DROUGHT-LIMITED WATER SUPPLY AND DEMAND FOR ST. MARY LAKE AND LAKE MAXWELL, SALT SPRING ISLAND, BRITISH COLUMBIA

by

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January 2018

Summary for Policymakers

The maximum amount of water available from St. Mary Lake and Lake Maxwell for potable supply is about 1,000 to 1,100 dam^3/year. This is the limit for the worst drought on record for the past 100 years. It is sufficient to supply about 4,000 single-family dwellings each year. Current demand (2017) is approximately 880 to 900 dam^3/yr, leaving a reserve of 15% to 20% of supply (about 170 dam^3 or 660 single-family dwellings).

Climate change over the next 100 years could potentially reduce this reserve by about one-half. The safe supply reserve would then be less than 100 dam^3, or approximately 300 to 350 single-family dwellings. The reduction in supply results from increases in air temperature during summer and attendant evaporation. There is no empirical evidence to indicate that rainfall would be lower than now.

These climate change projections are based solely on reliable measurements of precipitation and air temperature over the past 100 years. Trends in temperature were linearly extrapolated forward in time. No tread to increasing drought severity was found, and hence no change in water supply caused by less rain has been incorporated. Doing so would not be supported by existing data. The worst drought on record occurred in 1925, although two other years, 1952 and 1987, were nearly as severe.

An alternative approach to climate change assessment is to use projections from global climate models that are "downscaled" to local geographical conditions. For this approach to be valid, it *must be shown* that the downscaled data possess the correct statistical properties for *extreme* drought events. These data must accurately describe both the frequency of events below a certain threshold, and the distribution of daily rainfall during the period when lake storage is used for supply within such events. The information required for testing downscaled model data has been derived in this study.

Water diversion licenses issued by the Province for both lakes total 2257 dam^3/yr, more than twice the supply available in a severe drought. License limits do not, therefore, seem appropriate for future planning, and for allocation of the water resource.

BACKGROUND

This study was undertaken by the author to investigate methods for determining the safe yield of water from surface reservoirs on Salt Spring Island, with a view to providing estimates applicable to St. Mary Lake and Lake Maxwell. 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, estimates of safe yield 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

Potable water supplies from surface reservoirs on Salt Spring Island are limited by summer drought. The critical time period is from April to about the end of October. During this period withdrawals and outflows, including evaporation, exceed inflows, and lake storage is used to meet the demand. Demand increases in July and August to more than twice winter levels, coinciding with the months of lowest rainfall.

Available storage is determined by license restrictions, or environmental protection requirements. The rate at which available storage is used depends, in part, on inflows from rainfall, storm water runoff and groundwater, and in part on evaporation. These are directly proportional to precipitation and air temperature over the spring and summer months. As a result, the *limiting supply* corresponds to the worst-case drought for a particular storage volume[1]. Hodgins (2017a) refers to this criterion as the safe yield.

Precipitation and temperature data are examined here to determine worst-case drought conditions over the past 100 years, pertaining to Salt Spring Island. Drought is defined by extreme low rainfall during summer, and the accompanying temperature regime. These affect net inflows to the lakes, and in turn, limit how much water can be obtained from available storage.

Data exist for Salt Spring Island for the last 40 years, are of good quality and contain drought events. However, this record is too short to draw conclusions about long-term trends in drought severity, and for this purpose, several stations on southern Vancouver Island and the BC Lower Mainland with long data series are incorporated into the analysis.

2.0 PREMISE

The premise is that supply-limiting drought can be defined using existing data, spanning slightly more than 100 years, and that inferences can then be made about future conditions in view of changing climate conditions. A corollary is that existing data are suitable to characterize severe drought conditions, statistically and mechanistically, providing a basis for testing downscaled time-series generated from global climate models. If the model output exhibits the same characteristics as actual measurements then there is some basis for accepting future predictions; if not then model simulations are not suitable for analysis of extremes of weather, even though they may provide information on average climate trends.

Several aspects of this issue are examined here:

(i) are extreme drought events becoming more frequent?

(ii) are drought extremes becoming more severe?

(iii) did more severe droughts occur before the Salt Spring Island record began, and if so, what are the implications for safe yield.

3.0 WHAT DOES DROUGHT ON SALT SPRING LOOK LIKE

An understanding of what a drought looks like is important. A typical dry summer rainfall sequence is plotted in Fig. 3.1, for 1987 in this case. The winter rainfall period ended abruptly in mid-March. Modest amounts of rain occurred through April, but tapered off during May. From June through to the end of October, there was, for all practical purposes no meaningful precipitation in terms of replenishing lake storage. The fall wet-season didn't begin until the first week of November, and only modestly until the end of the month.

[1] For a given rate of withdrawal and outflow to creeks (Hodgins, 2017a)

An extreme drought year is *not* characterized by lack of rainfall from June to September, which is essentially zero and thus cannot be less. The *severity* of drought is determined by the shoulder seasons, a dry spring and most importantly a dry fall with a delayed start to winter rains. When these conditions occur, outflows from the lake continue to exceed inflows well into October or early November and draw down of storage reaches limiting conditions in late fall, a month or so later than normal.

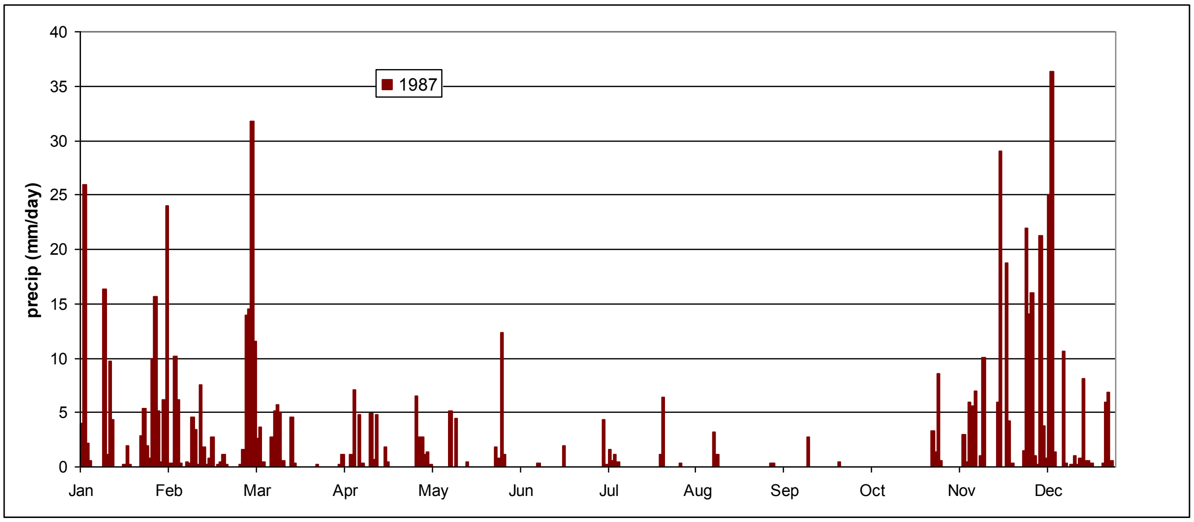


Figure 3.1 Daily rainfall at St. Mary Lake during 1987.

Storage available for withdrawal is proportional to rainfall from, roughly, early April until fall rains begin in October or November. The cumulative rainfall from April 1st to October 31st is thus a useful measure of the amount of precipitation to the watershed over the draw down period, and may be compared with a similar amount for a climate average to gauge drought severity. The cumulative curve also provides a useful method for characterizing droughty summers. This curve is calculated from total daily precipitation data to provide adequate time resolution of changes in the rate of accumulation (Fig. 3.2)

In a normal year some precipitation occurs in each summer month, and the spring-summer regime exhibits a fairly uniform positive slope (steadily increasing cumulative rainfall). Around the end of October the regime shifts to the fall wet-season and the slope increases significantly. During droughty summers, the absence of rainfall from late June until mid October results in a summer slope of virtually zero. The *severity* of the drought, as it pertains to limiting use of lake storage, is determined by how far rainfall in the spring, and in September through November, is below average.

In the particular example shown in Fig. 3.2, the 1987 fall rains began after mid-November and the cumulative curve climbs rapidly. However, the total amount of precipitation to the watershed remained far below a normal year.

4.0 DATA

4.1 <u>NSSWD Record</u>

Daily rainfall data were recorded at the St. Mary Lake water treatment facility, located on the west side of the lake at elevation 42 m above mean sea level. Rainfall amounts were collected in a tipping bucket rain gauge. Snowfall was measured when present and converted to rainfall using the relation 1 cm of snow equals 10 mm of rain. These data were combined to provide an estimate of total daily precipitation. All recordings were logged by hand, entered into a computer file and provided to Environment Canada who archived the data. The data span 1976 to 2016.

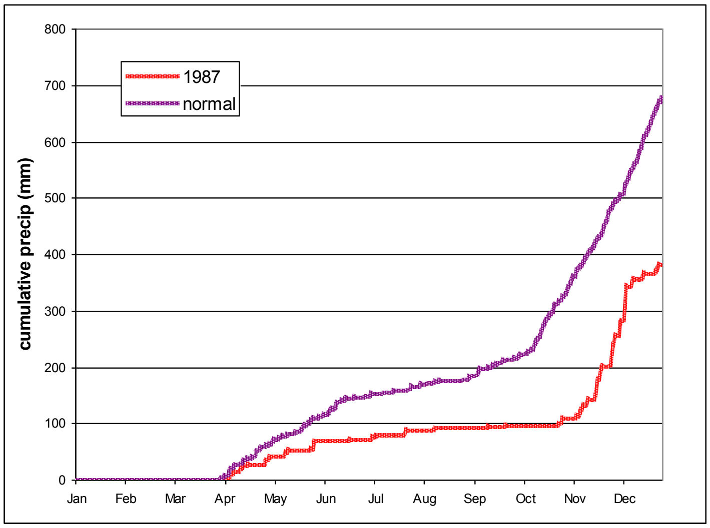


Figure 3.2 Schematic diagram showing the difference in cumulative precipitation curves for a normal year, and for a drought year (data from St. Mary Lake).

Precipitation data were also collected at a station in Vesuvius at an elevation of about 8 m, from 1956 to 1973. These measurements have been concatenated with the St. Mary Lake record.

4.2 The Adjusted Long-term Record

Environment Canada has created long-term data sets of climate variables, including total monthly precipitation, for a number of stations across Canada. These are referred to as the adjusted, homogenized data sets (Vincent et al., 2012). There are seven stations on southern Vancouver Island and the Lower Mainland with similar climate variability (Table 4.1). These are suitable for screening for extreme drought years.

Table 4.1 Adjusted long-term data stations on southern Vancouver Island and Lower Mainland of BC.

station name	stnid	beg yr	lat (deg)	long (deg)	elev (m)	stns joined
Agassiz	1100120	1890	49.2431	-121.7603	15	No
Nanaimo City Yard	10253G0	1913	49.1989	-123.9878	114	Yes
Saanichton	1016940	1914	48.6217	-123.4189	61	No
Shawnigan Lake	1017230	1911	48.6469	-123.6264	138	No
Vancouver	1108447	1896	49.1950	-123.1819	4	Yes
Victoria	1018620	1899	48.6472	-123.4258	19	Yes
Duncan Kelvin Creek	1012573	1926	48.7347	-123.7275	103	Yes

Adjustment of the raw data follows the steps described in Mekis and Vincent (2011). Daily rainfall gauge and snowfall ruler data were extracted from the National Climate Data Archive. For each rain gauge type, corrections to account for wind undercatch, evaporation, and gauge specific wetting losses were implemented. For snowfall, density corrections based upon coincident ruler and Nipher measurements were applied to all snow ruler measurements. Trace precipitation were adjusted to avoid the underestimation of total precipitation. This has particular importance over the Canadian Arctic but is, perhaps, not so critical in our region. Monthly rain, snow and total precipitation were calculated by adding the station's daily rain gauge, snow ruler and total precipitation observations, over the month. The impact of the adjustments on rainfall and snowfall total amounts and trends was examined in detail in Mekis and Vincent (2011).

Daily data were extracted from the Environment Canada archive for calculation of the cumulative rainfall time-series at observing stations similar to Salt Spring Island.

5.0 PRECIPITATION

5.1 Isolating Drought Events

(a) Adjusted Long-term Data

Let P = total precipitation for the period April through October, calculated from the monthly long-term data at each station. <P> is the low-frequency signal calculated using a 3-pass moving average (ma) filter $A12A11^2$ (successive averages with length 12 years, 11 years and 11 years). The 11-year ma coincides with the average sunspot cycle. The precipitation anomaly is then defined as:

$$P' = P - \langle P \rangle \qquad (1)$$

which is normalized using the standard deviation σ of P'; i.e.,

$$P'' = P'/\sigma \qquad (2)$$

The records were extended in time using the average of the ten valid observations in the data record before applying the first low-pass filter. This approach introduces some unavoidable uncertainty near the ends of the filtered data record, and in the corresponding anomalies. Such error is most serious for 2015 since this was a dry year next to the last observation in the record. The graphs for P, <P> and P'' are shown in Appendix A.

All years with $P'' < -1$ were identified as potential drought events, and compared for all seven stations shown in Table 4.1. The normalized anomalies P'' for three of these stations with the longest records are shown in Fig. 5.1. Clearly there are several common severe years when anomalies exceed the -1.5 threshold, and several more when $P'' < -1$.

The value for 1907 at Vancouver seems unusually large. Vancouver is a blended station in the adjusted database, but which stations were used for this purpose are not identified, and I could not locate daily data suitable for confirmation. Accordingly, this value is considered erroneous and discarded given its inconsistency with Victoria.

The results in Fig. 5.2 suggest two things. First, the *frequency* of drought conditions is *not* increasing with time. In fact, the first half of the 20^{th} century contained the same number of drought years as the second half.

Second, there is no empirical evidence that droughts are becoming more severe with time (no significant difference in Y'' with time). In addition, it is noted that the low frequency curves for <Y> show a slight increasing trend with time; that is, to wetter conditions on average.

In order to gauge the differences between stations, the standard deviation, minimum value and maximum value was calculated for precipitation anomaly (P') for each. These results are listed in Table 5.1.

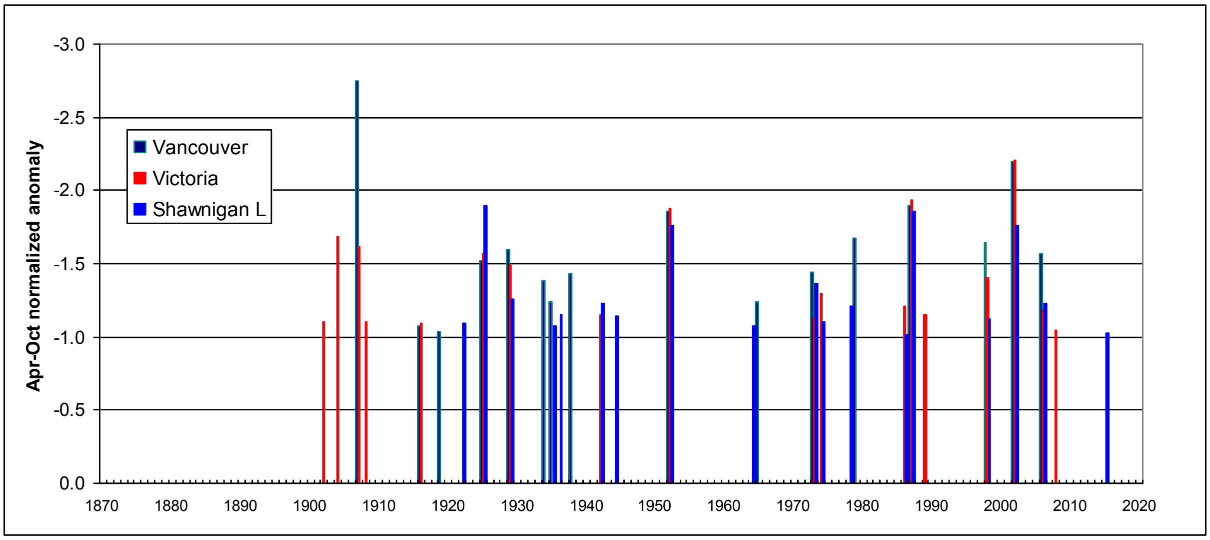


Figure 5.2 Years with a precipitation anomaly less than –1 (droughty years).

Table 5.1 Precipitation anomaly statistics for seven long-term stations on southern Vancouver Island and the Lower Mainland of BC. The anomaly is for the April to October total precipitation.

	Agassiz	Vancouver	Victoria	Saanichton	Shawnigan	Duncan	Nanaimo	St. Mary L.
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
stdev	150	87	70	67	96	99	100	81
min	-308	-240	-155	-171	-183	-177	-205	-199
max	554	266	229	206	306	350	322	235

The statistics indicate that Agassiz is not representative of conditions on southern Vancouver Island and southern Gulf Islands: the standard deviation, and the data range, are significantly larger than St. Mary Lake and all other stations. Shawnigan Lake, Duncan, Nanaimo and Vancouver are similar to St. Mary Lake; Victoria and Saanichton are less variable with less severe extreme dry years. Given the long record, and the satisfactory match for Shawnigan Lake, it is considered the best station for comparison with St. Mary Lake.

Candidate drought years are listed in Table 5.2, along with the P″ values. Four years, 1925, 1952, 1987 and 2002 appear to be about equally severe.

(b) St. Mary Lake Data

Figure 5.3a shows the Apr-Oct precipitation results along with the low-pass filtered signal. The normalized anomaly is plotted in Fig. 5.3b. Six years with $P'' < -1$ are potential drought events: 1987, 1989, 1998, 2002, 2015 and 2016. The P″ values are compared in Table 5.2 and Fig. 5.4, and the correlation of St. Mary Lake on Shawnigan Lake (Fig. 5.5) is consistent with a scaling factor of about 1.2.

These results suggest that extreme drought conditions at Shawnigan Lake would occur on Salt Spring Island, with a slightly greater deviation from normal rainfall conditions over the draw down period.

Table 5.2 Extreme drought years between 1911 and 2016.

	normalized anomaly	
Year	**Shawnigan Lake**	**St Mary Lake**
1925	-1.89	0
1929	-1.26	0
1935	-1.07	0
1944	-1.14	0
1952	-1.76	0
1973	-1.36	0
1987	-1.86	-2.44
1989	-0.99	-1.22
1998	-1.13	-1.37
2002	-1.76	-2.07
2015	-1.02	-1.45
2016	0.65	0.38

5.2 Drought Analysis

(a) Cumulative Precipitation Curve (CPC) and Deficit Curve

For each drought year the CPC was calculated using the total daily precipitation from "eng-daily" data archived by Environment Canada (see for example Fig. 3.1). A climate normal CPC was also computed as the average daily value for five independent years, each having a normalized anomaly $P'' < \pm 0.02$. These normal years were selected, as far as possible, over the full time span of the data series.

The deficit curve was then calculated as the drought CPC minus the climate normal CPC. Units of mm were preserved throughout. The objective here was to have a measure of the amount that rainfall fell below average conditions at each of the relevant stations (Shawnigan Lake and St. Mary Lake).

The deficit curves were then compared with each other for each long-term station to gauge the relative severity of droughty years. These curves were also compared with matching years at St. Mary Lake to judge how extreme droughts at the long-term stations might affect St. Mary Lake.

(b) Drought Characteristics at Shawnigan Lake

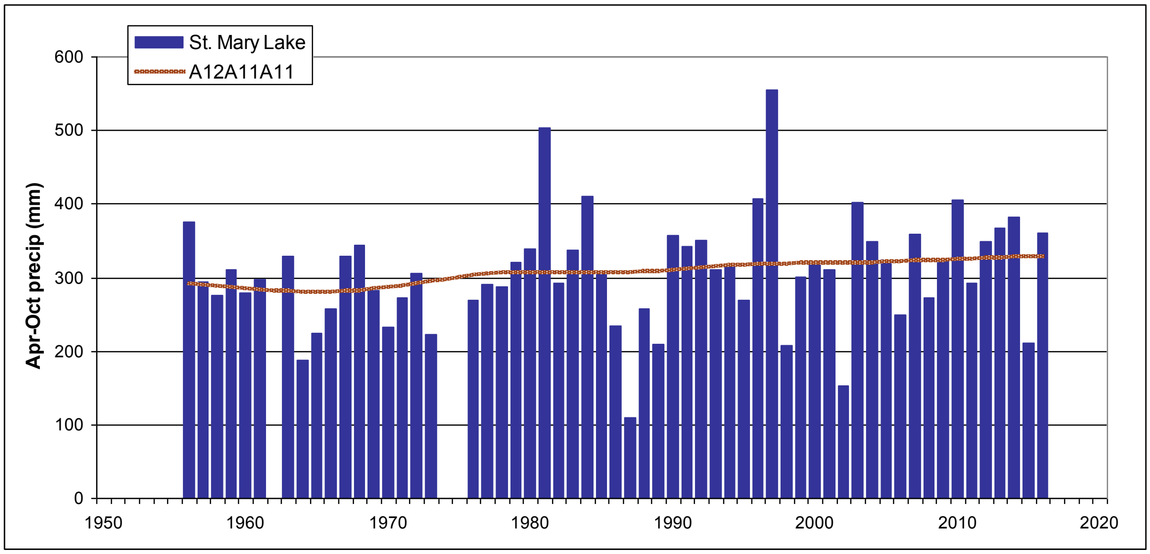
The rank-ordered drought years at Shawnigan Lake are plotted in Fig. 5.6 as a fraction of normal rainfall from April to October. Clearly the worst four, listed previously, are well under 60% of normal and 1925 is the worst. The common year with St. Mary Lake is 1987, which is the worst on record for St. Mary Lake and the third worst at Shawnigan Lake (about equal with 1952). 2016 has been retained here for comparison purposes, but it does not rank as a drought year for our context because fall rains started early and St. Mary Lake began to refill in October.

The CPC curves for the four worst drought years are plotted in Fig. 5.7a, and the corresponding deficit curves in 5.7b. It is evident that 1925 rainfall was below normal from April onward, with a significant deficit persisting through year-end. The other observation is that by the end of October all three of the worst years approached about the same deficit from normal, approximately 180 to 201 mm (50 to 60% below normal). The ratio of 1925 to 1987 is 1.15, suggesting that 1925 was about 15% worse than 1987.

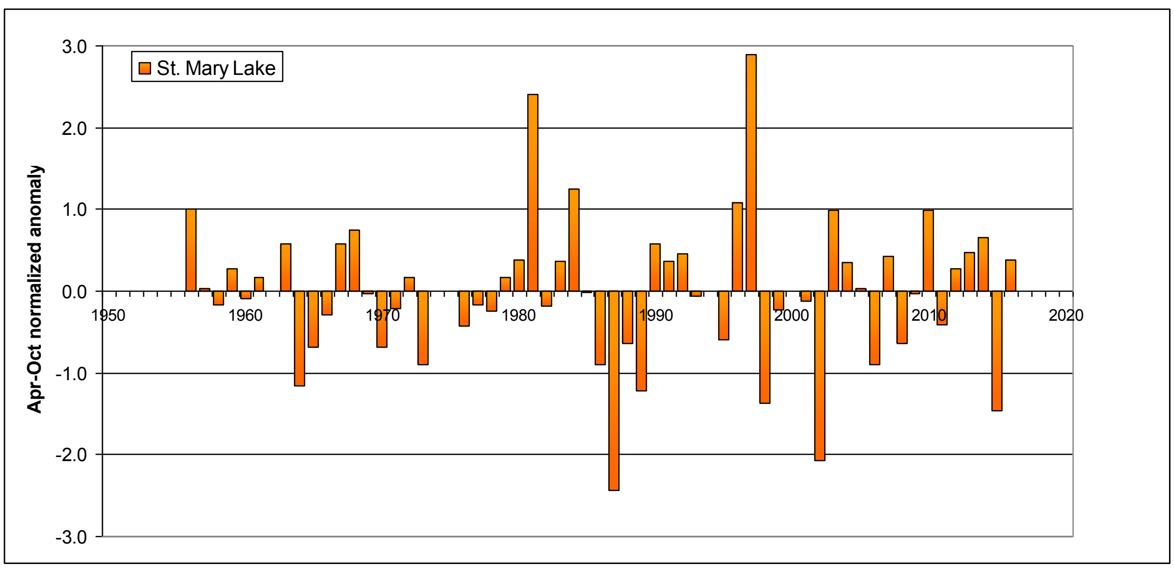
(c) Drought Characteristics at St. Mary Lake

The CPCs for the three worst drought years (1987, 2002 and 2015) are plotted in Fig. 5.8a. The deficit curves are shown in Fig. 5.8b. 2015 was particularly dry through spring, leading to a rapid increase in the deficit early in the summer season, reaching 100 mm below normal by early June. However, fall rains began in October and the total deficit by the end of that month was considerably lower than 1987. 1987 is clearly the benchmark drought year in the St. Mary Lake record.

Given the similarities between St. Mary Lake and Shawnigan Lake – the characteristic shapes for both CPC and deficit curves are well matched, as are the drought years (Table 5.2) and the deficit ratios (Fig. 5.5) – we can infer that the 1925 drought would have been worse than 1987 by about 15% in terms of the deficit on October 31st (a value of, say, -250 mm). We will consider this to be the worst drought of record for St. Mary Lake, and examine the implications for safe water yield.



(a)



(b)

Figure 5.3 (a) total precipitation P for Apr-Oct, and the low-passed signal <P> for the St. Mary Lake precipitation record (including the 1956-1973 Vesuvius record); (b) normalized precipitation anomaly P″ corresponding to (a).

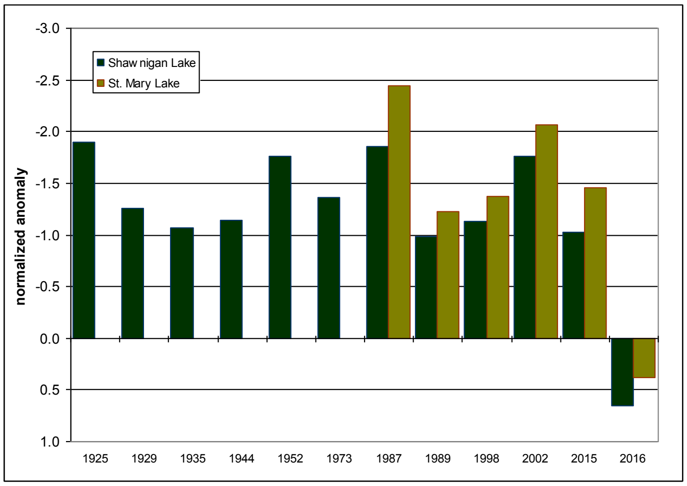


Figure 5.4 Normalized anomaly P″ for droughty years at Shawnigan Lake and St. Mary Lake.

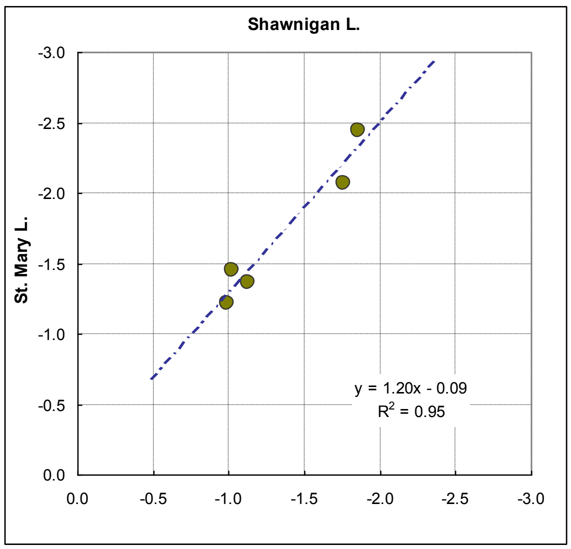


Figure 5.5 Correlation of St. Mary Lake on Shawnigan Lake (normalized anomaly P″).

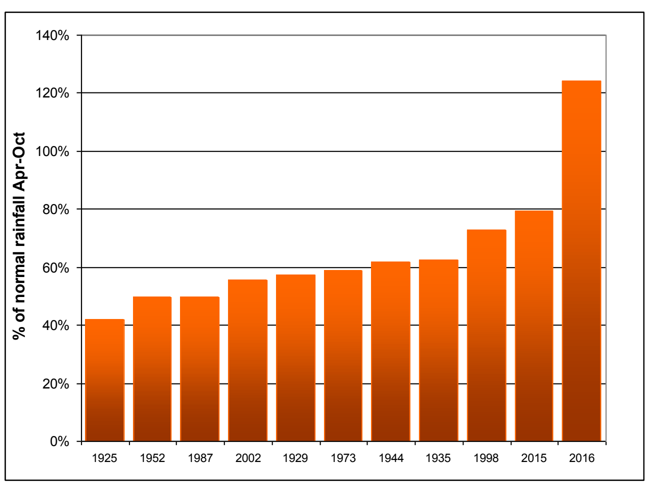
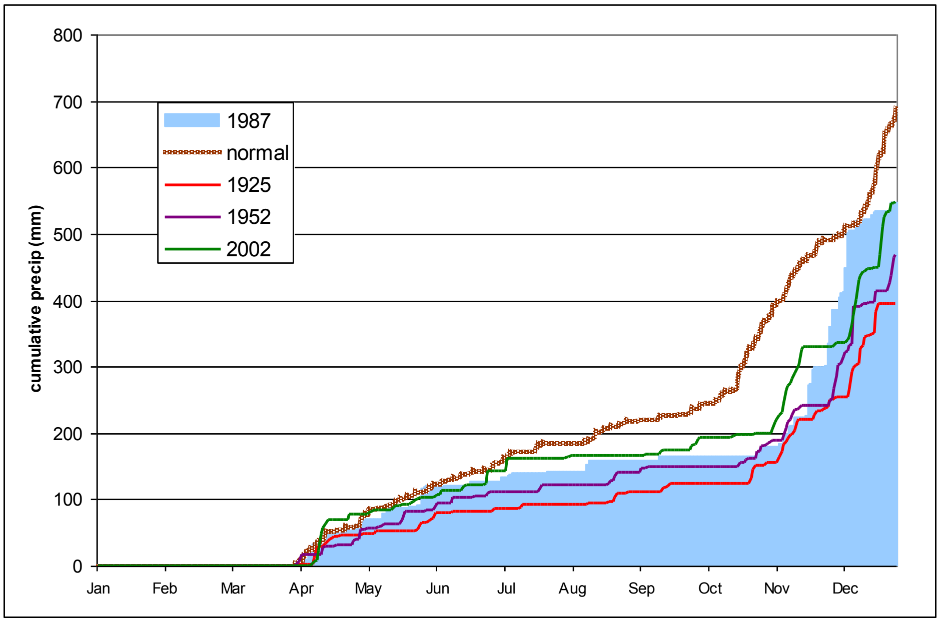
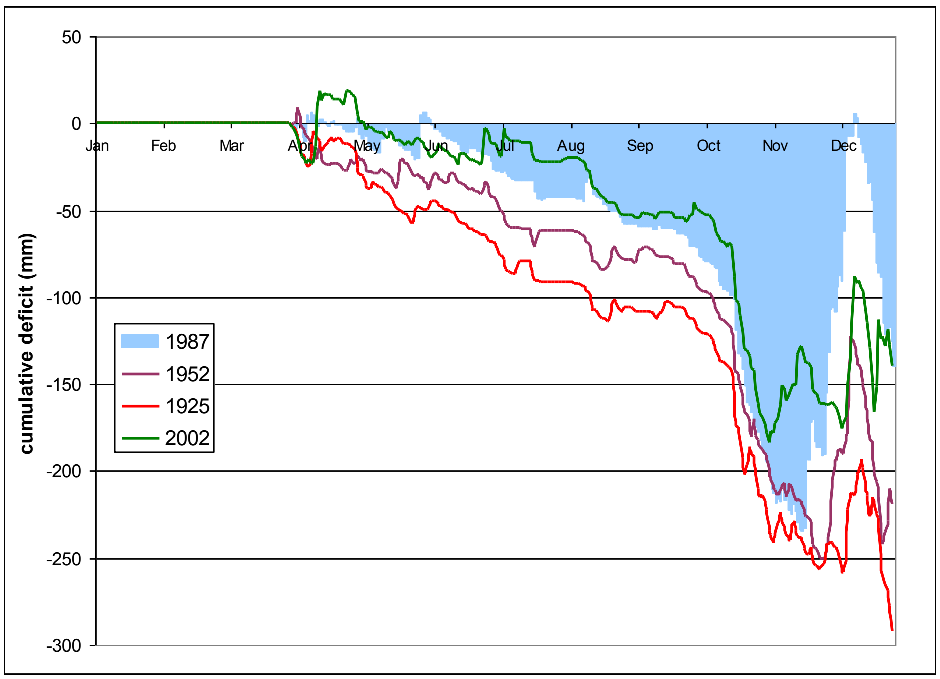


Figure 5.6 Rank-ordered droughty years at Shawnigan Lake, as a percentage of normal rainfall from April to October.

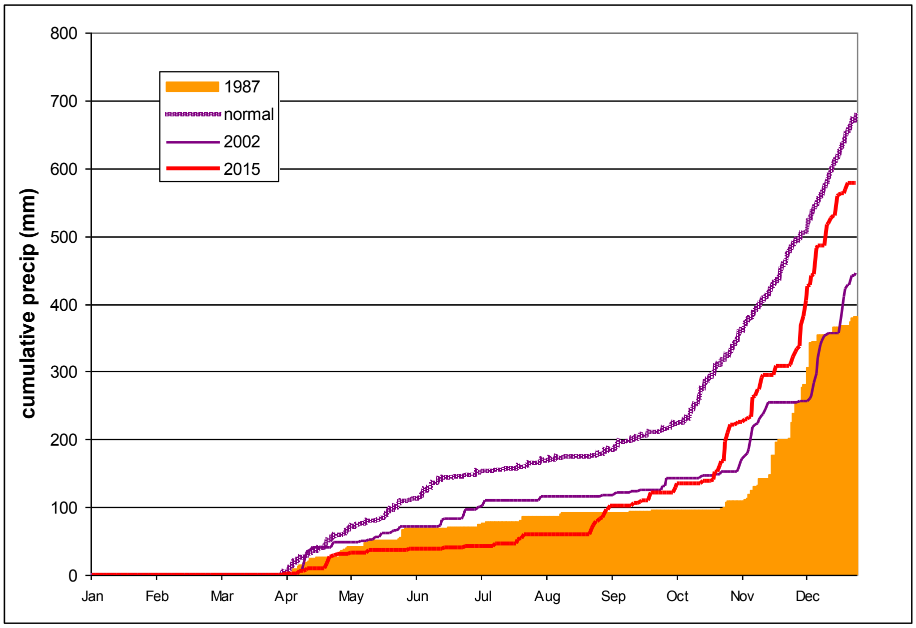


(a)

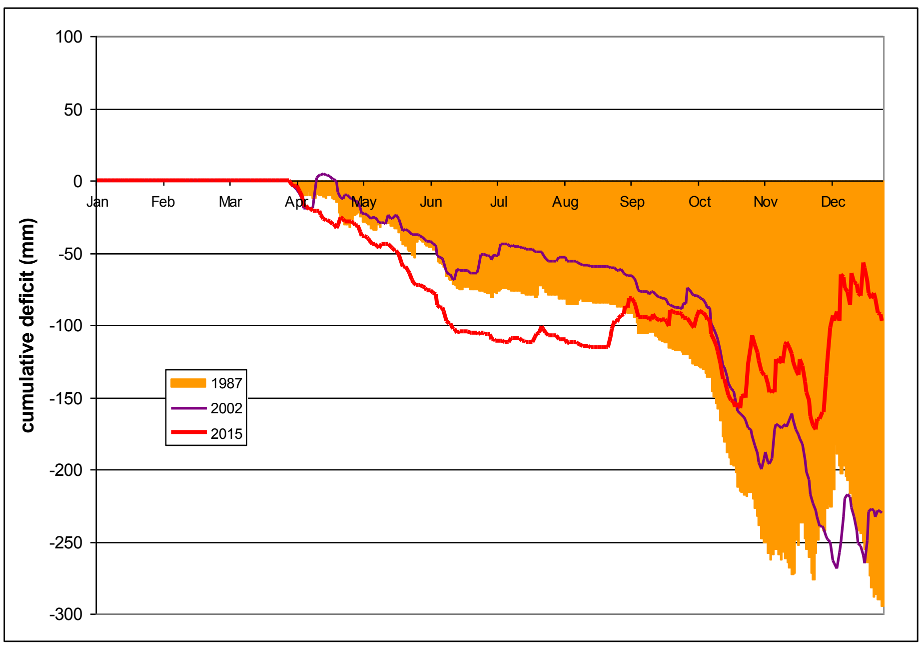


(b)

Figure 5.7 (a) Cumulative precipitation curve commencing on April 1st, and (b) cumulative deficit curve for Shawnigan Lake.



(a)



(b)

Figure 5.8 (a) Cumulative precipitation curve commencing on April 1st, and (b) cumulative deficit curve for St. Mary Lake.

6.0 TEMPERATURE

The question posed here is: how have air temperatures, *corresponding to drought years determined by precipitation*, varied over the past 100 years? The purpose is to examine the implications for evaporation during summer, and in turn its impact on safe water yield. We are not interested in the general trend in temperature for all years combined, but only for those coinciding with droughty conditions.

6.1 Data

The data are direct measurements of the maximum and minimum daily temperatures (T) archived by Environment Canada. The analysis was carried out for the long-term stations at Shawnigan Lake and Saanichton CDA. Figure 6.1 illustrates the raw data. The smoothed curves were calculated using a 3-pass fortnightly filter A15A14A14. The temperature anomaly (raw data point minus smoothed data point) typically has a standard deviation of about 3°C and a range spanning 15°C or more over a year. The differences between the smoothed time-series for maximum T are not significant in a long-term sense, reflecting simply the interannual variations in weather.

On the other hand, the consistent difference between the smoothed curves for minimum T suggests that night-time lows have increased with time.

6.2 Climate Trend

The cumulative distributions for daily max and daily min T (Fig. 6.2) lend support to the observation that summer day-time high temperatures have not changed significantly over the last 100 years (T > 15°C), although warming of winter max T may have occurred. Minimum T, however, shows a progressive warming trend over most of its range of values.

Two additional statistics are plotted in Fig. 6.3: the June-August average temperature, and the 75th percentile of the daily observations for the whole year. These results also suggest that the daily max T of interest (summer) shows no trend, but that night-time low T has increased. The June-August means are of interest because this is the period of highest evaporation and maximum water demand.

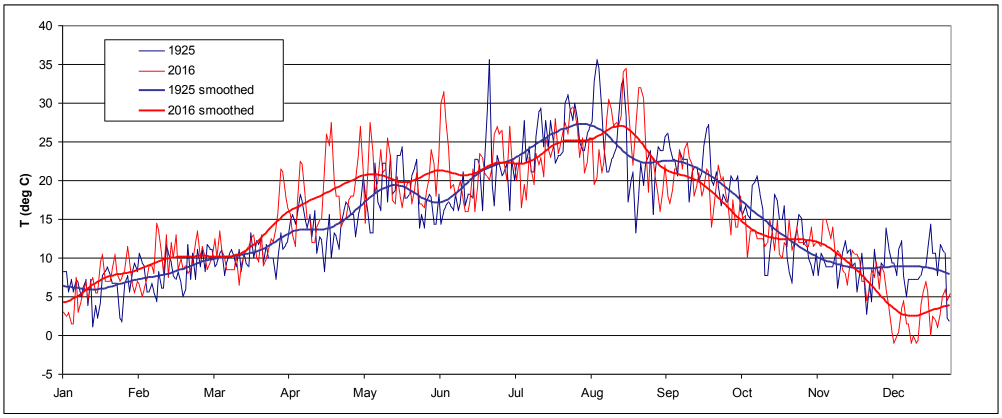
The third graph shows the statistics for the daily mean T, which is input to the evaporation calculation. Mean T was calculated as the average of the daily max and min T values, and the trend line shows an increase of about 0.2°C/decade at Shawnigan Lake.

The elevation of the Shawnigan Lake station is 159 m ASL, considerably higher than St. Mary Lake (elevation 42 m). The higher elevation may cause a difference in temperature, and its trend, between these two stations. The analysis was repeated for Saanichton CDA (elevation 61 m), which is much closer to St. Mary Lake (Fig. 6.5). The same trends were noted here too: no significant difference in daytime highs but warmer night-time lows. The slope for daily average temperature is about 0.11°C/decade over 100 years.

Both long-term stations exhibit deviations from a linear trend, from say the 1960s through the 1970s when average temperatures were lower than in the decades before and after. It is possible (likely) that the climate trend is not linear, but that the estimates of the change in temperature over the 100-year span, of about 0.2°C/decade are reasonable for a projection into the future. If the trend is calculated over the last 40 years for the St. Mary Lake record, the rate of change is about 0.6°C/decade. The higher rate results the low starting value in 1973, which may not accurately reflect conditions prior to the 1940s, and a climate regime that would be sustained into the future.

6.3 Effect on Evaporation

In order to gauge how much additional storage would be lost to evaporation over the next 50 and 100 years, the Thornthwaite model (Xu and Singh, 2001) was evaluated by increasing the monthly average temperatures by 1°C and 2°C respectively. The results are shown in Fig. 6.6, compared with 2016, and listed in Table 6.1. Roughly, the loss of storage could amount to 50 dam^3 in 50 years, to over 90 dam^3 in 100 years.



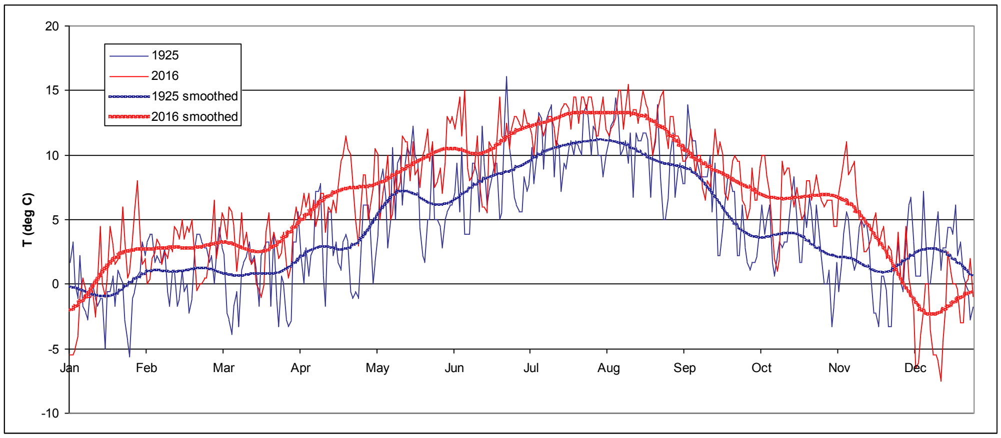
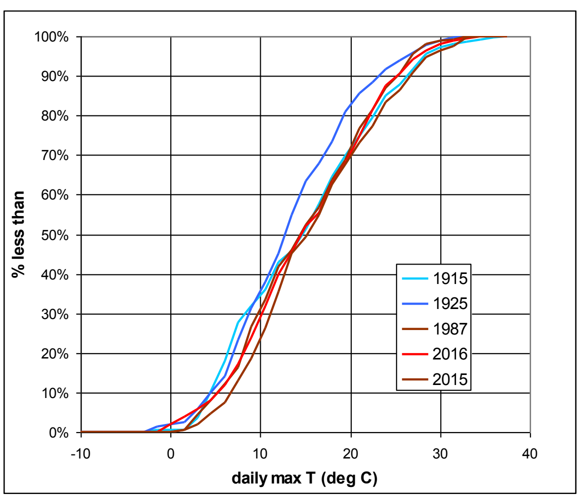


Figure 6.1 Time-series of daily maximum air temperature (upper panel) and daily minimum air temperature (lower panel) at Shawnigan Lake.



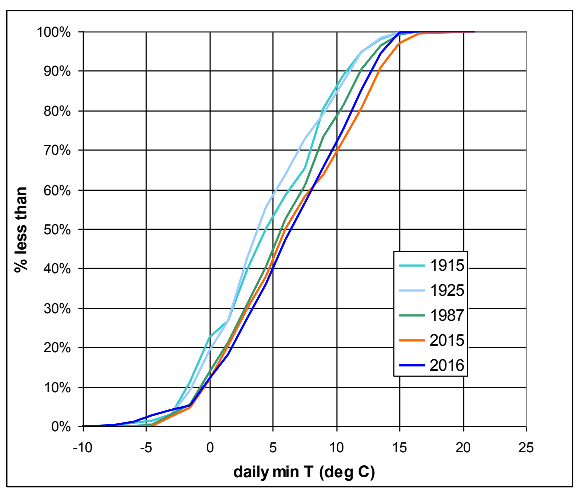


Figure 6.2 Cumulative distributions for daily max T (left panel) and daily min T (right panel) for selected drought years at Shawnigan Lake.

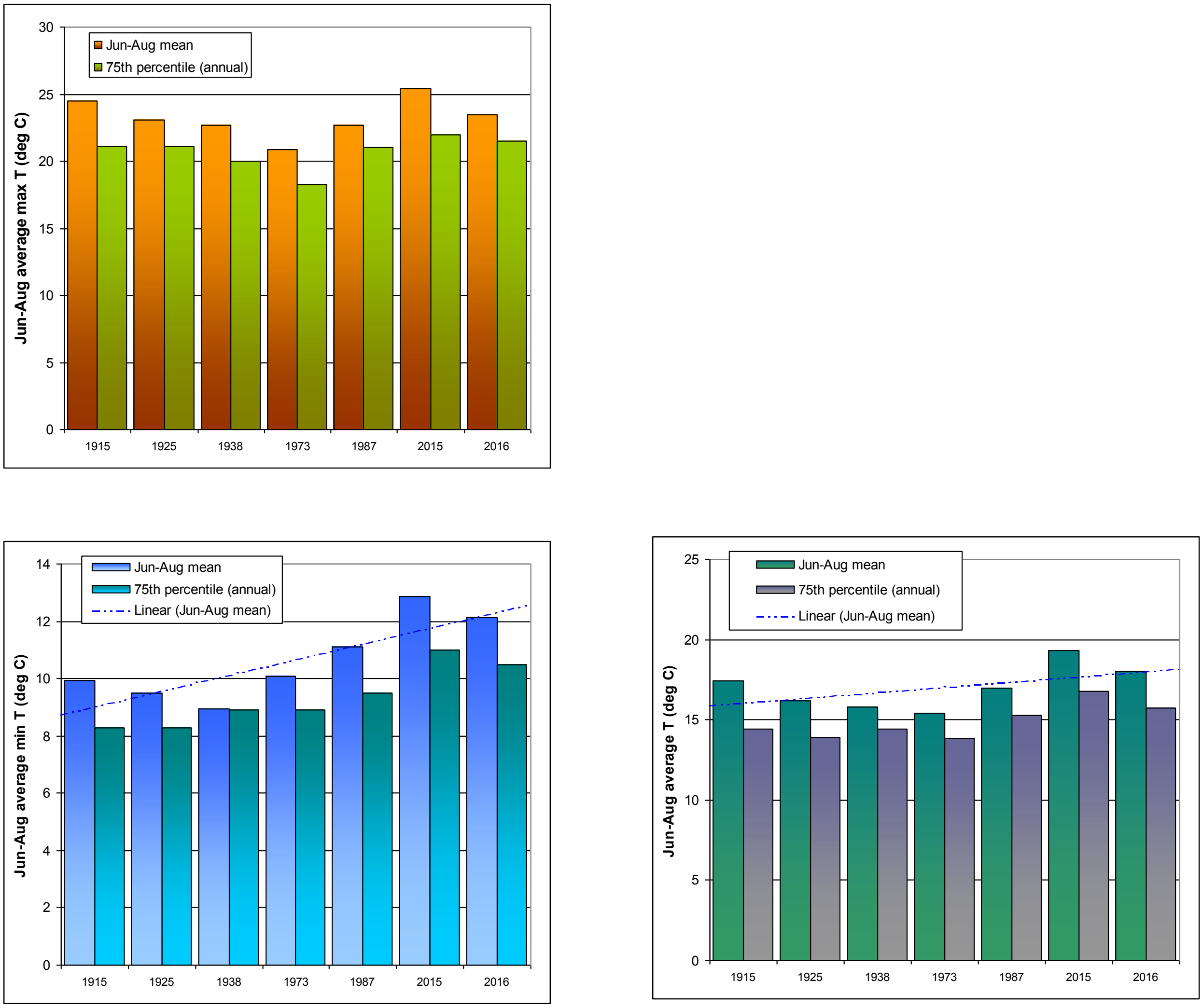


Figure 6.3 Temperature statistics for daily max T (upper left), daily min T (lower left) and daily mean T (lower right) for Shawnigan Lake.

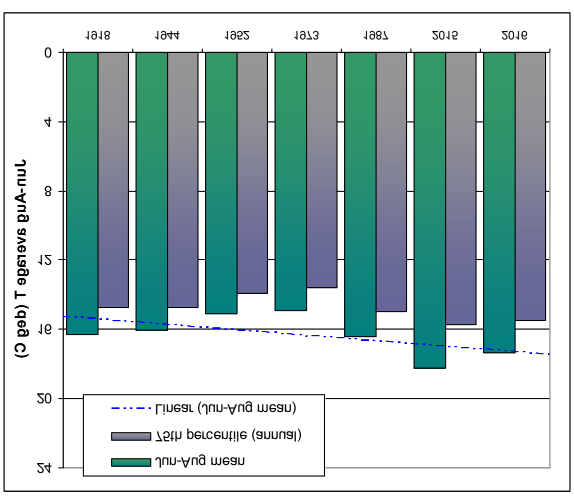


Figure 6.5 Temperature statistics for daily mean T for Saanichton CDA.

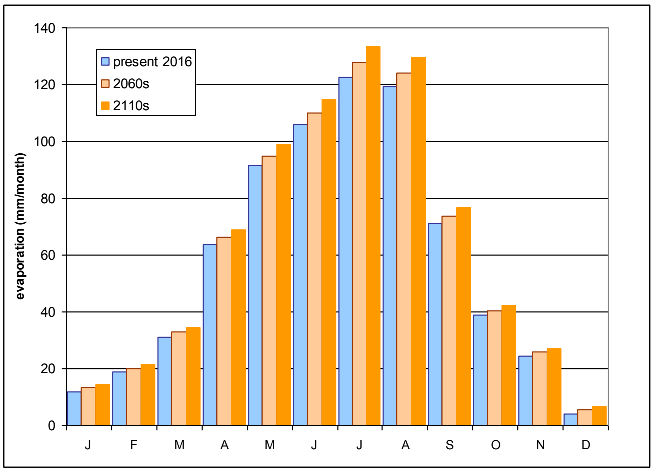


Figure 6.6 Monthly evaporation from the Thornthwaite temperature-based model, assuming an increase of 0.2°C/decade in each month for St. Mary Lake. Starting conditions are the monthly mean temperatures for 2016.

Table 6.1: Projected increase in evaporation for the period April through October, and in storage lost.

	total evaporation		
	Apr-Oct		
2016	**613**	increase	
50-yr future	637	24	mm
100-yr future	664	51	mm
lake area	1.82E+06		m^2
50-yr future		44	dam^3
100-yr future		93	dam^3

7.0 IMPLICATIONS FOR SAFE YIELD

7.1 Drought

Water balance calculations for St. Mary Lake provide a maximum yield estimate of 460 dam^3 for the 1987 event, based on total withdrawals for April through October.[2] The annual equivalent is 640 dam^3. In this case withdrawals are constrained by the draw down limit of 40 m ASL. In order to gauge the effect of a more severe "1987" event, the yields for the other droughty years in the St. Mary Lake record were correlated with the precipitation anomaly P′ values (Fig. 7.1). Four values provide a reasonable linear fit:

$$Y = 628 + 0.75\,P' \qquad (3)$$

where P′ is the rainfall deficit on October 31st (from equation (1)). Substituting P′ = - 250 mm, provides Y = 445 dam^3. The annual total is approximately 620 dam^3.

[2] Safe yield values were obtained by Hodgins (2017a) for the period June to October, and scaled by 1.7 to provide the equivalent annual yield for the current demand curve. The maximum 1987 Jun-Oct yield for the summer is 365 dam^3. The period April to October is used here for consistency with the analysis of precipitation. The corresponding scale factor for annual yield is 1.4.

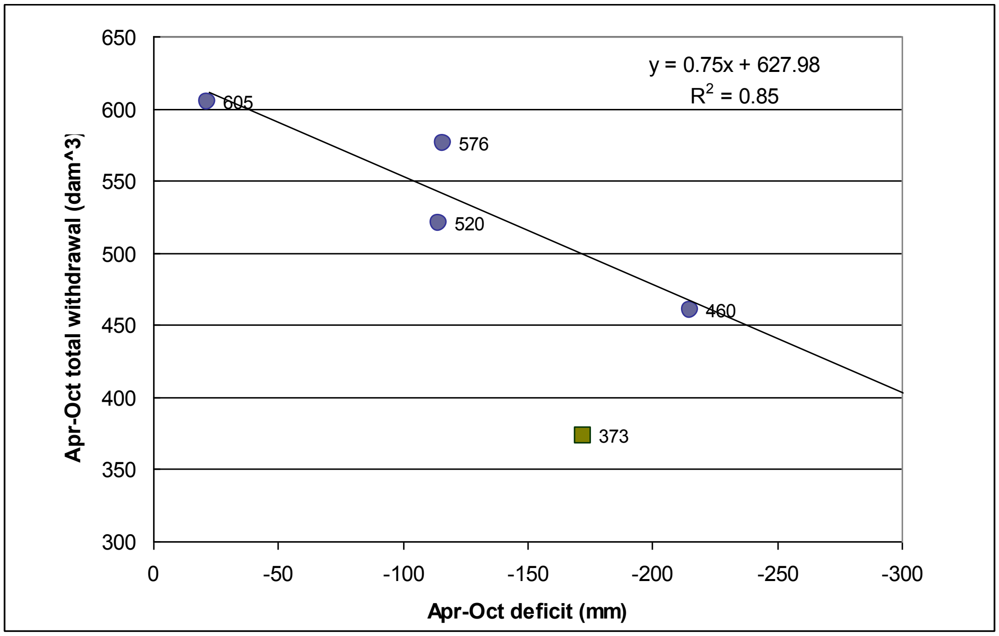


Figure 7.1 Correlation of April-October withdrawal (yield) on precipitation deficit. The data-point values are the estimated total withdrawals.

One data point was omitted from the regression: 2002 with a modelled yield of 373 dam^3. This value is inconsistent with the differences in precipitation between 2002 and all other points. Two of the other values, the withdrawals for 2009 and 2015, agree with simple back-of-the-envelope hand checks (shown in Hodgins, 2017a) and fall close to the line. The low yield for 2002 likely arises from error in adjusted water levels resulting from the filtering method applied to the pre-2007 data. The error resulted in under-estimates of inflow and associated withdrawals at limiting draw down (also too low).

Thus, what appears to be the worst drought on record provides an Apr-Oct safe yield of about 445 dam^3. If we repeat the extreme value analysis of summer yields calculated from the water balance model for each of the droughty years in the St. Mary Lake record, the yield curve by return period is shown in Fig. 7.2. The worst-case drought has a return period of approximately 95 years by this type of analysis. Accordingly, a 100-yr return estimate provides a good working value for safe yield: about 440 dam^3 for Apr-Oct, and 615 dam^3 annually.

Given no empirical evidence to support either increasing frequency of extreme droughts, or increasing severity over the past 100 years, it seems reasonable to use the 100-yr return estimates for future application.

7.2 Temperature

Assuming, then, that drought limited yield is about 440 dam^3 from April to October, increases in evaporation could potentially reduce this amount by 40 to 50 dam^3 in 50 years, and perhaps 100 dam^3 in 100 years. Annual yields would then look like 560 dam^3 in the 2070s, to less than 480 dam^3 after 2100. These numbers all assume that permitted outflows to Duck Creek would be allowed to remain at current low levels over summer ($\leq$ 9L/s).

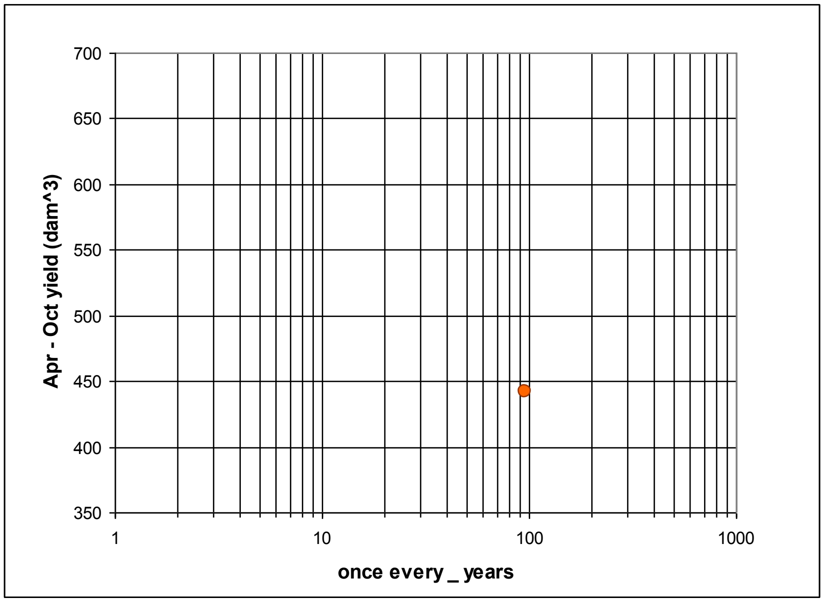


Figure 7.2 April-October yield curve by return period. The orange dot shows the drought-limited yield value with a return period of 95 years. This analysis is equivalent to that described in Hodgins (2017a) for the June-October yield.

7.3 <u>Supply-Demand Projections</u>

A summary of the current supply-demand balance is shown in Table 7.1. The drought-limited supply for the two lakes just exceeds 1,000 dam^3. Current demand (2017) is about 900 dam^3, or a little less, allowing for committed, but unconnected users for the two water suppliers, and accounting for the other users at their full license limits. This leaves a reserve of approximately 150 to 200 dam^3, about 15% to 20% of the safe yield.

Data from the last 100 years *do not* support an increase in drought severity. There is no empirical evidence to suggest that the supply limit of 1,000 dam^3 would be significantly reduced by climate-induced changes in precipitation.

However, long-term changes in air temperature, and accompanying evaporation, could erode this reserve by about one-half over the next 50 to 100 years. A working number for the reserve would then be 50 to 100 dam^3, or about 7% to 10% of the total amount of water available now.

A summary of the water diversion licenses issued by the Province is contained in Table 7.2, for both lakes. The domestic use licenses are shown as the total usage for 365 days with a maximum withdrawal of 2.273 m^3/day (500 gallons per day). The license total of 2257 dam^3/yr is more than twice the drought-limited yield, and implies a reserve exceeding 130% of the supply. Use of license limits for future planning does not appear justified in light of the analysis based on drought-limited safe yield.

Table 7.1 Summary of water supply and demand in 2017.

Safe Supply	
	dam^3
St. Mary Lake	615
Lake Maxwell	450
Total	**1065**
Demand	
NSSWD	642
CRD (Fernwood,Highlands)	90
SML other licenses (full allocation)	161
Total	**893**
Reserve	**172**
	16%

Assumptions and sources:

i. Safe yield for St. Mary Lake assumes that fisheries flow requirements to Duck Creek remain at current low levels during summer (≤ 9 L/s).

ii. Safe yield for Lake Maxwell is described in Hodgins (2017b).

iii. NSSWD demand based on 2016 water audit report plus allowance for 200 committed SFEs[3] with a demand of 0.26 dam^3/yr.

iv. Average of 2013-2016 production as published by CRD plus allowance for 30 committed SFEs with a demand of 0.24 dam^3/yr.

v. All other licenses for St. Mary Lake are fully allocated to license limit. This is likely a conservative assumption.

Table 7.2 Summary of water diversion license limits for Lake Maxwell and St. Mary Lake (source: BC Ministry of Forest, Lands and Resource Operations)

Use	License
	dam^3/yr
Irrigation	99.7
Domestic	28.2
Enterprise	29.9
Stock watering	2.9
Fire	0.03
Waterworks Max	664
Waterworks SML	1432
Total	2256.9

[3] SFE – single family dwelling equivalent.

References

Hodgins, D.O., 2017a. Safe Yield Analysis for Surface Water Resources. Revision 2 August 2017, 35 p.

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Mekis, É and L.A. Vincent, 2011. An overview of the second generation adjusted daily precipitation dataset for trend analysis in Canada. *Atmosphere-Ocean*, 49 (2), 163-177.

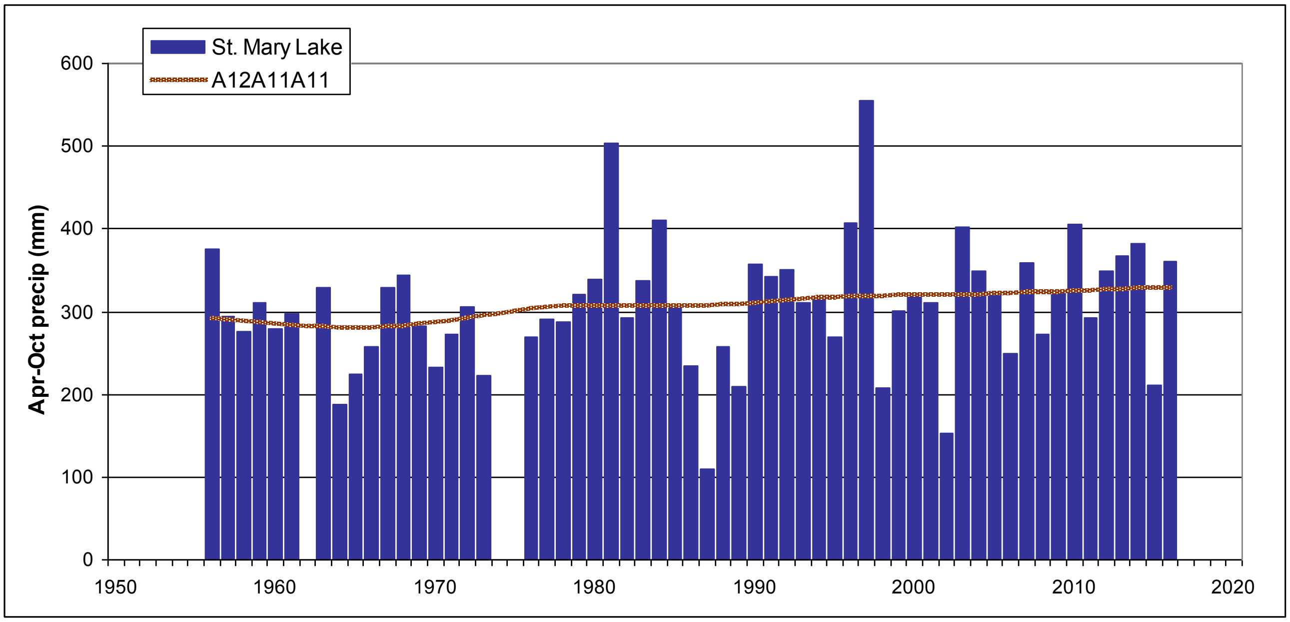
Vincent, L. A., X. L. Wang, E. J. Milewska, H. Wan, F. Yang, and V. Swail, 2012. A second generation of homogenized Canadian monthly surface air temperature for climate trend analysis, *J. Geophys. Res*., 117, D18110, doi:10.1029/2012JD017859.

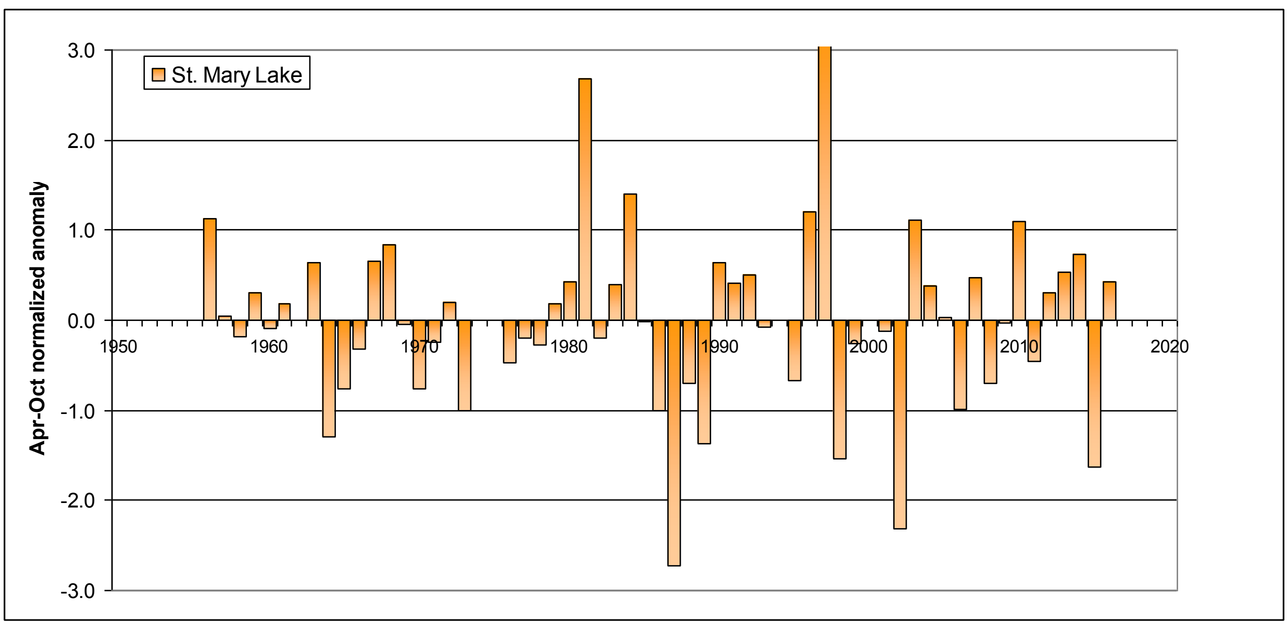
Xu, C.-Y. and V.P. Singh, 2001. Evaluation and generalization of temperature-based methods for calculating evaporation. *Hydrological Processes.* 15, 305–319.

Appendix A Graphs for precipitation and normalized anomaly

For each pair of graphs, the upper panel shows P and <P>. The lower panel shows the normalized anomaly P″.

St. Mary Lake 1976-2017, Vesuvius (1955-1975)

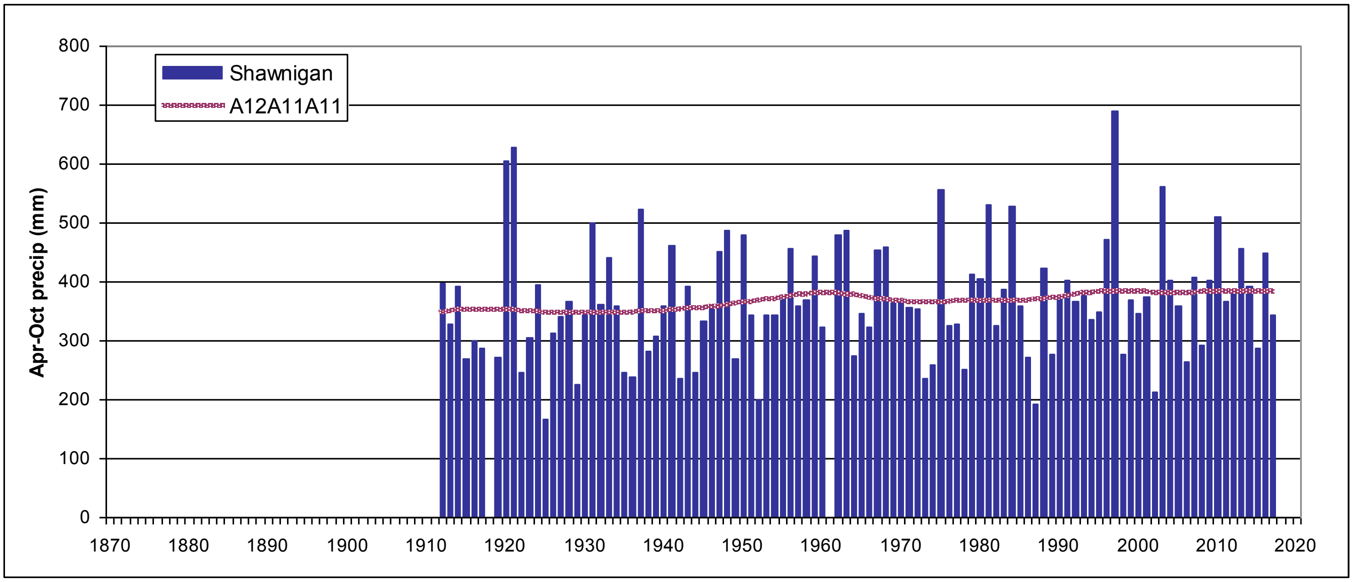


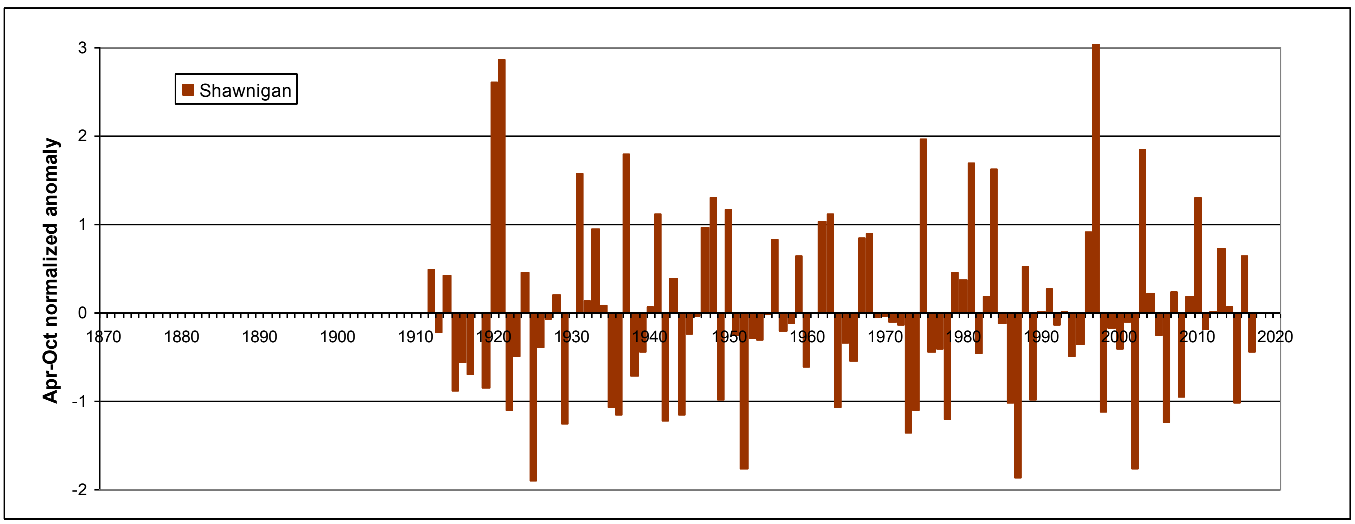


Note: Monthly data for the station *Saltspring Vesuvius* were added to the St. Mary Lake time-series to extend the period of coverage. It is impossible to quantify how representative Vesuvius is for the lakeside station since there is no overlap of measurements. Both stations are located on Salt Spring Island less than 10 km apart, although Vesuvius is closer to sea-level (elevation 8 m vs 42 for St. Mary Lake).

Appendix A cont'd.

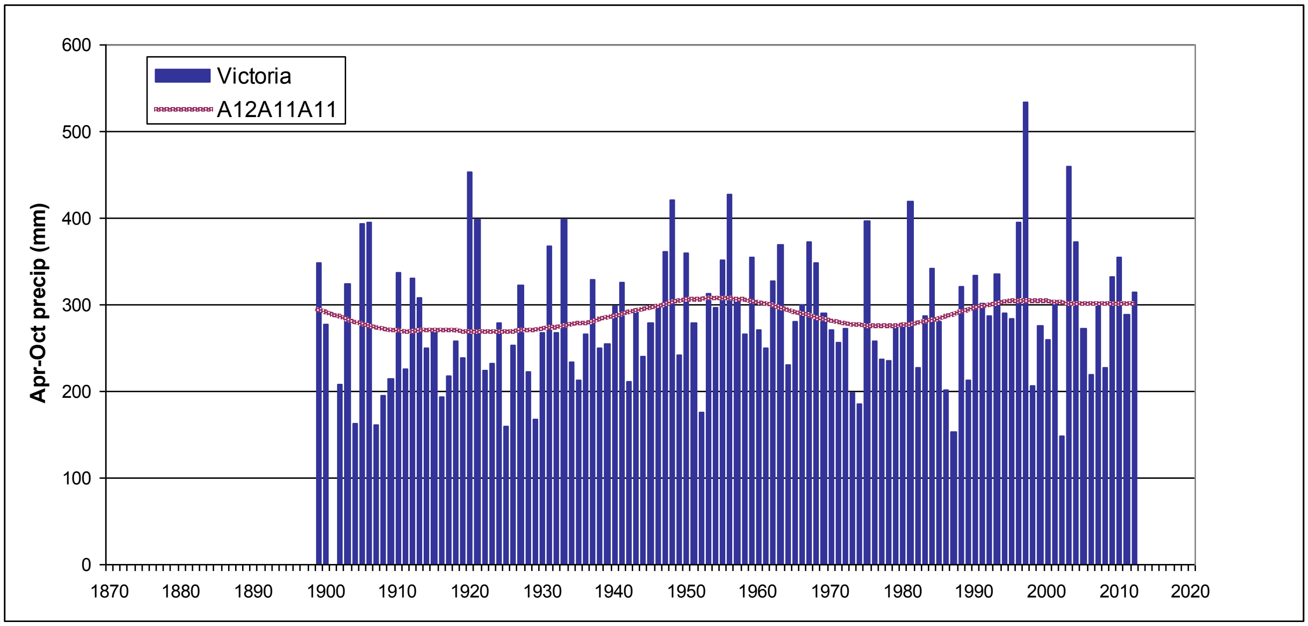
Shawnigan Lake (1912-2017)

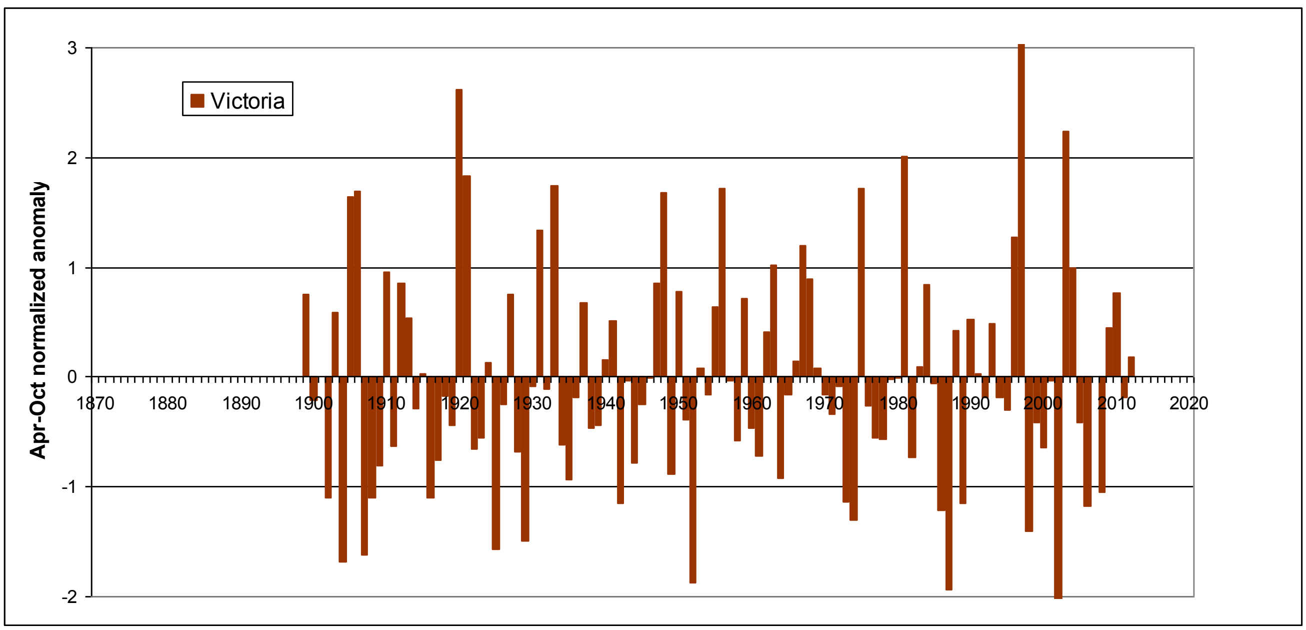




Appendix A cont'd.

Victoria (1899-2012)





Appendix A cont'd.

Saanichton CDA (1899-2012)