THEODOSIA WATERSHED
CLIMATE CHANGE IMPACTS AND ADAPTATIONS PLAN

Prepared for: Theodosia Stewardship Roundtable

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Video

A 20 minute video was created in conjunction with this report that highlights the major points covered in the following pages. This video is available for viewing at www.youtube.com by searching keywords: **Theodosia River climate change**

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Disclaimer

The findings and recommendations are based on the author's assessments and consultations and do not necessarily reflect the views of all of the members of the Theodosia Stewardship Roundtable or Living Rivers - Georgia Basin /Vancouver Island. The author will not be held liable for any damages whatsoever arising out of the use of the findings and recommendations of this report.

Executive Summary

The Theodosia watershed is a 140 km^2 coastal basin situated approximately 30 km north of Powell River. Land and water use in the watershed includes forestry and diversion of water for hydroelectricity. Well over half of the basin area has been harvested at least once and the diversion extracts over 60% of the water from the upper Theodosia River. The river supports substantial populations of Chum and Coho salmon, which have severely declined since the early 1950s, and provides habitat for several other salmonids.

Increased CO_2 concentration in the earth's atmosphere is resulting in several changes to the climate and hydrology of the Theodosia watershed. Summers are projected to become dryer and hotter with more frequent heat waves and increased year-to-year variability compared to historical levels. Winters will likely be warmer and wetter. Large and frequent winter rain-storms and a large decrease in snowfall at all elevations in the watershed should be expected. Changes in climate will result in changes in the hydrology of the Theodosia River. Reduced snowpack will result in a shift in timing of streamflow to earlier and diminished spring peak flows. By the middle of the 21st century, it is likely that very little snowpack will be left to contribute to spring streamflow. Furthermore, reduced snowfall, decreased summer precipitation, and increased temperatures will likely result in lower summer/fall stream flow and more extreme low flow periods. The river will also likely experience increases in the frequency and magnitude of fall and winter flood events. Increased stream temperature at all times of year should also be expected.

Climate change will impact stream habitat and salmonids in several ways. The greatest impacts will likely come from increased frequency and magnitude of winter floods that will increase scouring and burial of both Coho and Chum salmon eggs. Lower summer and early fall streamflow will also be detrimental to fish populations, as will possible complex interactions due to mismatched timing of predator/prey interactions or mismatched life history stages with the hydrologic regime. Chum salmon may be able to better adapt to the future climate regime than Coho although yet unknown complex interactions add uncertainty to this statement. Impacts to forest resources may be less severe than impacts to fisheries, with the most common impact being lower growth rates. However, it is possible that large-scale disturbances due to fire and/or insect/disease outbreaks may have severe consequences to the forests of the watershed. The likelihood of such impacts is very difficult to predict.

The final chapter of this document outlines several adaptation strategies that may serve to increase the resilience of ecosystems in the watershed. The Theodosia Stewardship Roundtable (TSR) must work to enhance the lines of communication between stakeholders and to develop shared decision making protocols in the face of climate change. A water use plan for the Olsen Lake diversion should be created and future infrastructure should reflect this plan. It is recommended that water extraction during the summer is decreased to mitigate effects of drought, while water use during the winter is managed to mitigate impacts of peak flows in the lower watershed. Forest companies and the BC Ministry of Forests, Lands and Natural Resource Operations should work with the TSR to develop a coordinated watershed-scale sustainable harvesting plan that details targeted harvest rates, new protocols for culvert sizing, and plans for restoration and conservation of floodplain forests. Flood risk, landslide risk and risk of storm surge due to sea level rise will increase in the lower floodplain area; thus, future settlement plans will require professional surveying to avoid locating buildings in high-risk areas.

PART I –THEODOSIA WATERSHED CURRENT STATUS

Chapter 1: Overview of Theodosia River watershed

1.1 Background, stakeholders, and current importance

This report was compiled for the Theodosia (Tohkwonon) Stewardship Roundtable group to document past and future challenges related to watershed stewardship and restoration and to suggest future steps towards stewardship and adaptation to climate change. The Theodosia Stewardship Roundtable (TSR) is a local watershed governance group dedicated to the development and implementation of a Theodosia Watershed Recovery Plan that reflects the community of interests represented at the Table. These interests include sustainable communities, land and water stewardship, fish and wildlife stock assessment and habitat restoration, education and outreach, and related environmental stewardship activities.

In order to realize the TSR vision of *A healthy and bio-diverse Tohkwonon (Theodosia) watershed ecosystem* the participants at the table are interested in incorporating the potential impacts of climate change into recovery strategy planning. Resource management (water, forestry, fish and wildlife) issues have been of primary interest to the TSR to date. Failure to consider and incorporate anticipated changes to climate patterns when developing management/recovery plans for these resources will reduce the likelihood of positive outcomes over the long term. This report aims to inform decisions of the TSR, allowing for the inclusion of climate change adaptation components in resource management and land use planning decisions in the future.

This report provides future decision makers with the knowledge necessary to support sustainable land and water use management decisions in the Theodosia River watershed. The objective is to recommend general approaches to maintain a viable watershed comprised of functioning interrelated ecosystems that are resilient to climatic change.

1.1.1 First Nations

The Theodosia watershed is of importance to the Tla'amin First Nation for geographic, resource, and spiritual reasons. Sliammon people have lived in the watershed for thousands of years and the river once provided an important village site due to the abundance of salmon, fresh water and other natural resources. Sliammon people are committed to environmental stewardship of the watershed and its valuable ecosystem functions including but not limited to rebuilding salmon stocks through river restoration and watershed stewardship activities.

1.1.2 Public sector

The Theodosia River watershed lies within the Powell River Regional District. Specific aspects of public interest in the Theodosia watershed are represented by the BC Ministry of Forests, Lands and Natural Resource Operations who govern forest harvesting practices within the watershed, and BC Timber Sales who currently operate forest harvesting endeavors within the watershed. Other interests include the Department of Fisheries and Oceans Canada which is interested in maintaining and restoring freshwater salmon stocks and salmon habitat of Theodosia River, and the BC Ministry of Environment, which has designated and protected several areas of mountain goat winter range within the watershed.

1.1.3 Other stakeholders

Other interests in the watershed are represented by several public groups and private sector stakeholders as follows: Western Forest Products, Island Timberlands, and Merrill and Ring own land and/or licenses to harvest valuable commercial timber products within the Theodosia watershed; Brookfield Renewable Power owns a water license to divert water from the upper Theodosia River for hydroelectricity generation; and Powell River Salmon Society and Powell River Parks and Wildlife Society have an interest in the conservation and restoration of species and ecosystem functions within the Theodosia River watershed.

1.2 Theodosia watershed biophysical overview

1.2.1 Basin characteristics

Physiography

The Theodosia watershed is a 140 km^2 coastal basin situated approximately 30 km north of Powell River (Figure 1). The 27 km Theodosia River runs north-to-south and drains this mountainous watershed into the Theodosia Inlet (Figure 2). About half of the watershed is above 900 masl, (meters above sea level), or above the transitional snow zone (Northwest 2000).

Thirteen kilometers upstream from the Theodosia estuary, a natural divide separates the watershed into upper and lower sections. At this divide, 175 masl, a portion of flow from the upper watershed is currently diverted into Olsen Creek/Lake, which drains into Powell Lake.

The lower Theodosia mainstem is a shallow grade (1.3% average slope), gravel-bed river punctuated by several steep confined, bedrock and canyon reaches (Miles 2000a). Seven kilometers upstream from the mouth, waterfalls act as a natural barrier, impassible to spawning fish. Below this barrier, several channels, most notably the main stem and farm stem, provide riffle and pool habitat used by several species of fish and other wildlife.

The upper watershed ($75km^2$) rises to elevations of 1830 masl, with 80% of the watershed area higher than 600 masl (Ward 1999). The 14 km mainstem channel of the upper Theodosia is steep, with an average slope of 7.4%, and is mostly confined with some wider reaches where alluvial floodplains have developed (Miles 2000a).

Climate

The climate of the Theodosia River watershed is influenced by maritime air masses, driven by westerly winds that meet steep mountainous topography. The mountainous topography results in orographic uplift of saturated air masses, which subsequently results in high precipitation during fall, winter, and spring months. The coastal influence, especially in the lower watershed, moderates temperatures throughout the year. As a result, very little snowfall accumulates within the lower watershed during the winter (Klohn Crippen 1998). However, higher elevations within the watershed experience colder winter temperatures and increased snowfall, resulting in high snowfall accumulations that remain on the ground until spring. Summers are generally quite dry.

Climate data within the Theodosia is unavailable, however data from nearby Powell River (~30km south) and Lois River Dam (~50km south) can be used to provide a rough estimate of what may be expected in the Theodosia watershed area. Average total annual precipitation for Powell River is 1104 mm and 1596mm for Lois River Dam. The topography of the Lois River station is probably more representative of the mouth of Theodosia; thus, average annual precipitation at the mouth of Theodosia is likely close to 1500mm, with higher precipitation values at higher elevations (Klohn Crippen 1998). Approximately 70% of annual precipitation falls between October and March. Average monthly precipitation at Lois River Dam is depicted in Figure 3, while Figure 4, long term precipitation data at Powell River, illustrates long term trends.

Hydrology

A river system's hydrologic regime consists of predictable peak and low flow periods throughout the year. This variation of streamflow plays a large role in structuring ecosystem functions and influencing population (e.g. salmonid) abundance. Climate change will affect the hydrologic regime of Theodosia River dramatically at different times of the year; thus, it is important to thoroughly describe the current hydrologic regime to understand how the climate may affect the river in the future.

The mixed rain and snow, or "hybrid" hydrologic regime of Theodosia River is typical of many rivers on the Pacific coast of British Columbia. This watershed does not have significant storage capacity (lakes) and therefore precipitation inputs result in a very fast, flashy watershed response. Peak discharges may be generated by three different mechanisms each occurring due to weather events at distinct times of the year. (1) Intense rainfall delivered by storms blowing in from the Pacific Ocean during October-December regularly results in one or several high magnitude flood events during the fall/early-winter season. (2) Occasional warm winter storms, characterized by rain falling on snow during the December-March winter season, can result in extremely high magnitude floods - often the largest of the year. (3) Later, during the spring, warming temperatures result in melting snowpack and another peak flow event known as the spring freshet. The summer season characterized by low rainfall and low stream flow.

Hydrologic data from the Water Survey of Canada is available for five hydrometric stations on the Theodosia River: Theodosia River Near Bliss Landing 08GC004 (1953-1993 partial), Theodosia River Diversion above Olsen Lake 08GC005 (2000-2010 + real-time data for 2011), Theodosia River Diversion Bypass 08GC006 (2000-2010 + real-time data for 2011), Theodosia River below Olsen Lake Diversion 08GC007 (2000-2010 + real-time data for 2011), and Theodosia River Above Scotty Creek 08GC008 (2003-2010 + real-time data for 2011). Station location maps are shown in Figures 2 and 5. Typical yearly hydrographs of the lower Theodosia River (above Scotty Creek) are shown in Figures 6 and 7. Average monthly discharge (Figures 8a and 8b) and typical monthly hydrographs (Figures 9a and 9b) of the upper Theodosia River are shown in the following chapter, as is average monthly discharge of the lower Theodosia River (Figure 11).

Regional hydrological analysis indicates that mean annual peak daily flow (i.e. the maximum daily average flow occurring in a year) is estimated to be 0.65 $m^3/s/km^2$ (Kerr Wood Leidal 1993). This results in an estimated mean annual daily flow of 91 m^3/s at the mouth (assuming one mouth, and assuming no flow is diverted into Olsen Lake). According to 2000/01 data water temperature peaks in July/August at 14-16^oC. By November temperature has decreased to 6^oC and over the winter season (Nov-March) fluctuates between 0-6^oC (Klohn Crippen 2001).

1.2.2 Biological overview

Salmonids

The Theodosia River supports populations of several anadromous salmonid species. Chum salmon (*Oncorhynchus keta*) are the most abundant species followed by Coho salmon (*O. kisutch*). Pink salmon (*O. gorbuscha*), steelhead (*O. mykiss*), chinook salmon (*O. tschawytscha*) and sockeye salmon (*O. nerka*) are also present in the system in smaller numbers (Klohn Crippen 1998). It has been reported that the Chum salmon from this river are exceptionally large (Living Rivers 2009). Resident salmonids include cutthroat trout (*O. clarki*) and Dolly Varden char (*Salvelinus malma*). Anadromous salmonids are restricted to the portion of Theodosia River downstream of a bedrock waterfall located approximately 7 km from the mouth. Above this natural barrier cutthroat trout and Dolly Varden are present in substantial numbers (Klohn Crippen 1998).

Riparian and upland forest

The Theodosia watershed lies within three biogeoclimatic subzones: Dry Maritime Coastal Western Hemlock (CWHdm), Montane Very Wet CWH ($CWHvm^2$), and Windward moist Maritime Mountain Hemlock (MHmm1), although the MHmm1 is only represented by small portions of upper watershed's mountainous regions. The CWHdm subzone covers the majority of the watershed area, from the lower watershed extending approximately 5 km upstream of the Olsen Lake diversion (Klohn Crippen 1998).

Common riparian species are western hemlock (*Tsuga heterophylla*), red alder (*Alnus rubra*), Sitka spruce (*Picea sitchensis*), and Douglas fir (*Pseudotsuga menziesii*). Although several mature riparian stands exist, most stands range in age from 21 to 46 years (GFC 2004), and classified as developing floodplains rather than established or mature terraces (Little 2011).

Wildlife

A diverse array of bird and mammal species are found in the watershed. Notable species include the Marbled Murrelet, which has been recorded in the Theodosia Inlet (Beauchamp 1999). This species is listed by COSEWIC as threatened and is a BC Red Listed species (MSRM 2004). The estuary is also used by cormorants, diving ducks, gulls, mergansers, grebes, dabbling ducks, shorebirds, geese, loons and swans (MSRM 2004).

Eelgrass and kelp beds at the mouth of the inlet provide rearing habitat for salmonids and other species. Clam beds also exist within the estuary and along the south side of the inlet (MSRM 2004). The spawning salmon of Theodosia provide an important food source for grizzly bears, black bears, and wolves. The watershed is also home to populations of mule deer, Roosevelt elk, and mountain goats.

Chapter 1 Figures

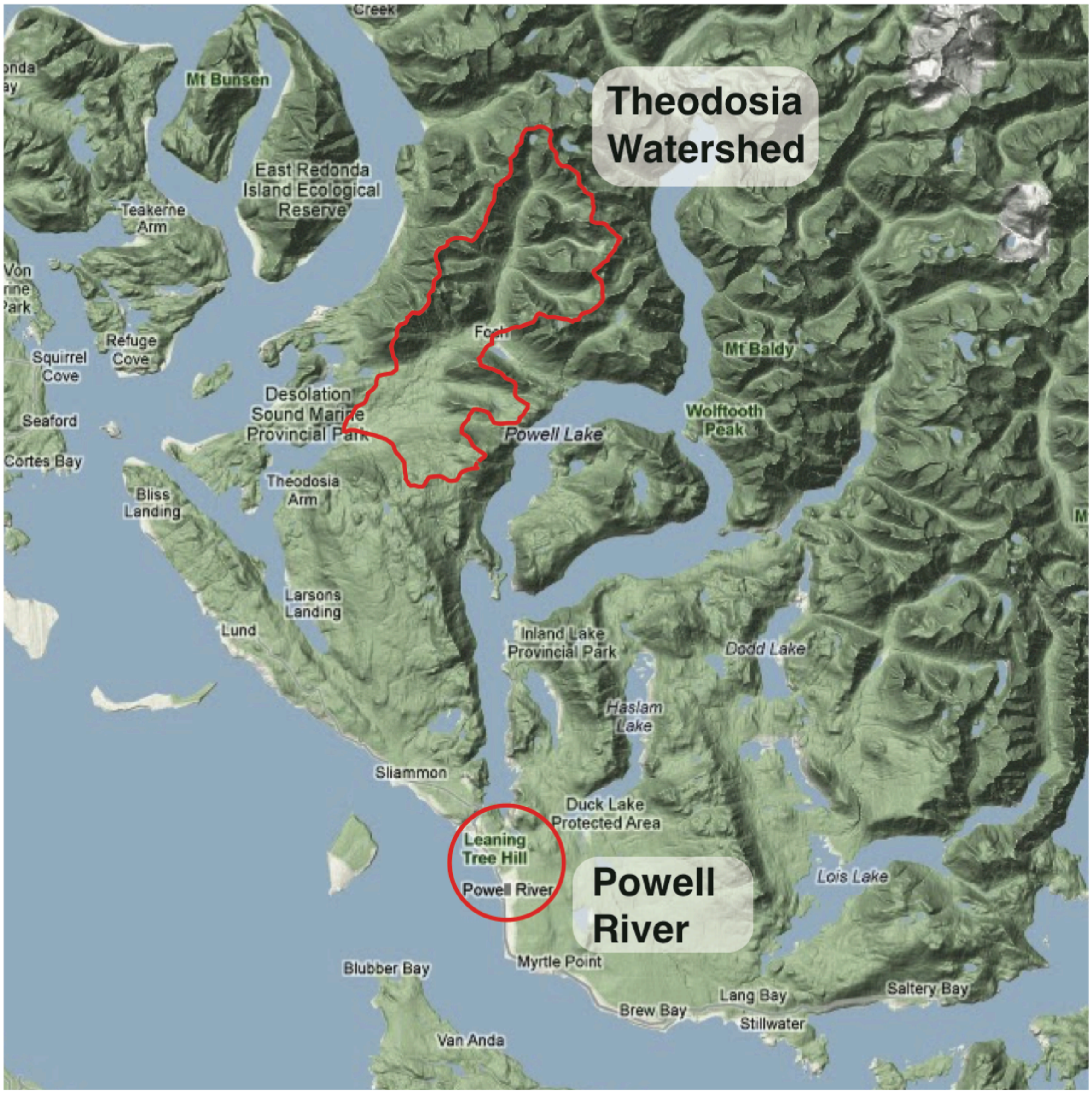

Figure 1 – Theodosia River watershed location map. The Theodosia watershed is located approximately 30 km north of Powell River, on the west coast of British Columbia.

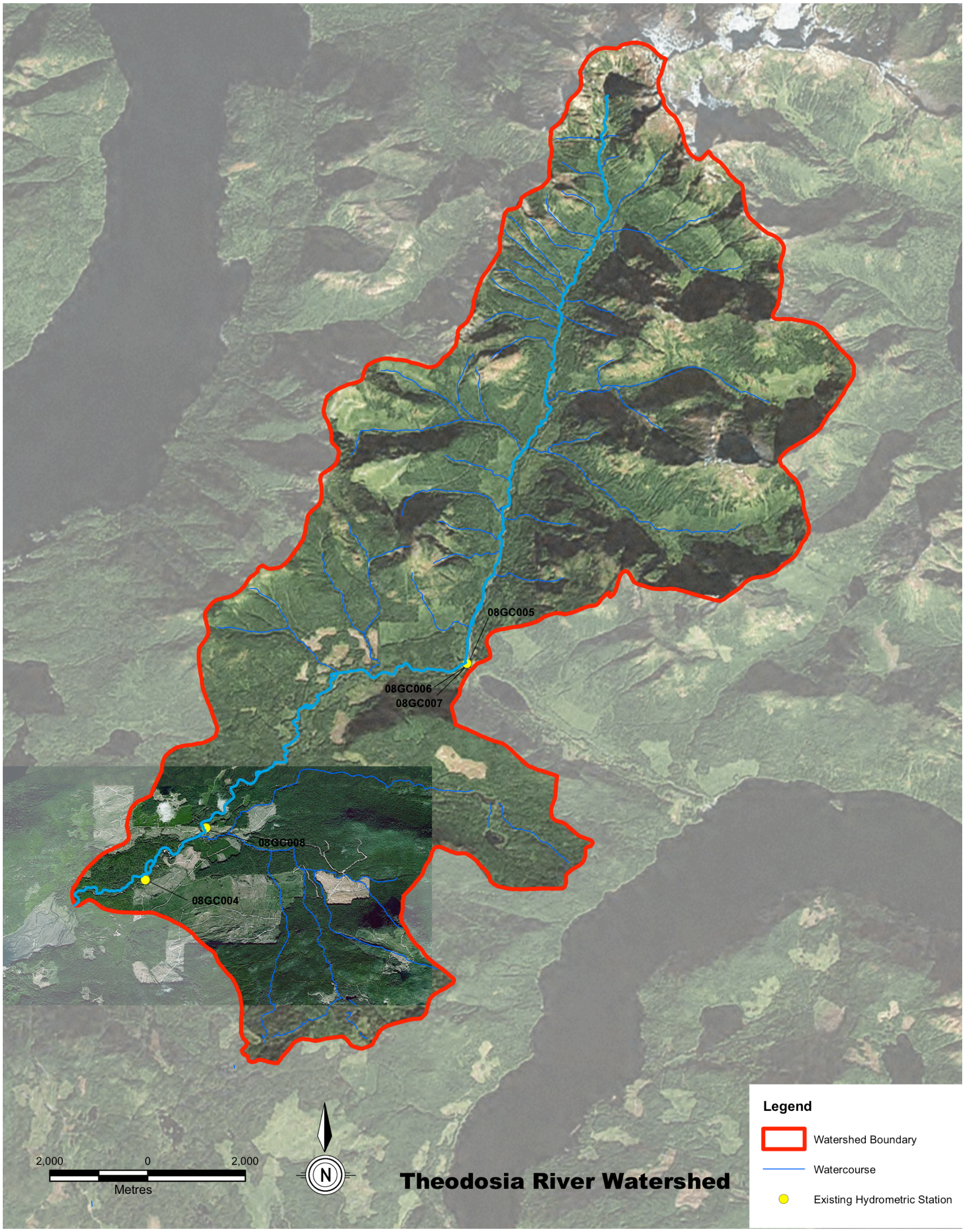

Figure 2 – Theodosia River watershed map. The boundary of the 140 km^2 watershed is shown in red. The mainstem river runs 27 km and is shown in light blue. Tributaries are shown in a darker blue. Hydrometric station locations are shown by yellow points with station numbers indicated in black.

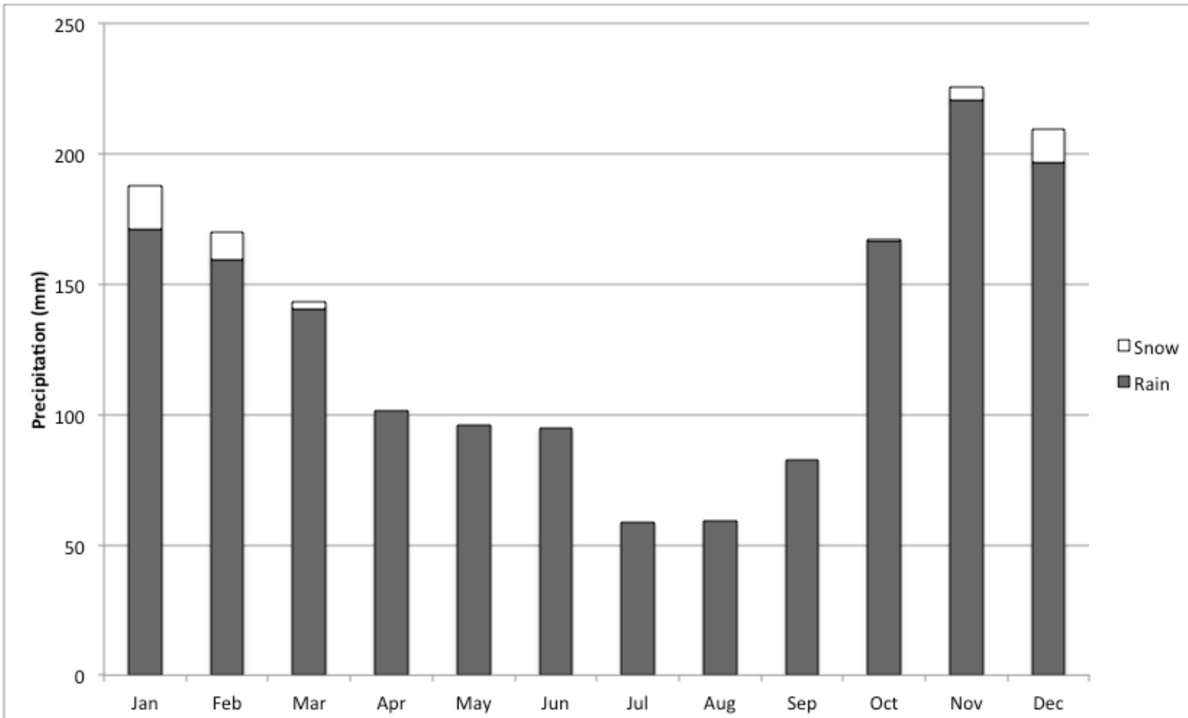

Figure 3 – Monthly precipitation averages for Lois River Dam (Station 1044710, 1971-2000)

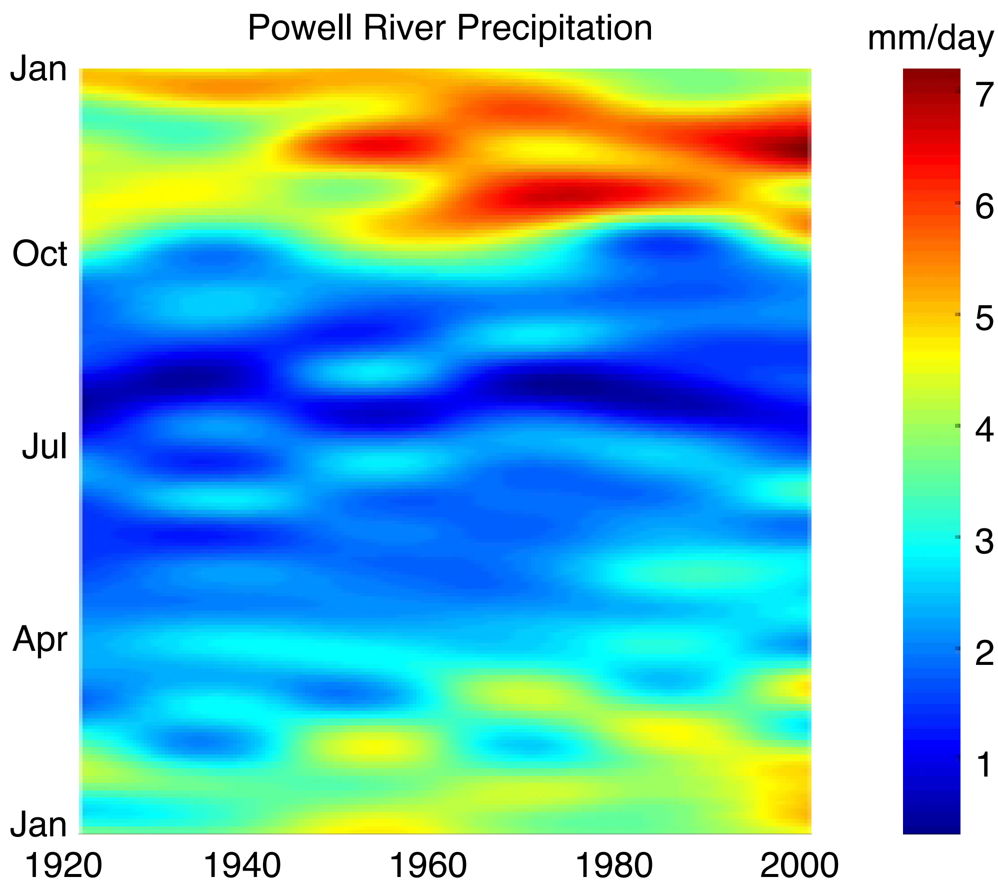

Figure 4 – Powell River smoothed daily precipitation. From Quilty et al. 2005.

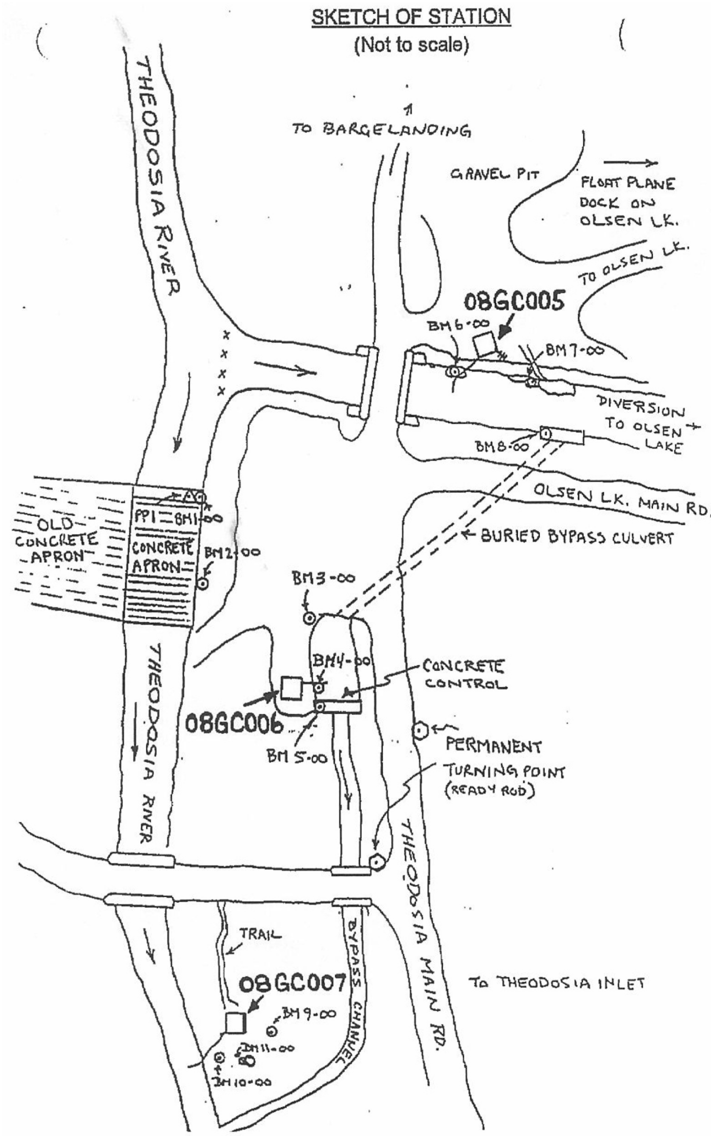

Figure 5 – Detailed hydrometric station locations map for staions near the Olsen Lake diversion. From the Water Survey of Canada, map author R.S. Furguson, 2000.

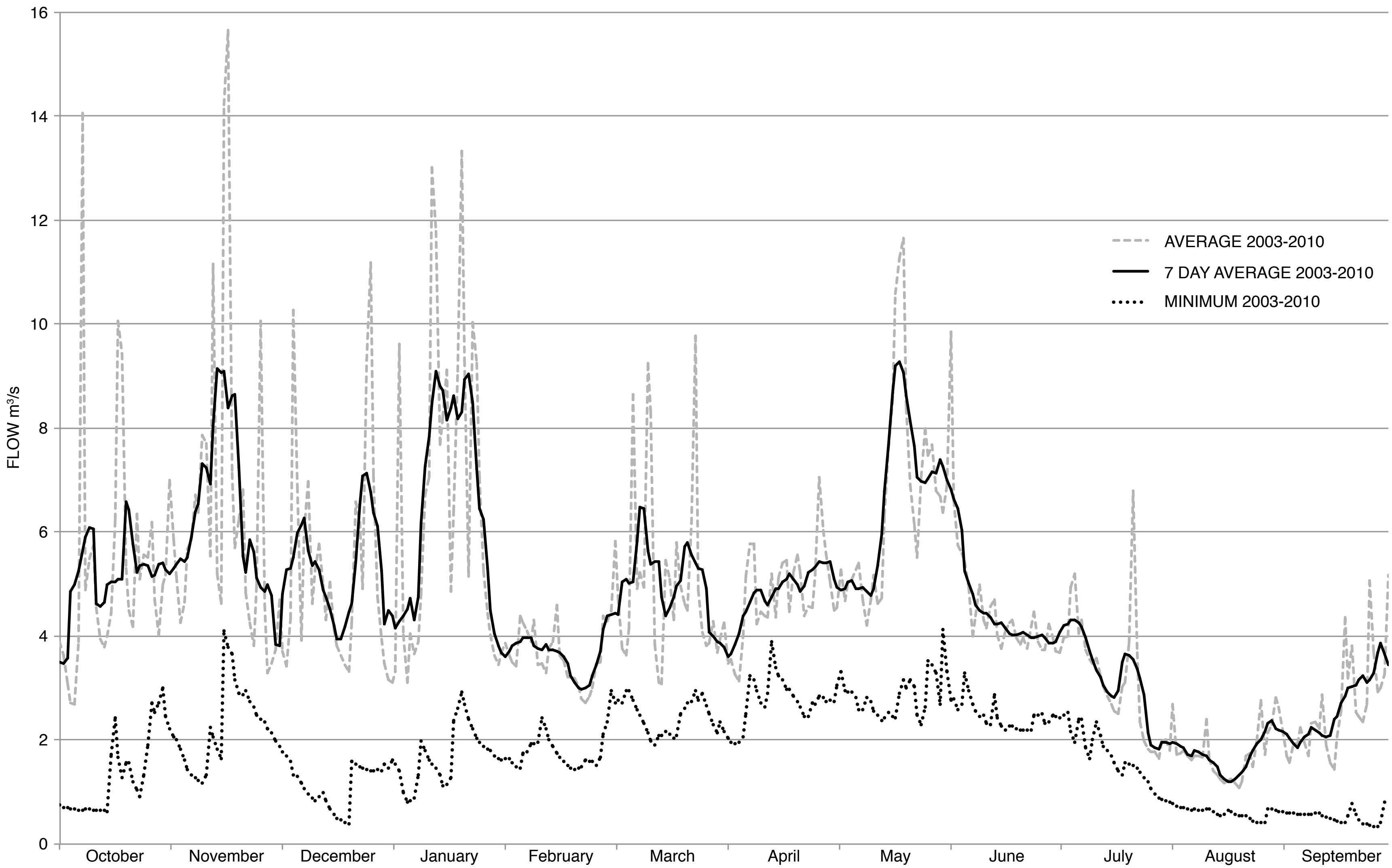

Figure 6 – Lower Theodosia River hydrograph normals. Average, 7 Day Average, and Minumum hydrograph normals for Theodosia River above Scotty Creek over the period 2003-2010.

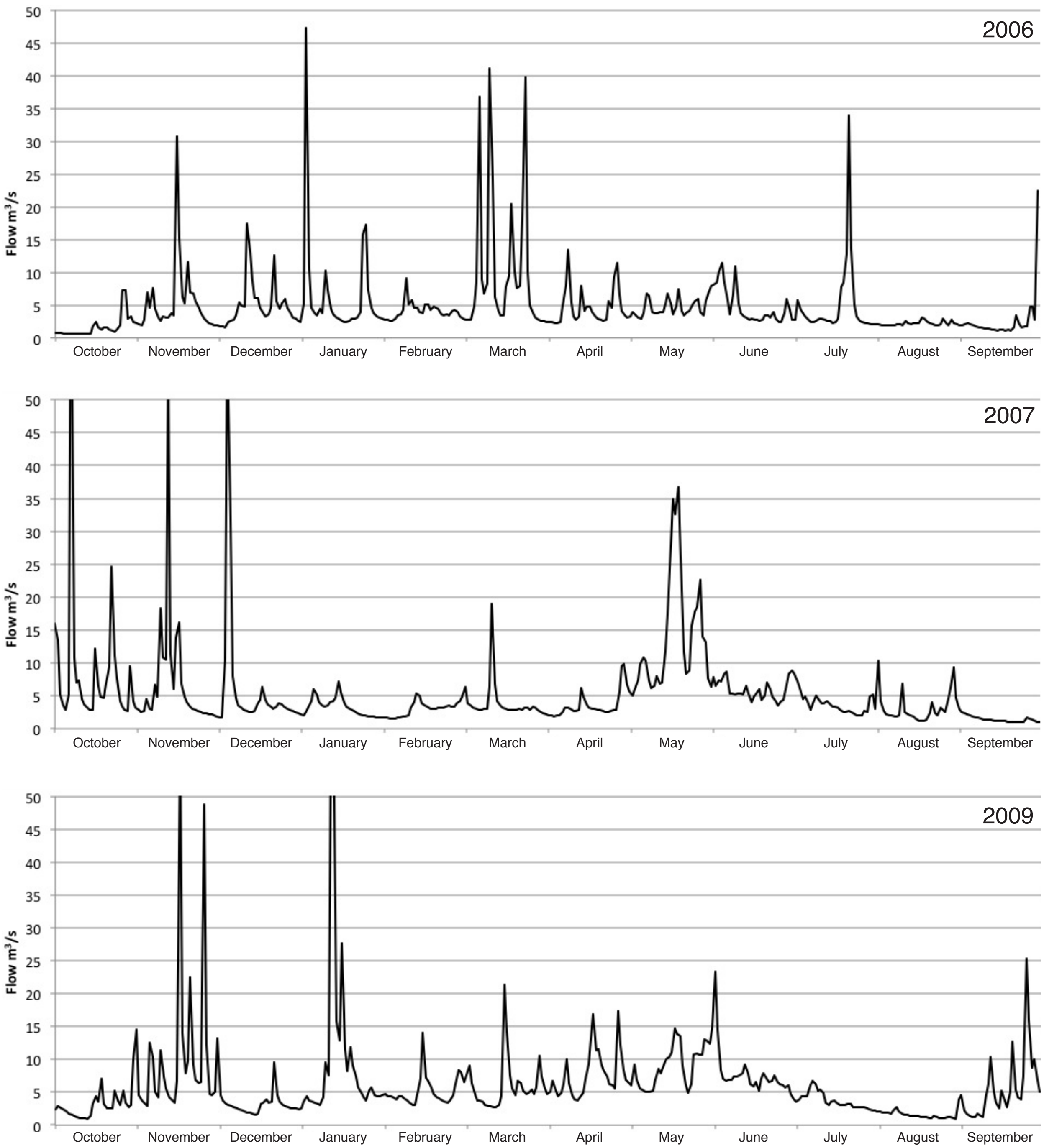

Figure 7 – Lower Theodosia River typical hydrographs. Selected yearly hydrographs of Theodosia River above Scotty creek for the 2006, 2007, and 2009 water years.

Chapter 2: Land and water use: history and cumulative impacts

2.1 First Nations

The Sliammon First Nation has traditionally consumed many species of fish and shellfish within the Theodosia watershed and region including salmon, butter clams, littleneck clams and cockles (Sliammon Treaty Society 1999). Although Sockeye was the preferred species it did not run in most of the main rivers in the territory. These rivers include Theodosia River, Powell River, Sliammon River, Okeover Creek and Lang Creek (Sliammon Treaty Society 1999).

The Theodosia River is important to the Sliammon people as it provided a bountiful salmon run. Within the Theodosia, Chum salmon were the main harvest due to their large size and distinct taste. Elders recall that the salmon from Theodosia were so large that they were too big to hang in the smokehouse and instead, Theodosia salmon were first barbequed and then laid flat on racks (Living Rivers 2009).

2.2 Forest harvest: history and effects

Over 52% of the watershed has been harvested at least once and much of the watershed has now been harvested multiple times (Klohn Crippen 1998). Both the hillslope and valley bottom forest composition and age structure has changed with forest harvest and replanting.

2.2.1 Landslides

Road building activities associated with forest harvest have caused several landslides within the watershed (Living Rivers 2009). In particular, a large debris flow event in 1995 caused damage to buildings and roads, increased stream sediment supply, and disturbed forest ecology on the Toquana Reserve. This event was likely triggered by saturation and subsequent failure of a fill slope of an old logging road on the hillslope above the Toquana Reserve (Rollerson 1995).

2.2.2 Forest harvest – floodplain stability

Forest harvest is of particular concern within valley bottom forests which function to stabilize and provide large wood inputs to river channel. Currently much of the valley bottom forest is young, aged between 21-46 years (GFC 2004). These young forests are currently unable to provide the large diameter conifers that serve to structure fish habitat within the river channel.

Riparian forest prescriptions have recommended a course of thinning of young forests in some areas in order to accelerate growth of conifers within the riparian corridor (GFC 2004).

2.2.3 Forest harvest – hydrology

Forest harvesting has likely had a large impact on the hydrology of the Theodosia watershed. In other watersheds tree removal and road construction has been shown to increase peak flows, increase annual water yield, increase sediment supply and increase flow variability (Hetherington 1998, Alila et al. 2009, Little et al. in review). Within Theodosia watershed this has resulted in an altered hydrologic regime that likely affects salmon populations. Furthermore, the riparian logging which occurred over the past decades resulted in channel widening, general channel instability, and salmon habitat disruption (Miles 2000a) and would have increased stream temperature for several years after tree removal (Holtby 1988).

2.3 Water use: history and impacts

The Olsen Lake diversion currently extracts ~40-70% of average monthly discharge, depending on the month, and has extracted 62% of the water from the upper Theodosia River during the 2000-2010 period of record (Figures 8a and 8b). In months of higher average discharge the quantity of water as well as the percentage of overall flow diverted from the upper Theodosia River is higher than in months with lower discharge. Typical monthly hydrographs during the summer and winter illustrate the daily streamflow from the upper Theodosia and that which is diverted to Olsen Lake or remaining to go towards the lower Theodosia river (Figures 9a and 9b. During low flow periods less than 2 m^3/s most water that enters the diversion channel is re-directed into the bypass channel and back to the Theodosia River (Figure 10). When flows in the diversion channel are between 2-4 m^3/s, the bypass re-directs an average of 1.9 m^3/s back to Theodosia River.

This water extraction results in a flattened hydrograph for the lower Theodosia River with lower peak flows and lower variability between peak and low flows. It also results in less water available for instream use in the salmon spawning and summer rearing habitat of lower Theodosia River. Figure 11 shows the average monthly discharge on the lower Theodosia River (above Scotty Creek) as well as a theoretical “natural” average monthly discharge that would have occurred without the upstream diversion.

The above figures were calculated using data from the Water Survey of Canada. The daily average flows diverted to Olsen Lake from Theodosia River were estimated by subtracting the Theodosia River By-pass flows (08GC006) from the Theodosia River diversion flows upstream the bypass (08GC005). In general, this results in a positive diversion flow to Olsen Lake. However, on certain low-flow days, subtracting the by-pass flows from the diversion flows upstream the bypass results in negative numbers meaning the flows in the by-pass are greater than the flows in the diversion channel upstream of the bypass. The WSC staff who operate the gauge have noted this anomaly as well, but have not yet determine the cause. It is likely that the stage-discharge relationship for the diversion channel, which receives high inputs of sediment, is quite dynamic and not accurate for low flows. For the above assessments, those days where negative diversion flows were calculated were altered to make diversion flow (08GC005) equal to the by-pass flow (08GC006) resulting in a daily value of 0 for the flow diverted to Olsen Lake. Flows to lower Theodosia were calculated by adding Theodosia River By-pass flows (08GC006) to Theodosia River below diversion (08GC007). The theoretical “natural” discharge for the lower Theodosia in Figure 11 was calculated by adding the daily average flow diverted to Olsen Lake to daily average flow recorded at the gauge above Scotty Creek. This assumes that water extracted at the Olsen Lake diversion would remain in the stream and add to the hydrograph downstream at the gauge above Scotty Creek.

The amount of water diverted to Olsen Lake at any given time is not tightly regulated and this value fluctuates from month to month and year to year as bedload sediment is deposited in the area upstream of the diversion. This is because the splitting of the upper Theodosia River into two rivers (the Olsen Lake diversion and lower Theodosia) results in less energy available to transport sediment, which subsequently results in a large amount of large sized bedload sediment (sand, gravels and cobbles) being deposited at the diversion. This issue is further discussed in section 2.3.1. However, it is important to note here that as this area builds with sediment over time, the ratio of water diverted to Olsen Lake to water remaining in Theodosia River changes.

Peak flows (floods) are important events that structure the channel geometry and salmon habitat, flush sediment through the stream network and maintain connectivity with the near-stream riparian forest. The 2-year return period peak flow was estimated for a “natural” (without the Olsen Lake diversion) and regulated (with the Olsen Lake diversion) channel. Currently regulated peak flows were estimated at ~55-60% of “natural” peak flow for the lower Theodosia river (Miles 2000a, Northwest 2000).

2.3.1 Sediment dynamics and channel stability

Sediment is supplied to Theodosia by both natural and harvesting related slope failures (Northwest 2000). Suspended sediment consisting of sand, silt and clay are maintained in the water column by turbulent flow. Bedload sediment is carried along the river channel bed and may consist of boulders, cobbles, gravel, and coarse sand.

The Olsen Lake diversion has caused a change in flow magnitude, which has had several consequences on sediment dynamics, channel geometry and channel stability. Annual suspended sediment yield in the Theodosia River above the diversion is estimated to be 4000-5000 Mg per year although forest harvesting may have increased this estimate (Northwest 2000). Approximately half of this is transported to the lower Theodosia River while the other half is transported to Olsen Lake (Northwest 2000). However, a relatively small portion of bedload has been carried over the dam at the diversion to the lower Theodosia River. It is estimated that 500 m^3/year has been transported below the diversion while 5000 m^3/year is deposited above the diversion or deposited along Olsen Creek (Northwest 2000). The majority of this large sediment is deposited above the dam resulting in an estimate of 70,000 m^3 of sediment remaining above the diversion (Northwest 2000).

The decreased bedload sediment supply to the lower Theodosia River has resulted in long-term bed lowering or degradation, a lack of gravel bars in some sections, and small quantities of sediment stored downstream of the dam (Northwest 2000). Furthermore, the suspended and bedload sediment that finds its way into the lower Theodosia is proportionally of a smaller grain size than in the upper Theodosia (i.e. more sand and small gravel than large gravel and cobbles).

The reduction in streamflow and bedload transport to the lower Theodosia River has resulted in a generally narrower and more stable river channel (Miles 2000a). It is estimated that the channel width is approximately 74% of the pre-diversion width in alluvial (unconstrained) sections. Post-diversion river depth and average water velocity during the annual average flood are estimated at 82% and 93% respectively.

Post logging slope instability as well as riparian harvesting has resulted in channel destabilization and temporary increases in channel width followed by stabilization and decrease in channel width as vegetation colonizes bare gravel (Miles 2000a).

Observations also indicate that decreased flushing flows results in sandy bottoms and stable reaches, especially in side channel habitats. This sort of lack of dynamism in side channels is detrimental to ecological diversity.

2.3.2 Estuary dynamics

A limited amount of evidence suggests that lowered flows due to the diversion have increased sediment deposition at the mouth of the Theodosia River and this has resulted in the estuary rising and retreating into the inlet. Further study is required to determine the state of the estuary.

2.3.3 Fisheries decline

Populations of salmonids in the Theodosia River have severely declined since the early 1950s. This decline may be due to many causes and complex interactions including changes to offshore ocean conditions, fishing pressures, changes in estuary conditions, decreased suitable spawning habitat, decreased suitable overwintering habitat, and decreased summer rearing habitat. Land use practices (forest harvest) and the Olsen Lake diversion are thought to be contributing factors to the salmon population decline.

Spawning escapement records are illustrated in Figures 12 and 13. Prior to the construction of the Olsen Lake diversion in 1955 yearly Chum salmon escapement was reported to be as high as 35,000 fish. Salmon escapement has been substantially lower in the recent decades. Long-term Chum escapement averaged 4600 fish over the period 1959-1985 (Hancock and Marshall, 1985). From 1986-1996 Chum escapement decreased to an average of 1000 (Klohn-Crippen 2001). Recent counts are higher with reports of 4500 in 1997, 3400 in 1998 and up to 6000 in 2000 (Living Rivers 2009). Figure 12 shows Chum salmon escapement from 1953-2000.

Coho salmon stocks have also declined considerably over the past 60 years. Average Coho escapement from 1947-1958 was 4800 but this number declined to an average of 164 between 1986-1996 (Klohn-Crippen 2001). Recent observations indicate increased Coho stocks, possibly related to the introduction of fry, however this population requires further observation to gauge the state of the fishery. Figure 13 shows Coho salmon escapement from 1953-2000.

Chapter 2 Figures

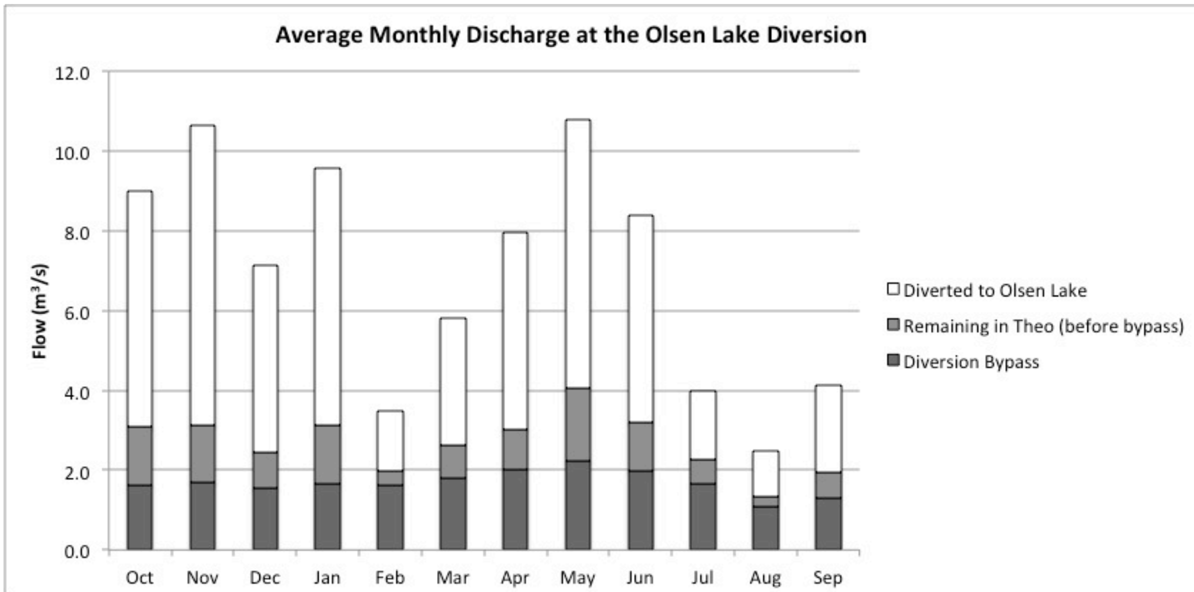

Figure 8a – Average monthly discharge at the Olsen Lake Diversion (2000-2010). Note: each class of flow is additive. For example, in October 1.6 m^3/s goes through the diversion bypass, while 1.5 m^3/s remains in Theodosia River; thus, 3.1 m^3/s are left in to flow into the lower Theodosia while 5.9 m^3/s, is diverted to Olsen Lake.

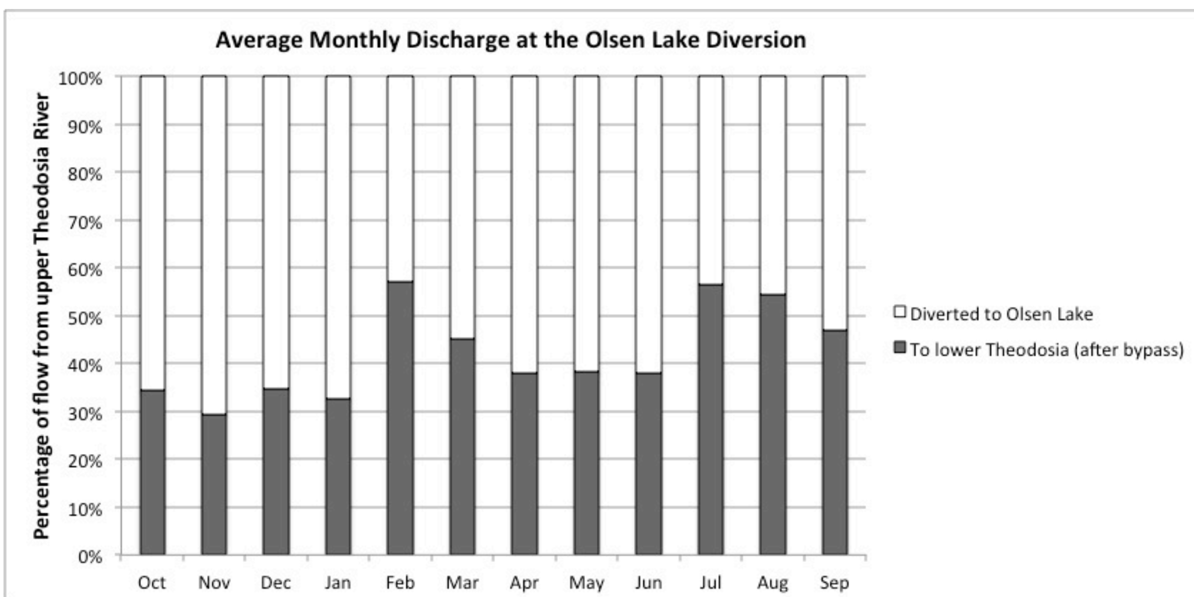

Figure 8b – Percentage of average monthly discharge diverted to Olsen Lake (2000-2010). Percentage of average monthly flow from the upper Theodosia River diverted to Olsen Lake and remaining in the Theodosia River is shown here. The months with the highest rates of diversion are those months with the highest average flow volumes.

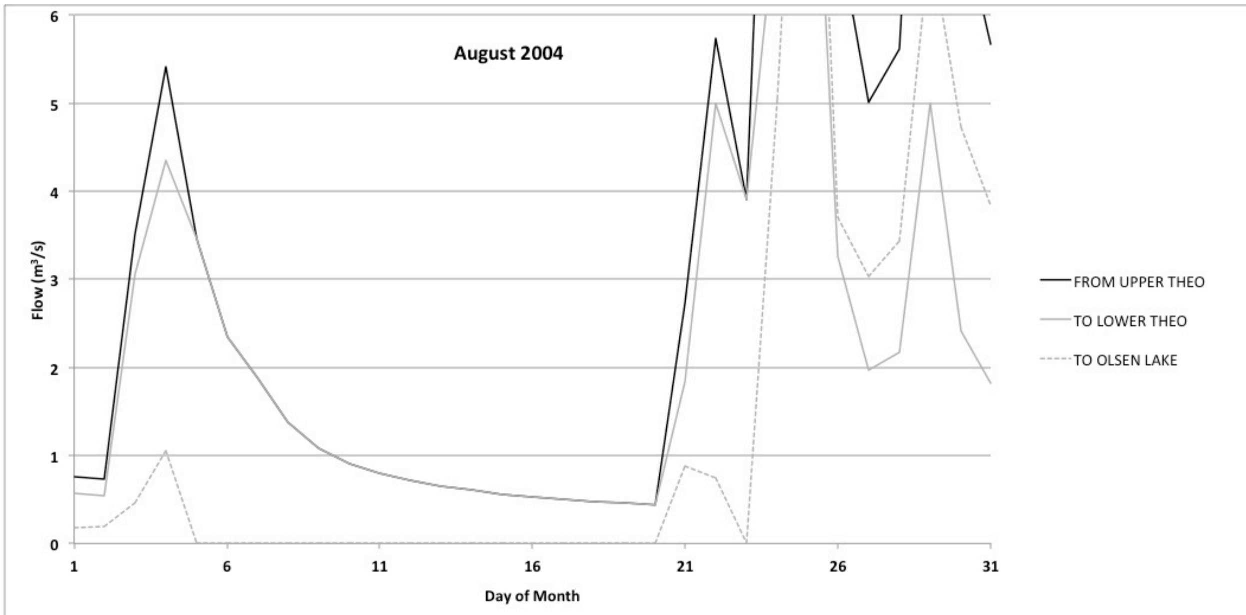

Figure 9a – Typical summer low flow hydrograph (August 2004). During low flow periods most flow remains in the Theodosia River. When flows increase, more flow is diverted to Olsen Lake.

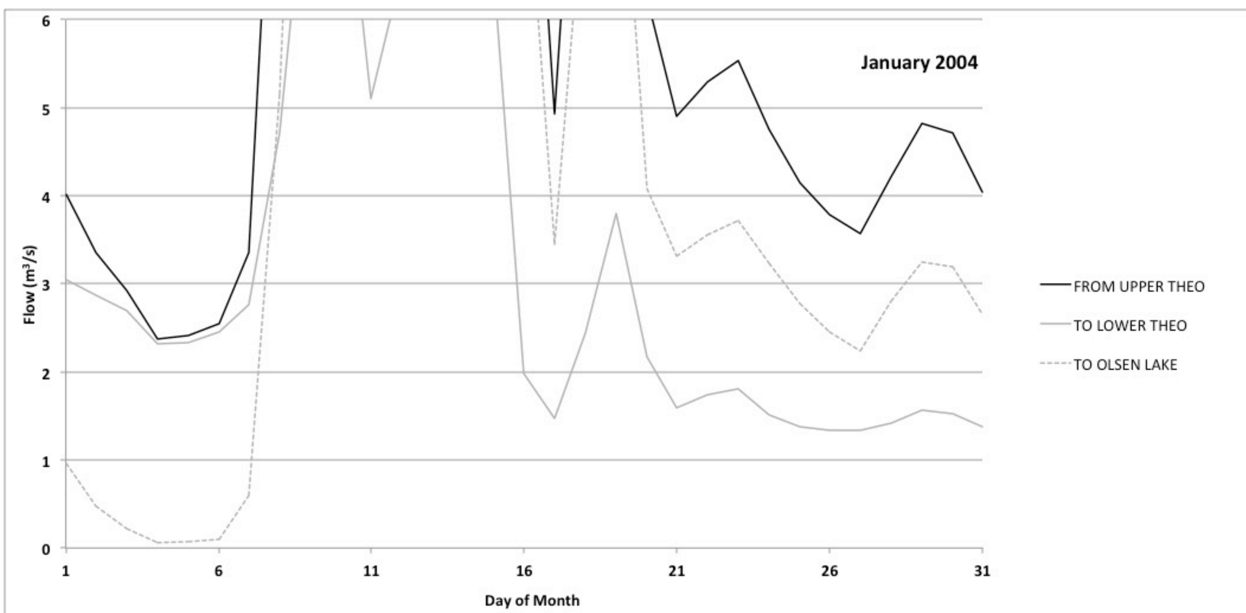

Figure 9b – Typical winter hydrograph (January 2004). During low flow periods most flow remains in the Theodosia River. When flows increase, more flow is diverted to Olsen Lake.

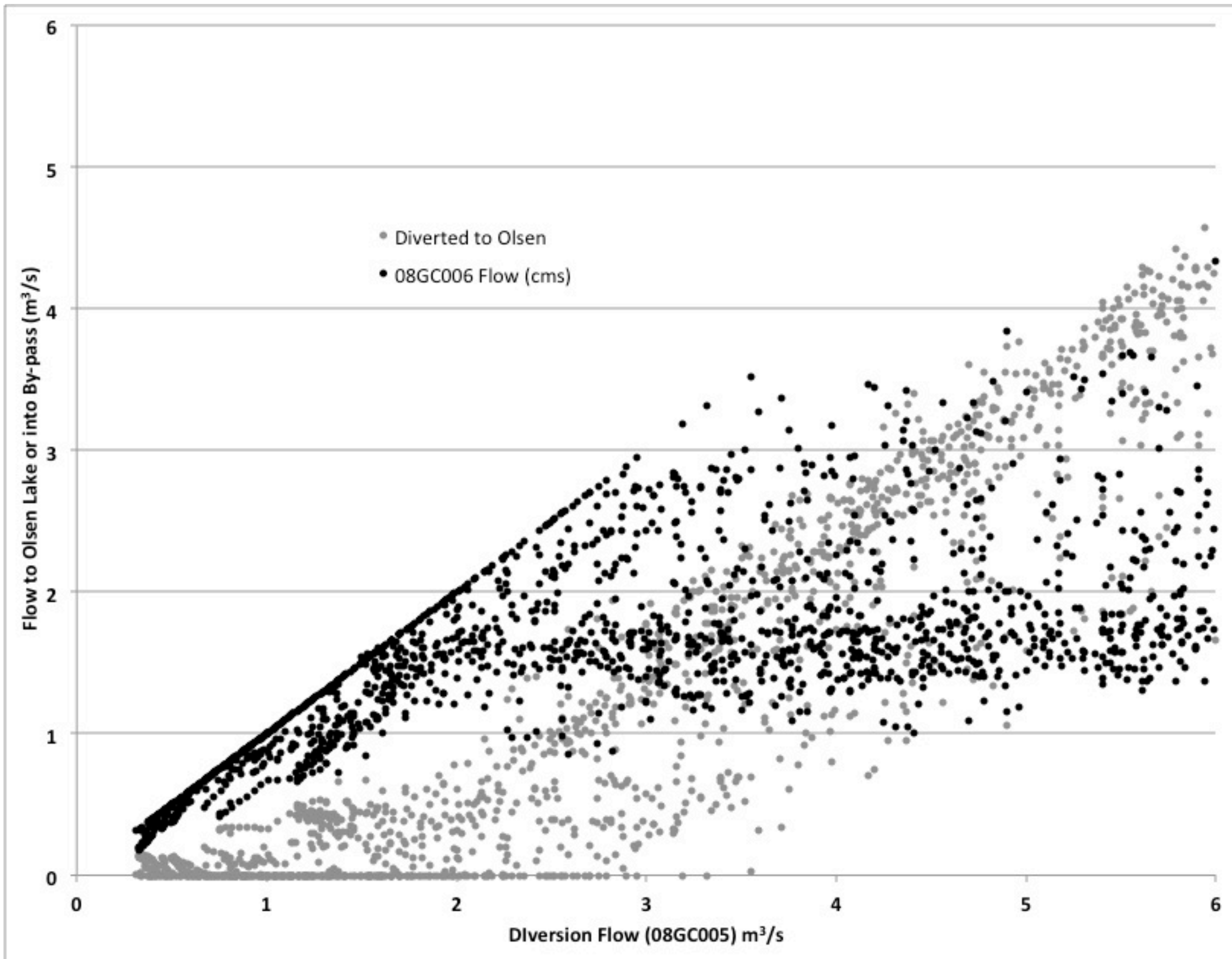

Figure 10 – Flow to Olsen Lake (grey) and by-pass flow (08GC006) redirected back into the Theodosia River (black) is plotted as a function of flow that is originally diverted away from the upper Theodosia (2004-2010). The x-axis is the flow at gauge 08GC005. Below 2 m^3/s the majority of flow that enters the diversion channel is re-directed back to the Theodosia River. Of diversion channel flows between 2-4 m^3/s, typically between 1.5 and 2 m^3/s is re-directed to the Theodosia while the remainder is left in the diversion channel to be exported to Olsen Lake.

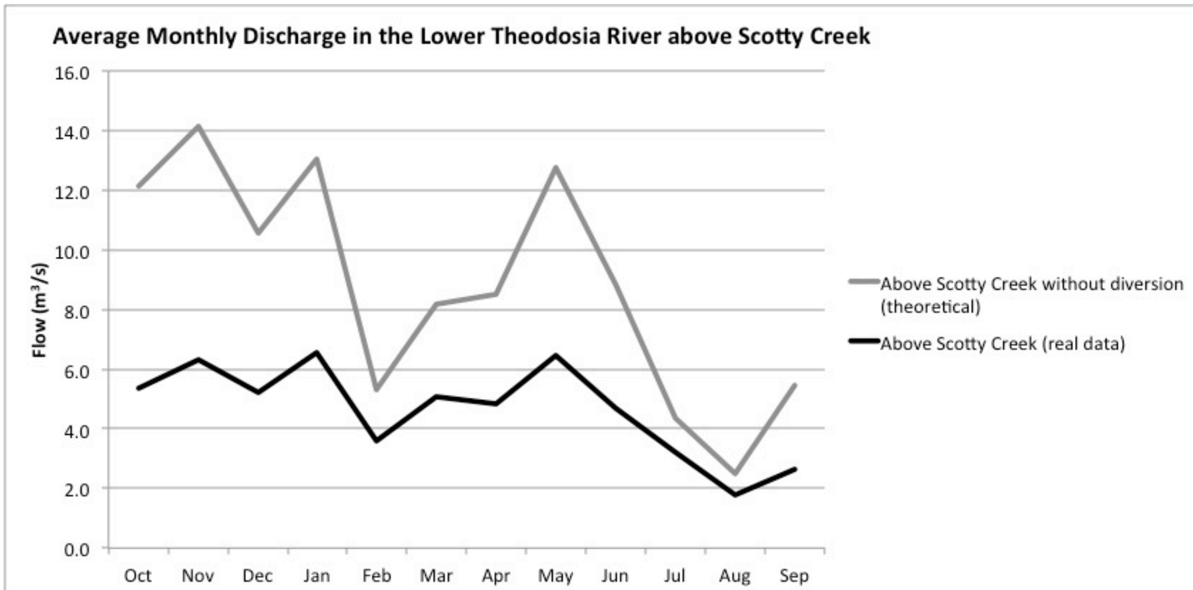

Figure 11 – Average monthly discharge in the lower Theodosia River above Scotty Creek (2003-2010). This figure shows average monthly discharge on the lower Theodosia River as measured by Water Survey of Canada in black. The grey line is a calculated value based on adding the volume of flow that was diverted to Olsen Lake to the volume that reaches the WSC gauge.

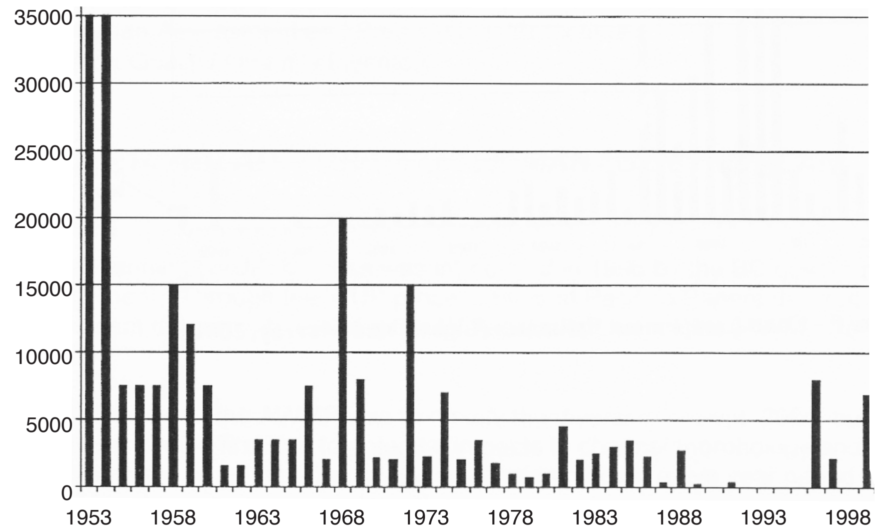

Figure 12 – Chum escapement estimates from 1953-2000. From Lightly and Murray 2001.

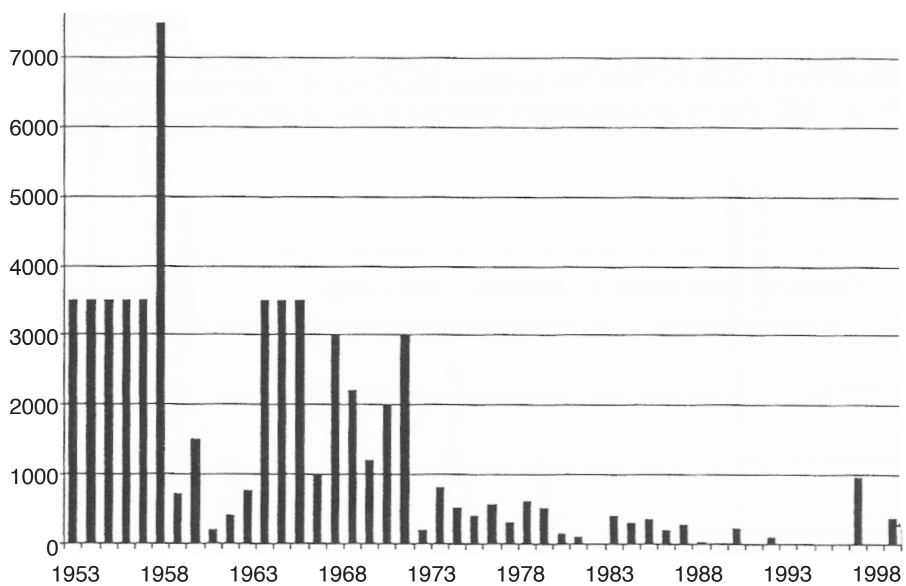

Figure 13 – Coho escapement estimates from 1953-2000. From Lightly and Murray, 2001.

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PART II – FUTURE PROJECTIONS FOR THE THEODOSIA WATERSHED

Chapter 3: Predicted climate changes in the Theodosia region

3.1 Global climate change

The earth's climate is changing due to increased concentrations of greenhouse gases in the atmosphere (IPCC 2007). These greenhouse gasses, such as CO_2, are being emitted into the atmosphere through various anthropogenic sources. The past decade (2001-2011) was the warmest ever recorded. In order to predict the amount of warming in coming decades scientists use scenarios of population and economic growth that result in different amounts of CO_2 emitted into the atmosphere to predict a range of possible emmisions and warming scenarios over the next century. The three most common scenarios used in modeling future climate change are called the A2, A1B, and B1 scenarios (IPCC 2007). Although no one is certain which scenario will most resemble the choices made by society in the coming years and decades, it is clear that all these scenarios will result in substantial global surface warming and climate change. Figure 14 shows projected increases in global surface temperature over the next century.

3.2 Climate change in the Powell River region

The Pacific Climate Impacts Consortium at the University of Victoria has used downscaled global climate models to estimate future climate parameters across British Columbia. These models have been used to predict changes in climate for individual regions in BC, such as the Powell River region. Several models are used in these projections and each of these models is run with climate global climate forcing data from each of the A2, A1B, and B1 scenarios such that projections can be made using multi-model averages. This results in a range of expected climate values that depend on the models inner workings as well as the choices made by society now and in the future. Although there is uncertainty in these projections they give us an idea of what to expect over the next decades. Box 1 summarizes projected impacts to the Powell River region.

3.2.1 Predicted change in temperature in the Powell River region

Average annual temperatures are expected to rise steadily over the next century. In the short term, the average temperature in the Powell River region from 2010-2039 (the 2020s) is expected to be 0.5°C to 1.3°C higher than the average over the baseline period 1961-1990 (PCIC 2010). By the 2050s (2040-2069) the average temperature is estimated to be 1.1 to 2.5°C higher and by the 2080s (2070-2099), the average is estimated at 1.5 to 3.8°C higher than the baseline period (PCIC 2010).

Average temperatures in all seasons are predicted to rise although the magnitude of temperature increase and the uncertainty around temperature change varies by season (Figure 15). The median model, predicts average fall, winter, and spring temperature in the 2050s to be around 1.5°C higher than the baseline period, however depending on the climate change scenario and specific climate model used, this figure varies between 1.0-2.3°C for fall, 0.6-2.5°C for winter, and 0.7-2.0 °C above baseline for spring (PCIC 2010). Average projected summer temperature increase is higher, at 1.9 °C above baseline, with a smaller range, 1.4-2.6 °C, between models (PCIC 2010).

These projections are averages over 30 year periods. Individual years are likely to vary dramatically. In fact, it is likely that although only a slight increase in average temperature will occur, year-to-year and day-to-day variability will increase (Medvigy and Beaulieu 2011). Extreme temperatures in both directions may become more common with extremely hot years and even extremely cold years occurring more frequently than in the past (Salinger 2005). Heat waves and hot temperature extremes are also very likely to become more frequent (IPCC 2007).

3.2.2 Predicted change in precipitation in the Powell River region

Precipitation: rain and snow

Projected changes in precipitation vary by season and are accompanied by a great deal of uncertainty (Figure 16). In general, fall, winter and spring precipitation in the Powell River region is predicted to increase by ~2-20% by the end of the century, although a few climate models predict decreases in the short term (2010-2050) followed by increases in the long term (2050-2099) (PCIC 2010). Conversely, average summer precipitation is expected to decrease by as little as 1% or as much as 35% by the end of the century, although a few models predict very little change or even a slight increase in the short term followed by a decrease by the end of the century (PCIC 2010). As with temperature, it is prudent to expect that although seasonal precipitation averages are likely to change slightly, a great deal of climate variability may be expected. Over the past two decades an increase in day-to-day variability in rain events has occurred worldwide and this trend can be expected to increase in the future (Medvigy and Beaulieu 2011). It is reasonable to expect both extreme droughts and floods, as both heat waves and extreme precipitation events will very likely become more frequent (IPCC 2007).

Snow

Projections of average seasonal and annual snowfall are less uncertain. All models predict a decrease in fall, winter, and spring snowfall in the Powell River region (Figure 17) (PCIC 2010). Annual snowfall is expected to decrease by 21-57% by the end of the century (PCIC 2010). Fall, winter, and springtime decreases of up to 60-85% are expected depending on the season. Recall that this decrease in snowfall is predicted to be accompanied by more precipitation in general, meaning that fall, winter and spring are expected to be warmer and wetter than they have been in the past. As snowfall becomes increasingly restricted to the highest elevation areas within the watershed, (Figure 18), due to warmer winter temperatures, snowpack available for spring streamflow will be severely diminished. This will result in substantial changes in the hydrologic regime, which will be discussed in the following chapter.

3.2.3 Predicted change in sea level

Sea level rise depends on several factors including: (1) changes in global ocean volume due to melting of ice sheets and glaciers; (2) global and regional changes in ocean water volume due to thermal and salinity related expansion (warmer, fresh water occupies more volume than cold, salt water); (3) changes due to atmospheric and ocean processes such as shifting major wind patterns and ocean currents, which result in regional volume changes; and (4) local vertical land shifting due to rebounding (recovery from the weight of glaciers during the last ice age), subsidence (sinking) in river deltas, and uplifting caused by plate tectonic processes (Bornhold 2008).

Global sea level has been rising since the last ice age. Recent global sea level rise is calculated to have been 1.8 mm/year since 1880 and 3.2 mm/year since 1993 (Bornhold 2008). Local sea level rise is extremely hard to predict due to the many factors that it's dependant on (1-4 above) as well as uncertainty of future CO_2 atmospheric concentrations however several estimates around BC predict sea levels to rise by approximately 1 m by 2100. Under a high global sea level rise scenario, estimates of local sea level rise by 2100 vary from 30-93 cm in Campbell River to 58-119 cm in Vancouver to 76-155 cm in Prince Rupert (Thomson et al. 2008). In Washington, under high global sea level rise scenarios, similar predictions of 35-88 cm by 2050 and 88-128 cm by 2100 are reported (Huppert et al. 2009). However, under medium global sea level rise scenarios, local sea level rise of only 4-34 cm in Washington and 11-46 cm rise around BC are predicted (Bornhold 2008, Huppert et al. 2009).

In addition to long term sea level rise, increased streamflow may result in even more sea level rise at certain times of the year. Fresh water from rivers filling coastal inlets results in sea level rise especially during times of heavy streamflow such as the winter (Bornhold 2008). This is due to the influx of relatively warm and fresh water, which occupies more volume than salt water.

Box 1 – Summary of projected climate change impacts to the Powell River Region

By the 2050s…

- Average **summer temperature increase**: up to 3^oC
- Average **summer precipitation decrease**: up to 25%

Dryer, hotter summers
More heat waves and **more year to year variability** (less predictable weather)

- Average winter precipitation increase: up to 13%
- Average snowfall decrease: 25-60% less
- Average winter temperature increase: up to 2.5^oC

Wetter, rainier winters
More large winter rain-storms

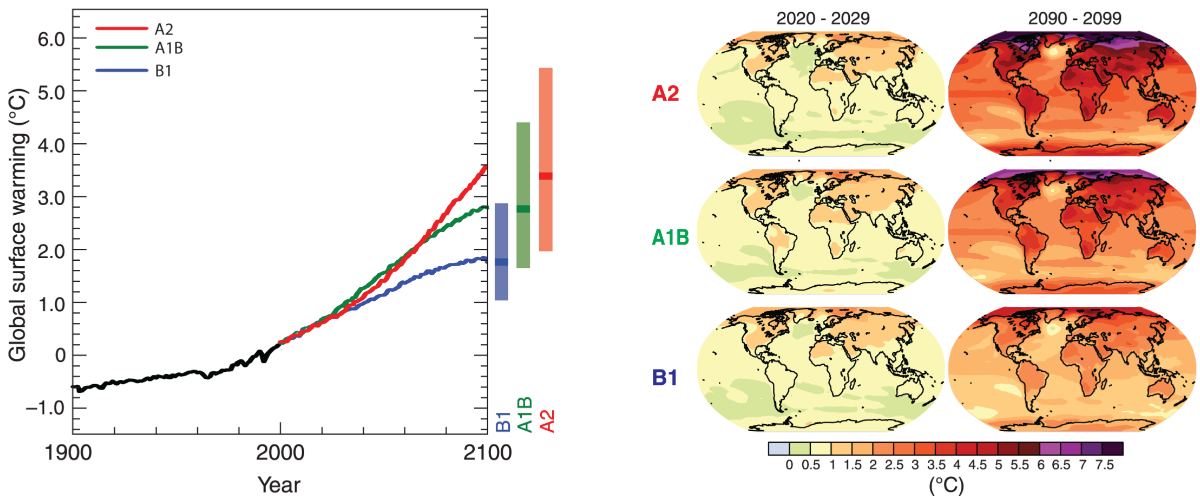

Figure 14 – Multi-model global averages of surface warming (relative to 1980-1999) for the emissions scenarios A2, A1B, and B1 are shown in the left graph. Global maps show projected surface warming under these different scenarios for two periods (2020-2029 and 2090-2099). Adapted from IPCC 2007.

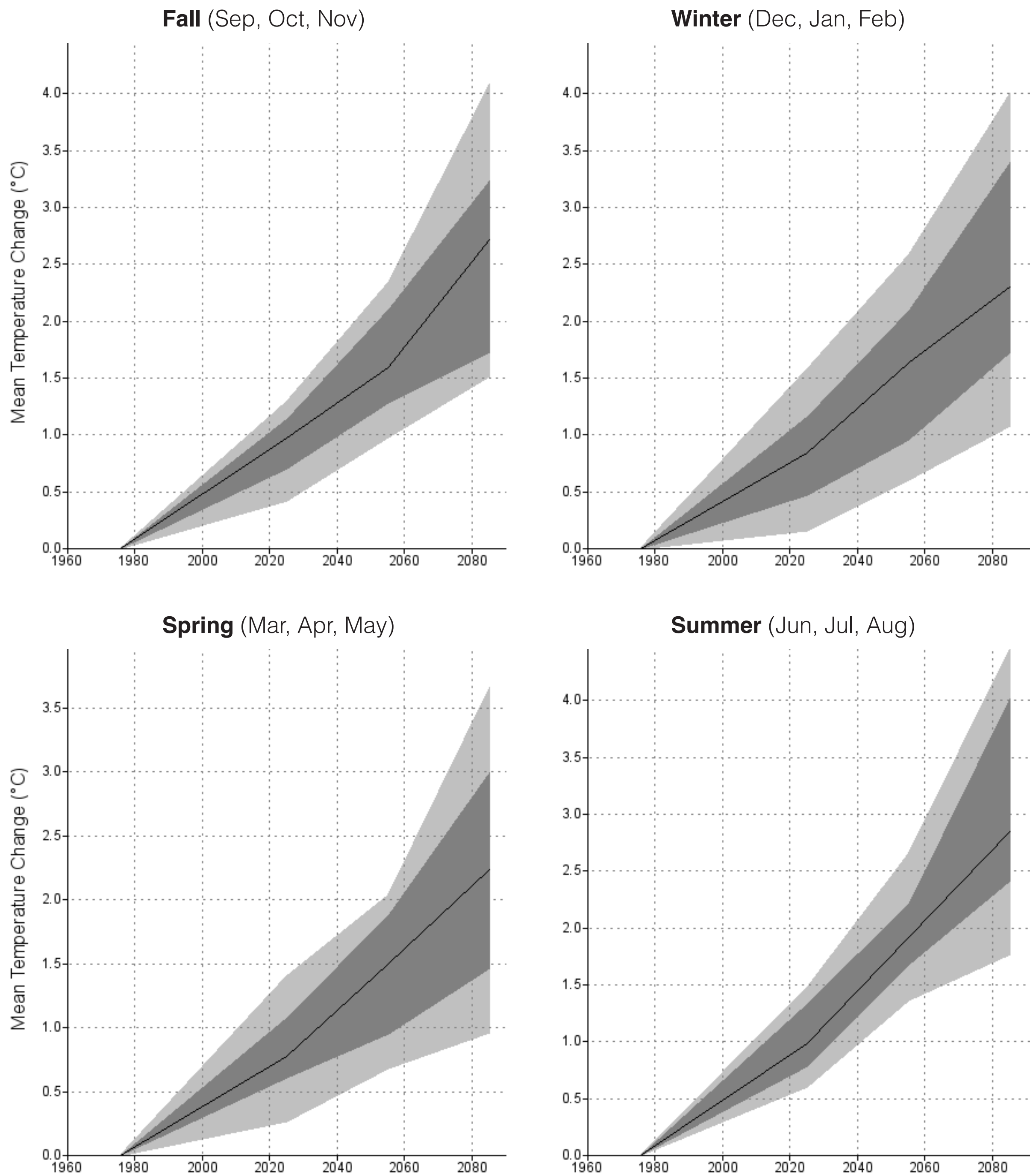

Figure 15 – Predicted seasonal average temperature change (relative to 1961-1990 baseline). Each graph shows a range of seasonal temperature change projections for the Powell River region according to a range of global climate models used by the Pacific Climate Impacts Consortium. The black line indicates the mid-point (median) model in the set, the dark grey shading shows the middle 50% of the projections in the set, and the light gray indicates a range of the middle 80% of the projections used. Adapted from PCIC 2010.

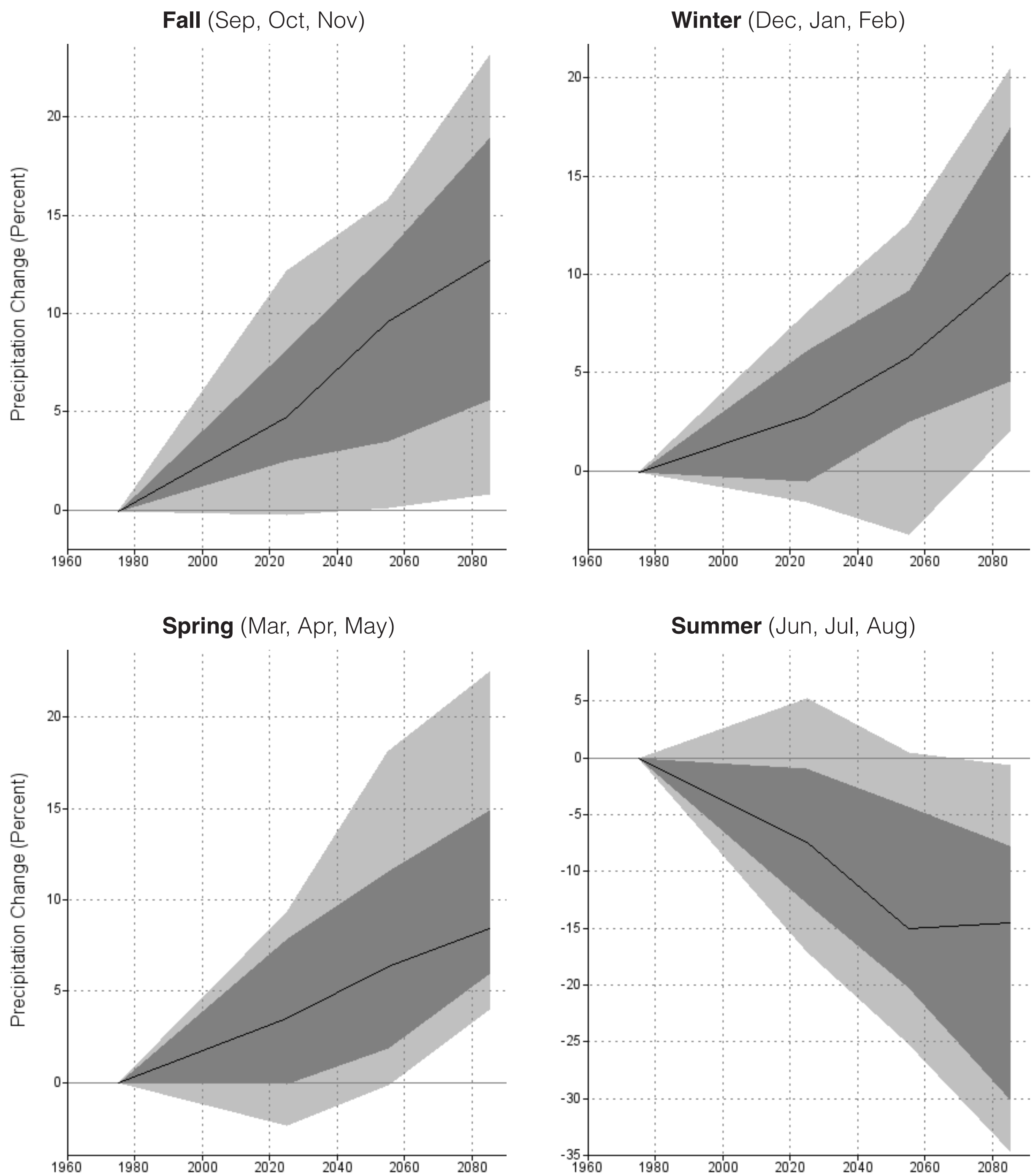

Figure 16 – Predicted seasonal average precipitation change (relative to 1961-1990 baseline). Each graph shows a range of seasonal precipitation change projections for the Powell River region according to a range of global climate models used by the Pacific Climate Impacts Consortium. The black line indicates the mid-point (median) model in the set, the dark grey shading shows the middle 50% of the projections in the set, and the light gray indicates a range of the middle 80% of the projections used. Adapted from PCIC 2010.

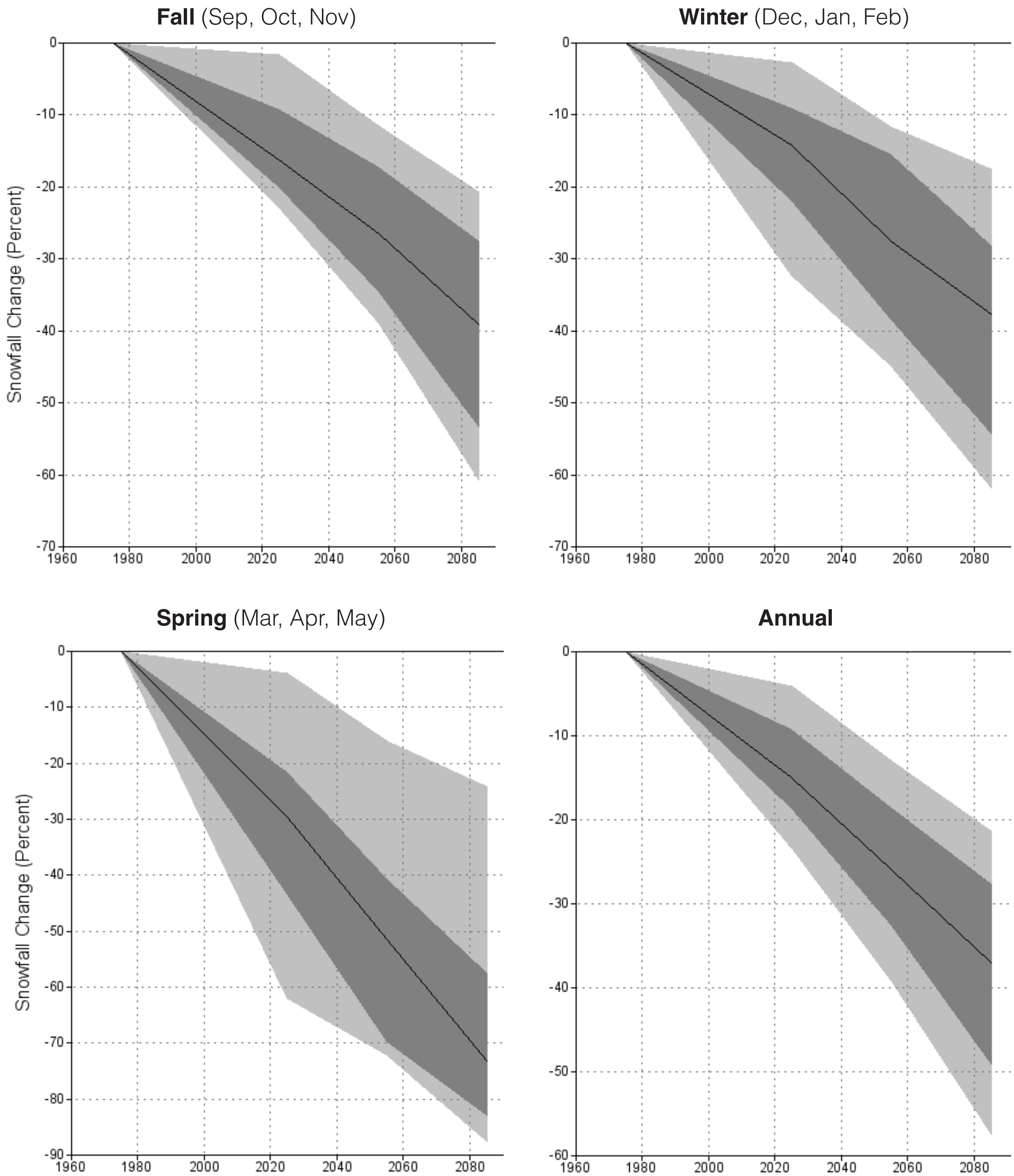

Figure 17 – Predicted average snowfall change (relative to 1961-1990 baseline). Each graph shows a range of seasonal or annual snowfall change projections for the Powell River region according to a range of global climate models used by the Pacific Climate Impacts Consortium. The black line indicates the mid-point (median) model in the set, the dark grey shading shows the middle 50% of the projections in the set, and the light gray indicates a range of the middle 80% of the projections used. Adapted from PCIC 2010.

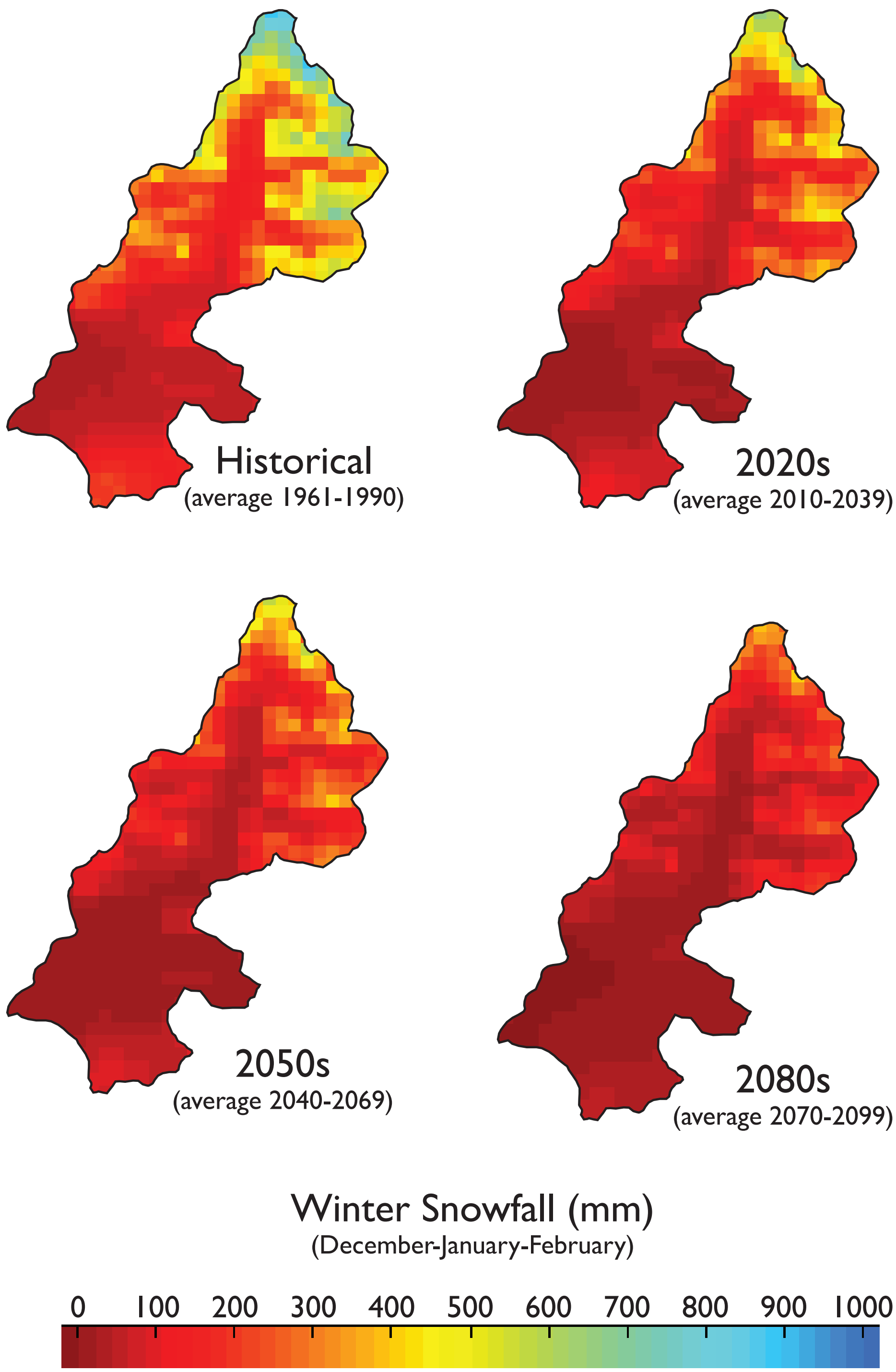

Figure 18 – Theodosia watershed winter snowfall projection maps. Maps show the outline of the Theodosia watershed. Colours indicate historical and future projections of winter snowfall at different areas within the watershed based on the A2 climate change scenario. Historically, substantial snowfall has fallen and accumulated over winter in the upper Theodosia watershed. Future projections indicate that by the end of the century very little snowfall will occur anywhere in the watershed. Adapted from PCIC 2010; model: SRES AR4 – CLIMATEBC ABS_A2-CGCM3_4 – Winter - DJF.

Chapter 4: Hydrological impacts of climate change

Climate change is expected to impact the hydrology of the Theodosia River watershed in several ways. Stewards of the watershed should expect changes in the magnitude and frequency of peak flow events (floods), changes in the magnitude and frequency of low flow events (droughts), changes in the timing of the hydrologic regime, changes in water temperature, and changes in seasonal and annual water yield. The following chapter will discuss these changes in detail using several case studies as examples.

To date, no hydrologic modeling studies have been completed for the Theodosia River however several studies of nearby rivers in British Columbia and Washington can provide insights into how the Theodosia River may be impacted by climate change. The Pacific Climate Impacts Consortium has modeled climate change impacts to the Campbell River on Vancouver Island. This river is located approximately 50 km from Theodosia and is characterized by a generally similar hydroclimate. Although it has a larger storage capacity (lakes), is somewhat influenced by glacial meltwater and has a larger basin size this well studied river is useful as a case study due to its proximity to Theodosia, its similar hydroclimate, and its similar elevational profile. The differences in watershed character are minor relative to the similarities. Lang Creek, only 30 km from Powell River, has been studied in terms of changes to river water temperature and can provide insights into these effects. The Dungenness River on Washinton's Olympic Peninsula also provides a well studied analog to Theodosia because, although further afield, it is similar to Theodosia in terms of basin size, hydroclimate, storage capacity and elevational range.

4.1 Change in hydroclimate

As the winter snowpack decreases throughout the next century, many coastal British Columbian rivers such as Theodosia are projected to change from a mixed rain and snow regime to a predominantly rainfall-dominated regime (Pike et al. 2010). These hybrid systems currently experience peak flows during winter rainstorms as well as during the spring as mountain snowpack melts and is delivered through the stream network. The projected decrease in snowfall and increase in temperatures along BC's coast will likely result in the spring freshet (i.e. the springtime peak flow event driven by melting snow) arriving earlier, and eventually spring melt may be diminished entirely. As early as the 2050s, the Campbell River is projected to change from a hybrid to a rainfall-dominated regime with increased monthly streamflow from October to April and decreased streamflow from May to September, due to a substantial reduction in snowpack and the disappearance of the spring freshet (Schnorbus et al. 2011). Elevation in the Campbell River watershed rises up to 2200 m, with approximately half the watershed above 900 m (Schnorbus et al. 2011). The Theodosia watershed is characterized by a similar elevational profile, where approximately half the watershed is over 900 m; thus, following projections for the Campbell River, we can expect spring peak flows to diminish and the spring freshet disappear within the same timeframe, by the 2050s.

Changes in hydroclimate are illustrated by examining projected changes in monthly average streamflow. This shows the amount of change to be expected in timing and water yield throughout the year. Figure 19 shows historical average monthly discharges for Campbell River as well as projected average monthly discharge over the years 2040-2069 as predicted by several models (Schnorbus et al. 2011). The range between models is due to the differences in the models themselves as well as different climate forcing scenarios. That is, depending on the degree of CO_2 output over the next century the degree of hydrological change will differ. The Campbell River monthly discharge graph differs from that of Theodosia (Figure 11) so this graph was transformed to show the range of percent changes from historic monthly discharge over the 2040-2069 time period (Figure 20). Wintertime increases in average monthly streamflow range from 0-145%, while summertime decreases range from 40-85%.

4.2 Summer low flows

Over the next decades, coastal British Columbian rivers such as the Theodosia will likely see dramatic decreases in summer low flow magnitude and an increase in the frequency and magnitude of extreme low flow periods. Average monthly discharge is predicted to decrease by ~40-85% during this time of year when flows are already at their lowest (Figure 20). This is due decreased snowmelt, decreased precipitation, increased average temperatures and increased heat waves that may result in prolonged summer droughts.

The magnitude of flow during the summer months is measured by the 7Q10, which is the 7-day average low flow magnitude with a 10-year return interval. In other words, it is the flow, measured as an average over a 7-day period, that is sufficiently low magnitude that less water in the stream occurs on average once every 10 years. Future estimates of the 7Q10 at the Dungeness River on the Olympic peninsula in Washington are 15-30% less than historical levels (CIG 2010) (Figure 21). We should prepare for similar low flows in the Theodosia River.

4.3 Peak flows

Increases in overall winter rainfall and storm frequency are predicted to result in more frequent high magnitude floods. Risk of increased peak flow magnitudes is highest in watersheds such as the Theodosia where winter precipitation has traditionally been stored as snow in the high elevation areas of the watershed. In the past, large winter storms from the Pacific colliding with the steep terrain of Theodosia would deposit large quantities of snow in the upper watershed. This snow remained as snowpack until the spring and gradually melted to enter the channel network. Under warmer temperature scenarios it is likely that storms such as these will result in large amounts of rain, rather than snow, at higher elevations. This rain will instantly drain through the watershed rather than being stored up and released slowly in the spring; thus, extremely high magnitude floods may result.

At the Dungeness River in Washington it is estimated that the magnitude and frequency of peak flows will increase dramatically. By the 2020s the 20-year peak flow magnitude will be larger than what is currently the 100-year peak flow event (CIG 2010) (Figure 22). That is, a flood event that has historically been surpassed in magnitude only once in 100 years on average will occur more frequently than once in 20 years. By the end of the century the magnitude of the 100-year event is predicted to be approximately double it's current magnitude (CIG 2010). Furthermore, what has historically been referred to as a 100-year flood is likely to occur as frequently as once in 5-20 years.

The downscaled global climate models used to generate these projections may underestimate the precipitation extremes that drive the peak flows according to some regional climate modeling in Washington (Salathé et al. 2010). This suggests that increased flooding frequency and magnitude in transient runoff watersheds such as Theodosia may be even more extreme than the above estimates from the Dungeness River (Mantua et al. 2010).

4.4 Water temperature

Increased air temperatures may result in warmer stream water temperatures. Air temperature is not the only factor that affects water temperature; it is also influenced by water source, terrain, stream depth, shading and other factors. Furthermore, there may be a lag of several decades for increased air temperatures to influence groundwater that supplies streamflow. It is difficult to predict specific water temperature increases for Theodosia without detailed modeling of terrain and the input of long term historical records, however studies in Washington and at Lang Creek may give some insight into the degree of warming that may occur.

In northwestern Washington, most low elevation stream maximum average weekly temperatures are predicted to rise 1-2^{o}C while only a few streams in the region may see increases of up to 3-4^{o} by the 2080s, (Mantua et al. 2010, 2011) (Figure 23). Historical maximum weekly average stream temperature on these streams was <17^{o}C for most streams while some streams had temperatures of up to 20^{o}C. Detailed statistics for Theodosia River are not available although the single complete year on record (2000/01) indicates a maximum daily water temperature of 16.5 with maximum weekly water temperature somewhere around 15^{o}C. Highest recorded temperature in Theodosia River is 19.5 ^{o}C, in July 1998 (Klohn-Crippen 2001). Although records are sparse it can be expected that maximum weekly average summer temperature in the lower Theodosia River is likely to increase at a similar rate to those on the Olympic Peninsula and western Washington, that is, 1^{o} by the 2020s and up to 2^{o} by the end of the century. It is important to note, however, that stream temperature is not uniform throughout the channel and thermal refugia may exist where cooler summer temperatures are the norm.

Studies at Lang Creek near Powell River indicate that water temperatures there may increase by 1^{o}C by the 2020s, 1.6-1.9^{o}C by the 2040s and 2-3^{o}C by the 2080s. This creek is fed by a lake that warms up substantially in the summer months, thus contributing to higher temperatures in the creek downstream. Theodosia is without a substantial upstream reservoir and summer streamflow is groundwater sourced. Therefore the stream is generally cooler than Lang Creek and is less likely to be influenced by warming air temperatures.

Box 2 – Summary of projected climate change effects on hydrology of the Theodosia River

- Reduced snowpack will result in a shift in timing of streamflow to **earlier and diminished spring peak flows**. By the middle of the 21st century, **very little snowpack will be left to contribute to spring streamflow**.
- Reduced snowfall, decrease in summer precipitation and increase in temperatures will result in **lower monthly stream flows and more extreme low flow periods**.
- **Increase in frequency and magnitude of fall and winter peak flow events**
- **Increase in stream temperature**

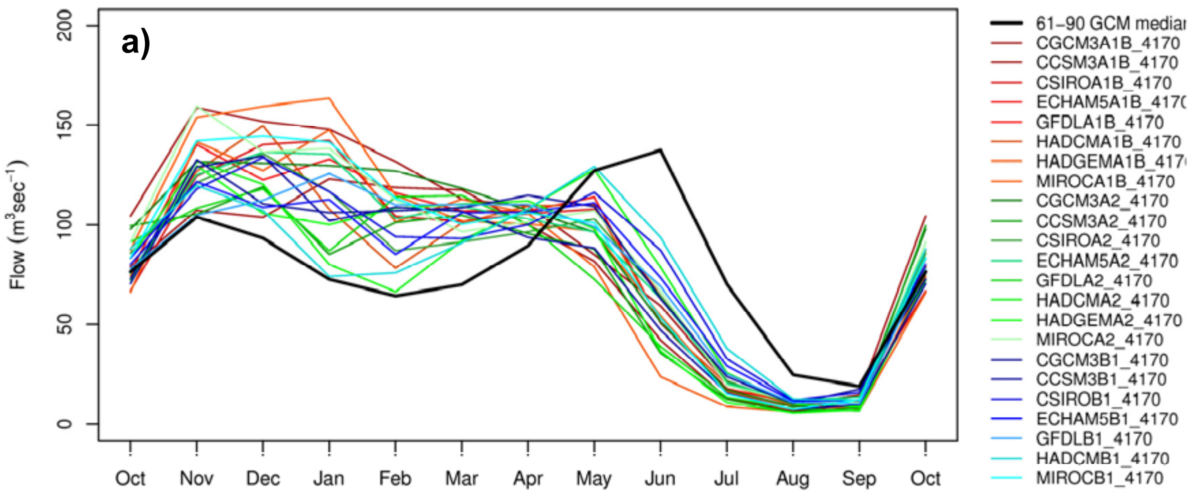

Figure 19 – Projected change in monthly average flow for Campbell River. Coloured lines indicate projections made by different models under different CO2 emissions scenarios while the black line represents median flow from 1961-90. The range of models is due to differences in internal model parameters as well as the uncertainty associated with future CO_2 emissions. Red and orange lines depict projections under the A1B scenario, Green lines use the A2 scenario, and Blue lines use the B1 scenario. From Schnorbus et al. 2010.

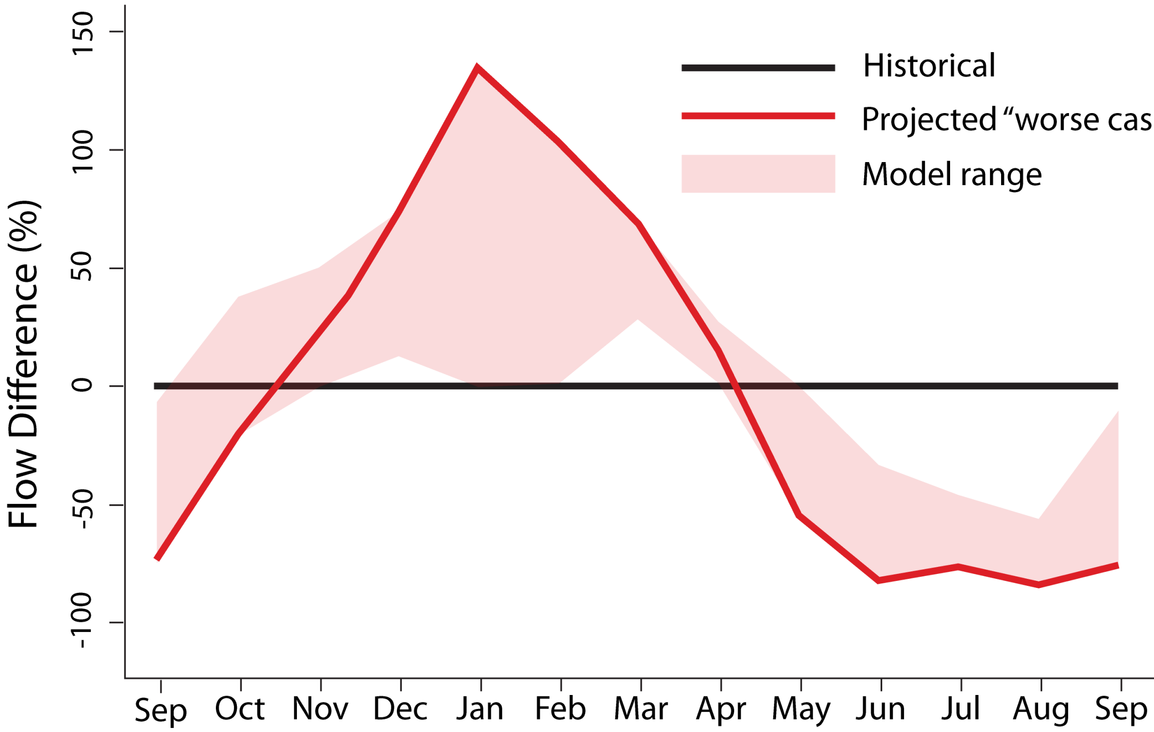

Figure 20 – Projected percent change in average monthly flow at Campbell River. The percent change from the historical average monthly streamflow is depicted here. Similar percent change can be expected for Theodosia River. The pink shaded area represents the range predicted by several models using 3 emmisions scenarios as seen in Figure 19. The red line represents the worst-case scenario of all models. Because this graph is based on average values calculated over 30 years, this worst case scenario is quite likely to be met or exceeded in many years, even under less extreme scenarios. Adapted from Schnorbus et al. 2010.

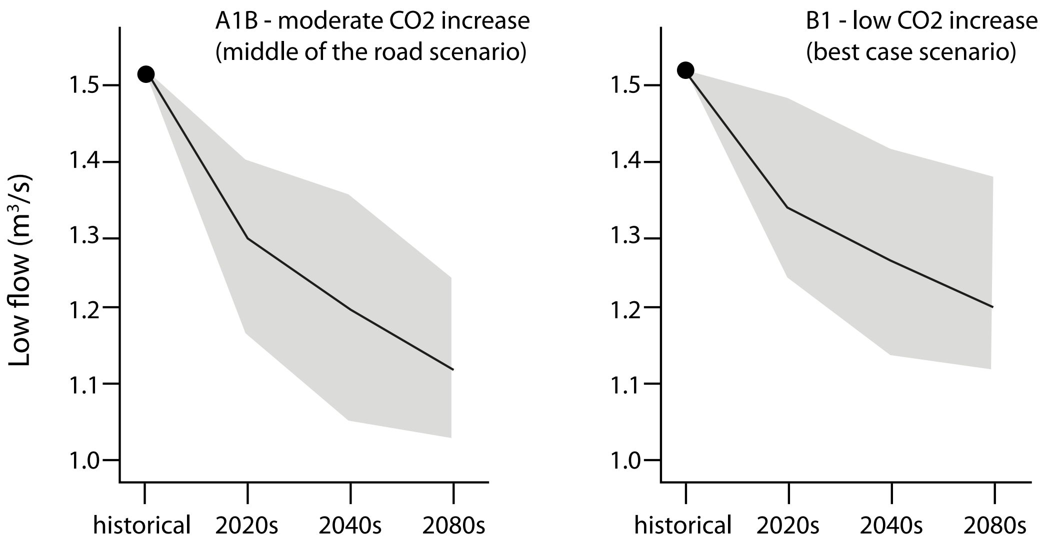

Figure 21 – Low flow projections for the Dungeness River. The magnitude of the 7-day average low flow with a recurrence interval of 10 years (7Q10) was modeled under low and moderate CO2 increase scenarios. The 7Q10 is a common way to measure extreme summer low flows. The black line shows the mean value obtained for different models while the grey area represents the range of models. Future estimates of the 7Q10 at the Dungeness River on the Olympic peninsula in Washington are decreased by as much as 30% by the 2080s. We should prepare for similar droughts at the Theodosia River. Adapted from CIG 2010.

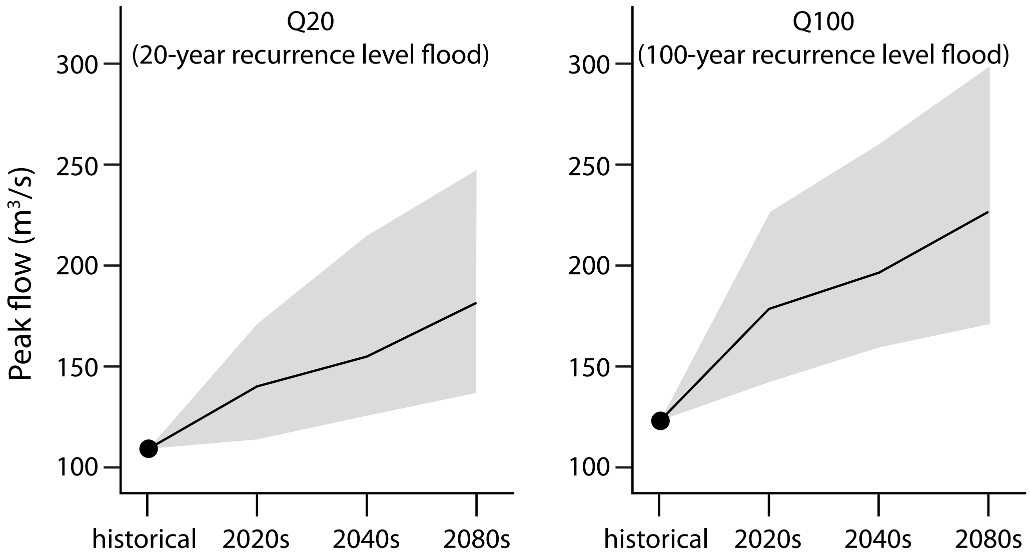

Figure 22 – Peak flow projections for the Dungeness River. The magnitude of the Q20 and Q100 peak flow events was modeled using a moderate (A1B) CO2 emissions scenario. Future projections illustrate that the magnitude and frequency of peak flows will increase dramatically. By the 2080s the magnitude of the 100-year event is predicted to be approximately double it's current magnitude. Furthermore, what has historically been referred to as a 100-year flood (i.e. 120 m3/s) is likely to occur far more frequently than every 20 years. Adapted from CIG 2010.

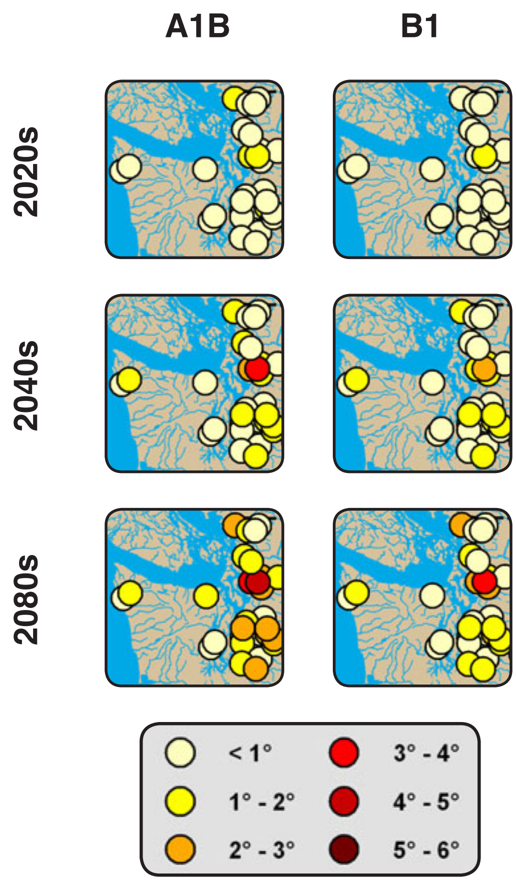

Figure 23 – Increase in the annual maximum of weekly average water temperature (^{o}C) relative to the 1980s for select locations in northwestern Washington. Top panels show projected change for the 2020s, middle panels show change for the 2040s and bottom panels for the 2080s. Composite A1B emissions scenarios are shown in the left column while composite B1 scenarios are on the right. Adapted from Mantua et al. 2010.

Chapter 5: Biophysical effects of climate change

In general, biological populations should have the capacity for responding to changes that fall within the bounds of historical natural disturbance regimes (Waples et al. 2008). Episodic disturbances such as floods may impact some or most areas of the stream network, although several factors will likely contribute to areas of habitat that may act as refugia for fish. Sustained effects of climate such as consistent low water levels or increased temperatures may also be patchy in their distribution and it is possible that present day populations may be able to adapt through phenological, phenotypic, or evolutionary responses. This means that they may be able to adapt to changes in timing of environmental events, they may be able to change morphological characteristics such as size in response to environmental cues, and/or they may adapt through genetic change over generations. However, if changes are too rapid, widespread or are exacerbated by non-climate-related human induced change populations may be less able to adapt and survive in the long term. As ecosystems reconfigure to changes in the environment it is reasonable to expect that certain species may benefit while others may suffer. The following chapter details possible climate related impacts to habitats and biological populations within the Theodosia River watershed.

5.1 Effects on stream habitat and salmonids

It is likely that the quantity and quality of habitat for salmon within the Theodosia River will be diminished with changes in climatic conditions over the next century. Mantua et al. (2010) suggest that "in the absence of rapid adaptation to changing habitat conditions, our assessment of future stream temperature and stream flow changes and historical limiting factors points to widespread declines in the quality and quantity of freshwater habitat for Washington's salmon and steelhead populations." Although future habitat conditions in Theodosia will likely be quite similar to current conditions in watersheds that support salmon populations elsewhere on the Pacific coast, the question remains whether Theodosia salmon will be able to adapt to a change in conditions at a fast enough rate. These fish will have to adapt to changes in peak flow magnitude and frequency, changes in low flow magnitudes, changes in streamflow timing and changes in temperature. Each of these impacts may affect different species of salmonids at different life cycle stages. The following sections detail expected effects to salmonids in the

Theodosia River system while Figure 24 summarizes these impacts for the two main salmon stocks, Chum and Coho.

5.1.1 Winter Peak flows

Predicted increases in the frequency and magnitude of peak flows will affect Theodosia salmonids and salmon habitat in several ways. Hybrid (rain and snow) watersheds such as Theodosia will experience substantial increases in flood magnitude compared to inland or low elevation, outer-coastal watersheds as winter storms that previously resulted in snowpack will result in intense rain and rain-on-snow events. This will result in increased intensity and frequency of redd scour and burial. Redd scour results in disruption of nests, crushing of embryos and release of eggs into the water column while burial of sediments may result in changing the quality of sediment and decreasing the supply of oxygen to incubating eggs. Thus, increased scour may result in decreased egg-to-fry survival rates for all salmonids present (Figure 24). However, impacts may vary across species and individuals because redd depth is a function of fish size (Mantua et al. 2010). For instance, large Theodosia Chum salmon are likely to dig deeper redds than Coho or other species in Theodosia and may therefore be less vulnerable to scouring and deposition of fine sediments. The effects of increased peak flows will also largely depend on the timing of floods and fry emergence.

Parr-to-smolt survival rates may also be reduced for Coho and Steelhead because increased winter peak flows will reduce the availability of slow-water habitat and may physically displace rearing juveniles downstream of preferred habitats (Mantua et al. 2010). These impacts may be reduced if juveniles are able to move to off-channel habitat that would not be available during normal flows. This may be the case within the lower Theodosia floodplain area, (where most Coho spawn), where small channels that become activated during peak flows may exist. However, species or individuals in more confined reaches may not have available refugia during such events.

The impacts of increased peak flows on egg scour, burial and sedimentation will also vary depending on the geomorphic location within the stream network. Wide unconfined reaches in the lower Theodosia (e.g. 0-3km upstream of the estuary) may experience less bedload movement and less scouring than reaches which are confined such as narrow valley reaches immediately below the waterfalls (4.2 to 7.5 km upstream of the estuary) or in the upper Theodosia. Thus, the primary spawning grounds of Chum and Coho are at less risk than salmonid residents (Cutthroat and Dolly Varden) or steelhead, which may spawn in narrower reaches. That is not to say that low gradient channels will not be impacted by bed load transport and redd disruption. We should expect increased scouring along most of the river. Furthermore, reaches downstream of junctions with tributaries (such as below Scotty Creek) may experience increased redd burial and scour as increased flows and sediment loads from hillslopes are transported into the main channel. Hillslope failures, landslides and debris torrents will also likely occur with increased frequency. Thus, any areas downstream of such occurrences may receive increased sediment loads which could result in increased redd burial and sedimentation.

Increased peak flows will decrease channel stability in general. During high magnitude peak flow events channel migration, bank erosion, bedload transport, and movement of large wood will alter fish habitat and the channel environment in general. This type of dynamism may result in both positive and negative effects on fish and fish habitat. In general, dynamic river environments result in diverse habitat and healthy riparian and aquatic populations. Healthy aquatic and riparian ecosystems require a certain disturbance regime to maintain the diversity of species, niches and habitats. However, climate change will result in definite but unknown changes in the disturbance regime and it is yet unclear how ecosystems will respond. Increased disturbance may negatively affect several species.

5.1.2 Spring, summer and fall flow reduction

The disappearance of springtime snowmelt could have a negative impact on the success of spring and early summer migrations of Chum fry to the Theodosia estuary. This population's seaward migration timing has evolved to match the timing of peak snowmelt flows, which will decrease in the coming decades and may no longer exist by the end of the century. Although it's unclear how/if lower spring flows will affect these fish it may result in an impact (Mantua et al. 2010). For example, it could be that freshwater inundation into the estuary results in increased food production that would be lost with the loss of the spring freshet. This sort of mismatch in timing could result in decreased fry/smolt growth rates and/or increased fry/smolt mortality rates.

Low flows during the summer and early fall are likely to impact Theodosia salmonids in two ways. First, reduced early-fall flow levels may reduce the availability of spawning habitat for the early run of Chum salmon. Shallow waters and increased stream temperature may force a later spawning entrance of this population or reduce available spawning habitat altogether. If this run is forced to wait in the Theodosia inlet for suitable flows they may be impacted by increased predation and exhaustion. Second, low flows combined with increased temperatures may result in the reduction of juvenile rearing habitat. Prolonged drought is likely to result in entire reaches drying up isolating populations in small, warm pools. This could result in decreased survival rates for Coho fry/parr and salmonids present during the summer.

It should be noted that interactions between changes in channel geomorphology and climate change effects are complex and may result in further unforeseen consequences. For example, channel widening caused by increased peak flows during the winter may exacerbate the effects of low flows as available water will be spread too thinly across the widened stream channel (Nelitz et al. 2007).

5.1.3 Temperature

Research has shown that the frequency of periods of stressful and possibly lethal temperatures may increase for many rivers along the BC and Washington coast (Quilty et al. 2005, Mantua et al. 2010). Most streams in western Washington are not forecasted to regularly increase in temperatures beyond lethal thresholds for fish by the end of this century (Mantua et al. 2010), however several low elevation streams and lake fed streams such as nearby Lang Creek may have the potential to periodically reach temperatures which are stressful or lethal to fish (Quilty et al. 2005). Upper thermal tolerances for common species in Theodosia are as follows: Chum salmon 19.8^{o}C; Coho salmon, 24^{o}C; cutthroat trout, 23.3^{o}C, steelhead, 24.0^{o}C; pink salmon, 21^{o}C (Mantua et al. 2010). Although Chum salmon are the most sensitive to warm temperatures, it is highly unlikely that Theodosia would reach lethal temperatures during the seasons (fall, winter, spring) during which Chum are present in the river. Coho and steelhead are the most likely to experience warm summer stream temperatures and these two species also have the highest thermal tolerance. Although it's possible that Theodosia could experience periods of temperatures above 24^{o}C in the next century, it is unlikely that the entire stream network would be at lethal temperatures. Rearing juveniles should be able to access thermal refugia at groundwater upwelling sites or tributary entrances if these habitats are readily accessable.

Winter stream temperatures may also increase, leading to earlier and possibly longer growing seasons, increased aquatic food-web productivity, and more rapid juvenile salmon growth and development rates (Schindler and Rogers 2009). This may result in earlier hatch times for all species, but also earlier seaward migration for Chum fry and increased growth rates resulting in possibly earlier seaward migration for Coho juveniles.

Warmer stream temperatures due to logging resulted in several effects on Coho salmon at Carnation Creek on the west coast Vancouver Island (Holtby 1988). 40% of this 10 km^2 watershed was logged over a six year period resulting in substantial stream warming (0.7^oC in December and 3^oC in August) likely due to a decrease in riparian shading. Warmer stream temperatures contributed to increased growth rates in juvenile Coho salmon, accelerations in the freshwater component of Coho life cycle, and an increase in overwinter survival rates for rearing juveniles. However, this resulted in earlier seaward smolt migrations which in turn resulted in reduced marine survival rates. Smolt migration timing may have been mismatched to the optimal season for ocean prey and/or predator interactions. As this example shows, the effects of warmer winter temperatures on salmon are complex. Furthermore, if warmer temperatures result in earlier fry emergence they may be either positively or negatively impacted by winter peak flows depending on their location and depending on the year. That is, an earlier emergence may make fry more prone to displacement by winter peak flows or it may result in fewer instances of egg scouring and sedimentation.

5.1.4 Salmonids discussion

In the Theodosia watershed, predicted increases in peak flows are likely to be more detrimental than changes in temperature for Chum and possibly for Coho salmon as well. Wenger et al. (2011) found that temperature increase associated with climate change was a weaker driver of loss of suitable habitat for certain fall spawning species of trout when compared to the effects of increased winter peak flow events. However, spring spawning rainbow trout and cutthroat trout were more affected by temperature (Wenger et al. 2011). In the context of Theodosia, increased temperatures and low summer stream flow are not likely to have a detrimental effect on Chum salmon populations, except for possibly delaying spawning in the early fall, whereas Coho salmon will be affected by both temperature and flow regime effects. That said, the actual mechanisms for temperature-driven population collapse are complex, involving growth rates, incubation times, competitive ability relative to other species, and asynchrony with prey, which can cause negative population growth rates even if temperatures never reach the lethal range for individuals (McCullough et al. 2009).

Life history attributes of Chum salmon may give this species an advantage, in terms of climate change effects, compared to Coho salmon. Chum salmon are less likely to experience direct impacts of increased temperatures. Furthermore, the redds of Chum salmon are likely to be deeper than those of Coho; thus, they may be less prone to increased flood induced egg scour. However, environmental change is complex, and several unforeseen complex interactions are likely to impact populations in unknown ways. Thus it is important to adopt an adaptive management framework that regularly monitors and reassesses management of water and land resources. It is also important that non-climate related anthropogenic change is managed in order to prevent cumulative and compounded impacts by many sources.

5.2 Forests

The effects of climate change on trees and forest populations are many and complex. Most tree species will be affected by a changing climate in some way although effects may range from decreased or even increased growth rates to total species dieback. Climate change may also trigger indirect and complex interactions that result in insect outbreaks, more frequent forest disturbances, or weather events such as drought that predispose trees to parasites or diseases.

5.2.1 Temperature effects

Warmer summer and winter temperatures will have both positive and negative effects on trees, depending on the species. Temperature increases could increase growth rates and could open up new territories for certain species. Tree species with their northern range limit in British Columbia could have the potential to increase their habitat range at a pace of about 100 km per decade (Hamann and Wang 2006). In contrast, species that are on the edge of their local range may become increasingly mismatched to future climatic conditions. In the context of Theodosia this may result in a shift in forest composition towards drier adapted species. Most of Theodosia watershed is classified as *coastal western hemlock dry maritime biogeoclimatic zone*, however the forest transitions to the *coastal western hemlock very dry maritime zone* near the entrance to Theodosia Inlet and further towards Georgia Strait the forest is classified as the even dryer *coastal Douglas fir zone*. This indicates that the lower Theodosia watershed may be the beginning of a transitional zone towards dryer conditions. Warmer summer temperatures in the future would increasingly favor species that are adapted to drier conditions resulting in dryer ecosystems pushing further into the Theodosia watershed over time. Specifically, growth rates of wet adapted species such as western redcedar and sitka spruce may decrease and individuals in marginal habitats will experience summer drought and become more susceptible to disease. Conversely, dry adapted species such as Douglas-fir may become more successful in the area. However, it is extremely difficult to predict exactly how communities will respond at the local scale because microhabitat characteristics, such as wet riparian zones, will allow many species to persist during warmer, drier summers. In general, drier conditions will prevail during the summer and wetter and warmer conditions during the winter resulting in increases or decreases in growth rates and increased competitive advantage of certain species. Table 3 illustrates possible shifts in species assemblages in different zones within the watershed although this should be taken as a best guess approximation.

It is unlikely that entire populations will die off within Theodosia, however complex interactions that result in widespread declines may be possible. For example, in several areas of coastal BC widespread yellow-cedar die-offs have been occurring in recent decades due to climate change (Daniels et al. 2011). Warmer winters in recent years have resulted in diminished snowpack during the spring. Snow is a very good insulator, and without this blanket of snow to protect their roots, cold snaps in the spring that damage yellow-cedar roots have resulted in entire stands of yellow-cedar being killed (Daniels et al. 2011). Yellow-cedar at high elevations in the Theodosia are vulnerable to this sort of event and it is likely that mortality rates of this species will rise in the coming decades in certain microclimates within the watershed.

5.2.2 Insects and disease

Some of the greatest effects of climate change may be related to insect and disease outbreaks. It is possible that insects and diseases may adapt more quickly and have a greater ability to spread than long-lived tree species (Spittlehouse 2008). For example, the current mountain pine beetle epidemic across BC is partially caused by a warming of winter temperatures that allow beetle populations to flourish (Hamann and Wang 2006). This epidemic will not affect forests in the Theodosia region however it provides an example of possible unknown effects of climate change.

In the Theodosia watershed severe summer drought may predispose some tree species to disease or pests. Outbreaks of insects or disease represent a severe effect of climate change in Theodosia although the likelihood of such outbreaks occurring is extremely difficult to predict.

5.2.3 Wind, fire and flood disturbance

Climate change will result in increased rates of several types of disturbance events. Warmer and drier summers will likely increase fire risk while more frequent and severe winter storms will increase windthrow events, increase the frequency of flood disturbance in floodplain forests and of landslides and debris flows on hillslopes. These types of disturbance could have the potential to impact large areas within the watershed and may facilitate the transition to species that are better adapted to future climate conditions.

5.3 Infrastructure

The main climate change impacts on infrastructure will likely be due to the increased frequency and magnitude of winter storms. More frequent large flood events will affect roads, future settlements, and the Olsen lake diversion.

5.3.1 Forest roads

Forest road culverts have generally been sized based on an approximation of the 100-year flood event. This approximation tends to underestimate the size of the 100-year flood because it assumes the 100-year event is 3 times larger than the 2-year flood, which may not always be true (Beckers et al. 2002). Furthermore, in the next decades it is likely that the 100-year flood will increase in magnitude dramatically (i.e. double in magnitude by the end of the century). Therefore, the capacity of many culverts may be too small to deal with future floods, resulting in culverts being plugged more frequently, which will lead to more frequent debris flows and landslides. Fill-slope failures that trigger landslides will also likely increase with the increase in heavy rain events. More landslides will result in forest disturbance, increased sediment supply to channels and possible unsafe living conditions or property damage in future settlements.

During heavy rain events the road network often functions as an extension of the channel network whereby large volumes of water run down roadways and ditches eventually reaching the main river channel. This results in increased channel response time, increased flood magnitudes and increased sediment loads within the channel. With more frequent large storms this response will happen more often on forest roads that have not been fully deactivated and this may result in larger floods in the lower Theodosia which will impact fish habitat as outlined in the previous section.

Forest roads adjacent to streams may become increasingly susceptible to wash outs in the future. Similarly, bridge foundations may experience higher levels of erosion and scour and low bridges will be more susceptible to destruction during times of extremely high flows.

5.3.2 Olsen Lake diversion

Sediment build-up rates at the Olsen Lake diversion will increase in the future. With larger and more frequent flood events more sediment will be transported from the upper Theodosia watershed and deposited in the area immediately upstream of the diversion. This will result in increased costs required to dredge sediment and to maintain the diversion. Furthermore, if the increase in bedload sediment is not dealt with regularly the chance of a right bank avulsion will increase. This would result in the channel bypassing the diversion completely and could have negative impacts in the coming decades as the current pile-up of sediment is transported into the lower Theodosia, eventually resulting in channel aggradation (sediment build-up) in areas of salmon habitat. This channel aggradation could result in destruction of spawning habitat and could increase the potential for channels to dry up during the summer months.

5.3.3 Future settlements

Future settlement on the lower Theodosia floodplain will be subject to increased risk of flooding resulting in unsafe living conditions and property damage. Increased frequencies of peak flows (floods) will result in overbank flow and an increase in channel migration that would bring unsafe channels closer to houses. Flood events can be extremely destructive due to the erosive power of water, logs and sediment that is immobilized during such events. Furthermore, settlements near tributary streams or the “alluvial fans” (zones where sediment has historically been deposited) of such streams will be very vulnerable to debris flow events in the future. These events are very destructive as was seen in the 1995 event that affected settlements in Indian Reserve Number 4. Furthermore, sea level rise and increased storm surge will pose a risk for any settlements situated near sea level.

Summary: Biophysical impacts of climate change

Table 1 – Summary of climate change impacts to stream habitats and salmonids in Theodosia River. Probability and consequence ranking should be taken as a "best guess" as future outcomes are highly uncertain.

STREAM HABITAT AND SALMONIDS				
CLIMATE CHANGE IMPACT	BIOPHYSICAL IMPACT	SPECIES	PROBABILITY	CONSEQUENCE
Increased frequency / magnitude of floods	Increased egg scour and burial – Lower egg-to-fry survival	Coho and Chum	HIGH	SEVERE
Decreased summer low flows	Decrease in available habitat – Lower fry-to-smolt survival	Coho and Steelhead	HIGH	UNKNOWN
Increased summer temperature	Thermal stress – Lower fry-to-smolt survival	Coho	MEDIUM	UNKNOWN
Decreased late summer / early fall flow volume and wetted area	Reduced spawning habitat – Lower successful spawning	Early run Chum	HIGH	UNKNOWN
Increased winter temperature	Faster incubation period, increased growth rate, and life cycle	All species	HIGH	UNKNOWN
Change in timing of seaward migration	Change in food availability Mismatch in predator/prey interaction	Chum and Coho fry	UNKNOWN	SEVERE
Increased frequency / magnitude of floods	Increased channel migration, degradation and aggradation. (General channel instability)	Stream habitat	HIGH	UNKNOWN
Increased frequency / magnitude of floods	Lack of habitat during peak flows	Coho fry/parr	HIGH	UNKNOWN

Table 2 – Summary of climate change impacts to forests and individual tree species in the Theodosia watershed. Probability and consequence ranking should be taken as a "best guess" as future outcomes are highly uncertain.

FORESTS				
CLIMATE CHANGE IMPACT	BIOPHYSICAL IMPACT	SPECIES	PROBABILITY	CONSEQUENCE
Summer drought	Decreased growth rates	Western redcedar and others	HIGH	LOW
Summer drought	Competitive advantage	Douglas fir	HIGH	LOW
Increased temperature	Increased growth rates during wet times	All	HIGH	NONE
Increased temperature	Drought stress may result in trees being more susceptible to insects and diseases	All	UNKNOWN	HIGH
Lack of snowpack followed by cold-snap	Root damage and tree death	Yellow-cedar	UNKNOWN	HIGH
Summer drought	Increased possibility of forest fires	All	HIGH	UNKNOWN
Increased storm magnitude and frequency	Increased landslides and channel migration events resulting in greater disturbance	All	HIGH	MEDIUM

Table 3 – Potential changes in dominant and associated species in the Theodosia watershed. Expected increases or decreases in success of species are indicated by (+) or (-) respectively. Potential dominant species in 2100 are based on Halofsky et al. 2011 and current knowledge of biogeoclimatic zones in Theodosia. This table should be taken as a "best guess" as potential changes in dominance are highly uncertain. Change in dominance is based on the assumption that the next century will be hotter, with increasing summer drought stress, and that disturbance frequency will increase to facilitate species transition. If species dispersal or transition is a limiting factor it can be expected that species dominance will not change as rapidly as laid out in this table.

Current vegetation zone	**Current dominant species**	**Current associated species**	**Potential dominant species in 2100**
Coastal western hemlock dry maritime	western hemlock (-), Douglas-fir (+), western redcedar (-)	Sitka spruce (-), red alder (+), bigleaf maple (-)	Douglas-fir, red alder
Coastal western hemlock very wet maritime	western hemlock (?), western redcedar (+), amabilis fir (-)	amabilis fir (?), yellow-cedar (+), Douglas-fir (+)	western hemlock, western redcedar, Douglas-fir
Mountain hemlock moist maritime	mountain hemlock (-), yellow-cedar (?)	western hemlock (+), amabilis fir (+), subalpine fir (+)	western hemlock, amabilis fir

Table 4 – Summary of climate change impacts to current and future infrastructure in the Theodosia watershed. Probability and consequence ranking should be taken as a "best guess" as future outcomes are highly uncertain.

INFRASTRUCTURE: FORESTRY ROADS, DIVERSION AND FUTURE SETTLEMENT				
CLIMATE CHANGE IMPACT	PHYSICAL IMPACT	WHAT	PROBABILITY	CONSEQUENCE
Increased storm magnitude and frequency	Culvert capacity too small for floods resulting in plugged culverts which would trigger debris flows and landslides	Forest road Culverts	HIGH	HIGH
Increased storm magnitude and frequency	Increased fill slope failure leading to landslides could impact future settlements	Forest roads	HIGH	UNKNOWN
Increased storm magnitude and frequency	Forest roads become an extension of the channel network during rain events resulting in increased channel response, larger flood magnitudes and increased river sediment load	Forest roads and channel	HIGH	MEDIUM
Increased storm magnitude and frequency	Roads adjacent to streams may be washed out	Stream-adjacent roads	UNKNOWN	UNKNOWN
Increased storm magnitude and frequency	Bridge foundation erosion or wash-outs	Bridges	UNKNOWN	HIGH
Increased storm magnitude and frequency	Increased sedimentation at the Olsen Lake diversion and increased possibility of channel avulsion	Olsen Lake diversion	HIGH	UNKNOWN
Increased storm magnitude and frequency	Increased frequency and magnitude of overbank flows on the lower Theodosia could flood future settlements	Future settlements	HIGH	SEVERE
Increased storm magnitude and frequency	Increased potential for debris flow events on tributary streams could affect future settlements near such streams or alluvial fans	Future settlements	HIGH	SEVERE
Sea level rise	Flooding and increase in storm surge in low elevation areas.	Future settlements	HIGH	SEVERE

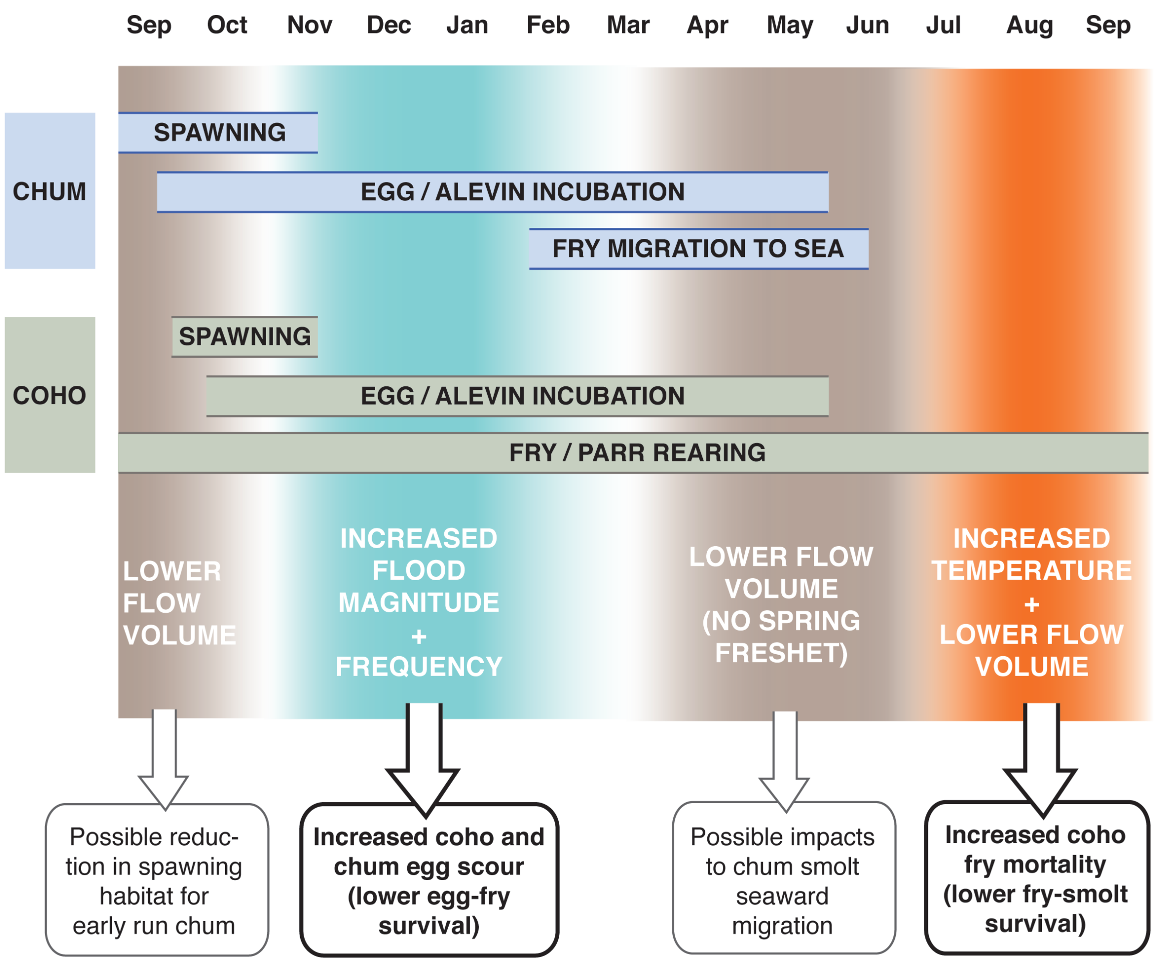

Figure 24 – Diagram of predicted climate change impacts to stream hydrology and expected effects on life stages of Chum and Coho salmon. Chum and Coho salmon life cycle stages are overlaid on a calendar with expected impacts to the Theodosia watershed. Impacts are colour coded and described in white. The effects of these impacts on different life history stages are reported below. Effects in bold are less uncertain and likely more detrimental than those in regular type.

Chapter 6: Climate change adaptation and watershed management strategies

In order to mitigate the effects of climate change on salmonids, stream ecosystems and forest ecosystems in general, a management approach that seeks to maintain, restore and add to the resilience of these ecosystems is necessary. Many management options may require trade-offs with other land and water uses. Nevertheless, in order to mitigate future climate change impacts to salmonid populations, existing impairments to stream habitats and hydrological processes caused by land and water use, actions must be recognized and appropriate management actions taken. Specific watershed processes must be identified and managed appropriately.

"Our bottom line is that sustainable salmon fisheries cannot be engineered with technological fixes and prediction programs, but that climate insurance for Pacific Northwest salmon can be enhanced by restoring and maintaining healthy, complex, and connected freshwater and estuarine habitat and ensuring adequate spawner escapements." (Mantua et al. 2004)

6.1 General management approaches

Develop a seasonal water use plan. Current water diversion rates should be re-evaluated and management actions taken in response to future decreases in summer low flows, increases in winter peak flows and decreased spring runoff. The diversion to Olsen Lake has the potential to provide an opportunity to mitigate climate change impacts to the lower Theodosia River if it is managed under a planning framework that considers the ecological integrity of the river. Specifically, it is recommended that during the summer, diversion away from Theodosia should be as minimal as possible while during the winter the diversion should increase extraction during times of flood events. A preliminary analysis that compares historical rates of diversion to Olsen Lake with recommended instream flows that will not cause *Harmful Alteration Disruption or Destruction* (HADD) of fish habitat is available in Appendix A. Flow requirements for spawning Chum salmon in the lower Theodosia River are also presented in a draft publication by DFO (2011) and a summer low flow assessment was undertaken by KWL (2011). Management planning should draw from the recommendations outlined in these reports.

Develop a coordinated harvesting plan. Several forestry companies operate in the Theodosia watershed and although some of these companies have a sustainability plan in place, without coordinating harvesting plans with other operators in the watershed, sustainable harvest rates are unlikely to be achieved at the watershed scale. Harvesting goals for the entire watershed should be discussed among forest operators and the Theodosia Stewardship Roundtable in order to ensure staggered harvesting. Staggered harvesting that follows guidelines of an annual rate of harvest for the entire watershed will mitigate hydrologic impacts of forest harvest such as increased water yield, increased peak flows, decreased water storage, increased flashiness, and increased slope failures. If large percentages of the Theodosia watershed are harvested over short time periods, the impacts on channel stability and fish habitat could be highly detrimental reducing the resilience of ecosystems in the face of climate change.

6.2 Adaptation strategies to manage for increased fall and winter peak flows

Olsen Lake diversion

- As mentioned above, a winter water use plan for the Olsen Lake diversion should discussed and future diversion infrastructure should reflect this plan. Streamflow should be managed with goals to maintain a healthy hydrologic disturbance regime within the lower Theodosia while mitigating against extreme peak flows. A system whereby excess water is diverted to Olsen Lake during peak flows while Theodosia is supplied with more water during regular flows would help mitigate climate change impacts. See appendix A for more details.
- Within the next 20 years the increased severity of winter storms will result in substantial maintenance costs for Brookfield Renewable Energy at the diversion as rates of sediment deposition increase in the coming years. Option 4 in the Northwest Hydraulics (2000) study provides a plan for constricting the diversion channel and allowing for more flow to reach the lower Theodosia without negatively impacting the river morphology in the future. This option should be discussed between the Theodosia Stewardship Roundtable and Brookfield as a way forward that could help mitigate some of the effects of climate change and result in lowered maintenance costs for Brookfield.

Cataloging, protection and restoration of off-channel habitat

- Infrastructure and management strategies to reduce the impact of extremely high flow events in the fall and winter should include the protection and restoration of off-channel habitat in floodplains. Current off channel habitats where fish can find refuge from high-energy flows should be identified and catalogued in a GIS in order to assess the merits of future restoration work that may provide such habitat. As well, cataloging these habitats may be beneficial in future harvest planning with sustainable forest operators. That is, harvesting should be avoided near any off channel habitat areas.
- If, after identifying the availability of off channel habitat, it is found that this habitat type is limited, construction of off-channel habitat could be a useful option.

Retention of forest cover

- Forest harvesting has been shown to increase peak flows as well as flow variability (Alila et al. 2009, Little et al. in review.) As mentioned above, a forest harvest plan coordinated between all forest operators should be put in place in order to limit harvest rates to a level of acceptable risk. This level should be discussed and negotiated among stakeholders, hydrologists, and the Theodosia Stewardship Roundtable.

Riparian forest restoration (bank stability and large wood inputs)

- Long term channel structure and fish habitat creation and retention relies on a steady input of large diameter conifers and existence of large diameter live trees at stream banks. Increased peak flow magnitudes and frequencies would result in channel widening and conversion of young deciduous forest to channel area whereas mature riparian forests have the potential to decrease the rate of these processes (Little 2011). This could have impacts on fish habitat including exacerbation of low flow problems as too little water is spread out over too much area. Past logging within the Theodosia floodplain area has reduced the abundance of suitable materials for key pieces of log jams and has increased the ratio of young deciduous forests to mature coniferous forests. Forests within the floodplain area should be evaluated and a forest management prescription should be undertaken to increase the rate of recovery of suitable conifers such as Sitka spruce and western redcedar.

- Sitka spruce and western redcedar may experience drought on dry sites far away from the river channel. Floodplain restoration more than 2 meters above the channel thalweg should focus on planting of species such as Douglas-fir that can withstand future summer drought. Two to two and a half meters is a preliminary best-guess at the elevation of terraces that are not frequently inundated during flood events. Future restoration projects should assess this threshold in the field.

6.3 Adaptation strategies to manage for decreased summer low flows and increased summer stream temperature

Olsen Lake diversion

- A summer / early fall water use plan for the Olsen Lake diversion that would manage streamflow with goals to limit water use during the summer low flow season should be discussed among stakeholders. This option may require trade-offs between economic gain of hydropower and ecological integrity of the lower Theodosia River. Based on the instream flow requirements calculated in Appendix A, it is recommended that diversion of water to Olsen Lake during the critical low flow summer season (July, August, September) should be decreased. It is recommended that the current 1 m^3/s minimum instream flow should be increased to 4-6 m^3/s (Appendix A).
- Other studies have recommended that optimal flows for Chum salmon spawning needs are approximately 7 m^3/s in the lower Theodosia (DFO 2011). Further study is necessary to correlate optimal flow levels with upstream diversion rates for management purposes.
- Connecting Olsen Lake to Theodosia could also be discussed as an option to augment flows during times of drought. However, if this options is explored it should be noted that flows from a reservoir or from Olsen Lake could result in increased temperatures during the hottest times of the year due to heating of unshaded standing water (Quilty et al. 2005). This could result in detrimental consequences to fish in the lower Theodosia. Water temperature in Olsen Lake should be monitored prior to implementing a plan to divert water from the lake to the Theodosia River. Preliminary studies by the BC

Conservation Foundation have indicated that this option may not be viable due to the insufficient size of Olsen Lake to act as a reservoir.

Thermal refugia management and construction

- Thermal refugia provided by groundwater and tributary inflow, undercut banks, and deep stratified pools should be identified, catalogued and protected. After cataloging available refugia it should be assessed whether additional thermal refugia should be constructed. It may be possible to construct groundwater fed ponds that could function as an area of thermal and low flow refuge during the summer and also function as refugia from high energy winter floods during. Another approach may be to focus restoration efforts on enhancing/increasing the capacity of current refugia/off channel habitat that utilize cold water inputs such as groundwater upwelling sources and tributary junctions.

Riparian forest management and restoration (shading)

- Restoring vegetation in riparian areas would help provide shade that would prevent dramatic stream temperature increases. Restoration plans for shading should be complementary with above plans to provide stream bank stability and future large wood inputs.

Upper watershed reconnection

- Possibility for fish passage to higher reaches to increase available spawning habitat and provide access to thermal refugia could be considered. Oral history suggests that salmon may have accessed the area above the falls in the past. However, this option is not highly recommended due to costs and because spawning habitat further upstream in constrained reaches would be more vulnerable to intense winter floods resulting in increased egg scour.

6.4 General adaptation strategies

Fish stocking

- A salmon enhancement program may increase fish stocks and mitigate against decreased freshwater and marine survival. If an on ongoing program was not financially feasable, periodic fish stocking after years of high magnitude flood events that reduce egg-to-fry survival rates may be an effective option. It is likely that Chum may be more resilient than Coho in this system so resources could go toward Chum stocks. However, an adaptive management approach in conjunction with fish monitoring is recommended to assess whether the target species is responding or if the target species is "the right one". Management actions that are robust to multiple future scenarios should be selected, (i.e. use a no regrets, "don't put all your eggs in one basket" type of approach).

Stream nutrient addition

- Fertilizing streams using salmon carcasses or other sources of nutrients could help increase the overall productivity of the system and increase the river's capacity to support more juvenile fish. This would mitigate against decreased freshwater or marine survival.

6.5 Forestry related adaptation strategies

Maintain, restore, or relocate roads and culverts to increase slope stability

- Expect that there will be some road and culvert failures. It is anticipated that without proactive action to reduce risk, the failure rate will increase in response to climate change.
- Culverts should be sized to accommodate flows considerably larger than historical Q100 flows in order to reduce plugging during future events. By 2080, the magnitude of the Q100 is expected to be twice as large as the historical Q100. Size culverts accordingly.
- Existing culverts should be assessed given knowledge of future storm scenarios and adapted if necessary. A GIS catalogue of existing culverts could be maintained to aid in identifying high-risk situations. Although this may be an added expense to forestry companies it may reduce long term remediation expenses if/when slides occur.

- Use "What if it fails?" scenarios to address risk when evaluating road management and culvert sizing alternatives. Options that will result in higher risk of failure or those that will result in the most severe impacts (near to future settlements) should be avoided.
- Un-used roads should be deactivated as soon as possible and sufficient drainage should be constructed.
- Areas prone to slope failures should be identified in the field and actions taken to reduce future slides and debris torrents.

Reforestation

- The climate will continue to change over the life of the stand and forest managers must decide which climate regime the planting stock should be selected to meet. Reforestation using genotypes from areas of dry summers (such as the Coastal Douglas-fir biogeoclimatic zone) may be prudent in order to maintain productive forests.
- The BC Ministry of Forests is conducting ongoing research looking at assisted genotype migration for forest trees in BC called the Assisted Migration and Transfer Trial (AMAT). Forest managers should keep up to date with this research and future publications available at http://www.for.gov.bc.ca/hre/forgen/interior/AMAT.htm

6.6 Future settlement strategies

Avoid flood zones

- Future settlements on the lower Theodosia floodplain area should be located on upper terrace areas far away from current river channels. Houses could be designed on stilts to avoid property damage. The higher above the contemporary river channel the better. A survey using a design flood of twice the magnitude of the Q100 should be done in order to delineate ground that would be flooded during an event of this magnitude.

Avoid debris flow and landslide zones

- Houses should not be located near tributary streams or on alluvial fans. These areas should be avoided as much as possible. Furthermore, areas below steep slopes, especially those with forest roads, should be avoided. Prior to locating settlements a professional geoscientist should be employed to delineate areas that have historically experienced debris flows and those that may be prone to future landslides and debris flow events.

Prepare for sea level rise

- Sea level is expected to rise by approximately one meter in the next century. Areas near sea level should be avoided and a professional geoscientist should assess the risk for storm surge in any future settlement sites.

6.5 Steps to move forward

Action items:

1. Maintain Theodosia Stewardship Roundtable in order to foster relationships of trust between all watershed stakeholders and to develop collaborative decision making protocols.
2. Work with Brookfield to develop goals for the diversion. Continue to develop science-based recommended fisheries flows (Appendix A, DFO 2011, KWL 2011) and work to cooperatively explore the possibility of providing these flows.
3. Involve private forest harvesting companies and the BC Ministry of Forests to facilitate the development of a watershed scale sustainable harvesting plan. Included in this plan would be acceptable limits to harvesting (% of watershed per year), new protocols for culverts and roads, and best management practices of limiting harvesting along the riparian corridor.
4. Continue yearly monitoring of fish stocks and begin constructing a GIS catalogue of spawning habitat, off channel habitat and thermal refugia. This information is vital in order to plan effective river restoration and make informed decisions regarding salmon stock management and enhancement.
5. Monitor existing logging and road drainage/slope stability.

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Appendix A: Instream flow assessment for water diversion to Olsen Lake

A.1 Introduction to instream flows

A preliminary instream flow assessment was undertaken to determine recommended levels of diversion from the upper Theodosia River and to compare historical levels of diversion to recommended guidelines. Guidelines for instream flow requirements have been set to ensure that *Harmful Alteration, Disruption or Destruction of Fish Habitat (HADD)* due to water extraction is avoided (Hatfield et al. 2003). A HADD is any change in fish habitat that reduces its capacity to support one or more life processes of fish. This includes: 1) harmful alteration, an indefinite reduction in capacity while maintaining some of the habitat; 2) disruption, a short term reduction in capacity; and 3) destruction, permanent loss of capacity (Hatfield et al. 2003).

Projects that have the potential to cause a HADD include those that change hydrology, hydraulics or geomorphology of a waterbody. Damage to fish habitat is legal if authorized by regulation or by the Minister. The decision to authorize a HADD is made through a decision framework that identifies the information needed to answer a series of questions that clearly link to a decision on whether a section 35(2) authorization can be granted (Hatfield et al. 2003). In the case of the Theodosia River diversion to Olsen Lake it is unclear how the decision to authorize a potential HADD was made and it is recommended that a full assessment be made to limit HADD while providing water for hydroelectricity use.

The calculations of flow thresholds below are provided as a basis for a conversation between stakeholders regarding the re-assessment of the 1 m^3/s minimum instream flow threshold and 56 m^3/s maximum diversion rate currently in place for the Olsen Lake diversion. Further study and negotiation between stakeholders is recommended in order to develop instream flow thresholds that ensure a balance between effective fisheries resource protection and hydroelectric water use. The expected changes to the hydrologic regime due to climate change require a fresh look at water use in the Theodosia.

A.2 Determining instream flow thresholds

Several methods for determining instream flow needs for fish have been developed. This report uses the most recent guidelines for fish bearing streams in British Columbia to calculate thresholds for water diversion (Hatfield et al. 2003.) These guidelines were developed for the British Columbia Ministry of Sustainable Resource Management and British Columbia Ministry of Water, Land, and Air Protection. The flow thresholds calculated using these guidelines are based on the general concept that risk for fish increases as water diversion increases, but that a balance between effective fisheries resource protection and water use development is achievable (Hatfield et al. 2003).

An out-of-date method (BC modified Tennant flow criteria) that had been used in the past by BC Fisheries branch was also calculated as a comparison. This method has been widely criticized due mainly to two factors: the method relies on extensive use of professional opinion and there is a lack of biological validation for flows calculated. The criteria and rationale of this method have been subjected to peer review and have performed poorly. Nevertheless, as this method has been widely used in the past it has been included here as a basis of comparison.

The period of record available to calculate instream flows on the Theodosia River at the Olsen Lake diversion is only 11 years (2000-2010) which is shorter than the minimum 20 year record suggested by Hatfield et al. 2003. Therefore, guidelines calculated are likely accurate only to within 20%. Table 5 shows key statistics used for determining instream flows.

A.3 Instream flows for the Theodosia River at the Olsen Lake diversion

Calculations indicate that both methods used in this study recommend minimum instream flows greater than the current 1 m^3/s minimum flow at all times of the year. Minimum flows suggested by the most current guidelines set out by Hatfield et al. (2003) range from 4.6 to 6.3 m^3/s (Table 6, Figures 25, 26, 27). Over the 11-year period of record the actual total flow diverted was 62% of the total available flow from the upper Theodosia River, while the recommended total diversion under this framework would have been 27%. The maximum recommended rate of diversion was calculated to be 9.9 m^3/s – substantially less than the current 56 m^3/s maximum.

The BC modified Tennant method was also used as a basis of comparison. The minimum instream flow ranged from 1.4 m^3/s during summer and winter rearing times to 5.4 m^3/s during spawning times (Table 7).

A.4 Instream flows and climate change

The above instream flow guidelines are to be used as a coarse level filter or a starting point to develop appropriate rates of diversion that balance hydroelectric water use with ecological stewardship. The Olsen Lake diversion has the potential to mitigate some of the hydrologic effects of climate change if water use is managed effectively.

Based on this preliminary investigation it is recommended that year round minimum instream flows should be maintained at in the range of 4-6 m^3/s. During the summer low flow period flows are generally less than this level and so it is recommended that no water extraction take place when this is the case. Lower summer streamflow due climate change represents a significant threat to fisheries in Theodosia, and higher instream flow requirements may help mitigate some of these effects. Increased frequency and magnitude of winter floods warrants an increase in the 9.9 m^3/s maximum recommended diversion rate. This maximum rate of diversion was developed such that large floods which maintain the geomorphology of the channel will be preserved. However, if these floods increase in size and frequency of occurrence it would be prudent that a greater amount of flow is diverted away from the lower Theodosia in order to prevent excessive scouring and burial of spawning habitat.

It is recommended that further studies build off of this work to develop instream flow thresholds that ensure a balance between effective fisheries resource protection and hydroelectric water use. The presence of the Olsen Lake diversion in the Theodosia watershed provides a unique opportunity to mitigate effects of climate change on the hydrologic regime if managed effectively.

Table 5 - Key statistics for the Theodosia River above the Olsen Lake diversion. Statistics are based on only 11 years of data (2000-2010) and therefore may be considered accurate to +/- 20%.

Statistic	Flow (cms)	Flow (%MAD)
MAD	7.2	100%
Median	4.5	63%
Min daily	0.1	2%
Max daily	160.8	2248%
10th %tile	1.0	13%
20th %tile	1.6	22%
80th %tile	9.9	138%
Freshet Median (April-June)	7.7	107%
CPSF Median (Aug-Sept)	1.3	18%

Table 6 - Recommended flow thresholds for the Theodosia River at the Olsen Lake diversion (Hatfield et al. 2003). Thresholds are based on only 11 years of data (2000-2010) and therefore may be considered accurate to +/- 20%.

Month	Median flow (cms)	Minimum flow threshold (%tile)	Minimum flow threshold (cms)	Maximum threshold (cms)
Jan	4.9	56	5.6	15.5
Feb	3.0	73	4.1	14.0
Mar	3.7	67	5.0	14.9
Apr	6.8	40	5.9	15.8
May	9.1	20	6.0	15.9
Jun	7.5	34	6.3	16.2
Jul	3.4	69	4.6	14.5
Aug	1.0	90	5.1	15.0
Sep	1.8	83	6.0	15.9
Oct	5.1	55	5.8	15.7
Nov	5.5	52	5.8	15.7
Dec	4.4	61	5.3	15.2
Annual	4.5	59	5.7	15.6

Table 7 – Flow recommendations based on the BC modified Tennant method of determining instream flow for the Theodosia River at the Olsen Lake diversion. Recommendations are based on only 11 years of data (2000-2010) and therefore may be considered accurate to +/- 20%.

Biological or Physical Requirement	Flow Recommendation (% MAD)	Flow Recommendation (cms)	Duration
A. Rearing			
Juvenile	20%	1.43	Months
Adult	> 55%	> 3.93	Months
B. Over-wintering	20%	1.43	Months
C. Incubation	20%	1.43	Months
D. Migration and Spawning:			
Summer Steelhead passage	50-100%	3.58-7.15	Days
Spawning	equation: 1.56 * MAD^0.63	5.39	Days-weeks
Smolt Migration	50%	3.58	Weeks
E. Short-term Maintenance	10%	0.72	Days to a Week
F. Channel maintenance	> 400%	> 28.6	Days
E. Wetland linkage	100%	7.15	Weeks

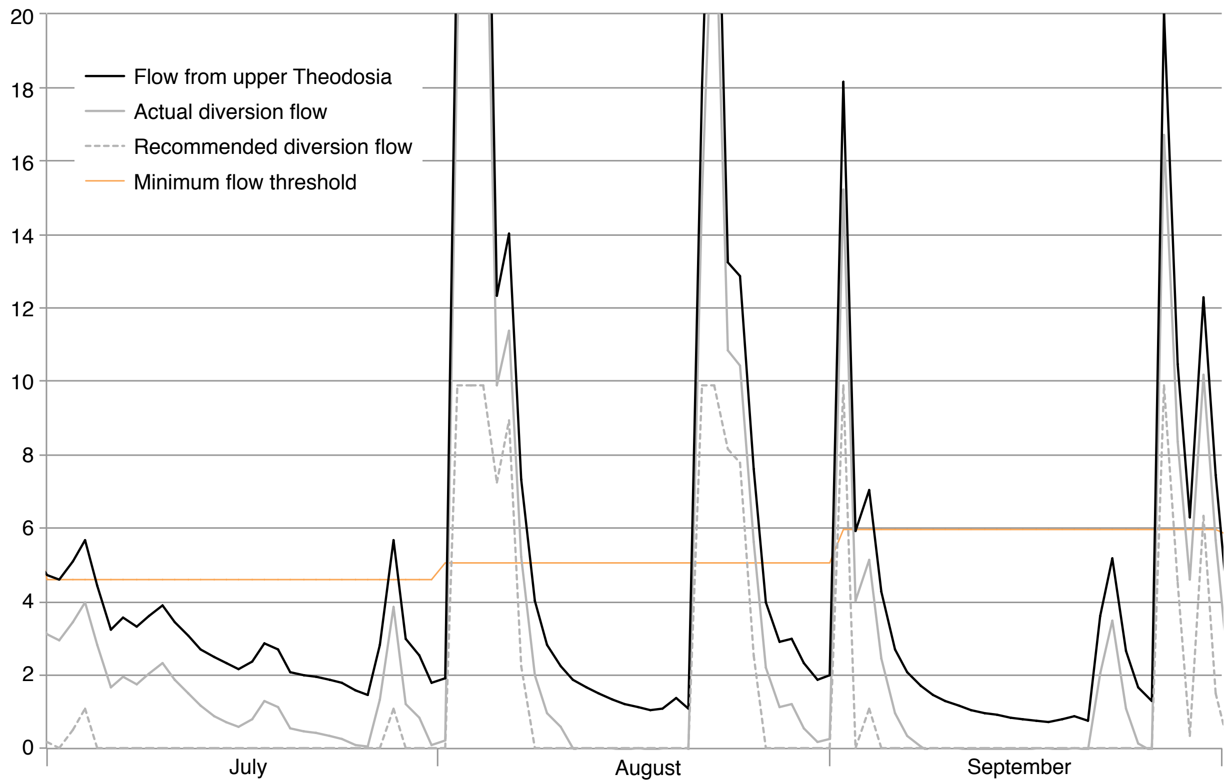

Figure 25 – Actual and recommended diversion flows during an example low flow period from July through September 2001. The black lines show the daily flow from the upper Theodosia River, the solid grey line shows the daily flow diverted to Olsen Lake, while the dashed grey line shows the recommended diversion flows. The orange line shows the minimum instream flow threshold. The recommended discharge was calculated using guidelines for fish-bearing streams from Hatfield et al. 2003.

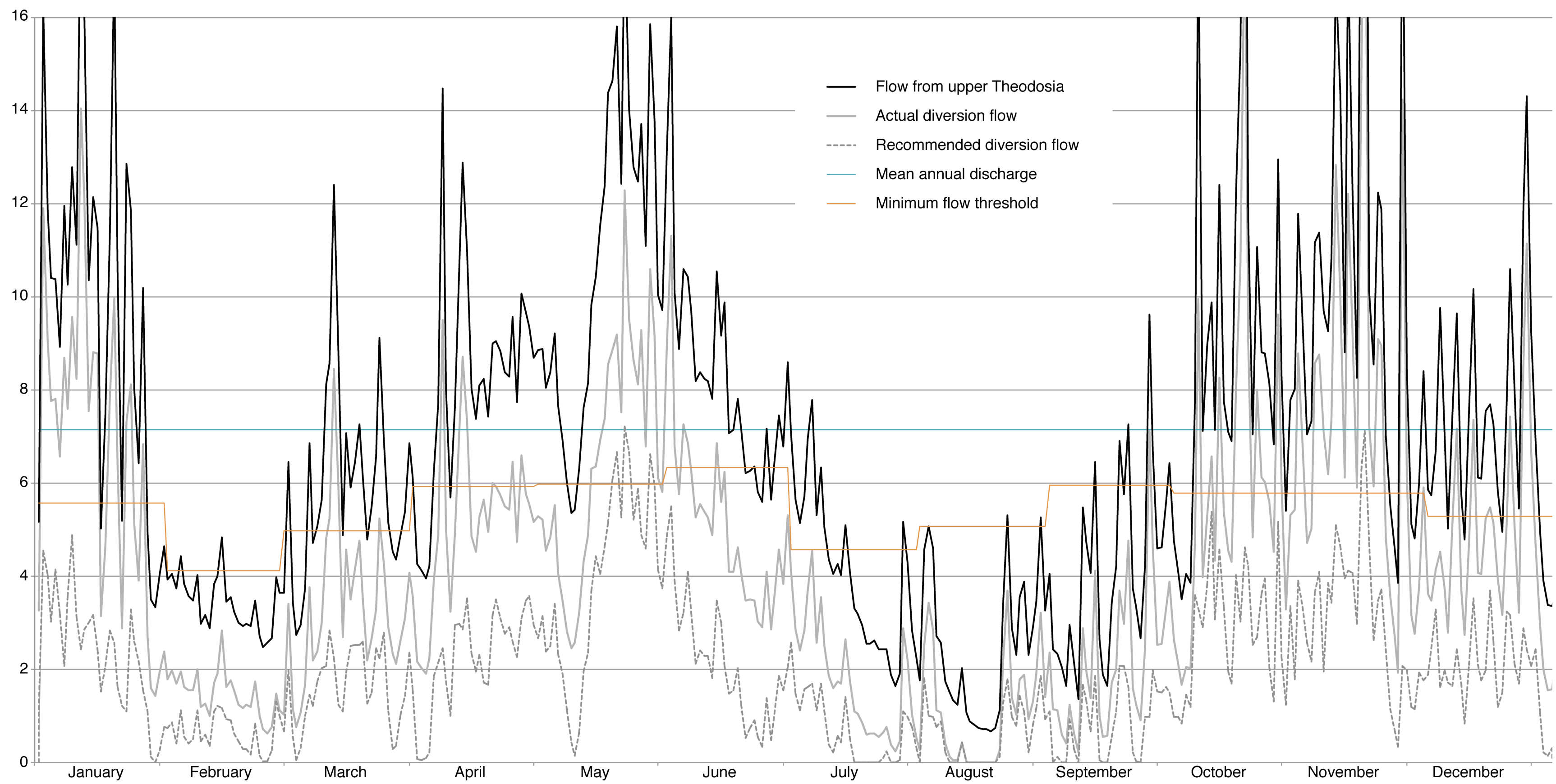

Figure 26 – Mean daily flows over the 11 year period of record for the Theodosia River at the Olsen Lake diversion. The black lines show the average daily flow from the upper Theodosia river, the solid grey line shows the average daily flow diverted to Olsen Lake, while the dashed grey line shows the recommended average diversion flows. The orange line shows the minimum instream flow threshold while the blue line shows mean annual discharge. The recommended discharge and minimum flow thresholds lines were calculated using guidelines for fish-bearing streams from Hatfield et al. 2003.

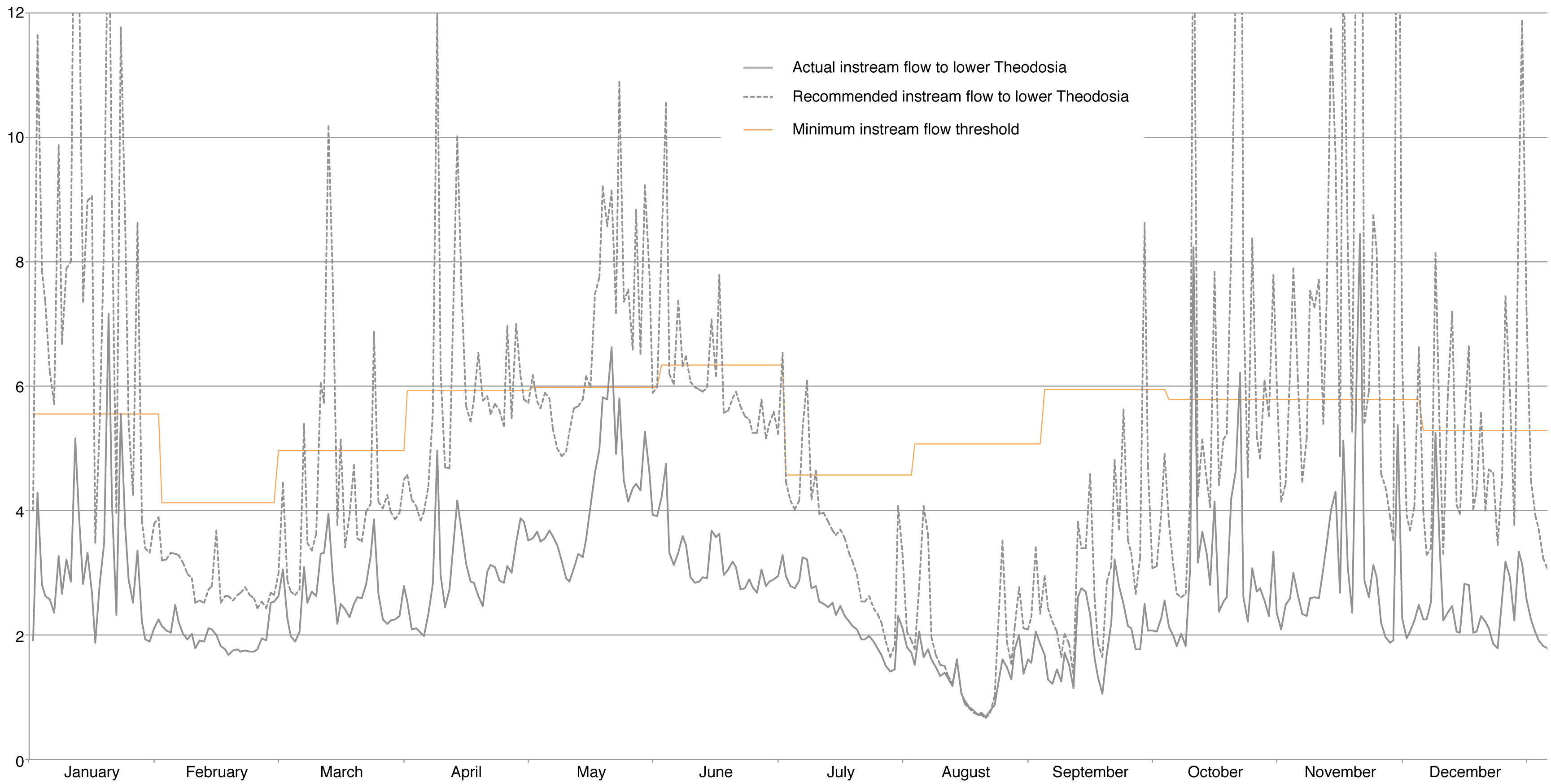

Figure 27 – Mean daily flows over the 11 year period of record for the Theodosia River below the Olsen Lake diversion. The solid grey line shows the average daily instream flow to lower Theodosia, while the dashed grey line shows the recommended average instream flows over the period of record. The orange line shows the recommended minimum instream flow threshold. The recommended instream and minimum flow thresholds lines were calculated using guidelines for fish-bearing streams from Hatfield et al. 2003.

Appendix B: Theodosia watershed climate change report card

Parameter	Climate Change Impact	Climate Change Effect	Probability	Consequence	Data Gaps	Adaptation Strategies
Stream habitat and Salmonids						
Salmonid spawning habitat	Increased frequency / magnitude of floods	Increased egg scour and burial Lower egg-to-fry survival	High	Severe	- Water use plan at diversion	- Divert extreme peak flows to Olsen Lake during the winter months - Retain as much forest cover as possible (Limit forest harvesting)
Stream habitat	Increased frequency / magnitude of floods	Increased channel migration, degradation and aggradation. (General channel instability)	High	Unknown	- Water use plan at diversion	- Maintain and restore riparian habitat to increase channel stability - Divert extreme peak flows to Olsen Lake during the winter months - Retain as much forest cover as possible (Limit forest harvesting)
Coho fry / parr	Increased frequency / magnitude of floods	Lack of habitat during peak flows	High	Unknown	- Mapping of off channel habitat - Water use plan at diversion	- Construction of off channel habitat - Divert extreme peak flows to Olsen Lake during the winter months - Retain as much forest cover as possible (Limit forest harvesting)
Early run chum spawning habitat	Decreased late summer / early fall flow volume and wetted area	Reduced spawning habitat Lower egg survival	High	Unknown	- Mapping of spawning habitat	- Reduce diversion of flows during summer months.
Coho rearing habitat	Decreased summer low flows	Decrease in available habitat Lower fry-to-smolt survival	High	Unknown	- Mapping of thermal refugia	- Reduce diversion of flows during summer months. - Construction of thermal refugia / deep water habitat
Coho rearing habitat	Increased summer temperature	Thermal stress Lower fry-to-smolt survival	Medium	Unknown	- Mapping of thermal refugia	- Reduce diversion of flows during summer months. - Construction of thermal refugia / deep water habitat
All aquatic species	Increased winter temperature	Faster incubation period, increased growth rate, and life cycle	High	Unknown		
Chum smolts and Coho fry	Change in food timing of seaward migration	Change in food availability. Mismatch in predator/prey interaction.	Unknown	Unknown		
Forests						
Western red-cedar and other wet adapted species	Increased summer drought	Decreased growth rates	High	Low	- Forest replanting plans	- Planting trees adapted to drier summer conditions
Douglas-Fir and other dry adapted species	Increased summer drought	Competitive advantage	High	Low	- Forest replanting plans	- Planting trees adapted to drier summer conditions
All forest species	Increased temperature	Increased growth rates during wet times	High	None		
All forest species	Increased summer drought	Drought stress may result in trees being more susceptible to insects and diseases	Unknown	Unknown	- Forest replanting plans	- Planting trees adapted to drier summer conditions
Yellow-cedar	Lack of snowpack followed by cold-snap	Root damage and tree death	Unknown	High		
All forest species	Summer drought	Increased possibility of forest fires	High	Unknown		
Forests near streams	Increased storm magnitude and frequency	Increased landslides and channel migration events resulting in greater disturbance	High	Medium		- No forest harvest near streams

Appendix B: Theodosia watershed climate change report card

Parameter	Climate Change Impact	Climate Change Effect	Probability	Consequence	Data Gaps	Adaptation Strategies
Infrastructure: Forestry roads, diversion, and future settlements						
Forest road Culverts	Increased storm magnitude and frequency	Culvert capacity too small for increased flood magnitudes resulting in plugged culverts which would trigger debris flows and landslides	High	High	- Culvert GIS database	- Oversize culverts at least twice the current recommended size
Forest roads and future settlements	Increased storm magnitude and frequency	Fill slope failure leading to landslides could impact future settlements	High	Unknown		- Relocate forest roads to areas of decreased risk
Forest roads and channel	Increased storm magnitude and frequency	Forest roads become an extension of the channel network during rain events resulting in increased channel response, larger flood magnitudes and increased sediment load in the river	High	Medium		- Relocate forest roads to prevent discharge of ditches into streams
Stream-adjacent roads	Increased storm magnitude and frequency	Roads adjacent to streams may be washed out	Unknown	Unknown	- Mapping of road network	- Relocate forest roads away from streams
Bridges	Increased storm magnitude and frequency	Bridge foundation erosion or wash-outs	Unknown	High		- Frequent inspection of bridges
Olsen Lake diversion	Increased storm magnitude and frequency	Increased sedimentation at the Olsen Lake diversion and increased possibility of channel avulsion	High	Unknown		- Increase removal/maintenance of sediments at diversion - Reduce flows towards Olsen Lake in order to prevent sedimentation at diversion
Future settlements	Increased storm magnitude and frequency	Increased frequency and magnitude of overbank flows (floods) on the lower Theodosia floodplain could damage future settlements	High	High	- Map elevations of floodplain and elevations of a flood that is twice the magnitude of the Q100	- Locate future settlements on terraces well above channels - House designs should be without basements and could be situated on stilts
Future settlements	Increased storm magnitude and frequency	Increased potential for debris flow events on tributary streams could affect future settlements near such streams or alluvial fans	High	High	- Map tributaries and alluvial fans	- Locate future settlements away from alluvial fans or streams