TECHNICAL NOTE

WATER DIVERSION LICENSE LIMITS FOR ST. MARY LAKE, SALT SPRING ISLAND

by

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Summary for Policymakers

The Province issues licenses for surface water withdrawal for a range of purposes. Each license specifies the maximum amount that can be withdrawn over a defined period of time, usually one day or one year. For St. Mary Lake, all licenses total 573 dam^3 for the critical June-October summer season[1]. However, for an extreme drought the available safe yield during summer is about 350 to 380 dam^3, substantially less than allowed by license.

In view of such a large difference, the purpose of this investigation was to uncover the guiding principle used by the Province in allocating a water resource, and to confirm the basis for the numbers applicable to St. Mary Lake as of 2015.

What I have concluded is this: the basic design principle is to allocate water licenses up to a limit that is available for *climate average* hydrological conditions, taking critical environmental flow thresholds into account. The Province recognizes that the full allocation will not be met during droughts, and has implemented a complex procedure for restricting or denying withdrawals[2]. These include rights by precedence based on when the license was issued.

The design principle is readily confirmed for Salt Spring Island, and for St. Mary Lake, as shown in this note. The weaknesses are obvious: there are dry winters when the runoff is inadequate to replenish the fully allocated storage, and there are summer droughts that result in significant shortages of water to meet the licensed withdrawal total. Periods when restrictions come into force are inevitable.

Current demand appears to be well below the licensed total for St. Mary Lake. NSSWD and CRD both withdraw less than their licenses (approximately 460 dam^3 annually), which together account for 90% of the allocated total (1593 dam^3). However, summer demand (June-October) is roughly 340 dam^3 without water restrictions, leaving a reserve of about 12% of the safe yield[3].

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[1] NSSWD has one license for a annual withdrawal of 364 dam^3 that is dependent upon adding 370 dam^3 of storage. This license has not been included in the totals shown here since the additional storage would require increasing the crest elevation of the current weir.

[2] See e.g., https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/drought-info/drought-response-plan-update-june-2015.pdf.

[3] Environmental flows at currently understood rates (9 L/s over summer) and evaporation have been taken into account.

BACKGROUND

This study was undertaken by the author to understand how water diversion licenses were allocated for Salt Spring Island, and to confirm the estimates for St. Mary Lake. The report was prepared to document the analytical methods and results, and is available in electronic format by request to don_hodgins@shaw.ca.

DISCLAIMER

While the results of the analyses are thought to be accurate within stated limits, and based on data that were available to the author, they are not guaranteed or warranted for any purpose, and persons or agencies wishing to use the results do so entirely at their own risk.

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1.0 CONTEXT

The BC Ministry of Forest, Lands and Natural Resource Operations (FLNR) issues licenses for water withdrawal from natural fresh water bodies, streams, rivers, lakes, swamps and ponds. Called water diversion licenses, they specify the use of the water, typically household potable water supply, waterworks, irrigation, industry, stockwatering, etc. Each license specifies a limit for withdrawal in a certain time period, either as a volume (m^3) for a day or for a year. For a given water body like St. Mary Lake, the total of the limits for all of the licenses would logically be the demand that could, theoretically, be supplied by that reservoir.

In a previous paper, I have shown that potable water supplies from surface reservoirs on Salt Spring Island are limited by summer drought (Hodgins, 2017). These are termed safe yields following the practice in some US states. Further, a second paper suggests that the total demand from licenses on St. Mary Lake and Lake Maxwell are more than twice the safe yield for a 1 in 100 year drought (Hodgins, 2018).

Here I examine some literature and data to explain the basis of the license limits and the logic behind the FLNR estimates of potentially available water for diversion.

2.0 CONCEPT

Limits to license allocation seem to be based on the concept of water storage to meet demand over the summer dry period. Net storage is the amount left after accounting for environmental flow requirements to protect fisheries, and evaporation.

Storage is a physically constrained amount unique to each water source. Figure 2.1 shows a schematic for St. Mary Lake where storage is shown by the hatched zone between the upper and lower water level limits.

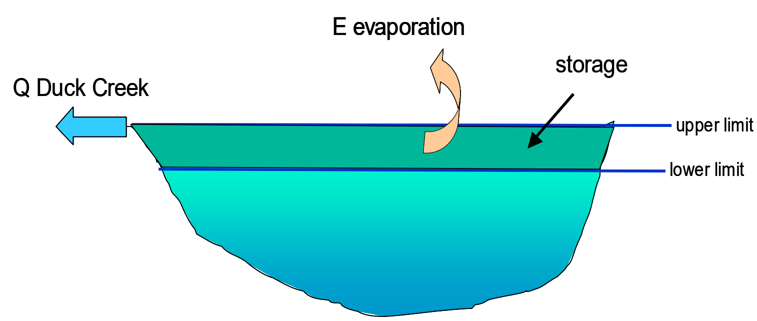

Figure 2.1 Schematic diagram for a lake reservoir showing storage between upper and lower limits. In this case St. Mary Lake flows out into Duck Creek, a fish-bearing stream.

In general:

- **upper limit** – is created by a natural constriction to an outflowing creek, by natural structures such as beaver dams, or by man-made structures (weirs or dams),
- **lower limit** – is usually set by environmental regulation.

One example of a lower limit for a water body supporting natural fisheries is a water level that does not reduce the shoal area of a lake or pond by more than 10%. The shoal area is defined as the area from the lakeshore at average summer level to a 6-m depth.

Conceptually then, water diversion licenses may be issued for all of the storage after subtracting instream fisheries flows and evaporation, *and* subject to complete refilling each year by *average* rainfall conditions. Such conditions are easily visualized for the southern Gulf Islands because there is no snowmelt to create a spring freshet. Here all of the draw down from May to October must be available from inflows over the preceding November-April period. I state it this way because the water allocation report for Salt Spring Island does not seem to take summer rainfall into account.

One of two situations governs: (i) physical arrangements determine the storage volume, and a hydrological check is made to ensure that November to April precipitation equals or exceeds that storage volume; or (ii) a hydrological estimate of net inflows for November to April is made to determine the amount of water that is available, and the storage limits are prescribed for that amount. In both cases the hydrological calculations are based on average precipitation/discharge conditions. Apparently storage determined this way may be fully allocated through licenses.

Droughts are not considered in these calculations.

I think of this as a "static" analysis: a fixed storage volume that is invariant with time, and available when winter rains exceed a climate average.

The amount of water available from lakes is, however, highly dependent on precipitation between about the middle to end of March, when the polar jet stream changes from its zonal regime to its meridional summer pattern, to the end of June. It is also dependent on when fall rains begin, which can vary from mid-September, to early November in droughty years. In addition the rate at which storage is utilized depends on when demand ramps up in May-June, and the peak values in July and August. In fact, the amount of water available in a given year is a dynamic process, highly weather dependent, regardless of the lake being full at the end of April. The dynamic (or time-varying) calculation method is shown in Hodgins (2017).

3.0 THE 1993 WATER ALLOCATION REPORT

The 1993 report was prepared by Barnett, Blecic and van Bruggen of the BC Ministry of Environment, Lands and Parks (Barnett et al., 1993, BBvB), and appears to be the definitive document for Salt Spring Island (confirmed by FLNR Feb. 14, 2018). The stated objective was to develop a water allocation plan to streamline the process of granting licenses and to provide a summary of relevant information for planning and assessing applications in regions of the Province rather than treating each license application independently (e.g., Salt Spring Island as a whole). The report provides some information on the hydrological basis for determining the amount of water that can be diverted for specific water bodies in that region. I have summarized their approach in the following sections.

3.1 Method

BBvB began with a hydrological calculation for net inflow using discharge data for Cusheon Creek, the only good dataset available to them in 1992. They divided the year into a draw down period (June to October) when storage would supply diversion water, and a filling season from November through April. To estimate the amount of storage available for diversion, allowance was made for instream flows to support fisheries during the winter filling season, and for evaporation during the summer. The water balance then looks like:

storage = inflow – instream fisheries outflow - evaporation

The balance equation was solved as follows.

inflow - outflow for Nov-Apr

Mean monthly net inflow I_{net} was calculated as:

$$I_{net} = I - 0.6\ MAD$$

where I = mean monthly discharge (in units of m^3/s)

MAD = mean annual discharge (in units of m^3/s).

The factor 0.6 was the upper limit for instream fisheries flow requirements according to a provincially modified version of the Tennant (Montana) method (see p. 20 of BBvB). No citation is provided for this method; however, flows above 60% of MAD are considered "excellent" spawning and rearing conditions according to the method. So presumably this factor provides a safe margin for fishery protection.

The total net inflow I_{tot} for storage replacement was calculated as the sum of I_{net} for November through April.

In 1993 flow data sufficient to determine a reliable MAD were available only for Cusheon Creek at the exit from Cusheon Lake. The time-series spanned 1976-1992 and consisted of daily discharge data. The monitoring station (08HA026) was decommissioned at the end of 1998.

I have reproduced their calculations with the entire dataset. The monthly mean data (plus other statistics) are listed in Table 3.1 and plotted in Fig. 3.1. As shown by the quartile curves there is considerable interannual variation in the data. The MAD from the full dataset is slighter greater than that calculated by BBvB. The calculation of available storage volume is shown in Table 3.2. The result is 2656 dam^3 for Cusheon Lake compared with 2550 dam^3 by the original authors. The six additional years of data do not make a significant difference to the answer.

Table 3.1 Monthly discharge statistics for Cusheon Creek (station 08HA026). Source: Water Survey of Canada statistical data (https://wateroffice.ec.gc.ca/report/)

	mean m^3/s	median m^3/s	25th m^3/s	75th m^3/s
January	0.377	0.367	0.287	0.528
February	0.362	0.44	0.253	0.525
March	0.248	0.254	0.165	0.323
April	0.099	0.104	0.064	0.133
May	0.037	0.034	0.017	0.055
June	0.01	0.006	0.004	0.016
July	0.002	0.002	0.001	0.003
August	0.001	0.001	0	0.001
September	0.001	0.001	0	0.001
October	0.004	0.001	0	0.001
November	0.084	0.066	0.002	0.182
December	0.311	0.38	0.124	0.535
MAD	0.128			
MAD	0.116	Barnett et al.		

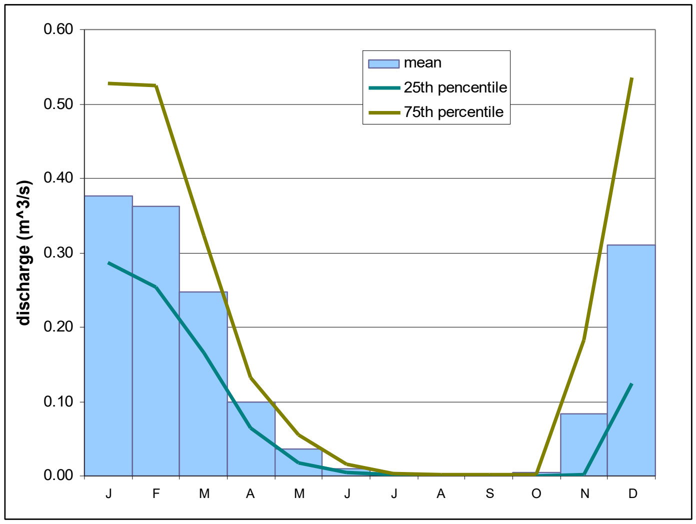

Figure 3.1 Monthly discharge statistics for Cusheon Creek (station 08HA026).

Table 3.2 Calculation of available storage volume allowing only for instream fishery flow requirements. This calculation repeats that done by Barnett et al. but using the longer dataset.

	monthly mean	flow in excess of 60% MAD > 0.077 m^3/s	available monthly storage volume
	(m^3/s)	(m^3/s)	(dam^3)
November	0.084	0.007	19
December	0.311	0.234	627
January	0.377	0.300	804
February	0.362	0.285	690
March	0.248	0.171	459
April	0.099	0.022	58
		Total I_{tot}	2656

The idea here is that the winter flow from the watershed *could* provide about 2600 dam^3 of water for storage to satisfy all water demands from June through October, for a winter with *average* precipitation (flow).

Problems with this approach

As noted earlier, this type of "static" analysis fails to take interannual variability in weather into account.

Figure 3.2 shows the actual November-April discharge (in dam^3) for the years 1977 to 1998. 1976 and 1984 are excluded because of missing data in the pertinent months. The heavy blue line shows the corresponding available storage using the calculation method in Table 3.2 applied to each year individually. Visual inspection suggests a trend to wetter winters over the 20-year data span, consistent with the findings described in Hodgins (2015) for a century of precipitation data. The solid green line is the data average storage from Table 3.2.

One measure of the interannual variability is the storage anomaly, calculated as the difference between the annual storage volumes and the target storage of 2656 dam^3. The anomalies, plotted in Fig. 3.3, range from a deficit of about -1700 dam^3 to a surplus of over 3000 dam^3.

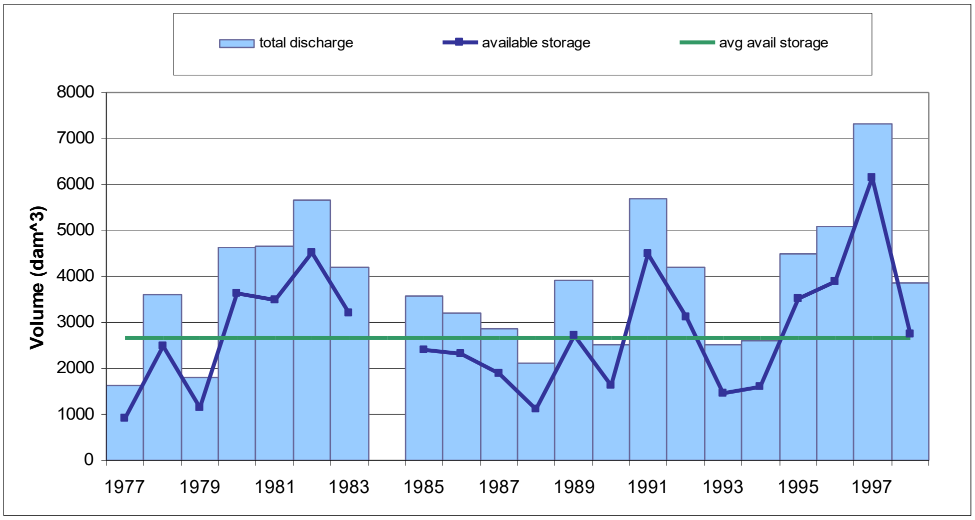

Figure 3.2 November-April discharge and available storage volumes calculated annually for Cusheon Lake.

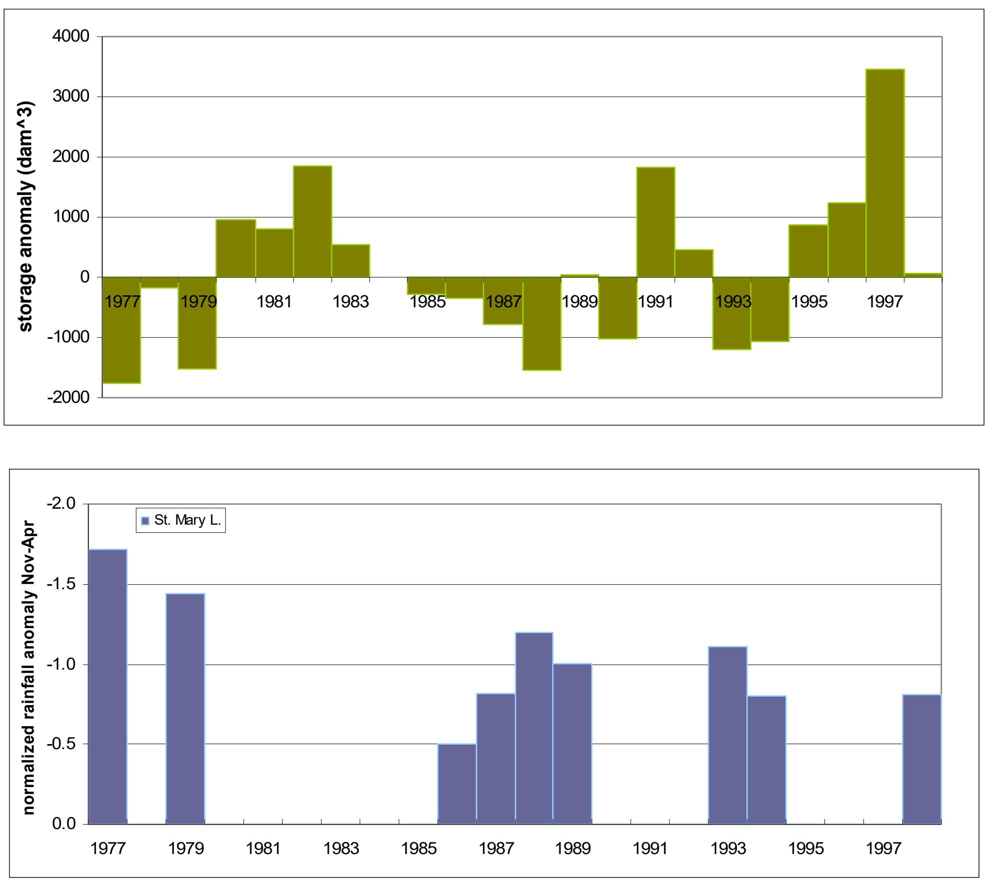

Figure 3.3 November-April discharge anomalies calculated annually for Cusheon Lake (upper panel), and corresponding precipitation anomalies for extreme low rainfall winters (lower panel).

The lower panel in Fig. 3.3 shows the precipitation anomaly for droughty winters, which is clearly correlated with the low storage years and simply confirms that low flows through the watershed result from low rainfall over winter.

There are seven deficit values exceeding 500 dam^3 in the record. Fitting these with a Gumbel extreme value distribution (Fig. 3.4) *suggests* that under extreme conditions (~100 year return) deficits might approach 2000 dam^3. While not a tremendously precise estimate, these results *indicate* that extreme dry winters could result in shortfalls approaching 60% of the hypothetical average storage volume.

In the case of Cusheon Lake, with an average storage of about 2600 dam^3, deficits of 1700 to perhaps 2000 dam^3 leave a utilizable volume of about 600 to 900 dam^3. BBvB note that an evaporation allowance of one foot (30 cm) should be applied to the summer low flow period. For a lake area of 27 ha this amounts to about 80 dam^3 of storage lost to evaporation. The remaining storage would range from about 520 to a little over 800 dam^3.

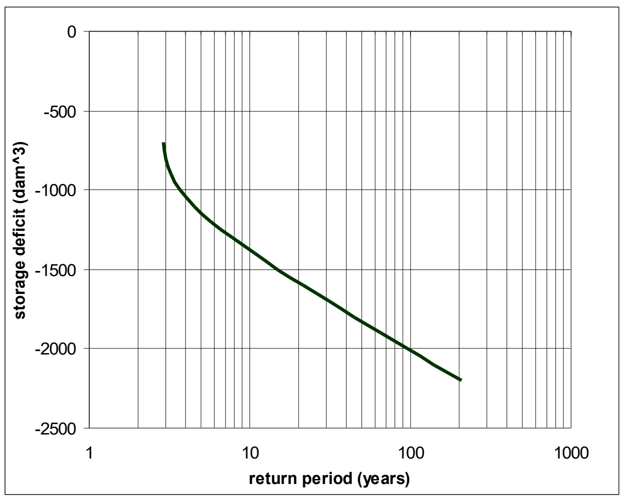

Figure 3.4 Storage deficit by return period (Cusheon Lake).

If diversion licenses fully allocate the average storage volume (2656 dam^3), then there is the potential of being unable to satisfy all licenses in an extreme dry year by a considerable margin.

3.2 St. Mary Lake

Translating this result to St. Mary Lake

Having only the Cusheon Lake data to work with, BBvB calculated a unit runoff value, R, for that watershed as follows:

$$R = I_{tot}/A_c$$

where I_{tot} is the total net runoff from November through April (Table 3.2),

A_c is the land catchment area of the watershed, calculated as the watershed area minus the lake surface area.

The total area of Cusheon watershed is 724 ha, and the lake surface area is 27 ha providing a catchment area of 697 ha (BBvB p. 8). With these values and the total from Table 3.2, R = 3.81 dam^3/ha (3.66 in BBvB).

Assuming that the runoff characteristics in the other watersheds are close to those in Cusheon, BBvB obtained estimates of the available annual storage volume by multiplying R by the watershed area. [I find this inconsistent with the calculation of R and suggest that the correct calculation would be R times the land catchment area.]

The calculations are shown below for St. Mary Lake:

R =	3.81	dam^3/ha
St. Mary Lake		
watershed area	707	ha
lake area	181	ha
land catchment area	526	ha
available storage		
using catchment area	2004	dam^3
using total area	2694	dam^3
from BBvB	2588	dam^3

This method yields net inflows of about 2600 dam^3 (or 2000 dam^3 using the catchment area). This inflow is theoretically net of instream fishery flows for the November to April high flow period, and by implication is an amount available to replenish summer storage. However, it assumes that the hydrological characteristics of the St. Mary Lake watershed are equivalent to those for Cusheon Lake, despite their difference in size and drainage characteristics.

The conclusion seems to be that average winter flows in excess of 2000 dam^3 would be sufficient to provide storage within St. Mary Lake's natural limits.

Checking the discharge from St. Mary Lake

One difficulty faced by BBvB was the lack of discharge data to Duck Creek. These data are shown in Fig. 3.5 together with water level data obtained from Water Survey of Canada. None of the years contain data from November and December and in most years, data collection commenced in April. BBvB chose to work with data from only 1980, which had the most complete coverage, but it was impossible to calculate a mean annual discharge with statistical significance. Nevertheless, scaling November and December discharges from those measured in January using factors found for the Cusheon watershed, yields an approximate annual hydrograph for monthly flows derived from all measurements (Fig. 3.6 – very close to that in BBvB, Figure 5, p. 16). The MAD is 0.10 m^3/s, exactly equal to the number reported by BBvB. Repeating the calculation shown in Table 3.2 for St. Mary Lake provides a storage volume for November to April of 2038 dam^3.

Thus, both approaches: transferring flows from Cusheon, and using the sparse data set from St. Mary Lake, yield estimates of storage volumes in excess of 2000 dam^3. This consistency provides some confidence in the number, applicable to average precipitation conditions over winter.

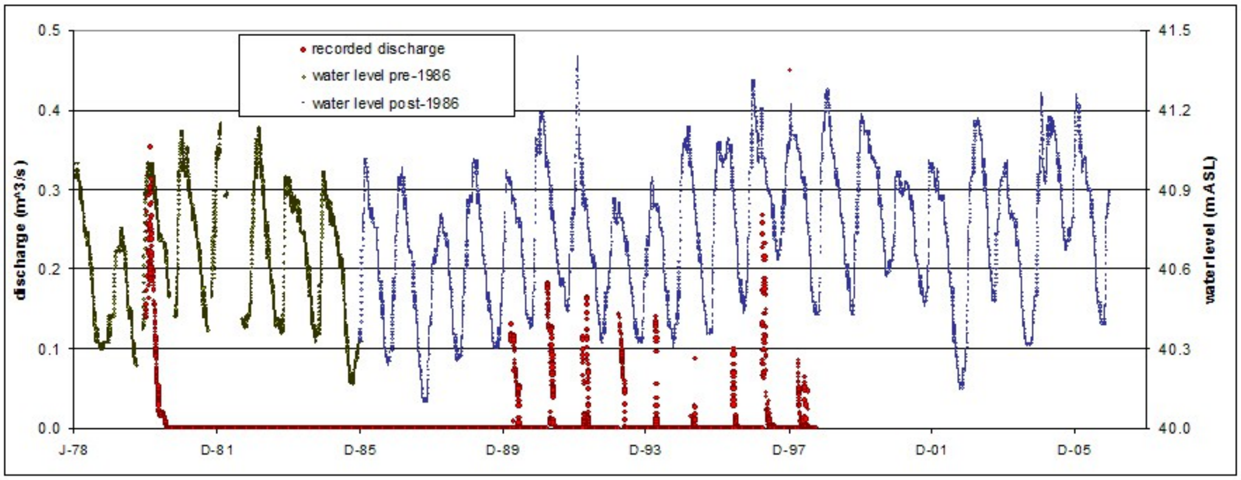

Figure 3.5 Time-series of water level and flow in Duck Creek (station 08HA046). The zero flow rates along the time axis represent observations or missing data. Source: https://wateroffice.ec.gc.ca/search/historical_e.html).

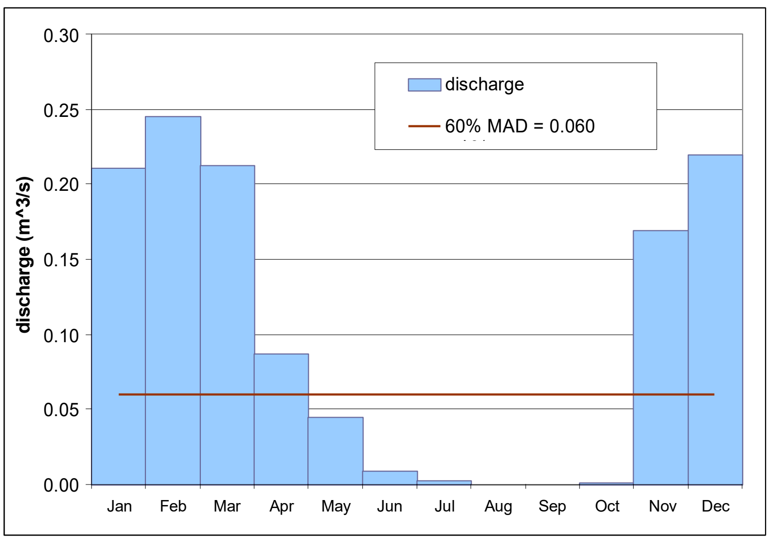

Figure 3.6 Monthly mean flows in Duck Creek derived from all measurements. The November and December data were derived by scaling January flows using ratios derived from Cusheon Lake.

Storage in St. Mary Lake – situation then and now

Prior to construction of the fixed weir in 2006 physical storage in the lake was controlled by beaver dams in Duck Creek. Average water levels fluctuated by about 30 cm due to changes in the "crest" of the dams. There was little or no flow past these dams during summer, and Duck Creek was essentially dry from late July to October. Water level was measured from 1978 onward, daily to begin with and then approximately weekly (Fig. 3.5). The monthly statistics are shown in Fig. 3.7. The 90th percentile level was 41.055 m, while the 10th percentile level was 40.362 m. The median levels in June and October were 40.75 and 40.37 m, suggesting that the naturally controlled storage was on average about 38 cm, or 692 dam^3 during the summer. Median levels for the weir period, 2007-2015, are shown by the green line in Fig. 3.7. Roughly, the weir lowered average water levels by about 15 cm throughout the year.

BBvB noted that "normal" water levels (1978-1992) fluctuated between 40 and 41 m ASL, which one could say looks about right visually scanning the data, although levels were never as low as 40 m. They proposed that a control structure be installed to create storage between these two limits, providing approximately 1820 dam^3 (= lake area times 1 m). Such a structure would considerably increase the available storage for withdrawals.

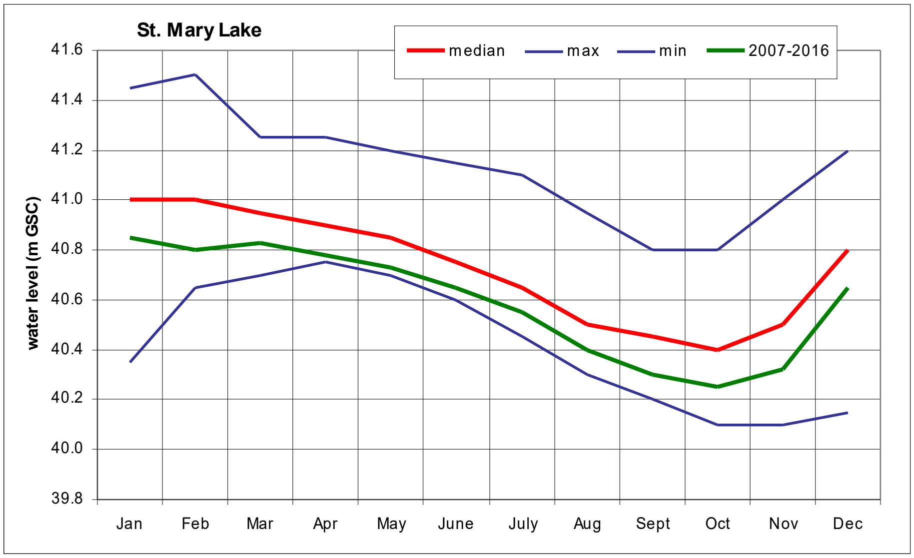

Figure 3.7 Monthly water level variations for measurements from 1978-2006. The green line shows the median water level after the weir was constructed in 2006 (2007-2015).

Currently, the fixed weir in Duck Creek has a crest elevation of 40.70 m, with licensed low water limit of 40.0 m. This provides 0.70 m of storage, or 1274 dam^3. The water balance during *summer* then looks like:

weir at	40.70	41.00	metres ASL
	dam^3	dam^3	
gross storage	1274	1820	
evaporation	546	546	
instream flows	132	132	
available storage	**596**	**1142**	
licensed demand	573	725	
+/-	23	417	

Notes: evaporation is the 30 cm allowance stated in BBvB.

The instream flows for summer are calculated using the MAD for Duck Creek of 0.1 m^3/s. The required discharge is 10% of the MAD (Barnett et al., p. 20). It is understood that BC Instream flow guidelines were modified after the 1993 report was prepared; see e.g. (http://www.geoscientific.com/technical/tech_references_pdf_files/BC%20Instream%20Flow%20Guidelines%20for%20Fish.pdf).

Diversion License Demand

The history of licensed diversions for St. Mary Lake is shown in Fig. 3.8 as a cumulative curve for the annual limits – the time axis is not linear, it simply increments by license priority date. The graph shows that after 1993, when BBvB wrote their report, annual demand totalled 1579 dam^3, and few additional licenses were issued.

BBvB also calculated the low-flow (June-October) licensed demand in 1993 as 724 dam^3 (BBvB p. 22). Repeating this estimate using the license records for 2015 yielded 725 dam^3, including one license to NSSWD that is dependent upon adding 300 acre-feet of new storage[4]. Subtracting that licensed limit (364 dam^3) reduces the current summer demand to about 573 dam^3. In both cases, the available storage apparently supports the licensed demand. BBvB assumed that with *average or greater* winter precipitation the lake would be refilled after utilizing all of the storage to meet full demand.

However, if rainfall during spring (April-June), or during the fall (September to November), is below normal, lake storage is required before June and after the end of October, extending the period when storage is required to meet demand. By way of an example, Fig. 3.9 shows the water level time-series from 2007 to 2015 and the time spans when storage was utilized to meet demand. The dates when lake levels fell below the weir crest, reached lowest elevation and when storage was replenished are listed in Table 3.3. On average, levels reached the weir crest on May 27th and their lowest level on October 16th. Even in this short period (9 years), the weir crest was passed as early as May 11th and did not reach the lowest level until October 27th. Thus the average draw down period of 146 days was extended to 168 days under droughty conditions.

Under extreme drought conditions (~100 year return period), the safe yield for the June-October period ranges from 350 to 380 dam^3 (Hodgins, 2017). In that case, the licensed demand exceeds the ability of the lake to supply the fully allocated water by roughly 200 dam^3, or ~55% of the supply.

Table 3.3 Summary of draw down statistics 2007-2015 for St. Mary Lake.

water level falls below weir crest	lake reaches minimum level	date to refill to weir crest	days from weir crest to min level	total days below crest
16-May-07	27-Sep-07	06-Dec-07	134	204
12-May-08	27-Oct-08	12-Jan-09	168	245
20-May-09	13-Oct-09	24-Nov-09	146	188
28-Jun-10	06-Sep-10	11-Dec-10	70	166
13-Jun-11	13-Nov-11	24-Jan-12	153	225
17-May-12	09-Oct-12	07-Dec-12	145	204
16-Jun-13	26-Sep-13	15-Feb-14	102	244
18-May-14	14-Oct-14	21-Dec-14	149	217
11-May-15	25-Oct-15	18-Dec-15	167	221
27-May	16-Oct	26-Dec	146	213

[4] 300 acre-feet equals 370 dam^3 or the equivalent of raising the weir by 20 cm.

Figure 3.8 Cumulative licensed demand (annual total) by priority date for St. Mary Lake.

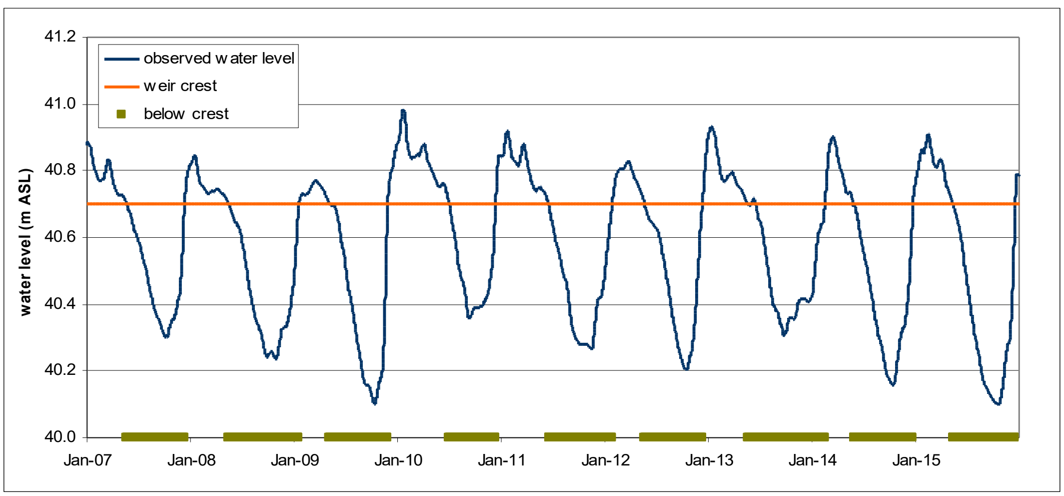

Figure 3.9 St. Mary Lake water level showing the periods each year when levels were below the weir crest of 40.70 m.

4.0 WRAP-UP

The climate of the Southern Gulf Islands is characterized by wet winters and dry summers. Consequently water withdrawals during summer (say June to October) are dependent upon storage, replenished by rainfall during winter months. Based on the water allocation study for Salt Spring Island (Barnett et al., 1993[5]) diversion licenses may be issued up to a total approximately equal to a climate-average storage volume. In practice the licensed demand for the critical June-October period is matched to the estimated storage, and inflow to the reservoir is checked to ensure that, on average, there is sufficient winter flow to maintain that storage. It is assumed that winter demand can be satisfied by surplus rainfall over that required for refilling the lake and environmental flows.

For St. Mary Lake physical constraints provide gross storage volumes of about 1274 dam^3 (weir at 40.7 m) or 1820 dam^3 (weir at 41.0 m). Barnett et al. estimated winter inflows in excess of 2000 dam^3 and concluded that these storage volumes were sustainable. Utilizable storage is approximately 600 dam^3 and 1140 dam^3 respectively accounting for evaporation and environmental flows based on methods used in 1993. Barnett et al. did not consider the effects of dry winters for failing to meet environmental flow thresholds over the wet season, and refilling the lakes, although they must have realized that this could occur regularly.

Summer demand for all diversion licenses currently totals about 570 dam^3 (weir at 40.7 m). The estimated storage thus appears to meet the licensed demand. (Corresponding figures for the weir at 41.0 m at 725 dam^3 for demand and 1140 dam^3 for storage.) However, this approach does not consider the effects of drought; specifically, lack of rainfall during the April-June period and the October-December period (in droughty years rainfall from July to September is essentially zero). Then the yield from the lake could be well under 400 dam^3 and the diversion licenses could not be met at full allocation. The Province recognizes this and has implemented a complex procedure for restricting or denying withdrawals[6] by licensees. These include rights by precedence based on when the license was issued (FITFIR – first in time, first in right).

Current demand appears to be well below the licensed total for St. Mary Lake. NSSWD and CRD both withdraw less than their licenses (approximately 460 dam^3 annually), which together account for 90% of the allocated total (1593 dam^3). However, summer demand (June-October) is roughly 340 dam^3 without water restrictions, leaving a reserve of about 12% of the safe yield based on current environmental flows.

[5] Still in effect – confirmed by FNLR Feb. 14, 2018.

[6] See e.g., https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/drought-info/drought-response-plan-update-june-2015.pdf.

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