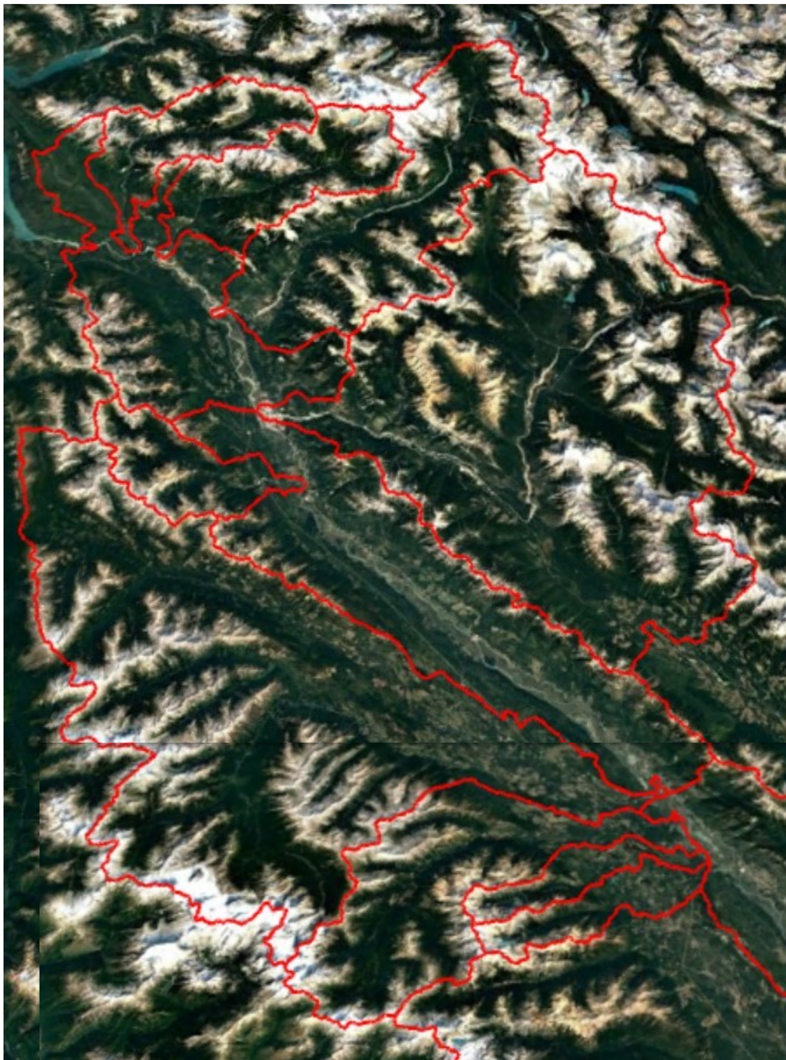
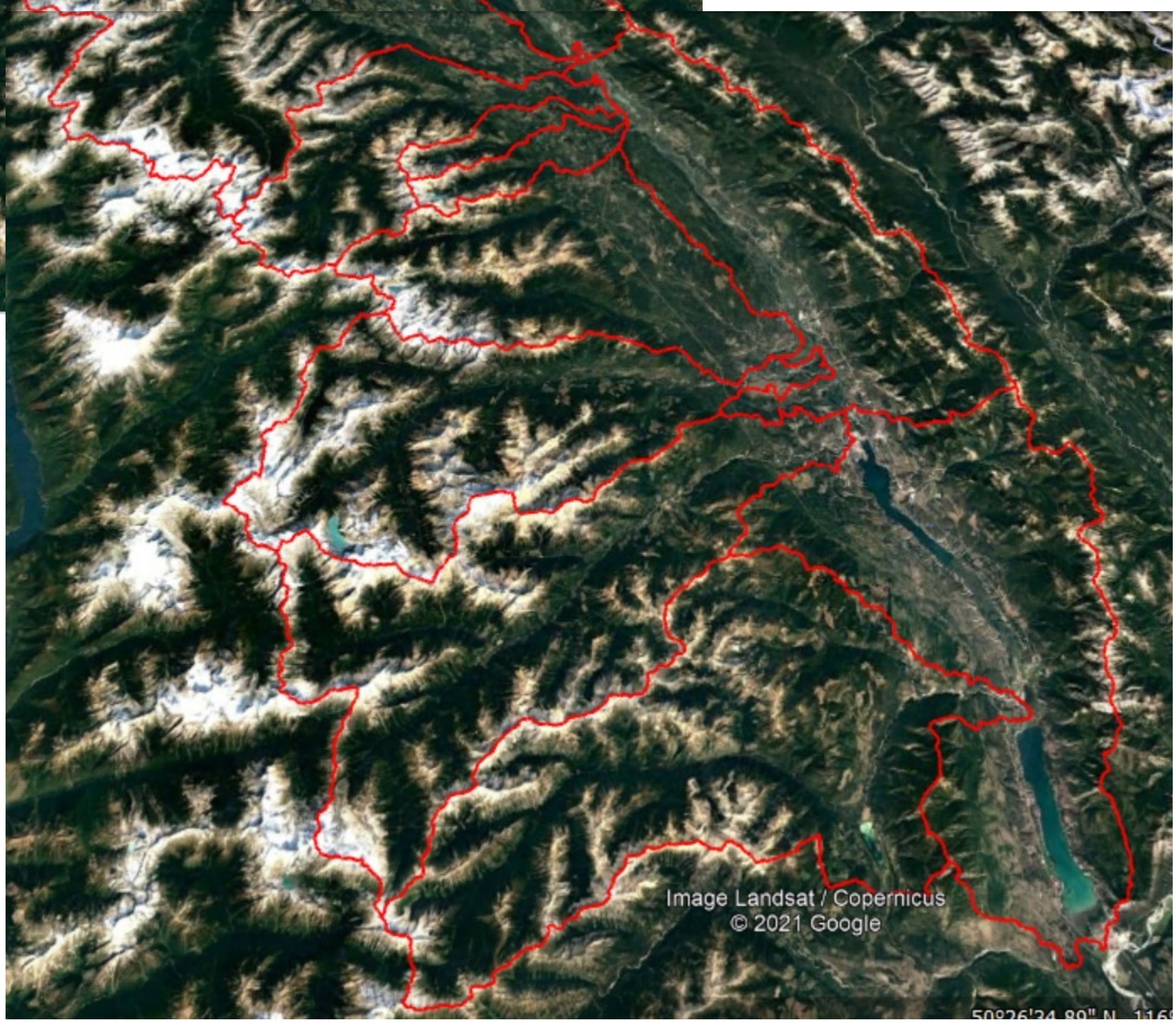


The Columbia Wetlands and Climate Disruption: A Preliminary Assessment

G. Utzig, P. Ag. ***Final*** 4/1/21

Prepared for: Kootenay Connect, a project of Kootenay Conservation Program



1.0 INTRODUCTION

The Columbia Wetlands (CW) occur in the Rocky Mountain Trench along the upper reaches of the Columbia River between Columbia Lake and the Kinbasket Reservoir in British Columbia (see Fig. 1). The Columbia Wetlands are a hot spot for biodiversity and climate resilience, and efforts are being made by the Columbia Wetlands Stewardship Partners and others to identify potential climate impacts and on-the-ground actions. The purpose of this report is to summarize the potential impacts of climate change on surface water inputs to the wetlands, and ecosystems surrounding the wetlands.

The majority of the wetlands are fed by the northward-flowing mainstem of the Columbia River and the larger tributary streams, while some may be fed by local face unit streams. Groundwater likely plays a role, especially in drought years, but the magnitude of its role is unknown at present. All the tributary streams are presently snow-dominated systems, which generally have peakflows in the late spring or early summer coinciding with maximum snowmelt, and low flows in the late summer, fall and winter. Many of the larger tributary valleys have significant glacier coverage, which further contribute to the wetland inflows, especially in late summer.

To examine the inflows to the wetlands, the watershed for the wetlands has been subdivided by two sets of contrasting criteria. The first subdivision splits the overall watershed into large individual tributary watersheds and groupings of small watersheds that occur along the face of the Trench (see Fig. 2 and 3). Although the face units in the Rocky Mountain trench are immediately adjacent to the wetlands, their importance in contributing water to the wetlands is minor compared to the larger tributaries.

The second subdivision divides the wetland watershed into segments according to

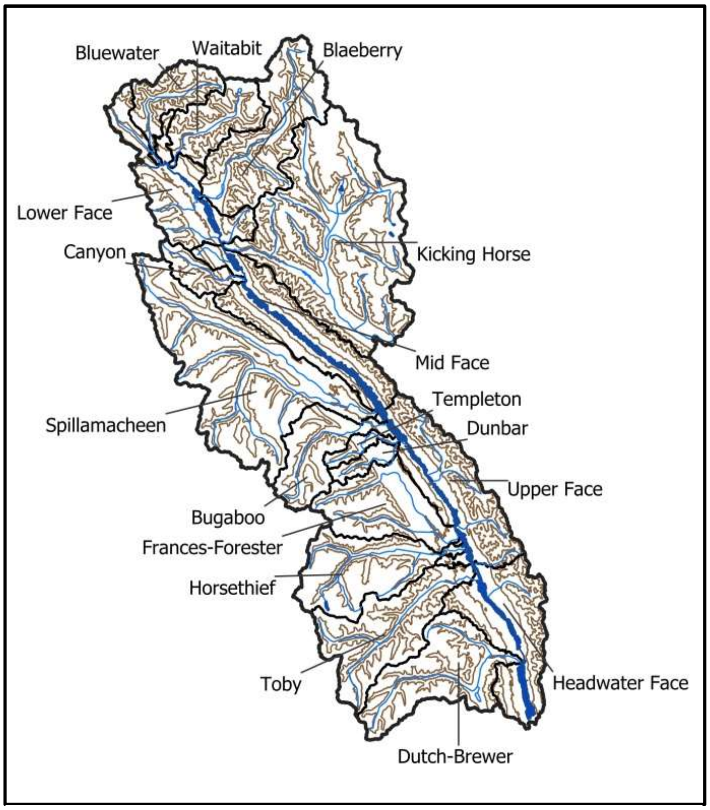


Figure 1. Topography and sub-watersheds within the overall Columbia Wetlands watershed (CI = 500m).

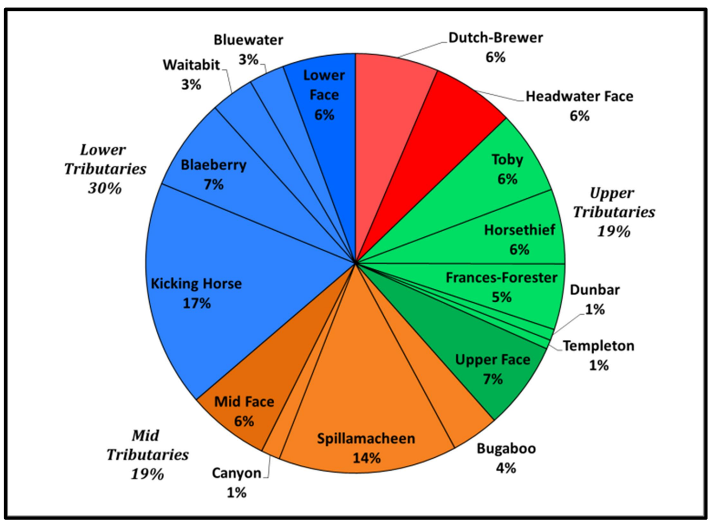
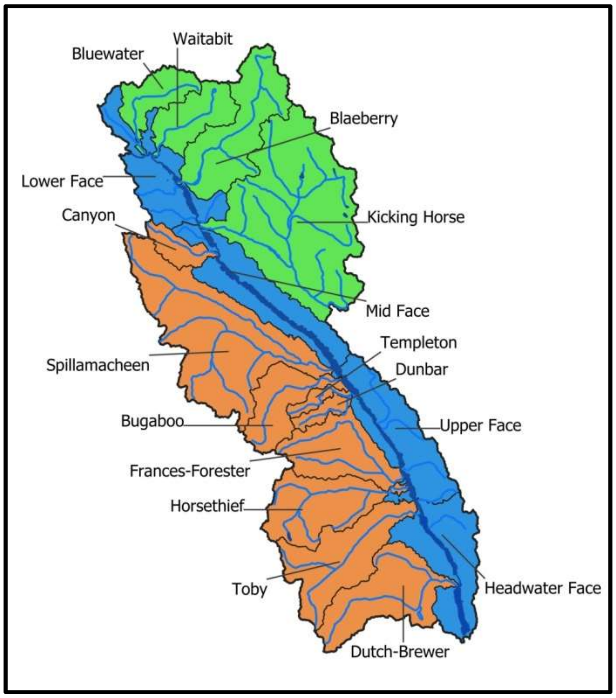


Figure 2. Percent area of the sub-watersheds; colouring by segments in Fig. 4, darker shades are face units.



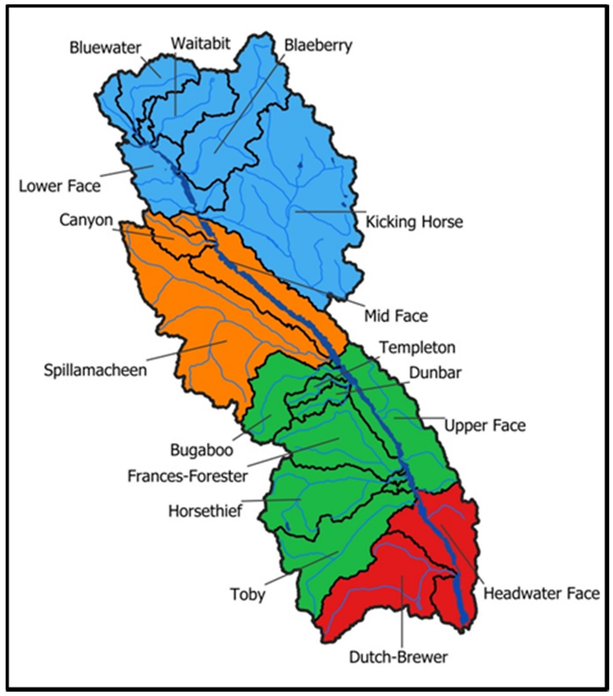


Figure 3. Columbia Wetlands watershed face units (blue), Purcell tributaries (brown) and Rocky Mountain tributaries (green).

Figure 4. Columbia Wetlands watershed segments: Headwaters (red), Upper (green), Mid (orange) and Lower (blue).

where they occur along the length of the watershed (see Fig. 4). The Headwater area is upstream of most of the wetlands themselves and includes Dutch and Brewer Creek drainages, as well as Columbia and Windermere Lakes. The Upper portion of the wetlands extends from the outlet of Windermere Lake to just beyond the junction with Bugaboo Creek. This portion begins at approximately 800 m in elevation at the lake outlet, dropping to approximately 785 m at the confluence with Bugaboo Creek. The Mid segment includes the area from just above the Spillimacheen River to just above the Kicking Horse River. The elevation in this segment drops from about 785 m to approximately 775 m at the confluence with the Kicking Horse River. The Lower segment includes the segment between the Kicking Horse River and the Kinbasket Reservoir. The elevation drops from about 775 m to approximately 755 m at the reservoir. The larger tributaries for the Headwater, Upper and Mid segments are all in the west side of the wetlands in the Purcell Mountains, while the larger tributaries to the Lower segment originate in the Rocky Mountains to the east. It should be noted that due to the steady gradient of the Columbia, the Upper segment of the wetlands are supplied only by the Headwaters and the Upper tributaries, while downstream the Mid and Lower segments accumulate inflows of all tributaries upstream of those segments.

The percentages of watershed area for each of the watershed components are summarized in Figure 2. The subsequent sections of the report utilize these various subdivisions to portray the variation in the roles the various components play on supplying water to the Columbia Wetlands. The subdivisions are also used to summarize how climate change impacts may vary between the various components, and their ability to supply water to the wetlands.

2.0 CLIMATE CHANGE

Determining the potential impacts of climate change on the Columbia Wetlands would ideally include detailed hydrologic modelling that examines the water balance for the wetland watershed as a whole. However there is insufficient data to complete that task, and it is beyond the scope of this project. As an alternative, this report presents information on the projected changes to the main drivers of the hydrologic regime, and infers from those, changes to the hydrologic regime itself. Further monitoring, data analysis and modelling will be required to refine this information. Climate data presented are from ClimateBC (v6.40), with outputs averaged from individual point data extracted from a 1 km grid (Wang et al. 2016). All the data are interpolated between individual climate stations and General Circulation Model (GCM, or Global Climate Model) outputs using the Parameter Regression of Independent Slopes Model (PRISM) interpolation method. Projections are taken from the mean of an ensemble of 15 GCM scenarios from the Coupled Model Intercomparison Project phase 5 database (CMIP5), corresponding to the Intergovernmental Panel on Climate Change Assessment Report 5 (IPCC AR5). Two emissions scenarios were considered: Representative Concentration Pathway (RCP) 4.5 represents a moderately-low emissions scenario consistent with intermediate GHG mitigation; RCP 8.5 represents a high GHG emissions scenario similar to current rates. More information on the projected data is available at: http://adaptwest.databasin.org/pages/adaptwest-climatena. Where appropriate, colour schemes in all the graphic outputs are consistent with the colours in Figures 3 or 4 for the various watershed components.

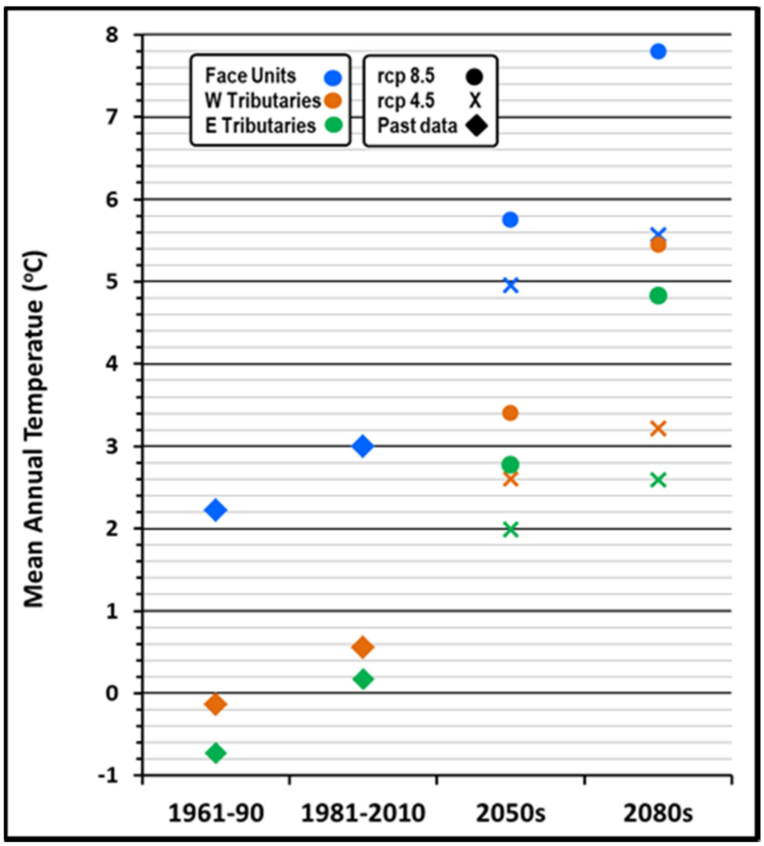


Figure 5. Historical and projected annual temperatures for face units (blue) and west (orange) and east (green) tributary valleys.

Annual temperatures in the main Columbia Valley (i.e. face units) are two to three degrees warmer than the main tributary valleys feeding the CWs (see Fig. 5). The cooler temperatures in the larger tributary valleys are primarily a result of their increased area of higher elevations. As would be expected with ongoing increases in GHG emissions and CO_2 concentrations in the atmosphere, temperatures are increasing in all portions of the CW watershed. Annual temperatures have increased almost 1 °C over the past few decades, and are projected to increase by a further 2 to 4+ °C in the coming decades, depending of the trajectory of GHG emissions.

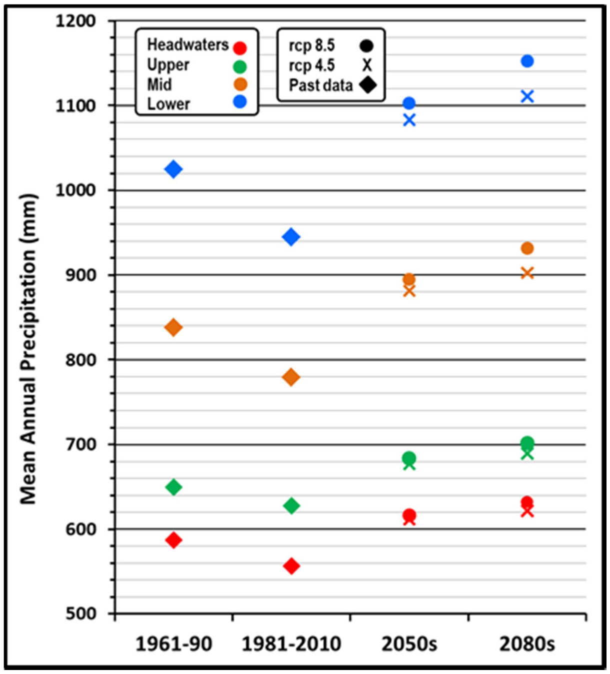


Figure 6. Historical and projected annual precipitation for face unit segments: Headwaters (red), Upper (green), Mid (orange) and Lower (blue).

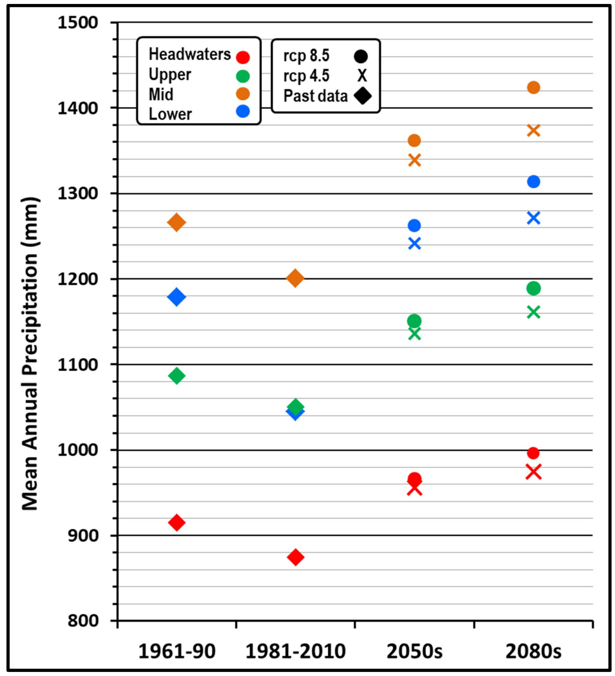


Figure 7. Historical and projected annual precipitation for tributary valleys: Headwaters (red), Upper (green), Mid (orange) and Lower (blue).

Annual precipitation patterns also vary substantially between the main Columbia Valley face units and the tributary valleys (see Figs. 6 and 7 – note Y-scale differences). Within the main Columbia Valley precipitation increases from south to north, with substantial increases in the Mid and Lower segments of the wetlands (Fig. 6). Annual precipitation within Purcell Mountain tributary valleys also increases from south to north from the Headwater to Mid segments. However, within the tributary valleys for the Lower segment located in the Rockies, the south to north increasing trend does not hold. This segment has precipitation that is between the Upper and Mid segments of the Purcells (Fig. 7). In contrast to the increasing temperatures, annual precipitation has decreased over the past few decades (~5-6% for most areas, Lower segment ~8-12%). However, annual precipitation is projected to moderately increase for all areas (~10-15%) in the coming decades.

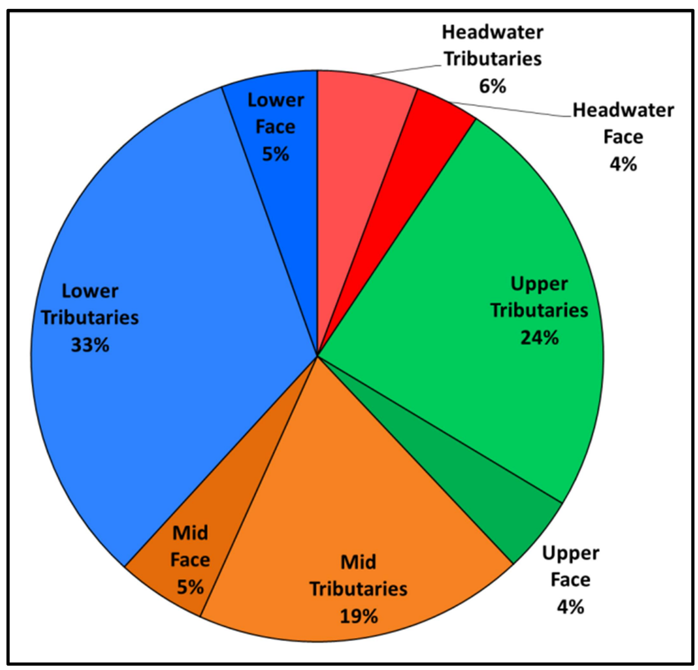


Figure 8. Proportional annual water supplied to the Columbia River by segment: Headwaters (red), Upper (green), Mid (orange) and Lower (blue).

The relative contributions of water to the mainstream Columbia River based on area weighted precipitation inputs are shown in Figure 8. When compared with the proportion of the total watershed area (see Fig. 2), the Headwaters and face units supply slightly smaller proportions of water, while the other areas are generally proportional to their area.

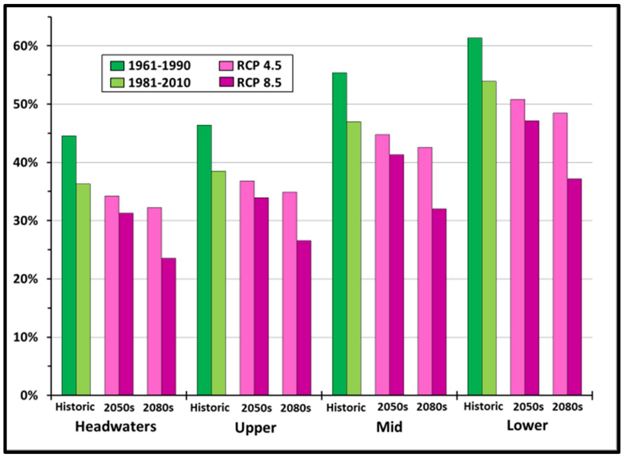


Figure 9. Historical and projected changes in the portion of annual precipitation arriving as snow for face units.

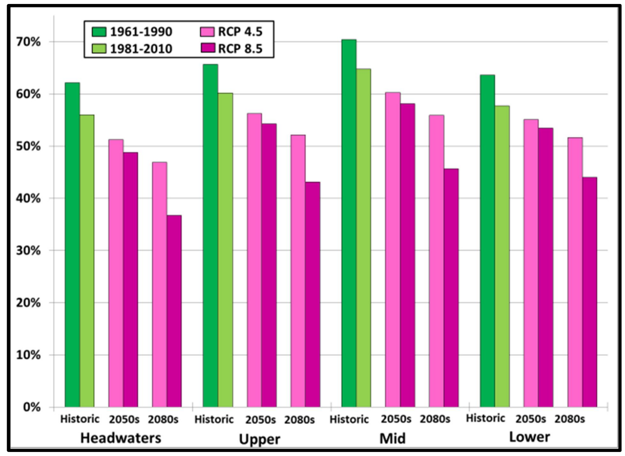


Figure 10. Historical and projected changes in the proportion of annual precipitation arriving as snow for tributary valleys.

Although precipitation is projected to moderately increase in the coming decades, the form of that precipitation is also projected to change. Due to increasing temperatures, the proportion of precipitation arriving as snow has decreased over the last few decades and is projected to continue to decrease in the coming decades (see Figs. 9 and 10). Annual snowpack is a major source of water storage in the CW watersheds. In late spring and early summer the melting snowpack fuels the peak flows that flood the wetlands, and later in the summer melting high elevation snow maintains seasonal streamflows. Substituting rain for snow will tend to increase flows in the spring, late fall and winter, and decrease flows in the late summer and early fall.

In addition to driving reductions in the proportion of precipitation as snow, increasing temperatures will also result in increased evaporative demand (see Fig. 11). The determination of evaporation and transpiration water losses associated with wetland environments is complex, and beyond the scope of this report. However, the Hargreaves reference evaporation index provides a reasonable estimate of the evapotranspiration for a standard crop, and can be adapted for use in other environments by adjusting with an appropriate constant (Hargreaves and Allen 2003). Even though the values presented here require adjustment, the relative changes through time are an indication of past and potential trends in evaporation. The values are presented for the main Columbia Valley, and will reflect changes in evaporation rates relevant to the Columbia Wetlands.

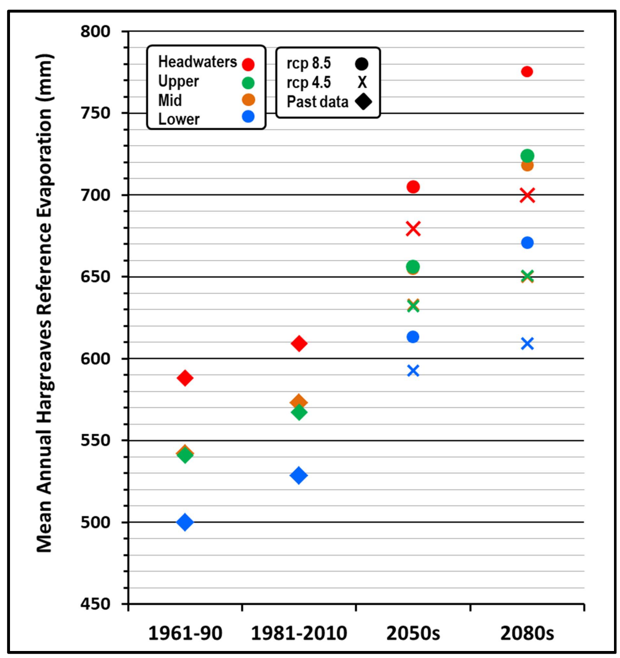


Figure 11. Historical and projected changes in evaporation for face units by segment.

Evaporation is highest in the Headwater area and lowest in the Lower segment of the wetlands. The Upper and Mid segments are similar and fall between the Headwater and Lower segment. As with annual temperatures, evaporation has been increasing over the past decades, and is expected to increase further in the coming decades (~15 to 25% by the 2080s).

While temperatures and evaporative demand are projected to continue rising, summer precipitation (defined as June, July and August) is generally projected to decrease, although the existing and projected trends vary by area (see Figs. 12 and 13).

Summer precipitation for the face units in the Trench has increased by 3-8% over recent decades. It is projected to continue to increase into the 2050s in the Mid and Lower face units and then subsequently decrease into the 2080s. In the Upper and Headwaters face units summer precipitation has also increased in recent decades, but it is projected to decline by the 2050s and continue to decline into the 2080s.

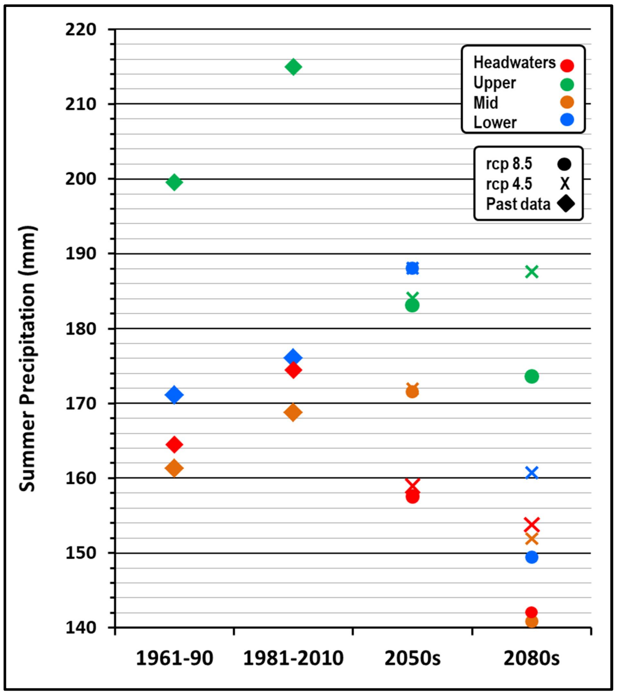


Figure 12. Historical and projected changes in summer precipitation for face units.

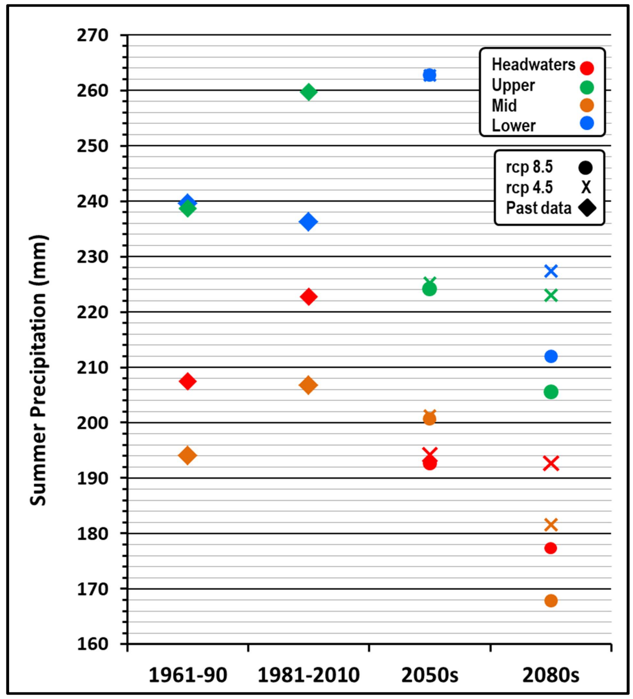


Figure 13. Historical and projected changes in summer precipitation for tributary valleys.

Summer precipitation for the larger tributary valleys feeding the CW has been increasing in the Purcells over recent decades (Headwaters, Upper and Mid segments, 7-9%). However it is projected to decrease in the coming decades, with decreases of 2 to 21% in relation to recent decades. In contrast summer precipitation has been decreasing slightly in the Rocky Mountain tributary valleys (Lower segment, ~1%). The Rocky Mountain tributary valleys are projected to increase in summer precipitation by the 2050s, and then decline below present levels by the 2080s (4-10%). For all of the summer precipitation projections, RCP 4.5 and 8.5 results (moderate emission controls vs. continued reliance on fossil fuels respectively) are similar for the 2050s, however by the 2080s the 8.5 results are distinctly drier in all cases.

In summary, the recent trend of increasing summer precipitation is projected to reverse direction in the coming decades, first in the Purcells and then in the Rockies. Due to increasing temperatures, there will also be increases in evaporative demand in all areas. Both of these two factors will place increasing pressure on late summer and early fall water supplies to the wetlands, and may result in decreased water levels.

3.0 GLACIERS

Glacier are very effective at storing water that arrives in the form of snow, often storing that water for centuries. As the air warms over the summer, the lower portions of the glaciers release that water as meltwater that feeds streams flowing downstream of the glaciers. Many of the tributary valleys contributing water to the CW have significant glacier area (see Figs. 14 and 15). The Headwaters segment has virtually no glacier area, while both the Upper and Lower segments have significant glacier area. The Mid segment has a moderate amount, while the face units have none, except for a very minor portion in the Lower face unit.

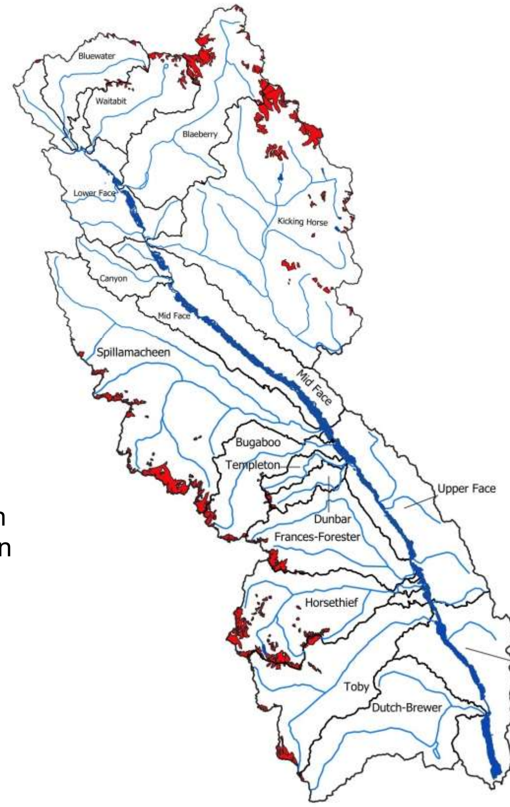


Figure 14. Glacier area (red) of the Columbia Wetlands watershed.

Increasing annual temperatures driven by climate change have also been having significant impacts on glaciers in the area. As is occurring in most places on earth, glaciers throughout the Columbia Basin are in decline (e.g., Bolch et al. 2010, Moore et al. 2009, IPCC 2019). Menounos et al. (2019) show that the rate of decline has been increasing across western North America, including in the CW watershed region.

As glaciers recede they release not only seasonal water, but also water that has been stored for centuries, or even millennia. This water is released in the late summer and early fall, and can contribute significantly to low flows in that season (Jost et al. 2012, Moore et al. 2020).The contributions are most significant in years with warm dry summers, and early snowmelt following a winter with low snow accumulation. Modeling just north of the Columbia Wetlands, in a basin with similar glacial extent to many of the main CW tributary valley demonstrated that glacier ice melt can contribute up to 25 or 35% of August and/or September streamflow in those years (Jost et al. 2012). In years with heavy snowpack and late melt, the contribution will be reduced.

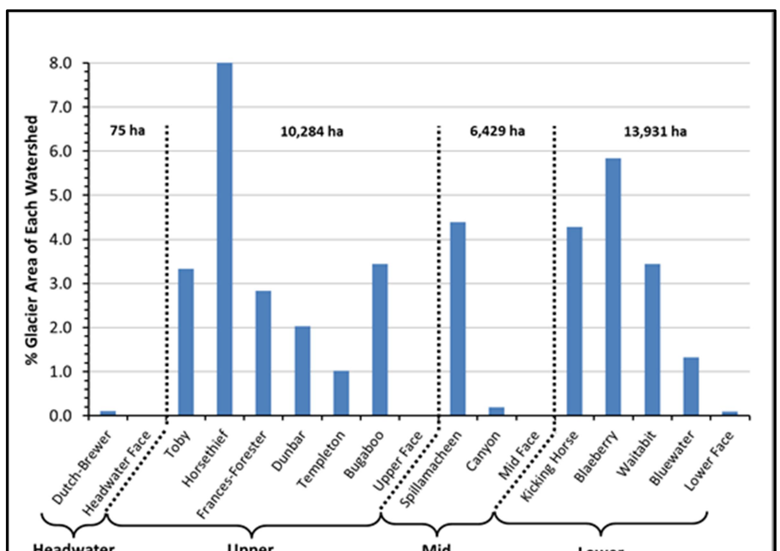


Figure 15. Glacier area by sub-watersheds and segments.

When glaciers stop advancing, and initially start to retreat, they will increase streamflow. However as the decrease in area of ice crosses a threshold, the meltwaters will gradually decrease to zero as the ice mass decreases to zero. Glaciers in the CW watershed have crossed that threshold (Moore et al. 2020). Analysis of the contribution of glacial meltwaters to streamflow has shown that the contribution of glacial meltwater to August streamflow in three of the CW tributary streams (Spillimacheen, Kicking Horse, Blaeberry) has been decreasing since about 2000, or even longer in Kicking Horse (Brahney et al. 2017). As shown in Figure 15, glaciers have already virtually disappeared from the Headwater segment, but the Upper, Mid and Lower segments are all vulnerable to increasing losses of water inputs during the late summer and early fall as glacier areas continue to decline.

In the future, increasing temperatures associated with climate disruption are likely to further increase the rate of glacial retreat and the associated reduction of meltwater contributions to streamflow. Decreased contributions from glacier meltwaters will also likely increase stream temperatures.

4.0 IMPLICATIONS FOR WETLAND WATER SOURCES

A recent hydrological assessment of the upper Columbia watershed has summarized the available streamflow records for the CW watershed area (MacDonald 2020). The assessment confirms that the major tributaries are the main source of water for the mainstem Columbia, being dominated by higher elevations with higher precipitation inputs and snow storage (see Fig. 8). The smaller face unit streams have a different seasonal pattern than the mainstem Columbia and the major tributaries, becoming snow-free much earlier in the spring. The assessment found that peak flows in the Columbia River and most tributaries were trending down between 1960 and 2018, but the trend was weak and generally not statistically significant. Similar to Brahney et al. (2017), the MacDonald (2020) assessment found that August flows were generally trending downward, likely the result of glacier retreat.

Based on limited information, an assessment by MacDonald (2021) has suggested that seasonal patterns of water levels in the wetlands are related to their connectivity to the mainstem Columbia. Wetlands with strong connectivity (low and/or breeched levees), were more correlated with Columbia River streamflow. Wetlands with weak connectivity were more likely to retain water longer in the year. The report also indicated that daily peakflow at Nicholson of 445 m^3/s is a potential threshold for wetland overland flooding; however it is unclear what portion of the wetlands this threshold applies to.

These findings indicate that a portion of the wetlands are vulnerable to decreases in peakflows, especially below the threshold for overland flooding, as well as decreases in low flows that will drain the wetlands with high connectivity. Although overall modest increases of annual precipitation are projected, decreases in the proportion of precipitation as snow may result in decreases in peakflow, while increasing winter flows.

Glacier area loss is already influencing low flows, and it is projected to continue. Increasing temperatures will increase water temperatures, and this will be compounded by the loss of glacial meltwaters. Increased evaporation demand is already occurring and projected to increase further. The projected increases in evaporative demand will further amplify the reductions in late summer low flows, further decreasing wetland water levels in many wetlands.

The variability in projected changes of temperature and precipitation, especially summer precipitation, demonstrate that climate change will impact different parts of the CW watershed in different ways. Recent work by MacDonald (2021) has tentatively defined a range of wetland groups, each with distinct patterns of water additions and losses. Linking the sources of water for each of the groups to the various watershed components described in this report, and their projected responses to climate change, will be key to understanding the vulnerability of individual wetlands. Differentiating between the various reaches of the Columbia River maintstem, segments of the wetlands and face unit streams vs. large tributaries should improve the ability to accurately assess the vulnerability of individual wetlands.

5.0 PROJECTED VEGETATION CHANGES

Changes in temperature and precipitation will have profound impacts on the vegetation and other components of ecosystems throughout the CW watershed. In addition, vegetation cover will be impacted by extreme events such as drought, landslide and flood events triggered by the occurrence of extreme weather. There will also be the secondary climate change effects such as increased infestations by bark beetles and other forest pests, and increased frequency and intensity of wildfire.

Analyses of projected shifts in bioclimates, as shown in Figure 16 for the 2080s, demonstrate three potential futures based on three GCM and emission scenarios (Utzig 2012). **The bioclimates shown are broad groupings of vegetation zones – NOT individual BEC units; the names and abbreviations are indicated in the discussion below.**

Three scenarios are presented to emphasize that there is considerable uncertainty of how climate disruption will be manifested. As is illustrated in the graph in the upper left of the figure, these scenarios were selected[1] to represent the outer limits of over 40 scenarios run for BC as a whole. The variability in the outcomes of the scenarios result from differences in individual GCMs, differing assumptions about how earth systems will respond to increased GHGs in the atmosphere and assumptions about the rate of GHG emissions over the coming decades. Using the 1961-90 normals as a baseline, the vertical axis in the graph is the projected increase in annual BC temperature in ^{o}C and the horizontal axis is the projected change in annual precipitation in percent. Note that all the scenarios project an increase in temperature, and almost all project an increase in annual precipitation. The actual outcome is likely to be somewhere between these three scenarios.

Current Mapping: The “Current Mapping” in the upper left shows the present distribution of broad vegetation zones across the CW watersheds. The Headwater and Upper face units are dominated by Dry Douglas-Fir (DDF) bioclimates at low elevations, dry montane spruce (DMS) at mid elevation and dry subalpine forest (DSF – i.e. drier ESSFs) types at upper elevations. The Lower face units have a combination of Moist Interior Cedar-Hemlock (MICH) and DMS at lower elevation and Wet Subalpine Forest (WSF), alpine parkland (AP) and alpine (A) at higher elevations. The Mid segment is transitional between the Upper and Lower segments.

The western tributary valleys within the Headwaters, Upper and Mid segments include DDF bioclimates near their mouths, DMS at mid elevations and DSF, AP and A at upper elevations. Near the headwaters of the tributary valleys the DSF transitions to WSF. The eastern tributary valleys include a similar pattern in the Kicking Horse drainage, but in the north the lower elevations are dominated by MICH and upper elevations by WSF, AP and A.

The following sections summarize projected bioclimate shifts by the various portions of CW watershed.

Face Units: The Warm/Moist scenario represents modest increases in annual temperature and precipitation. In this scenario the lower elevations of the face units shift to distinctly warmer and drier bioclimates which are typical of Grassland/ Steppe (GS) and Ponderosa Pine (PP) ecosystems in all segments. In the Very Hot/Dry scenario, with large increases in temperature and little change in annual precipitation, the face units are projected to shift to GS environments along the full length of the Columbia Wetlands, with upland areas dominated by PP bioclimates. The Hot/Wet scenario, with larger increases in annual precipitation and moderate increases in temperature, the Headwaters and Upper face units are a mix of DDF, PP and GS bioclimates, while the Mid and Lower face units are dominated by Grand Fir (GF) bioclimates, with some area of PP and minor GS types.

[1] The scenarios were recommended by the Pacific Climate Impacts Consortium (PCIC) for use in exploring the range of potential climate outcomes for BC, for further information on the scenarios and modelling see Utzig (2012)

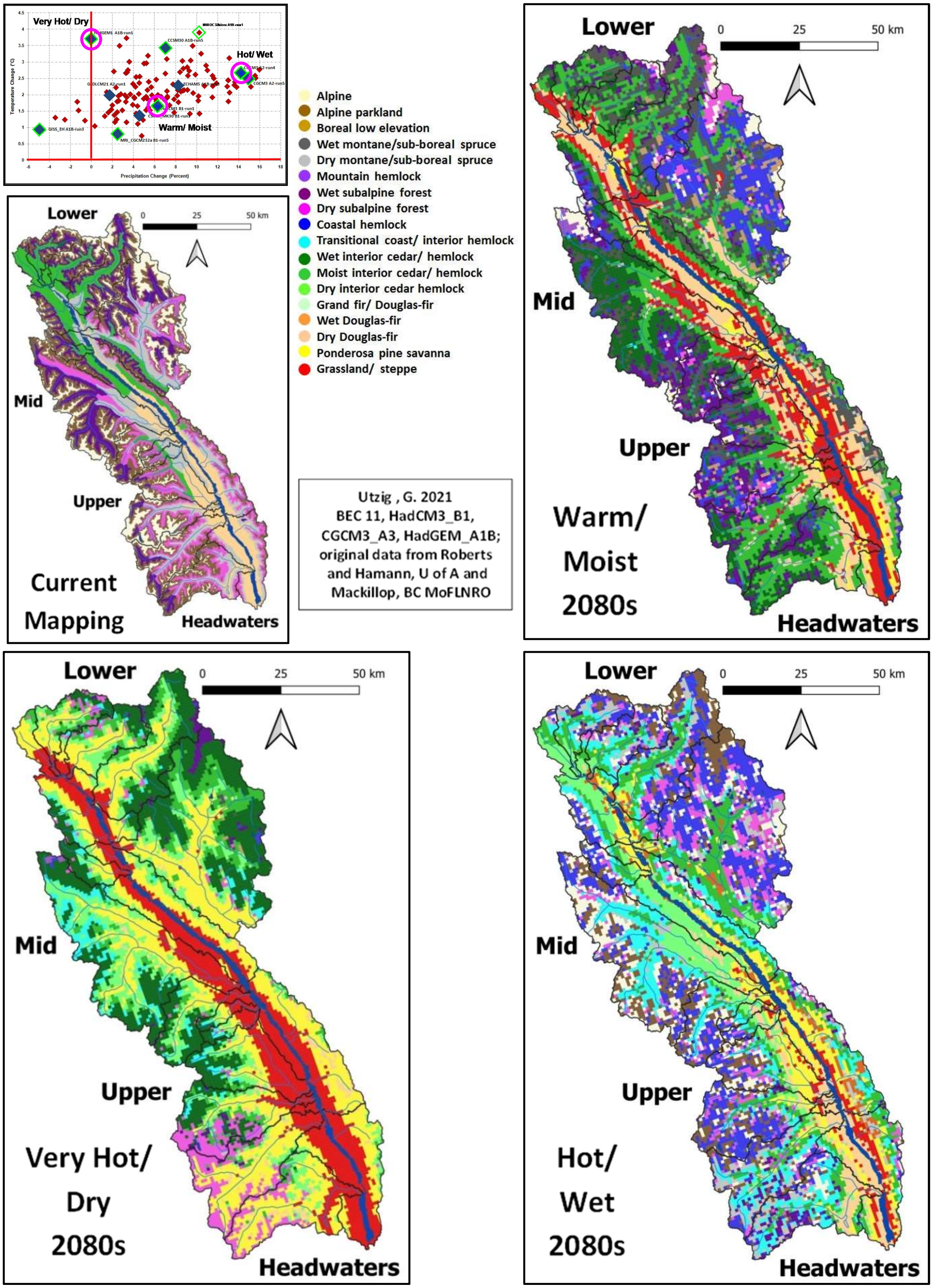


Figure 16. Three scenarios of projected shifts in bioclimates for the CW watershed.

Western Tributary Valleys: With the Very Hot/Dry scenario, western tributary valleys linked to the Headwater, Upper and Mid segments, lower elevations are projected to shift to GS and PP bioclimates, while in the other two scenarios they shift to a combination of DDF and PP, along with GF in the Mid segment. At mid elevations they shift to MICH or Transition Coast/Interior hemlock (TCIH) bioclimates, except in the Very Hot/Dry where they shift to PP bioclimates. At upper elevations bioclimates shift to Wet Interior Cedar-Hemlock (WICH), TCIH or Coastal hemlock (CH), except in the south under the Very Hot/Dry scenario where DSF is retained at the highest elevations, replacing WSF and AP. Patches of A and AP are only retained under the Hot/Wet scenario, likely due to deep snowpacks.

Eastern Tributary Valleys: In the Warm/Moist scenario the eastern tributary valleys are dominated by MICH and WICH bioclimates in the north at mid and upper elevations, with some areas of CH at upper elevations. The lowest elevations near the creek mouths include some PP, GS and IDF, along with more DDF in the extreme south. The Hot/Wet scenario has a mix of CH and DSF, and minor A and AP at upper elevations, with a mix of MICH and TCIH at mid elevations. Lowest elevations include some PP bioclimates. In the Very Hot/Dry scenario lower elevations are dominated by PP bioclimates, and upper elevations are dominantly WICH with a thin band of MICH at mid elevations.

Although there is significant variation in the projections there are also some consistent trends. The face units are trending to distinctly warmer and drier environments including the potential for extensive GS and PP ecosystems, the only difference between the scenarios is the strength of the shift. The other consistent change is the dramatic reduction in subalpine forest bioclimates (i.e. loss of the ESSF). Due to increasing temperatures and sustained precipitation at upper elevations, these areas are shifting to bioclimates more typical of ICH, CH or transitions between the two. Alpine and Parkland bioclimates are generally eliminated, except under the Hot/Wet scenario.

These shifts in vegetation communities are unlikely to be a smooth transition, but more likely to occur after a stand-replacing event such as wildfire, windthrow, drought or pest infestation. Following the stand-replacing disturbance, conditions may not be suitable for re-establishment of historical vegetation and new species will begin to establish – ***IF*** there is a suitable seed source. Without a suitable seed source, the present vegetation shift may be stalled, leading to a prolonged period of invasive species or shrub/herb early seral communities.

6.0 ECOSYSTEM CONNECTIVITY IMPLICATIONS

Projected shifts in bioclimates for the coming decades have serious implications for landscape connectivity. As species are forced to extend their ranges to the north or upslope to compensate for increasing temperatures there will be increased requirements for connectivity along those gradients.

The projections for Grassland/Steppe and Ponderosa Pine bioclimates in the Rocky Mountain Trench also have implications for cross-valley connectivity. Other than where there has been agricultural clearing, at present there is generally continuous forest cover linking the wetlands with upland mountain slopes to the east and west. As the climate shifts to hotter and drier summers and wildfires become more frequent and extensive, forest cover surrounding the wetlands will become more open or shift to grassland/steppe vegetation types. Species requiring continuous forest cover for movement will be limited to remnant patches in an otherwise non-forested or savanna landscape.

Riparian habitats and other seepage areas that can retain forest species in a drought-prone environment will increase in importance to maintain forest-dependent species. These will included those along the wetlands themselves creating a north-south corridor, as well as those along tributary streams linking to higher elevation habitats to the east and west.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Projected changes in seasonal patterns of temperature and precipitation accompanied by the increased frequency of extreme weather events will result in changes to the watersheds that supply water to the Columbia Wetlands, the ecosystems that surround the wetlands, as well as the wetlands themselves.

Climate change projections indicate that peakflows in the Columbia River will likely be earlier in the spring/summer and late summer and fall flows will likely be decreased. Winter flows will likely increase. Glacial retreat will contribute to reduced late summer and fall flows, and increased stream temperatures. Increased air temperatures will also contribute to increased stream temperatures, as well as increased evaporation. All of this points to decreased wetland water levels in late summer and fall.

Bioclimate projections indicate a shift to more open forest or grassland/steppe environments in the lower elevations surrounding the wetlands. There is also the likelihood of increased frequency of disturbances, including stand-replacing wildfire, windthrow, insects and disease, landslides and debris torrents. Bioclimate projections suggest that the upper elevations of the CW watershed are likely to remain forested, but with significant shift in species from subalpine forests to types more similar to coastal or interior cedar-hemlock forests.

There is an ongoing necessity for monitoring of streamflow, glacial retreat, seasonal wetland water levels and groundwater contributions within the CW watershed. Although there have been some recent increases in hydrologic monitoring of the wetlands themselves (MacDonald 2021), much of the data is limited to a single year or only a few years. There is also a need to monitor the primary tributary streams, especially with the decreasing inputs of glacial meltwaters, and water quality variables, including temperature and chemistry. Although there has been some investigation of direct groundwater inputs within the wetlands, there appears to be limited information on regional groundwater patterns and their potential role in wetland water levels (Romuld and Bayley 2017), or the possibility of connections between the Kootenay River flows and Columbia Lake at Canal Flats.

At present there are historical and projected streamflow data from the University of Washington that include daily streamflow data covering 1950 to 2099 for various GCMs and emission scenarios. The relevant sites include: Spillimacheen River, Kicking Horse River, and the Columbia River at Nicholson and Donald (available at: UW Hydro | Columbia River Climate Change - Data (washington.edu)). These projections could be used to better quantify the expected changes to water sources due to future climate change for various portions of the CW watershed. With output from the Pacific Impacts Consortium (PCIC), there are also opportunities to apply hydrologic models to other portions of the CW watershed (available at: Gridded Hydrologic Model Output | Pacific Climate Impacts Consortium).

Assuming that reductions in late summer and fall flows may negatively impact the wetlands, it may be prudent to begin investigating alternatives to increase water retention of spring runoff in some of the tributary watersheds. This could include nature-based options such as reconnecting wetlands that may have been isolated by road construction, or potential installation of storage reservoirs. There may also be opportunities to mitigate water temperatures through riparian zone reforestation in some drainages.

To maximize connectivity both north-south, east-west and upslope from the wetlands, the protection of riparian forests along the wetlands and tributary streams from forest harvesting and development will be of increasing importance. These along with other sites with seepage may become the only densely forested areas in the Trench if the more severe climate change projection comes to fruition. Protection of riparian forests also will partially mitigate increasing stream temperatures, and assist in stabilizing stream channels for extreme streamflow events. Forest retention also has the added advantage of contributing to CO_2 sequestration, which will ultimately slow the pace of climate change.

Increasing climate change resilience of upland forests in the Rocky Mountain Trench will require stand management to favour drought resistant tree species and fuel treatments to reduce the potential for stand-replacing fires (e.g. Utzig 2019). Identification and protection of potential fire refugia (i.e. areas less likely to be consumed by wildfire) can also contribute to wildfire resilience at the landscape level.

Climate change will bring changes to the Columbia Wetlands. Through increased monitoring and development of models of how the wetlands function within the broader landscape, it will be possible to develop strategies and actions to adapt to those changes. However, these will only be successful if the world moves to slow and eventually reverse the global climate crisis now underway.

Potential actions to limit impacts, build resiliency and reduce vulnerability to the Columbia Wetlands themselves, and their function as an integral part of an important climate change corridor:

- reduce global greenhouse gas emissions to zero as soon as possible
- maintain and potentially expand monitoring of streamflow, glacial retreat, seasonal wetland water levels and groundwater contributions
- utilizing existing historical data, current modeling outputs and GCM projections develop models to better project changes to seasonal flows of water inputs and water levels in the wetlands themselves as a basis for developing strategies to minimize future risks
- expand the area and rate of trench ecosystem restoration activities, consistent with creating fire resilient communities throughout the lower elevations of the Trench south of Golden and other areas projected to shift to areas frequented by drought and frequent wildfire regimes, including:
    - remove forest in-growth and ladder fuels (e.g. Utzig 2019)
    - reduce stand densities (to reduce risk of crown fires and build resilience to drought and forest pests)
    - protect large fire-resistant trees (ponderosa pine, Douglas-fir and western larch)
    - re-introduce low intensity fire, and make controlled burning a primary ecosystem management tool
    - reduce fire risk to riparian communities
- protect and enhance riparian areas along streams and rivers, as well as wetlands and lakes – minimize disturbance to riparian areas, restore native vegetation, and minimize upstream disturbances that may affect peakflows
- monitor and manage outbreaks of forest pests where possible (utilizing environmentally acceptable methods)
- protect and enhance deciduous trees and stands – trembling aspen, cottonwood and paper birch
- control invasive plants – especially during ecosystem restoration activities

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