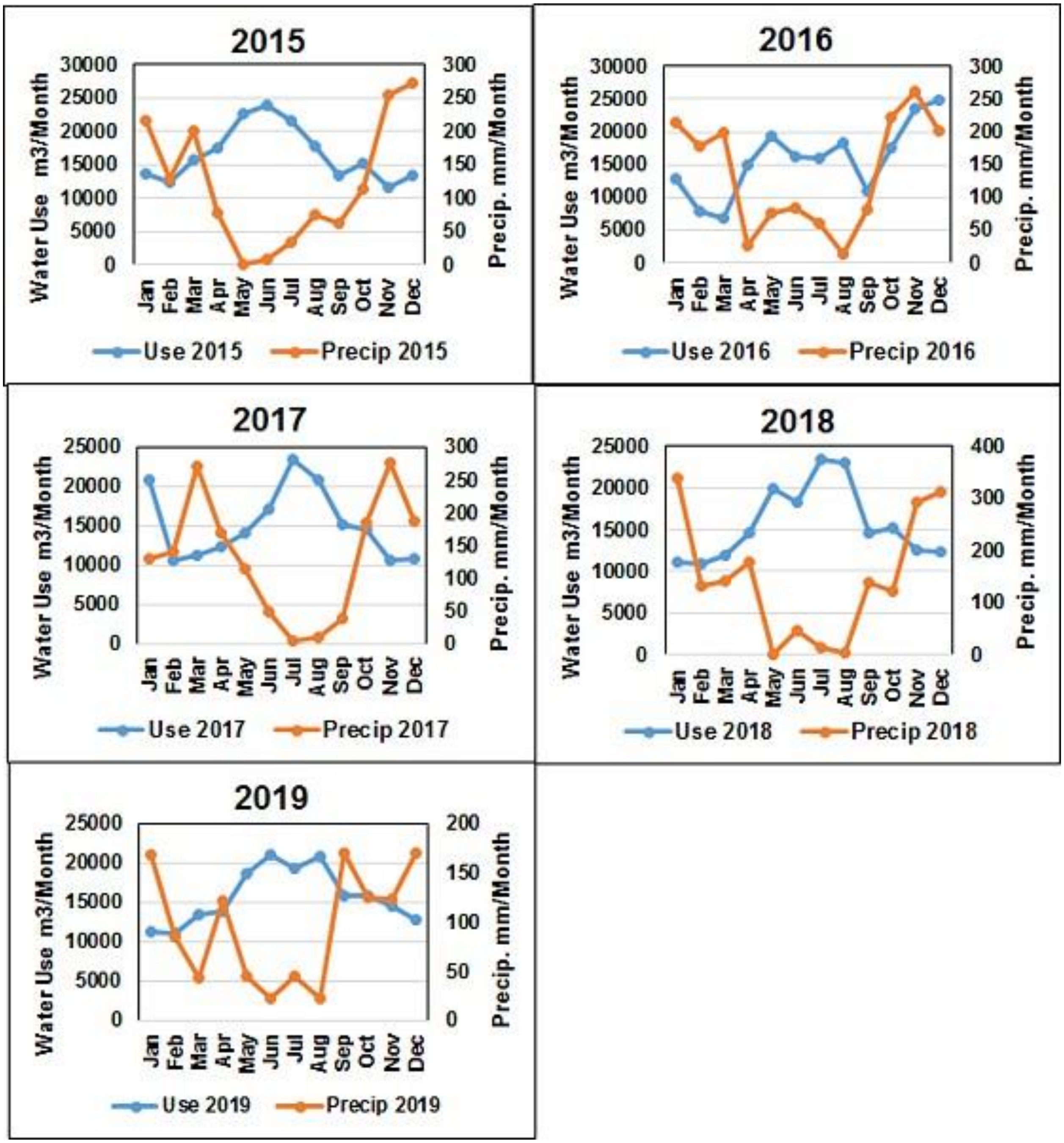


Figure 12: Monthly Water Use Versus Monthly Precipitation for 2015-2019

The Summer water use data for all 5 years was plotted against the summer precipitation and the regression was found to be significant (d=0.05) explaining 69% of the variance (Figure 13). This suggests that this type of regression could be used to project future summer increases in water use based on precipitation projections. A similar regression was performed for summer mean maximum temperatures versus water use but as shown in Figure 14, the regression was not significant.

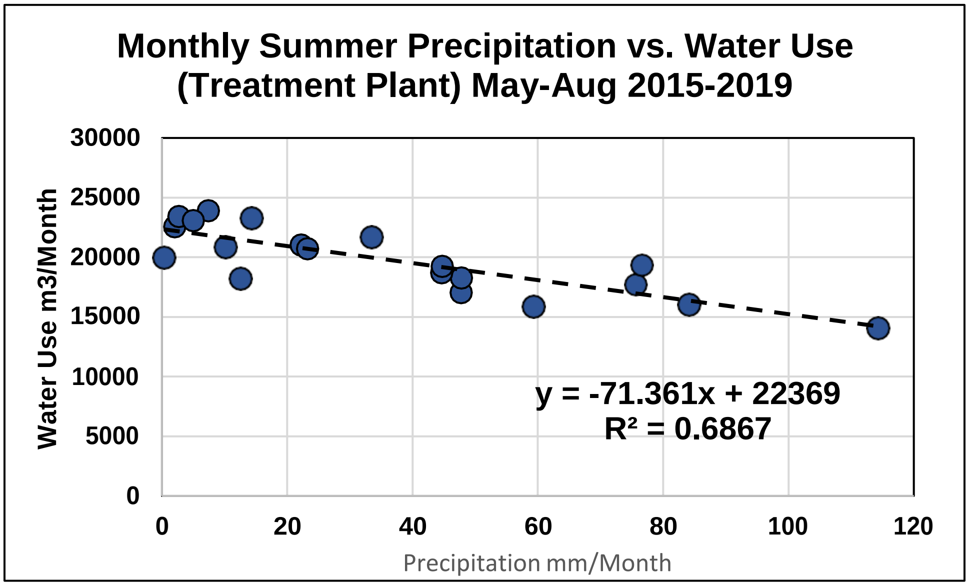


Figure 13: Relationship Between Summer Precipitation Versus Water Use

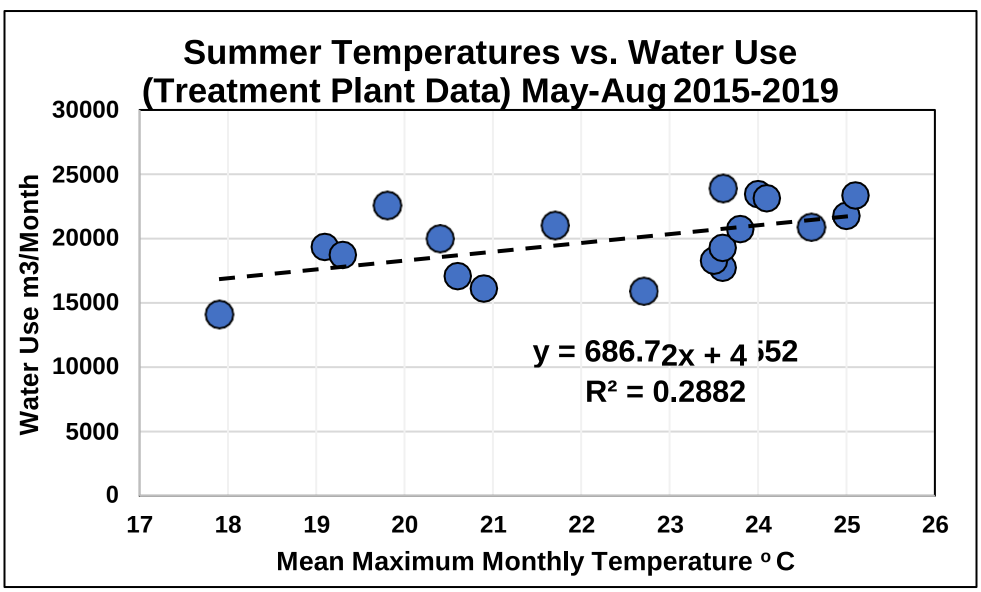


Figure 14: Relationship Between Summer Mean Maximum Temperatures versus Water Use

2.6 Water Use Summary

The overall average residential water consumption is relatively low compared with similar settings near urban centers in Canada. The reasons for this are that several landowners are retired (low number of people /connection) and many are part-time users of their properties (cottages, and summer residences). However, about 50 % of the residents use excessive amounts of water during the summer seasons (>300 L/P/D) and this means that a concerted effort needs to be made for summer water conservation. This could be in the form of outdoor water restriction, rainwater harvesting, xeriscaping, lawn water restrictions, etc. This is of particular concern since the past 5 years showed a clear trend towards higher temperatures and lower precipitation during the summer. The summer water use seems to be particularly sensitive to the amount of summer precipitation and a lesser degree to increasing temperatures.

3.1 THE GRAFTON LAKE WATERSHED WATER BALANCE AND POTENTIAL CONTRIBUTION INTO THE GRAFTON LAKE

3.2 Watershed Water Balance

The water balance was computed for the watershed using the available climate data (Monthly Precipitation and Evapotranspiration) and presented in Table 9.

Table 9: Grafton Lake Watershed Water Balance Model for the First 3 Years

1					GRAFTON LAKE WATERSHED BALANCE							
2												
3		P	Ref ET	Potential ET	Actual ET	Water deficit (WD)	P - Act ET	Drainage (Runoff +GW)	Soil water storage	Soil water deficit		Drainage (Runoff +GW)
4		mm	mm	mm	mm	mm	mm	mm	mm	mm		m3
5						Pot ET-Act ET				AWSC-WS		
6	Jan	215	16	11.4133	11.4133	0	203.587	203.587	84	0		1341636
7	Feb	130	24	15.0826	15.0826	0	114.917	114.917	84	0		757306
8	Mar	201.6	46	27.5	27.5	0	174.1	174.1	84	0		1147319
9	Apr	76.9	74	41.2612	41.2612	0	35.6388	35.6388	84	0		234860
10	May	2	114	47.0225	47.0222	0	-45.022	0	38.9775	45.0225		0
11	Jun	7.4	149	67.252	46.37	20.882	-38.97	0	0	84		0
12	Jul	33.4	144	66.4129	33.4	33.0129	0	0	0	84		0
13	Aug	75.6	120	51.8864	51.88	0.00644	23.72	0	23.7136	60.2864		0
14	Sep	62.7	67	35.5158	35.51	0.00576	27.19	0	50.7978	33.2022		0
15	Oct	114.4	41	24.1483	24.14	0.0083	90.26	57.1	84	0		376289
16	Nov	254	20	13.9785	13.9785	0	240.022	240.022	84	0		1581742
17	Dec	272.3	12	9.62069	9.62069	0	262.679	262.679	84	0		1731057
18	Jan	215	16	11.4133	11.4133	0	203.587	203.587	84	0		1341636
19	Feb	178.2	24	15.0826	15.0826	0	163.117	163.117	84	0		1074944
20	Mar	198.2	48	28.6956	28.6956	0	169.504	169.504	84	0		1117034
21	Apr	26.3	81	45.1643	45.1643	0	-18.864	0	65.1357	18.8643		0
22	May	76.6	116	47.8474	47.8474	0	28.7526	9.8883	84	0		65163.9
23	Jun	84.1	116	52.3573	52.3573	0	31.7427	31.7427	84	0		209184
24	Jul	59.2	120	55.3441	55.3441	0	3.85588	3.85588	84	0		25410.2
25	Aug	12.5	120	51.8864	51.8864	0	-39.386	0	44.6136	39.3864		0
26	Sep	81.9	68	36.0458	36.0458	0	45.8542	6.4742	84	0		42665
27	Oct	221.7	34	19.9948	19.9948	0	201.705	201.705	84	0		1329237
28	Nov	262.2	19	13.2796	13.2796	0	248.92	248.92	84	0		1640386
29	Dec	202.3	11	8.81896	8.81896	0	193.481	193.481	84	0		1275040
30	Jan	129.3	14	9.98666	9.98666	0	119.313	119.313	84	0		786275
31	Feb	139	22	13.8257	13.8257	0	125.174	125.174	84	0		824899
32	Mar	271.8	38	22.7174	22.7174	0	249.083	249.083	84	0		1641454
33	Apr	168.2	62	34.5702	34.5702	0	133.63	133.63	84	0		880620
34	May	114.2	109	44.9601	44.9601	0	69.2399	69.2399	84	0		456291
35	Jun	47.7	123	55.5168	55.5168	0	-7.8168	0	76.1832	7.81679		0
36	Jul	2.7	139	64.1069	64.1069	0	-61.407	0	14.7763	69.2237		0
37	Aug	10.1	127	54.9131	24.8763	30.0368	-14.776	0	0	84		0
38	Sep	37.8	82	43.4671	37.8	5.66705	0	0	0	84		0
39	Oct	184.3	41	24.1114	24.1114	0	160.189	76.1886	84	0		502083
40	Nov	275.5	17	11.8817	11.8817	0	263.618	263.618	84	0		1737244
41	Dec	187.3	11	8.81896	8.81896	0	178.481	178.481	84	0		1176190

Generally, the simplified equation for Water Balance (modified after Healy et al 2007 and Wrinkler et al, 2010) of a watershed is:

R = P – ET – G ± ΔS

Where:

R = Runoff/Streamflow

P = Precipitation

ET = Evapotranspiration

G = Groundwater

ΔS = Change in soil storage

These parameters are measured in depth (mm/month) and are multiplied by the area of the watershed to get their volumes in litres/month and/or cubic meters/month.

Ultimately, this water balance is computed to know how much water is being contributed to the Grafton Lake from the catchment area, as streamflow.

3.1 Precipitation and Seasonal Variations

The precipitation data for the watershed were retrieved from the Environment Canada website, at the Vancouver Harbour Climate Station. A 48-year trend for the annual and seasonal precipitation for the study area is presented in Figures 15 and 16 respectively.

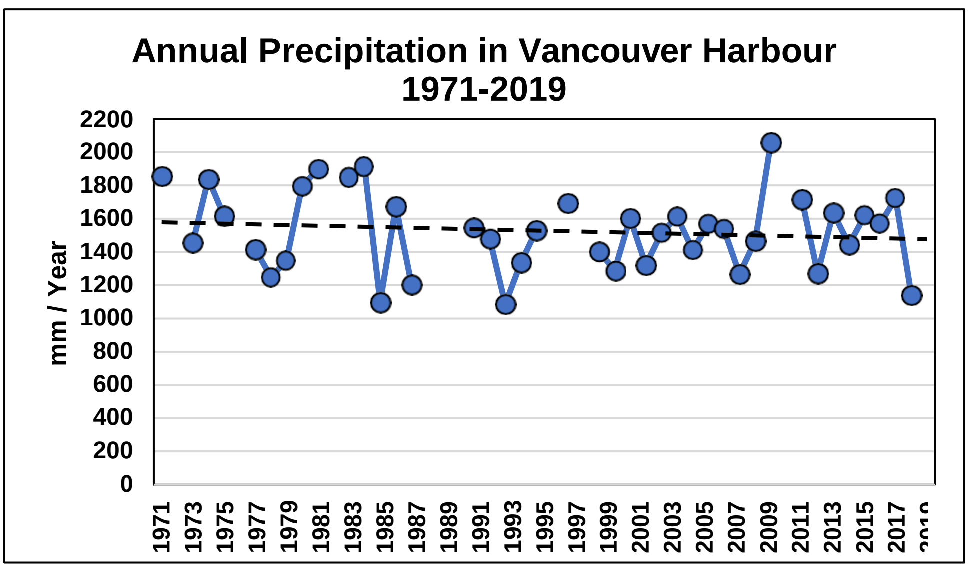


Figure 15: Annual Precipitation Trend in Bowen Island between 1971 and 2019

In all cases, it could be observed that precipitation is gradually and steadily declining. This means that the Island is receiving less rainfall as the years go by. It could also be observed in Figure 16 that the summer precipitation is declining to a greater extent than the winter precipitation.

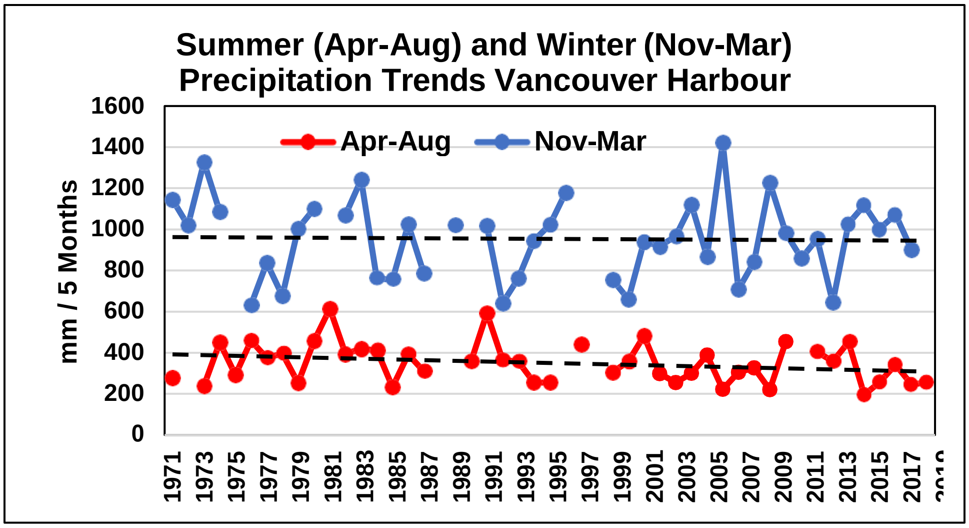


Figure 16: Seasonal Precipitation Trends in Bowen Island between 1971 and 2019

For this water balance computation, data from 2015-2019 were used. The 5-year data was used to compute and analyze the watershed balance.

3.2 Evapotranspiration - ET

Evapotranspiration refers to the amount of water that is lost by a surface to the atmosphere. It is usually a combination of evaporation and transpiration from vegetations. Evapotranspiration appears to be determined by climatic and vegetation properties. In computing a water balance, evapotranspiration appears to be the most difficult to estimate, of all the components of the hydrological cycle.

Reference ET values were retrieved from the website of the Pacific Field Corn Association (farmwest.com) for the watershed. To get the potential ET values for the watershed, the ET measurements by Rachhpal et al, 2009 for different-aged Pacific Northwest Douglas-fir stands which are also prevalent in the watershed were extrapolated. Actual ET values are the same as the potential ET values when the sum of total precipitation and the available soil water is greater than the potential ET. Otherwise, the Actual ET shall be the sum of total precipitation and available soil water.

Figure 17 shows the relationship between the potential ET and the actual ET values for the 5 years. It is obvious that for some summer months in 2015, 2017, and 2018, there is a slight difference between the potential ET and the actual ET. That is, the actual ET is less than the potential because the soil water storage and the total precipitation for that month could not meet the potential ET requirement. Conversely, in 2016 and 2019, the potential ET equals the actual ET all year long. This means that during these two years, there is enough precipitation and soil water to meet the estimated potential ET.

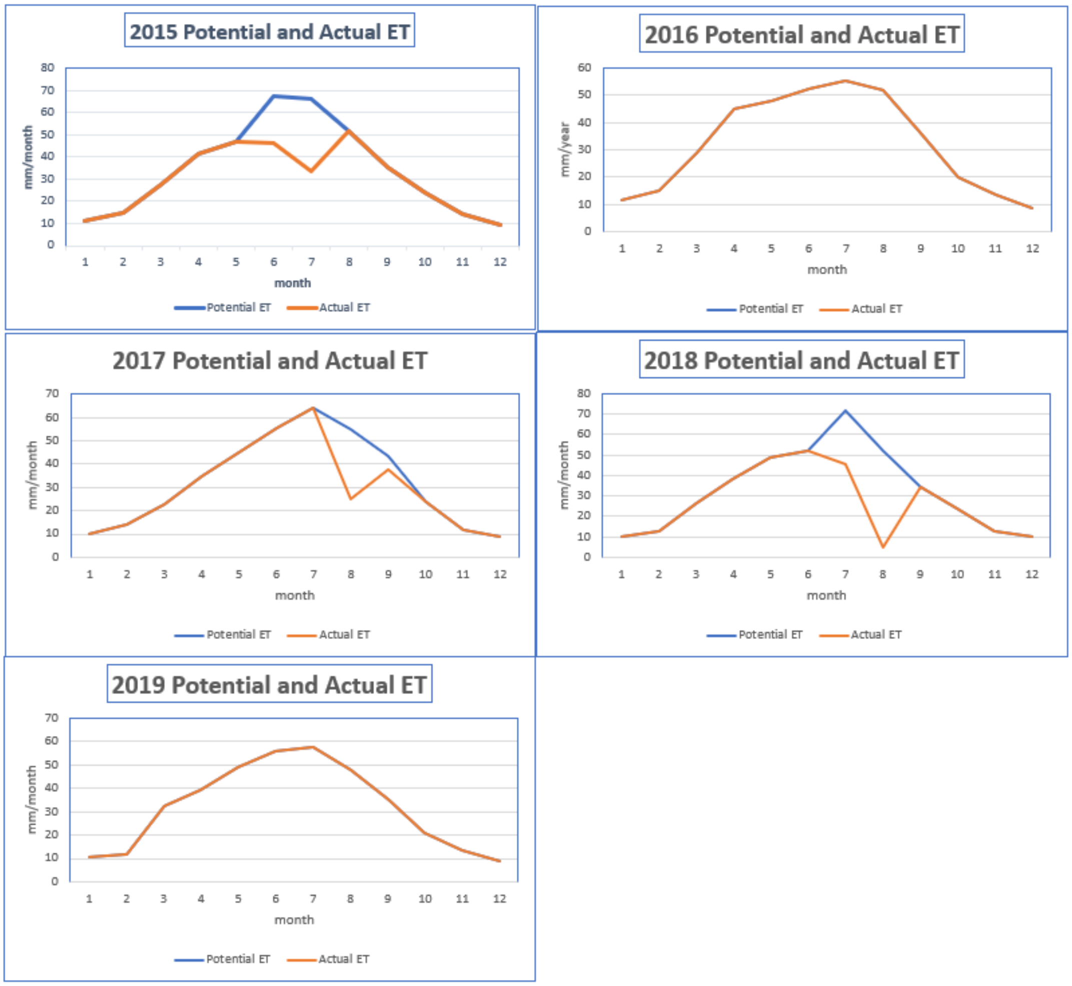


Figure 17: Monthly Potential ET and Monthly Actual ET 2015-2019

3.3 Soil Water Storage

As shown in Figure 18, the soils of the watershed are majorly BOSE (BO), BURWELL (BW), CANNEL (CA), EUNICE (EU), MURRAYVILLE (MY), ROSS (RS), and Rock Outcrops; which are generally gravelly to coarse-textured sands (Luttmerding, 1981). The bulk density of the soils is averagely 1500 kg/m^3 for the 0-1m soil with a degree of stoniness ranging from 30 to 40%. The total soil porosity is 0.43 and Field Capacity and Wilting Point values are estimated to be 0.19 and 0.05, respectively.

Therefore, for 1m depth, the Available Soil Water is 140 mm and with an average stone content of 40%, the Available Soil Water Capacity (ASWC) for the watershed is estimated to be 84mm. That is, the soil storage is considered full at 84mm and any more water input will lead to runoff. Also, in cases whereby the actual ET is greater than the total precipitation, the soil water storage will be used to make the balance. This usually occurs in the summer.

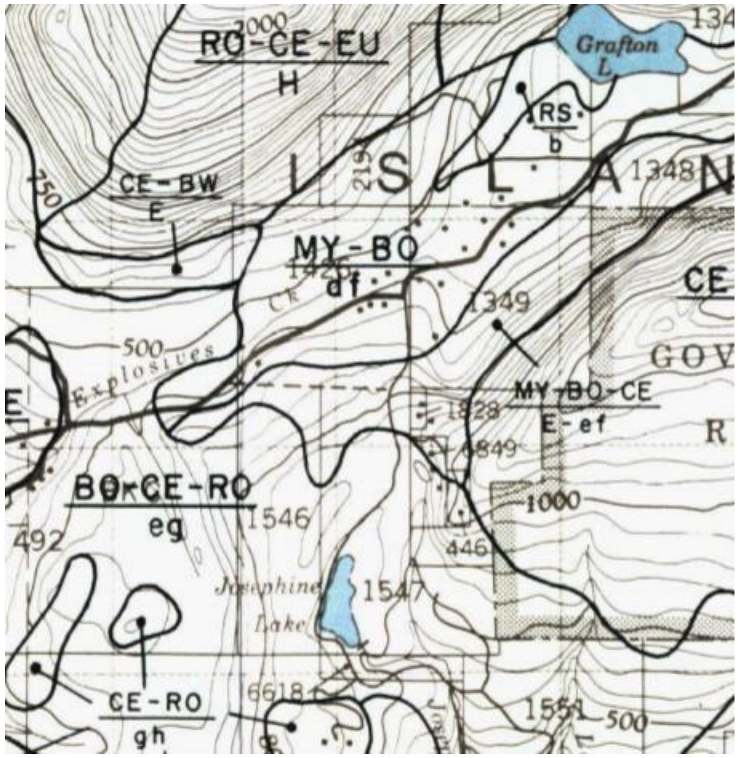


Figure 18: The Soil Map of the Watershed cropped out of the Soil Map of BC (Modified after Luttmerding, 1980)

3.4 Runoff and Groundwater

Drainage is the result of the water balance calculation. It was calculated by subtracting water output (that is, actual ET) from the input (Precipitation). It should however be noted that there would only be a runoff when the soil storage is full at 84mm. In some dry summers, when the storage is emptied or not full, there was little or no drainage and consequently, low or no flow into the lake.

Due to the thin layer of soils underlain by bedrock in the watershed, and the topography of the watershed, most drainage water is assumed to be a runoff in the first water balance calculation for the watershed. It is therefore assumed that the watershed drainage into the lake is directly equal to the difference between the total precipitation and the actual ET.

The monthly drainage in the watershed between 2015 and 2019 is presented in Figure 19. As expected, drainage is greatest in the winter months (November to February) and lowest in the summer (May to August). The highest drainage per month (327mm) in the watershed between 2015 and 2019 was recorded in January 2018. Interestingly, there was no flow in the month of august throughout the 5 years.

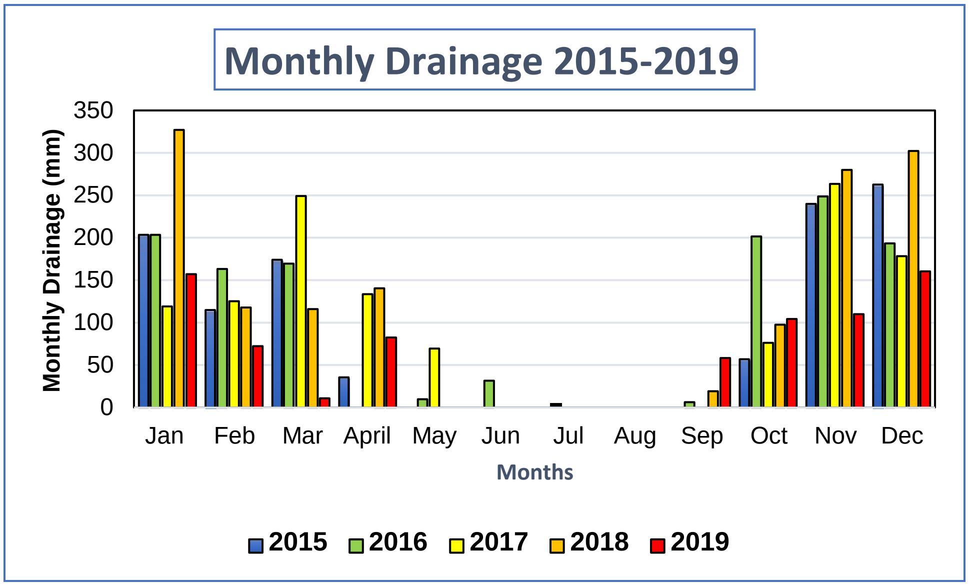


Figure 19: Monthly Drainage 2015-209

As shown in Figure 20, the monthly average drainage for the 5 years study shows that drainage is greatest in November with approximately 229mm, followed by December and January with 220mm and 202mm respectively. On average, there is no flow in July and August. The significance of this result is that drainage into the lake has been little to nothing between May and August in the last 5 years.

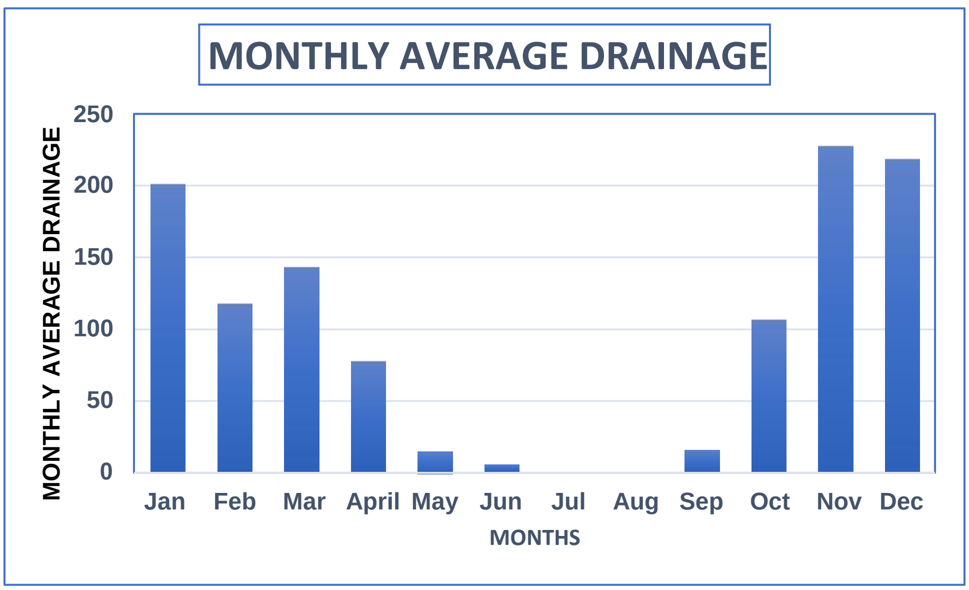


Figure 20: Monthly Average Drainage 2015-2019

4.1 THE GRAFTON LAKE WATER BALANCE

The lake water balance was computed in a similar way to the watershed balance. Each component was calculated/computed in volume (cubic meter) as presented in Table 10. Ideally, the total volume of water leaving the lake was subtracted from the total amount of water entering the lake. Inputs are direct precipitation into the lake and drainage from the watershed while outputs are evaporation from the lake, water demand as recorded from the treatment plant, and the controlled release into the Terminal Creek.

Therefore, the water balance equation for the Grafton Lake is:

$P + R = E + N + T_r$

Where:

P = Direct Precipitation into the Lake

R = Drainage obtained from the watershed water balance

E = Evaporation from the surface of the lake

N = Water Demand as recorded from the lake's treatment plant, and

T_r = Controlled release of water into the Terminal Creek for ecological services

4.2 Lake Precipitation and Drainage from the Watershed

The amount of precipitation that the lake receives is the same as that of the watershed. The only difference is the receiving area. The area of the watershed is about 659 ha whereas that of the lake is about 15.6 ha. Therefore, the monthly precipitation was multiplied by the lake surface area and converted to cubic meter to obtain the precipitation component of the lake water balance.

The drainage component has been calculated from the watershed water balance and the figures were used for the lake water balance.

4.3 Lake Evaporation

The estimated monthly evaporation values were obtained from the website of the Pacific Field Corn Association (farmwest.com). The values, like the precipitation values, were multiplied by the lake surface area to obtain the volume of water lost to evaporation by the lake every month.

In Figure 21, the monthly evaporation from the lake between 2015 to 2019 is presented. The highest water loss due to evaporation from the Grafton Lake between 2015 and 2019 was $24180m^3$ in July 2018 and the lowest was $1716m^3$ in the December months of 2016, 2017, and 2019. The average monthly evaporation is also presented in Figure 22. It could be observed that the highest monthly average evaporation occurred in July with a value of $21310m^3$ whereas the lowest was in December with a value of $1809.6m^3$. These values could be improved once better surface water temperatures are available for field studies.

Table 10: Grafton Lake Water Balance Model for the First 3 Years

	GRAFTON LAKE WATER BALANCE																
	LAKE INFLOW		LAKE OUTFLOW					0% Loss to Groundwater			10% Loss to Groundwater			20% Loss to Groundwater			
	P	Drainage (Runoff +GW)	Lake Evaporation	Water Demand	Minimum Terminal Creek Release	Total Inflow	Total Outflow	Lake Balance	Lake Storage	Lake Control Weir Spill Volume	10% Lake Balance	Lake Storage	Lake Control Weir Spill Volume	20% Lake Balance	Lake Storage	Lake Control Weir Spill Volume
	m3	m3	m3	m3	m3	m3	m3	m3								
Jan	33540	1341636	2496	13790	22766.4	1375176	39052.4	1336124	1259000	1336124	1201960	1259000	1201960	1067797	1259000	1067797
Feb	20280	757306	3744	12289	20563.2	777586	36596.2	740990	1259000	740990	665259	1259000	665259	589529	1259000	589529
Mar	31449.6	1147319	7176	15797	22766.4	1178769	45739.4	1133029	1259000	1133029	1018297	1259000	1018297	903565	1259000	903565
Apr	11996.4	234860	11544	17455	22032	246856	51031	195825	1259000	195825	172339	1259000	172339	148853	1259000	148853
May	312	0	17784	22590	22766.4	312	63140.4	-62828	1196172	0	-62828	1196172	0	-62828	1196172	0
Jun	1154.4	0	23244	23911	22032	1154.4	69187	-68033	1128139	0	-68033	1128139	0	-68033	1128139	0
Jul	5210.4	0	22464	21746	22766.4	5210.4	66976.4	-61766	1066373	0	-61766	1066373	0	-61766	1066373	0
Aug	11793.6	0	18720	17697	22766.4	11793.6	59183.4	-47390	1018983	0	-47390	1018983	0	-47390	1018983	0
Sep	9781.2	0	10452	13413	22032	9781.2	45897	-36116	982867	0	-36116	982867	0	-36116	982867	0
Oct	17846.4	376289	6396	15144	22766.4	394135	44306.4	349829	1259000	73696	312200	1259000	36067.5	274571	1257439	0
Nov	39624	1581742	3120	11741	22032	1621366	36893	1584473	1259000	1584473	1426299	1259000	1426299	1268124	1259000	1266563
Dec	42478.8	1731057	1872	13464	22766.4	1773535	38102.4	1735433	1259000	1735433	1562327	1259000	1562327	1389222	1259000	1389222
Jan	33540	1341636	2496	12810	22766.4	1375176	38072.4	1337104	1259000	1337104	1202940	1259000	1202940	1068777	1259000	1068777
Feb	27799.2	1074944	3744	7779	21297.6	1102743	32820.6	1069923	1259000	1069923	962428	1259000	962428	854934	1259000	854934
Mar	30919.2	1117034	7488	6876	22766.4	1147953	37130.4	1110822	1259000	1110822	999119	1259000	999119	887416	1259000	887416
Apr	4102.8	0	12636	14797	22032	4102.8	49465	-45362	1213638	0	-45362	1213638	0	-45362	1213638	0
May	11949.6	65163.9	18096	19330	22766.4	77113.5	60192.4	16921.1	1230559	0	10404.7	1224043	0	3888.32	1217526	0
Jun	13119.6	209184	18096	16099	22032	222304	56227	166077	1259000	137636	145159	1259000	110201	124240	1259000	82766.2
Jul	9235.2	25410.2	18720	15913	22766.4	34645.4	57399.4	-22754	1236246	0	-25295	1233705	0	-27836	1231164	0
Aug	1950	0	18720	18266	22766.4	1950	59752.4	-57802	1178444	0	-57802	1175903	0	-57802	1173362	0
Sep	12776.4	42665	10608	11071	22032	55441.4	43711	11730.4	1190174	0	7463.88	1183367	0	3197.38	1176559	0
Oct	34585.2	1329237	5304	17564	22766.4	1363822	45634.4	1318188	1259000	1249362	1185264	1259000	1109631	1052340	1259000	969899
Nov	40903.2	1640386	2964	23644	22032	1681289	48640	1632649	1259000	1632649	1468610	1259000	1468610	1304572	1259000	1304572
Dec	31558.8	1275040	1716	24837	22766.4	1306599	49319.4	1257279	1259000	1257279	1129775	1259000	1129775	1002271	1259000	1002271
Jan	20170.8	786275	2184	20742	22766.4	806446	45692.4	760753	1259000	760753	682126	1259000	682126	603498	1259000	603498
Feb	21684	824899	3432	10501	20563.2	846583	34496.2	812087	1259000	812087	729597	1259000	729597	647107	1259000	647107
Mar	42400.8	1641454	5928	11345	22766.4	1683855	40039.4	1643816	1259000	1643816	1479670	1259000	1479670	1315525	1259000	1315525
Apr	26239.2	880620	9672	12433	22032	906860	44137	862723	1259000	862723	774660	1259000	774660	686598	1259000	686598
May	17815.2	456291	17004	14096	22766.4	474106	53866.4	420240	1259000	420240	374611	1259000	374611	328982	1259000	328982
Jun	7441.2	0	19188	17059	22032	7441.2	58279	-50838	1208162	0	-50838	1208162	0	-50838	1208162	0
Jul	421.2	0	21684	23425	22766.4	421.2	67875.4	-67454	1140708	0	-67454	1140708	0	-67454	1140708	0
Aug	1575.6	0	19812	20885	22766.4	1575.6	63463.4	-61888	1078820	0	-61888	1078820	0	-61888	1078820	0
Sep	5896.8	0	12792	15092	22032	5896.8	49916	-44019	1034801	0	-44019	1034801	0	-44019	1034801	0
Oct	28750.8	502083	6396	14434	22766.4	530834	43596.4	487237	1259000	263038	437029	1259000	212830	386821	1259000	162622
Nov	42978	1737244	2652	10644	22032	1780222	35328	1744894	1259000	1744894	1571170	1259000	1571170	1397446	1259000	1397446
Dec	29218.8	1176190	1716	10702	22766.4	1205409	35184.4	1170224	1259000	1170224	1052605	1259000	1052605	934986	1259000	934986

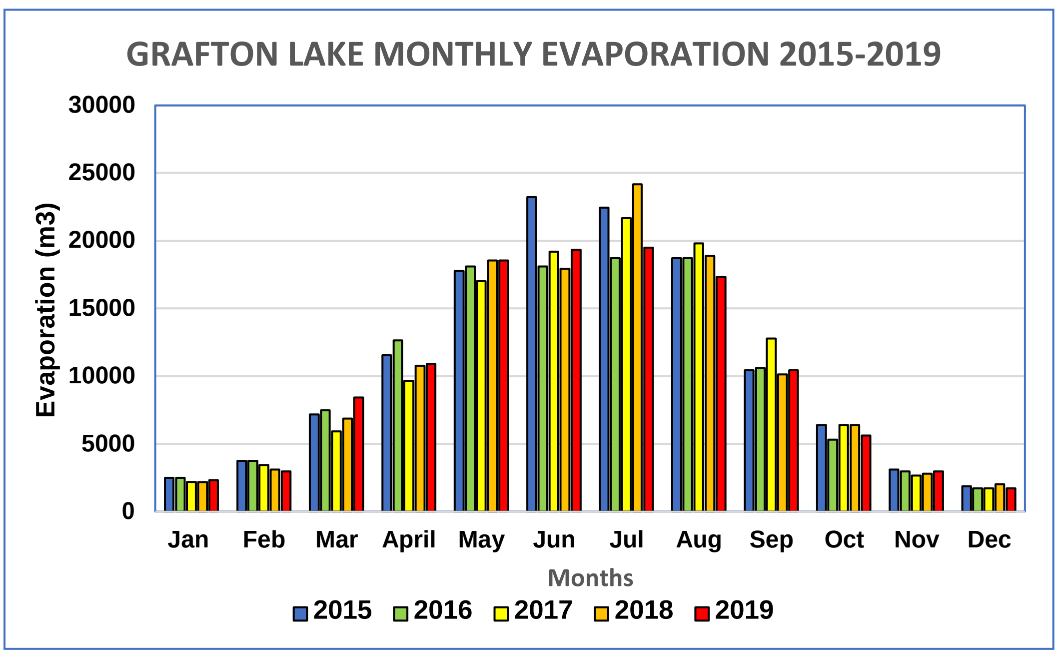


Figure 21: Lake Monthly Evaporation 2015-2019

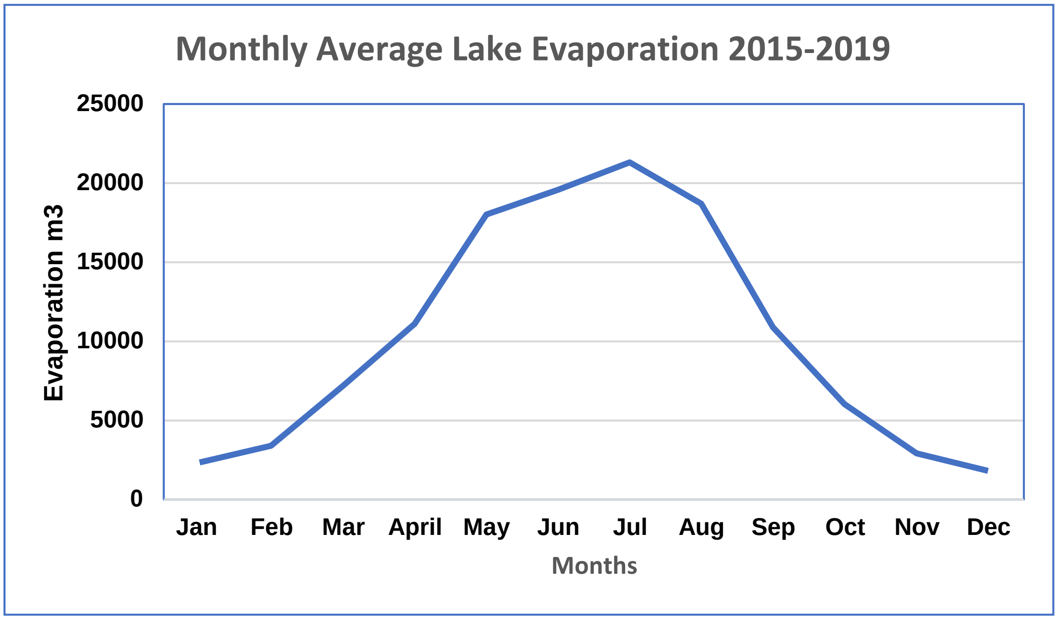


Figure 22: Lake Average Monthly Evaporation 2015-2019

4.4 Water Demand as recorded from the Lake Treatment Plant

The water demand data has been comprehensively analyzed and discussed in the water use section of this report. The water use data from the treatment plant was used for this calculation instead of the water demand metered data because the treatment plant data is the one that shows the actual volume of water that is withdrawn from the lake for distribution to consumers. The data is presented in Table 1 and Figure 4.

4.5 Controlled Release of Water into the Terminal Creek for Ecological Services

This data is an important component of the lake's output. This is a supervised, controlled release of water into the natural water system for ecological services. As informed by the Bowen Island Municipality, a minimum volume of 8.5litres per second is released from the lake for this purpose. This value is converted to cubic meter per month for all the months from 2015 to 2019. Since no data on monthly river discharge and lake level fluctuation was available, this calculation does not account for the water released to the river during the period of excess water.

4.6 Balance and Lake Storage

The result of the Grafton Lake water balance shows the difference between the total water input into the lake and the total water output. As described earlier, water enters the lake through direct precipitation and runoff from the catchment/drainage area (the watershed). Water leaves the lake by direct evaporation, water withdrawal for distribution or supply, and the controlled release of water into the Terminal Creek.

The balance was calculated monthly and is given as:

Balance = Total Inflow – Total Outflow

Where:

Total Inflow = P + R and

Total Outflow = E + N + T_r

Therefore,

Balance = P + R – E – N - T_r

Despite some water conservation measures (e.g. water pricing) that the municipality has put in place, the result of the lake balance, presented in Figure 23 for the chart with minimum or 0% groundwater, shows that there was a rise in the lake balance between 2015 and 2016 which declined in 2017 with an increase in 2018. Also, there was a very sharp decline between 2018 and 2019 which may be due to the relatively low precipitation that the island received in the winter of 2019 which in turn led to lower drainage. In this calculation, it was assumed that there was a minimum loss to groundwater. That is, there was 100% runoff from the drainage.

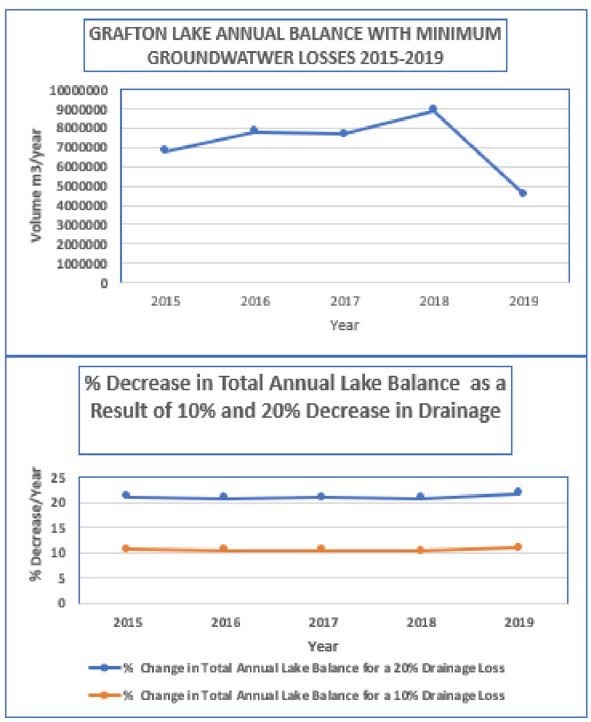


Figure 23: Relationship between a 0%, 10% and 20% Loss in Annual Drainage to the Annual Lake Balance

Also, Figure 24 represents the annual drainage from the watershed (for the chart assuming there is a minimum of 0% loss to the groundwater). The graph, being similar to the total annual balance graph shows that the watershed drainage determines, to a greater extent, the annual balance than any other component of the analysis. Therefore, it confirms that the lower precipitation that the watershed received in 2019 was the major reason there was a decline in the annual balance between 2018 and 2019.

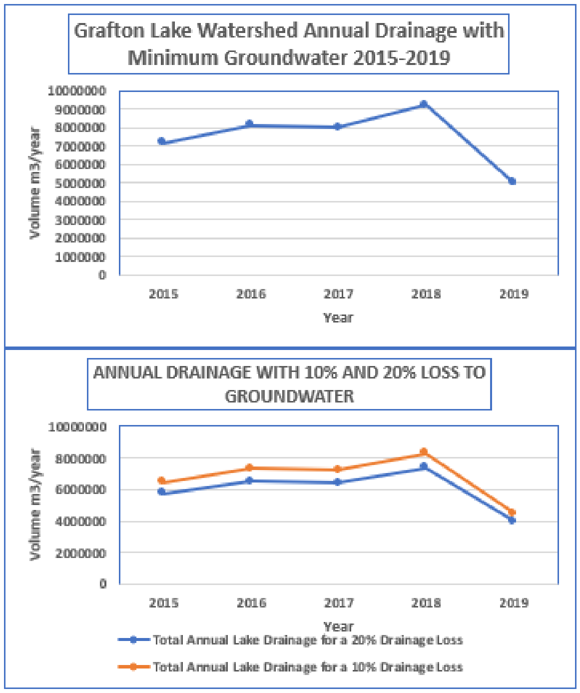


Figure 24: Annual Drainage with Minimum, 10% and 20% Drainage Losses to Groundwater

4.7 Sensitivity Analysis

Sensitivity assessments were conducted on the water balance data to estimate the influence of a slight increase or decrease in some components of the water balance on another component and ultimately, the balance. These assessments became necessary as a result of the assumption that most of the drainage from the watershed is runoff and because the lake level fluctuation data and discharge during periods of excess water were not available. All monthly lake balance and storage data are presented in Table 11.

4.7.1 Annual Drainage with 0%, 10% and 20% Drainage Losses to Groundwater

Since it was challenging to estimate how much of the drainage goes into the groundwater, testing the influence of a portion of the drainage became necessary. Here, 10% and 20% of drainage losses were calculated and compared to the 0% groundwater contribution in Figure 24.

4.7.2 Decrease in Annual Lake Balance as a result of a 10% Drainage Loss to Groundwater

The effect of the 10% and 20% drainage loss to groundwater on the annual lake balance is presented in Figure 23. It indicates that the annual lake balance decreases at the same or a slightly higher proportion as the drainage decreases. A 10% drainage loss to groundwater led to a 10.5% decrease in the annual lake balance for the 5 years and a 20% change decreased the water balance by 20.97.

Table 11: Monthly Lake Balance and Monthly Lake Storage for Minimum (0%), 10%, and 20% Drainage Loss to Groundwater

	EFFECTS OF 0%, 10% AND 20% DRAINAGE LOSS TO THE GROUNDWATER ON LAKE BALANCE AND LAKE STORAGE										
	Monthly Lake Balance with Minimum Groundwater						Monthly Lake Storage with Minimum Groundwater				
	2015	2016	2017	2018	2019		2015	2016	2017	2018	2019
Jan	1336124	1337104	760753	2171437	1025121	Jan	1259000	1259000	1259000	1259000	1259000
Feb	740990	1069923	812087	764189	454797	Feb	1259000	1259000	1259000	1259000	1259000
Mar	1133029	1110822	1643816	746332	34781	Mar	1259000	1259000	1259000	1259000	1259000
Apr	195825	-45362.2	862723	905833	516848	Apr	1259000	1213638	1259000	1259000	1259000
May	-62828.4	16921.1	420240	-61284.6	-53087.8	May	1196171.6	1230559	1259000	1197715.4	1205912.2
Jun	-68032.6	166077	-50837.8	-50803.2	-58966.8	Jun	1128139	1259000	1208162	1146912.2	1146945.4
Jul	-61766	-22754	-67454.2	-68057.5	-54537.2	Jul	1066373	1236246	1140708	1078854.7	1092408.2
Aug	-47389.8	-57802.4	-61887.8	-63957.4	-57183.2	Aug	1018983.2	1178444	1078820	1014897.3	1035225
Sep	-36115.8	11730.4	-44019.2	101584	363073	Sep	982867.4	1190174	1034801	1116481.1	1259000
Oct	349829	1318188	487237	616962	662939	Oct	1259000	1259000	1259000	1259000	1259000
Nov	1584473	1632649	1744894	1855005	705403	Nov	1259000	1259000	1259000	1259000	1259000
Dec	1735433	1257279	1170224	2003672	1047490	Dec	1259000	1259000	1259000	1259000	1259000
Annual	6799570	7794775	7677775	8920912	4586677						
	Monthly Lake Balance with 10% Drainage Loss						Monthly Lake Storage with 10% Drainage Loss				
Jan	1201960	1202940	682126	1955936	921593	Jan	1201960	1259000	1259000	1259000	1259000
Feb	665259	962428	729597	686340	407178	Feb	1259000	1259000	1259000	1259000	1259000
Mar	1018297	999119	1479670	669759	27520.6	Mar	1259000	1259000	1259000	1259000	1259000
Apr	172339	-45362.2	774660	813292	462369	Apr	1259000	1213638	1259000	1259000	1259000
May	-62828.4	10404.7	374611	-61284.6	-53087.8	May	1196171.6	1224043	1259000	1197715.4	1205912.2
Jun	-68032.6	145159	-50837.8	-50803.2	-58966.8	Jun	1128139	1259000	1208162	1146912.2	1146945.4
Jul	-61766	-25295	-67454.2	-68057.5	-54537.2	Jul	1066373	1233705	1140708	1078854.7	1092408.2
Aug	-47389.8	-57802.4	-61887.8	-63957.4	-57183.2	Aug	1018983.2	1175903	1078820	1014897.3	1035225
Sep	-36115.8	7463.88	-44019.2	88901.7	324596	Sep	982867.4	1183367	1034801	1103799	1259000
Oct	312200	1185264	437029	552717	594186	Oct	1259000	1259000	1259000	1259000	1259000
Nov	1426299	1468610	1571170	1670341	632834	Nov	1259000	1259000	1259000	1259000	1259000
Dec	1562327	1129775	1052605	1804471	941667	Dec	1259000	1259000	1259000	1259000	1259000
Annual	6082549	6982705	6877269	7997655	4088168						
	Monthly Lake Balance with 20% Drainage Loss						Monthly Lake Storage with 20% Drainage Loss				
Jan	1067797	1068777	603498	934986	818064	Jan	1067796.53	1259000	1259000	1259000	1259000
Feb	589529	854934	647107	1740434	359559	Feb	1259000	1259000	1259000	1259000	1259000
Mar	903565	887416	1315525	608492	20260.1	Mar	1259000	1259000	1259000	1259000	1259000
Apr	148853	-45362.2	686598	593186	407890	Apr	1259000	1213638	1259000	1259000	1259000
May	-62828.4	3888.32	328982	720751	-53087.8	May	1196171.6	1217526	1259000	1197715.4	1205912.2
Jun	-68032.6	124240	-50837.8	-61284.6	-58966.8	Jun	1128139	1259000	1208162	1146912.2	1146945.4
Jul	-61766	-27836	-67454.2	-50803.2	-54537.2	Jul	1066373	1231164	1140708	1078854.7	1092408.2
Aug	-47389.8	-57802.4	-61887.8	-68057.5	-57183.2	Aug	1018983.2	1173362	1078820	1014897.3	1035225
Sep	-36115.8	3197.38	-44019.2	-63957.4	286120	Sep	982867.4	1176559	1034801	1091117	1259000
Oct	274571	1052340	386821	76219.7	525433	Oct	1257438.6	1259000	1259000	1259000	1259000
Nov	1268124	1304572	1397446	488472	560264	Nov	1259000	1259000	1259000	1259000	1259000
Dec	1389222	1002271	934986	1485676	835844	Dec	1259000	1259000	1259000	1259000	1259000
Annual	5365528	6170635	6076764	6404114	3589659						

5.1. POTENTIAL WATER CONSERVATION INITIATIVES

The average daily water use is generally low by many house owners in Bowen Island. This is because many landowners 0only live on the island on a seasonal basis; mostly during the summer, and a significant portion of the residents are retired (low number of people/connection). However, almost 50% of the water users have daily water uses in the summer that exceeds 300 L/P/D. This means conservation measures should be focused on summer water use.

5.2. Year-Round Recommendation and Conservation Measures for All Users

1. Increasing the Storage Capacity of the Lake

Presently, the maximum storage capacity of the lake is 1259 cubic decameters at the spillway crest elevation. This means once the storage reaches this volume or exceeds it as is usually the case during winter, the excess water goes into the discharge. As observed in Table 10, at least 7 of the 12 months of the year receive more water than the maximum storage capacity of the lake, which usually spills. If the storage capacity were larger than it is, it would be able to save more water during the period of excess to save for the drier months.

2. Pricing

The use of pricing as a conservation measure has already been adopted by the Bowen Island Municipality. The price for Cove Bay is set at a flat rate of $260 if people use less than $34m^3$ per month. However, if they use more than $34m^3$, there is a surcharge of $1.55 per cubic meter above the 34m3 limit. This strategy could be further improved by volumetric pricing using block rates (with very high rates for high water users).

3. Mandatory Low Flush Toilets

The other issue that applies to all users is Mandatory Low Flush Toilets which can save 25-30% of the daily water use. This will help conserve a lot of water for other use.

4. Reducing Non-Revenue Water

Prevention of water loss from water distribution and water treatment systems. The Canadian Council of Ministers of the Environment (CCME), in 2006 stated that across Canada, about 15% of the actual water withdrawals (example of which is recorded at the Treatment Plant) are from non-revenue water which could include leakages from distribution and treatment systems. It added that the amount of this loss could go as high as 37%.

As shown in Table 6, the difference between the treatment plant data and the metered water use data between 2015 and 2019, which constitutes unaccounted water is about 8-16% of the total annual treatment plant data. This means that a lot of conservation can be achieved by fixing the leakages and pipe replacement program. These could help to reduce non-revenue water to about 6% but may not eliminate it.

5.2 Recommendation for Summer Water Conservation Options

1. Rainwater Harvesting for Outdoor and Future Reuse

Rainwater could be harvested and reused for non-potable domestic uses (e.g. laundry, toilet flushing, and lawn irrigation). These practices particularly help to reduce a community's demand for freshwater, since winter precipitation yields excess water.

This can reduce summer use by 10-20% depending on outdoor activities (Gardens, lawns, etc.). The Municipality could also ban the use of domestic water for most outdoor water uses.

2. Lawn Water Use Restriction

Residents should embrace more efficient irrigation practices like adopting drip irrigation. Also, planting drought-tolerant plants and using-landscaping techniques that conserve water should be encouraged. Minimizing the size of lawns, xeriscaping, or adding 30cm of topsoil before planting lawns is a good way to reduce summer water use. Ultimately, limiting lawn irrigation during July and August should be considered. Lawns will turn yellow but will recover within 14 days as soon as the rainy season starts in the fall.

3. Water Use Restrictions

More restrictions could be placed on how water is being used during dry summer. Different stages/levels of restriction could be implemented depending on how drought and temperatures progress during the summer.

6.1 CONCLUSION

This study determined the water use of the residents of the Cove Bay Water System and evaluated the water inflow from the watershed into the lake and determined the water balance of the lake for the past 5 years.

- Water Consumption: Based on the metered data from the water treatment plant and the metered residential water use data, it was shown that the average daily water use is relatively low (220 L/P/D), but more than 50% of the residents use more than 300 L/P/D during the summer (May-Aug). About 30% of the total water use is for institutional and commercial (ICI) purposes and about 8-16% of the water is unaccounted for (non-revenue water & leakages).
- Watershed Balance and lake inflow Determination: Using a water balance approach a good estimate of the precipitation and evapotranspiration relationship was established but without stream runoff data into the lake, it was a challenge to decide how much of the drainage is lost to groundwater and how much are surface and subsurface flow into the lake. An estimated 0%, 10%, and 20% loss to groundwater was used to determine how this impacts the lake inflow.
- Lake Water Balance: Little data was available for the lake outflow into the stream, except for the minimum summer flow requirement during the summer of 8.5m^3/sec/day. This was used as an approximation but will need to be modified when more seasonal flow data is available. The evaporation of the lake was estimated at 123209m^3 annually. The impact of 10% and 20% changes in inflow was used to determine how sensitive the lake balance is to such changes. The results showed that impacted the water balance by 10.5% and 20.97%, respectively.
- Summer Precipitation and Temperatures as a predictor of water Use: It appears that summer precipitation is a good determinant of summer water use. The regression of monthly precipitation versus monthly water use was found to be significant when using the combined monthly data for all five years (2015-2019). In contrast, temperature versus water use was not significantly correlated.
- Potential Water Conservation Measures: Since 50% of the residents use relatively high amounts of water during the summer, recommendations were made for additional conservation measures, such as rainwater harvesting, lawn restrictions, soil amendments for outdoor use activities, additional water use restriction measures and using water-saving devices.
- Current Water Situation: Something like the current situation is adequate but there are concerns about future conditions because of population growth and climate change.

Recommendation and Limitations:

1. Some monitoring has been initiated and the modelled result will need to be modified and calibrated once inflow and outflow data will be available in the coming season.

2. The projected climate change data from the Pacific Climate Impacts Consortium (PCIC) is now available for 2100 and this data should be used to project the effect this has on the watershed and lake balance.

3. The Vancouver Harbour climate station data for 2015-2019 was used in all water balance calculations. It is the closest data that matches the conditions on Bowen Island. Since no calibration data was available from the Bowen Island stations since 2012, it is recommended that climate monitoring at the island station should be resumed.

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