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FINAL - Technical Memorandum

DATE: July 22, 2011

TO: Craig Wightman, BCCF

FROM: Craig Sutherland, P.Eng.

CC:

RE: **BC CONSERVATION FOUNDATION**
Cowichan River Watershed – Climate Change Impact Assessment
Our File 0673.019

BACKGROUND

A climate change assessment was completed as part of the Cowichan Basin Water Management Plan (CBWMP) process in 2006. However, significant advancements in climate change science and data availability have been made in the past five years including the fourth update of the UN Intergovernmental Panel on Climate Change (IPCC) assessment report (AR4) in 2007 as well as the launch of the Pacific Climate Impacts Consortium (PCIC) Online Regional Analysis tool. The BC Conservation Foundation has retained Kerr Wood Leidal Associates Ltd. (KWL) to prepare an update to the Cowichan River climate change assessment using the latest climate change forecasts provided by PCIC.

The scope of the study included:

1. Review of climate change forecast data for the Cowichan Valley Region provided by PCIC based at the University of Victoria;
2. Development of a distributed monthly water balance model of the watershed;
3. Calibration and verification of the model using recorded river discharge data and back calculated inflow data used in the CBWMP study;
4. Calculation of monthly average discharges for both the current (1961 to 1990 normal period) and future (2050s) climate conditions; and
5. Compare the results with the previous results developed as part of the CBWMP.

STUDY AREA, CLIMATE AND HYDROLOGY

The Cowichan Valley is located on Vancouver Island about halfway between Nanaimo and Victoria (see Figure 1). The Cowichan River is the largest river in the valley and flows from the headwaters at Cowichan Lake eastward for nearly 45 km to the estuary in Cowichan Bay near Duncan. The Cowichan River watershed has a total watershed area of 930 km^2 and rises from sea level to a maximum elevation of 1,520 m at El Capitan Mountain on the northern boundary of the watershed. Cowichan Lake has a surface area of 62 km^2 and stretches nearly 31 km from west to east.

The climate of the area is typical of the southern west coast of British Columbia with cool and wet fall and winter and warm and drier spring and summer periods. Average annual temperature at both Lake Cowichan and Duncan for the 1961 to 1990 Normal Period is 9.4 ^{o}C. There is a strong precipitation gradient decreasing from west to east as a result of the rain shadow effect of the Vancouver Island Mountains with total annual precipitation at Lake Cowichan and Duncan recorded at 2,018 mm and 1,051 mm, respectively. The average precipitation in the mountains in the western part of the watershed is estimated to be up to 4,500 mm annually. Plots of average monthly temperature and precipitation recorded at Lake Cowichan and Duncan are shown in Figure 2.

During the winter months, snow accumulates at higher elevations in the watershed (usually at elevations higher than 800 m). The average maximum snow water equivalent recorded at the Jump Creek snow pillow located in the Nanaimo River watershed to the north of the Cowichan Valley is 1,358 mm. The average snow-water equivalent recorded at the Jump Creek snow pillow is shown in Figure 3.

CLIMATE CHANGE IN THE COWICHAN VALLEY

Overview – Global and Provincial Perspective

Variability and change in the climate will have an impact on hydrology of the Cowichan River. Changes in temperature and precipitation as a result of climate change, as well as climate cycles such as the El-Nino Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO), change the magnitudes of evapotranspiration, snowpack accumulation and melt, and ultimately streamflows. Climatic changes will also have impact on land-cover, with changes in the type of vegetation cover and the range of species.

The science of climate change and its impact on hydrology is a broad and complex topic. A brief summary of current research and regional climate impact results for this study, are presented in this report. Cited references may be reviewed to provide for an in-depth consideration of the topic.

Globally, the IPCC (2007) estimates that global average temperature will rise between 1.4° to 5.8°C by the year 2100. This relatively wide range results primarily from difficulty in forecasting future greenhouse gas emissions and from limits to precisely estimating the effect of many feedback processes in the climate system. There are also significant spatial variations in forecast average temperature change, with greater increases typically occurring over landmasses and at higher latitude.

Models used to forecast change in global climate tend to agree that average temperatures are likely to increase but vary widely in projections of change in precipitation. All models indicate an increase in average global precipitation as a result of higher air temperature leading to more evapotranspiration, and warmer air holding more moisture. However, the spatial distribution of the changes varies from model to model.

For British Columbia, PCIC has prepared an overview of hydro-climatology and future climate impacts (Rodenhuis et. al., 2009). The major findings for changes in climate are:

- Across BC over the past century, annual minimum temperature has risen by 1.0°C to 2.5°C, while annual maximum temperature has risen by 0.5°C to 1.5°C. In the Cowichan Valley region, annual minimum temperature has increased by between 1.0°C to 1.5°C, and maximum temperatures have increased by about 0.5°C over the same period (1900-2000).

- Trends in precipitation over the last century were also generally positive (+22% per century on average across BC) and some observations of +50% per century occurred in winter in the Interior.

- Historical climate cycles had a pronounced influence on seasonal temperature and precipitation in BC, especially in the winter and spring seasons. During the warm phase of ENSO, the temperature was higher (+0.5°C to +2.8°C) and the precipitation was somewhat less (-5%) compared to the cool phase. There was also a comparable influence of the PDO warm phase on temperature (+2.9°C) although precipitation was not significantly different. The magnitude of climate variability was comparable to climatic trends over the century.

- By the middle of this century (2050s) the average annual temperature in BC is projected using an ensemble of Global Circulation Models (GCMs) to be warmer by +1.7°C (+1.2°C to +2.5°C) compared to the GCM baseline (1961-1990) climate, and this shift is projected to occur in both winter and summer seasons.

- The average annual precipitation in BC is projected to increase by +6% (+3% to 11%). However, most of this increase is projected to occur in the winter season, while decreases are projected to be -3% (-9% to +2%) in the summer.

Recent trends in climate and hydrology in Cowichan Valley.

Recent trends in climate and hydrology in the Cowichan Valley have been assessed using available climate records and river flow records. The Cowichan Lake Forestry climate station provides a nearly continuous record of daily precipitation and temperature since 1950. The data indicates that both the minimum and maximum daily temperatures, as well as the total annual precipitation, appear to have an increasing trend. A plot of the annual temperature and precipitation trends are shown in Figure 4. The linear trend fit shown in the figures has been included to show general trends. However, it does not indicate statistical significance of the trend and therefore should be not be used to estimate the magnitude of the trend.

Although annual precipitation tends to be increasing, the spring and summer precipitation tends to be decreasing. Figure 4 also shows the total recorded precipitation for the April 1st to September 30th period for each year. This is similar to the PCIC findings for other areas on the south coast of BC.

Net inflow to Cowichan Lake has been calculated using the Water Survey of Canada (WSC) data for the Cowichan Lake level and Cowichan River discharge data using the mass balance equation:

$$Qnet_n = Qi_n - (E_n * A)/dT = Qo_n + (WL_n - WL_{n-1}) \text{ x } A \text{ x } / \ dT$$

Where:
Qnet = daily net inflow (m^3/s)
Qi = daily watershed inflow (m^3/s)
E = daily lake evaporation (m)
Qo = daily river discharge (m^3/s)
WL = Cowichan Lake level (m)
A = Cowichan Lake Surface Area (m^2)
dT = time step (seconds)
n = date of the record

Figure 5 show the calculated annual and spring/summer inflows to Cowichan Lake. The data indicates the total annual net inflow appears to be decreasing since 1953. The average annual net inflow for the period from 1953 to 1980 (28-years) is 2,514 mm while the average from 1981 to 2007 is 2345 mm. Other hydrological studies in basin have indicated similar trends showing a 36% decrease in summer net inflow after 1984 (Chapman, 2010). There are two potential reasons why the net annual inflow to Cowichan Lake is decreasing:

1. as net inflow includes evaporation from the lake, the increased evaporation from the lake surface as a result of higher temperatures would decrease net inflow; and
2. the change in land cover in the watershed with regeneration of second growth forest since the 1950s may be increasing evapotranspiration from the watershed.

On a monthly basis, the inflow appears to be decreasing during the spring and summer months and increasing in the winter; except for December (see Figure 6). These trends appear to be following similar trends found in other watersheds in the region including decreased spring runoff as a result of reduced snowpack volume in the watershed, and reduced spring runoff, reduced summer inflows as a result of reduced summer precipitation, increased lake evaporation from increased temperatures, and possibly increased evapotranspiration from regeneration of second growth forest. In general, winter runoff is increasing as a result of increased winter precipitation and a higher percentage of precipitation falling as rain in the watershed rather than snow.

Forecast Regional Climate for 2050s

As previously discussed, the wide range of climate change forecasts requires the need of a range of scenarios for climate change impact analysis. PCIC has taken results of many of the various GCMs and combined them into an ensemble dataset (PCIC, 2011). This dataset provides a good indication of the forecast variation in average temperature and precipitation in the region. Output from the PCIC ensemble datasets for the Cowichan Valley Region is shown in Figures 7, 8 and 9, for annual temperature and precipitation, seasonal precipitation and seasonal temperature, respectively.

On an annual average basis, the Cowichan Valley Region is expected to become warmer and wetter. The models estimate that annual average temperatures will continue to increase as by +0.7^{o}C to +1.1^{o}C by 2020 and by about +1.3^{o}C to +1.9^{o}C by 2050s[1].

IMPACTS OF CLIMATE CHANGE ON COWICHAN RIVER HYDROLOGY

Hydrological Modelling

The response of the Cowichan River watershed to forecast changes in climate has been modelled using a monthly water balance model developed by the United States Geological Survey (USGS) (McCabe and Markstrom, 2007). This model uses a monthly water balance which uses monthly average precipitation and temperature forecasts to predict monthly average runoff from the watershed. It accounts for evapotranspiration and evaporation, snow accumulation and snow melt, soil moisture and ground water infiltration. The spatial distribution of precipitation and temperature across the watershed is accounted for by using gridded precipitation and

[1] Future climate projections described in this study are based on absolute changes in temperature and percent change in precipitation from 1961-1990 Normal Period. This study uses standard naming convention developed by the IPCC for future periods with 2020s representing the 2011 to 2040 Normal Period and 2050s representing the 2041 to 2060 Normal Period. The range of values shown describes the range from the 25th-percentile to the 75th-percentile of the ensemble of GCM model results from the PCIC regional analysis tool (http://pacificclimate.org/tools/regionalanalysis/).

temperatures at a 1 km^2 grid size based on the ClimateBC dataset (Wang et. Al., 2006). This accounts for the trend in temperature and precipitation across the watershed at different elevations. The model is used to estimate runoff for each 1 sq. km grid cell in the watershed. A GIS system is then used to accumulate all the runoff amounts throughout the watershed to estimate the total watershed runoff. A diagram showing how the model functions is shown in Figure 10.

Model Calibration

The model has been calibrated using the average monthly lake net inflow data for the 1971 to 2000 normal period. The model parameters were adjusted until model results matched closely with the recorded values. A comparison of the modelled values and recorded values for the Cowichan Lake net inflow are shown in Figure 11.

To verify the model results, the model values were also compared with the discharge values for the Cowichan River near Duncan. The recorded values where adjusted to account for the releases from the Cowichan Lake weir and the withdrawals at the Crofton Mill pump-station upstream from the gauge. Average withdrawal at the Crofton Mill pump station was assumed to be 73.82 million m^3 per year or at a constant rate of 2.34 m^3/s for the 1961 to 1990 period. The water consumption at the mill is now 20% to 25% less than what was recorded in 1990 (Westland, 2005).

Both the calibration and verification results indicate that the model provides a reasonable fit to the recorded data. The model is tending to under-predict the late winter/early spring discharges and over-predict the late summer flows. The total volume error is about +1.3% and Nash-Sutcliff value is 0.96, both within the accepted standard values for hydrological modelling. The Nash-Sutcliff value is a measure how well the shape of the modelled hydrograph fits the recorded values with a value 1.0 indicating a perfect fit.

Cowichan River Hydrology in the 2050s

Average monthly precipitation and temperature data for the 2050s period provided by PCIC was used to forecast how monthly runoff in the Cowichan River watershed may change in the future. The results of the modeling are shown in Figure 12. A range of values have been estimated which represent the range of climate forecasts based on the different emission scenarios and global circulation model results. The upper and lower bounds roughly represent the 25th and 75th percentile of the range of future streamflow values.

The results indicate that by the 2050s the average annual runoff for Cowichan River at Lake Cowichan and Cowichan River at Duncan is expected to increase by 11% and 14%, respectively. However, the increase is primarily in the winter and falls with reduced streamflows in the spring and summer (see Table 1). As shown in Table 1, there is considerable variation in forecast depending on which GCM model results are used. The uncertainties of the results are outlined further in the section below.

TABLE 1 – Forecast percent change in monthly average flow from 1971 to 2000 Normal Period to 2050s

Month	Cowichan River at Lake Cowichan			Cowichan River at Duncan		
	Median	High	Low	Median	High	Low
January	11%	17%	8%	13%	21%	11%
February	15%	18%	8%	18%	21%	9%
March	5%	16%	0%	6%	19%	-1%
April	-9%	6%	-20%	-11%	7%	-25%
May	-14%	-13%	-21%	-16%	-15%	-24%
June	-15%	-11%	-17%	-16%	-12%	-18%
July	-7%	-5%	-8%	-12%	-8%	-12%
August	-12%	-7%	-18%	-18%	-11%	-24%
September	3%	33%	-14%	1%	30%	-17%
October	30%	71%	15%	33%	81%	17%
November	16%	26%	14%	21%	32%	18%
December	29%	49%	7%	36%	60%	10%
Annual	11%	24%	3%	14%	28%	4%

Note: Range of values based on 25th and 75th percentile of model results for Planners Ensemble of GCM model results provided by PCIC.

The results of the Cowichan River study have similar trends to other studies in the region. The percentage change in spring runoff is slightly less than predicted for other watersheds on central Vancouver Island as the snow-melt contribution to the annual runoff is less than higher elevation watersheds such as Englishman and Puntledge rivers.

Comparison with CBWMP Climate Change Assessment Results

During preparation of the CBWMP in 2006 an estimate of the climate change impacts for Cowichan Lake was completed using climate change data available at the time (Table 2)

TABLE 2 – Forecast climate change impacts prepared as part of CBWMP

Month	% Change in Average Monthly Net Inflow from 1971 to 2000 Normal Period to 2050s Period	
	Low Range	High Range
January	10%	0%
February	21%	-3%
March	13%	-13%
April	0%	-13%
May	-10%	-34%
June	-5%	-26%
July	-2%	-38%
August	0%	-79%
September	28%	-13%
October	4%	-7%
November	3%	-8%
December	25%	-3%
Annual	12%	-8%

Source: Assessment of Water Supply Alternatives memorandum prepared by UMA Engineering dated December 19, 2005.

The range of estimates provided in this updated climate change impact assessment fall within the original range of estimates from the CBWMP.

UNCERTAINTIES AND LIMITATIONS

Forecasting climate change and its impacts on streamflow involves significant uncertainties including the following four factors, discussed further below:

1. forecasting future greenhouse gas emissions and concentrations in the atmosphere;
2. modelling how changes in greenhouse gas emissions impact climate on a global scale;
3. downscaling the results of the global scale analysis to local or regional scales; and
4. modelling hydrological response of watersheds under changed climatic conditions.

Future changes in greenhouse gas emissions and concentrations in the atmosphere are unknown. The IPCC has developed a range of possible future conditions which take into account how climate change policy will develop (global versus regional greenhouse gas reduction policies), as well as how future economies will develop (unrestrained economic growth versus sustainable growth). This leads to four future emission scenarios ranging from high emissions (A1), medium-high emissions (A2), medium-low emissions (B2) and low-emissions (B1). For this climate change assessment, we have selected results based on medium-high and medium-low ranges. These results tend to provide a range of temperature and precipitation forecasts from the 25^{th}-percentile to the 75^{th}-percentile over the entire range of future forecasts using all four emissions scenarios.

How climate responds to future greenhouse gas concentrations is modelled using GCMs. Many different GCM models have been developed. For instance, PCIC has used 15 separate models for analysis of ensemble model results (Rodenhuis et. al., 2009). Each of the models has different assumptions and limitations resulting in different temperature and precipitation forecasts, even for the same emission scenario. For instance, in BC the portion of uncertainty resulting from variation in GCM model results is larger than the portion of uncertainty as a result of using different emission scenarios. This is most likely due to variations in how the models account for the complex topography of BC, and its influence on regional climate.

The GCM model results must be downscaled to account for the nature of topography in the Cowichan River Watershed. As previously described, we have used results of the Canadian Regional Climate Model, which downscales data from Global Circulation models, which has then been further downscaled using the ClimateBC model. The ClimateBC model uses statistical relationships to develop lapse rates (change with elevation) for temperature and precipitation. There are uncertainties associated with using these statistical relationships to estimate spatial changes in precipitation and temperature both under present and future climate conditions.

Finally, there is uncertainty in how changes in temperature and precipitation change streamflows. Some of the important influences on hydrological response include changes in snow accumulation and melt, and future changes in land cover and land use. The hydrological model used in the study does account for changes in snowpack accumulation and melt, which shows that this is an important variable in forecasting streamflow response (model results show that higher elevation watersheds have more significant changes to hydrological response than lower elevation catchments where snowpack accumulation and melt do not have as large an influence on streamflow). However, due to the limited information and research on local changes in land cover in the future, changes in land cover have not been accounted for in the analysis. Accordingly, a range of future streamflow conditions have been developed to try to account for the uncertainty in forecasts.

SUMMARY OF RESULTS AND IMPLICATIONS

The results of the preliminary hydrological assessment indicate that:

1. Review of climate data for the Lake Cowichan Forestry Climate Station near Mesachie Lake and the Duncan Forestry Climate Station near Duncan indicate that average minimum and maximum air temperatures appear to have increased in the Cowichan River Watershed since the 1950s.

2. A review of the Cowichan Lake net inflow record from 1953 to 2009 indicates that inflow to the watershed has followed similar trends to other watersheds in south-eastern BC with reduced spring/summer runoff. Average April to September flows have decreased by about 17% for the 1981 to 2009 period compared with the 1953 to 1980 period.

3. Downscaled results of global circulation models indicates that average annual temperatures are forecast to increase by +1.3 ^{o}C to +1.9 ^{o}C on average in the Cowichan Valley by the 2050s. The GCM results also indicate a 0.8 % to 9.4 % increase in annual precipitation. Fall, winter, and spring precipitation is expected to increase but summer precipitation (June to August) is forecast to decrease.

4. Hydrological modelling of the Cowichan River watershed indicates that on average the annual runoff is expected to increase. However, streamflows are forecast to increase in the fall/winter and decrease in the spring/summer. For Cowichan River at Cowichan Lake, the largest increase is forecast for December with a 29% increase in average flow and the largest decrease is forecast for June with a 15% decrease. Similar results for the largest decrease in average flow were forecast for Cowichan River near Duncan for May and June with the largest increase in average flow of 36% for December.

5. Comparing results of this updated climate change impact assessment with the previous climate change assessment prepared as part of the CBWMP indicates the updated forecasts fall within the original range of future monthly discharge forecasts.

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CLOSING

If you have any questions or concerns regarding this assessment, please contact the undersigned at (250) 595-4223.

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CS/ami

Encl.

STATEMENT OF LIMITATIONS

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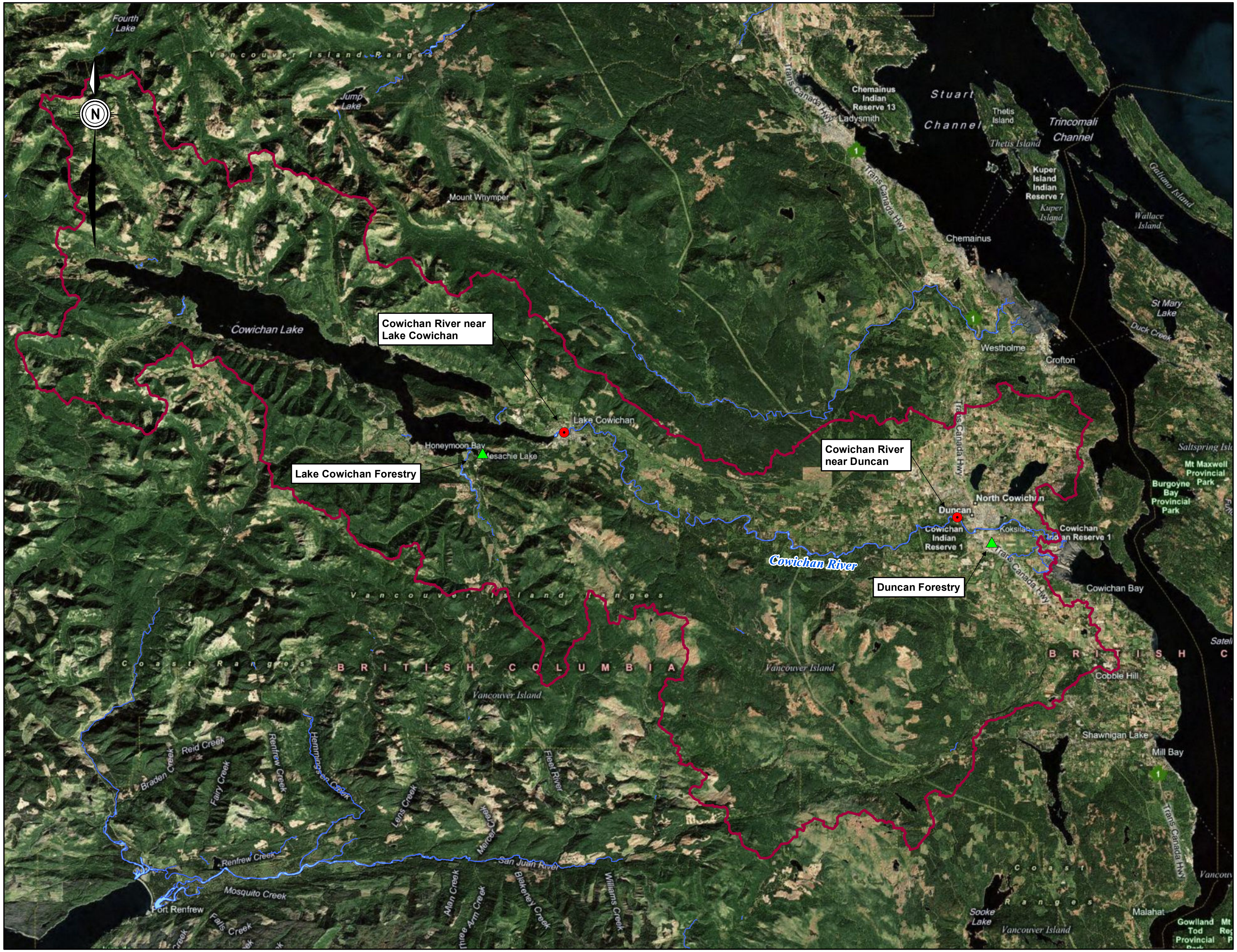
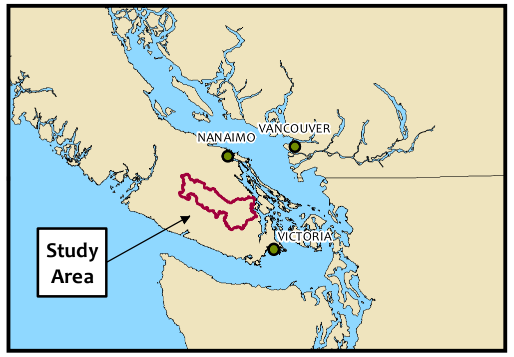


Cowichan River Hydrology Climate Change Impact Assessment

Legend

- Watersheds Boundary
- Climate Station
- River Discharge Gauge



Reference: Orthophoto from Bing aerial image map.

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Project No.	Date
0673-019	April 2011

Study Area

Figure 1

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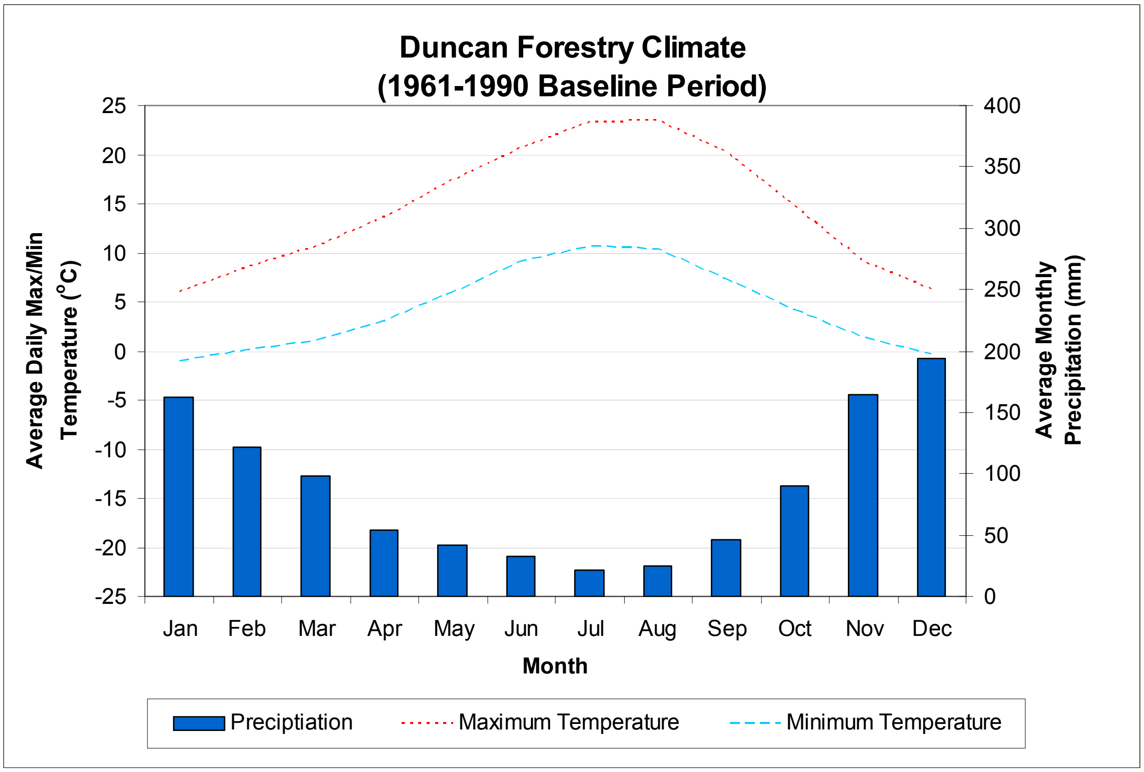

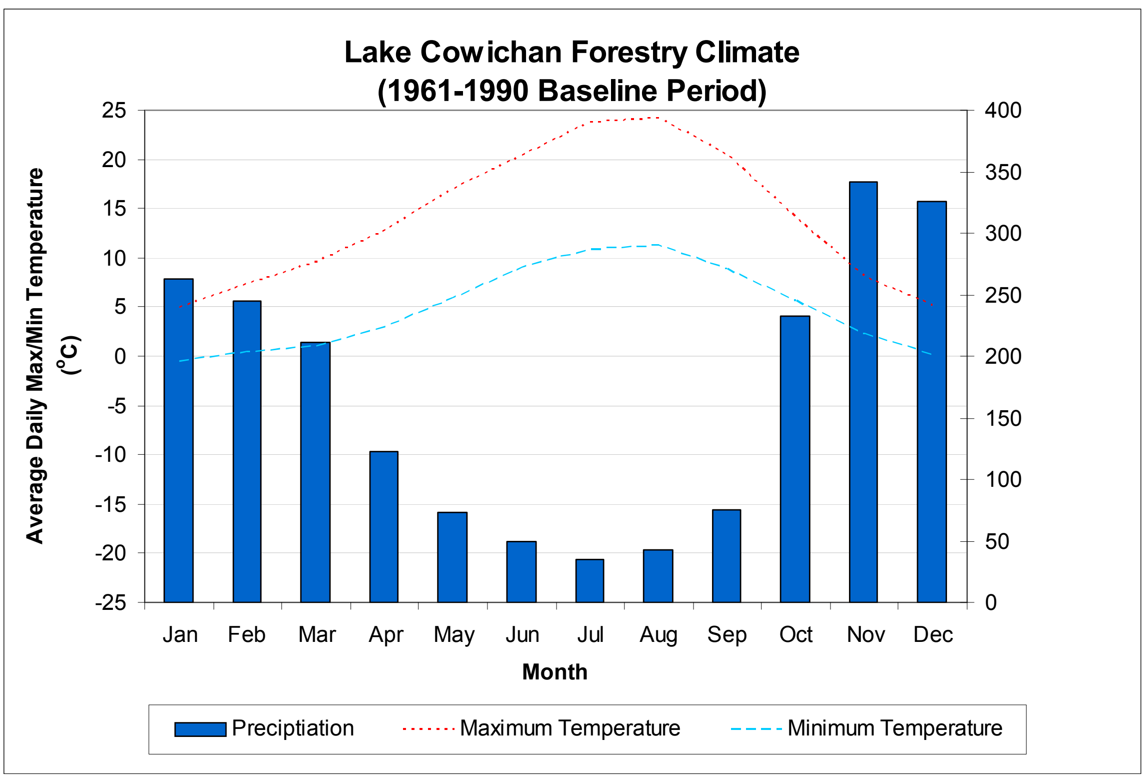

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BC Conservation Foundation – Cowichan River Climate Change Assessment

Project No.	Date
0673.019	Jul. 2011

Cowichan River Watershed Baseline Climate

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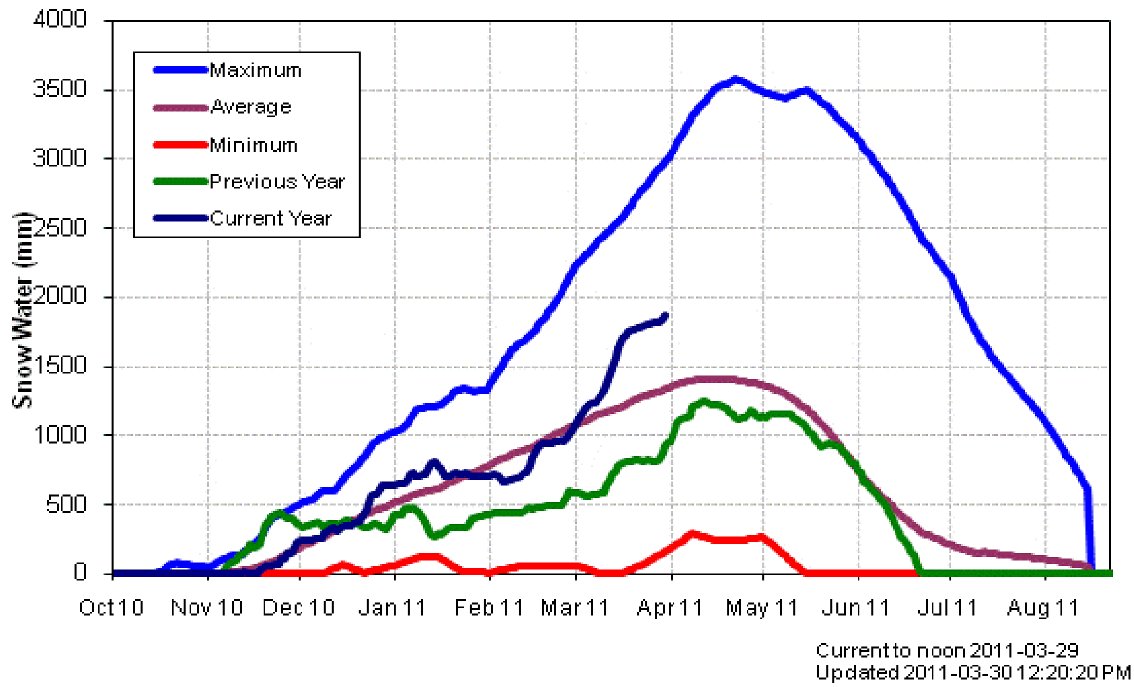
Baseline_Hydrology.xls

Figure 2



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Project No.	Date
0673.019	Jul. 2011

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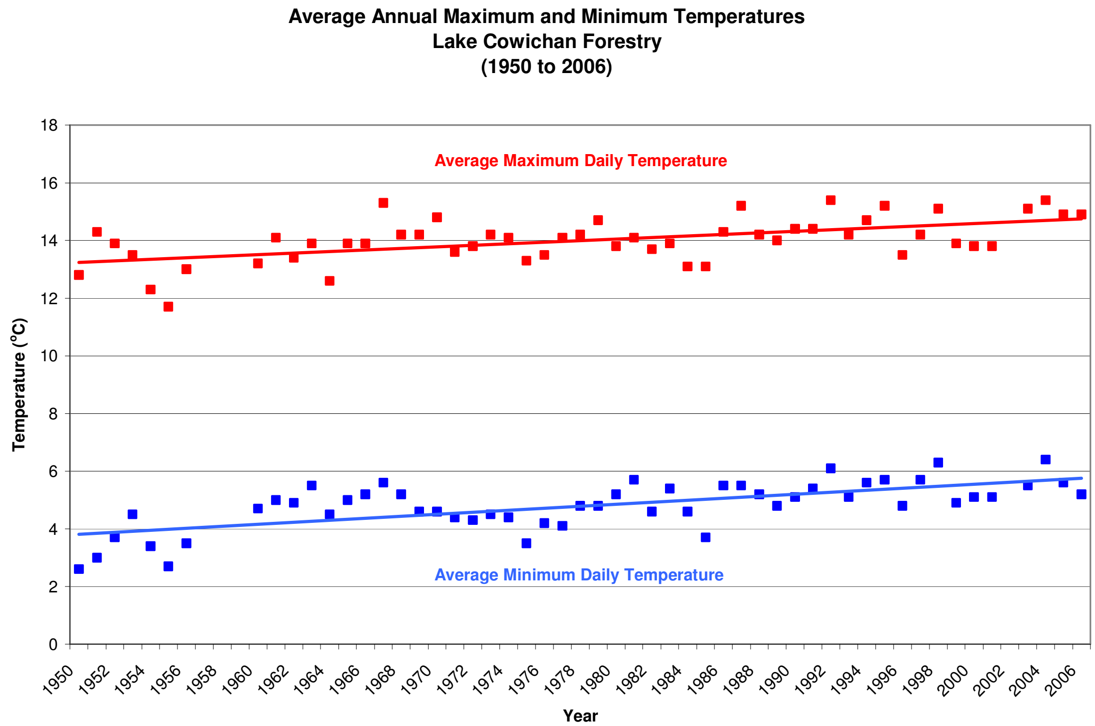
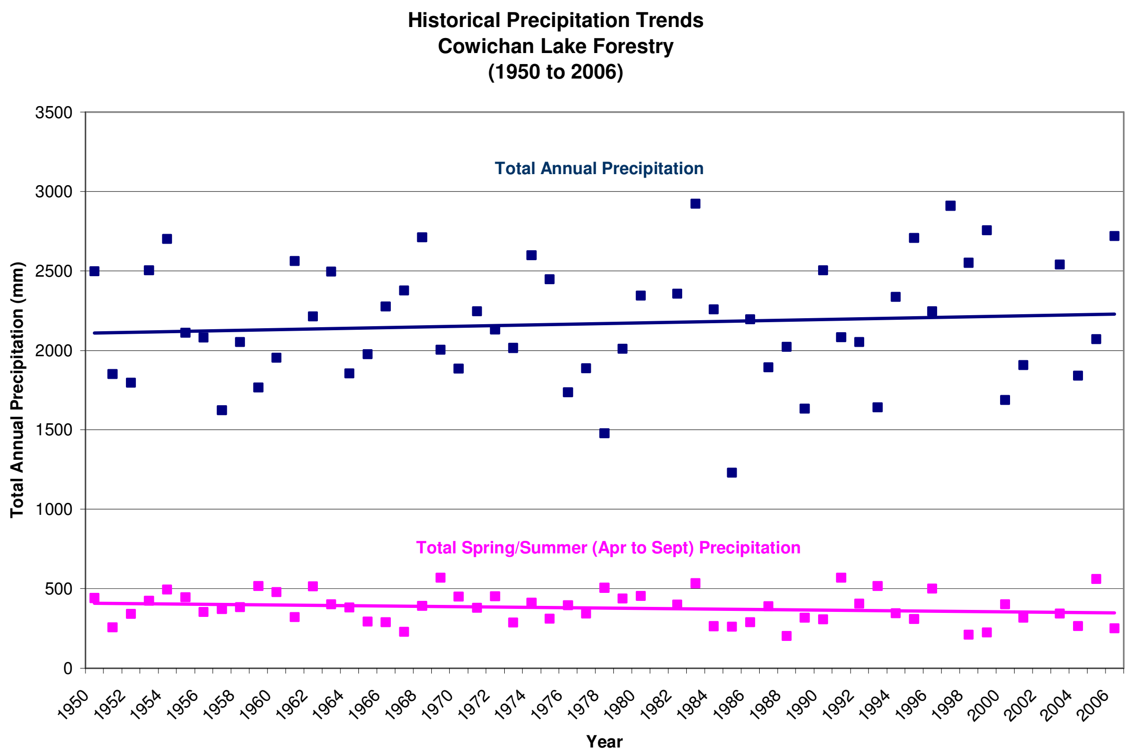
Baseline_Hydrology.xls

Jump Creek Snow Pillow – Snow Water Equivalent

Figure 3





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Project No.	Date
0673.019	Jul. 2011

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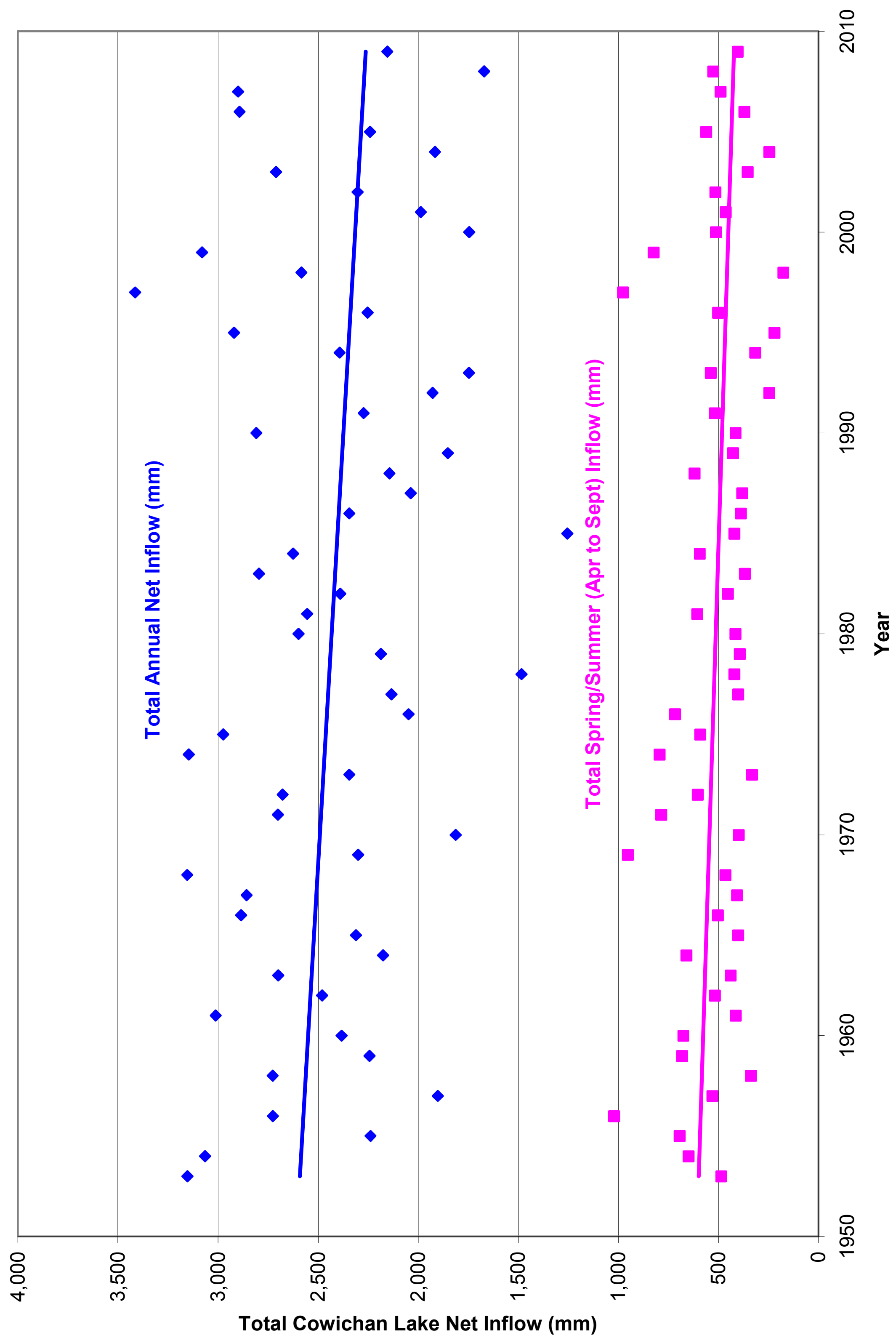
Temperature and Preciptation Trends.xls

Cowichan Lake Forestry Climate Station
Historical Climate Trends
Figure 4



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Project No.	Date
0673.019	Jul. 2011

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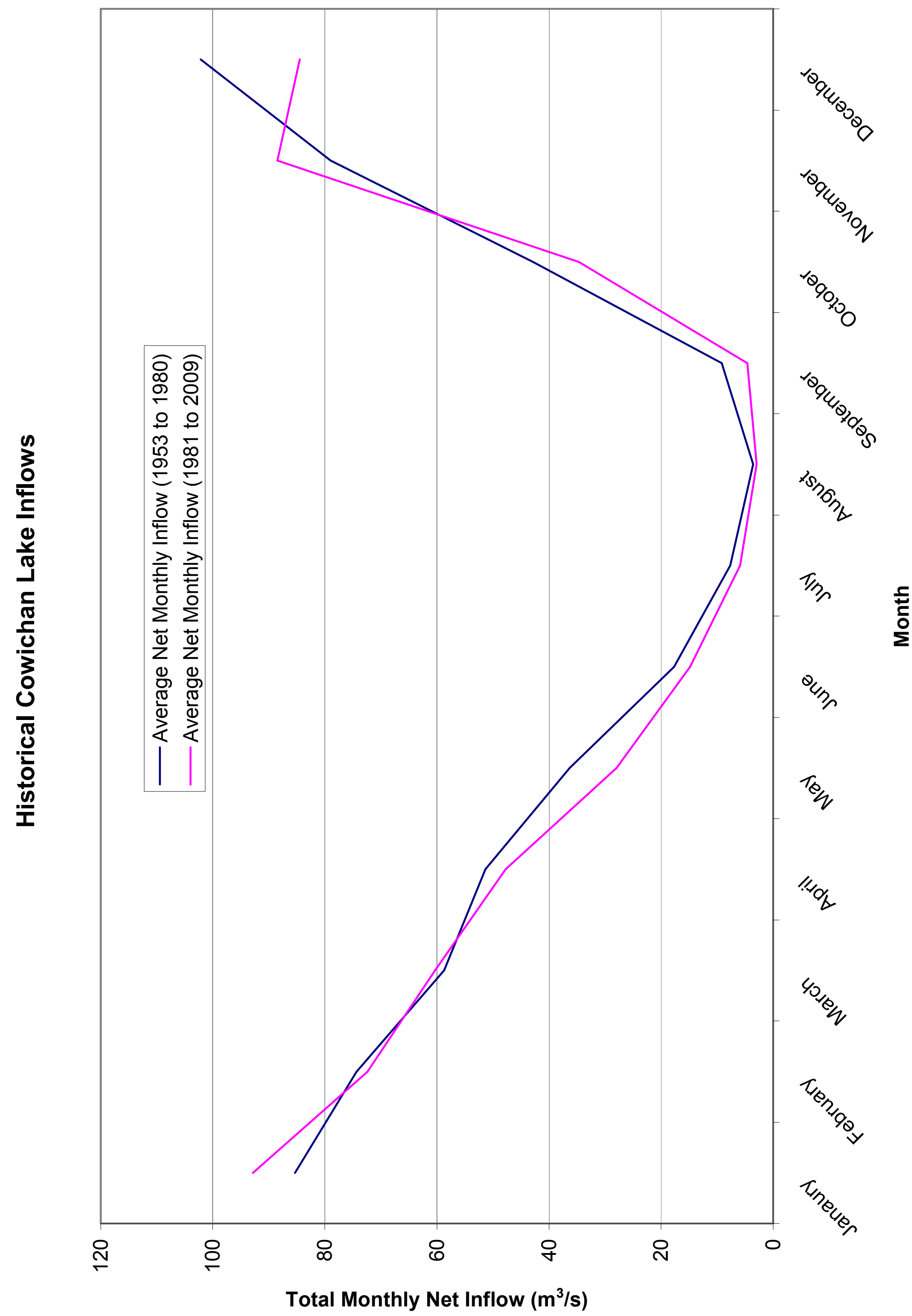
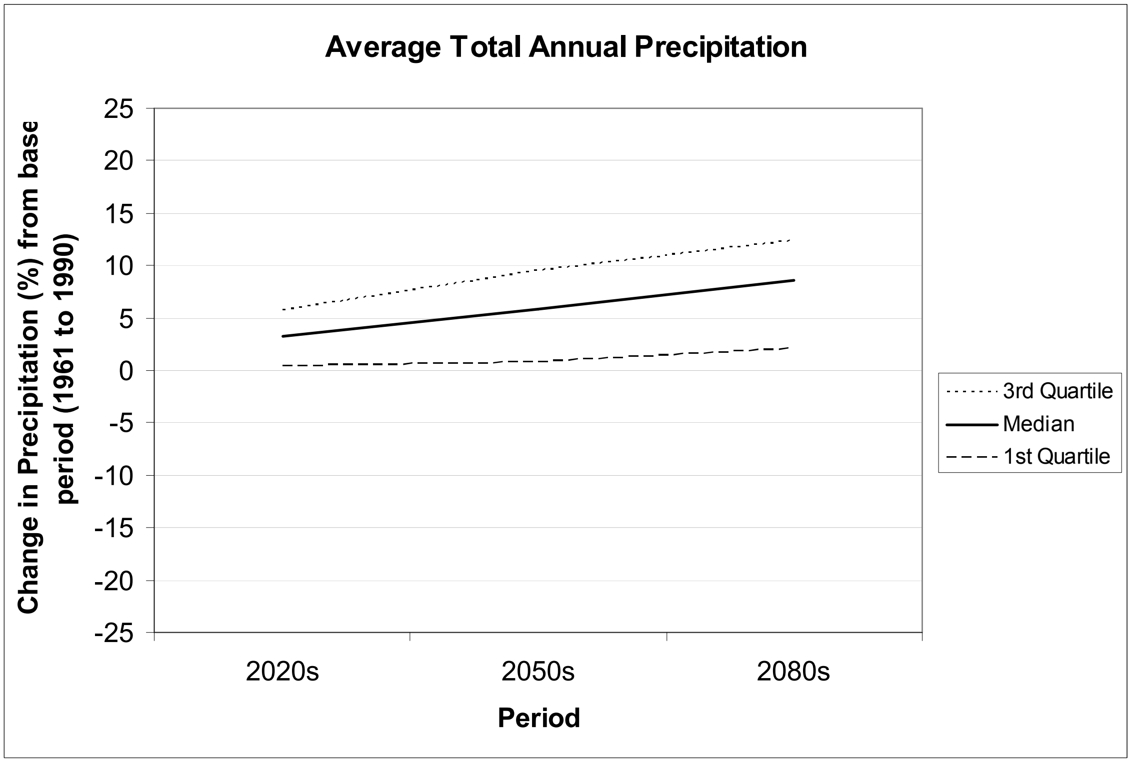
CowichanLakeInflow1953to2009.xls

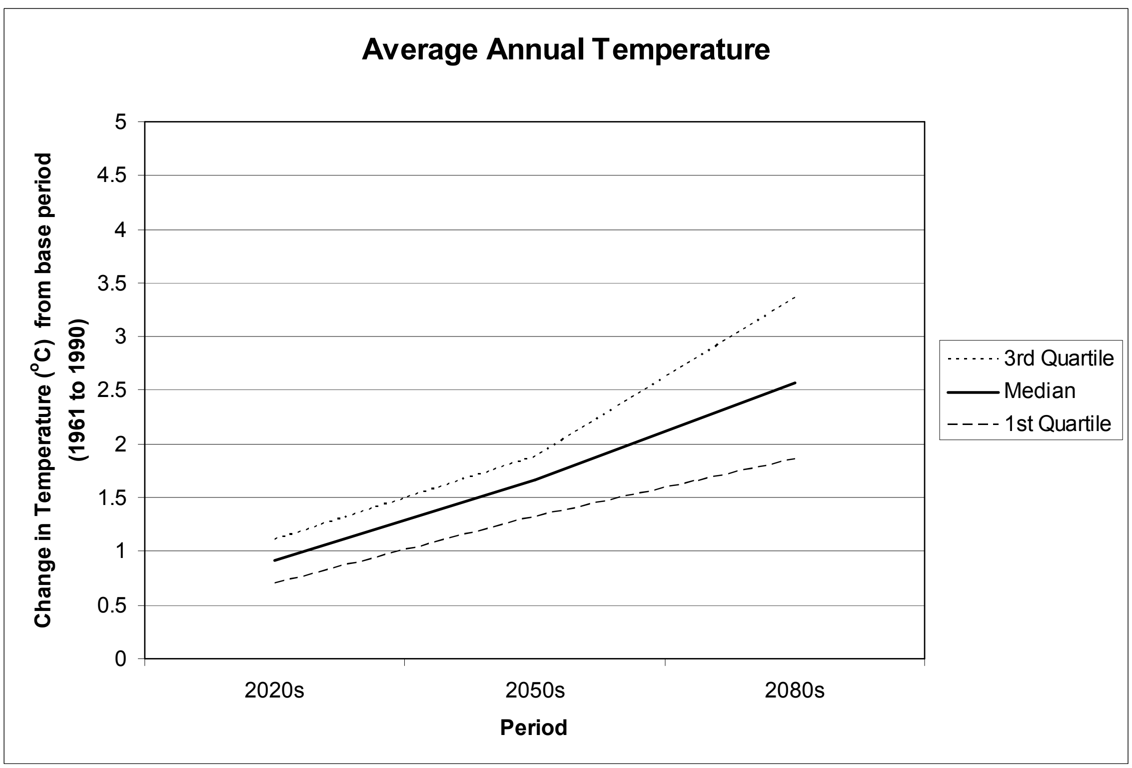
Cowichan Lake Net Inflow
Historical Trends (1953 to 2007)
Figure 5



Source: Pacific Climate Impacts Consortium – Regional Analysis Tool – Planners Ensemble GCM Results - http://pacificclimate.org/tools-and-data/regional-analysis-tool

KERR WOOD LEIDAL associates limited CONSULTING ENGINEERS	**BC Conservation Foundation – Cowichan River Climate Change Assessment**
Project No. 0673.019 / **Date** Jul. 2011	**Cowichan Lake Net Inflow**
0600-0699\673-019\400-Work\Data\PCICRegionalAnalysisTool\CowichanValley-ClimateTrends.xls	**Trends in Monthly Inflow**
	Figure 6





Source: Pacific Climate Impacts Consortium – Regional Analysis Tool – Planners Ensemble GCM Results - http://pacificclimate.org/tools-and-data/regional-analysis-tool

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Project No.	Date
0673.019	Jul. 2011

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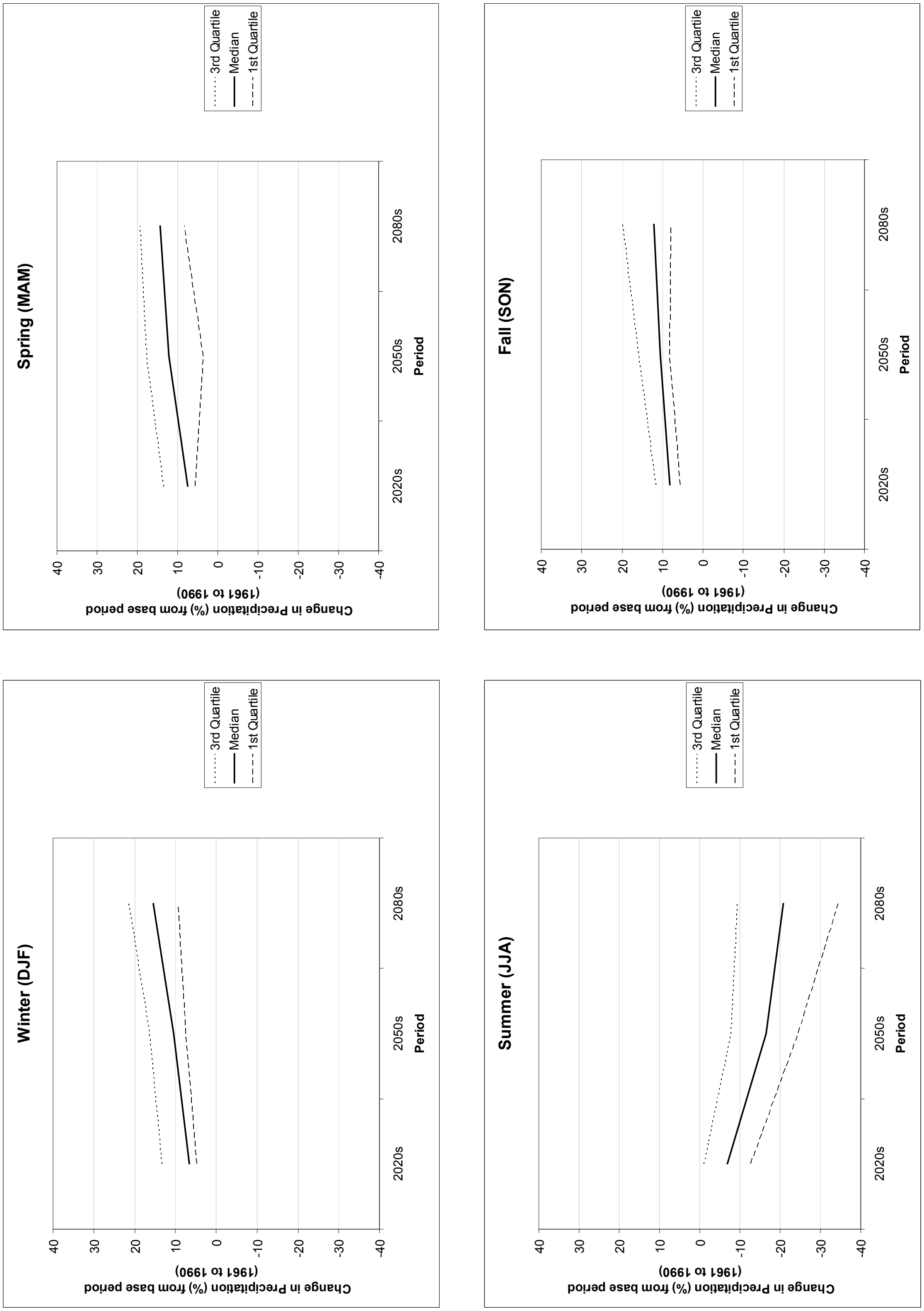
Cowichan Valley Region

Forecast Climate Trends – Annual Average

Figure 7



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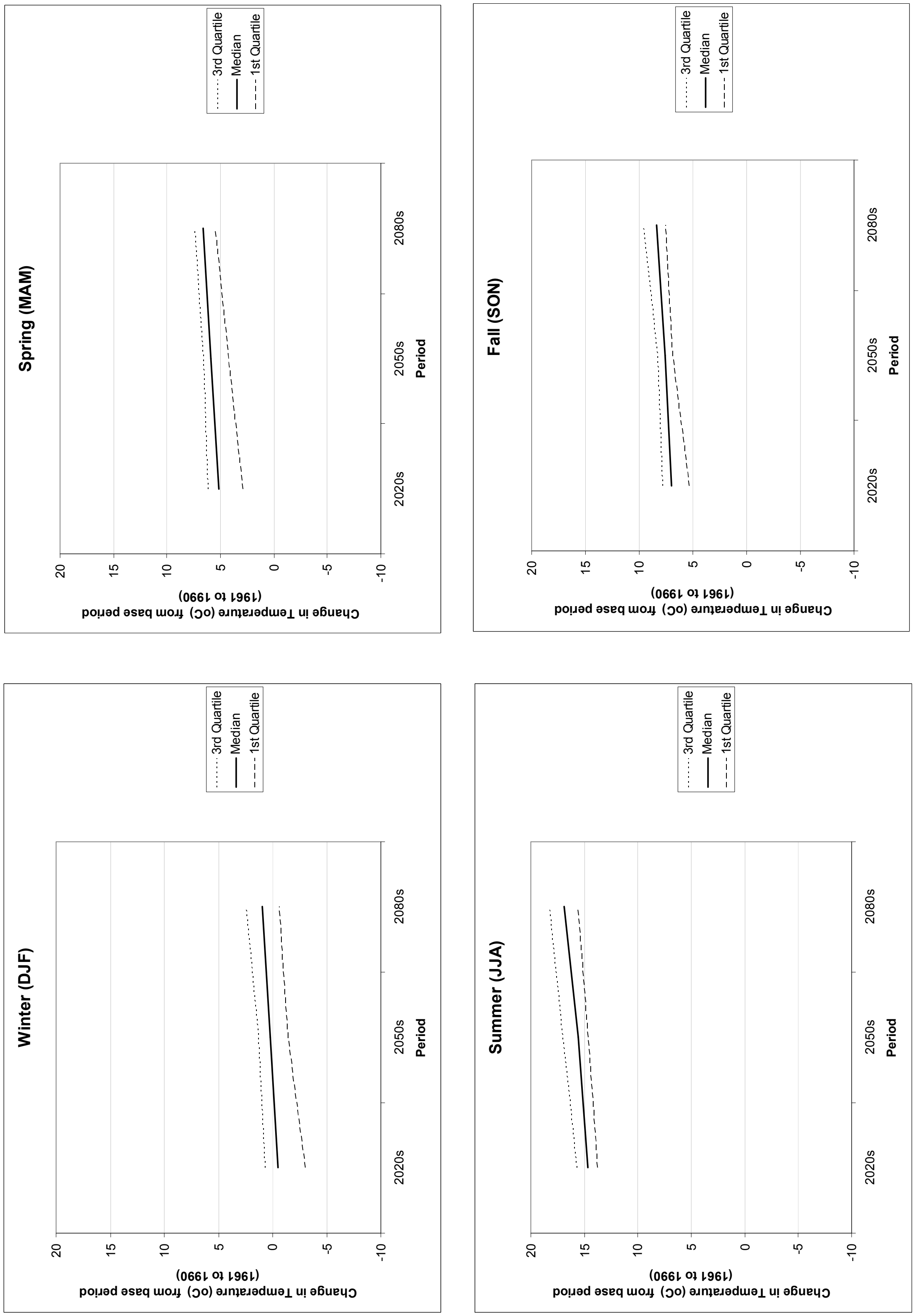
0600-0699\673-019\400-Work\Data\PCICRegionalAnalysisTool\CowichanValley-ClimateTrends.xls

Cowichan Valley Region
Forecast Climate Trends – Seasonal Precipitation
Figure 8



Source: Pacific Climate Impacts Consortium – Regional Analysis Tool – Planners Ensemble GCM Results - http://pacificclimate.org/tools-and-data/regional-analysis-tool

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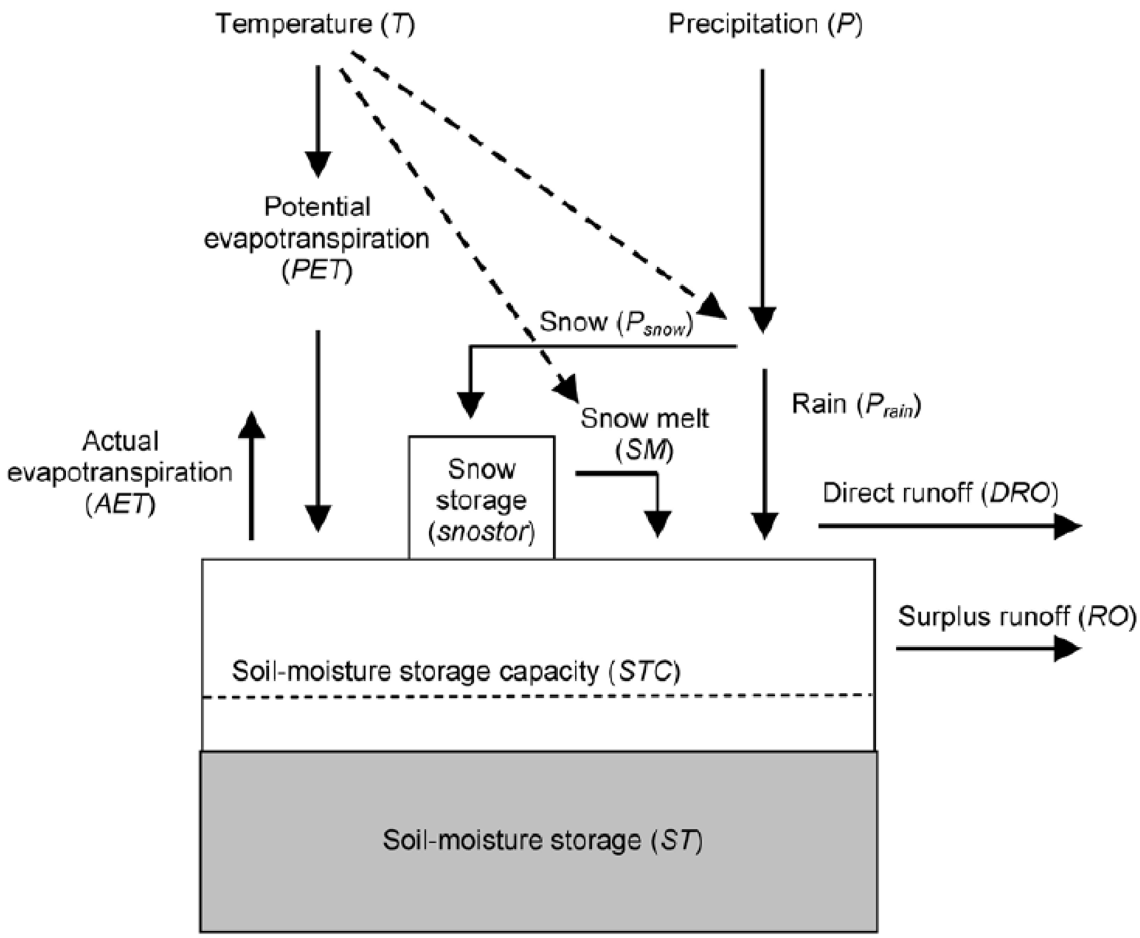
Project No.	Date
0673.019	Jul. 2011

0600-0699\673-019\400-Work\Data\PCICRegionalAnalysisTool\CowichanValley-ClimateTrends.xls

Cowichan Valley Region
Forecast Climate Trends – Seasonal Temperature
Figure 9



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Project No.	Date
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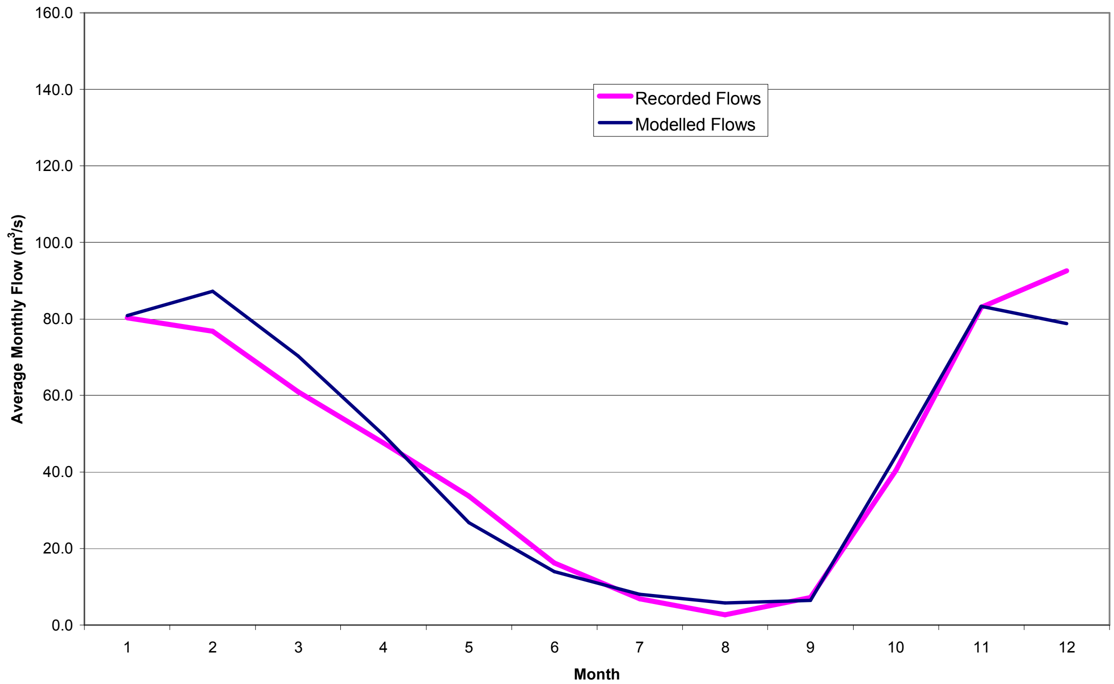
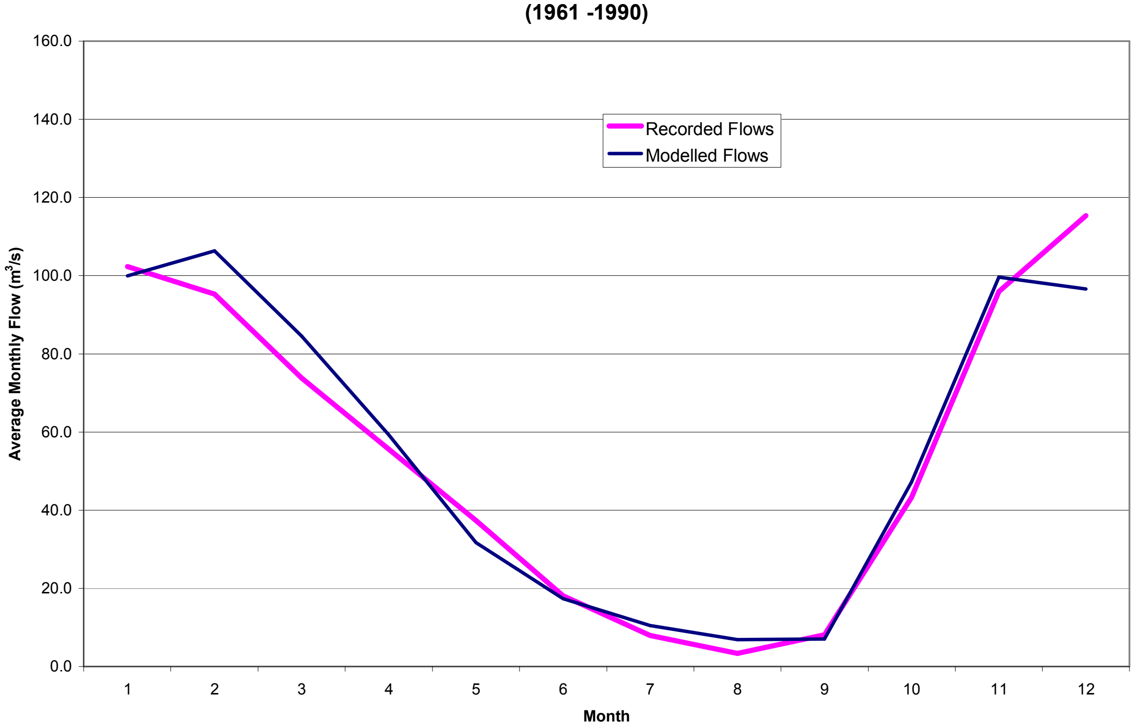
Monthly Water Balance Model Diagram

Figure 10

Calibration Results
Cowichan River at Lake Cowichan
(1961 - 1990)



Verification Results
Cowichan River at Duncan
(1961 -1990)



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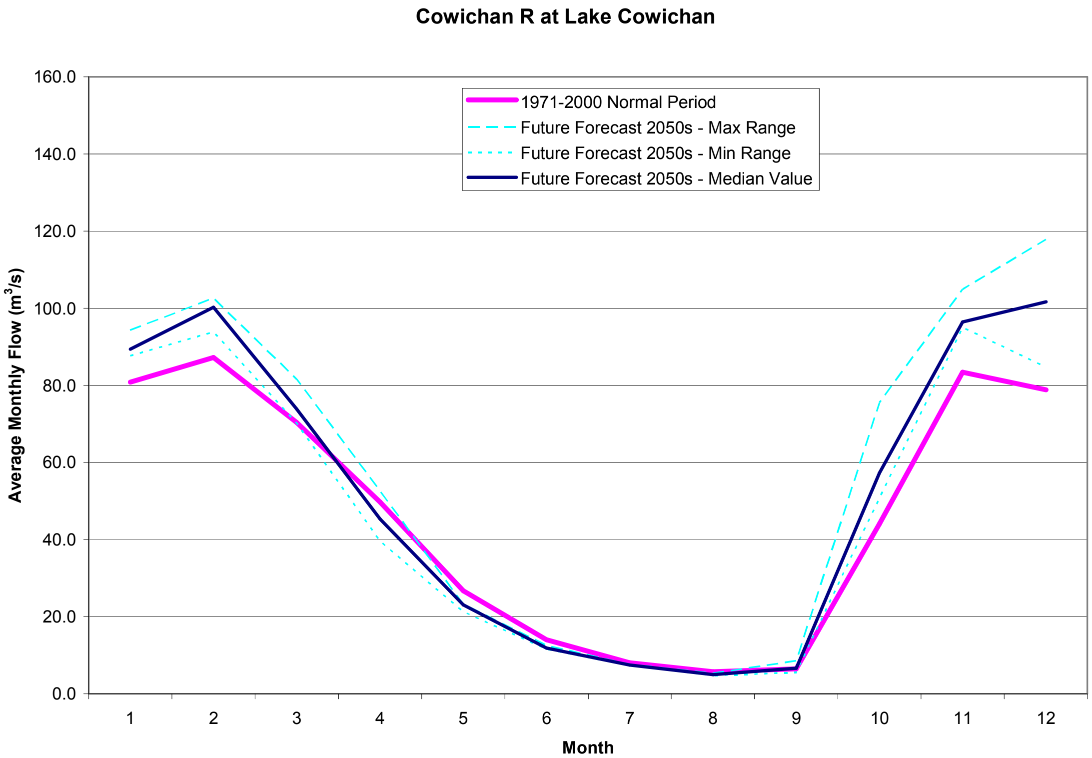
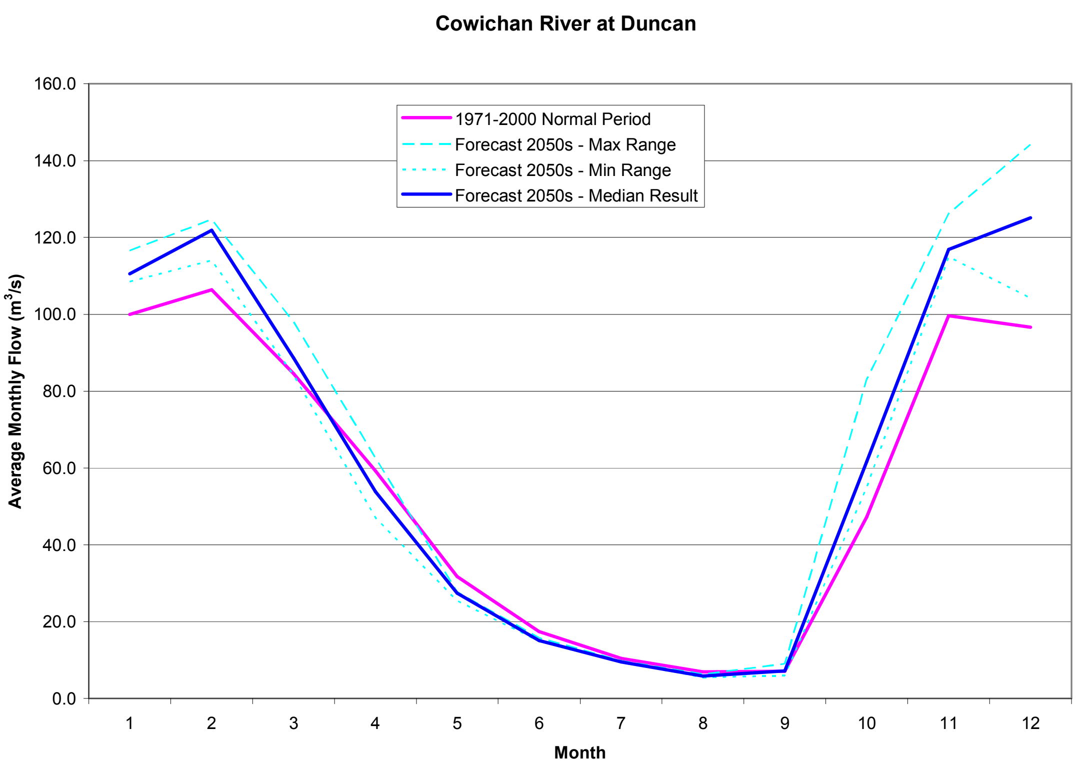
Monthly Water Balance Model Calibration and Verification

Figure 11





Note: Flows shown are estimates of natural flows and do not include releases from Cowichan Lake Weir or withdrawls at Crofton Mill Pump Station

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Cowichan River Watershed
2050s Forecast Monthly Average Flow
Figure 12