Chapter 3
Hydrology of the Chilko-Chilcotin River System

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Abstract

This chapter is part of a larger report on the Chilko-Chilcotin River (CCR) system that analyzes physical and biological aspects of the watershed to provide insights on ecosystem functions and processes, highlighting the important role of Sockeye Salmon. The hydrology of the CCR system beginning at Chilko Lake and ending at the confluence with the Fraser River is described in detail. A conceptual model is developed that connects physical hydrologic elements to the watershed ecosystem.

The CCR system begins at the western boundary of the interior plateau of British Columbia and flows to the northeast before turning south and joining the Fraser River. Its climate is influenced by the Pacific Ocean and it experiences a rain-shadow effect from coastal mountains. Annual precipitation ranges from 1-2 meters/year in the mountains to <0.4 meters/year in the dry interior. The CCR system contains two major headwater lakes, Chilko and Taseko, which drain a portion of the eastern slope of the Pacific coastal mountains. These glacially created lakes act as buffers for perennial rivers, delaying the spring snowmelt pulse and reducing and broadening peak discharge. July and August usually produce the highest flows on the Chilko River ranging from 100 - 200 m^3/sec, followed by low flows during the winter months of 5 - 25 m^3/sec. The river network beginning at Chilko Lake has limited complexity with three major confluences in 195 km before emptying into the Fraser River.

Introduction

The hydrology of the Chilko-Chilcotin River (CCR) system plays a defining role in physical habitat maintenance, water quality and timing cues for fishes, insects, and mammals that live in this lake and river environment. Driven by large scale processes such as tectonics, climate and glaciers, the regional hydrology in turn impacts ecosystem level processes (Conceptual Model, this volume). Within this ecosystem the Sockeye Salmon is a critical link that regulates lower trophic levels, provides food for higher order predators, and replenishes the broader ecosystem through carcass marine derived nutrients (Hoff; Jauregui, this volume). The Sockeye Salmon's importance to the ecosystem stems from its abundance, which historically exceeded 10 million fish in some dominate-year runs.

The hydrology of the CCR system can be broken into 4 major elements: (1) climate and precipitation, (2) snow accumulation and melt, (3) headwater lakes, and (4) river networks. Following presentation of these elements, a conceptual model is presented that focuses on drivers, linkages and outcomes of this system. Drivers are like knobs that can adjust or reset the system, such as tectonics, glaciers, and climate change. Drivers are the most important consideration for predicting how a system will change in the future. Linkages are the connections between these drivers and their intermediate or final outcomes such as the connection between snowpack and river flow, or river flow and ecologic processes. Linkages are important for understanding how ecosystems respond to change. Lastly, outcomes are the result of drivers and linkages that are usually observed at the community or species level. Examples include stress on juvenile salmon in Chilko Lake, formation of large woody debris jams in the CCR system, and Grizzly bear foraging range.

An ancillary benefit of using conceptual models is the compartmental structure that allows multiple researchers to build a larger model based on specialized technical backgrounds. This benefit is leveraged for the CCR system with a consistent focus on strong linkages between individual conceptual models. To faithfully describe a natural system like the CCR this step is principally important.

CCR Hydrologic Cycle

The hydrologic cycle is a convenient way to describe water movement through a natural system. The CCR system includes a few non-traditional elements such as a delayed discharge after snowmelt due to large headwater lakes, and a significant loss of near-surface groundwater due to fractured basalt formations underlying the watershed.

Climate & Precipitation

British Columbia sits on the eastern edge of the Pacific Ocean between the states of Alaska and Washington. Its climate is strongly influenced by ocean moisture and weather patterns as well as mountain topography. Prominent features are shown in Figure 3.1. The coastal mountains rise from sea level to peaks above 2500 meters within 100 km of shore. Eastward of these mountains is the high interior plateau, which ranges in elevation from 1000 to 1500 meters but can drop to less than 500 meters in river drainages. On the eastern margin of the interior plateau are the Columbia and Rocky Mountains. For further discussion on the geologic landscape see Garber (this volume) and glacial activity see Austin (this volume).

Weather patterns typically move inland from the ocean and eastward across the Province. The coastal mountains in southwest British Columbia drain much of the Pacific Ocean moisture and produce a semi-arid climate on the interior plateau. Precipitation remains low across the interior plateau, only increasing when the eastern mountains are encountered. The northern portion of the Province drains to the north and does not significantly affect the Chilko-Chilcotin watershed or the lower Fraser River.

Figure 3.1. Mountain ranges of British Columbia, adapted from Heidorn, 2004.

Annual precipitation varies greatly across British Columbia. Precipitation along the coast generally follows topographic lines with 3 to 4 meters of total precipitation recorded near sea level and 1 meter near the crest-line of the coastal range. Beyond the mountains, on the interior plateau, precipitation drops dramatically. In the Chilko-Chilcotin watershed mean annual precipitation is less than 400 mm/yr (15.7 in/yr), which indicates a semi-arid environment.

Seasonally, the majority of the precipitation falls as rain during the summer months of June, July and August with average temperatures of 18 deg C and overnight minimum temperatures of 10 deg C. Winter precipitation falls as snow. Temperatures average -8 deg C with minimum overnight temperatures of -12 deg C. Figures 3.2 and Figure 3.3 show precipitation and temperatures during different times of the year at a weather station (Wineglass Ranch, 51.85N, 122.66 W) near the confluence of the Chilcotin River and Big Creek. Although precipitation peaks in the summer months the accumulation of snow plays a key role in determining the annual hydrograph.

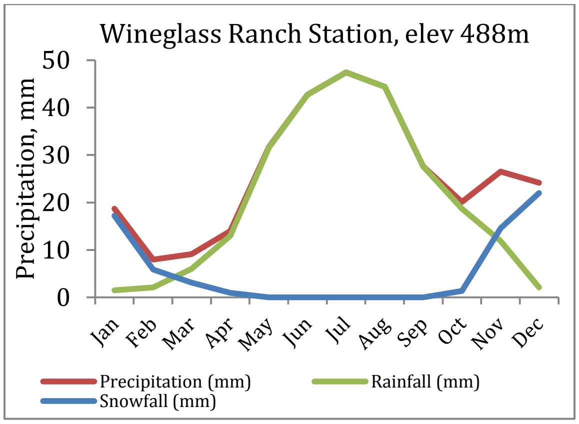

Figure 3.2. Total precipitation, rain and snow for each month at a weather station located near the confluence of the Chilcotin River and Big Creek.

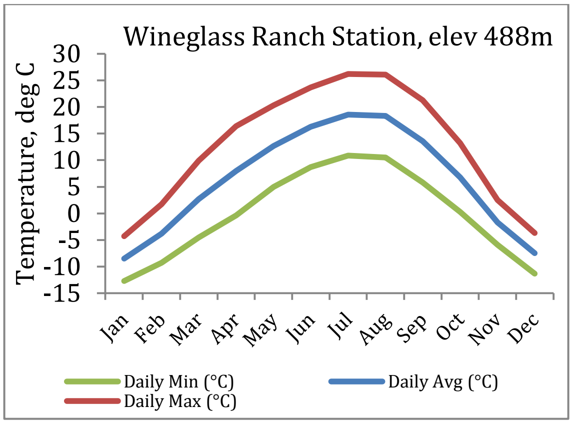

Figure 3.3. Daily temperatures by month at the same weather station.

Snow Accumulation & Melt

Precipitation in the winter and early spring falls as snow across much of the Chilko-Chilcotin watershed. Temperatures are cold enough for accumulation of a snowpack that varies in depth, with the largest values occurring in the coastal range and lesser amounts eastward on the interior plateau. This snow is modestly wet in the mountains and drier eastward on the plateau.

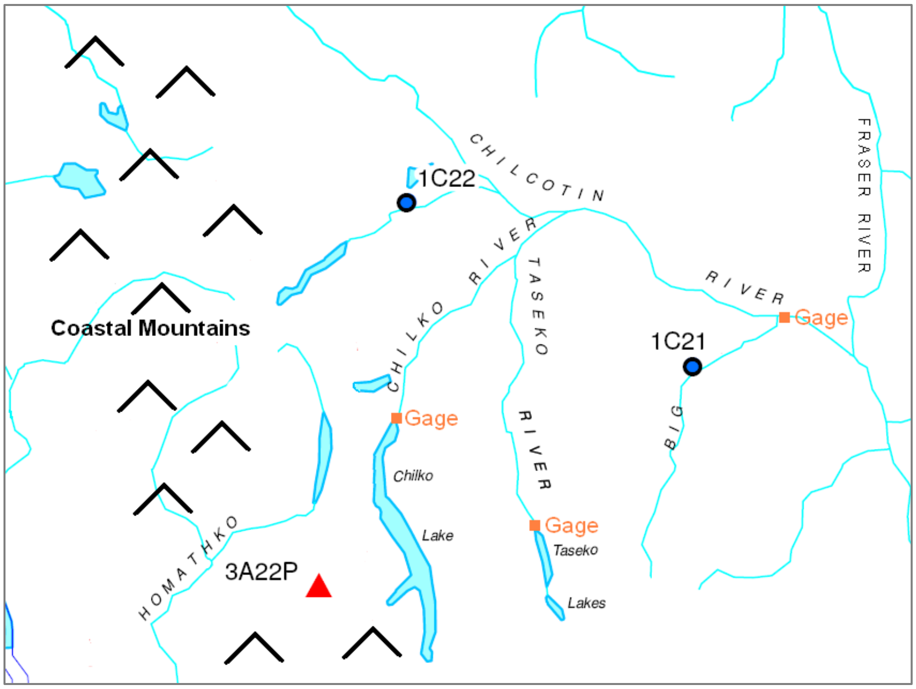

Figure 3.4. Map of the Chilko-Chilcotin watershed with markers for snow (red triangle and blue circles) and river flow (green squares) stations. Figure adapted from Environment Canada.

This plateau is between 1000 and 1500 meters in elevation and experiences enough moisture and cold temperatures to build a small snowpack of 10 – 20 cm. Figure 3.4 shows a map of the watershed with snow and flow stations, and Figure 3.5 and Figure 3.6 show data from these stations.

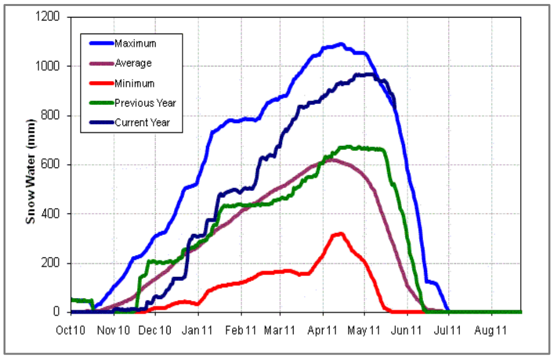

Figure 3.5. Nostetuko River automated snow station is located adjacent to Chilko Lake at 1500 meters (moderately higher than the lake at 1170 meters). The current year is 2011.

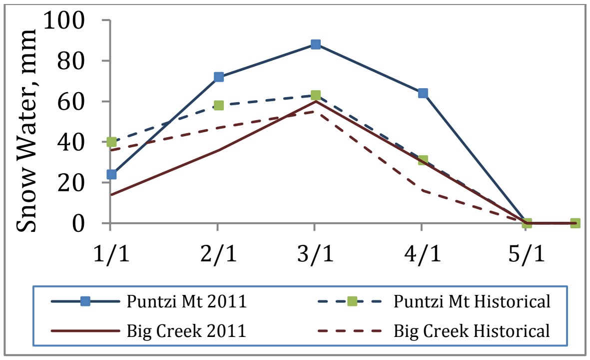

Figure 3.6. Two lower elevation manual snow stations (1C22 – Puntzi Mountain & 1C21 – Big Creek) are located at 940 and 1140 meters respectively. These are shown on Figure 4 as blue circles.

In both graphs the current year snowpack (2011) is quite large compared with historical averages. These stations have 20 - 25 years of historical data for comparison. The upper elevation snow station has 10 times the snow accumulation of the lower stations in an average year. It is significant to note the timing of the end of the snowpack. At the lower snow stations (Puntzi Mt. and Big Creek) snow melts completely by May 1st, contributing to groundwater and river flow. For the higher elevation station (Nostetuko River) complete snowmelt usually occurs by mid June and runoff flows into headwater lakes.

Headwater Lakes

Headwater lakes in the interior of British Columbia play an important role in watershed hydrology and ecosystem functions. Two effects of headwater lakes are discussed here: (1) changes in turbidity, and (2) the delay of seasonal runoff due to temporary lake storage.

Headwater lakes can significantly affect the turbidity of rivers that flow through them which in turn affects water quality and food web dynamics (Winters, this volume). In the CCR system there are two important headwater lakes: Chilko Lake and Taseko Lake (shown in Figure 3.4). A third lake located on the Chilanko River, tributary to the upper Chilcotin River, is also pictured but plays a small role due to the Chilanko's small flow contribution. Chilko and Taseko Lakes are geographically close together, but they have very different characteristics. (Desloges and Gilbert, 1998). These parameters differentiate the lakes and allow Chilko Lake to sustain a thriving food web that supports higher order species such as Sockeye Salmon and other resident fishes (Hoff; Jauregui; Montgomery, this volume). For discussion of other water quality factors such as seasonal temperature and eutrophic depths in Chilko Lake see Winters, this volume.

Table 3.1 compares the lakes and helps explain the difference in lake appearance, suspended sediment and associated water quality. Chilko and Taseko Lakes drain similar areas and experience similar magnitude snowmelt inflows, however the shallow depth and partial separation into two effective lakes gives Taseko Lake a much shorter residence time. This impacts the settling of particles and ultimately transports them downstream. Chilko Lake does not experience this level of suspended sediment due to its larger size, multiple inflow locations and long residence time (Desloges and Gilbert, 1998). These parameters differentiate the lakes and allow Chilko Lake to sustain a thriving food web that supports higher order species such as Sockeye Salmon and other resident fishes (Hoff; Jauregui; Montgomery, this volume). For discussion of other water quality factors such as seasonal temperature and eutrophic depths in Chilko Lake see Winters, this volume.

Table 3.1. Characteristics of CCR headwater lakes: Chilko and Taseko.

Characteristic	Chilko Lake	Taseko Lake
Surface area	185 km2	31 km2
Mean depth	134 m	43 m
Volume	25 km3 (20.3 maf)	1.3 km3 (0.1 maf)
Annual flow	1.9 km3/year	1.8 km3/year
Residence time	13 years	0.7 years
Catchment area	2,110 km2	1,520 km2
Regulation type	Natural	Natural
Appearance	Glacially turbid	Clear and blue

Data sources: (1) Canadian Science Advisory Secretariat Research Document 2001/098, (2) Environment Canada historical gage flows for Chilko and Taseko Lakes. Notes: Residence times for Chilko and Taseko Lakes is calculated based as volume/flow, other estimates put Chilko Lake residence time between 17-35 years (see Winters, this volume for more details).

A second characteristic of these lakes is the hydrologic routing effect they have on the seasonal snowmelt pulse that travels through the system. Hydrologic routing is the physical translation of an inflow event through the lake and downstream. The inflow hydrograph is delayed in time and reduced in peak magnitude relative to typical river flow. For large lakes the effects of hydrologic routing is significant. Figure 3.7 shows the work of Haktanir and Ozmen (1997) who demonstrate these trends for differing volume canyon lakes in Turkey. The largest lake in the study is smaller than Chilko Lake, but can used for comparison. Haktanir and Ozmen found a 100% delay of the lake's discharge time to peak relative to the inflow time to peak (t/tp). They also found a reduction in the peak flow of approximately half as compared to the inflow peak (Q/Qp). For the smaller lakes in the study the discharge hydrograph had a stronger connection to the inflow hydrograph and showed less distortion.

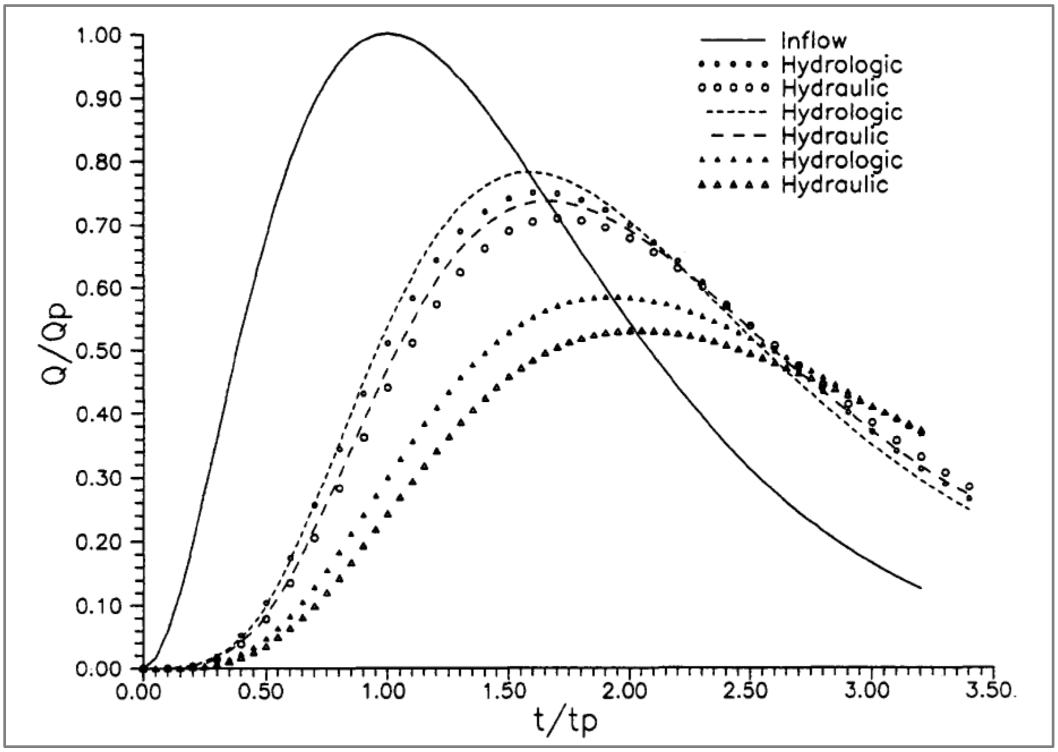

Figure 3.7. The lake routing effect is observed by comparing an inflow hydrograph with three outflow hydrographs for different sized lakes. The largest lake (solid triangles) produces the lowest normalized discharge value and is the most delayed. Q/Qp represents normalized flow, and t/tp represents normalized time, both relative the peak of the inflow hydrograph. Two types of routing are shown.

Applying the non-dimensional parameters of Q/Qp and t/tp to Chilko Lake (assuming the snowmelt curve approximates the timing of lake inflows), the Chilko Lake hydrograph delay can be compared with the results of Haktanir and Ozmen. Figure 3.8 shows three estimated snowmelt hydrographs for years 2007, 2009, and 2010. These years where chosen to represent large, small, and average snowpacks respectively. Also on this figure are the lake outflows for the following spring and summer. Table 3.2 shows estimates of time to peak for inflow and discharge hydrographs. The ratio of tp (discharge) / tp (inflow) ranges from 2.1 to 4.8 with a trend of less routing time for the larger inflow hydrographs. These values are expected because Chilko Lake is larger than the lakes in the earlier study. The last point on lake routing is the change in flow magnitude between inflow and discharge was not analyzed because it does not directly impact the CCR hydrology or ecosystem.

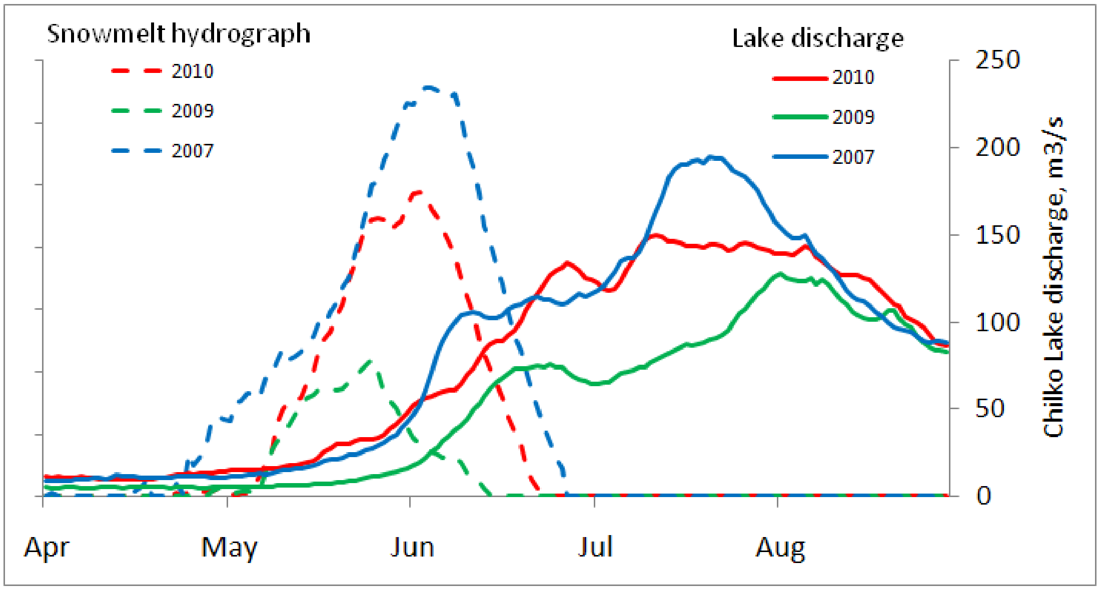

Figure 3.8. Chilko Lake inflow and discharge hydrographs showing the time delay due to hydrologic routing through a large water body. Note: no axis values are given for the inflow snowmelt hydrograph due to its direct estimation from snow water equivalents. The time to peak for the discharge hydrographs is roughly 2 to 4 times the inflow time to peak (agrees with Haktanir and Ozmen).

Table 3.2. Time to peak (tp) for inflow and discharge hydrographs pictured in Figure 3.8.

Time to Peak	Inflow Hydrograph	Discharge Hydrograph	Ratio
2007	46 days (4/20 – 6/5)	96 days (5/1 – 7/25)	2.1
2009	15 days (5/5 – 5/20)	72 days (5/20 – 8/1)	4.8
2010	31 days (5/5 – 6/5)	71 days (5/1 – 7/10)	2.3

River Flow

Gage data is located in a few places throughout the watershed (Figure 3.4). A key location with a 40 year record is the station downstream of the Big Creek – Chilcotin confluence. This site provides a clear picture for the overall flows and associated geomorphic impacts due to water velocity and sediment transport capacity. Figure 3.9 shows the average hydrograph of the Chilko – Chilcotin River downstream of Big Creek with the 10th and 90th percentiles included to demonstrate the system's consistency. There is surprisingly little variation in yearly peaks.

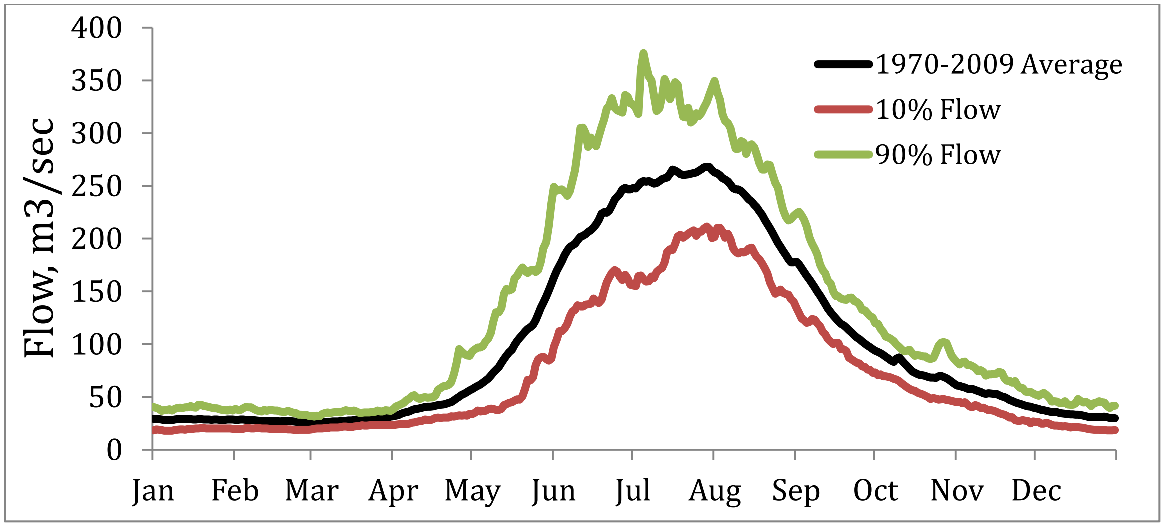

Figure 3.9. Gaged flow in the Chilko – Chilcotin River downstream of Big Creek.

This consistency is likely due to a consistent annual snowpack and the buffering effect of hydrologic routing in large headwater lakes. The gage data at this location is made up of 4 inflows: Chilko River (discharge from Chilko Lake), Taseko River (Taseko Lake), Chilcotin River, and Big Creek. The two largest contributors to flow at this location are the Chilko and Taseko Rivers, which join upstream of the confluence with the Chilcotin River. As discussed in the Headwater Lakes section, these two rivers are produced by similar drainage areas and only differ by lake size. Figure 3.10 shows 3 years of discharge from the two lakes (2002 – 2004). It is hypothesized that the slightly longer discharge occurring from Chilko Lake is due to a longer lake routing delay (due to its larger size).

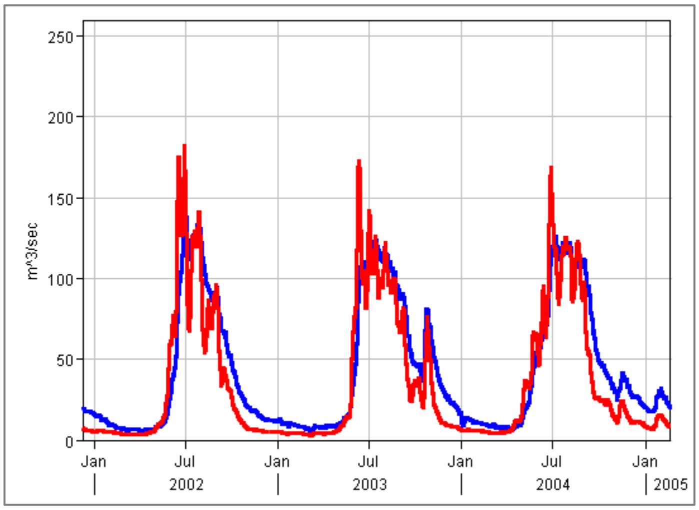

Figure 3.10. Discharges from Chilko Lake (blue line), and Taseko Lake (red line).

Inflows from the Chilcotin River are smaller in magnitude and drain a lower elevation watershed than the Taseko and Chilko Rivers. The drainage area near the confluence with the Chilko River is 6220 km2 (roughly equal to the Taseko-Chilko drainage area). Gage data for this location is very sparse and not continuous. Flows range from 5 – 10 m3/s during the winter months to 20 – 80 m3/s in the summer months. It is hypothesized that this river flow is more variable due to the lack of large headwater lakes upstream.

Big Creek's contribution to the system comes in the lower reach of the Chilcotin above the confluence with the Fraser River. It also does not drain a high elevation watershed – mainly the mountain range margins and the interior plateau. The watershed area is estimated at 1500 km^2. Figure 3.11 shows 5 years of the runoff hydrograph for Big Creek. The peak discharge is more representative of a rain driven system with slightly earlier runoff than the upper watershed produces.

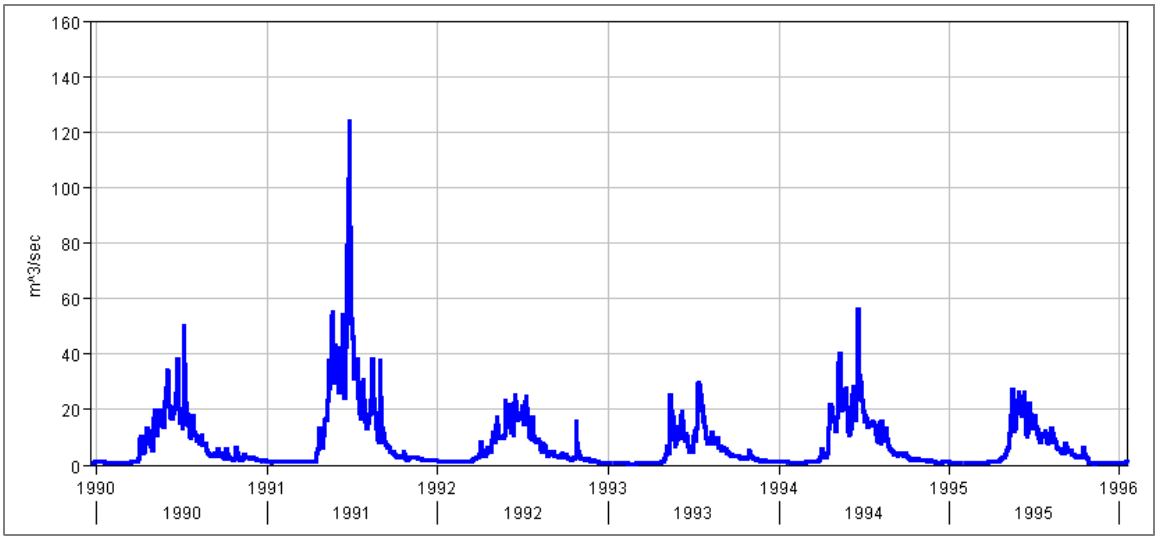

Figure 3.11. Discharge from Big Creek upstream of the confluence with the Chilcotin River.

A simple flow balance was calculated around 4 input rivers to compare with the flows observed on the Chilcotin River below Big Creek. Based on the limited data for the upper Chilcotin River this task provided an approximate picture of a minor level of interaction between the groundwater and the surface water. The possibility of large losses of stream flow due to the underlying rock type – fractured basalt, was verified not to be true. More research into groundwater's role in this system is needed before connections to the watershed and ecosystem can be discussed.

Conceptual Model

The following conceptual model relies heavily on the material presented in the Hydrologic Cycle section. It offers a few knob-adjusting cases to manipulate the connections within the system and speculate on the outcomes. Figure 3.12 is the hydrologic conceptual model.

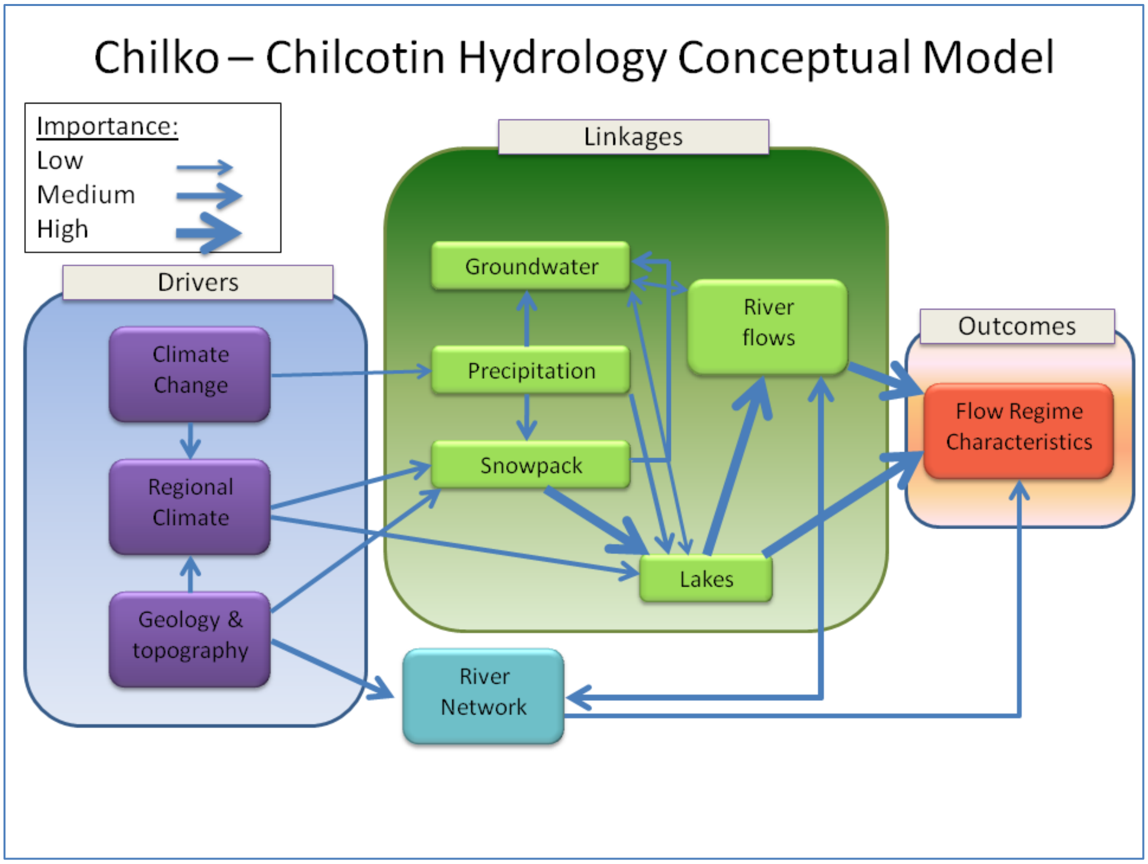

Figure 3.12. Conceptual hydrologic model with tan boxes representing connections to other conceptual models.

Drivers

The drivers in the hydrologic conceptual model are Geology & Topography, Regional Climate, and Climate Change. These drivers act on different timescales. Geology & Topography have brought the landscape up to the current period. It primarily includes tectonic and glacial activity. In terms of the current ecosystem these drivers are considered stationary. The two remaining drivers – Regional Climate and Climate Change, are active on a timescale of decades to centuries and can have major impacts on the hydrologic cycle of the CCR system. The timing of flows, especially down the upper Chilcotin River and Big Creek could see a shift earlier in the year as the amount of snow and the timing of its melt on the interior plateau changes.

Linkages

The major linkages discussed in the hydrologic cycle are snowpack to lakes, and lakes to river discharge. These make up the heart of the hydrologic cycle in the CCR system and affect all ecosystem processes that rely on the lakes or river to function. Precipitation does increase in the summer months and this is seen in the flashiness of the Chilcotin River hydrograph below Big Creek, however the majority of the consistent seasonal runoff comes through the outlets of Chilko and Taseko Lakes reducing the relative importance of this model element.

A fundamental feed-back linkage which is found in every river system is the connection between river discharge and the physical flow network. Geomorphic processes (Selander, this volume) describe this complex interaction between the water and its surroundings. In the context of the larger ecosystem conceptual model this is an important connection that establishes physical habitat in which the biotic community interacts.

Outcomes

The hydrologic model outcomes are centered on two connected locations, the lakes and downstream river network. These outcomes are set in place by the long-term drivers (Geology & Topography), put into motion by Regional Climate and the effects of Climate Change on the snowpack, and realized throughout the spring and summer as physical processes of the lake and river network distribute water throughout the surrounding ecosystem. A few specific examples can highlight changes in this process: (1) reduced snowpack on the interior plateau and earlier melt, and (2) faster melt of the high elevation snowpack in the mountains above Chilko and Taseko lakes.

Climate change effects on British Columbia have been estimated by the Pacific Climate Impacts Consortium as having a general warming trend over much of the interior plateau (Dawson, 2008). The mountain regions will be buffered from this warming due to elevation, however scenarios of 2 to 6 degrees C warming have been proposed. The impact of this change would be a reduced snowpack on the interior plateau and an earlier melt. This is then linked to ecosystem outcomes through the adjustment of the seasonal hydrograph emerging from the lower elevation watershed areas such as Big Creek and the Upper Chilcotin River. In this case, these adjustments to the overall hydrologic system are small due to the smaller contributing flows from lower elevation drainages. Without the mix of high and low elevation areas this type of change could result in outcomes that significantly impact the ecosystem communities adapted to historical conditions.

The second example, a faster snowmelt in the mountains, is also driven from a possible Climate Change impact. As discussed in the Headwater Lakes section a shorter time to peak for the inflow hydrograph will result in a shorter time to peak for the discharge (all other things held constant). This lake process links to a result of an earlier peak discharge from lakes and a shift in timing of the mid to late summer high flows that species like the Sockeye Salmon require for spawning. Once a change reaches a significant member of the ecosystem community such as Sockeye Salmon the impacts can magnify. This example can be further investigated in the conceptual models of the Sockeye Salmon (Hoff; Jauregui, this volume).

Summary

The description of the CCR system hydrology and development of a conceptual model has helped inform a larger ecosystem understanding and provided a mechanism for assessing change and stressors on the system. Within the hydrologic conceptual model the impact of the headwater lakes provides resiliency against change. It will help buffer the future impacts of climate change for important species such as Sockeye Salmon and their connected food web. In the context of the larger ecosystem model the hydrology sub-model fulfills a process or linkage that transitions from large-scale landform and climate drivers to community and species scale ecosystem processes that are the ultimate outcomes of this study.

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