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MEMORANDUM

TO: **Zoe Norcross-Nu'u, Engineering Analyst, Comox Valley Regional District**
FROM: **Krystal Chin, M.Sc., P.Geo., Joseph Demarais, M.Sc., and Patrick Little, M.Sc., P.Ag., Nicole Wright, Ph.D., P.Geo., Ecofish Research Ltd.**
DATE: **January 29, 2024**
FILE: **1374-15**

RE: Updated Graham Lake Hydrological Assessment

1. OBJECTIVES AND BACKGROUND

Ecofish Research Ltd. (Ecofish) was retained by Comox Valley Regional District (CVRD) to conduct a hydrological assessment at Graham Lake on Denman Island (the Project). The objective is to review current water demands at Graham Lake and assess its long-term feasibility as a continual water source under available climate change projections. Climate change is an important factor to consider in long-term planning, as it may affect the lake's current and future capacity as a water source by changing the timing, duration, and magnitude of precipitation and water inflow.

The assessment was completed and summarized previously in Chin *et al.* (2023)[1]; upon review an error was discovered in the data used for the analysis. The incorrect drainage area (9.8 km^2) was used to derive the synthetic flow series at the outlet of Graham Lake, which resulted in an overestimation in projected flow under different climate scenarios. This memo provides an updated assessment using a revised delineation of watershed boundary and drainage area (2.38 km^2) calculated from LiDAR digital elevation model (DEM) data. The results now show the likelihood of a water deficit in July as well as August, and an increased risk of water deficit in June and September.

2. METHODS

A desktop review of available meteorological and hydrological data was completed to determine the key components of the water balance at the Graham Lake watershed, and how water availability compares with water use records provided by CVRD (Norcross-Nu'u pers. comm. 2023[2]). The following equation was used to calculate the water balance at Graham Lake:

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[1] Chin, K., J. Desmarais, and P. Little. 2023. RE: Graham Lake Hydrological Assessment. Memorandum prepared by Ecofish Research Ltd. September 15, 2023.

[2] Norcross-Nu'u, Z. 2023. Engineering Analyst, Comox Valley Regional District. Email communication with Pam Dinn, Ecofish Research Ltd. June 12, 2023.

$$\left(\boldsymbol{P} + \boldsymbol{Q}_{\boldsymbol{inflow}}\right) - \left(\boldsymbol{E} + \boldsymbol{U} + \boldsymbol{Q}_{\boldsymbol{outflow}}\right) = \Delta \boldsymbol{S} \qquad \textbf{Equation 1}$$

where P is precipitation, Q_{inflow} is the surface runoff from the Graham Lake drainage basin, E is evaporation, U is water use, and $Q_{outflow}$ is the outflow from the lake. Precipitation and surface runoff are considered inputs to Graham Lake, while evaporation, water use, and lake outflow are outputs (i.e., removal of water from the lake); ΔS is lake storage and is the resulting difference in water inputs and outputs.

Water use data were available for this assessment, while precipitation, surface runoff, and evaporation were estimated. These four variables were combined and compared to gain insight into how the combined change in storage/outflow may differ from month to month, during historical periods and under a climate change scenario.

2.1. Climate and Hydrology

No continuous climate time series that allowed the calculation of evaporation and that covered the past decade was available for Denman Island or nearby Hornby Island. Historical hourly climate data (1989–2023) were provided by the Bowser FLNRO-WMB weather station (PCIC 2023a[3]). The station is located on Vancouver Island, 9-km southeast of Graham Lake, at an elevation of 184 m above sea level (Map 1). The station measures hourly air temperature, precipitation, and relative humidity; the data were summarized to average daily values to inform the model.

As solar radiation data were not measured by the Bowser weather station, a simplified version of the Penman formula (Linacre 1977[4]) that uses air temperature as the only meteorological input variable was selected:

$$\boldsymbol{E} = \frac{\left(\frac{700\boldsymbol{T}_{\boldsymbol{m}}}{100-\boldsymbol{A}}\right)+15(\boldsymbol{T}-\boldsymbol{T}_{\boldsymbol{d}})}{(80-\boldsymbol{T})} \qquad \textbf{Equation 2}$$

where, T is the mean daily air temperature (°C), $T_m = (T + 0.006h)$, h is elevation (Graham Lake elevation is 33.65 m), A is the latitude of Graham Lake (degrees), and T_d is the mean daily dew point temperature (°C). The mean daily dew point was calculated using the Magnus formula (Magnus 1844[5]) from relative humidity (RH) and temperature.

$$\boldsymbol{T}_{\boldsymbol{d}} = \boldsymbol{T} - \frac{(100-\boldsymbol{RH})}{5} \qquad \textbf{Equation 3.}$$

There were no hydrometric data available at Graham Lake, therefore data from nearby Water Survey Canada (WSC) gauge at Dove Creek near the Mouth (Station ID: 08HB075;

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[3] PCIC (Pacific Climate Impacts Consortium). 2023a. BC Station Data: Bowser ID: 1020910. Available online at: https://services.pacificclimate.org/met-data-portal-pcds/app/. Accessed August 16, 2023.

[4] Linacre, E.T. 1977. A simple formula for estimating evaporation rates in various climates, using temperature data alone. Agri. Meteorol., 18; 409-424.

[5] Magnus, G.1844. Versuche über die Spannkraft des Wasserdampfs. Annalen der Physik und Chemie, 138; 225-247.

Government of Canada 2023[6]) was used to estimate daily inflow for Graham Lake. For this study, discharge in an ungauged river (Q_u) (i.e., Graham Lake inflow) was estimated using discharge at a nearby gauge (Q_g) (i.e., WSC at Dove Creek) according to the drainage area scaling method:

$$\boldsymbol{Q_u = Q_g \cdot \left(\frac{A_u}{A_g}\right)^b} \qquad \textbf{Equation 4}$$

where *A* is the area of the gauged and ungauged catchments, and *b* is a scaling exponent which varies with the ecozone of the watershed, and in this case is equal to 1 (NHC 2020[7]). The WSC Dove Creek gauge has a drainage area of 41.1 km^2, is located nearby on the eastern coast of Vancouver Island (Map 1), and has a daily discharge record covering the period 1985 to 2022. Watershed boundary, stream network, and lake area for Graham Lake were calculated using LiDAR DEM data from 2018 and 2019 with 1 m grid resolution (LiDAR BC 2024[8]). Tiles were first merged to create a single full-coverage DEM, followed by utilization of ArcGIS Spatial Analyst tools for watershed delineation and stream network extraction. The pourpoint of the watershed delineation was selected at a location approximately 100 m downstream of the lake outlet at a suitable location for future gauge installation. Lake area was extracted from LiDAR DEM by extracting surface elevation of the lake at 33.65 m.

Although the WSC gauge watershed is larger than the Graham Lake watershed, which is 2.38 km^2 (without Graham Lake; LiDAR 2024[8]), it has similar watershed characteristics (i.e., minimal high elevation snowmelt contribution) and has a substantive long-term dataset, which makes it suitable to estimate discharge at Graham Lake using the drainage area scaling method (Equation 4). Using this method, a discharge flow series of inflow to Graham Lake from 1985 to 2022 was derived, though only data from 2014-2021 were used to provide a consistent assessment considering the availably of water use data. Water use data prior to 2014 were omitted from this assessment because licence C124755 was not active until 2009, and there were no water use data available for the licence from 2009 to 2013. Water use data in 2022 were omitted due to it being an incomplete dataset.

2.2. Climate Projections

Climate change projections were gathered from the Pacific Climate Impacts Consortium (PCIC) Climate Explorer for the Denman Island area. The projections used the CanESM5, model run 8, for

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[6] Government of Canada. 2023. Historical Hydrometric Data: Station ID: 08HB075. Available online at: https://wateroffice.ec.gc.ca/mainmenu/historical_data_index_e.html. Accessed on August 24, 2023.

[7] NHC (Northwest Hydraulic Consultants Ltd.). 2020. British Columbia Extreme Flood Project, Regional Flood Frequency Analysis – Technical development report and manual to complete a regional flood frequency analysis. Bulletin 2020-1-RFFA, NHC PM3004476. Report prepared by Northwest Hydraulic Consultants Ltd. (NHC) for the British Columbia Ministry of Forests, Lands, Natural Resources Operations, and Rural Development.

[8] LiDAR BC. 2024. BC LiDAR Data Portal Digital Elevation Model BCGS Tiles 92F056, 92F057, and 92F047. Available online at: https://www2.gov.bc.ca/gov/content/data/geographic-data-services/lidarbc. Accessed on January 25, 2024.

the SSP5-85 climate scenario (PCIC 2023b[9]). Mean daily precipitation (mm/d) for each month, minimum daily temperature (°C) for each month (i.e., the mean of daily minimum temperature for the calendar month), and maximum daily temperature (°C) for each month were modelled for four time periods: 1981 to 2010, 2010 to 2039, 2040 to 2069, and 2070 to 2099.

PCIC does not provide projections of flows for each period. Because precipitation is the main driver of flow inputs into Graham Lake, it was deemed suitable that projected precipitation changes could be applied to prorated flow data at Graham Lake, to estimate projected flows for each future period. The PCIC modelled data suggested that summer (July and August) precipitation during the 1981 to 2010 period was lower than the 2010 to 2039 period. Based on the assumption that the amount of precipitation is directly correlated to flow, these projections assert that summer flow during the 2010 to 2039 period are greater than the 1981 to 2010 period. This trend was not observed; the measured hydrology data show that mean July and August flow during the 2011 to 2022 period were 30% and 60% lower than the respective monthly flows during 1981 to 2010. For this reason, the modelled and estimated data from 1981-2010 data were omitted and the historical flow data for 2011-2022 was assumed to be representative of 2010-2039 flows. This period was then used as our baseline period. Thus, the percent change in mean monthly precipitation, relative to 2010-2039, was calculated for each month for the 2040-2069 and 2070-2099 periods. Percent changes in precipitation were then applied to the median value of mean monthly flow during the 2011-2022 period to estimate monthly flow during 2040-2069 and 2070-2099.

Mean daily temperature for each month in each period was calculated by taking the average of the projected daily minimum and maximum temperatures. The mean temperature was then used in Equation 2 to calculate projected evaporation for the two future periods (2040-2069 and 2070-2099).

3. RESULTS

3.1. Climate and Hydrology

The monthly total direct precipitation onto the lake surface, and mean inflow estimated at Graham Lake from 2007 to 2022 is shown in Figure 1; though only data from 2014-2022 were used for this assessment (as described in Section 2.1). Total precipitation for each month in m^3 was calculated by multiplying the estimated monthly columnar precipitation (mm) by the lake surface area (136,550 m^2; LiDAR 2024[8]). Total estimated monthly inflow into Graham Lake from 2014 to 2021 ranged from 5,562 m^3 (with a standard deviation of 7,365 m^3) in August to 853,373 m^3 (with a standard deviation of 425,346 m^3) in January. Mean monthly total precipitation on the lake surface from 2014 to 2021 was 19,909 m^3 (with standard deviation of 15,819 m^3), ranging from 0 m^3 in July (2021), and 82,531 m^3 in November (2017) Mean annual total precipitation on the lake surface from 2014 to 2021

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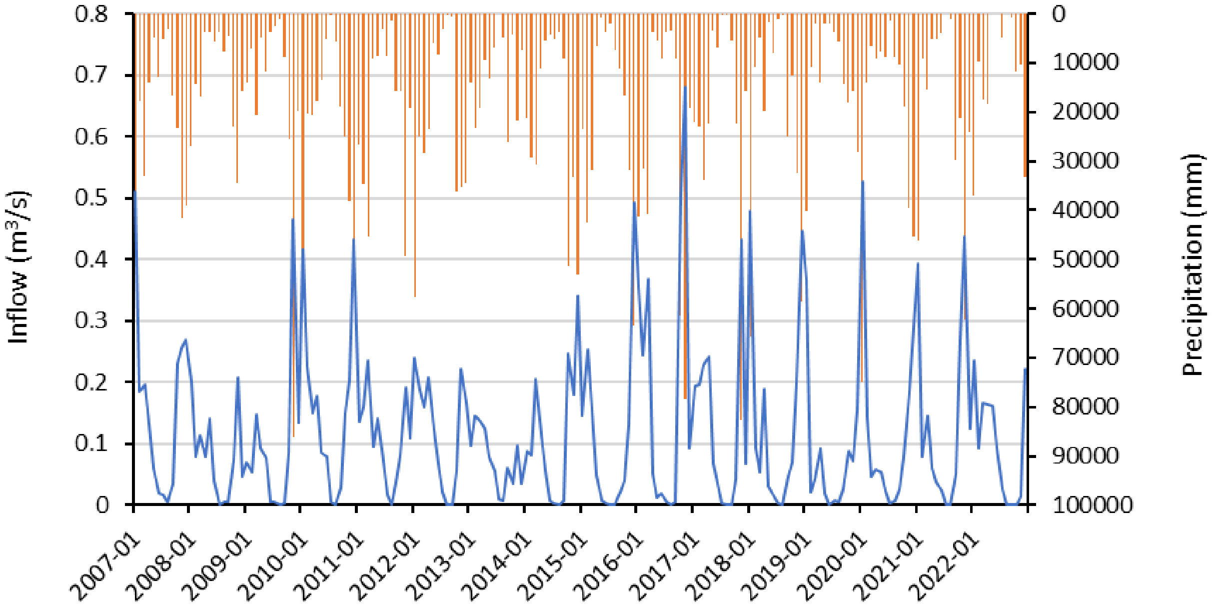
[9] PCIC (Pacific Climate Impacts Consortium). 2023b. PCIC Climate Explorer. Available online at: https://services.pacificclimate.org/pcex/app/. Accessed on August 16, 2023.

was 238,908 m^3 (with standard deviation of 41,629 m^3), ranging from the lowest total annual rainfall in 2019 with 156,404 m^3, and the highest in 2016 with 307,265 m^3.

Mean monthly total evaporation on the lake surface from 2014 to 2022 was 5,774 m^3 (with standard deviation of 4,795 m^3), ranging from 32.9 m^3 in December (2019)and 15,290 m^3 in July (2018) Evaporation was likely over-estimated during the winter period, with values given by Equation 2 typically differing from measured values by about 1.7 mm/day (Linacre 1977[4]). However, this potential magnitude of bias was considered acceptable and is not expected to have a substantive effect on the results of the scenario analysis. To verify estimates of evaporation at Graham Lake, results were compared to estimates of evaporation from nearby lakes on Vancouver Island and were found to be within the range of other estimates.

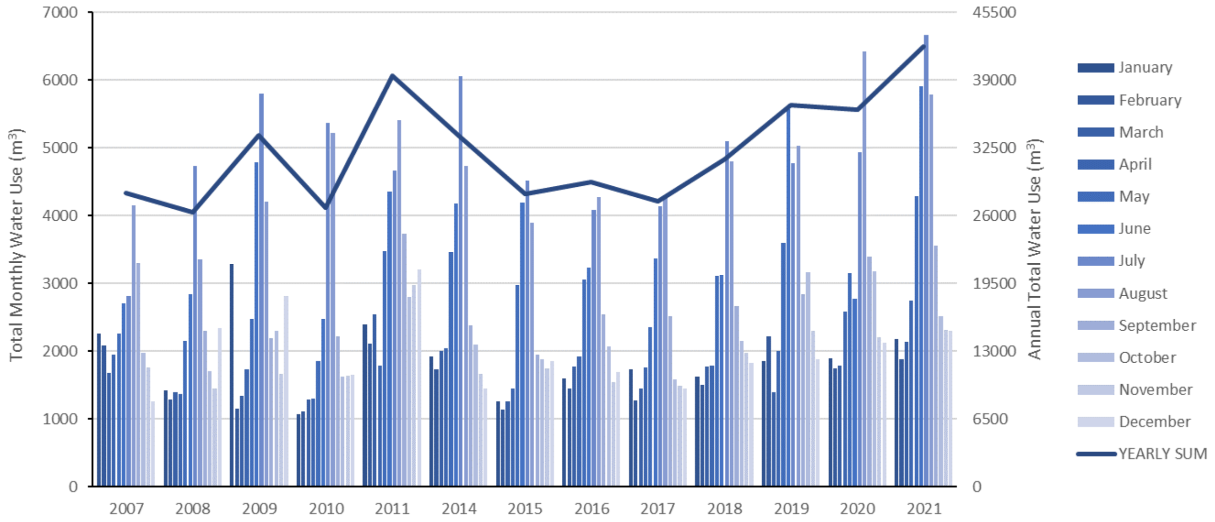
Figure 1. **Monthly direct precipitation on the lake and mean monthly inflow to Graham Lake from 2007 to 2022.**



3.2. Water Use at Graham Lake

Monthly water use records from 2014 to 2021 are compared with yearly average water use in Figure 2. Months with highest total water use consistently occurred in July and August, whereas, the month with the lowest water demand occurred between November to April in different years. The average monthly water demand in each year fluctuates between the years but appears to be increasing since 2017.

Figure 2. Monthly and annual water use at Graham Lake from 2014 to 2021.



To examine the current water demands at Graham Lake, the monthly water use data were compared with the Graham Lake water balance parameters from 2014 to 2021 (Figure 3). Results show that Graham Lake has positive net inflow for most months (October to May), which would result in outflow spilling from the lake, unless the lake has been drawn down below the level of the outflow channel. During five of the eight years, the water balance at the lake in both July and August were in deficit, meaning that outflow (spilling) would cease during these months (Figure 3). Fall precipitation would recharge any deficit that had accumulated (i.e., drawdown) over the summer, and once the lake is filled to the level of the outflow channel, would start spilling again for the fall and winter seasons. Measured outflow and lake level data were unavailable, and we were unable to estimate these parameters, given the relatively small scope of this study (a hydrologic modelling study would be required). For this reason, it is difficult to say how long the lake typically takes to refill. Generally, higher flows would start refilling the lake in September, with the exception of 2017, which was dry.

Figure 3. **Monthly comparison of lake inputs (blue bars; lake inflow + direct precipitation on the lake) and monthly losses from the lake (orange bars; lake evaporation + water use) for each year from 2014 to 2021. Note volume above 40,000 m^3 is not shown in the graphs.**

Monthly water losses (use and evaporation) at Graham Lake are compared with monthly inputs (precipitation and inflow) in Table 1. During the summer, lake evaporation and water use commonly exceeded the sum of direct preciptiation and lake inflow for at least one month of the year or more. August generally has the highest monthly water loss relative to inputs where losses exceeded >1000% of input in 2017, 2018, and 2021 (Table 1). However, losses were low compared to inputs from October to April due to high precipitation and low evaporation during those months (<10% of net inflow), which suggests that the lake would refill during this season.

Table 1. **Monthly water losses (water use and evaporation) presented as percentage relative to inputs (inflow and direct precipitation) at Graham Lake from 2014 to 2021. The red shading indicates months where losses exceed 100% of the lake inputs.**

Month	2014	2015	2016	2017	2018	2019	2020	2021
Jan	1%	0%	0%	1%	0%	0%	0%	0%
Feb	2%	0%	0%	1%	1%	6%	1%	2%
Mar	1%	1%	1%	1%	3%	6%	4%	1%
Apr	2%	5%	7%	1%	1%	3%	6%	6%
May	8%	64%	39%	5%	15%	28%	8%	11%
Jun	57%	176%	24%	14%	26%	330%	15%	27%
Jul	152%	747%	90%	206%	179%	58%	136%	1811%
Aug	475%	130%	271%	1502%	5000%	78%	66%	1107%
Sep	38%	14%	46%	168%	6%	12%	15%	6%
Oct	1%	5%	0%	4%	3%	3%	3%	1%
Nov	1%	1%	0%	0%	1%	2%	1%	0%
Dec	0%	0%	1%	1%	0%	0%	0%	1%

3.3. Climate Projections and Water Use Scenarios

Projected change in monthly precipitation and mean daily air temperatures are shown in Table 2 (PCIC 2023b[9]). These projections show that, relative to current (2010-2039) conditions, precipitation (and thus flow) is expected to be lower during the summer season (with the largest magnitude decrease occurring in July and August), and higher during fall and winter seasons (although some months show an increase in the 2040-2069 period and a decrease in the 2070-2099 period, or vice versa). Temperature is expected to increase during all months of the year in both the medium (2040-2069) and long term (2070-2099) periods.

Table 2. Summary of monthly climate change projections for the Denman Island area for future time periods. Change in mean precipitation (relative to current conditions of 2010-2039 period, expressed in %) is shown in the top table and projected mean air temperature in the bottom table.

Period	Change in Precipitation from 2010 to 2039 Period (%)											
	January	February	March	April	May	June	July	August	September	October	November	December
2040-2069	1%	-7%	7%	0%	20%	-16%	-13%	-10%	23%	12%	7%	4%
2070-2099	9%	7%	16%	-8%	-2%	0%	-39%	-30%	-6%	39%	19%	11%

Period	Mean Temperature (°C)											
	January	February	March	April	May	June	July	August	September	October	November	December
2023-2039	4.6	6.1	6.7	9.8	13.8	17.2	19.8	20.3	16.8	11.1	6.5	4.3
2040-2069	7.1	7.8	9.7	12.9	15.8	20.1	22.8	22.7	19.3	13.9	9.0	6.4
2070-2099	9.1	10.5	11.9	14.8	18.6	22.6	26.7	26.6	22.8	16.9	12.1	9.1

Climate change is expected to alter watershed hydrology at Graham Lake. Water demand may also increase but is constrained by the maximum annual volume authorized under the Graham Lake Improvement District and CVRD water licences. Therefore, climate projections were compared to two scenarios of water use; the first scenario used the maximum observed monthly total water use from 2007 to 2021, and the second scenario used an estimate of the monthly water allocation of existing water licences (C67571, C67572, and C124755) (Table 3). The water licences authorize an annual allocated volume rather than a monthly volume, so to compare the maximum water use to monthly inputs to Graham Lake, the monthly allocated volume was estimated based on the historical average distribution of water use across the year.

Table 3. Monthly water demand for the two water use scenarios.

Month	Maximum Observed Water Use (m^3)	Maximum Licensed Allocation (m^3)
Jan	3281	3719
Feb	2215	3417
Mar	2548	3591
Apr	2748	4311
May	4285	6878
Jun	5913	8562
Jul	6662	10653
Aug	6422	10385
Sep	3729	5777
Oct	3183	4930
Nov	2976	4027
Dec	3207	3852

Table 4 shows historical maximum water use or allocated water use plus estimated mean evaporation (i.e., water losses) compared to estimated lake inputs (i.e., the median value of mean monthly inflow during the period plus mean monthly precipitation) for the current period as well as for future periods. Comparisons between lake inputs and losses are also shown graphically for the two future time periods under the two water use scenarios in Figure 4 and Figure 5. The median value of mean monthly inflow during the 2010-2022 period was used as the baseline estimate of monthly flow in this analysis. Median of mean monthly flow was chosen because the median value is generally closer to what is "typically" seen and is not skewed by one or two annual observations of high monthly inflow that can cause the mean to be much higher than what is "normally" observed. Choosing the median of mean monthly flow over the period means that the monthly flow value shown for each month was higher than mean monthly flow for half the years and lower for the other half of years.

During the current period (2011-2022, representing the 2010-2039 period), the maximum observed July and August water use plus estimated evaporation was 119% and 305%, respectively, of lake inputs. This means that during July, inputs were lower than losses for approximately quarter of the time. Climate change predictions suggest that precipitation will be lower during the summer months (Table 2), which will result in lower lake inflow at Graham Lake. In addition, higher temperatures are predicted (Table 2), which will result in greater evaporation, particularly for July and August. During future periods, typical water losses during July and August are predicted to be 153-293% of July water inputs and over 300% of August inputs, which suggests that summer lake drawdown will be more severe than it has been historically. Predicted water loss in June and September range from 27-34%

and 16-29% relative to inputs, respectively, while April, May, and October losses are expected to be fairly similar to current conditions (3-12% of inputs). Losses during fall and winter months are still expected to be less than or equal to 2% of water inputs, which suggests that the lake will continue to fill and outflow will continue to occur over the fall, winter, and spring seasons in the future.

Table 4. Water losses (water use and evaporation) expressed as a percentage of water inputs (direct precipitation and median of mean monthly inflow) at Graham Lake during baseline and future periods.

Month	Allocated water use and evaporation as % of total lake inputs			Maximum historical water use and evaporation as % of total lake inputs		
	2011-2022	2040-2069	2070-2099	2011-2022	2040-2069	2070-2099
Jan	1%	1%	1%	1%	1%	1%
Feb	1%	2%	2%	1%	1%	1%
Mar	1%	2%	2%	1%	1%	1%
Apr	3%	4%	4%	3%	3%	4%
May	10%	9%	12%	8%	7%	10%
Jun	26%	34%	31%	22%	29%	27%
Jul	146%	184%	293%	119%	153%	249%
Aug	376%	369%	532%	305%	306%	451%
Sep	18%	19%	29%	15%	16%	25%
Oct	4%	4%	4%	3%	3%	3%
Nov	1%	1%	1%	1%	1%	1%
Dec	1%	1%	1%	1%	1%	1%

Figure 4. **Comparison of monthly water losses from the lake (orange bars; lake evaporation + maximum historical monthly water use) with lake inputs (blue bars; median monthly lake inflow + direct precipitation on the lake) for historical data (2011-2022) and for two future time periods (2040-2069 and 2070-2099) based on modelled climate change projections. Note monthly water volume above 40,000 m^3 is not shown in the figures.**

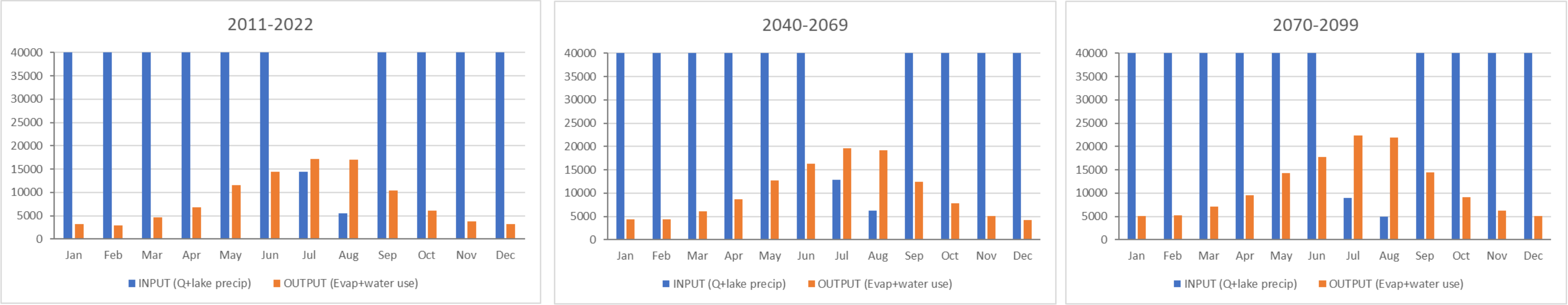
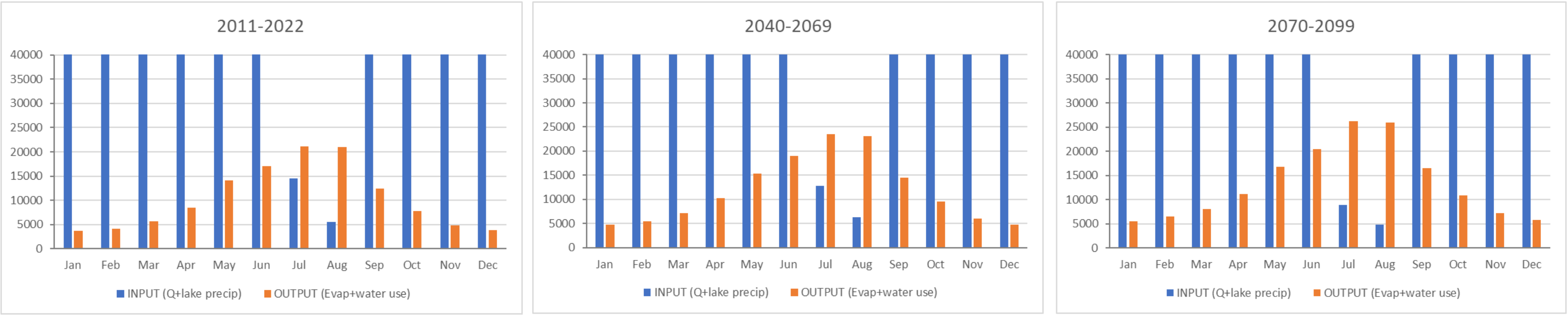


Figure 5. **Comparison of monthly water losses from the lake (orange bars; lake evaporation + maximum monthly allocation) with lake inputs (blue bars; median monthly lake inflow + direct precipitation on the lake) for historical data (2011-2022) and for two future time periods (2040-2069 and 2070-2099) based on modelled climate change projections. Note monthly water volume above 40,000 m^3 is not shown in the figures.**



3.4. Uncertainty

There are several sources of uncertainty that affect this study. The estimated rates of lake inflow, direct on-lake precipitation, and lake evaporation all have uncertainty associated with their calculations. Although, these are the best estimates that could be produced given the sparse data records and scope of this study, they may not align with anecdotal observations of Graham Lake; for example Norcross-Nu'u pers. comm. 2023[2] noted that the lake outflow dries up annually and storage decreases throughout the summer. Disparities between anecdotal reports and results from this analysis may be due to several uncertainties including the lack of measured Graham Lake inflow data, the lack of measured water level and/or outflow data, uncertain climate change predictions, and high interannual variability in precipitation from year to year that is not captured by climate change projections.

Hydrometric inflow data to Graham Lake was not available, so a daily inflow time series was estimated based on the Dove Creek near the Mouth (08HB075) WSC gauge using the watershed area proration method described in Section 2.1. This method can provide reliable results when the watersheds in question are comparable in size and have similar watershed characteristics and processes, but any differences in characteristics may result in inaccuracies in flow estimates. Although Dove Creek was chosen as the most analogous watershed with a long-term streamflow record in the vicinity of Graham Lake, there are several differences that could result in inaccurate estimates, including differences in area, elevation range, and physiographic characteristics. Spatial variability of hydrologic processes increases with watershed size, and the resultant streamflow at Dove Creek may not be representative of conditions in the Graham Lake watershed due to the large difference in watershed size; Graham Lake watershed is 2.51 km^2, while Dove Creek near the Mouth is 41.1 km^2. Differences in elevation can result in differences in runoff process and storage; higher elevation watersheds on the east coast of Vancouver Island will have snowpack that may result in a spring freshet or higher water table that could supplement baseflow further into the summer. The Dove Creek watershed has elevations exceeding 960 m, while the Graham Lake watershed extends to only 127 m above sea level. Additionally, these watersheds also have differing physiographic characteristics (e.g., soil types, geology, and upland water storage, etc.) that result in uncertainty in the derived Graham Lake inflow data. For example, the upper watershed of Dove Creek consists of lakes and wetlands that likely contribute to sustaining downstream flow later into the dry summer season, which are absent in the Graham Lake watershed. Overall, evidence suggests that inflow to Graham Lake is likely overestimated in the dry summer months.

The lack of measured water level or outflow data is another source of uncertainty that prevents the completion of a full water balance analysis. That is, without being able to estimate outflow and change in storage, the effects of water use on these factors could not be quantified. This data limitation imposes a great deal of uncertainty on the overall conclusions of the study including not being able to estimate changes in the timing of lake filling/outflow ceasing in the summer or returning in the fall.

This study relies on climate change projections provided by PCIC. PCIC offers climate change projections based on many (> 30) different Global Circulation Models (GCMs) for three different climate change scenarios. The SSP5-85 scenario that was chosen for this study can be described as a scenario that would occur under high economic growth and strong reliance on fossil fuels. Other scenarios would result in lower CO_2 emissions. Furthermore, the predictions offered by different GCMs for the same scenario can be very different – there is a great deal of uncertainty involved in predicting how local climate will change relative to increased CO_2 in the global atmosphere. The GCM that was chosen for this study was the CanESM5, model run 8, which provides estimates of precipitation and temperature that were not extreme relative to other GCMs (i.e., they were within the middle of the range of predictions made by other models). This all means that the trends in the climate projections are likely useful to understand, but quantifying these trends is loaded with uncertainty.

Interannual variability is an important factor in understanding how a lake water source may be affected by changes in hydrology or water use. Lake levels during one year can be affected by the preceding year's history of inflow and drawdown. However, the climate change projections used in this study show expected changes to the 30-years average but do not provide insight into how interannual variability will be affected. That is, these climate change predictions show expected changes to average conditions but do not predict how frequently low or high water years may occur, or the change in magnitude of low or high inflows. Thus, we can gain insight into the average, or typical, performance of Graham Lake as it relates to the water balance, but are unable to predict the potential effects of non-typical conditions, such as multiple consecutive dry years, which could change in frequency in the future.

4. CLOSURE

Climate change projections were applied to modelled hydrometric data at Graham Lake. It is reasonable to predict that the magnitude of lake drawdown experienced in summer months will continue to intensify as water demand continues to increase, and evaporation increases due to rising temperatures while precipitation decreases. This study alone is insufficient in providing a complete assessment of Graham Lake's reliability as a water source under future conditions; however, the study does provide valuable context and general trends of what may be expected in the future. Namely, lower summer inflows and potentially higher winter inflows are expected. This means that lake drawdown will likely be more severe in the summer, particularly July and August, with potentially increased drawdown in June and September, and that lake storage recharge will continue to occur in typical years. Given the scope of this study, we are unable to comment on any changes in the frequency of low flow water years that could affect lake storage recharge. In addition, the timing of these processes may change, which has implications for the timing of outflow from Graham Lake and aquatic life that relies on flow downstream of the lake; however, this study is unable to quantify how that timing is likely to change.

Understanding the current conditions of the lake can increase certainty of future scenarios. Thus, installing hydrometric gauges to measure flow at the inflow and outlet channels, as well as a water level gauge to measure change in lake storage is recommended. More detailed hydrologic modelling, such as a physically based hydrologic model, could be used to assess a year-round water balance to gain more certainty of how this water source is expected to perform in the future, but having measured data to parameterize such a model would be necessary.

Yours truly,

Ecofish Research Ltd.

EGBC Permit to Practice: 1002952

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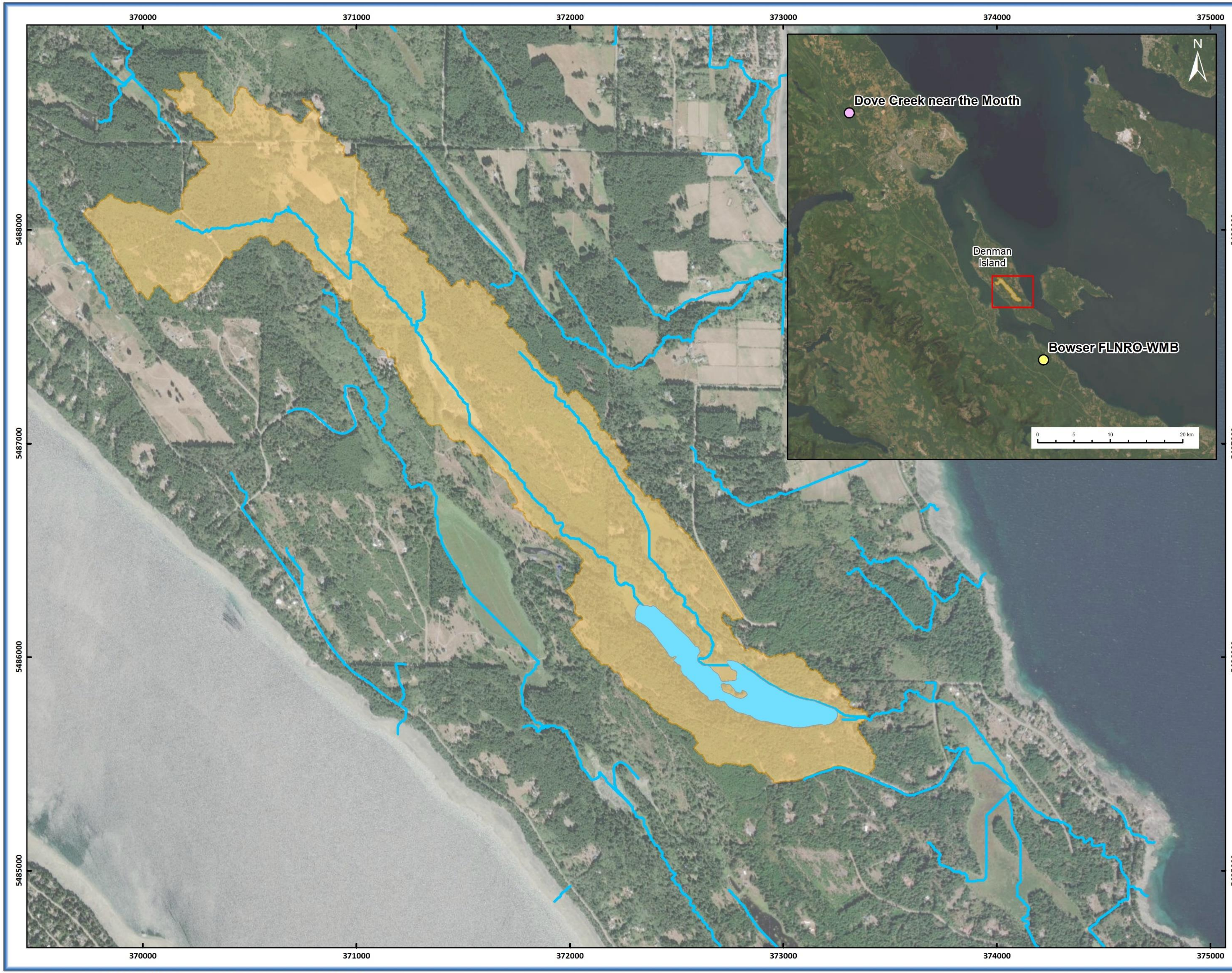
Disclaimer:

PROJECT MAP



COMOX VALLEY REGIONAL DISTRICT

Graham Lake Hydrology Project Overview

Legend
- 🟦 Graham Lake[1]
- 🟧 Graham Lake Watershed[1]
- — Stream Network[1]

Gauge Stations
- ● WSC Gauge
- ● Weather Station

[1] Lake, watershed, and stream network derived from LiDAR Digital Elevation Model (LiDAR BC 2024)

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 100 200 400 600 800 1,000 m

Scale: 1:17,000

NO.	DATE	REVISION	BY
1	1/26/2024	1374_GrahamLake_6369_20240124	NKN
2			
3			
4			
5			

Date Saved: 1/26/2024
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 1

Path: M:\Projects-Active\1374 CVRD\MXD\Hydrology\1374_GrahamLake_6369_20240124.mxd