Associated Environmental

MEMO

Date:	July 7, 2021	File:	2020-2838.040
To:	Kim Vanderkooy, Mill Bay Waterworks District	Page:	Page 1 of 12
From:	Drew Lejbak, M.Sc.		
Project:	Mill Bay Aquifer Recharge		
Subject:	Precipitation Variability and Trends Assessment		

1 INTRODUCTION

Associated Engineering (AE) was retained by Mill Bay Waterworks District (MBWD) to assess precipitation variability in and around Aquifers 203, 206, and 208 in the Mill Bay area (Figure 1-1). The results of this assessment are to inform decision-making about whether a new precipitation monitoring station is necessary or if current monitoring at Shawnigan Lake (by Environment and Climate Change Canada [ECCC]) is sufficient to help inform aquifer recharge estimates to support long-term water supply planning for MBWD.

AE completed the following scope of work as part of this assessment, as requested by MBWD:

- Perform a correlation analysis on available overlapping precipitation data between the Shawnigan Lake (ECCC No. 1017230) and Cobble Hill Deloume Road (ECCC No. 1011745) climate stations, including an assessment of data quality and continuity.
- Perform a correlation analysis on available overlapping precipitation data between the Shawnigan Lake (ECCC No. 1017230) and Bolduc (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development [FLNRORD] No. 540) climate stations for available overlapping records.
- Complete a trend assessment of monthly, seasonal, and annual precipitation measured at the Shawnigan Lake (ECCC No. 1017230) climate station.
- Provide advice and a recommendation on the necessity for a new precipitation monitoring station within the Mill Bay area to support aquifer recharge assessments.

This memorandum provides a summary of the work completed and the results of the assessment.

2 MILL BAY AQUIFERS AND GENERAL AQUIFER WATER BALANCE

MBWD draws water for supply and distribution from Aquifers 203, 206, and 208 (Figure 1-1). Selected characteristics of Aquifers 203 and 208 are provided by Hammond et al. (2019).[1] Harris and Usher (2017)[2] and WWAL (2018)[3] provide a general summary of the aquifer water balance for Aquifer 206. A summary of each aquifer water balance is provided below.

[1] Hammond, Z.M., A.C. Hinnell, and J.J. Clague. 2019. Detailed Aquifer Mapping Study: Shawnigan Lake Area, Vancouver Island, BC. Water Science Series, WSS2019-02. Province of BC, Victoria, BC.

[2] Harris, M., and S. Usher. 2017. Preliminary Groundwater Budgets – Cobble Hill / Mill Bay Area, Vancouver Island, BC. Water Science Series, WSS2017-01. Province of BC, Victoria, BC.

[3] Western Water Associates Ltd. (WWAL). 2018. Mill Bay Waterworks District Local Aquifer Study. Prepared for Mill Bay Waterworks District.

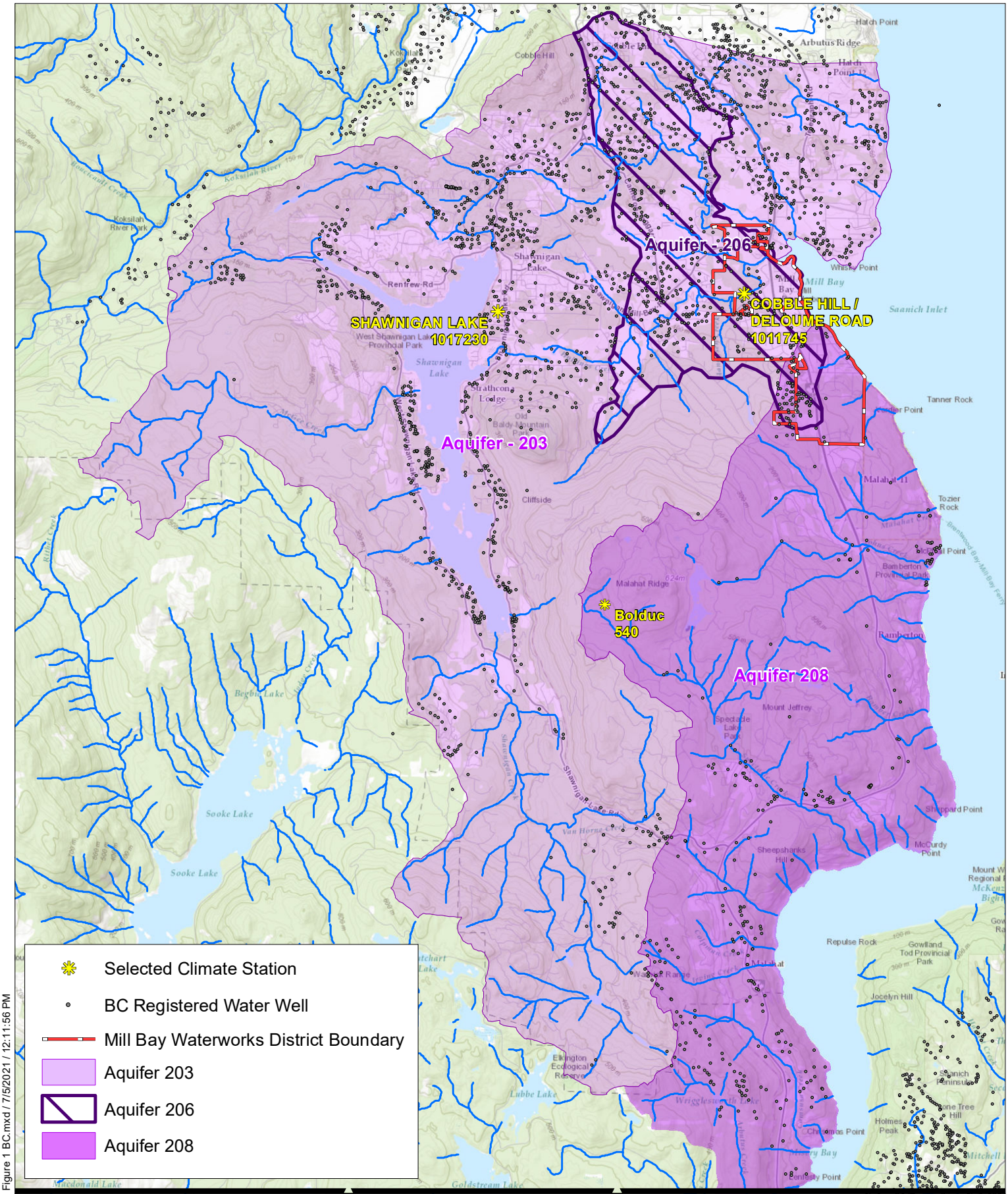

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FIGURE 1-1: MILL BAY AREA AQUIFERS AND SELECTED CHARACTERISTICS

Mill Bay Waterworks District

Mill Bay Precipitation Variability and Trend Assessment

Aquifer 203 – Shawnigan Lake / Cobble Hill / Mill Bay
The aquifer covers an area of 122.7 km^2 west and southwest of Mill Bay (Figure 1-1). The total land area includes Shawnigan Lake and some urban/rural developments but is largely undeveloped. The BC Ministry of Environment and Climate Change Strategy (ENV) classifies Aquifer 203 as Class IIA (12), which indicates that it is moderately developed and moderately vulnerable to surface contamination.

Aquifer 203 is classified as a bedrock aquifer that is overlain by thick colluvium in some areas. Groundwater within the aquifer can be confined or unconfined (based on location of groundwater well) and generally flows east towards the coastline. Groundwater recharge is likely to occur within the upgradient mountainous terrain where precipitation infiltrates into bedrock deformities, while mountain block recharge, leakage from unconsolidated deposits, and surface water hydraulic connections also contribute to recharge.

Hammond et al. (2019) recommended additional studies to confirm or update fault zone structural hydrogeology and surface water/groundwater interactions for Aquifer 203 to support further assessments and water balance studies.

Aquifer 206 – Mill Bay
The aquifer covers an area of 2.57 km^2 southwest of Mill Bay (Figure 1-1). The land area has some urban and rural-residential development and the remainder is undeveloped forest. ENV classifies Aquifer 206 as Class IIA (11), which indicates that it is moderately developed, has a moderate demand, but highly vulnerable to surface contamination. The aquifer underlies an area of moderate relief with surface elevations ranging from 20 to 150 metres above sea level (masl).

Aquifer 206 overlays Aquifer 203 and is classified as a surficial aquifer that consists primarily of sand and gravel deposits that are 5 to 15 m thick but may have greater thickness in places with thicker overburden. However, groundwater storage potential is likely variable due to depositional textural variability and thick unsaturated deposits near the ground surface. Groundwater within the aquifer is primarily unconfined although there may be interbedded clay or till deposits producing localized confined aquifer conditions. Groundwater generally flows to the north / northeast towards Mill Bay. The aquifer receives vertical inflow (recharge) from precipitation, stream losses, and irrigation / sewerage dispersal returns, while lateral inflows from adjacent bedrock aquifers and surface runoff also contribute to subsurface recharge. Outflow from the aquifer is largely through baseflow to small watercourse and springs down gradient.

Harris and Usher (2017) noted moderate and high aquifer recharge from rainfall and negligible recharge from snowmelt due to the general low elevation of the aquifer area and WWAL. (2018) noted that recharge primarily occurs during the spring from the upgradient area towards Mt. Wood.

Aquifer 208 – Malahat Ridge
The aquifer covers an area of 58 km^2 south of Mill Bay (Figure 1-1). The land area has some urban and rural-residential development and the remainder is undeveloped forest. ENV classifies Aquifer 208 as Class IIA (12), which indicates that it is moderately developed and moderately vulnerable to surface contamination.

Aquifer 208 is classified as a bedrock aquifer with near surface bedrock (i.e., <1 m below the surface) in some locations, while a till and clay layer overlain by sands and gravels may be present in areas below 100 to 150 masl. Groundwater within the aquifer can be confined or unconfined (based on location of groundwater well) and generally flows east towards

the Saanich Inlet. Groundwater recharge is likely to occur within the upgradient mountainous terrain where precipitation infiltrates into bedrock deformities, while lakes and wetlands to the west may also contribute to recharge.

Hammond et al. (2019) recommended additional studies to confirm or update surface water/groundwater interactions for Aquifer 208 to support further assessments.

3 MILL BAY PRECIPITATION VARIABILITY ASSESSMENT

3.1 Precipitation Datasets

Prior to MBWD's request of the assessment scope of work summarized in Section 1, AE completed a general review of active and discontinued hydrometric stations in and around the Mill Bay area to provide MBWD with a general idea of available precipitation datasets. Using the information provided, MBWD identified that precipitation records from the discontinued Cobble Hill Deloume Road (ECCC No. 1011745) and Bolduc (FLNRORD No. 540) climate stations (Figure 1-1) would provide useful information to support aquifer recharge estimates for Aquifers 203 and 206 (Young, pers. comm., 2020)[4]. Currently, aquifer recharge and water balance estimates completed by MBWD and/or others generally use Shawnigan Lake (ECCC No. 1017230) climate station (Figure 1-1) precipitation records.

A summary of the three climate station precipitation records is as follows:

- Shawnigan Lake (ECCC No. 1017230)
    - Elevation of climate station: 159 masl
    - Period of record: May 1911 to present
    - Comments: Active and operates annually with daily data. Good data quality.
- Cobble Hill Deloume Road (ECCC No. 1011745)
    - Elevation of climate station: 61 masl
    - Period of record: April 1970 to December 1981
    - Comments: Discontinued but operated annually with daily data. Generally good quality data with some data quality flags for missing and estimated data.
- Bolduc (FLNRORD No. 540)
    - Elevation of climate station: 482 masl
    - Period of record: June 1992 to October 1994
    - Comments: Discontinued but operated seasonally during May and October. Limited data available after removing monthly values with >5 days missing records.

The Cobble Hill Deloume Road climate station data help provide an understanding of precipitation variability across the lower elevation terrain of Aquifers 203, 206, and 208. The Bolduc climate station data provide information on the higher elevation differences (if any).

[4] Brian Young. Trustee. Mill Bay Waterworks District. 2020. Personal and email communications with Drew Lejbak and Jonathan Musser of AE, August and September 2020.

3.2 Climate Station Correlation Assessment

Using the available periods of overlapping records for the climate stations, monthly, seasonal (summer and winter),[5] and annual correlation analyses (i.e., linear regression) between Shawnigan Lake and Cobble Hill Deloume Road and Shawnigan Lake and Bolduc climate stations were completed to assess precipitation variability. The results of the assessments are provided in Figures 3-1 and 3-2.

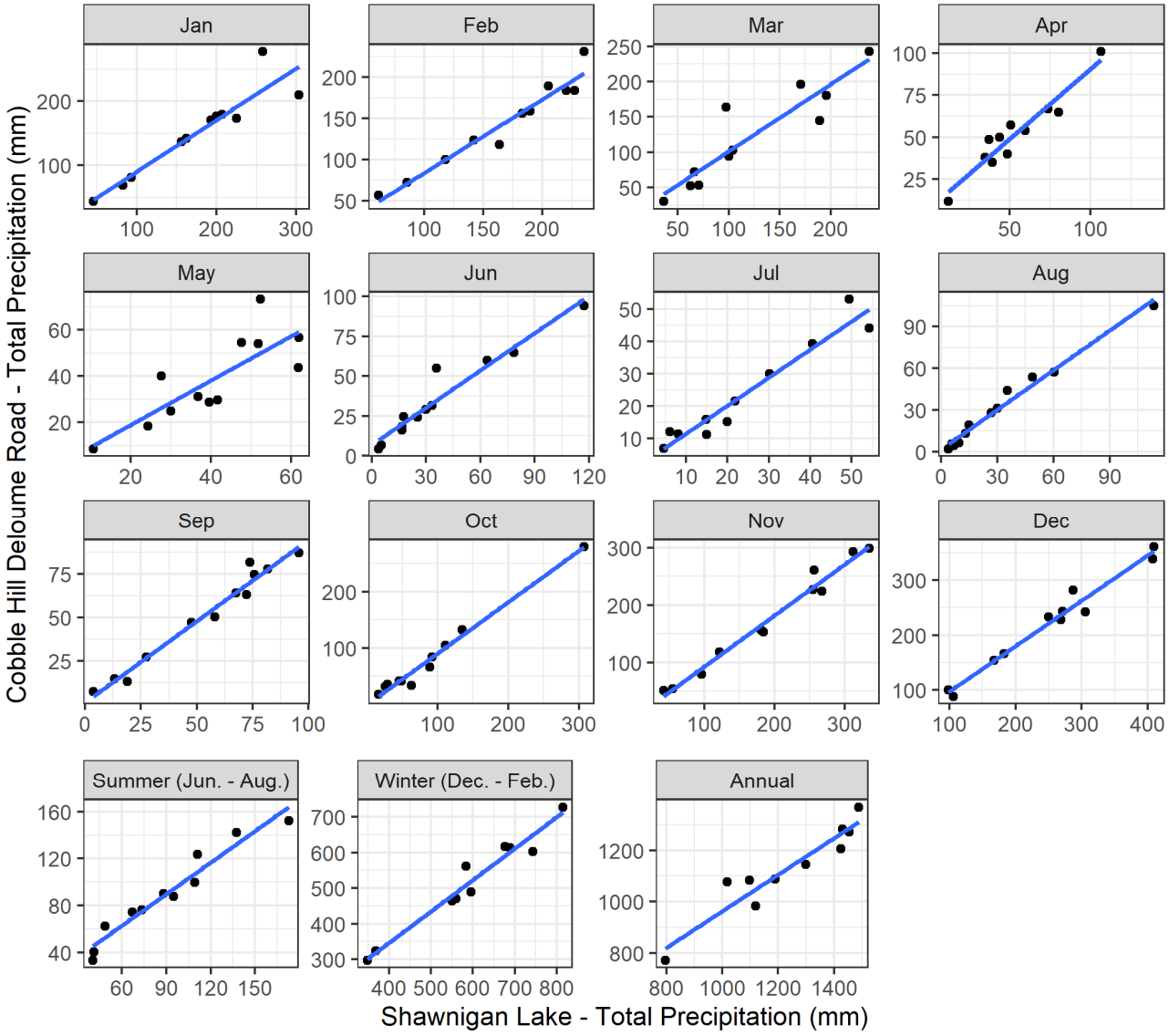

Figure 3-1 Summary of monthly, seasonal, and annual precipitation correlations between Shawnigan Lake (No. 1017230) and Cobble Hill Deloume Road (No. 1011745) climate stations (1970-1981)

[5] Summer period = June to August; Winter period = December to February

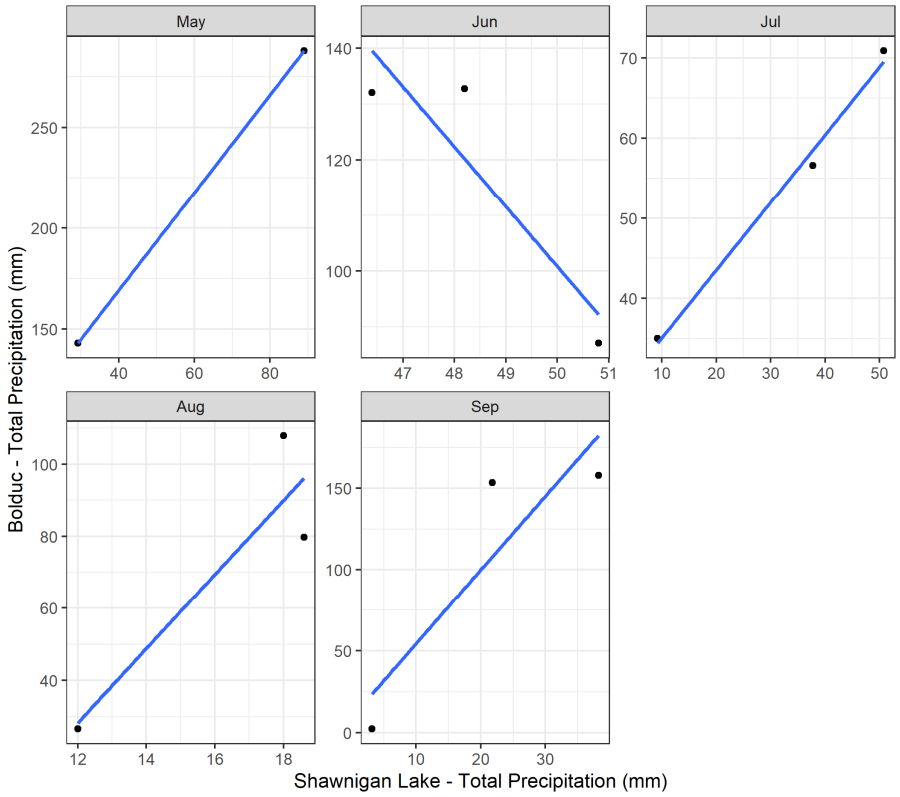

Figure 3-2 Summary of monthly precipitation correlations between Shawnigan Lake (No. 1017230) and Bolduc (No. 540) climate stations (1992-1994)

The results indicate the following:

- A strong correlation for monthly, seasonal, and annual precipitation exists between the Shawnigan Lake and Cobble Hill Deloume Road climate stations. The correlation indicates that on average the Shawnigan Lake climate station overpredicts the amount of precipitation in the Cobble Hill area by approximately 9% annually and seasonally the overprediction ranges from 15% for the winter and 0.5% for the summer periods. The results are based on the overlapping period of record (1970-1981), so may only reflect conditions for that period and not long-term conditions.
- Due to the limited data available for the overlapping period, seasonal and annual correlations could not be completed between the Shawnigan Lake and Bolduc climate stations. Weak monthly correlations for available months are due to the limited precipitation records available for these climate stations.

3.3 Shawnigan Lake Precipitation Trend Assessment

A precipitation trend analysis of available data (1911-2020) from the Shawnigan Lake climate station was completed on monthly, seasonal (summer and winter), and annual records (Figure 3-3). The trend analysis used the Mann-Kendall non-parametric trend test to identify statistically significant trends

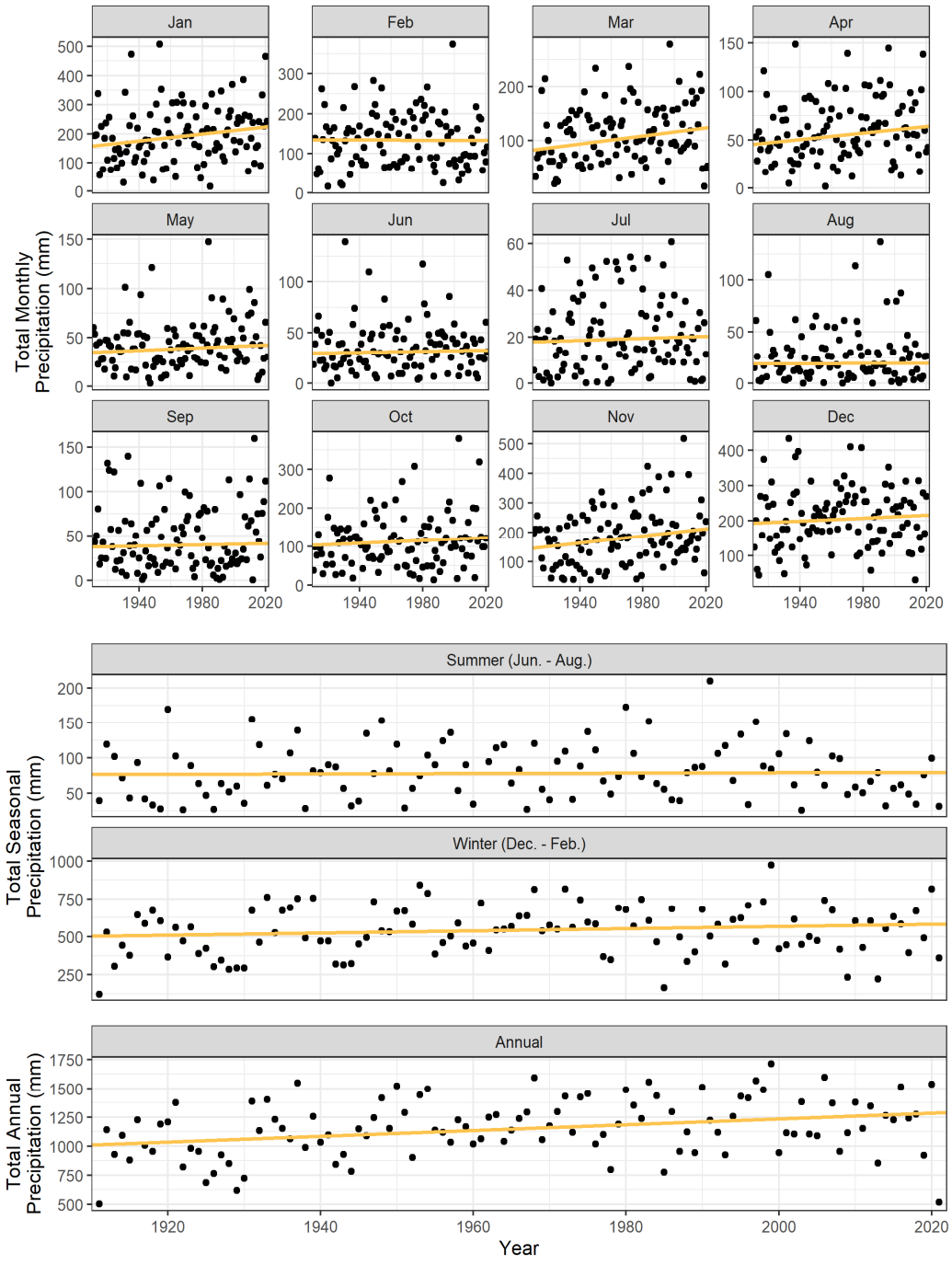

Figure 3-3 Summary of monthly, seasonal, and annual precipitation trends for Shawnigan Lake (No. 1017230) climate station (1911-2020)

The Mann-Kendall trend tests were evaluated against the null hypothesis that the test statistic, *S*, equals zero indicating no trend. If the p-value of the test was <0.10 then the null hypothesis was rejected, and the alternate hypothesis was accepted that a statistically significant trend exists. The trend direction and magnitude of change over time was estimated with Sen's slope estimates. The Sen's slope estimate is derived by taking the median slope of all pairs of observations and provides a trend slope with units of the input variable per dataset time step. Both the Mann-Kendall trend test and Sen's slope estimation were completed using the *trend*[6] package in the R programming language.

The results indicated the following:

- Statistically significant increasing trends exist for the winter months of January, March, April, and November, and the annual and winter season periods, but no consistent significant trends exist for the summer months or summer season periods. The results suggest that the annual precipitation in the area around Shawnigan Lake has been increasing by approximately 0.2% over the period of record.

3.4 Gridded Climate Dataset Review

Historical gridded climate datasets from ClimateWNA[7] provided additional information about precipitation variability around the areas of Aquifers 203 and 206. The gridded climate data are available at 800 m by 800 m grid cell size and are developed and calibrated for BC using information from actual climate stations. ClimateWNA provides historical data for a set of annual, seasonal, and monthly temperature and precipitation variables, as well as a set of future temperature and precipitation variables.

Figure 3-4 provides a summary of the mean 1981-2010 total annual precipitation that exists across the mapped extents of Aquifers 203, 206, and 208. The 1981-2010 period represents the most recent climate normal[8] published by ECCC. The gridded precipitation dataset indicates that for the mapped Aquifer 203, 206, and 208 areas, the lower elevation areas show generally consistency in total annual precipitation. However, for the higher elevation areas of Aquifer 203 and Aquifer 206, total annual precipitation can be 300-500 mm and 100 mm higher than the low elevation areas, respectively. Mean total annual precipitation per 25 masl elevation band are provided in Figure 3-5 for the mapped extent of each aquifer using the gridded precipitation data included in Figure 3-3. Although the mapped aquifer extent does not necessarily reflect that full aquifer recharge area by precipitation (i.e., Aquifer 203), Figure 3-5 provides insight into the general variability that exists across the geographic areas.

[6] Thorsten Pohlert (2020). trend: Non-Parametric Trend Tests and Change-Point Detection. R package version 1.1.4. https://CRAN.R-project.org/package=trend

[7] http://www.climatewna.com/ClimateBC_Map.aspx

[8] A climate normal is an average 30-year period of climate variables including air temperature and precipitation.

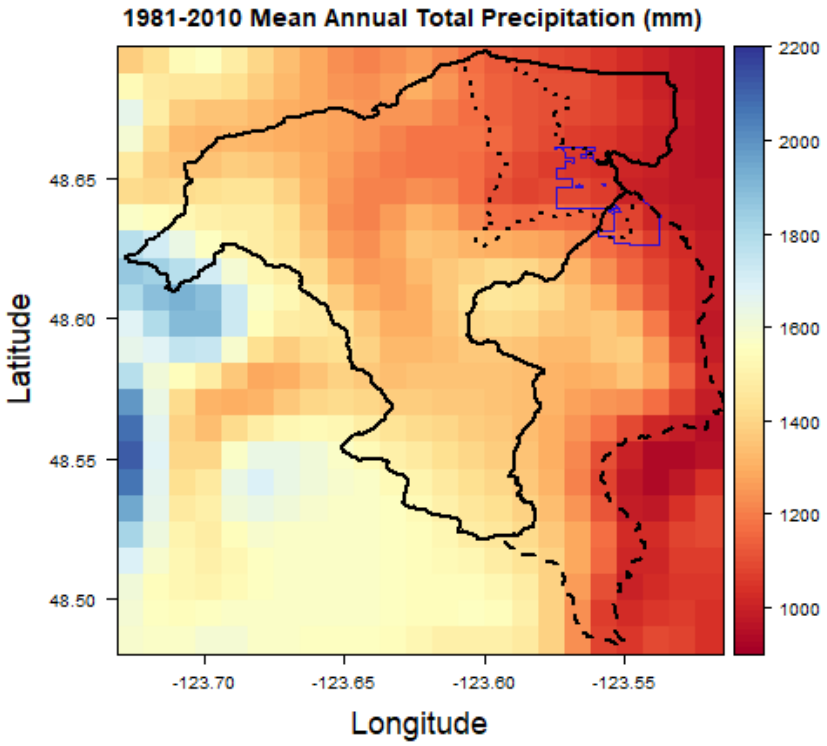

Figure 3-4 Summary of mean annual total precipitation (1981-2010) distribution across the mapped Aquifer 203 (solid line), 206 (dotted line), 208 (dashed line) and Mill Bay Waterworks District (blue line) extents

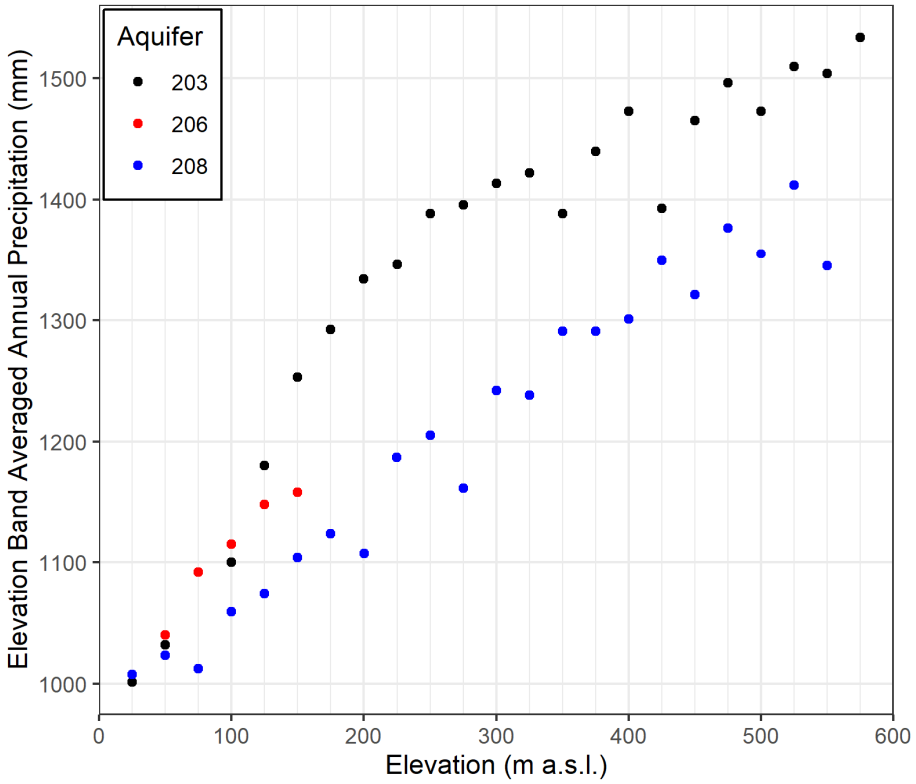

Figure 3-5 Summary of mean annual total precipitation (1981-2010) per 25 masl elevation band across mapped Aquifer 203, 206, and 208 extents

4 CLIMATE CHANGE

Based on available information for the Pacific Climate Impacts Consortium,[9] the general future (2040-2069) climate and hydrologic trends predicted for the Mill Bay area are as follows:

- The local climate is predicted to warm, and annual precipitation is predicted to slightly increase (+1.3%). Summer precipitation is likely to decrease (-13%) and winter precipitation is likely to increase (+2.8%).
- Snowpacks (if present) are predicted to decrease in both winter and spring.
- The spring freshet period is predicted to occur earlier.
- The magnitude of extreme peak flows is projected to increase, which could cause an increase in flood and natural hazards.
- Low flows could occur earlier and last for a longer period, increasing the risk of drought.

The predicted future results of precipitation trends for the Mill Bay area are consistent with that identified at the Shawnigan Lake climate station (Section 3.3). Accordingly, MBWD may need to plan for the implementation of additional water restrictions due to current and future expected increases in summer water demands.

[9] https://www.pacificclimate.org/analysis-tools/plan2adapt

5 SUMMARY AND RECOMMENDATIONS

To aid MBWD in the assessment of precipitation variability in and around Aquifers 203, 206, and 208 a correlation and trends assessment was completed using precipitation records available at the Shawnigan Lake (ECCC No. 1017230) climate station and historical records available from the Cobble Hill Deloume Road (ECCC No. 1011745) and Bolduc (FLNRORD No. 540) climate stations. The results of the assessment indicate that the Shawnigan Lake precipitation records can be used to support precipitation estimates for the lower elevations of the terrain in the mapped aquifer areas, but not likely the higher elevations. Also, precipitation at Shawnigan Lake has been increasing annually over time, which is consistent with predicted future climate conditions for the area.

AE provides the following recommendations to support further precipitation monitoring around the Mill Bay area and for aquifer recharge estimation for Aquifers 203, 206, and 208:

- To inform Aquifer 206 recharge estimates by direct precipitation, the general correlation results between the Shawnigan Lake and Cobble Hill Deloume Road climate stations should be considered to account for the apparent geographic differences between climate station locations. The ClimateWNA gridded precipitation datasets should also be used to support recharge estimates for Aquifer 206.
- As outlined by Hammond et al. (2019) and WWAL (2018), additional studies should be conducted to provide more information about the aquifer water balance for Aquifers 203, 206, and 208. Aquifers 203 and 208 have some aquifer recharge within the upgradient mountainous terrain by direct precipitation into bedrock deformities, but also recharge through mountain block recharge, leakage from unconsolidated deposits, surface water hydraulic connections, and recharge through lakes and ponds, whereas Aquifer 206 receives vertical inflow (recharge) from precipitation and lateral recharge from other aquifers. Therefore, a better understanding of water balances for all aquifers is needed to fully inform aquifer recharge estimates and to identify potential discharge areas. Specifically, a study to identify aquifer recharge areas would be useful to support water supply planning for Aquifers 203, 206, and 208.
- Because of the large spatial extent of all aquifers and the general precipitation variability identified across the Mill Bay area (Figure 3-4), a new climate station could be installed to help provide more information about precipitation variability in the area. However, additional discussions are required to identify a preferred location for the station and the reasoning for the selected location. The goal of a new station would be to help inform specific water balance estimates for Aquifers 203, 206, and 208. Therefore, the station should not be installed at a location where recharge is only assumed to occur (e.g., installing a station on Mount Wood because it is at a higher elevation), when aquifer recharge through direct precipitation may be largely occurring elsewhere.
- Due to the current water demands on Aquifers 203 and 206 and the observed and future predicted changes to precipitation in the Mill Bay area, if not already developed, MBWD should develop a drought management plan (DMP) to help plan for current and future water supply challenges. The DMP can be developed following guidance provided in *Dealing with Drought: A Handbook for Water Suppliers in BC*.[10]

[10] BC Ministry of Environment. 2016. Dealing with Drought: A Handbook for Water Suppliers in BC. Deputy Ministers' Committee on Drought.

6 CLOSURE

This technical memorandum provides a summary of an assessment of precipitation variability around the Mill Bay area. We are available to answer any questions regarding the content in this memorandum. Please contact Drew Lejbak at (250) 826-9486.

Prepared by:

Drew Lejbak, M.Sc.
Senior Hydrologist

Reviewed by:

Paul Hague, B.Sc., RPF
Operations Manager